Q01 | Official learning outcome

BIO.3.3.02.011 Explain the concepts of genotype, phenotype, dominance, incomplete dominance, codominance, recessiveness, and sex linkage according to Mendelian laws of inheritance.

EXACT COVERAGE: Q1 | Textbook printed page 5 | Information from text; Figure 2

STUDY TARGET: Mendel's F1/F2 results; true-breeding parents; dominant and recessive seed color

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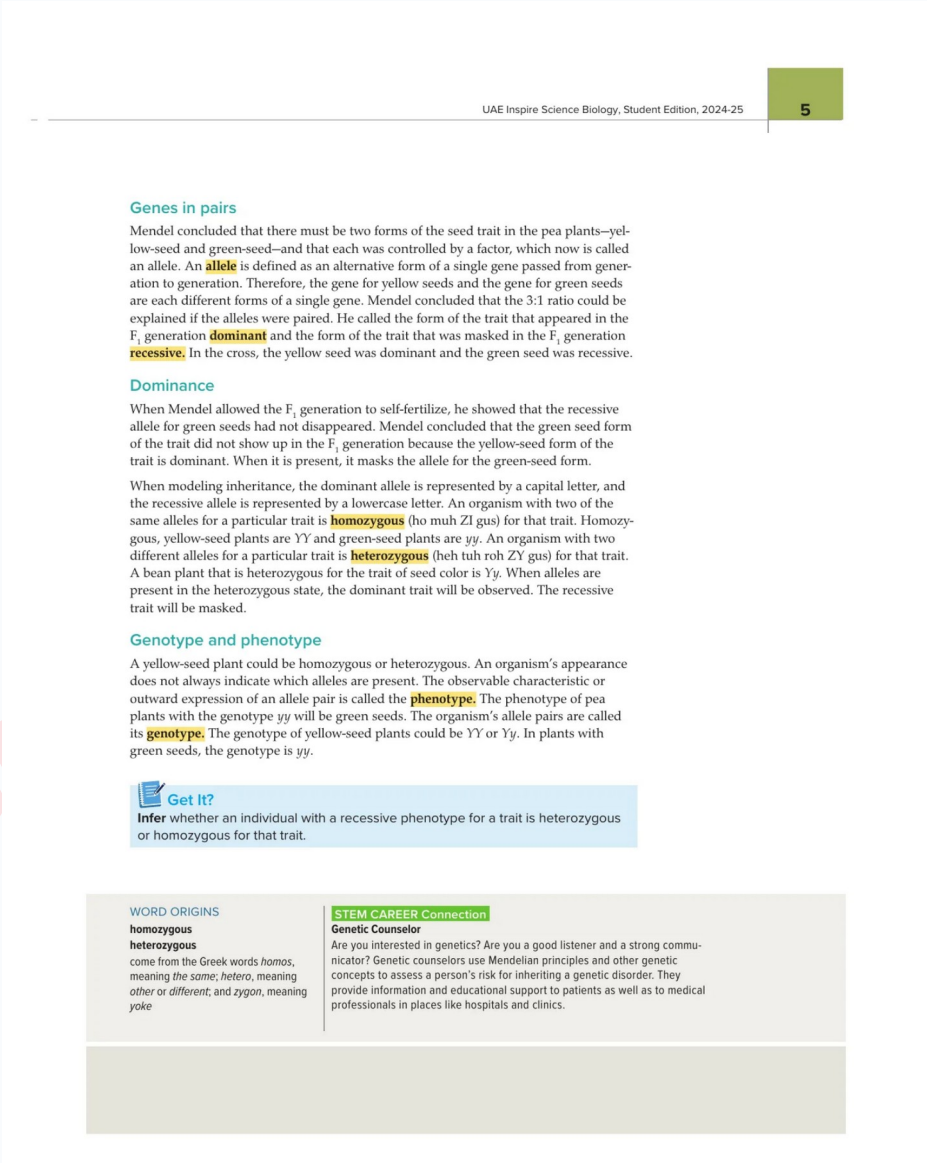
Q01 | Original textbook page



Genes in pairs

Mendel concluded that there must be two forms of the seed trait in the pea plants—yellow-seed and green-seed—and that each was controlled by a factor, which now is called an allele. An **allele** is defined as an alternative form of a single gene passed from generation to generation. Therefore, the gene for yellow seeds and the gene for green seeds are each different forms of a single gene. Mendel concluded that the 3:1 ratio could be explained if the alleles were paired. He called the form of the trait that appeared in the F_1 generation **dominant** and the form of the trait that was masked in the F_1 generation **recessive.** In the cross, the yellow seed was dominant and the green seed was recessive.

Dominance

When Mendel allowed the F_1 generation to self-fertilize, he showed that the recessive allele for green seeds had not disappeared. Mendel concluded that the green seed form of the trait did not show up in the F_1 generation because the yellow-seed form of the trait is dominant. When it is present, it masks the allele for the green-seed form.

When modeling inheritance, the dominant allele is represented by a capital letter, and the recessive allele is represented by a lowercase letter. An organism with two of the same alleles for a particular trait is **homozygous** (ho muh ZI gus) for that trait. Homozygous, yellow-seed plants are *YY* and green-seed plants are *yy*. An organism with two different alleles for a particular trait is **heterozygous** (heh tuh roh ZY gus) for that trait. A bean plant that is heterozygous for the trait of seed color is *Yy*. When alleles are present in the heterozygous state, the dominant trait will be observed. The recessive trait will be masked.

Genotype and phenotype

A yellow-seed plant could be homozygous or heterozygous. An organism's appearance does not always indicate which alleles are present. The observable characteristic or outward expression of an allele pair is called the **phenotype.** The phenotype of pea plants with the genotype *yy* will be green seeds. The organism's allele pairs are called its **genotype.** The genotype of yellow-seed plants could be *YY* or *Yy*. In plants with green seeds, the genotype is *yy*.

Get It?
Infer whether an individual with a recessive phenotype for a trait is heterozygous or homozygous for that trait.

WORD ORIGINS
homozygous
heterozygous
come from the Greek words *homos*, meaning *the same*; *hetero*, meaning *other* or *different*; and *zygon*, meaning *yoke*

STEM CAREER Connection
Genetic Counselor
Are you interested in genetics? Are you a good listener and a strong communicator? Genetic counselors use Mendelian principles and other genetic concepts to assess a person's risk for inheriting a genetic disorder. They provide information and educational support to patients as well as to medical professionals in places like hospitals and clinics.

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NTED TEXTBOOK PAGE

Q01 | Figure 2 – Mendel's Pea Plant Cross

Original textbook Figure 2 • Printed page 4 • Coverage sheet cites page 5

position—and found that the F_2 generation from these crosses also showed a 3:1 ratio.

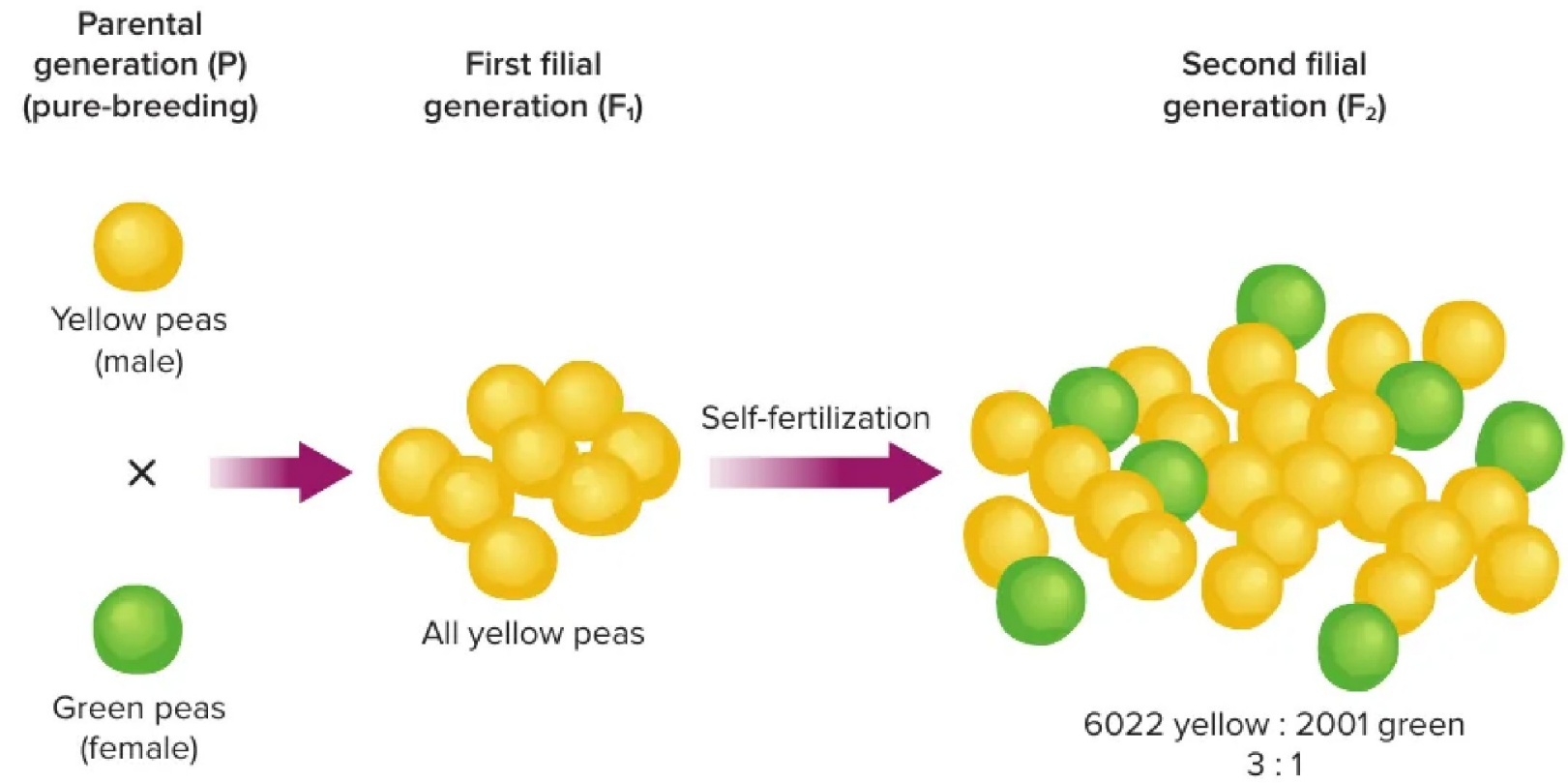

Figure 2 The results of Mendel's cross involving true-breeding pea plants with yellow seeds and green seeds are shown here.

Q01 | Original Textbook Page Containing Figure 2

Printed page 4 • Read the F_1 and F_2 explanation alongside the diagram

The Inheritance of Traits

Mendel noticed that certain varieties of garden pea plants produced specific forms of a trait, generation after generation. For instance, he noticed that some varieties always produced green seeds and others always produced yellow seeds. In order to understand how these traits are inherited, Mendel performed cross-pollination by transferring male gametes from the flower of a true-breeding green-seed plant to the female organ of a flower from a true-breeding yellow-seed plant. To prevent self-fertilization, Mendel removed the male organs from the flower of the yellow-seed plant. Mendel called the green-seed plant and the yellow-seed plant the parent generation—also known as the P generation.

F_1 and F_2 generations

When Mendel grew the seeds from the cross between the green-seed and yellow-seed plants, all of the resulting offspring had yellow seeds. The offspring of this P cross are called the first filial (F_1) generation. The green-seed trait seemed to have disappeared in the F_1 generation, and Mendel decided to investigate whether the trait was no longer present or whether it was hidden, or masked.

Mendel planted the F_1 generation of yellow seeds, allowed the plants to grow and self-fertilize, and then examined the seeds from this cross. The results of the second filial (F_2) generation—the offspring from the F_1 cross—are shown in **Figure 2**. Of the seeds Mendel collected, 6022 were yellow and 2001 were green; almost a perfect 3:1 ratio of yellow to green seeds. Mendel studied seven traits—seed or pea color, flower color, seed pod color, seed shape or texture, seed pod shape, stem length, and flower position—and found that the F_2 generation from these crosses also showed a 3:1 ratio.

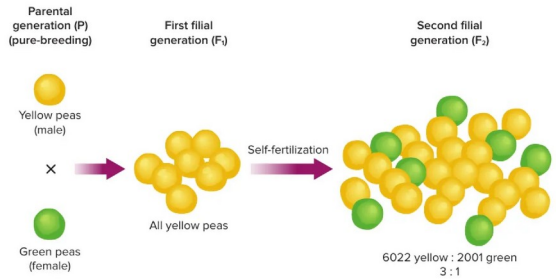

Figure 2 The results of Mendel's cross involving true-breeding pea plants with yellow seeds and green seeds are shown here.

Explain *why the seeds in the F_1 generation were all yellow.*

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Q01 | Learning outcome explanation (1/4)

Specific textbook focus: Mendel's true-breeding yellow- and green-seeded plants: parental (P), first filial (F1) and second filial (F2) generations; Figure 2.

Key terms (definitions for understanding the learning outcome; not all terms are necessarily examined in this particular reference):

Gene — A segment of DNA that contains information for a functional product and can influence an inherited trait.

Allele — An alternative version of a gene.

Genotype — The combination of alleles an organism carries for a particular gene, such as Yy.

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Q01 | Learning outcome explanation (2/4)

Phenotype — An observable characteristic produced by genotype and environmental influences.

Dominant allele — An allele whose effect appears in the heterozygous phenotype in complete dominance.

Recessive allele — An allele masked in a heterozygote under complete dominance; its phenotype appears when homozygous.

Homozygous — Having two identical alleles at a gene locus, such as YY or yy.

Heterozygous — Having two different alleles at a gene locus, such as Yy.

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Q01 | Learning outcome explanation (3/4)

Incomplete dominance — An inheritance pattern in which a heterozygote has an intermediate phenotype.

Codominance — An inheritance pattern in which both alleles are expressed in a heterozygote.

Sex-linked trait — A trait influenced by a gene located on a sex chromosome.

How to distinguish the concepts: genotype refers to allele combination; phenotype refers to observable expression. Complete dominance masks the recessive phenotype in heterozygotes; incomplete dominance is intermediate; codominance expresses both alleles.

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Q01 | Learning outcome explanation (4/4)

Study focus: Mendel’s pea crosses; F1 and F2 generations. Read the exact cited textbook page and interpret its labeled diagram, table or question. The official coverage description identifies a broader learning outcome; the cited reference narrows the emphasis for this item.

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Q01 | Practice MCQ 1

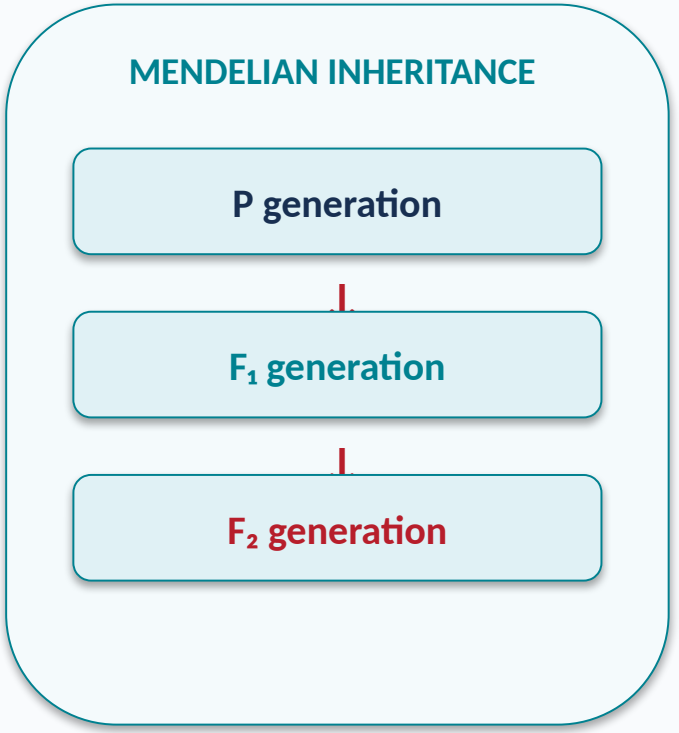
1.1 What phenotype appeared in all F1 plants when true-breeding yellow and green peas were crossed?

A. Mixed yellow-green seeds

B. No seeds

C. Yellow seeds

D. Green seeds



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Q01 | Practice MCQ 2

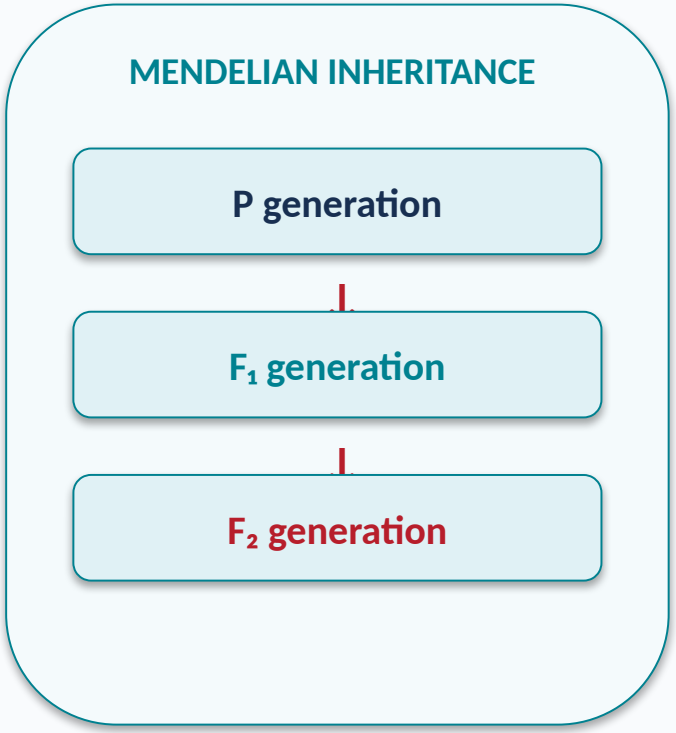
1.2 What does the reappearance of green seeds in F2 indicate?

A. Yellow is recessive

B. The recessive allele was retained in F1

C. The green allele disappeared in F1

D. All F1 plants were homozygous



Q01 | Practice MCQ 3

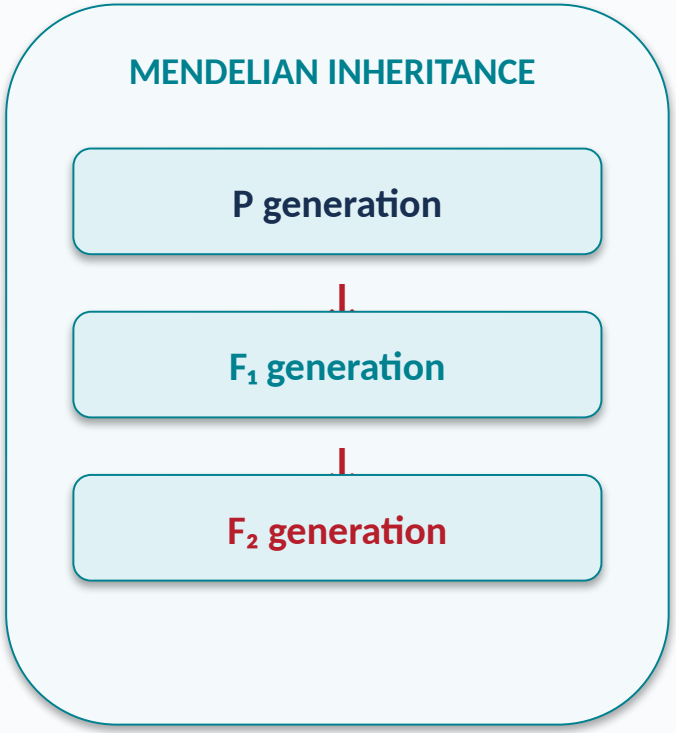
1.3 Which term describes offspring of the first parental cross?

A. F1 generation

B. P generation

C. F2 generation

D. Gamete generation



Q01 | Practice MCQ 4

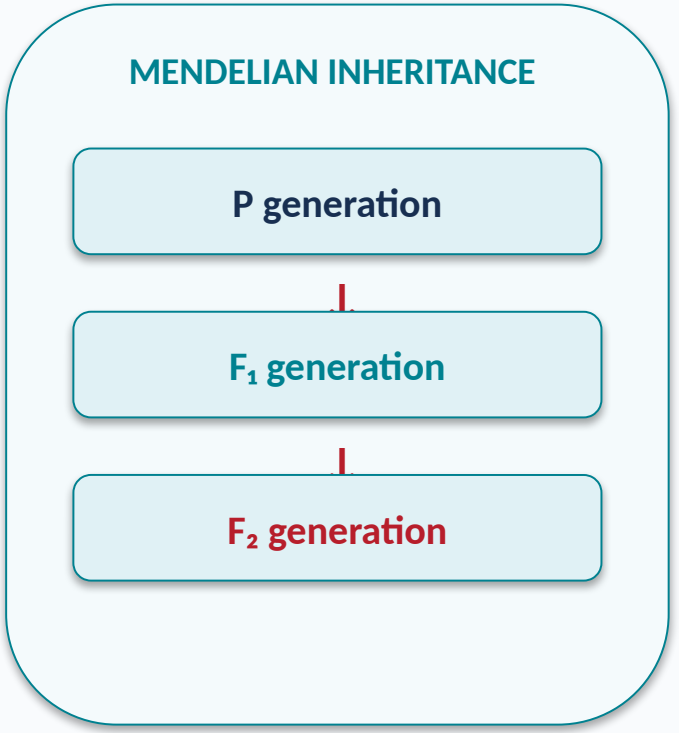
1.4 Which approximate F2 ratio was observed for yellow to green seeds?

A. 1:1

B. 1:2

C. 9:7

D. 3:1



Q01 | Practice MCQ 5

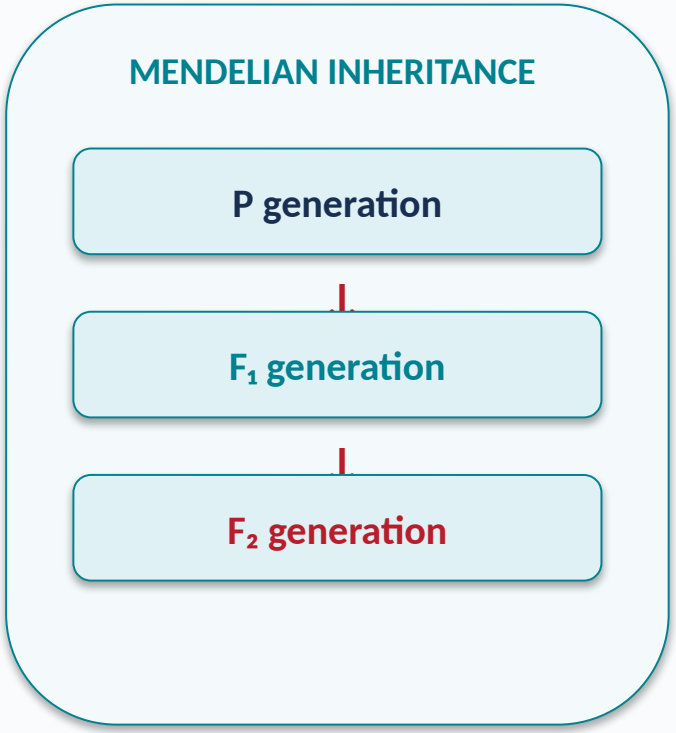
1.5 Why did Mendel begin with true-breeding plants?

A. They had no genes

B. They could not self-fertilize

C. Their inherited traits were predictable

D. They produced only recessive alleles



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Q02 | Official learning outcome

BIO.3.3.02.011 Explain the concepts of genotype, phenotype, dominance, incomplete dominance, codominance, recessiveness, and sex linkage according to Mendelian laws of inheritance.

EXACT COVERAGE: Q2 | Textbook printed page 7 | Information from text; Figure 3

STUDY TARGET: Law of segregation; allele separation during gamete formation

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Q02 | Original textbook page

Law of independent assortment Mendel also experimented with the shape of the peas as well as the color. He noticed that smooth, round peas were expressed more than wrinkled peas. He noted the dominant, round peas to have an allele *R* and the recessive, wrinkled peas to have an allele *r*.

Mendel crossed two types of peas in the parental generation: a dominant round, yellow pea (*YYRR*) with a recessive wrinkled, green pea (*yyrr*). He found that all of the F_1 generation had the same phenotype: round, yellow peas, or the genotype *YyRr*.

Mendel allowed F_1 pea plants with the genotype *YyRr* to self-fertilize in a dihybrid cross. Mendel calculated the genotypic and phenotypic ratios of the offspring in both the F_1 and F_2 generations. From these results, he developed the **law of independent assortment,** which states that a random distribution of alleles occurs during gamete formation. Genes on separate chromosomes sort independently during meiosis, as shown in **Figure 4.**

The random assortment of alleles results in four possible gametes: *YR*, *Yr*, *yR* or *yr*, each of which is equally likely to occur. When a plant self-fertilizes, any of the four allele combinations could be present in the male gamete, and any of the four combinations could be present in the female gamete.

Get It?
Evaluate How can the random distribution of alleles result in a predictable ratio?

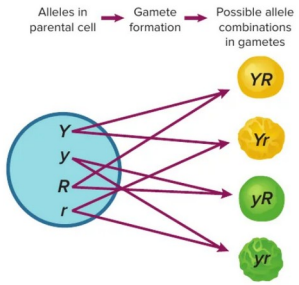

Figure 4 The law of independent assortment is demonstrated by the equal chance that each pair of alleles (*Yy* and *Rr*) can randomly combine with each other.
Predict *how many possible gamete types can be produced.*

Q02 | Learning outcome explanation (1/4)

Specific textbook focus: Law of segregation: paired alleles separate during gamete formation; Figure 3.

Key terms (definitions for understanding the learning outcome; not all terms are necessarily examined in this particular reference):

Gene — A segment of DNA that contains information for a functional product and can influence an inherited trait.

Allele — An alternative version of a gene.

Genotype — The combination of alleles an organism carries for a particular gene, such as Yy.

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Q02 | Learning outcome explanation (2/4)

Phenotype — An observable characteristic produced by genotype and environmental influences.

Dominant allele — An allele whose effect appears in the heterozygous phenotype in complete dominance.

Recessive allele — An allele masked in a heterozygote under complete dominance; its phenotype appears when homozygous.

Homozygous — Having two identical alleles at a gene locus, such as YY or yy.

Heterozygous — Having two different alleles at a gene locus, such as Yy.

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Q02 | Learning outcome explanation (3/4)

Incomplete dominance — An inheritance pattern in which a heterozygote has an intermediate phenotype.

Codominance — An inheritance pattern in which both alleles are expressed in a heterozygote.

Sex-linked trait — A trait influenced by a gene located on a sex chromosome.

How to distinguish the concepts: genotype refers to allele combination; phenotype refers to observable expression. Complete dominance masks the recessive phenotype in heterozygotes; incomplete dominance is intermediate; codominance expresses both alleles.

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Q02 | Learning outcome explanation (4/4)

Study focus: Law of segregation and gamete formation. Read the exact cited textbook page and interpret its labeled diagram, table or question. The official coverage description identifies a broader learning outcome; the cited reference narrows the emphasis for this item.

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Q02 | Practice MCQ 1

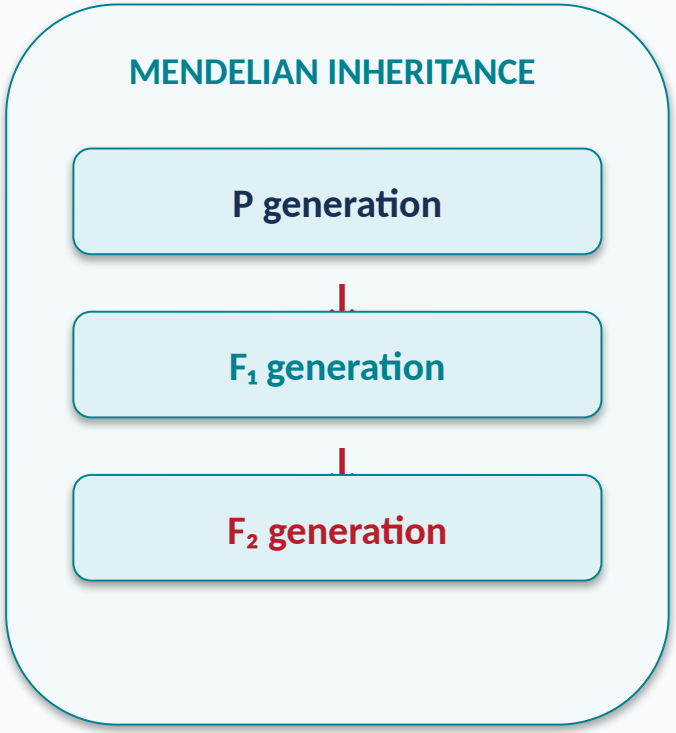
2.1 What happens to two alleles of a gene during gamete formation?

A. They fuse before fertilization

B. They separate into different gametes

C. They remain paired in every gamete

D. Both are destroyed



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Q02 | Practice MCQ 2

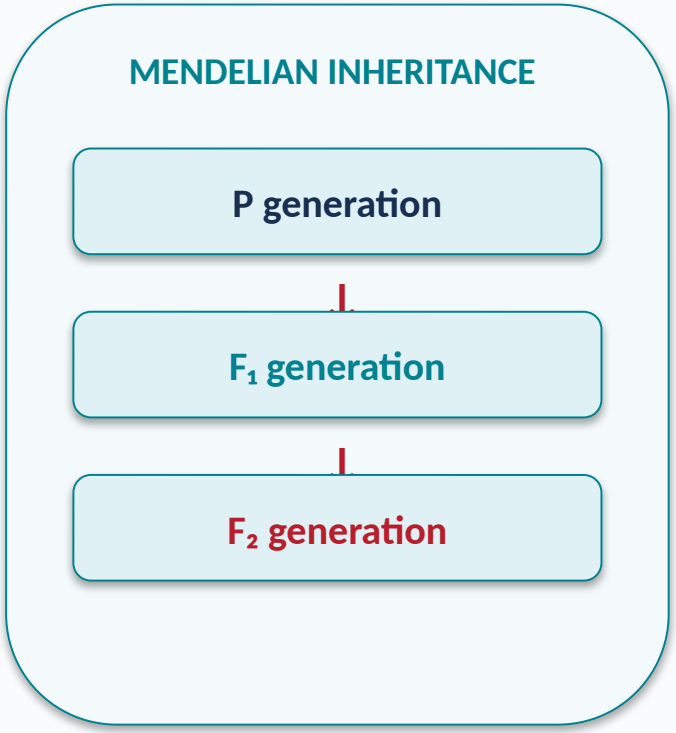
2.2 A Yy plant can produce which gametes?

A. Y and y

B. YY only

C. Yy only

D. yy only



Q02 | Practice MCQ 3

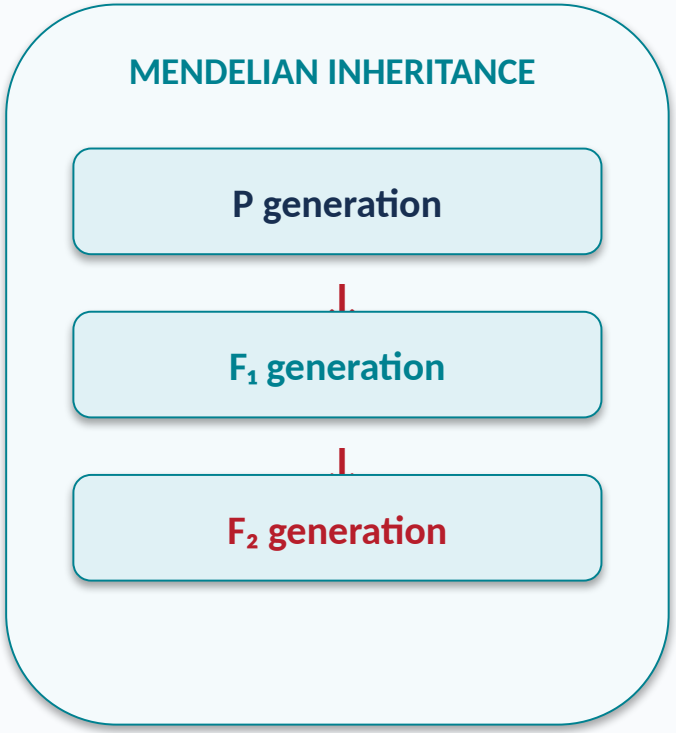
2.3 Which process restores an allele pair in an offspring?

A. Transcription

B. Mutation

C. Crossing over only

D. Fertilization



Q02 | Practice MCQ 4

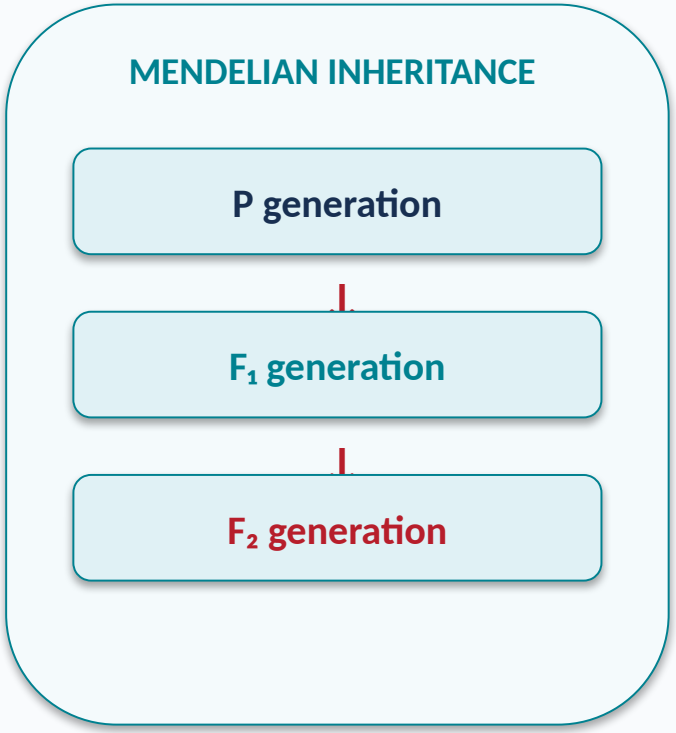
2.4 What genotype is produced by fusion of Y and y gametes?

A. yy

B. Y

C. Yy

D. YY



Q02 | Practice MCQ 5

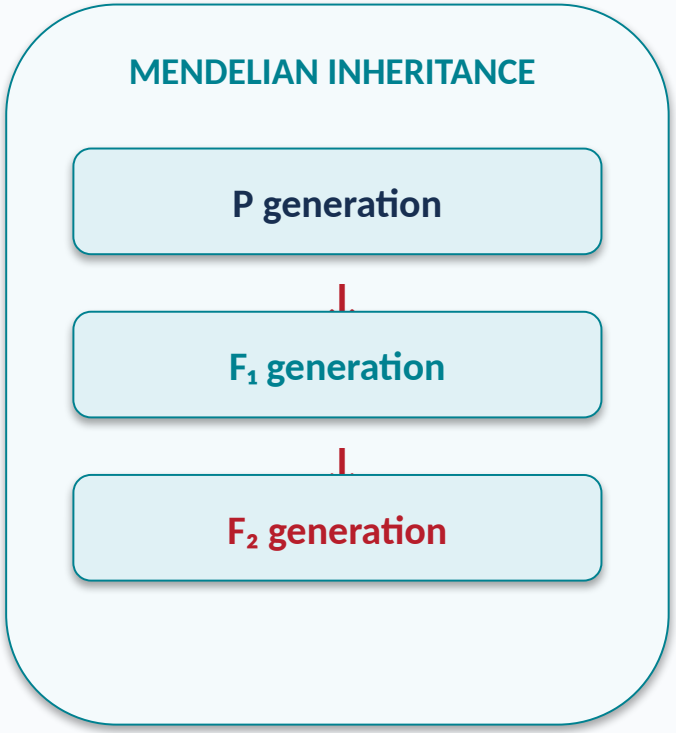
2.5 Why can a recessive phenotype reappear in F2?

A. F1 plants have no recessive allele

B. Two recessive alleles may combine

C. A dominant allele becomes recessive

D. Gametes contain two allele pairs



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Q03 | Official learning outcome

BIO.3.3.02.011 Explain the concepts of genotype, phenotype, dominance, incomplete dominance, codominance, recessiveness, and sex linkage according to Mendelian laws of inheritance.

EXACT COVERAGE: Q3 | Textbook printed page 8 | Figure 4

STUDY TARGET: Independent assortment; possible allele combinations in gametes

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Q03 | Original textbook page

Punnett Squares

In the early 1900s, Dr. Reginald Punnett developed what is known as a Punnett square to predict the possible offspring of a cross between two known genotypes. Punnett squares help keep track of the possible genotypes involved in a cross.

Monohybrid cross

The diagram in **Figure 5** shows how Mendel continued his experiments by allowing the *Yy* plants to self-fertilize. A cross such as this one that involves hybrids for a single trait is called a monohybrid cross. The *Yy* plants produce two types of gametes—male and female—each with either the Y or y allele. The combining of these gametes is a random event. This random fertilization of male and female gametes results in the following genotypes—*YY, Yy, Yy,* or *yy,* as shown in **Figure 5.** Notice that the dominant *Y* allele is always written first, whether it came from the male gamete or the female gamete. In Mendel's F_1 cross, there are three possible resulting genotypes: *YY, Yy,* and *yy;* and the genotypic ratio is 1:2:1. The phenotypic ratio is 3:1—yellow seeds to green seeds. The genotypic ratio and the phenotypic ratio differ, because two different genotypes—*YY and Yy* produce the same phenotype.

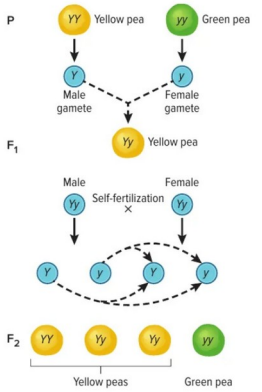

Figure 5 During the F_1 generation self-fertilization, the male gametes randomly fertilize the female gametes.

Do you have freckles like the boy in **Figure 6?** The appearance of freckles is a dominant trait that can be represented by (*F*). Suppose both of your parents have freckles and are heterozygous (*Ff*) for the trait. What possible phenotypes could you or your siblings have?



Figure 6 Freckles are a dominant trait.
Identify *the genotypes that can produce this phenotype.*

Realistic Reflections

Q03 | Learning outcome explanation (1/4)

Specific textbook focus: Law of independent assortment and the possible allele combinations in gametes; Figure 4.

Key terms (definitions for understanding the learning outcome; not all terms are necessarily examined in this particular reference):

Gene — A segment of DNA that contains information for a functional product and can influence an inherited trait.

Allele — An alternative version of a gene.

Genotype — The combination of alleles an organism carries for a particular gene, such as Yy.

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Q03 | Learning outcome explanation (2/4)

Phenotype — An observable characteristic produced by genotype and environmental influences.

Dominant allele — An allele whose effect appears in the heterozygous phenotype in complete dominance.

Recessive allele — An allele masked in a heterozygote under complete dominance; its phenotype appears when homozygous.

Homozygous — Having two identical alleles at a gene locus, such as YY or yy.

Heterozygous — Having two different alleles at a gene locus, such as Yy.

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Q03 | Learning outcome explanation (3/4)

Incomplete dominance — An inheritance pattern in which a heterozygote has an intermediate phenotype.

Codominance — An inheritance pattern in which both alleles are expressed in a heterozygote.

Sex-linked trait — A trait influenced by a gene located on a sex chromosome.

How to distinguish the concepts: genotype refers to allele combination; phenotype refers to observable expression. Complete dominance masks the recessive phenotype in heterozygotes; incomplete dominance is intermediate; codominance expresses both alleles.

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Q03 | Learning outcome explanation (4/4)

Study focus: Independent assortment; possible gametes. Read the exact cited textbook page and interpret its labeled diagram, table or question. The official coverage description identifies a broader learning outcome; the cited reference narrows the emphasis for this item.

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Q03 | Practice MCQ 1

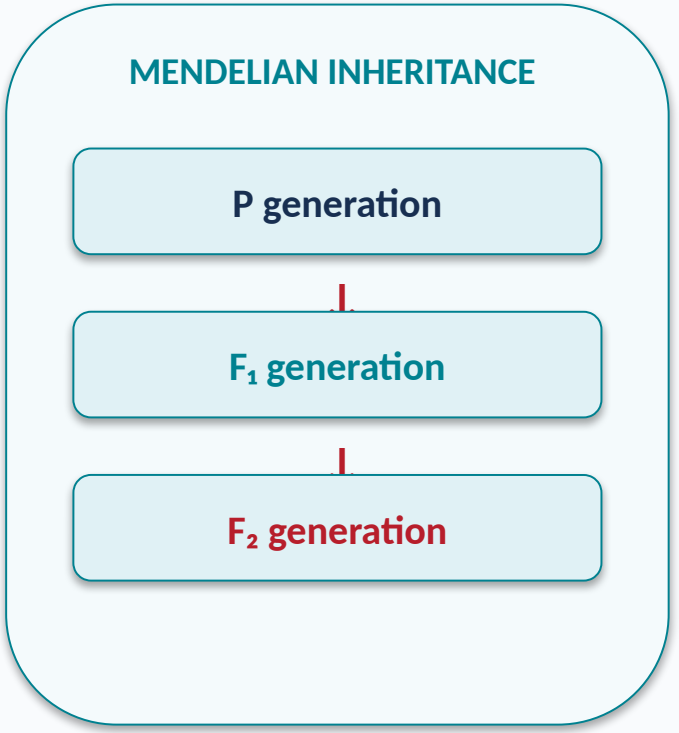
3.1 Which gamete combination is possible from genotype YyRr?

A. Yr

B. YY

C. Rr

D. Yy



Q03 | Practice MCQ 2

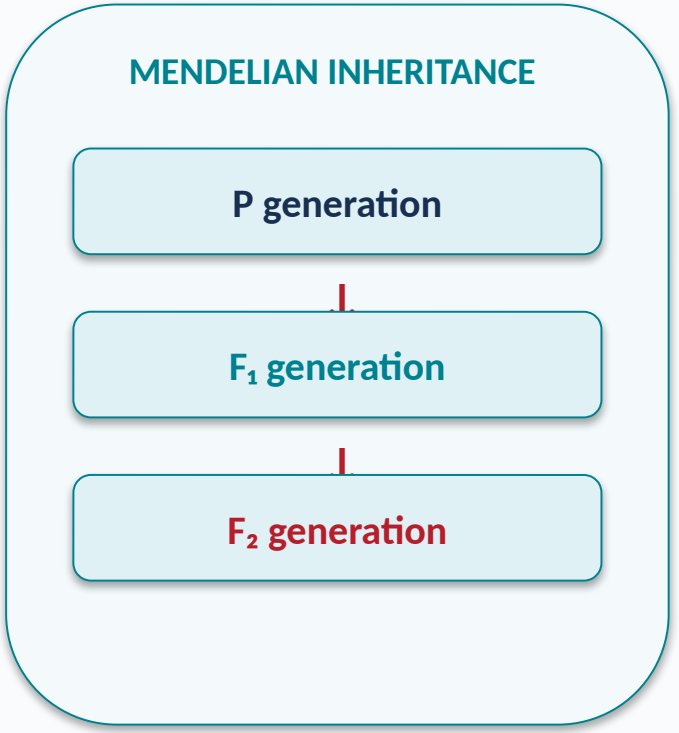
3.2 How many gamete allele combinations can YyRr produce by independent assortment?

A. 2

B. 8

C. 16

D. 4



Q03 | Practice MCQ 3

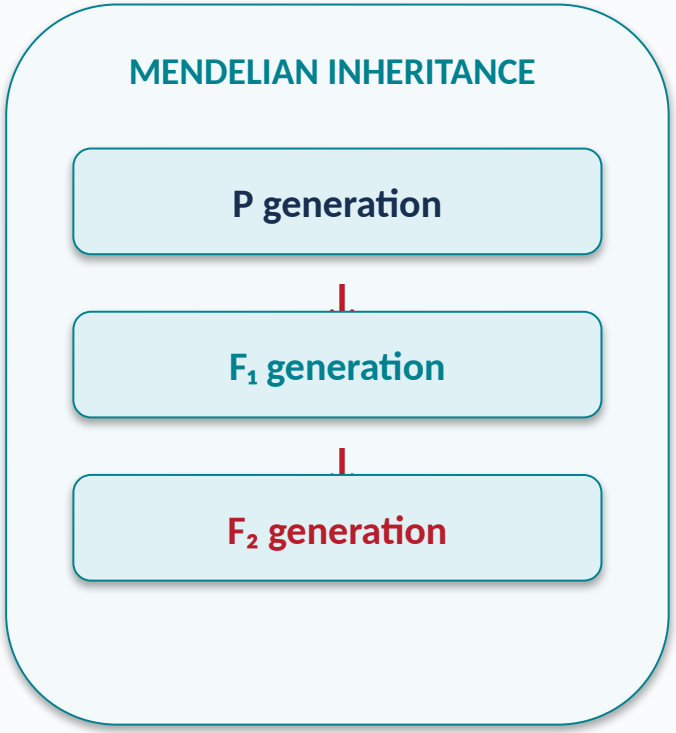
3.3 Which statement describes independent assortment?

A. All genes are linked

B. Offspring inherit only maternal genes

C. Alleles of different genes may segregate independently

D. Alleles of one gene always remain together



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Q03 | Practice MCQ 4

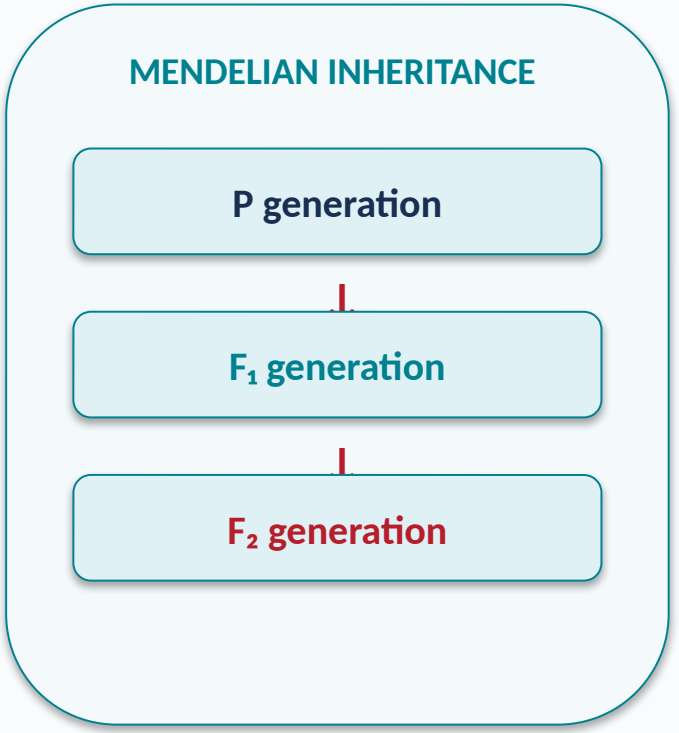
3.4 Which list contains all gametes from YyRr?

A. YR, YR, yr, yr

B. YR, Yr, yR, yr

C. YY, yy, RR, rr

D. Yy, Rr, YY, RR



Q03 | Practice MCQ 5

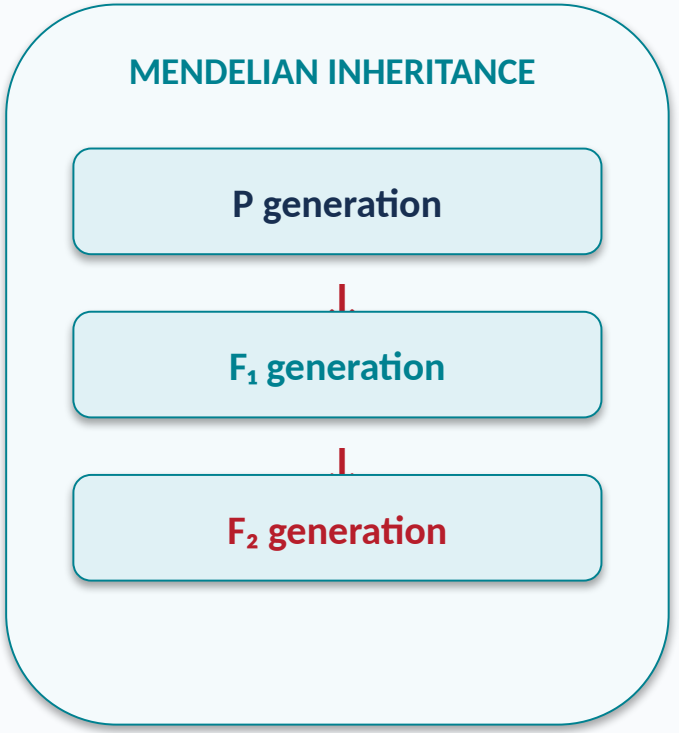
3.5 Why is independent assortment important?

A. It increases genetic variation

B. It eliminates recessive traits

C. It prevents fertilization

D. It copies DNA



Q04 | Official learning outcome

BIO.3.3.02.012: Use the Punnett square method to solve basic genetics problems involving monohybrid crosses, incomplete dominance, codominance, dihybrid crosses, and sex-linked genes.

EXACT COVERAGE: Q4 | Textbook printed page 9 | Figure 5

STUDY TARGET: Monohybrid cross; F1 genotype and phenotype predictions

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Q04 | Original textbook page

Examine the Punnett square in **Figure 7**. The number of squares is determined by the number of different types of alleles–*F* or *f*–produced by each parent. In this case, the square is 2 × 2 squares because each parent produces two different types of gametes. The male gametes are written across the horizontal side and the female gametes are written on the vertical side. The possible combinations of each male and female gamete are written on the inside of each corresponding square.

How many different genotypes are found in the Punnett square? One square has *FF*, two squares have *Ff*, and one square has *ff*. Therefore, the genotypic ratio of the possible offspring is 1:2:1. The phenotypic ratio of freckles to non freckles is 3:1.

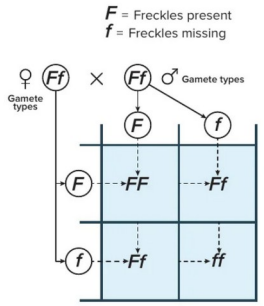
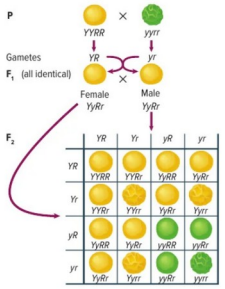


Figure 7 Freckles are a dominant trait. The Punnett square is a visual summary of the possible combinations of the alleles for the trait of freckles.

Dihybrid cross

Once Mendel established the inheritance patterns of a single trait, he began to examine simultaneous inheritance of two or more traits in the same plant. In garden peas, round seeds (*R*) are dominant to wrinkled seeds (*r*), and yellow seeds (*Y*) are dominant to green seeds (*y*). If Mendel crossed homozygous yellow, round-seed pea plants with homozygous green, wrinkle-seed pea plants, the P cross could be represented by *YYRR* × *yyrr*. The F_1 generation genotype would be *YyRr*–yellow, round-seed plants. These F_1-generation plants are called dihybrids because they are heterozygous for both traits.

Examine the Punnett square in **Figure 8**. The number of squares for a dihybrid cross in a Punnett square is determined by the number of different types of alleles–*YR*, *Yr*, *yR*, or *yr*–produced by each parent from the first filial generation (F_1). In this case, the square is 4 squares × 4 squares because each parent produces four different types of gametes. The male gametes are written across the horizontal side and the female gametes are written on the vertical side. The possible combinations of each male and female gamete are written on the inside of each corresponding square.



Type	Genotype	Phenotype	Number	Phenotypic ratio
Parental	*Y_R_*	yellow round	$\frac{315}{556}$	9:16
Recombinant	*yyR_*	green round	$\frac{108}{556}$	3:16
Recombinant	*Y_rr*	yellow wrinkled	$\frac{101}{556}$	3:16
Parental	*yyrr*	green wrinkled	$\frac{32}{556}$	1:16

Figure 8 The dihybrid Punnett square visually presents the possible combinations of the possible alleles from each parent.

Q04 | Learning outcome explanation (1/3)

Specific textbook focus: Predicting gametes and offspring of a monohybrid cross; Figure 5.

Key terms (definitions for understanding the learning outcome; not all terms are necessarily examined in this particular reference):

Punnett square — A diagram that combines possible parental gametes to predict offspring genotypes.

Monohybrid cross — A genetic cross examining one inherited characteristic.

Dihybrid cross — A genetic cross examining two inherited characteristics.

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Q04 | Learning outcome explanation (2/3)

Genotypic ratio — The relative frequencies of different allele combinations among offspring.

Phenotypic ratio — The relative frequencies of observable traits among offspring.

Probability — The likelihood that a particular genetic outcome will occur.

Worked approach: identify parental genotypes, list possible gametes, fill the Punnett square, count offspring genotypes, then translate them into phenotypes and probabilities.

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Q04 | Learning outcome explanation (3/3)

Study focus: Monohybrid Punnett square. Read the exact cited textbook page and interpret its labeled diagram, table or question. The official coverage description identifies a broader learning outcome; the cited reference narrows the emphasis for this item.

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Q04 | Practice MCQ 1

4.1 In a cross Ff × Ff, what fraction of offspring are ff?

A. 1/2

B. 3/4

C. 1

D. 1/4

PUNNETT SQUARE

	Y	y
Y	YY	Yy
y	Yy	yy

Allele combinations

Q04 | Practice MCQ 2

4.2 In Ff × Ff, what is the genotype ratio FF:Ff:ff?

A. 1:1:1

B. 2:1:1

C. 1:2:1

D. 3:1:0

PUNNETT SQUARE

	Y	y
Y	YY	Yy
y	Yy	yy

Allele combinations

FREIWAN

Q04 | Practice MCQ 3

4.3 If F is dominant for freckles, which genotype lacks freckles?

A. Both FF and Ff

B. ff

C. FF

D. Ff

PUNNETT SQUARE

	Y	y
Y	YY	Yy
y	Yy	yy

Allele combinations

Q04 | Practice MCQ 4

4.4 Which parental gametes are produced by Ff?

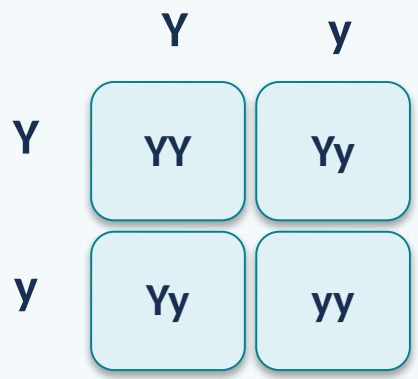
A. F and f

B. FF only

C. ff only

D. Ff only

PUNNETT SQUARE



Allele combinations

Q04 | Practice MCQ 5

4.5 What is the probability of a heterozygous offspring from Ff × Ff?

A. 1/4

B. 3/4

C. 1/8

D. 1/2

PUNNETT SQUARE

	Y	y
Y	YY	Yy
y	Yy	yy

Allele combinations

Q05 | Official learning outcome

BIO.3.3.02.012: Use the Punnett square method to solve basic genetics problems involving monohybrid crosses, incomplete dominance, codominance, dihybrid crosses, and sex-linked genes.

EXACT COVERAGE: Q5 | Textbook printed page 10 | Figure 7

STUDY TARGET: Punnett square for dominant and recessive alleles

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Q05 | Original textbook page

Probability

The inheritance of genes can be compared to the probability of flipping a coin, as shown in **Figure 9**. The probability of the coin landing on heads is 1 out of 2, or 1/2. If the same coin is flipped twice, the probability of it landing on heads is 1/2 each time or 1/2 × 1/2, or 1/4 both times.

Actual data might not perfectly match the predicted ratios. You know that if you flip a coin twice you might not get heads 1 out of the 2 times. You might get heads twice, or you might get tails twice. However, the more times you flip the coin, the closer your results will be to the predicted ratio of heads to tails. Mendel's experimental results were not exactly a 9:3:3:1 ratio. However, the larger the number of offspring involved in a cross, the more likely it will match the results predicted by the Punnett square.



Figure 9 The probability of inheritance of genes can be modeled by flipping a coin.

Check Your Progress

Summary

- The study of genetics begins with Gregor Mendel, whose experiments with garden pea plants gave insight into the inheritance of traits.
- Mendel developed the law of segregation and the law of independent assortment.
- Punnett squares help predict the offspring of a cross.

Demonstrate Understanding

1. **Diagram** Use a Punnett square to explain how a dominant allele masks the presence of a recessive allele.
2. **Apply** the law of segregation and the law of independent assortment by giving an example of each.
3. **Use a Punnett square** In fruit flies, red eyes (*R*) are dominant to pink eyes (*r*). What is the phenotypic ratio of a cross between a heterozygous male and a pink-eyed female?

Explain Your Thinking

4. **Evaluate** the significance of Mendel's work to the field of genetics.
5. **MATH Connection** What is the probability of rolling a 2 on a six-sided die? What is the probability of rolling two 2s on two six-sided dice? How is probability used in the study of genetics?

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Q05 | Learning outcome explanation (1/3)

Specific textbook focus: Monohybrid Punnett square and dominant/recessive phenotypes; Figure 7.

Key terms (definitions for understanding the learning outcome; not all terms are necessarily examined in this particular reference):

Punnett square — A diagram that combines possible parental gametes to predict offspring genotypes.

Monohybrid cross — A genetic cross examining one inherited characteristic.

Dihybrid cross — A genetic cross examining two inherited characteristics.

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Q05 | Learning outcome explanation (2/3)

Genotypic ratio — The relative frequencies of different allele combinations among offspring.

Phenotypic ratio — The relative frequencies of observable traits among offspring.

Probability — The likelihood that a particular genetic outcome will occur.

Worked approach: identify parental genotypes, list possible gametes, fill the Punnett square, count offspring genotypes, then translate them into phenotypes and probabilities.

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Q05 | Learning outcome explanation (3/3)

Study focus: Monohybrid cross and phenotype prediction. Read the exact cited textbook page and interpret its labeled diagram, table or question. The official coverage description identifies a broader learning outcome; the cited reference narrows the emphasis for this item.

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Q05 | Practice MCQ 1

5.1 In Yy × Yy, what fraction is expected to show the dominant trait?

A. 1/2

B. 1/8

C. 3/4

D. 1/4

PUNNETT SQUARE

	Y	y
Y	YY	Yy
y	Yy	yy

Allele combinations

Q05 | Practice MCQ 2

5.2 Which genotype is homozygous recessive?

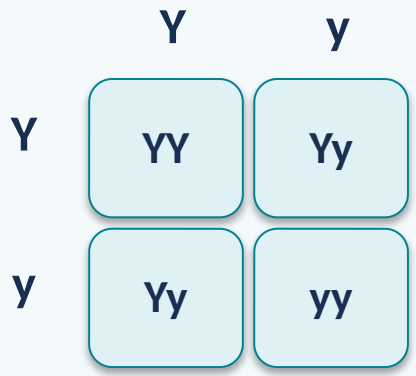
A. Y

B. yy

C. Yy

D. YY

PUNNETT SQUARE



Allele combinations

Q05 | Practice MCQ 3

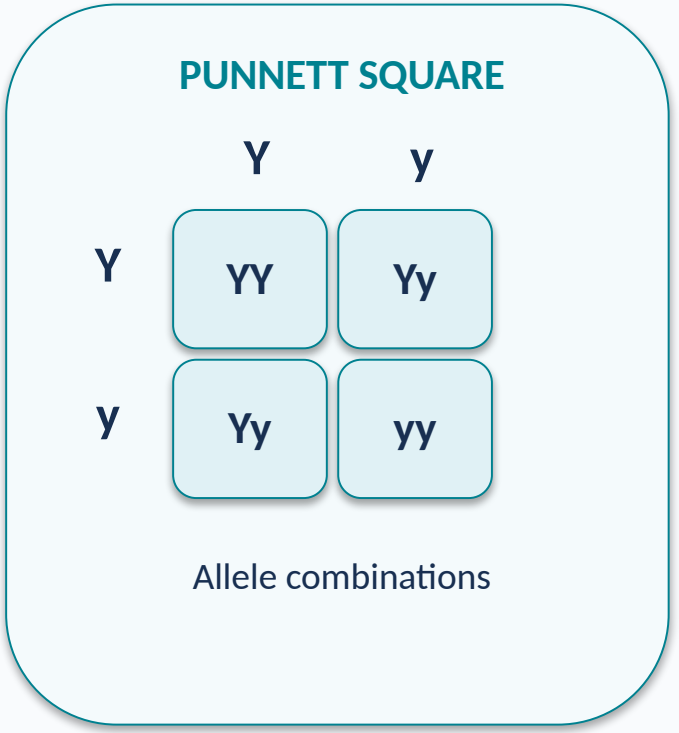
5.3 What does each box in a Punnett square represent?

A. A possible offspring allele combination

B. An actual offspring count

C. A parental chromosome number

D. A mutation rate



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Q05 | Practice MCQ 4

5.4 What is the probability of YY from Yy × Yy?

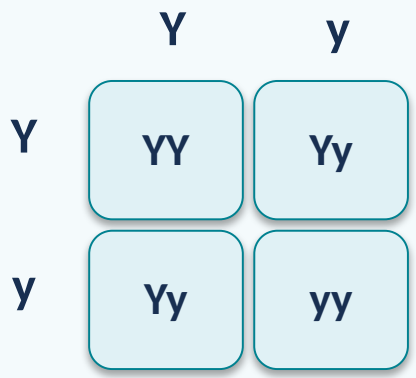
A. 50%

B. 75%

C. 100%

D. 25%

PUNNETT SQUARE



Allele combinations

Q05 | Practice MCQ 5

5.5 Why do Yy and YY share a phenotype under complete dominance?

A. Both are homozygous

B. They have identical genotypes

C. One dominant allele is sufficient

D. The recessive allele is absent in Yy

PUNNETT SQUARE

	Y	y
Y	YY	Yy
y	Yy	yy

Allele combinations

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Q06 | Official learning outcome

BIO.3.3.02.012: Use the Punnett square method to solve basic genetics problems involving monohybrid crosses, incomplete dominance, codominance, dihybrid crosses, and sex-linked genes.

EXACT COVERAGE: Q6 | Textbook printed page 10 | Figure 8

STUDY TARGET: Dihybrid Punnett square; genotype and phenotype ratios

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Q06 | Original textbook page

Probability

The inheritance of genes can be compared to the probability of flipping a coin, as shown in **Figure 9**. The probability of the coin landing on heads is 1 out of 2, or 1/2. If the same coin is flipped twice, the probability of it landing on heads is 1/2 each time or 1/2 × 1/2, or 1/4 both times.

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Figure 9 The probability of inheritance of genes can be modeled by flipping a coin.

Check Your Progress

Summary

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Explain Your Thinking

4. **Evaluate** the significance of Mendel's work to the field of genetics.
5. **MATH Connection** What is the probability of rolling a 2 on a six-sided die? What is the probability of rolling two 2s on two six-sided dice? How is probability used in the study of genetics?

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Q06 | Learning outcome explanation (1/3)

Specific textbook focus: Dihybrid Punnett square and predicted genotype/phenotype combinations; Figure 8.

Key terms (definitions for understanding the learning outcome; not all terms are necessarily examined in this particular reference):

Punnett square — A diagram that combines possible parental gametes to predict offspring genotypes.

Monohybrid cross — A genetic cross examining one inherited characteristic.

Dihybrid cross — A genetic cross examining two inherited characteristics.

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Q06 | Learning outcome explanation (2/3)

Genotypic ratio — The relative frequencies of different allele combinations among offspring.

Phenotypic ratio — The relative frequencies of observable traits among offspring.

Probability — The likelihood that a particular genetic outcome will occur.

Worked approach: identify parental genotypes, list possible gametes, fill the Punnett square, count offspring genotypes, then translate them into phenotypes and probabilities.

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Q06 | Learning outcome explanation (3/3)

Study focus: Dihybrid Punnett square. Read the exact cited textbook page and interpret its labeled diagram, table or question. The official coverage description identifies a broader learning outcome; the cited reference narrows the emphasis for this item.

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Q06 | Practice MCQ 1

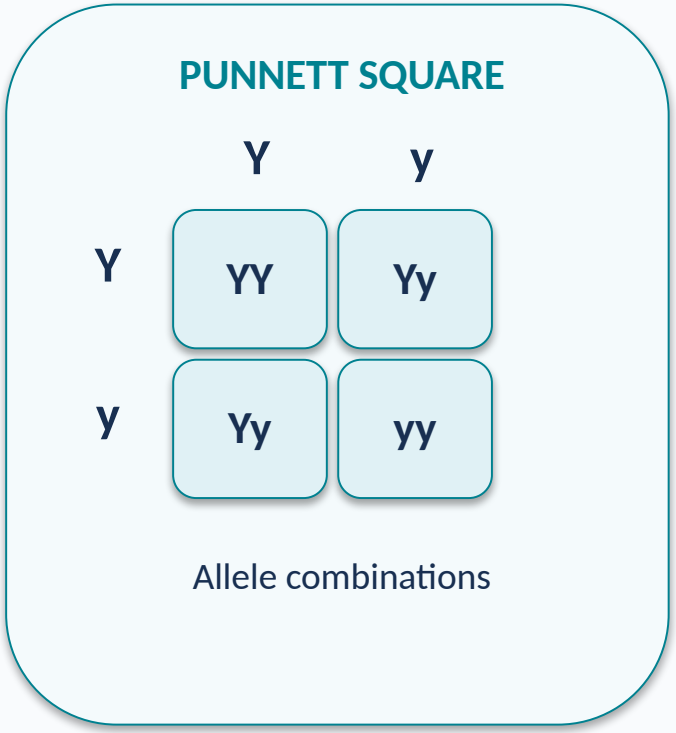
6.1 How many boxes are in a standard YyRr × YyRr Punnett square?

A. 32

B. 16

C. 4

D. 8



Q06 | Practice MCQ 2

6.2 What is the classic dihybrid phenotypic ratio for independently assorting genes with complete dominance?

A. 9:3:3:1

B. 3:1

C. 1:2:1

D. 1:1:1:1

PUNNETT SQUARE

	Y	y
Y	YY	Yy
y	Yy	yy

Allele combinations

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Q06 | Practice MCQ 3

6.3 Which gamete can a YyRr parent form?

A. Yy

B. Rr

C. YY

D. yR

PUNNETT SQUARE

	Y	y
Y	YY	Yy
y	Yy	yy

Allele combinations

FREIWAN

Q06 | Practice MCQ 4

6.4 What fraction of YyRr × YyRr offspring is yyrr?

A. 3/16

B. 9/16

C. 1/16

D. 1/4

PUNNETT SQUARE

	Y	y
Y	YY	Yy
y	Yy	yy

Allele combinations

FREIWAN

Q06 | Practice MCQ 5

6.5 What is the chance of both dominant phenotypes in this dihybrid cross?

A. 1/2

B. 9/16

C. 3/16

D. 1/16

PUNNETT SQUARE

	Y	y
Y	YY	Yy
y	Yy	yy

Allele combinations

Q07 | Official learning outcome

BIO.3.3.02.011 Explain the concepts of genotype, phenotype, dominance, incomplete dominance, codominance, recessiveness, and sex linkage according to Mendelian laws of inheritance.

EXACT COVERAGE: Q7 | Textbook printed page 12 | Math Connection

STUDY TARGET: Recombination probability and mathematical interpretation

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Q07 | Original textbook page

Linked genes usually travel together during meiosis. However, some results using the fruit fly *Drosophila melanogaster* revealed that linked genes do not always travel together during meiosis. Scientists concluded that linked genes can separate during crossing over. Recall that in sexual reproduction, chromosomes can sometimes swap sections during the process of meiosis, thereby creating new genetic combinations and thus more genetic variation. The linkage of genes on a chromosome results in an exception to Mendel's law of independent assortment because linked genes usually do not segregate independently.

Get It?
Analyze the effect of crossing over on linked genes.

Chromosome maps

Crossing over occurs more frequently between genes that are far apart than those that are close together. A drawing called a chromosome map shows the sequence of genes on a chromosome and can be created by using crossover data. The very first chromosome maps were published in 1913 using data from thousands of fruit fly crosses.

Figure 11 shows the first chromosome map created using fruit fly data. Recall that the higher the crossover frequency, the farther apart the two genes are. Genes that are closer together have a lower frequency of crossing over. In the example below, the genes for yellow body and white eyes are close together on the map because they show a low frequency of crossing over.

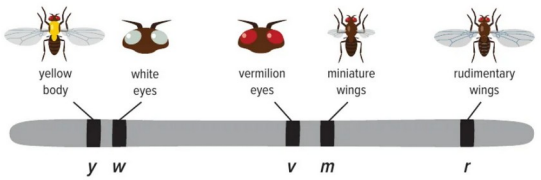

Figure 11 This chromosome map of the X chromosome of the fruit fly *Drosophila melanogaster* was created in 1913.

CCC CROSSCUTTING CONCEPTS
Scale, Proportion, and Quantity Geneticists measure the distance between genes on a chromosome using map units. A higher number of map units between two genes means they are farther apart on the chromosome. There are three genes on a chromosome: *c*, *t*, and *x*. The distance between the genes are: *c* and *t*: 20 map units; *c* and *x*: 10 map units; *t* and *x*: 2 map units. Explain which two genes are most likely to cross over. Cite evidence from the text in your response.

ACADEMIC VOCABULARY
confirmed
validated or made certain
Many crosses confirmed that linked genes usually travel together during meiosis.

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PRINTED TEXTBOOK PAGE

Q07 | Learning outcome explanation (1/4)

Specific textbook focus: Probability and the mathematical connection to genetic crosses.

Key terms (definitions for understanding the learning outcome; not all terms are necessarily examined in this particular reference):

Gene — A segment of DNA that contains information for a functional product and can influence an inherited trait.

Allele — An alternative version of a gene.

Genotype — The combination of alleles an organism carries for a particular gene, such as Yy.

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Q07 | Learning outcome explanation (2/4)

Phenotype — An observable characteristic produced by genotype and environmental influences.

Dominant allele — An allele whose effect appears in the heterozygous phenotype in complete dominance.

Recessive allele — An allele masked in a heterozygote under complete dominance; its phenotype appears when homozygous.

Homozygous — Having two identical alleles at a gene locus, such as YY or yy.

Heterozygous — Having two different alleles at a gene locus, such as Yy.

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Q07 | Learning outcome explanation (3/4)

Incomplete dominance — An inheritance pattern in which a heterozygote has an intermediate phenotype.

Codominance — An inheritance pattern in which both alleles are expressed in a heterozygote.

Sex-linked trait — A trait influenced by a gene located on a sex chromosome.

How to distinguish the concepts: genotype refers to allele combination; phenotype refers to observable expression. Complete dominance masks the recessive phenotype in heterozygotes; incomplete dominance is intermediate; codominance expresses both alleles.

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Q07 | Learning outcome explanation (4/4)

Study focus: Recombination calculations. Read the exact cited textbook page and interpret its labeled diagram, table or question. The official coverage description identifies a broader learning outcome; the cited reference narrows the emphasis for this item.

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Q07 | Practice MCQ 1

7.1 A recombination frequency of 12% means what proportion of offspring are recombinant?

A. 12%

B. 88%

C. 50%

D. 24%

PUNNETT SQUARE

	Y	y
Y	YY	Yy
y	Yy	yy

Allele combinations

Q07 | Practice MCQ 2

7.2 If 24 of 200 offspring are recombinant, what is the recombination frequency?

A. 24%

B. 6%

C. 48%

D. 12%

PUNNETT SQUARE

	Y	y
Y	YY	Yy
y	Yy	yy

Allele combinations

Q07 | Practice MCQ 3

7.3 Which calculation gives recombination frequency?

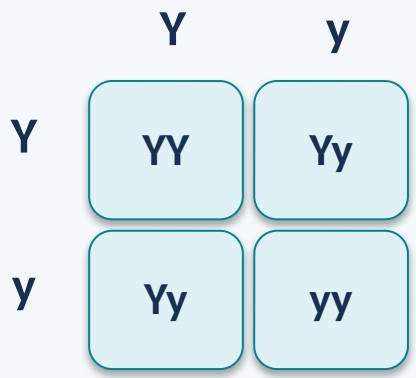
A. Total offspring × recombinants

B. Dominant offspring ÷ recessive offspring

C. Recombinants ÷ total offspring × 100

D. Parental offspring ÷ recombinants

PUNNETT SQUARE



Allele combinations

FREIWAN

Q07 | Practice MCQ 4

7.4 Which pair of genes is generally farther apart on a chromosome?

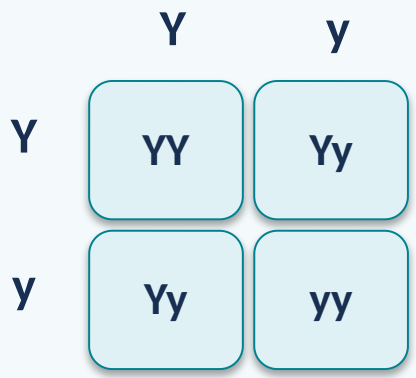
A. Genes with 1% recombination

B. Genes with 20% recombination

C. Genes with 2% recombination

D. Genes with 0% recombination

PUNNETT SQUARE



Allele combinations

FREIWAN

Q07 | Practice MCQ 5

7.5 What is the maximum observable recombination frequency for two genes?

A. 50%

B. 100%

C. 75%

D. 25%

PUNNETT SQUARE

	Y	y
Y	YY	Yy
y	Yy	yy

Allele combinations

Q08 | Official learning outcome

BIO.3.3.02.011 Explain the concepts of genotype, phenotype, dominance, incomplete dominance, codominance, recessiveness, and sex linkage according to Mendelian laws of inheritance.

EXACT COVERAGE: Q8 | Textbook printed page 12 | Gene Linkage

STUDY TARGET: Gene linkage and inheritance of nearby genes

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Q08 | Original textbook page

Linked genes usually travel together during meiosis. However, some results using the fruit fly *Drosophila melanogaster* revealed that linked genes do not always travel together during meiosis. Scientists concluded that linked genes can separate during crossing over. Recall that in sexual reproduction, chromosomes can sometimes swap sections during the process of meiosis, thereby creating new genetic combinations and thus more genetic variation. The linkage of genes on a chromosome results in an exception to Mendel's law of independent assortment because linked genes usually do not segregate independently.

Get It?
Analyze the effect of crossing over on linked genes.

Chromosome maps

Crossing over occurs more frequently between genes that are far apart than those that are close together. A drawing called a chromosome map shows the sequence of genes on a chromosome and can be created by using crossover data. The very first chromosome maps were published in 1913 using data from thousands of fruit fly crosses.

Figure 11 shows the first chromosome map created using fruit fly data. Recall that the higher the crossover frequency, the farther apart the two genes are. Genes that are closer together have a lower frequency of crossing over. In the example below, the genes for yellow body and white eyes are close together on the map because they show a low frequency of crossing over.

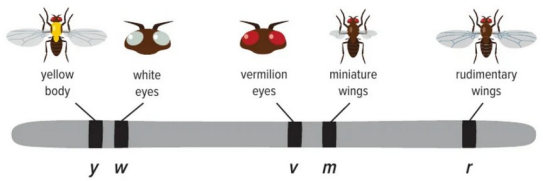

Figure 11 This chromosome map of the X chromosome of the fruit fly *Drosophila melanogaster* was created in 1913.

CCC CROSSCUTTING CONCEPTS
Scale, Proportion, and Quantity Geneticists measure the distance between genes on a chromosome using map units. A higher number of map units between two genes means they are farther apart on the chromosome. There are three genes on a chromosome: *c*, *t*, and *x*. The distance between the genes are: *c* and *t*: 20 map units; *c* and *x*: 10 map units; *t* and *x*: 2 map units. Explain which two genes are most likely to cross over. Cite evidence from the text in your response.

ACADEMIC VOCABULARY
confirmed
validated or made certain
Many crosses confirmed that linked genes usually travel together during meiosis.

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INTED TEXTBOOK PAGE

Q08 | Learning outcome explanation (1/2)

Specific textbook focus: Linked genes on the same chromosome and their tendency to travel together.

Key terms (definitions for understanding the learning outcome; not all terms are necessarily examined in this particular reference):

Genetic recombination — The formation of new allele combinations through independent assortment or crossing over.

Gene linkage — The tendency of genes located close together on the same chromosome to be inherited together.

Crossing over — Exchange of corresponding DNA segments between nonsister chromatids of homologous chromosomes during meiosis.

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Q08 | Learning outcome explanation (2/2)

Chromosome map — A diagram indicating gene order and relative positions on a chromosome.

Recombination frequency — The percentage of recombinant offspring; used to estimate distance between linked genes.

Study focus: Linked genes and crossing over. Read the exact cited textbook page and interpret its labeled diagram, table or question. The official coverage description identifies a broader learning outcome; the cited reference narrows the emphasis for this item.

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Q08 | Practice MCQ 1

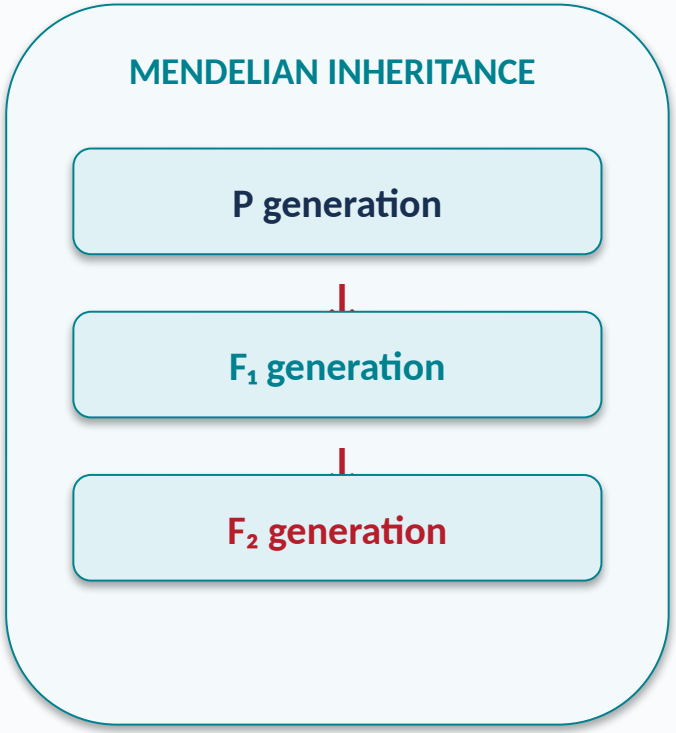
8.1 Where are linked genes located?

A. On different cells

B. Only on mitochondria

C. Only on homologous chromosomes of different pairs

D. On the same chromosome



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Q08 | Practice MCQ 2

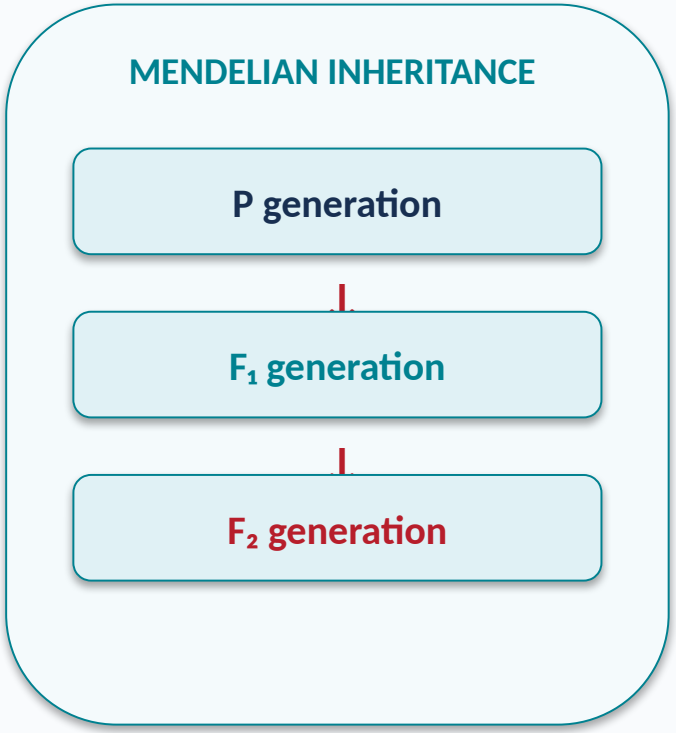
8.2 Why are closely linked genes often inherited together?

A. They cannot be expressed

B. They are recessive

C. Crossing over is less likely between them

D. They always have identical alleles



Q08 | Practice MCQ 3

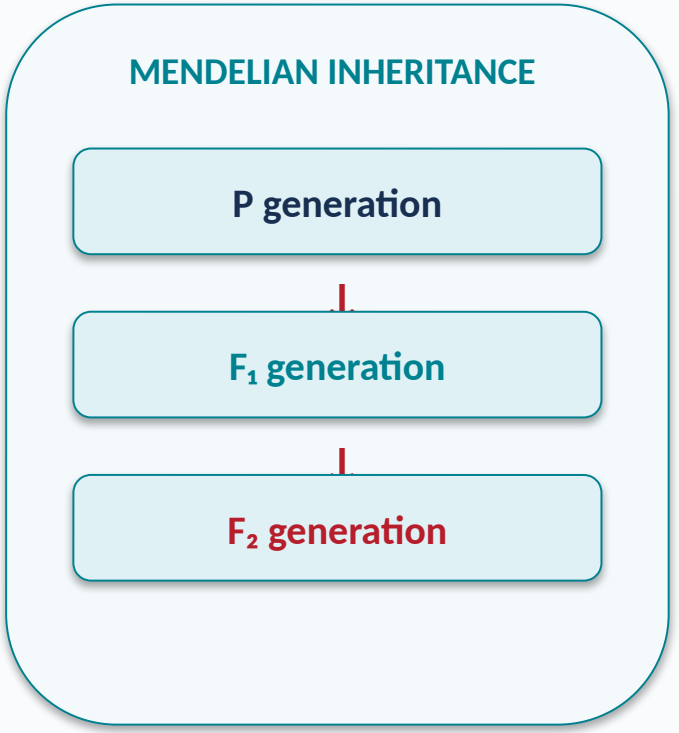
8.3 What can separate linked alleles?

A. Protein folding

B. Crossing over

C. DNA translation

D. Cytokinesis alone



FREIWAN

Q08 | Practice MCQ 4

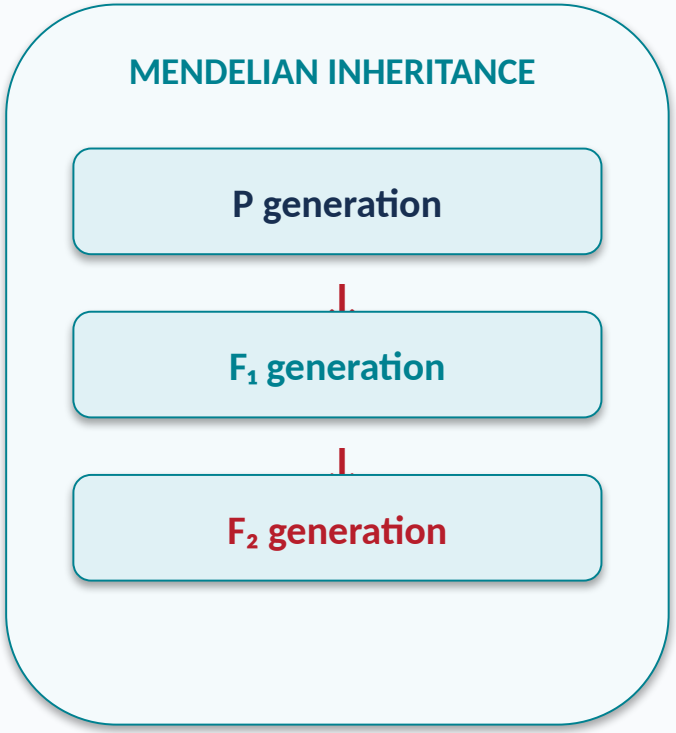
8.4 Which genes have the lowest recombination frequency?

A. Genes closest together

B. Genes farthest apart

C. Genes on different chromosomes

D. Genes assorting independently



Abedalsalam Freiwan | 0558847702

Q08 | Practice MCQ 5

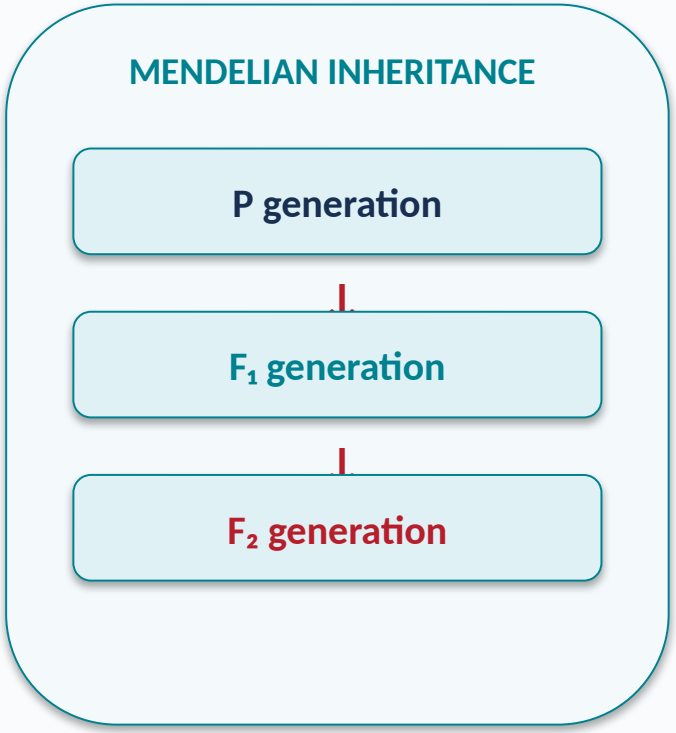
8.5 Which observation suggests linkage?

A. All offspring are recombinant

B. Recombination is exactly 50%

C. Each gene is absent in gametes

D. Parental combinations exceed recombinant combinations



FREIWAN

Q09 | Official learning outcome

BIO.3.3.01.036 Investigate that variations of inherited traits between parent and offspring arise from genetic differences that result either from the subset of chromosomes and therefore from inherited genes or rarely from mutations and show the variations of inherited traits in a pedigree.

EXACT COVERAGE: Q9 | Textbook printed page 13 | Get It

STUDY TARGET: Crossing over and its effects on linked genes

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0558847702

Q09 | Original textbook page

Polyploidy

Most species have diploid cells, but some have polyploid cells. **Polyploidy** is the occurrence of one or more extra sets of all chromosomes in an organism. A triploid organism, for instance, would be designated $3n$, which means that it has three complete sets of chromosomes. Polyploidy rarely occurs in animals. In humans, polyploidy is always lethal.



Figure 12 Various commercial plants, such as coffee, are polyploids.

Roughly one in three species of known flowering plants are polyploid. Polyploid plants are often selected for by plant growers for their desirable characteristics, such as large flowers. Commercially grown bread wheat ($6n$), oats ($6n$), sugar cane ($8n$), and strawberries ($8n$) are polyploid crop plants. Polyploid plants, such as the one that produced the coffee shown in **Figure 12**, often have increased vigor and larger size.

Get It?

Explain why plant growers often select for polyploid plants.

Check Your Progress

Summary

- Genetic recombination involves both crossing over and independent assortment.
- Early chromosome maps were created based on the linkage of genes on the chromosome.
- Polyploid organisms have one or more extra sets of chromosomes.

Demonstrate Understanding

1. **Analyze** how crossing over is related to variation.
2. **Draw** Suppose genes C and D are linked on one chromosome and genes c and d are linked on another chromosome. Assuming that crossing over does not take place, sketch the daughter cells resulting from meiosis, showing the chromosomes and position of the genes.
3. **Describe** how polyploidy is used in the field of agriculture.

Explain Your Thinking

4. **Construct** a chromosome map for genes *A*, *B*, *C* and D using the following crossing over data: *A* to *D* = 25 percent; *A* to *B* = 30 percent; *C* to *D* = 15 percent; *B* to *D* = 5 percent; *B* to *C* = 20 percent.
5. **Evaluate** what advantage polyploidy would give to a plant breeder.
6. **WRITING Connection** Write a short story describing a society with no genetic variation in humans.

LEARNSMART Go online to follow your personalized learning path to review, practice, and reinforce your understanding.

AB
VAN

Q09 | Learning outcome explanation (1/2)

Specific textbook focus: How crossing over can separate linked genes; the Get It prompt.

Key terms (definitions for understanding the learning outcome; not all terms are necessarily examined in this particular reference):

Genetic recombination — The formation of new allele combinations through independent assortment or crossing over.

Gene linkage — The tendency of genes located close together on the same chromosome to be inherited together.

Crossing over — Exchange of corresponding DNA segments between nonsister chromatids of homologous chromosomes during meiosis.

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Q09 | Learning outcome explanation (2/2)

Chromosome map — A diagram indicating gene order and relative positions on a chromosome.

Recombination frequency — The percentage of recombinant offspring; used to estimate distance between linked genes.

Study focus: Crossing over on linked genes. Read the exact cited textbook page and interpret its labeled diagram, table or question. The official coverage description identifies a broader learning outcome; the cited reference narrows the emphasis for this item.

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Q09 | Practice MCQ 1

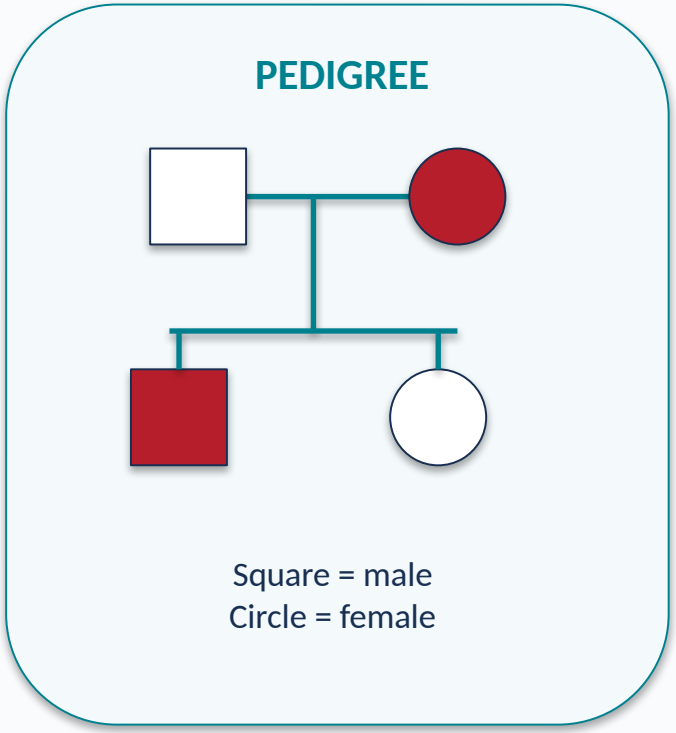
9.1 What is the effect of crossing over on linked genes?

A. It prevents genetic variation

B. It duplicates all genes

C. It can produce new allele combinations

D. It always removes a chromosome



Q09 | Practice MCQ 2

9.2 During which division does crossing over occur?

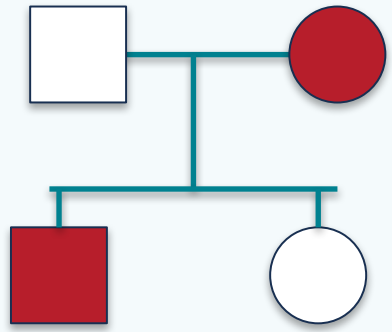
A. Binary fission

B. Meiosis I

C. Mitosis only

D. Meiosis II only

PEDIGREE



Square = male
Circle = female

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Q09 | Practice MCQ 3

9.3 Which chromosome structures exchange segments?

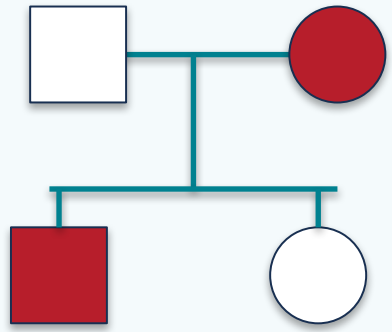
A. Nonsister chromatids of homologous chromosomes

B. Sister chromatids only

C. Unrelated chromosomes in different cells

D. Ribosomes

PEDIGREE



Square = male
Circle = female

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Q09 | Practice MCQ 4

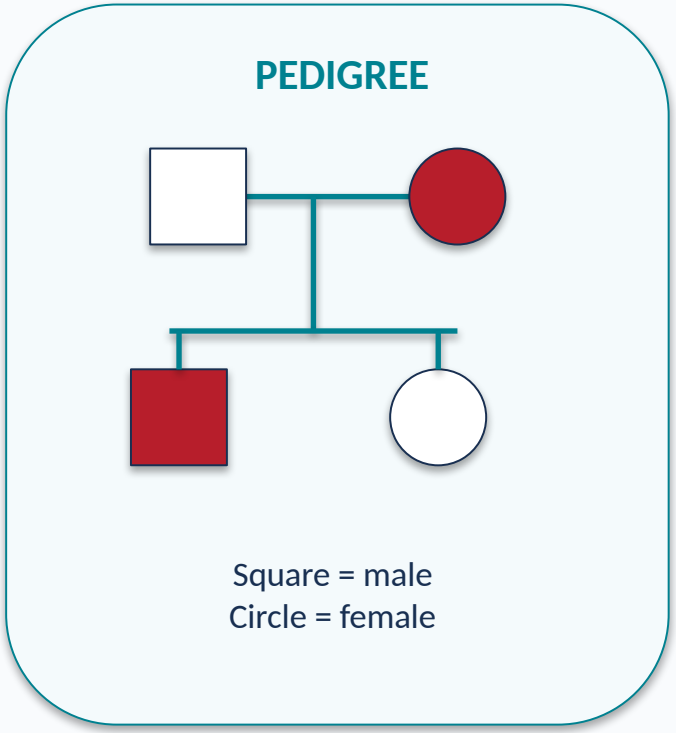
9.4 What is a recombinant chromosome?

A. A chromosome without DNA

B. An unchanged parental chromosome

C. A chromosome with no centromere

D. A chromosome with a new allele arrangement



Q09 | Practice MCQ 5

9.5 Why are distant linked genes more likely to recombine?

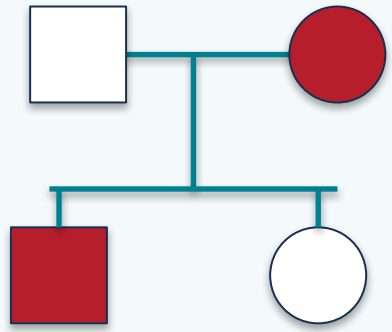
A. They never pair

B. They are always dominant

C. More opportunities exist for crossing over between them

D. They have fewer nucleotides

PEDIGREE



Square = male
Circle = female

FREIWAN

Q10 | Official learning outcome

BIO.3.3.01.036 Investigate that variations of inherited traits between parent and offspring arise from genetic differences that result either from the subset of chromosomes and therefore from inherited genes or rarely from mutations and show the variations of inherited traits in a pedigree.

EXACT COVERAGE: Q10 | Textbook printed page 13 | Figure 11

STUDY TARGET: Chromosome mapping in fruit flies and crossover frequency

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Q10 | Original textbook page

Polyploidy

Most species have diploid cells, but some have polyploid cells. **Polyploidy** is the occurrence of one or more extra sets of all chromosomes in an organism. A triploid organism, for instance, would be designated $3n$, which means that it has three complete sets of chromosomes. Polyploidy rarely occurs in animals. In humans, polyploidy is always lethal.



Figure 12 Various commercial plants, such as coffee, are polyploids.

Roughly one in three species of known flowering plants are polyploid. Polyploid plants are often selected for by plant growers for their desirable characteristics, such as large flowers. Commercially grown bread wheat ($6n$), oats ($6n$), sugar cane ($8n$), and strawberries ($8n$) are polyploid crop plants. Polyploid plants, such as the one that produced the coffee shown in **Figure 12**, often have increased vigor and larger size.

Get It?
Explain why plant growers often select for polyploid plants.

Check Your Progress

Summary

- Genetic recombination involves both crossing over and independent assortment.
- Early chromosome maps were created based on the linkage of genes on the chromosome.
- Polyploid organisms have one or more extra sets of chromosomes.

Demonstrate Understanding

1. **Analyze** how crossing over is related to variation.
2. **Draw** Suppose genes C and D are linked on one chromosome and genes c and d are linked on another chromosome. Assuming that crossing over does not take place, sketch the daughter cells resulting from meiosis, showing the chromosomes and position of the genes.
3. **Describe** how polyploidy is used in the field of agriculture.

Explain Your Thinking

4. **Construct** a chromosome map for genes *A*, *B*, *C* and D using the following crossing over data: *A* to *D* = 25 percent; *A* to *B* = 30 percent; *C* to *D* = 15 percent; *B* to *D* = 5 percent; *B* to *C* = 20 percent.
5. **Evaluate** what advantage polyploidy would give to a plant breeder.
6. **WRITING Connection** Write a short story describing a society with no genetic variation in humans.

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Q10 | Learning outcome explanation (1/2)

Specific textbook focus: Chromosome mapping and relative gene positions; Figure 11.

Key terms (definitions for understanding the learning outcome; not all terms are necessarily examined in this particular reference):

Genetic recombination — The formation of new allele combinations through independent assortment or crossing over.

Gene linkage — The tendency of genes located close together on the same chromosome to be inherited together.

Crossing over — Exchange of corresponding DNA segments between nonsister chromatids of homologous chromosomes during meiosis.

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Q10 | Learning outcome explanation (2/2)

Chromosome map — A diagram indicating gene order and relative positions on a chromosome.

Recombination frequency — The percentage of recombinant offspring; used to estimate distance between linked genes.

Study focus: Drosophila chromosome gene map. Read the exact cited textbook page and interpret its labeled diagram, table or question. The official coverage description identifies a broader learning outcome; the cited reference narrows the emphasis for this item.

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Q10 | Practice MCQ 1

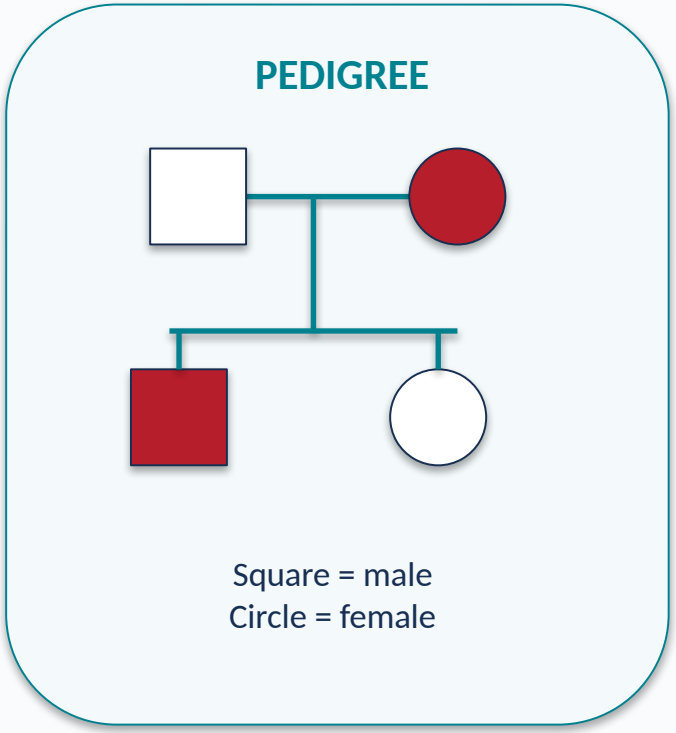
10.1 What does the gene map in Figure 11 show?

A. An entire pedigree

B. Relative positions of genes on a chromosome

C. Numbers of cells in a fly

D. Protein synthesis steps



FREIWAN

Q10 | Practice MCQ 2

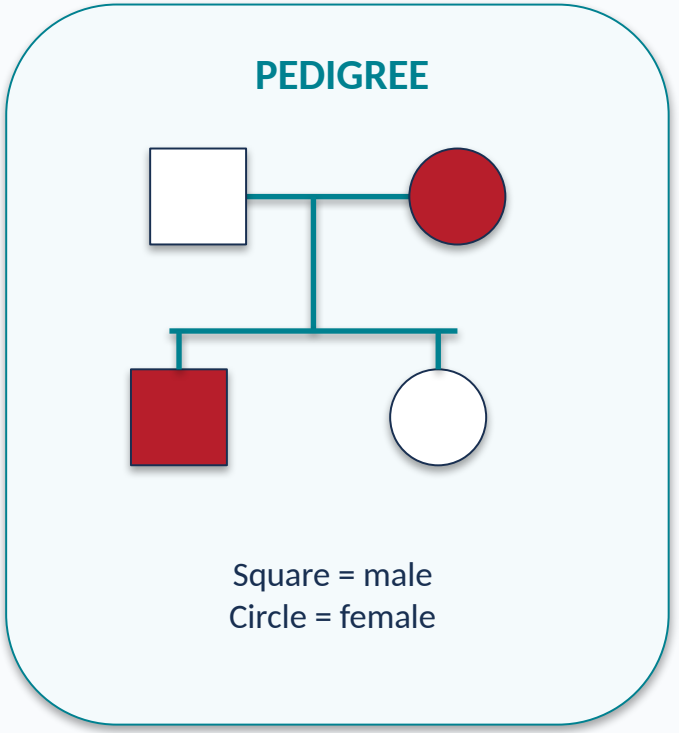
10.2 What does greater distance between mapped genes generally indicate?

A. Higher crossing-over frequency

B. Lower mutation rate always

C. Identical traits

D. No inheritance



Q10 | Practice MCQ 3

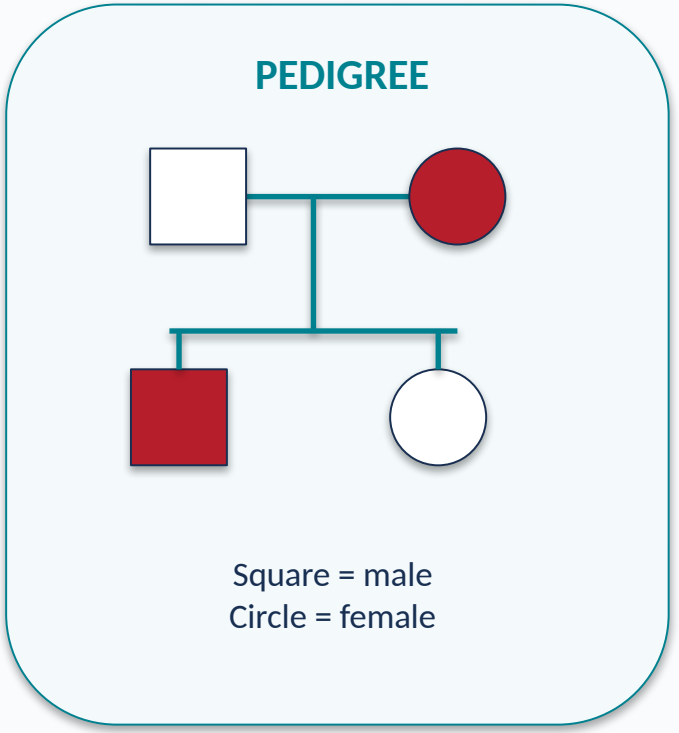
10.3 What organism is used for the gene map?

A. Garden pea

B. Human

C. Rabbit

D. Fruit fly (Drosophila)



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Q10 | Practice MCQ 4

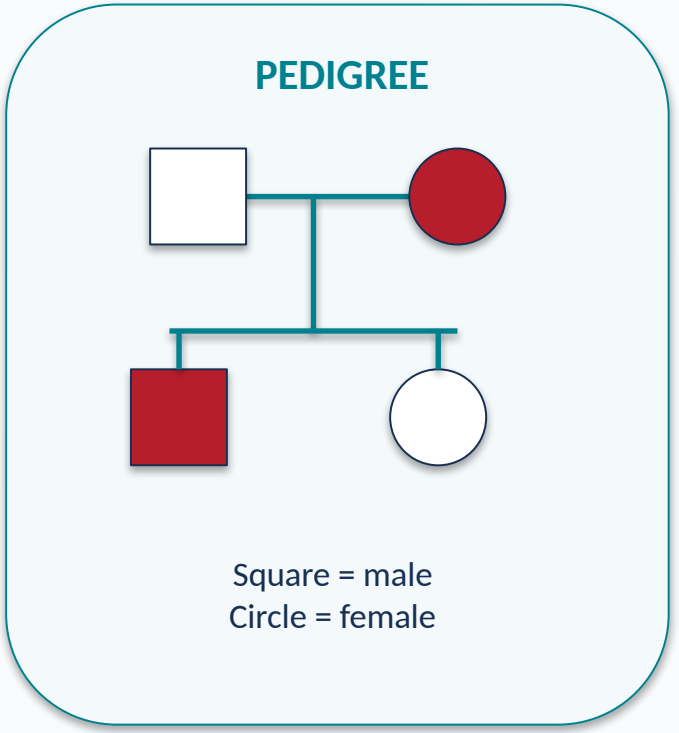
10.4 What is the purpose of a chromosome map?

A. To identify protein shapes

B. To measure cell size

C. To estimate gene order and relative distances

D. To count ribosomes



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Q10 | Practice MCQ 5

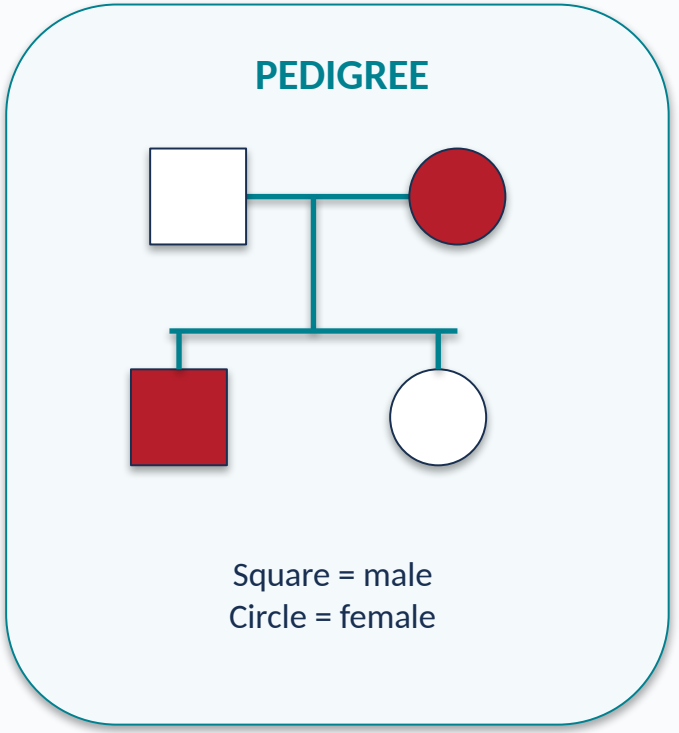
10.5 Which gene pairs are most tightly linked?

A. Those in separate organisms

B. Those located nearest each other

C. Those on different chromosomes

D. Those with 50% recombination



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Q11 | Official learning outcome

BIO.3.3.01.036 Investigate that variations of inherited traits between parent and offspring arise from genetic differences that result either from the subset of chromosomes and therefore from inherited genes or rarely from mutations and show the variations of inherited traits in a pedigree.

EXACT COVERAGE: Q11 | Textbook printed page 14 | Figure 12

STUDY TARGET: Polyploid organisms and chromosome sets

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Q11 | Original textbook page

LESSON 3

APPLIED GENETICS

FOCUS QUESTION

What are examples of selective breeding?

Selective Breeding

You might be familiar with different breeds of dogs, such as Saint Bernards, huskies, and German shepherds. Observe some of the phenotypic traits of these breeds in **Figure 13**. All three have strong, muscular bodies. Saint Bernards have traits such as a keen sense of smell that make them good rescue dogs. Huskies are endurance runners and pull sleds long distances. German shepherds are highly trainable for special services. Since ancient times, humans have bred animals with certain traits to obtain offspring that have desired traits. As a result, these traits become more common. Breeding for desired traits is not restricted to animals alone. Plants also are bred to produce desired traits, such as larger fruits and shorter growing times. The process by which desired traits of certain plants and animals are selected and passed on to their future generations is called **selective breeding.** Through the processes of hybridization and inbreeding, desired traits can be passed on to future generations.



(l)GlobalP/iStock/Getty Images; (c)Dora Zett/Shutterstock.com; (r)G.K. & Vikki Hart/Photodisc/Getty Images

Figure 13 Dogs have traits that make them suited for different tasks: Saint Bernard—keen sense of smell; husky—endurance to run long distances; and German shepherd—high trainability.

3D THINKING DCI Disciplinary Core Ideas CCC Crosscutting Concepts SEP Science & Engineering Practices

COLLECT EVIDENCE

Use your Science Journal to record the evidence you collect as you complete the readings and activities in this lesson.

INVESTIGATE

GO ONLINE to find these activities and more resources.

Quick Investigation: Model Hybridization

Use a model to determine the effect hybridization has on lily production.

Review the News

Obtain information from a current news story about the applied genetics and selective breeding. Evaluate your source and communicate your findings to your class.

AB
VAN

Q11 | Learning outcome explanation (1/2)

Specific textbook focus: Polyploidy and its effects in plants; Figure 12.

Key terms (definitions for understanding the learning outcome; not all terms are necessarily examined in this particular reference):

Genetic recombination — The formation of new allele combinations through independent assortment or crossing over.

Gene linkage — The tendency of genes located close together on the same chromosome to be inherited together.

Crossing over — Exchange of corresponding DNA segments between nonsister chromatids of homologous chromosomes during meiosis.

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Q11 | Learning outcome explanation (2/2)

Chromosome map — A diagram indicating gene order and relative positions on a chromosome.

Recombination frequency — The percentage of recombinant offspring; used to estimate distance between linked genes.

Study focus: Polyploidy in plants. Read the exact cited textbook page and interpret its labeled diagram, table or question. The official coverage description identifies a broader learning outcome; the cited reference narrows the emphasis for this item.

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Q11 | Practice MCQ 1

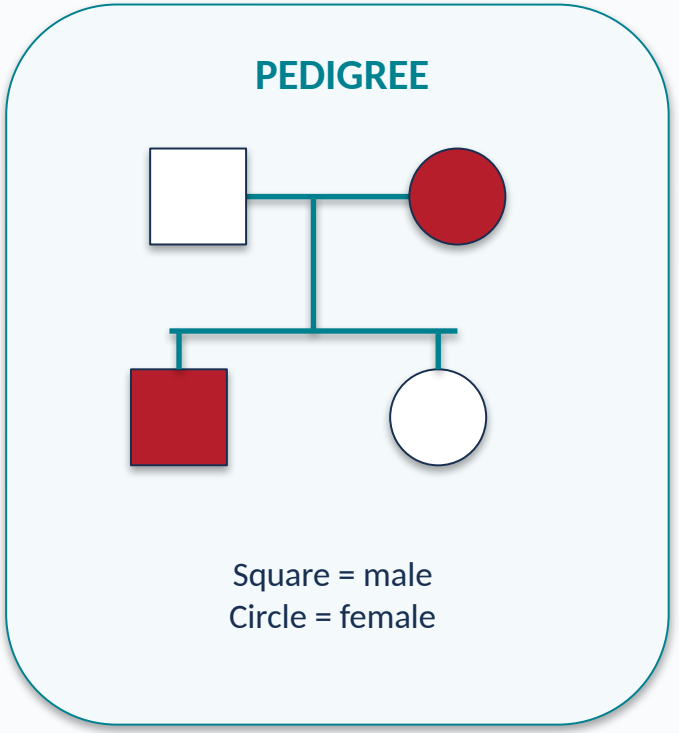
11.1 What does polyploidy mean?

A. More than two complete chromosome sets

B. Loss of every chromosome

C. Only one allele per gene

D. Two different phenotypes



FREIWAN

Q11 | Practice MCQ 2

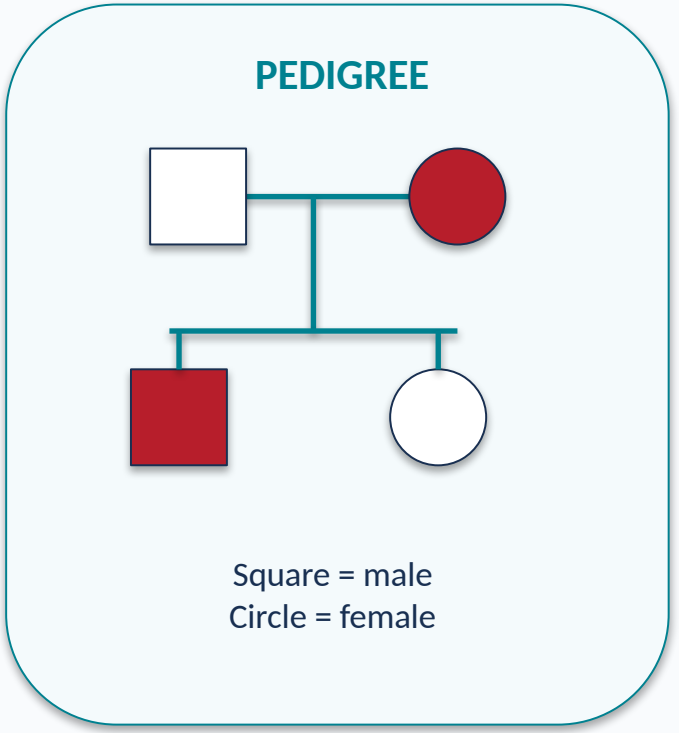
11.2 Which group commonly includes polyploid species?

A. Viruses only

B. Bacteria only

C. All mammals

D. Flowering plants



Q11 | Practice MCQ 3

11.3 Which characteristic may result from polyploidy in cultivated plants?

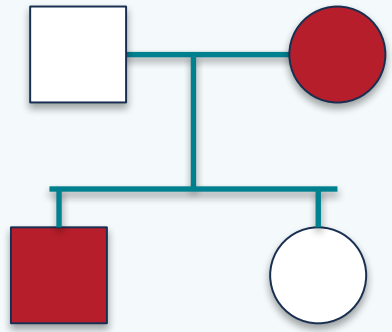
A. No reproduction in any case

B. Loss of all traits

C. Larger flowers or fruits

D. Absence of DNA

PEDIGREE



Square = male
Circle = female

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Q11 | Practice MCQ 4

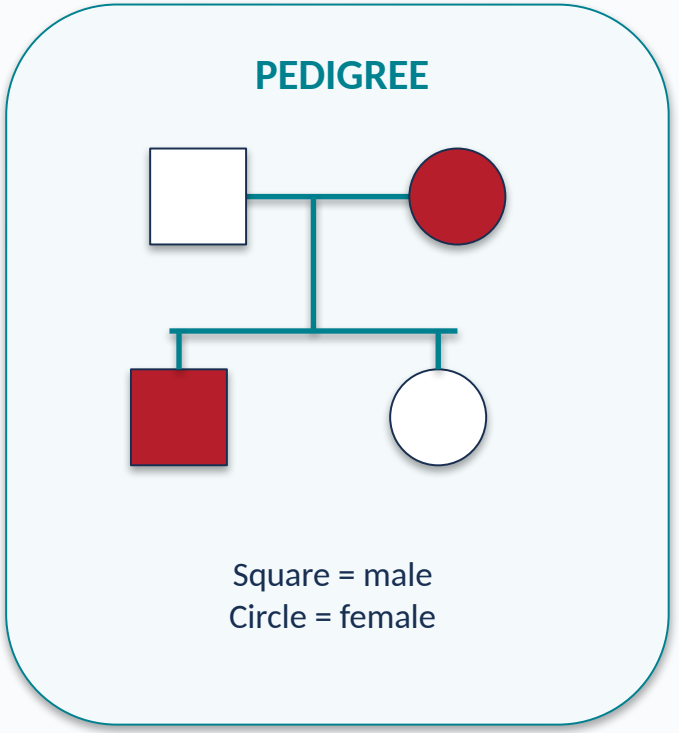
11.4 How is a tetraploid represented?

A. 3 chromosomes

B. 4n

C. n

D. 2n



Q11 | Practice MCQ 5

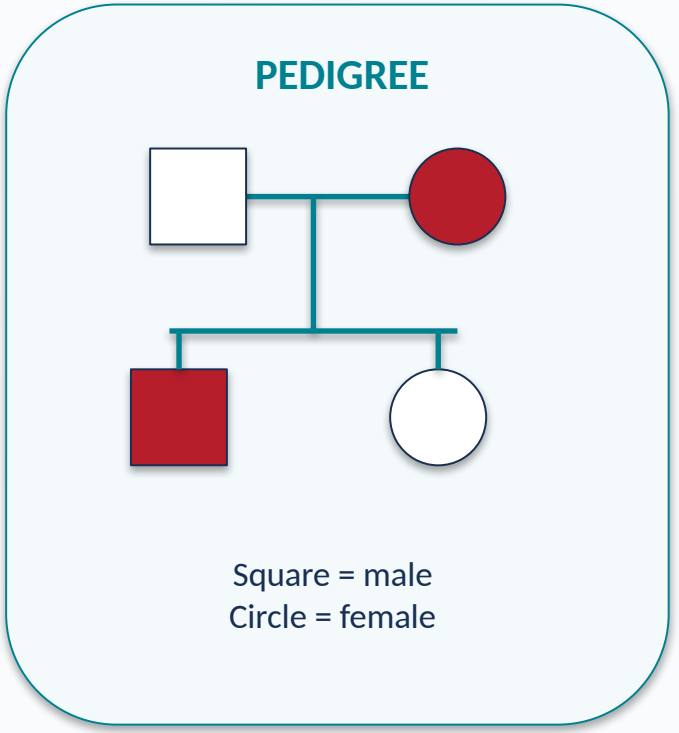
11.5 Why might growers select polyploid plants?

A. Desirable size or yield traits

B. To eliminate all variation

C. To prevent photosynthesis

D. To remove chromosomes entirely



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Q12 | Official learning outcome

BIO.3.2.04.010: Explain that in artificial selection, humans have the capacity to influence certain characteristics of organisms through selective breeding.

EXACT COVERAGE: Q12 | Textbook printed page 15 | Figure 13

STUDY TARGET: Artificial selection of traits in dog breeds

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Q12 | Original textbook page

Hybridization

Crossing parent organisms with different forms of a trait to produce offspring with specific traits results in hybrids. Farmers, animal breeders, scientists, and gardeners often use the production of hybrids, also known as hybridization. They select traits that will give hybrid organisms a competitive edge, such as disease-resistance or faster growth. For example, plant breeders might choose to cross two different varieties of tomato plants in order to produce a hybrid that has both the disease resistance of one parent and the fast growth rate of the other parent.

Care must be taken to cross organisms to yield the right combination of traits from both parents. A disadvantage of hybridization is that it is time consuming and expensive. For example, it took rice breeders three decades to produce hybrid rice varieties that can produce higher yields than nonhybrid varieties. Because hybrids can be bred to be more nutritious, to have the ability to adapt to a wide range of changes in the environment, and to produce greater numbers of offspring, the advantages of hybridization sometimes outweigh the disadvantages.

Inbreeding

Once a breeder observes a desired trait in an organism, a process is needed to ensure that the trait is passed on to future generations. This process, in which two closely related organisms are bred to have the desired traits and to eliminate the undesired ones in future generations, is called **inbreeding.**

Pure breeds are maintained by inbreeding. Clydesdale horses, Angus cattle, and German shepherd dogs are all examples of organisms produced by inbreeding. You might have seen Clydesdale horses at parades and petting zoos. Horse breeders first bred the Clydesdale horse in Scotland hundreds of years ago for use as a farm horse. Because of their strong build, agility, and obedient nature, Clydesdales originally were inbred and used extensively for pulling heavy loads.

A disadvantage of inbreeding is that harmful recessive traits also can be passed on to future generations. Inbreeding increases the chance of homozygous recessive offspring. If both parents carry the recessive allele for a harmful trait, that harmful trait likely will not be eliminated.

Get It?
Describe the disadvantages associated with hybridization and inbreeding.

Test Cross

When producing a hybrid, breeders must determine the genotype of the hybrid. The genotype is determined by performing a test cross. A **test cross** involves breeding an organism that has the unknown genotype with one that is homozygous recessive for the desired trait. If the parent's genotype is homozygous dominant, all the offspring will have the dominant phenotype; if it is heterozygous, the offspring will show a 1:1 phenotypic ratio.

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ED TEXTBOOK PAGE

Q12 | Learning outcome explanation (1/2)

Specific textbook focus: Selective breeding and variation among dog breeds; Figure 13.

Key terms (definitions for understanding the learning outcome; not all terms are necessarily examined in this particular reference):

Artificial selection — Human-directed breeding that increases the frequency of desired inherited characteristics.

Selective breeding — Choosing parents with desired traits to produce offspring with those traits.

Hybridization — Crossing genetically different organisms to combine desirable traits.

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Q12 | Learning outcome explanation (2/2)

Inbreeding — Mating closely related organisms to preserve particular characteristics.

Test cross — Crossing an organism with a dominant phenotype to a homozygous recessive organism to help infer genotype.

Study focus: Selective breeding in dogs. Read the exact cited textbook page and interpret its labeled diagram, table or question. The official coverage description identifies a broader learning outcome; the cited reference narrows the emphasis for this item.

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Q12 | Practice MCQ 1

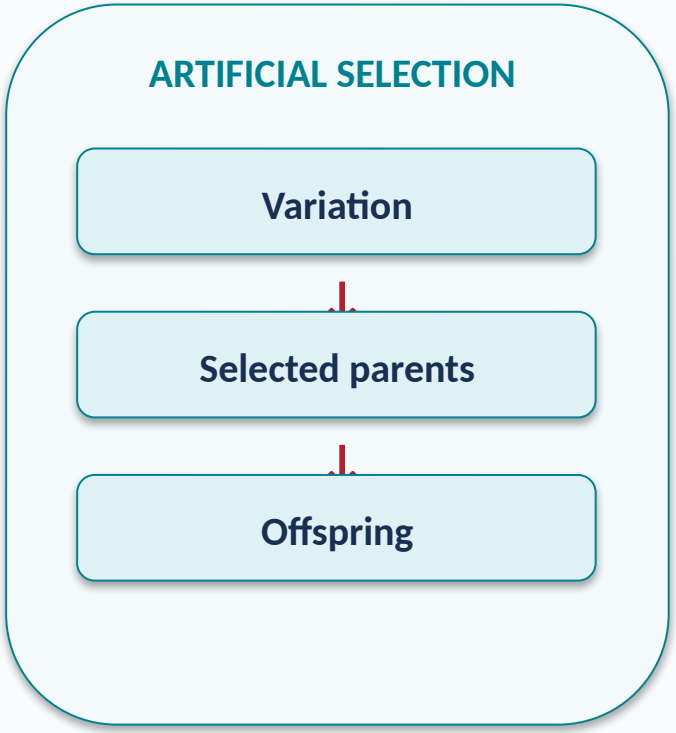
12.1 What is selective breeding?

A. Randomly selecting all parents

B. Changing the genetic code of every cell directly

C. Preventing inheritance

D. Choosing parents with desired traits



Q12 | Practice MCQ 2

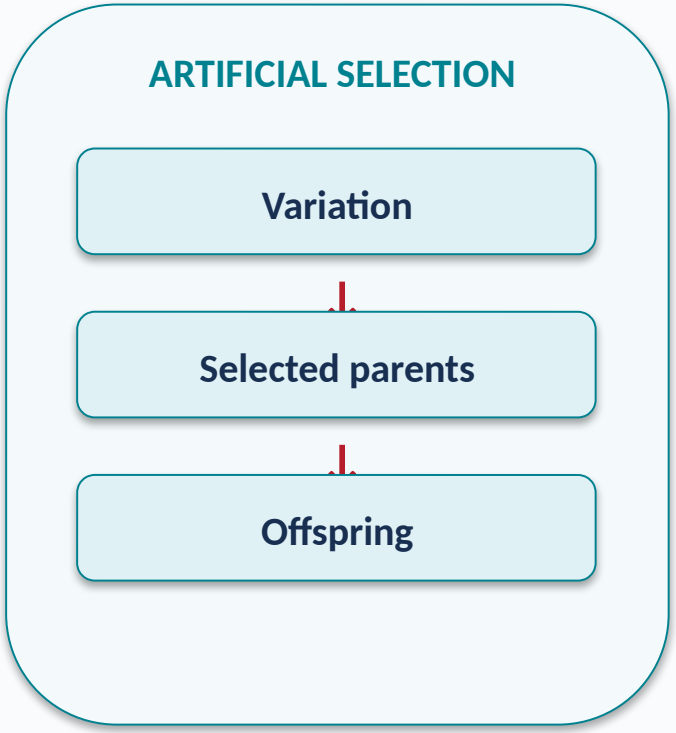
12.2 What do different dog breeds illustrate?

A. Independent species origins only

B. Asexual reproduction

C. Human selection of inherited traits

D. Absence of genetic variation



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Q12 | Practice MCQ 3

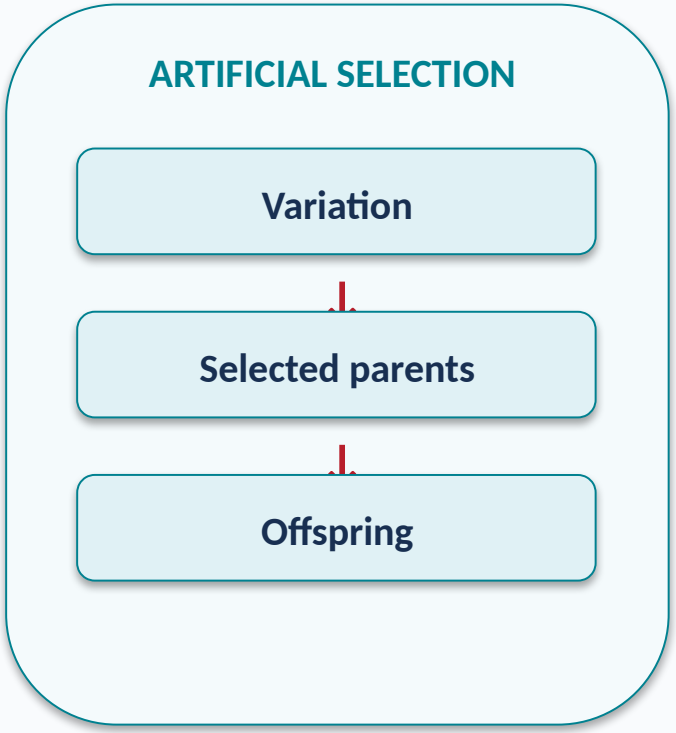
12.3 Why might breeders choose particular dogs?

A. To create chromosomes

B. To increase desired traits in offspring

C. To remove every recessive allele

D. To stop fertilization



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Q12 | Practice MCQ 4

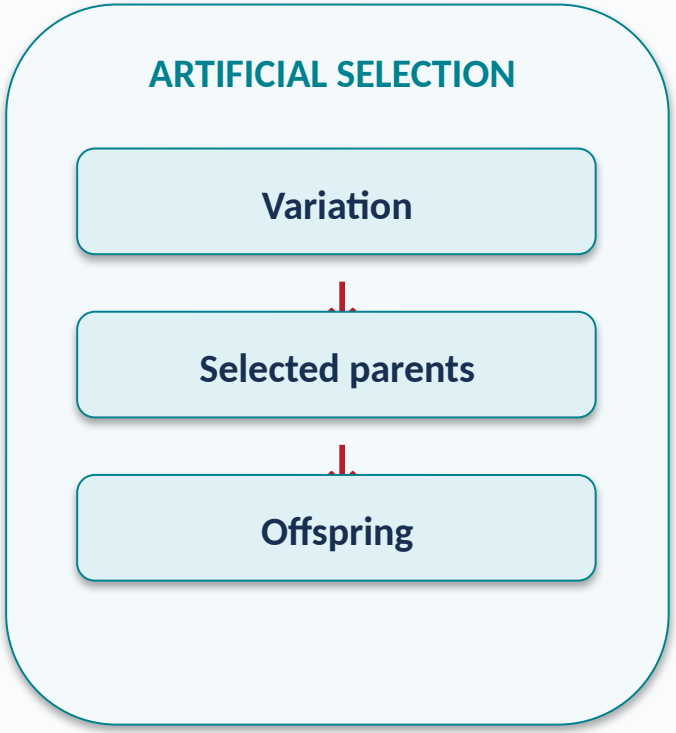
12.4 Which is an example of artificial selection?

A. Breeding dogs for herding ability

B. Wind dispersing seeds

C. Predators selecting prey

D. Random fertilization without human choice



Q12 | Practice MCQ 5

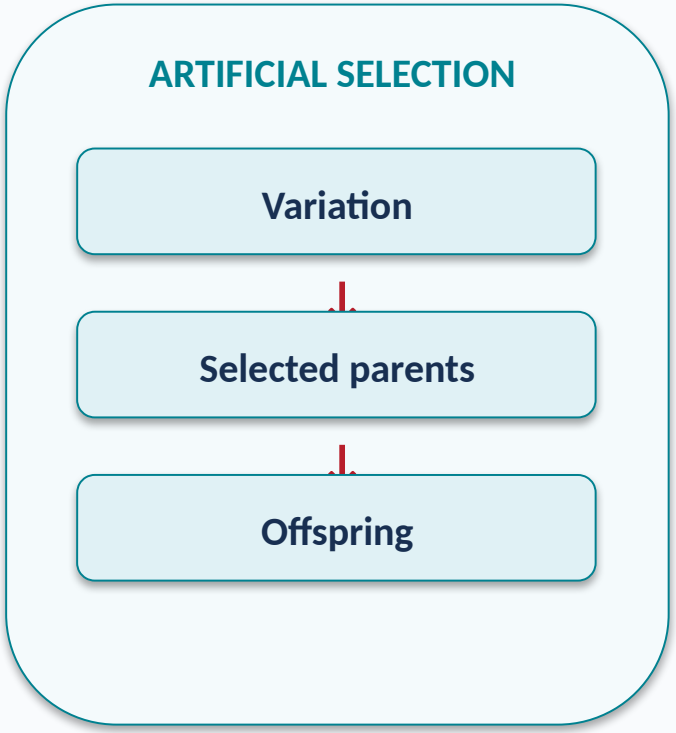
12.5 What must a selected trait generally be for breeding to work?

A. Always acquired by training

B. Always recessive

C. Unrelated to genes

D. Heritable



Q13 | Official learning outcome

BIO.3.2.04.010: Explain that in artificial selection, humans have the capacity to influence certain characteristics of organisms through selective breeding.

EXACT COVERAGE: Q13 | Textbook printed page 16 | Get It

STUDY TARGET: Hybridization versus inbreeding; advantages and disadvantages

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Q13 | Original textbook page

Performing a test cross

Suppose a breeder wants to produce hybrid white grapefruits. In grapefruit trees, white fruit color is the dominant trait; red is recessive. Therefore, the red grapefruit trees in the orchard must be homozygous recessive *(ww)*. The genotype of the hybrid white grapefruit tree can be homozygous dominant *(WW)* or heterozygous *(Ww)*. The breeder can use a test cross to determine the genotype of the white grapefruit tree. When performing a cross, pollen from the flower of one plant is transferred to the female organ in a flower of another plant.

As shown in the top Punnett square in **Figure 14,** if the white grapefruit tree is homozygous dominant *(WW)* and is crossed with a red grapefruit tree *(ww)*, then all the offspring will be heterozygous *(Ww)* and white in color; the dominant phenotype. However, as shown in the second Punnett square in **Figure 14,** if the white grapefruit tree is heterozygous *(Ww)*, then half the number of offspring will be white and half will be red, and the phenotypic ratio will be 1:1.

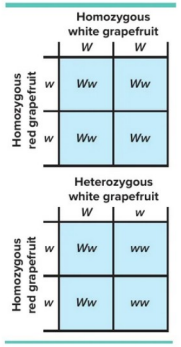

Figure 14 The genotype of a white grapefruit tree can be determined by a test cross.

Explain *How does a test cross show the relationship between genotype and phenotype?*

Check Your Progress

Summary

- Selective breeding is used to produce organisms with traits that are considered desirable.
- Hybridization produces organisms with desired traits from parent organisms with different traits.
- Inbreeding creates pure breeds.
- A test cross can be used to determine an organism's genotype.

Demonstrate Understanding

1. **Assess** the effect of selective breeding on food crops.
2. **Describe** three traits that might be desired in sheep. How can these traits be passed on to the next generation? Explain.
3. **Compare** and contrast inbreeding and hybridization.
4. **Predict** the phenotype of offspring from a test cross between a seedless orange (ss) and an orange with seeds (Ss).

Explain Your Thinking

5. **Evaluate** Should a cow and a bull that both carry recessive alleles for a mutation that causes decreased milk production be bred? Explain your answer using probability.
6. MATH Connection A breeder performs a test cross to determine the genotype of a black cat. He crosses the black cat (*BB* or *Bb*) with a white cat (*bb*). If 50 percent of the offspring are black, what is the genotype of the black cat?

LEARNSMART Go online to follow your personalized learning path to review, practice, and reinforce your understanding.

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Q13 | Learning outcome explanation (1/2)

Specific textbook focus: Advantages and disadvantages of hybridization and inbreeding; Get It.

Key terms (definitions for understanding the learning outcome; not all terms are necessarily examined in this particular reference):

Artificial selection — Human-directed breeding that increases the frequency of desired inherited characteristics.

Selective breeding — Choosing parents with desired traits to produce offspring with those traits.

Hybridization — Crossing genetically different organisms to combine desirable traits.

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Q13 | Learning outcome explanation (2/2)

Inbreeding — Mating closely related organisms to preserve particular characteristics.

Test cross — Crossing an organism with a dominant phenotype to a homozygous recessive organism to help infer genotype.

Study focus: Hybridization and inbreeding. Read the exact cited textbook page and interpret its labeled diagram, table or question. The official coverage description identifies a broader learning outcome; the cited reference narrows the emphasis for this item.

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Q13 | Practice MCQ 1

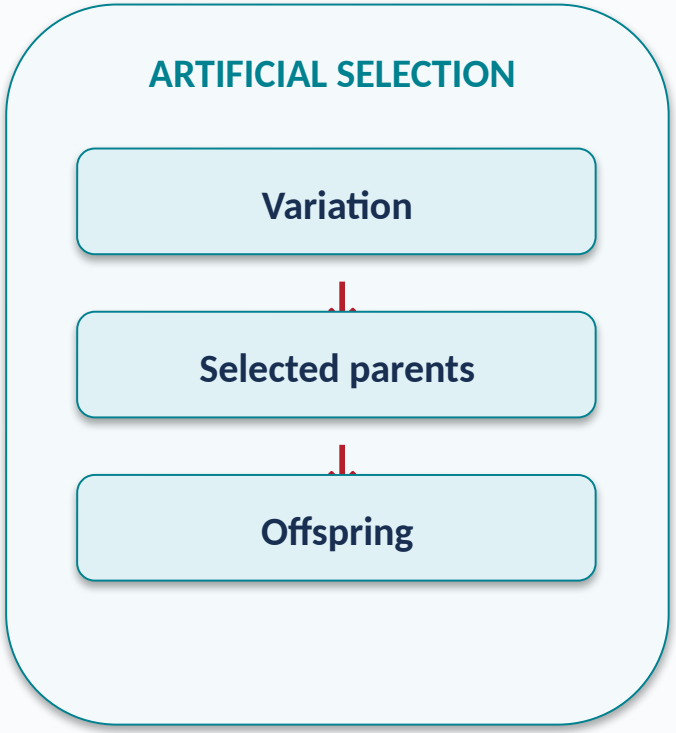
13.1 What is hybridization?

A. Removing a chromosome

B. Producing gametes without meiosis

C. Crossing genetically different individuals

D. Breeding identical clones only



Q13 | Practice MCQ 2

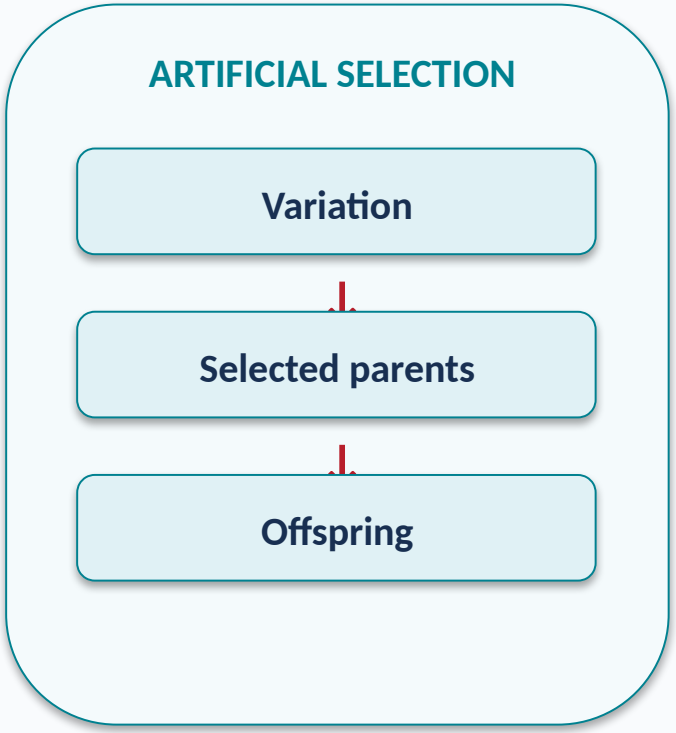
13.2 Which is a possible advantage of hybridization?

A. Elimination of all alleles

B. Combining useful traits from different parents

C. Guaranteed identical offspring

D. No variation



Q13 | Practice MCQ 3

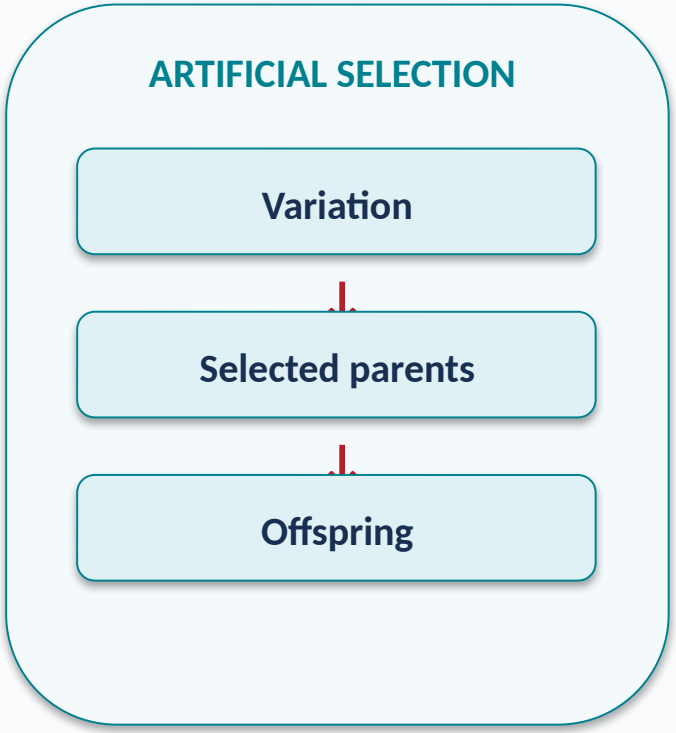
13.3 What is inbreeding?

A. Crossing closely related organisms

B. Crossing unrelated species only

C. A mutation in DNA

D. A type of meiosis



Q13 | Practice MCQ 4

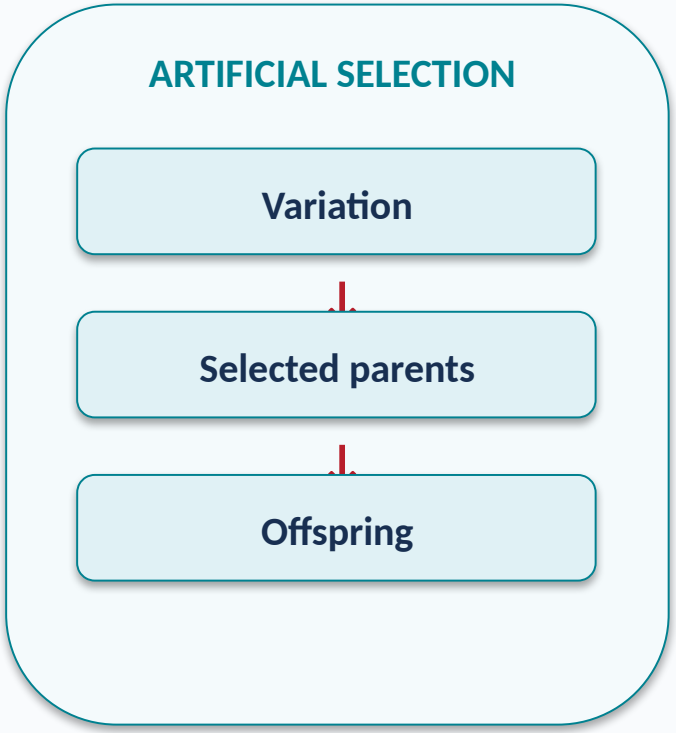
13.4 What is one risk of inbreeding?

A. Loss of all recessive alleles

B. Guaranteed hybrid vigor

C. No homozygosity

D. Increased expression of harmful recessive traits



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Q13 | Practice MCQ 5

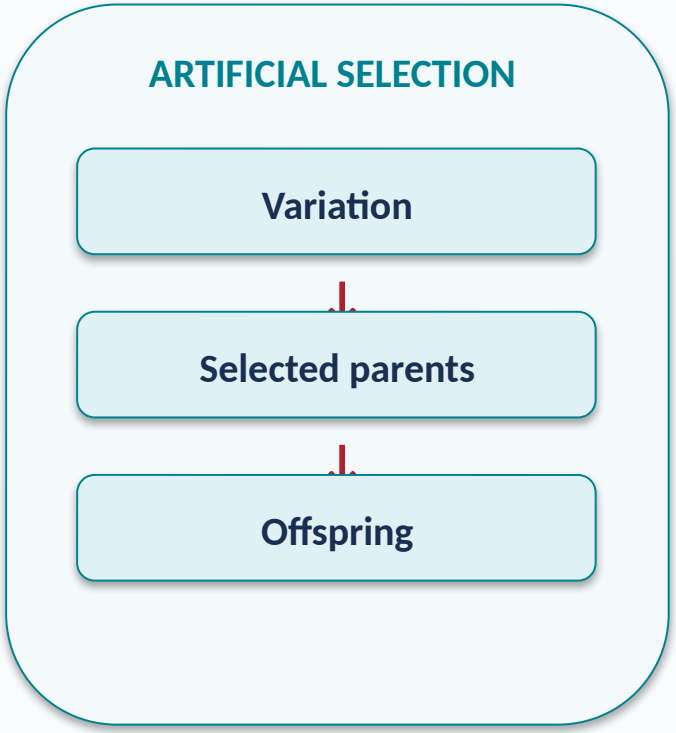
13.5 Why can inbreeding preserve a desired trait?

A. It prevents fertilization

B. It changes all genes

C. It increases the chance of homozygous offspring

D. It always creates new alleles



Q14 | Official learning outcome

BIO.3.2.04.010: Explain that in artificial selection, humans have the capacity to influence certain characteristics of organisms through selective breeding.

EXACT COVERAGE: Q14 | Textbook printed page 17 | Figure 14

STUDY TARGET: Test crosses to identify an unknown genotype

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Q14 | Original textbook page

LESSON 4

BASIC PATTERNS OF HUMAN INHERITANCE

FOCUS QUESTION

Why is a pedigree helpful in analyzing the inheritance of traits through several generations?

Pedigrees

Review **Table 1,** and recall that a recessive trait is expressed when the individual is homozygous recessive for that trait. Therefore, those with at least one dominant allele will not express the recessive trait. An individual who is heterozygous for a recessive disorder is called a **carrier.** This information is applied to help study patterns of human inheritance, including the inheritance of dominant and recessive disorders.

Table 1 Review of Terms

Term	Example	Definition
Homozygous	True-breeding yellow-seed pea plants would be *YY*, and green-seed pea plants would be *yy*. 	An organism with two of the same alleles for a particular trait is said to be homozygous for that trait.
Heterozygous	A plant that is *Yy* would be a yellow-seed pea. 	An organism with two different alleles for a particular trait is said to be heterozygous for that trait. When alleles are present in the heterozygous state, the dominant trait will be observed.

3D THINKING DCI Disciplinary Core Ideas CCC Crosscutting Concepts SEP Science & Engineering Practices

COLLECT EVIDENCE

Use your Science Journal to record the evidence you collect as you complete the readings and activities in this lesson.

INVESTIGATE

GO ONLINE to find these activities and more resources.

Quick Investigation: Investigate Human Pedigrees

Obtain, evaluate, and communicate information about the patterns of genetic traits in a pedigree.

Revisit the Encounter the Phenomenon Question

What information from this lesson can help you answer the Unit and Module questions?

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ED TEXTBOOK PAGE

Q14 | Learning outcome explanation (1/2)

Specific textbook focus: Interpreting a test cross for an unknown dominant phenotype; Figure 14.

Key terms (definitions for understanding the learning outcome; not all terms are necessarily examined in this particular reference):

Artificial selection — Human-directed breeding that increases the frequency of desired inherited characteristics.

Selective breeding — Choosing parents with desired traits to produce offspring with those traits.

Hybridization — Crossing genetically different organisms to combine desirable traits.

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Q14 | Learning outcome explanation (2/2)

Inbreeding — Mating closely related organisms to preserve particular characteristics.

Test cross — Crossing an organism with a dominant phenotype to a homozygous recessive organism to help infer genotype.

Worked approach: identify parental genotypes, list possible gametes, fill the Punnett square, count offspring genotypes, then translate them into phenotypes and probabilities.

Study focus: Test crosses. Read the exact cited textbook page and interpret its labeled diagram, table or question. The official coverage description identifies a broader learning outcome; the cited reference narrows the emphasis for this item.

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Q14 | Practice MCQ 1

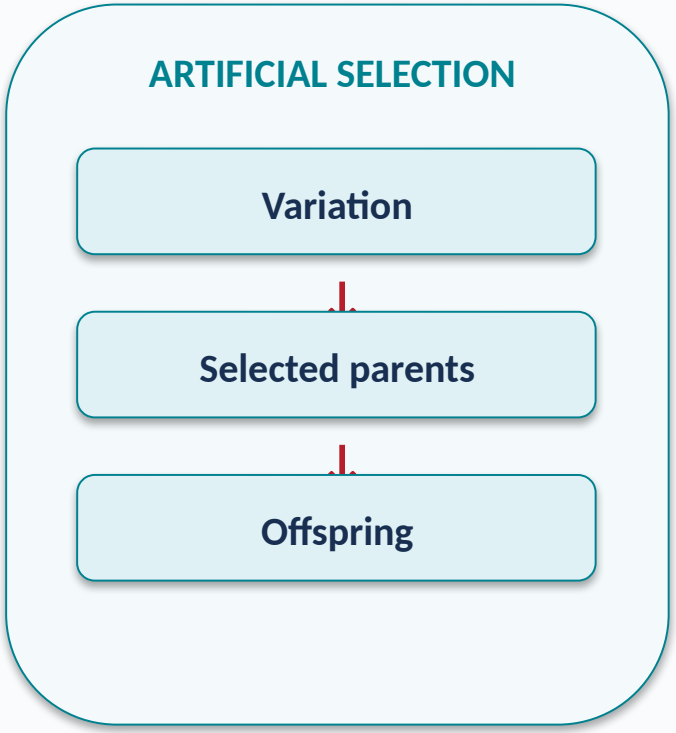
14.1 What is the purpose of a test cross?

A. To clone the parent

B. To identify an unknown dominant-phenotype genotype

C. To determine the number of chromosomes

D. To measure DNA length



Q14 | Practice MCQ 2

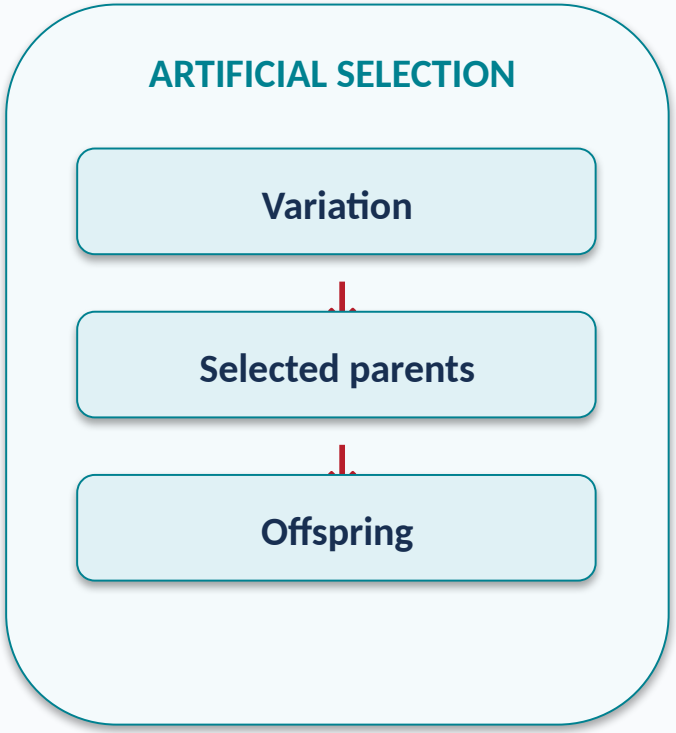
14.2 With which genotype is the unknown dominant-phenotype individual crossed?

A. Homozygous recessive

B. Homozygous dominant

C. Heterozygous only

D. Any genotype with no alleles



Q14 | Practice MCQ 3

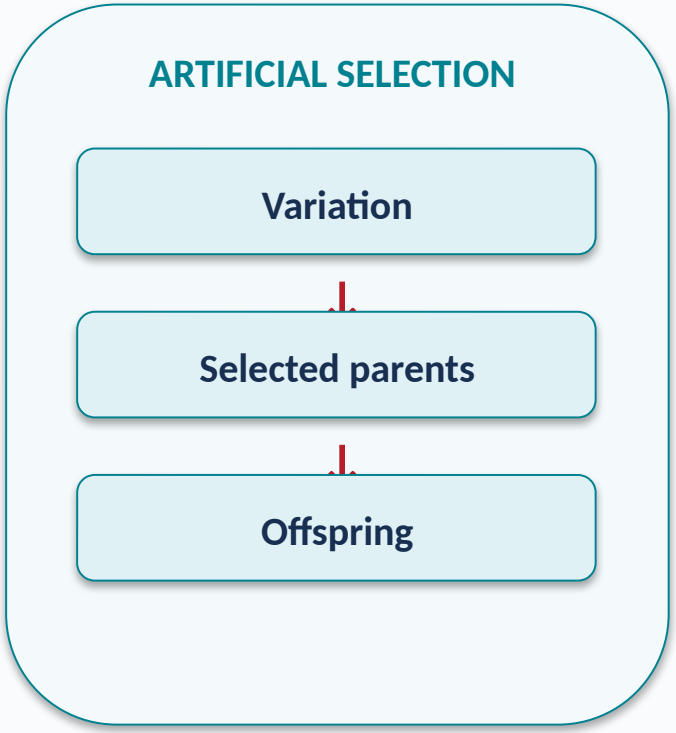
14.3 If a white grapefruit parent is ww, which cross yields all white offspring when the other is WW?

A. Ww × ww

B. ww × ww

C. Ww × Ww

D. WW × ww



Q14 | Practice MCQ 4

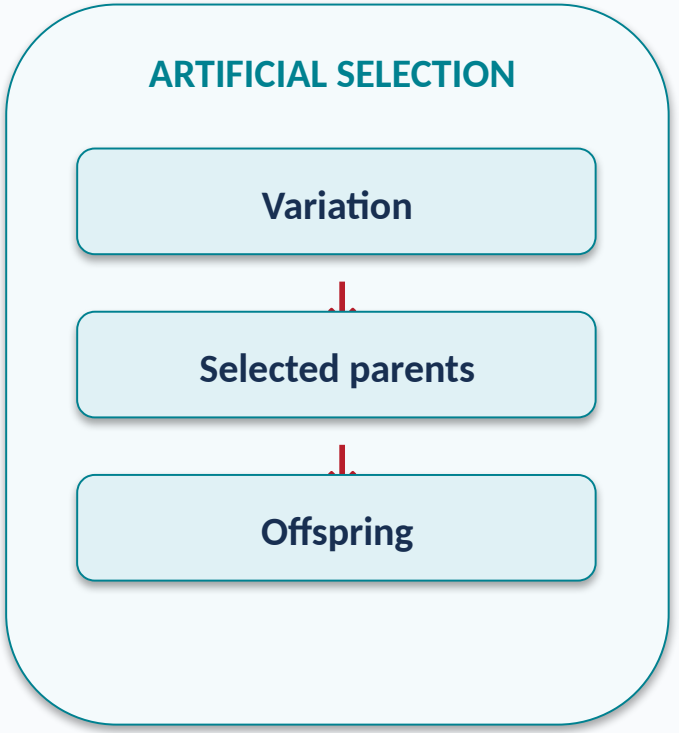
14.4 In Ww × ww, what fraction is expected to be recessive?

A. 1/4

B. 3/4

C. 1/2

D. 0



Q14 | Practice MCQ 5

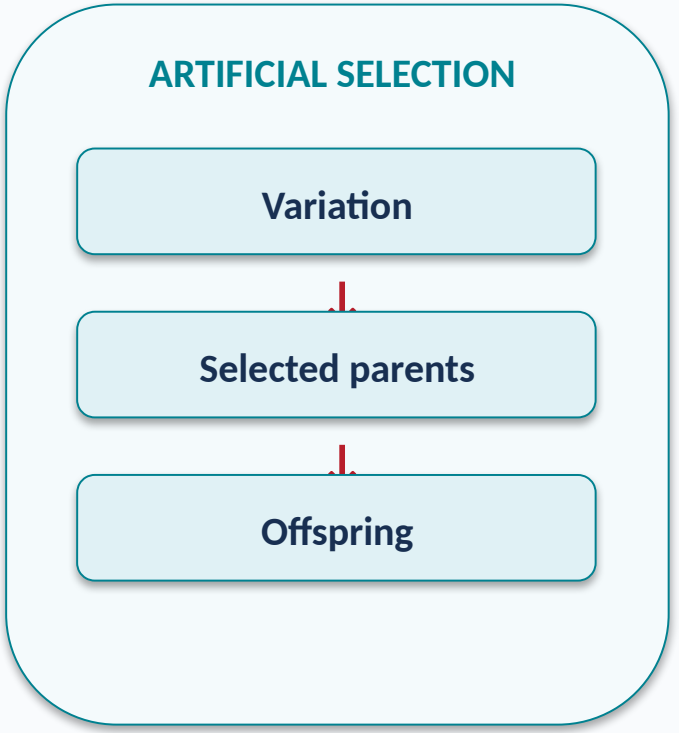
14.5 If a test cross produces recessive offspring, the unknown parent must be what?

A. Haploid

B. Heterozygous

C. Homozygous dominant

D. Missing the gene



Q15 | Official learning outcome

BIO.3.3.02.011 Explain the concepts of genotype, phenotype, dominance, incomplete dominance, codominance, recessiveness, and sex linkage according to Mendelian laws of inheritance.

EXACT COVERAGE: Q15 | Textbook printed page 18 | Table 1

STUDY TARGET: Homozygous and heterozygous genotypes; Table 1

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Q15 | Original textbook page

In organisms such as peas and fruit flies, scientists can perform crosses to study genetic relationships. In the case of humans, a scientist studies a family history using a **pedigree,** a diagram that traces the inheritance of a particular trait through several generations.

A pedigree, such as the one shown in **Figure 15,** uses symbols to illustrate inheritance of the trait. Males are represented by squares, and females are represented by circles. One who expresses the trait being studied is represented by a dark, or filled, square or circle, depending on their gender. One who does not express the trait is represented by an unfilled square or circle.

Get It?
Explain how symbols are used to represent individuals in a pedigree.

A horizontal line between two symbols shows that these individuals are the parents of the offspring listed below them. Offspring are listed in descending birth order from left to right and are connected to each other and their parents.

A pedigree uses a numbering system in which Roman numerals represent generations, and individuals are numbered by birth order using Arabic numbers. For example, in **Figure 15,** individual II1 is a female who is the firstborn in generation II.

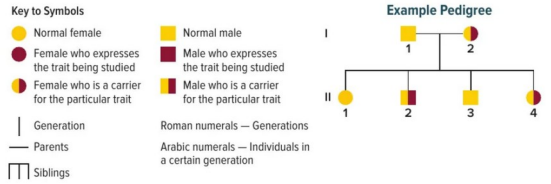

Figure 15 A pedigree uses standard symbols to indicate what is known about the trait being studied.
Summarize *the genotypes and phenotypes of the individuals in generation II for the trait being studied.*

Analyzing Pedigrees

Pedigrees can be applied to study the inheritance of both recessive traits and dominant traits within a family. A pedigree is constructed using all of the information available about the presence or absence of a particular trait in members of a family. It is then analyzed to reveal patterns of inheritance.

The study of pedigrees can be used to determine both X-linked and autosomal traits. The patterns revealed in a pedigree can be used to determine the mode of inheritance of a disease, disorder, or other trait. Patterns can also be used to infer genotypes of specific individuals and to predict the possibility of disorders occurring in future offspring of family members.

Q15 | Learning outcome explanation (1/4)

Specific textbook focus: Homozygous versus heterozygous genotypes; Table 1.

Key terms (definitions for understanding the learning outcome; not all terms are necessarily examined in this particular reference):

Gene — A segment of DNA that contains information for a functional product and can influence an inherited trait.

Allele — An alternative version of a gene.

Genotype — The combination of alleles an organism carries for a particular gene, such as Yy.

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Q15 | Learning outcome explanation (2/4)

Phenotype — An observable characteristic produced by genotype and environmental influences.

Dominant allele — An allele whose effect appears in the heterozygous phenotype in complete dominance.

Recessive allele — An allele masked in a heterozygote under complete dominance; its phenotype appears when homozygous.

Homozygous — Having two identical alleles at a gene locus, such as YY or yy.

Heterozygous — Having two different alleles at a gene locus, such as Yy.

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Q15 | Learning outcome explanation (3/4)

Incomplete dominance — An inheritance pattern in which a heterozygote has an intermediate phenotype.

Codominance — An inheritance pattern in which both alleles are expressed in a heterozygote.

Sex-linked trait — A trait influenced by a gene located on a sex chromosome.

How to distinguish the concepts: genotype refers to allele combination; phenotype refers to observable expression. Complete dominance masks the recessive phenotype in heterozygotes; incomplete dominance is intermediate; codominance expresses both alleles.

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Q15 | Learning outcome explanation (4/4)

Study focus: Homozygous and heterozygous terminology. Read the exact cited textbook page and interpret its labeled diagram, table or question. The official coverage description identifies a broader learning outcome; the cited reference narrows the emphasis for this item.

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Q15 | Practice MCQ 1

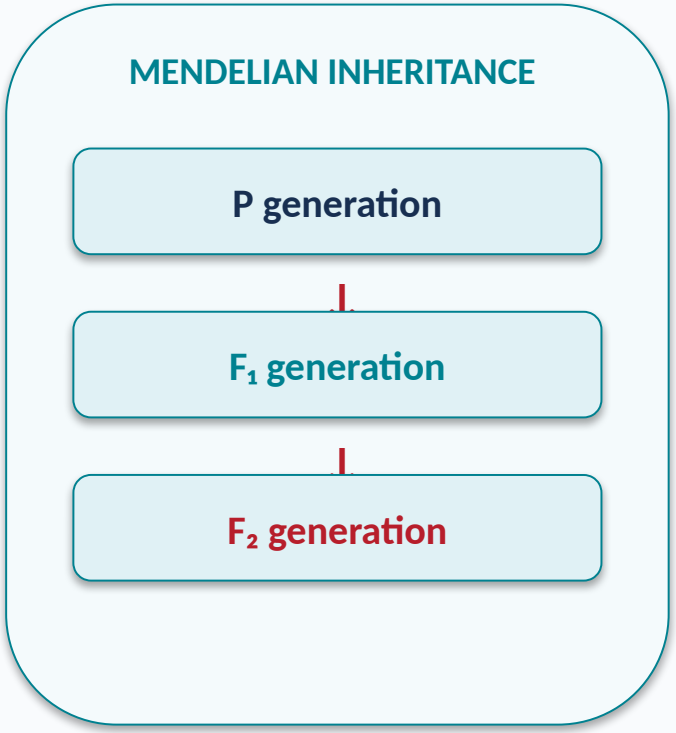
15.1 Which genotype is heterozygous?

A. Yy

B. YY

C. yy

D. Y



Q15 | Practice MCQ 2

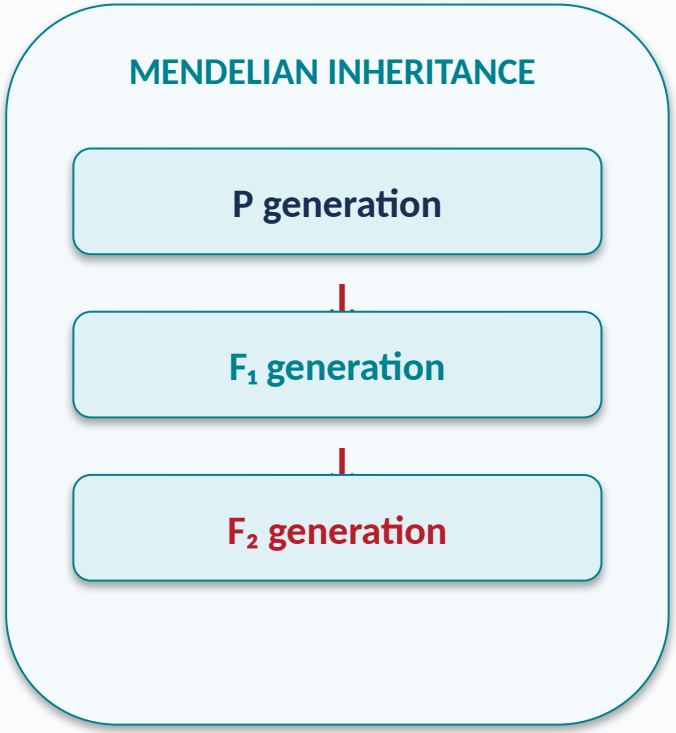
15.2 Which genotype is homozygous dominant?

A. Yy

B. yy

C. y

D. YY



Q15 | Practice MCQ 3

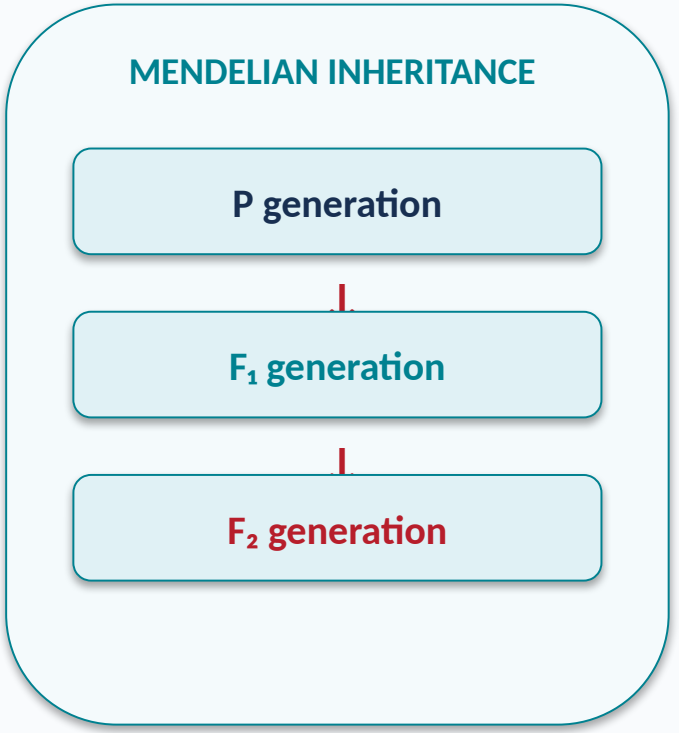
15.3 What does homozygous mean?

A. No alleles

B. Two chromosomes with different genes

C. Two identical alleles for a gene

D. Two different alleles for a gene



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Q15 | Practice MCQ 4

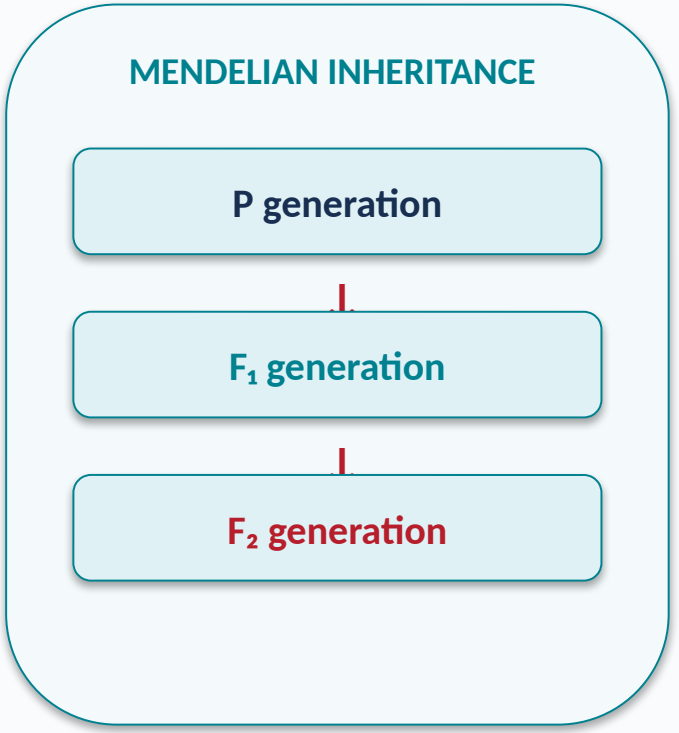
15.4 Which plant genotype can carry a recessive allele without showing it?

A. No genotype

B. Yy

C. YY

D. yy



Q15 | Practice MCQ 5

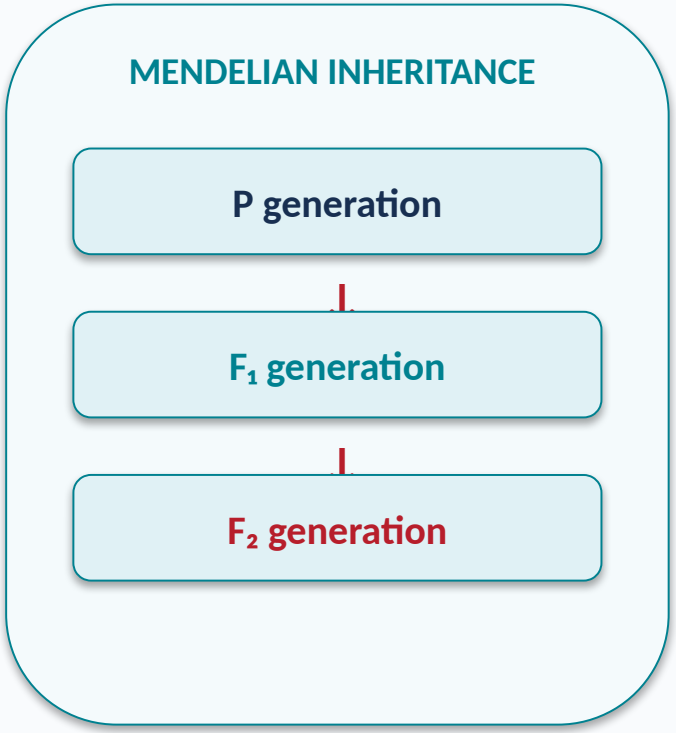
15.5 What does genotype refer to?

A. An organism's allele combination

B. Its visible trait only

C. Its environment only

D. Its body size only



Q16 | Official learning outcome

BIO.3.3.01.036 Investigate that variations of inherited traits between parent and offspring arise from genetic differences that result either from the subset of chromosomes and therefore from inherited genes or rarely from mutations and show the variations of inherited traits in a pedigree.

EXACT COVERAGE: Q16 | Textbook printed page 19 | Figure 15

STUDY TARGET: Pedigree symbols and relationships

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Q16 | Original textbook page

Recessive genetic disorders

A pedigree illustrating Tay-Sachs disease is shown in **Figure 16**. Tay-Sachs disease is a recessive genetic disorder caused by the lack of an enzyme involved in lipid metabolism. The missing enzyme causes lipids to build up in the central nervous system, which can lead to death.

Examine the pedigree in **Figure 16.** Note that two unaffected parents, I1 and I2, have an affected child–II3, indicating that each parent has one recessive allele–they both are heterozygous and carriers for the trait. The half-filled square and circle show that both parents are carriers.

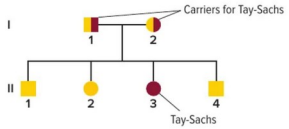

Figure 16 This pedigree illustrates the inheritance of the recessive disorder Tay-Sachs disease. Note that two unaffected parents (I1 and I2) can have an affected child (II3).

Dominant genetic disorders

The pedigree in **Figure 17** shows the inheritance of the dominant genetic disorder polydactyly (pah lee DAK tuh lee). People with this disorder have extra fingers and toes. Recall that with dominant inheritance the trait is expressed when at least one dominant allele is present. An individual with an unaffected parent and a parent with polydactyly could be either heterozygous or homozygous recessive for the trait. Each unaffected person would be homozygous recessive for the trait.

For example, in **Figure 17**, individual I2 has polydactyly, indicated by the dark circle. Because she shows the trait, she is either homozygous dominant or heterozygous. It can be inferred that she is heterozygous–having one dominant gene and one recessive gene–because offspring II3 and II4 do not have the disorder. Notice that II6 and II7, two unaffected parents, have an unaffected offspring–III2. What can be inferred about II2, based on the phenotype of her parents and her offspring?

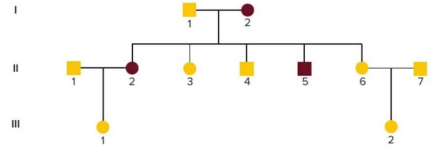

Figure 17 This pedigree illustrates the inheritance of a dominant disorder. Note that affected parents can pass on their genes (II2, II5), but unaffected parents cannot have an affected child (III2).

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Q16 | Learning outcome explanation (1/2)

Specific textbook focus: Pedigree symbols, family relationships and trait transmission; Figure 15.

Key terms (definitions for understanding the learning outcome; not all terms are necessarily examined in this particular reference):

Pedigree — A family diagram showing the inheritance of a trait across generations.

Carrier — A heterozygous individual who possesses a recessive disease allele but typically does not express the disorder.

Autosomal dominant — A trait caused by a dominant allele on a non-sex chromosome.

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Q16 | Learning outcome explanation (2/2)

Autosomal recessive — A trait expressed when two recessive alleles on a non-sex chromosome are inherited.

Affected individual — A person who expresses the trait being traced in a pedigree.

Pedigree approach: identify the trait pattern, compare affected and unaffected family members, infer possible genotypes, and avoid assigning a genotype that the pedigree cannot establish.

Study focus: Pedigree symbols and inheritance. Read the exact cited textbook page and interpret its labeled diagram, table or question. The official coverage description identifies a broader learning outcome; the cited reference narrows the emphasis for this item.

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Q16 | Practice MCQ 1

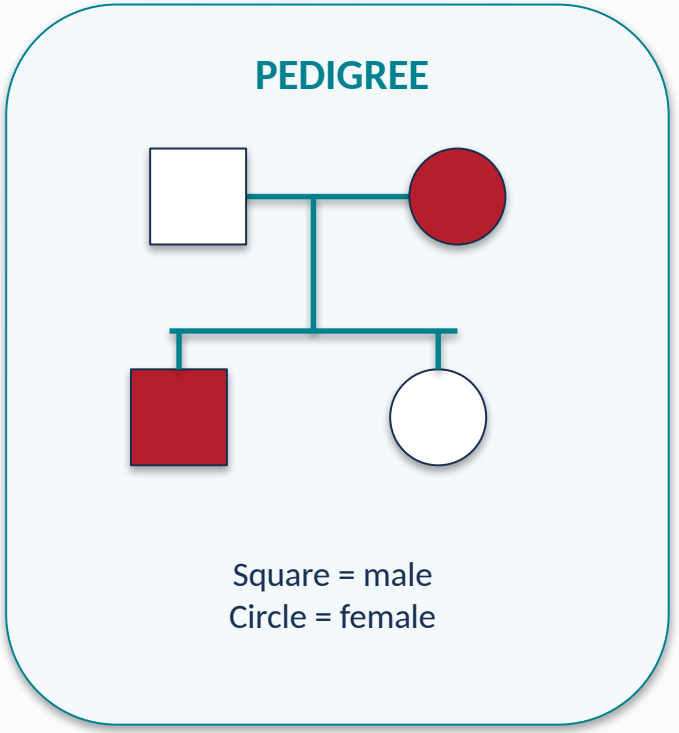
16.1 In a pedigree, what does a square represent?

A. Female

B. Carrier always

C. Deceased individual always

D. Male



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Q16 | Practice MCQ 2

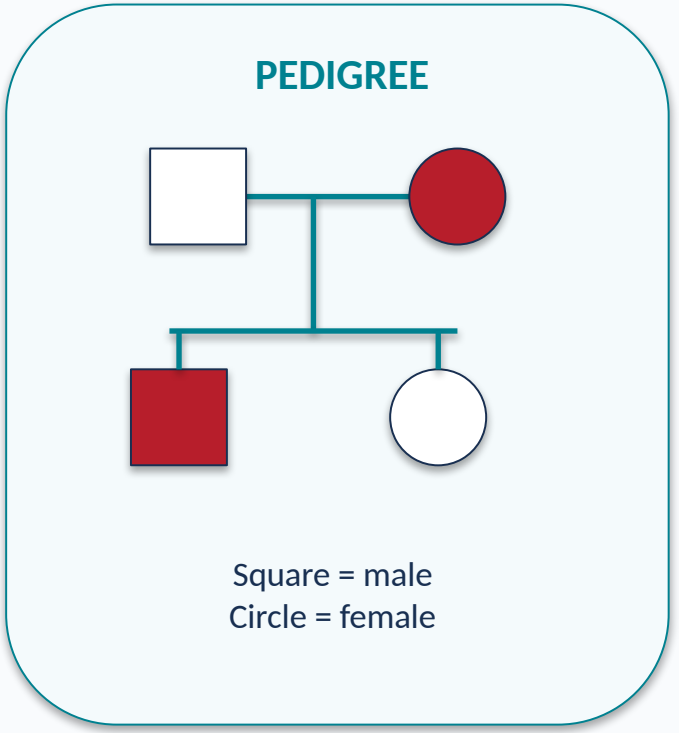
16.2 In a pedigree, what does a circle represent?

A. Mutation

B. A gamete

C. Female

D. Male



Q16 | Practice MCQ 3

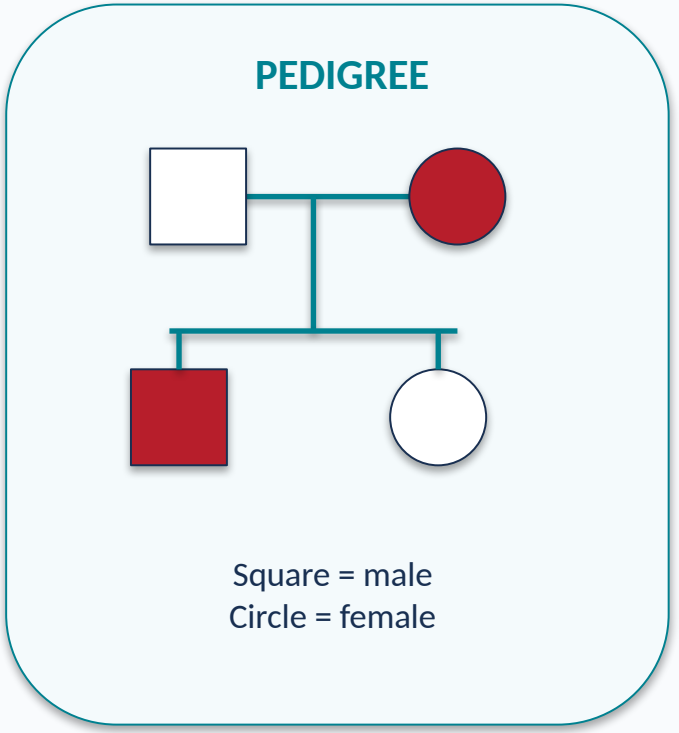
16.3 What does a shaded pedigree symbol commonly indicate?

A. A marriage

B. Individual expressing the studied trait

C. An unaffected individual

D. Unknown sex



Q16 | Practice MCQ 4

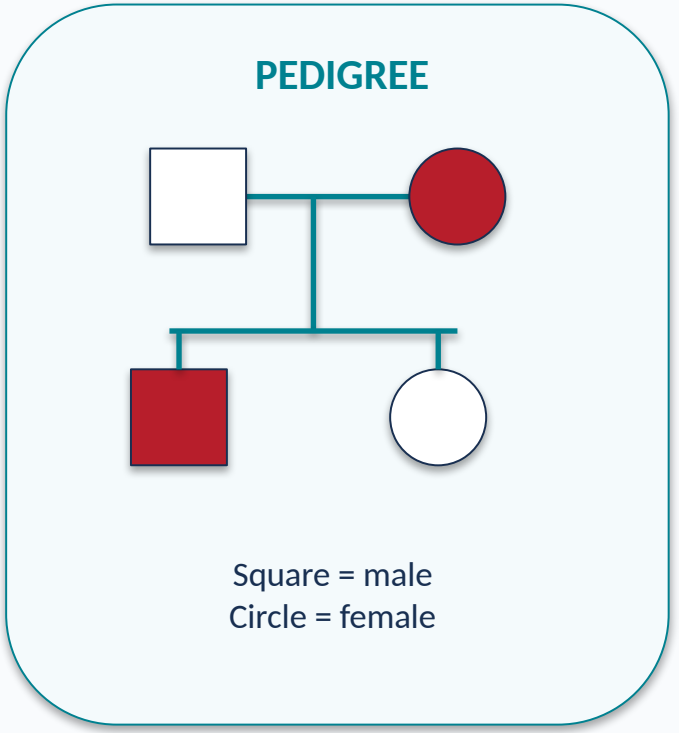
16.4 What does a horizontal line joining two individuals usually show?

A. A parental mating pair

B. A gene mutation

C. A chromosome

D. A gamete



Q16 | Practice MCQ 5

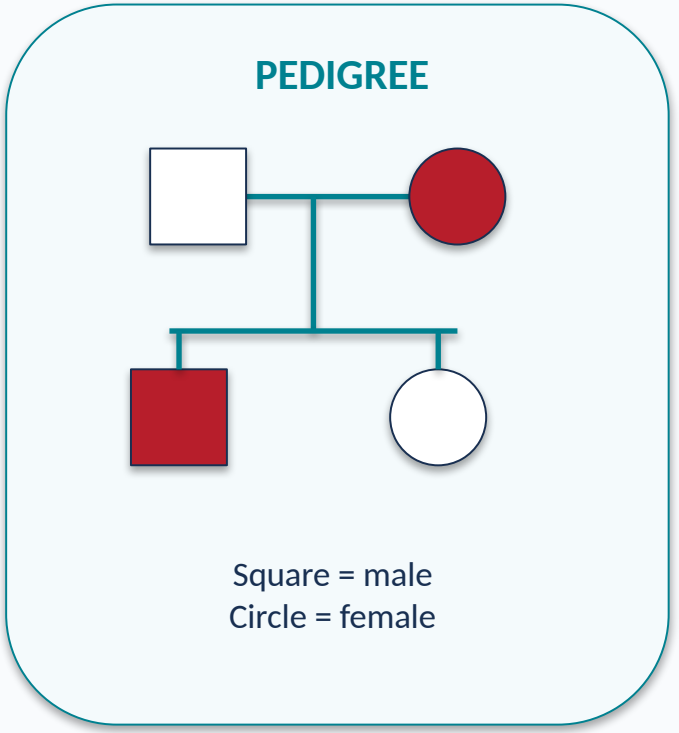
16.5 What do Roman numerals label in a pedigree?

A. Alleles

B. Chromosomes

C. Mutations

D. Generations



Q17 | Official learning outcome

BIO.3.3.01.036 Investigate that variations of inherited traits between parent and offspring arise from genetic differences that result either from the subset of chromosomes and therefore from inherited genes or rarely from mutations and show the variations of inherited traits in a pedigree.

EXACT COVERAGE: Q17 | Textbook printed page 20 | Figure 17

STUDY TARGET: Dominant inheritance patterns in pedigrees

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Q17 | Original textbook page

Inferring genotypes

Pedigrees are used to infer genotypes from the observation of phenotypes. By knowing physical traits, genealogists can determine what genes an individual is most likely to have. Phenotypes of entire families are analyzed in order to determine family genotypes.

Pedigrees help genetic counselors determine whether inheritance patterns are dominant or recessive. Once the inheritance pattern is determined by analyzing the available information, the genotypes of the individuals can largely be resolved, or identified, through pedigree analysis.

To analyze pedigrees, one particular trait is selected to be studied, and a determination is made as to whether that trait is dominant or recessive. Dominant traits are easier to recognize than recessive traits because dominant traits are exhibited in the phenotype of individuals.

A recessive trait will not be expressed unless the person is homozygous recessive for the trait. That means that a recessive allele is passed on by each parent. When recessive traits are expressed, the ancestry of the person expressing the trait is followed for several generations to determine which parents and grandparents were carriers of the recessive allele.

Get It?

Analyze What can be determined about the genotypes of the parents of an individual who expresses a recessive trait?

Predicting disorders

If good records have been kept within families, the possibility of disorders occurring in future offspring can be predicted. However, more accuracy can be expected if several individuals within the family can be evaluated. Having information about several generations of family members can provide valuable information. The study of human genetics can be difficult, because scientists are limited by time, ethics, and and availability of information.

For example, it takes decades for each generation to mature and then to have offspring when the study involves humans. Therefore, good record keeping, where it exists, helps scientists use pedigree analysis to study inheritance patterns, to determine phenotypes, and to ascertain genotypes within a family.

CCC CROSSCUTTING CONCEPTS

Cause and Effect Prepare a visual presentation that includes the pedigree of an inheritable condition or disorder in humans. Then present information that explains how the condition is inherited, using the information in the pedigree as evidence.

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ED TEXTBOOK PAGE

Q17 | Learning outcome explanation (1/2)

Specific textbook focus: Dominant inheritance in a pedigree; Figure 17.

Key terms (definitions for understanding the learning outcome; not all terms are necessarily examined in this particular reference):

Pedigree — A family diagram showing the inheritance of a trait across generations.

Carrier — A heterozygous individual who possesses a recessive disease allele but typically does not express the disorder.

Autosomal dominant — A trait caused by a dominant allele on a non-sex chromosome.

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Q17 | Learning outcome explanation (2/2)

Autosomal recessive — A trait expressed when two recessive alleles on a non-sex chromosome are inherited.

Affected individual — A person who expresses the trait being traced in a pedigree.

Pedigree approach: identify the trait pattern, compare affected and unaffected family members, infer possible genotypes, and avoid assigning a genotype that the pedigree cannot establish.

Study focus: Dominant pedigree analysis. Read the exact cited textbook page and interpret its labeled diagram, table or question. The official coverage description identifies a broader learning outcome; the cited reference narrows the emphasis for this item.

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Q17 | Practice MCQ 1

17.1 A dominant trait can be expressed in which genotype?

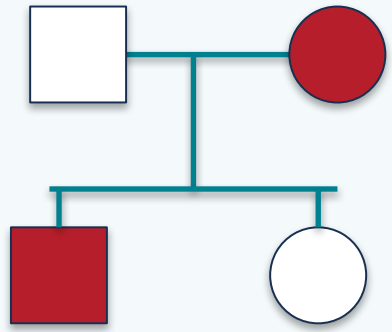
A. Only a genotype with no allele

B. Only haploid cells

C. Heterozygous

D. Homozygous recessive only

PEDIGREE



Square = male
Circle = female

FREIWAN

Q17 | Practice MCQ 2

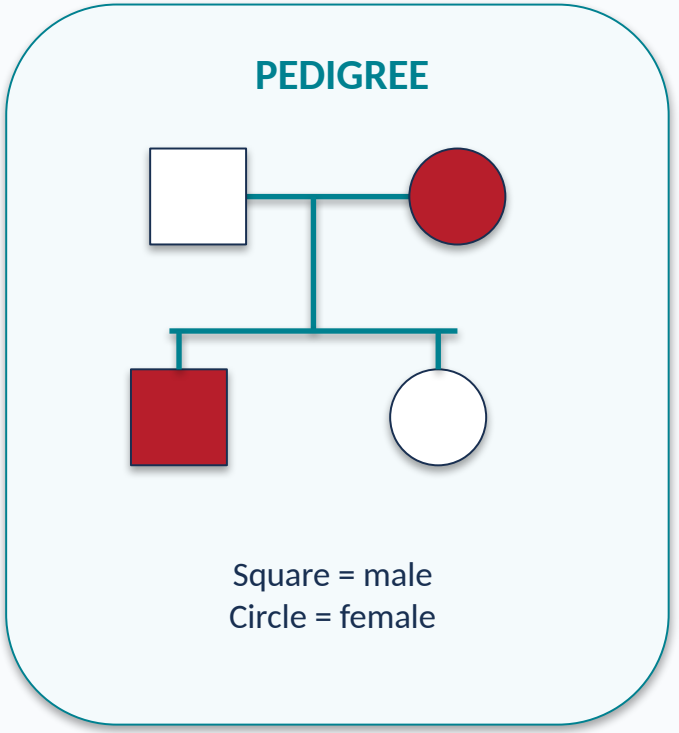
17.2 In a typical autosomal dominant pedigree, the trait often appears how?

A. Only in one generation always

B. In successive generations

C. Only in males

D. Only after two unaffected carriers mate



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Q17 | Practice MCQ 3

17.3 If D is dominant, which genotype is unaffected?

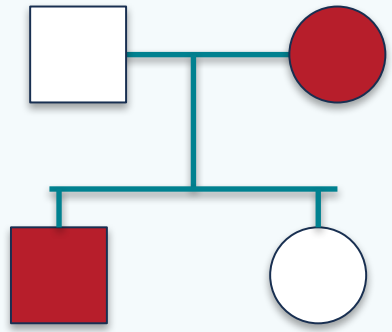
A. dd

B. Dd

C. DD

D. D

PEDIGREE



Square = male
Circle = female

Q17 | Practice MCQ 4

17.4 If an affected Dd parent and unaffected dd parent have a child, what is the probability of an affected child?

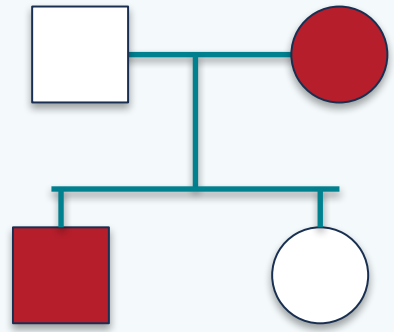
A. 1/4

B. 3/4

C. 1

D. 1/2

PEDIGREE



Square = male
Circle = female

Q17 | Practice MCQ 5

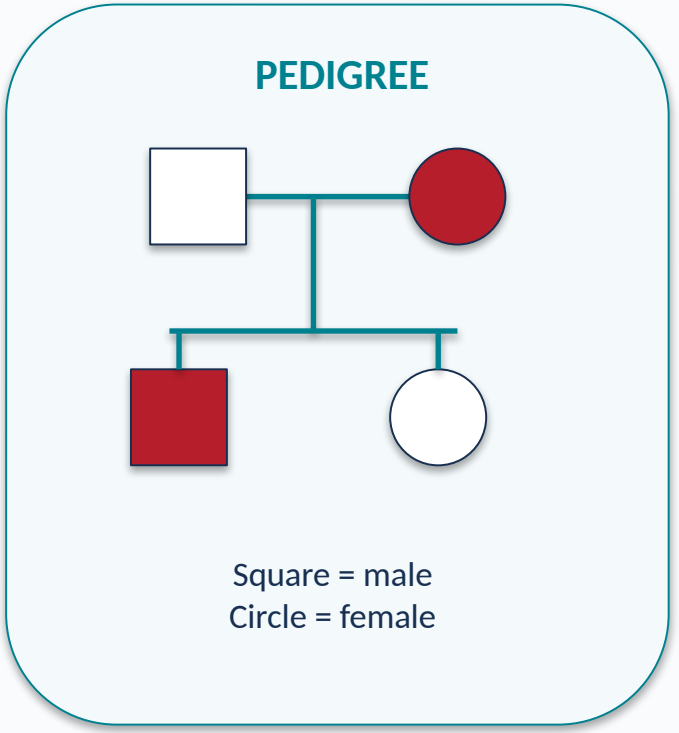
17.5 Which evidence is consistent with dominant inheritance?

A. Only daughters are affected

B. Every child must be affected

C. An affected parent passes the trait to some children

D. Two unaffected carriers always show the trait



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Q18 | Official learning outcome

BIO.3.3.01.036 Investigate that variations of inherited traits between parent and offspring arise from genetic differences that result either from the subset of chromosomes and therefore from inherited genes or rarely from mutations and show the variations of inherited traits in a pedigree.

EXACT COVERAGE: Q18 | Textbook printed page 22 | Table 2

STUDY TARGET: Recessive disorders in humans and their causes

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Q18 | Original textbook page

Cystic fibrosis

One of the most common recessive genetic disorders that occurs among Caucasians is cystic fibrosis, which affects the mucus-producing glands, digestive enzymes, and sweat glands. Chloride ions are not properly transported out of the cells of a person with cystic fibrosis. This causes a high concentration of chloride ions in the cells, and water does not diffuse from the cells. This causes a secretion of thick mucus. The mucus clogs the ducts in the pancreas, interrupts digestion, and blocks the tiny respiratory pathways in the lungs. Patients with cystic fibrosis are at a higher risk of infection because of excess mucus that builds up in their lungs.

Treatment for cystic fibrosis currently includes physical therapy, medication, special diets, and the use of replacement digestive enzymes. Genetic tests are available to determine whether a person is a carrier.

Tay-Sachs disease

Tay-Sachs (TAY saks) disease is a recessive genetic disorder in humans. The gene for Tay-Sachs is found on chromosome 15. Often identified by a cherry-red spot on the back of the eye, Tay-Sachs disease (TSD) seems to be predominant among Jews of eastern European descent.

TSD is caused by the absence of the enzymes that are responsible for breaking down fatty acids called gangliosides. Normally, gangliosides are made and then are dissolved as the brain develops. In a person with Tay-Sachs disease, the gangliosides accumulate in the brain rather than being broken down. The gangliosides inflate and damage brain nerve cells and cause mental deterioration.

Types of Dominant Genetic Disorders

Some human disorders, such as the rare disorder Huntington's disease, are caused by dominant alleles. That means those who do not have the disorder are homozygous recessive for the trait. Review **Table 3** as you read about several dominant genetic disorders that occur in humans.

Table 3 Dominant Genetic Disorders in Humans

Disorder	Occurrence in the U.S.	Cause	Effect	Cure/Treatment
Huntington's disease	1 in 10,000	A gene affecting neurological function is defective.	• Decline of mental and neurological functions • Ability to move deteriorates	• No cure or treatment
Achondroplasia	1 in 25,000	A gene that affects bone growth is abnormal.	• Short arms and legs • Large head	• No cure or treatment

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Q18 | Learning outcome explanation (1/2)

Specific textbook focus: Recessive genetic disorders, their causes and effects; Table 2.

Key terms (definitions for understanding the learning outcome; not all terms are necessarily examined in this particular reference):

Pedigree — A family diagram showing the inheritance of a trait across generations.

Carrier — A heterozygous individual who possesses a recessive disease allele but typically does not express the disorder.

Autosomal dominant — A trait caused by a dominant allele on a non-sex chromosome.

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Q18 | Learning outcome explanation (2/2)

Autosomal recessive — A trait expressed when two recessive alleles on a non-sex chromosome are inherited.

Affected individual — A person who expresses the trait being traced in a pedigree.

Pedigree approach: identify the trait pattern, compare affected and unaffected family members, infer possible genotypes, and avoid assigning a genotype that the pedigree cannot establish.

Study focus: Recessive genetic disorders. Read the exact cited textbook page and interpret its labeled diagram, table or question. The official coverage description identifies a broader learning outcome; the cited reference narrows the emphasis for this item.

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Q18 | Practice MCQ 1

18.1 Which condition in Table 2 affects chloride transport and produces thick mucus?

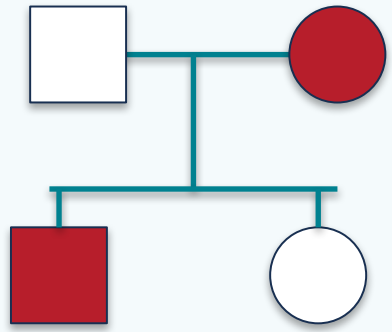
A. Huntington’s disease

B. Cystic fibrosis

C. Albinism

D. Tay-Sachs disease

PEDIGREE



Square = male
Circle = female

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Q18 | Practice MCQ 2

18.2 Which recessive disorder involves insufficient melanin?

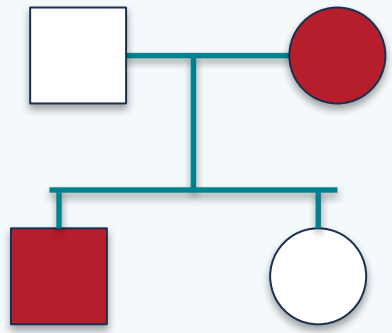
A. Albinism

B. Achondroplasia

C. Huntington’s disease

D. Hemophilia

PEDIGREE



Square = male
Circle = female

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Q18 | Practice MCQ 3

18.3 Which condition involves deficiency of the GALT enzyme?

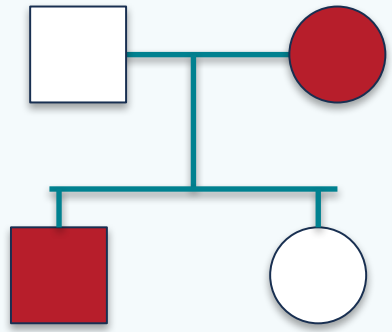
A. Cystic fibrosis

B. Achondroplasia

C. Color blindness

D. Galactosemia

PEDIGREE



Square = male
Circle = female

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Q18 | Practice MCQ 4

18.4 Which disorder is associated with breakdown of nervous-system function due to lipid buildup?

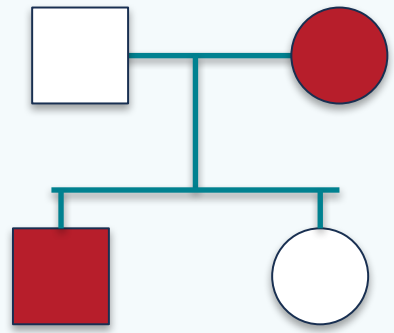
A. Achondroplasia

B. Huntington's disease

C. Tay-Sachs disease

D. Albinism

PEDIGREE



Square = male
Circle = female

Q18 | Practice MCQ 5

18.5 For an autosomal recessive disorder, what is the usual genotype of an unaffected carrier?

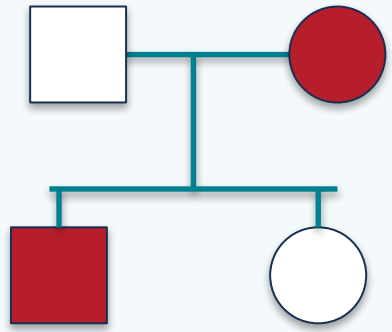
A. Always homozygous dominant

B. Heterozygous

C. Homozygous recessive

D. No alleles

PEDIGREE



Square = male
Circle = female

Q19 | Official learning outcome

BIO.3.3.02.011 Explain the concepts of genotype, phenotype, dominance, incomplete dominance, codominance, recessiveness, and sex linkage according to Mendelian laws of inheritance.

EXACT COVERAGE: Q19 | Textbook printed page 25 | Figure 18

STUDY TARGET: Incomplete dominance in snapdragons

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Q19 | Original textbook page

Codominance

Recall that when an organism is heterozygous for a particular trait, the dominant phenotype is expressed. In a complex inheritance pattern called **codominance,** both alleles are expressed in the heterozygous condition. Sickle-cell disease in humans provides a case study of codominant inheritance.

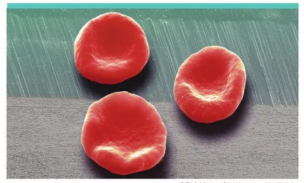
Sickle-cell disease

The allele responsible for sickle-cell disease is particularly common in people of African descent, with about nine percent of African Americans having one form of the trait. Sickle-cell disease affects red blood cells and their ability to transport oxygen. The middle photograph in **Figure 19** shows the blood cells of an individual who is heterozygous for the sickle-cell trait. Compare the shape of the blood cell to the top photograph in **Figure 19** that shows a normal blood cell. Changes in hemoglobin—the protein in red blood cells—cause those blood cells to change to a sickle, or C-shape.

Sickle-shaped cells do not effectively transport oxygen because they block circulation in small blood vessels. Those who are heterozygous for the trait have both normal and sickle-shaped cells. These individuals can lead relatively normal lives, as the normal blood cells compensate for the sickle-shaped cells.

Sickle-cell disease and malaria

Note in the bottom image of **Figure 19** the distribution of both sickle-cell disease and malaria in Africa. Some areas with sickle-cell disease overlap with areas where malaria is widespread. Why might such high levels of the sickle-cell allele exist in central Africa? Scientists have discovered that those who are heterozygous for the sickle-cell trait also have a higher resistance to malaria. The death rate due to malaria is lower where the sickle-cell trait is higher. Because less malaria exists in those areas, more people live to pass on the sickle-cell trait to offspring. Consequently, sickle-cell disease continues to increase in Africa.



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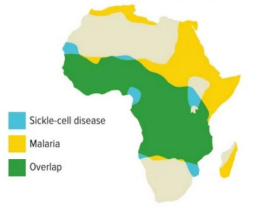

Figure 19

Top: Normal red blood cells are flat and disk-shaped.

Middle: Sickle-shaped cells are elongated and/or C-shaped. They can clump, blocking circulation in small vessels.

Bottom: The sickle-cell allele increases resistance to malaria.

(t)SCIENCE PHOTO LIBRARY/Alamy; (b)CDC/Sickle Cell Foundation of Georgia; Jackie George; Beverly Sinclair; photo by Janice Haney Carr

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Q19 | Learning outcome explanation (1/3)

Specific textbook focus: Incomplete dominance in flower color; Figure 18.

Key terms (definitions for understanding the learning outcome; not all terms are necessarily examined in this particular reference):

Incomplete dominance — A heterozygote shows an intermediate phenotype between the two homozygotes.

Codominance — Both alleles are expressed in a heterozygote, as in AB blood type.

Multiple alleles — More than two allelic forms exist in a population for one gene, although each diploid individual carries two.

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Q19 | Learning outcome explanation (2/3)

Epistasis — An interaction in which one gene masks or modifies expression of another gene.

Dosage compensation — A mechanism that balances expression of X-linked genes between sexes.

X-inactivation — Silencing of one X chromosome in most cells of female placental mammals.

Polygenic trait — A characteristic influenced by multiple genes.

Environmental influence — A non-genetic factor that can alter phenotype.

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Q19 | Learning outcome explanation (3/3)

How to distinguish the concepts: genotype refers to allele combination; phenotype refers to observable expression. Complete dominance masks the recessive phenotype in heterozygotes; incomplete dominance is intermediate; codominance expresses both alleles.

Study focus: Incomplete dominance in snapdragons. Read the exact cited textbook page and interpret its labeled diagram, table or question. The official coverage description identifies a broader learning outcome; the cited reference narrows the emphasis for this item.

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Q19 | Practice MCQ 1

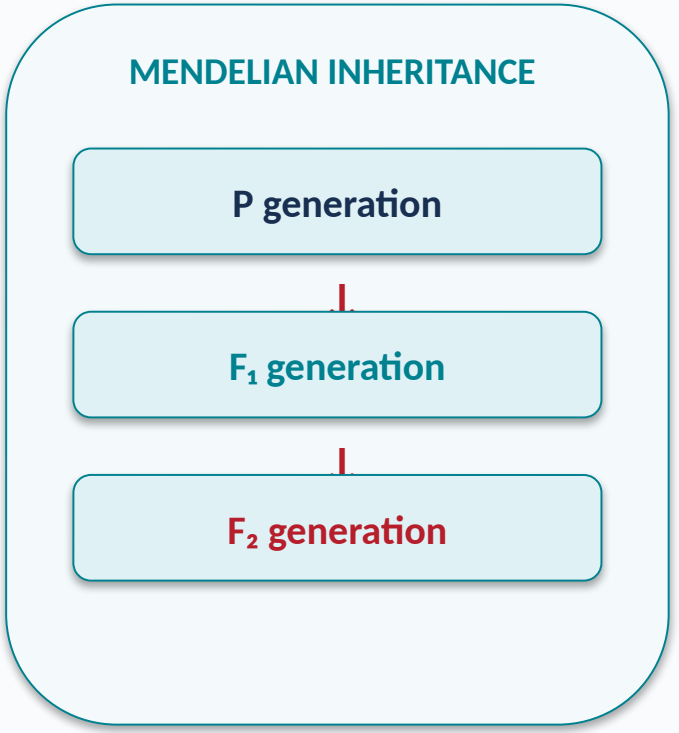
19.1 What color results from crossing true-breeding red and white snapdragons under incomplete dominance?

A. Pink

B. Red only

C. White only

D. Red-and-white patches



Q19 | Practice MCQ 2

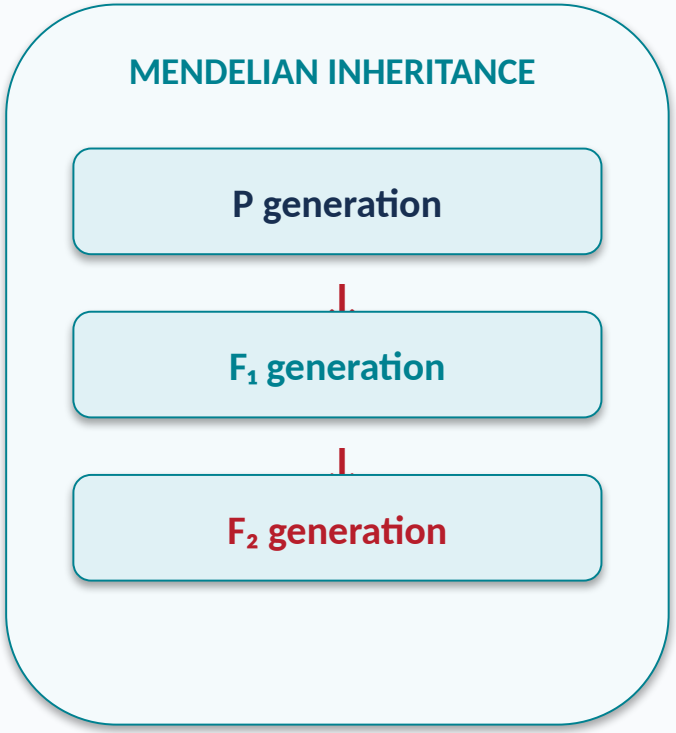
19.2 What does incomplete dominance mean?

A. Both traits are fully and separately expressed

B. Only the recessive trait appears

C. The gene is on the X chromosome

D. The heterozygote shows an intermediate phenotype



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Q19 | Practice MCQ 3

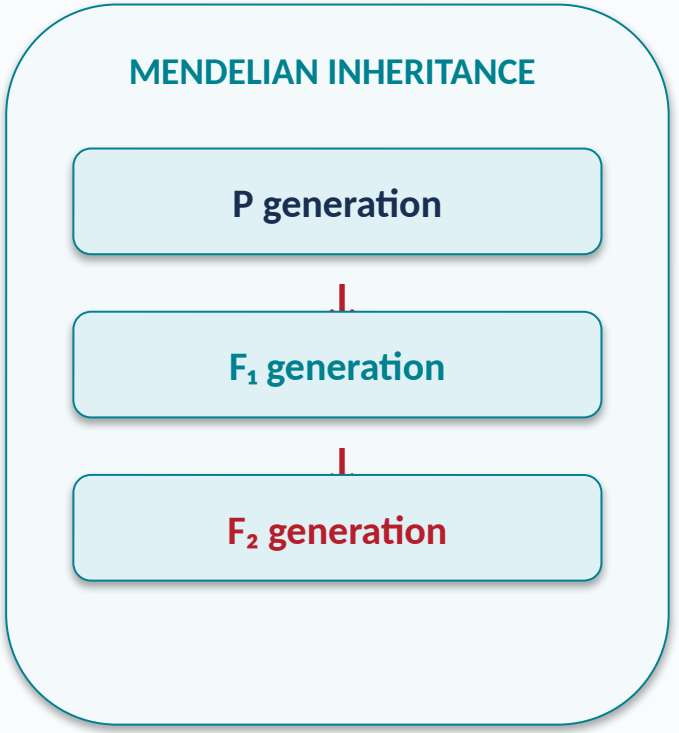
19.3 What is the phenotypic ratio for pink × pink snapdragons?

A. All pink

B. 9:3:3:1

C. 1 red:2 pink:1 white

D. 3 red:1 white



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Q19 | Practice MCQ 4

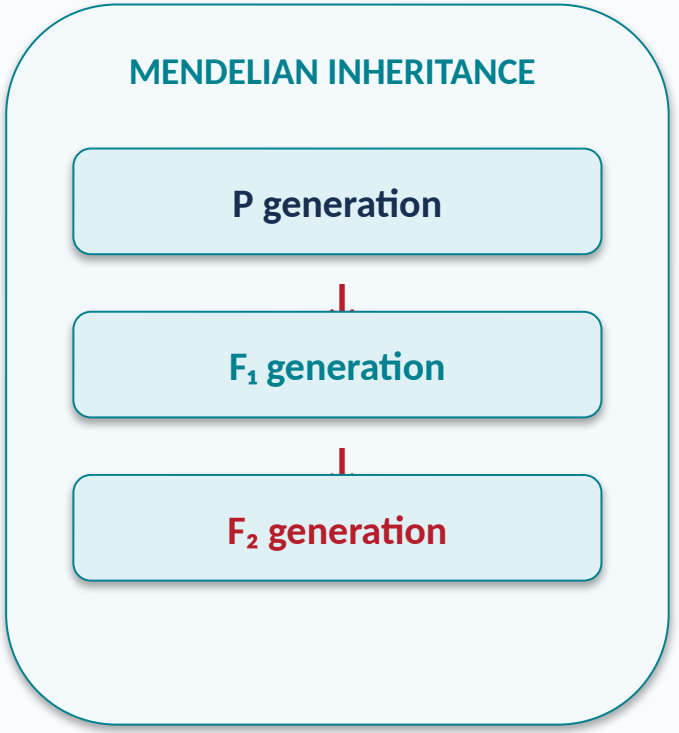
19.4 Which genotype represents a heterozygous pink snapdragon in the textbook model?

A. CC only

B. C^RC^W

C. C^RC^R

D. C^WC^W



Q19 | Practice MCQ 5

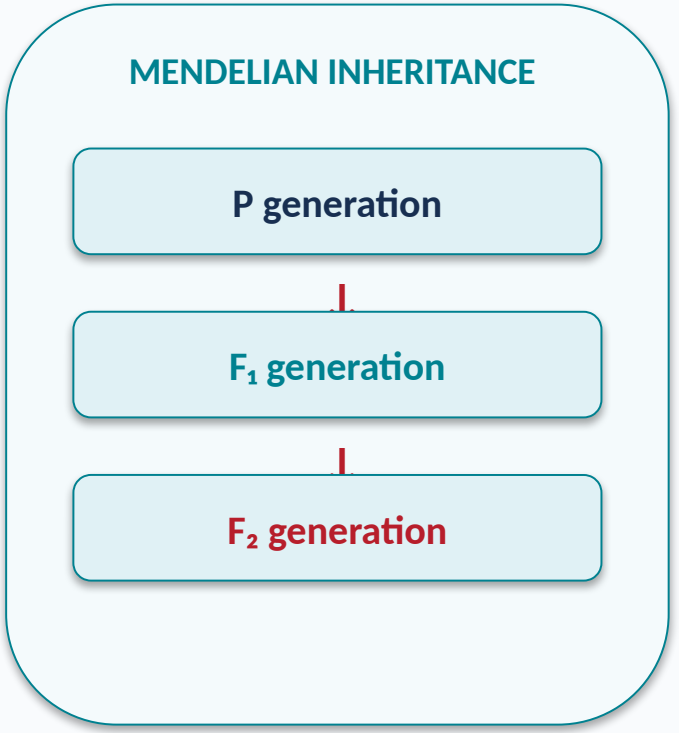
19.5 Which cross produces all pink offspring?

A. True-breeding red × true-breeding white

B. Pink × pink

C. White × white

D. Red × red



Q20 | Official learning outcome

BIO.3.3.02.011 Explain the concepts of genotype, phenotype, dominance, incomplete dominance, codominance, recessiveness, and sex linkage according to Mendelian laws of inheritance.

EXACT COVERAGE: Q20 | Textbook printed page 26 | Figure 19

STUDY TARGET: Codominance in sickle-cell trait

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Q20 | Original textbook page

Multiple Alleles

Not all traits are determined by two alleles. Some forms of inheritance are determined by more than two alleles. This is referred to as **multiple alleles.** An example of such a trait is human blood group.

Blood groups in humans

The ABO blood group, shown in **Figure 20,** has three forms of alleles, sometimes called AB markers: I^A is blood type A; I^B is blood type B; and i is blood type O. Type O is the absence of AB markers. Individuals with blood type O have the genotype ii.

Note that allele i is recessive to I^A and I^B. However, I^A and I^B are codominant. Blood type AB results when an individual inherits both an I^A allele and an I^B allele. Therefore, the ABO blood group is an example of both multiple alleles and codominance.

Get It?
Explain how genetic traits carried on multiple alleles can lead to a wide range of characteristics in humans.

The Rh blood group includes Rh factors, inherited from each parent. Rh factors are either positive or negative (Rh+ or Rh–); Rh+ is dominant and Rh– is recessive. The Rh factor is a blood protein named after the rhesus monkey because studies of the rhesus monkey led to discovery of that blood protein.

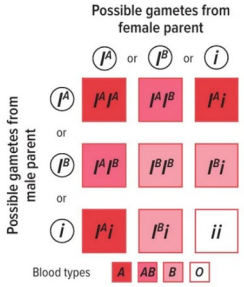

Figure 20 There are three forms of alleles in the ABO blood group—I^A, I^B, and i. I^A and I^B are codominant. i is recessive to both I^A and I^B.

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ED TEXTBOOK PAGE

Q20 | Learning outcome explanation (1/3)

Specific textbook focus: Codominance illustrated by sickle-cell disease; Figure 19.

Key terms (definitions for understanding the learning outcome; not all terms are necessarily examined in this particular reference):

Incomplete dominance — A heterozygote shows an intermediate phenotype between the two homozygotes.

Codominance — Both alleles are expressed in a heterozygote, as in AB blood type.

Multiple alleles — More than two allelic forms exist in a population for one gene, although each diploid individual carries two.

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Q20 | Learning outcome explanation (2/3)

Epistasis — An interaction in which one gene masks or modifies expression of another gene.

Dosage compensation — A mechanism that balances expression of X-linked genes between sexes.

X-inactivation — Silencing of one X chromosome in most cells of female placental mammals.

Polygenic trait — A characteristic influenced by multiple genes.

Environmental influence — A non-genetic factor that can alter phenotype.

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Q20 | Learning outcome explanation (3/3)

How to distinguish the concepts: genotype refers to allele combination; phenotype refers to observable expression. Complete dominance masks the recessive phenotype in heterozygotes; incomplete dominance is intermediate; codominance expresses both alleles.

Study focus: Codominance and sickle-cell disease. Read the exact cited textbook page and interpret its labeled diagram, table or question. The official coverage description identifies a broader learning outcome; the cited reference narrows the emphasis for this item.

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Q20 | Practice MCQ 1

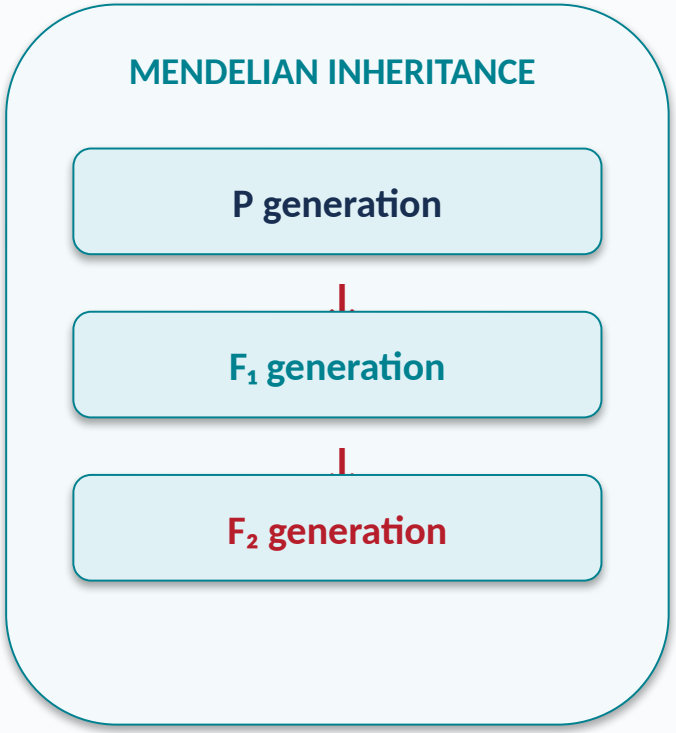
20.1 What is codominance?

A. One allele completely masks the other

B. A blended intermediate phenotype always appears

C. Alleles are never inherited

D. Both alleles are expressed in a heterozygote



FREIWAN

Q20 | Practice MCQ 2

20.2 Which cells are shown in Figure 19?

A. Plant guard cells

B. White blood cells only

C. Normal and sickle-shaped red blood cells

D. Neurons and muscle cells

MENDELIAN INHERITANCE

P generation

↓

F_1 generation

↓

F_2 generation

FREIWAN

Q20 | Practice MCQ 3

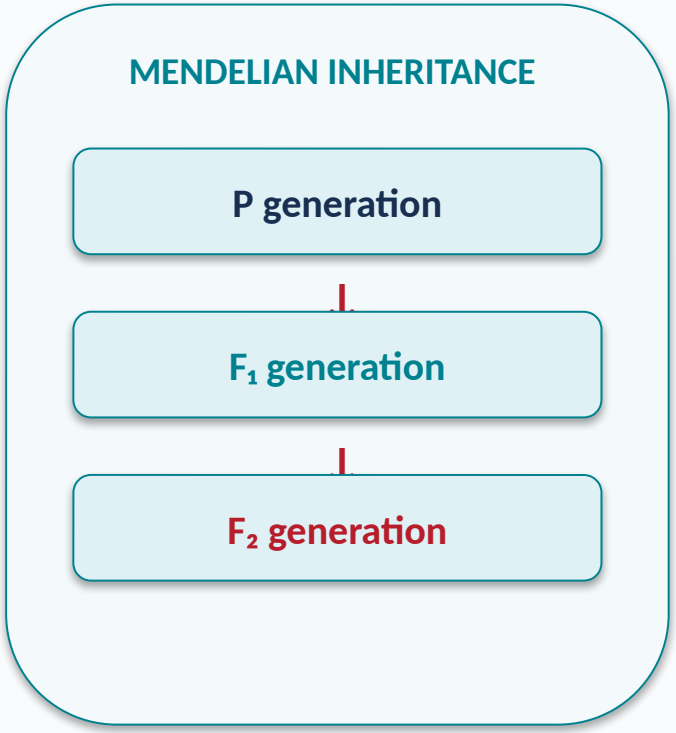
20.3 Which blood-cell shape is associated with sickle-cell disease?

A. Spiral shaped

B. Crescent or sickle shaped

C. Perfectly square

D. Star shaped



Q20 | Practice MCQ 4

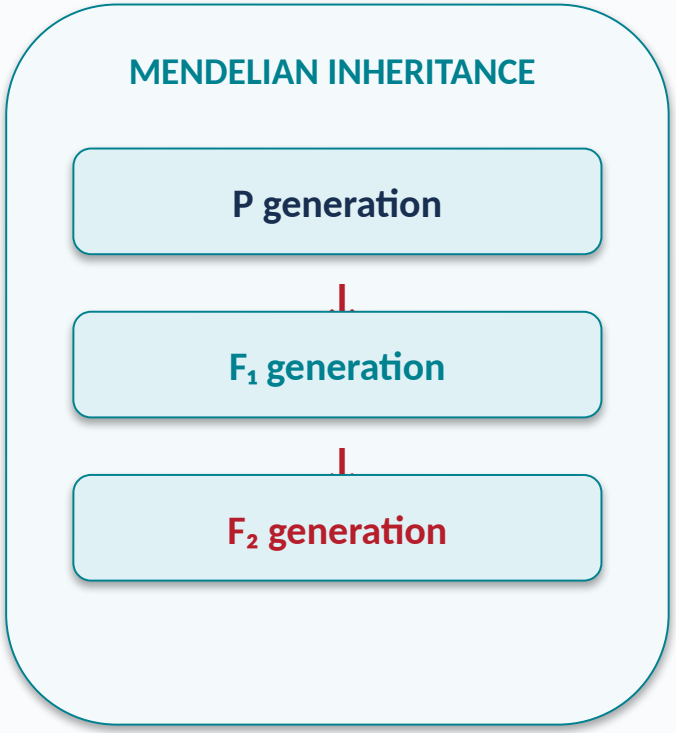
20.4 What does a heterozygous sickle-cell genotype illustrate in the textbook?

A. Expression of both hemoglobin forms

B. Loss of both hemoglobin genes

C. Absence of red blood cells

D. Only dominant inheritance



Q20 | Practice MCQ 5

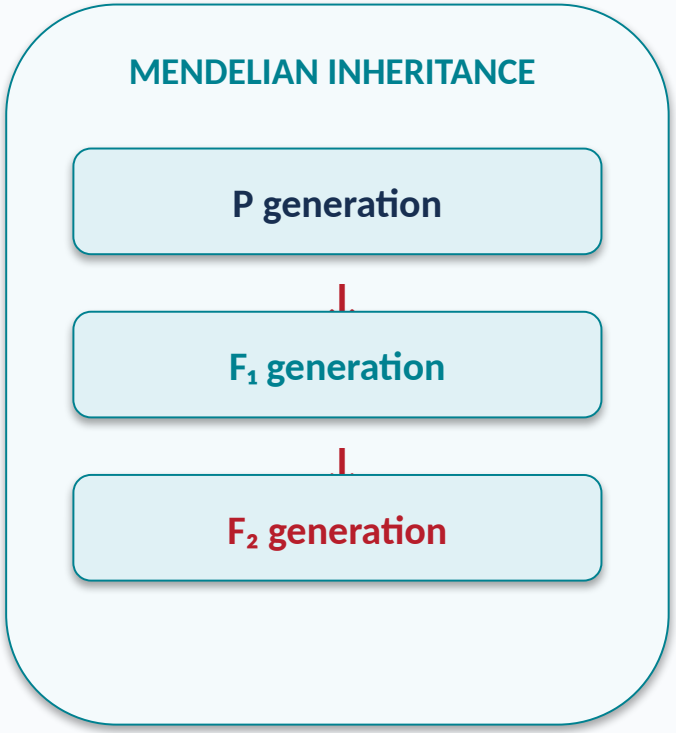
20.5 Why can sickle-shaped cells cause health problems?

A. They carry extra chromosomes

B. They produce chlorophyll

C. They prevent all protein synthesis

D. They may block small blood vessels



Q21 | Official learning outcome

BIO.3.3.02.012: Use the Punnett square method to solve basic genetics problems involving monohybrid crosses, incomplete dominance, codominance, dihybrid crosses, and sex-linked genes.

EXACT COVERAGE: Q21 | Textbook printed page 27 | Figure 20

STUDY TARGET: Multiple alleles, ABO blood groups and Punnett squares

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Q21 | Original textbook page

Coat color in rabbits

Multiple alleles can demonstrate a hierarchy of dominance. In rabbits, four alleles code for coat color: C, c^{ch}, c^{h}, and c. Allele C is dominant to the other alleles and results in a full color coat. Allele c is recessive and results in an albino phenotype when the genotype is homozygous recessive. Allele c^{ch} is dominant to c^{h}, and allele c^{h} is dominant to c. The hierarchy of dominance can be written as $C > c^{ch} > c^{h} > c$.

Figure 21 shows the genotypes and phenotypes possible for rabbit-coat color. Full color is dominant over not full color, which is dominant over Himalayan, which is dominant over albino.

The presence of multiple alleles increases the possible number of genotypes and phenotypes. Without multiple-allele dominance, two alleles, such as T and t, produce only three possible genotypes—in this example TT, Tt, and tt—and two possible phenotypes. However, the four alleles for rabbit-coat color produce ten possible genotypes and four phenotypes, as shown in **Figure 21.** More variation in rabbit coat color comes from the interaction of the color gene with other genes.



Full color
CC or Cc or Cc^{h} or Cc^{ch}

Chinchilla
$c^{ch}c^{ch}$ or $c^{ch}c^{h}$ or $c^{ch}c$



Himalayan
$c^{h}c^{h}$ or $c^{h}c$



Albino
cc

Figure 21 Rabbits have multiple alleles for coat color. The four alleles provide four basic variations in coat color.

(tl) kickers/iStock/Getty Images; (tr) GlobalP/iStock/Getty Images; (bl) Custom Life Science Images/Alamy; (br) StockPhotosArt/Shutterstock.com

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Q21 | Learning outcome explanation (1/3)

Specific textbook focus: ABO blood groups and multiple alleles; Figure 20.

Key terms (definitions for understanding the learning outcome; not all terms are necessarily examined in this particular reference):

Punnett square — A diagram that combines possible parental gametes to predict offspring genotypes.

Monohybrid cross — A genetic cross examining one inherited characteristic.

Dihybrid cross — A genetic cross examining two inherited characteristics.

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Q21 | Learning outcome explanation (2/3)

Genotypic ratio — The relative frequencies of different allele combinations among offspring.

Phenotypic ratio — The relative frequencies of observable traits among offspring.

Probability — The likelihood that a particular genetic outcome will occur.

How to distinguish the concepts: genotype refers to allele combination; phenotype refers to observable expression. Complete dominance masks the recessive phenotype in heterozygotes; incomplete dominance is intermediate; codominance expresses both alleles.

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Q21 | Learning outcome explanation (3/3)

Study focus: ABO blood groups and multiple alleles. Read the exact cited textbook page and interpret its labeled diagram, table or question. The official coverage description identifies a broader learning outcome; the cited reference narrows the emphasis for this item.

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Q21 | Practice MCQ 1

21.1 Which alleles are codominant in the ABO blood group system?

A. I^B and i

B. i and i

C. I^A and I^B

D. I^A and i

PUNNETT SQUARE

	Y	y
Y	YY	Yy
y	Yy	yy

Allele combinations

FREIWAN

Q21 | Practice MCQ 2

21.2 What blood type results from genotype I^AI^B?

A. O

B. AB

C. A

D. B

PUNNETT SQUARE

	Y	y
Y	YY	Yy
y	Yy	yy

Allele combinations

FREIWAN

Q21 | Practice MCQ 3

21.3 Which genotype produces blood type O?

A. ii

B. I^Ai

C. I^Bi

D. I^AI^B

PUNNETT SQUARE

	Y	y
Y	YY	Yy
y	Yy	yy

Allele combinations

FREIWAN

Q21 | Practice MCQ 4

21.4 What is the phenotype of genotype I^Ai?

A. Type AB

B. Type B

C. Type O

D. Type A

PUNNETT SQUARE

	Y	y
Y	YY	Yy
y	Yy	yy

Allele combinations

FREIWAN

Q21 | Practice MCQ 5

21.5 Why is ABO inheritance an example of multiple alleles?

A. There is only one allele

B. ABO genes are on every chromosome

C. More than two allele forms exist in the population

D. Each person carries three alleles

PUNNETT SQUARE

	Y	y
Y	YY	Yy
y	Yy	yy

Allele combinations

FREIWAN

Q22 | Official learning outcome

BIO.3.3.02.012: Use the Punnett square method to solve basic genetics problems involving monohybrid crosses, incomplete dominance, codominance, dihybrid crosses, and sex-linked genes.

EXACT COVERAGE: Q22 | Textbook printed page 30 | Information from text; Figure 23

STUDY TARGET: X-inactivation and calico coat patterns

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Q22 | Original textbook page

Sex-Linked Traits

Traits controlled by genes located on the X chromosome are called **sex-linked traits**, or X-linked traits. Because genetically classified males have only one X chromosome, they are affected by recessive X-linked traits more often than are genetically classified females. Females are less likely to express a recessive X-linked trait because the other X chromosome may mask the effect of the trait.

Some traits that are located on autosomes may appear to be sex-linked, even though they are not. This occurs when an allele appears to be dominant in one sex, but recessive in the other. For example, the allele for baldness is recessive in females but dominant in males, causing hair loss that follows a typical pattern called male-pattern baldness. A male would be bald if he were heterozygous for the trait, while a female would be bald only if she were homozygous recessive.

Red-green colorblindness

The trait for red-green colorblindness, most commonly, is a recessive X-linked trait. About 8 percent of males in the United States have the trait of red-green color blindness. The right photo in **Figure 25** show how a person with red-green color blindness might view colors compared to the left photo that shows how colors appear to a person who does not have red-green color blindness.

Study the Punnett square shown in **Figure 25.** The mother is a carrier for color blindness because she has the recessive allele for color blindness on one of her X chromosomes. The father is not color blind because he does not have the recessive allele on his one X chromosome. The sex-linked trait is represented by writing the allele on the X chromosome. Notice that the only offspring that can possibly have red-green color blindness is a male child, and that it is also possible for male offspring of this cross to have normal vision. As a result of it being an X-linked trait, red-green color blindness is very rare in females.



X^B = Normal
X^b = Red-green color blindness
Y = Y chromosome

	X^B	Y
X^B	X^BX^B	X^BY
X^b	X^BX^b	X^bY

Figure 25 People with red-green color blindness view red and green as shades of gray.

Explain *why there are fewer females who have red-green color blindness than males.*

Ryan McVay/Photodisc/Getty Images

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Q22 | Learning outcome explanation (1/3)

Specific textbook focus: X-chromosome inactivation and the calico cat example; Figure 23.

Key terms (definitions for understanding the learning outcome; not all terms are necessarily examined in this particular reference):

Incomplete dominance — A heterozygote shows an intermediate phenotype between the two homozygotes.

Codominance — Both alleles are expressed in a heterozygote, as in AB blood type.

Multiple alleles — More than two allelic forms exist in a population for one gene, although each diploid individual carries two.

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Q22 | Learning outcome explanation (2/3)

Epistasis — An interaction in which one gene masks or modifies expression of another gene.

Dosage compensation — A mechanism that balances expression of X-linked genes between sexes.

X-inactivation — Silencing of one X chromosome in most cells of female placental mammals.

Polygenic trait — A characteristic influenced by multiple genes.

Environmental influence — A non-genetic factor that can alter phenotype.

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Q22 | Learning outcome explanation (3/3)

How to distinguish the concepts: genotype refers to allele combination; phenotype refers to observable expression. Complete dominance masks the recessive phenotype in heterozygotes; incomplete dominance is intermediate; codominance expresses both alleles.

Study focus: X-chromosome inactivation and coat color. Read the exact cited textbook page and interpret its labeled diagram, table or question. The official coverage description identifies a broader learning outcome; the cited reference narrows the emphasis for this item.

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Q22 | Practice MCQ 1

22.1 What produces patches of different coat colors in a calico cat?

A. Identical expression in all cells

B. Random X-chromosome inactivation

C. Independent assortment of autosomes only

D. No sex chromosomes

PUNNETT SQUARE

	Y	y
Y	YY	Yy
y	Yy	yy

Allele combinations

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Q22 | Practice MCQ 2

22.2 In typical female mammals, how many X chromosomes are largely inactivated per somatic cell?

A. One

B. Zero

C. Two

D. Four

PUNNETT SQUARE

	Y	y
Y	YY	Yy
y	Yy	yy

Allele combinations

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Q22 | Practice MCQ 3

22.3 Why can female calico cats display two coat-color patches?

A. All cells express both X chromosomes equally

B. Their fur lacks pigment genes

C. Their cells have no nuclei

D. Different cells express different X-linked alleles

PUNNETT SQUARE

	Y	y
Y	YY	Yy
y	Yy	yy

Allele combinations

FREIWAN

Q22 | Practice MCQ 4

22.4 What is the inactive X chromosome condensed into?

A. A centriole

B. A spindle fiber

C. A Barr body

D. A ribosome

PUNNETT SQUARE

	Y	y
Y	YY	Yy
y	Yy	yy

Allele combinations

FREIWAN

Q22 | Practice MCQ 5

22.5 When does X inactivation usually occur?

A. After death

B. Early in development

C. Only at fertilization of every gamete

D. Only during meiosis II

PUNNETT SQUARE

	Y	y
Y	YY	Yy
y	Yy	yy

Allele combinations

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Q23 | Official learning outcome

BIO.3.3.02.012: Use the Punnett square method to solve basic genetics problems involving monohybrid crosses, incomplete dominance, codominance, dihybrid crosses, and sex-linked genes.

EXACT COVERAGE: Q23 | Textbook printed page 31 | Information from text; Figure 25

STUDY TARGET: X-linked inheritance and color-blindness crosses

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Q23 | Original textbook page

Hemophilia

Hemophilia, another recessive sex-linked disorder, is characterized by delayed clotting of the blood. Like red-green color blindness, this disorder is more common in males than in females.

A famous pedigree of hemophilia is one that arose in the family of Queen Victoria of England (1819-1901). Her son Leopold died of hemophilia, and her daughters Alice and Beatrice, as illustrated in the pedigree in **Figure 26,** were carriers for the disease. Alice and Beatrice passed on the hemophilia trait to the Russian, German, and Spanish royal families. Follow the generations in this pedigree to see how this trait was passed through Queen Victoria's family. Queen Victoria's granddaughter Alexandra, who was a carrier for this trait, married Tsar Nicholas II of Russia. Irene, another granddaughter, passed the trait on to the German royal family. Hemophilia was passed to the Spanish royal family through a third granddaughter, whose name also was Victoria.

Men with hemophilia usually died at an early age until the twentieth century when clotting factors were discovered and given to hemophiliacs. However, blood-borne viruses such as Hepatitis C and HIV were often contracted by hemophiliacs until the 1990s, when safer methods of blood transfusion were discovered.

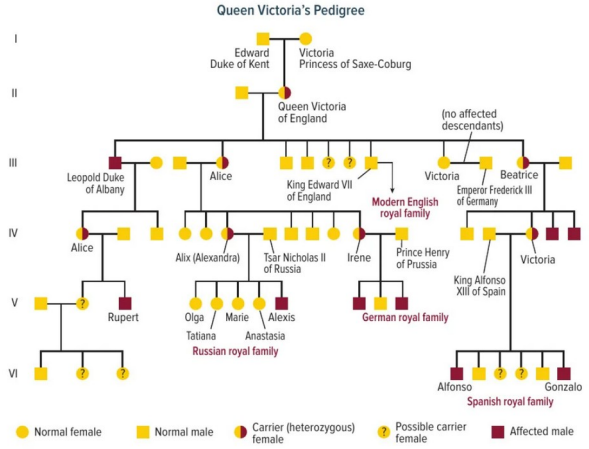

Figure 26 The pedigree above shows the inheritance of hemophilia in the royal families of England, Germany, Spain, and Russia, starting with the children of Queen Victoria.

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Q23 | Learning outcome explanation (1/3)

Specific textbook focus: X-linked recessive inheritance and red-green color blindness; Figure 25.

Key terms (definitions for understanding the learning outcome; not all terms are necessarily examined in this particular reference):

Incomplete dominance — A heterozygote shows an intermediate phenotype between the two homozygotes.

Codominance — Both alleles are expressed in a heterozygote, as in AB blood type.

Multiple alleles — More than two allelic forms exist in a population for one gene, although each diploid individual carries two.

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Q23 | Learning outcome explanation (2/3)

Epistasis — An interaction in which one gene masks or modifies expression of another gene.

Dosage compensation — A mechanism that balances expression of X-linked genes between sexes.

X-inactivation — Silencing of one X chromosome in most cells of female placental mammals.

Polygenic trait — A characteristic influenced by multiple genes.

Environmental influence — A non-genetic factor that can alter phenotype.

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Q23 | Learning outcome explanation (3/3)

How to distinguish the concepts: genotype refers to allele combination; phenotype refers to observable expression. Complete dominance masks the recessive phenotype in heterozygotes; incomplete dominance is intermediate; codominance expresses both alleles.

Study focus: Sex-linked inheritance: red-green color blindness. Read the exact cited textbook page and interpret its labeled diagram, table or question. The official coverage description identifies a broader learning outcome; the cited reference narrows the emphasis for this item.

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Q23 | Practice MCQ 1

23.1 Why is X-linked recessive color blindness more common in males?

A. Males typically have only one X chromosome

B. Males have two X chromosomes

C. The allele is on the Y chromosome

D. The allele is always dominant

PUNNETT SQUARE

	Y	y
Y	YY	Yy
y	Yy	yy

Allele combinations

FREIWAN

Q23 | Practice MCQ 2

23.2 What genotype represents an affected male for an X-linked recessive trait?

A. X^NY

B. X^NX^c

C. X^NX^N

D. X^cY

PUNNETT SQUARE

	Y	y
Y	YY	Yy
y	Yy	yy

Allele combinations

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Q23 | Practice MCQ 3

23.3 A carrier mother X^NX^c and unaffected father X^NY have what chance of an affected son?

A. 0% of sons

B. 25% of sons

C. 50% of sons

D. 100% of sons

PUNNETT SQUARE

	Y	y
Y	YY	Yy
y	Yy	yy

Allele combinations

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Q23 | Practice MCQ 4

23.4 Which parent supplies the X chromosome to a son?

A. Neither parent

B. Mother

C. Father

D. Both parents supply an X

PUNNETT SQUARE

	Y	y
Y	YY	Yy
y	Yy	yy

Allele combinations

FREIWAN

Q23 | Practice MCQ 5

23.5 Can an unaffected carrier female pass an X-linked recessive allele to her son?

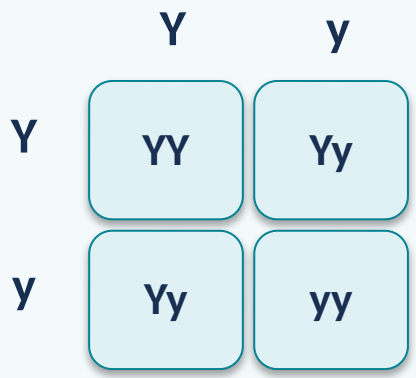
A. Yes

B. No

C. Only if the father is affected

D. Only through the Y chromosome

PUNNETT SQUARE



Allele combinations

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Q24 | Official learning outcome

BIO.3.3.01.012: Analyze a simulated strand of DNA to determine the genetic code and base pairing of DNA.

EXACT COVERAGE: Q24 | Textbook printed page 41 | Information from text; Figure 2

STUDY TARGET: DNA nucleotide components and base pairing

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Q24 | Original textbook page

Follow Griffith's study in **Figure 2**. The coated strain causes pneumonia and is called the smooth (S) strain. The noncoated, or rough (R) strain, does not cause pneumonia. The live S cells killed the mouse in the study. The live R cells did not kill the mouse, and the killed S cells did not kill the mouse. When Griffith made a mixture of live R cells and killed S cells and injected the mixture into a mouse, the mouse died. Griffith isolated live bacteria from the dead mouse. When these isolated bacteria were cultured, the smooth trait was visible, suggesting that a disease-causing factor was passed from the killed S bacteria to the live R bacteria. Griffith concluded that there had been a transformation from live R bacteria to live S bacteria. This experiment set the stage for the search to identify the transforming substance.

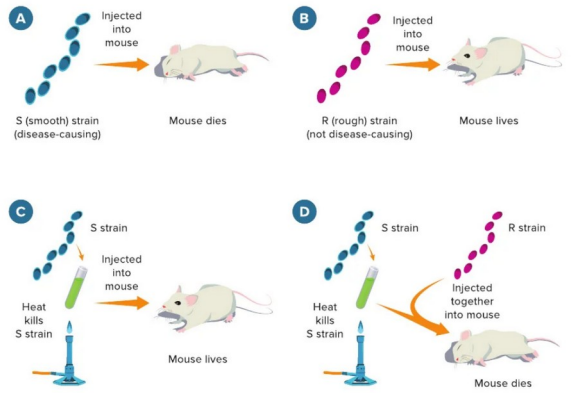

Figure 2 Griffith's transformation experiment demonstrates the change of rough bacteria into smooth bacteria.

Avery

In 1944, Oswald Avery and his colleagues identified the molecule that transformed the R strain of bacteria into the S strain. Avery isolated different macromolecules, such as DNA, proteins, and lipids, from killed S cells. Then he exposed live R cells to the macromolecules separately. When the live R cells were exposed to the S strain DNA, they were transformed into S cells. Avery concluded that when the S cells in Griffith's experiments were killed, DNA was released. Some of the R bacteria incorporated this DNA into their cells, and this changed the bacteria into S cells. Avery's conclusions were not widely accepted by the scientific community, and many biologists continued to question and experiment to determine whether proteins or DNA were responsible for the transfer of genetic material.

Get It?
Explain how Avery discovered the transforming factor.

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Q24 | Learning outcome explanation (1/3)

Specific textbook focus: DNA composition and nucleotide components; Figure 2.

Key terms (definitions for understanding the learning outcome; not all terms are necessarily examined in this particular reference):

DNA — Deoxyribonucleic acid, the molecule that stores hereditary information.

Nucleotide — The building block of DNA, containing a phosphate, deoxyribose sugar and nitrogenous base.

Complementary base pairing — A pairs with T, and C pairs with G in DNA.

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Q24 | Learning outcome explanation (2/3)

Double helix — The twisted two-stranded structure of DNA.

Antiparallel strands — The two DNA strands run in opposite 5′→3′ directions.

DNA replication — The process by which DNA is copied before cell division.

Semiconservative replication — Each daughter DNA double helix contains one parental strand and one newly synthesized strand.

DNA polymerase — An enzyme that adds complementary DNA nucleotides and can proofread during replication.

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Q24 | Learning outcome explanation (3/3)

DNA helicase — An enzyme that separates the two DNA strands at the replication fork.

DNA ligase — An enzyme that joins DNA fragments by sealing the sugar-phosphate backbone.

DNA reasoning: apply complementary base-pair rules (A–T, C–G) and distinguish the original template strands from newly synthesized strands.

Study focus: DNA nucleotide structure and base pairing. Read the exact cited textbook page and interpret its labeled diagram, table or question. The official coverage description identifies a broader learning outcome; the cited reference narrows the emphasis for this item.

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Q24 | Practice MCQ 1

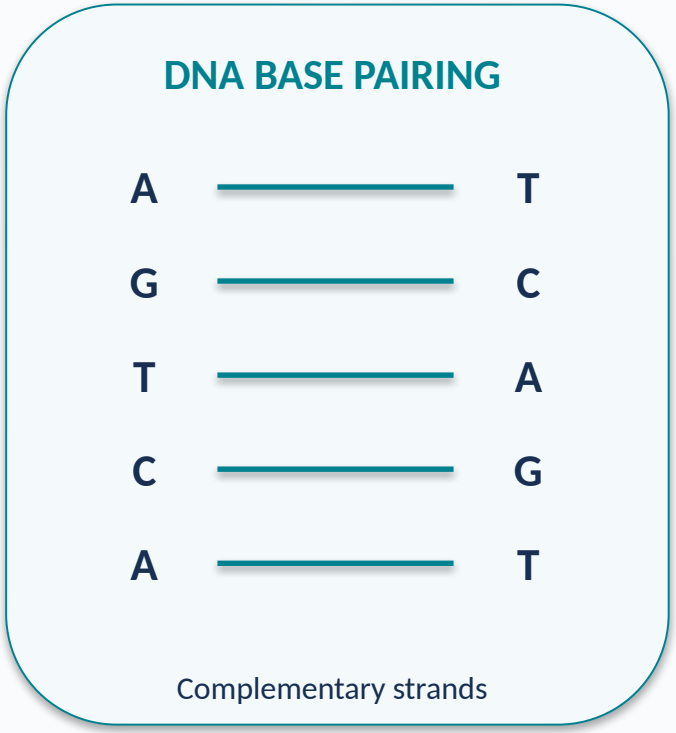
24.1 Which three components make up a DNA nucleotide?

A. Protein, lipid, carbohydrate

B. Ribosome, enzyme, base

C. Amino acid, sugar, lipid

D. Sugar, phosphate, nitrogenous base



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Q24 | Practice MCQ 2

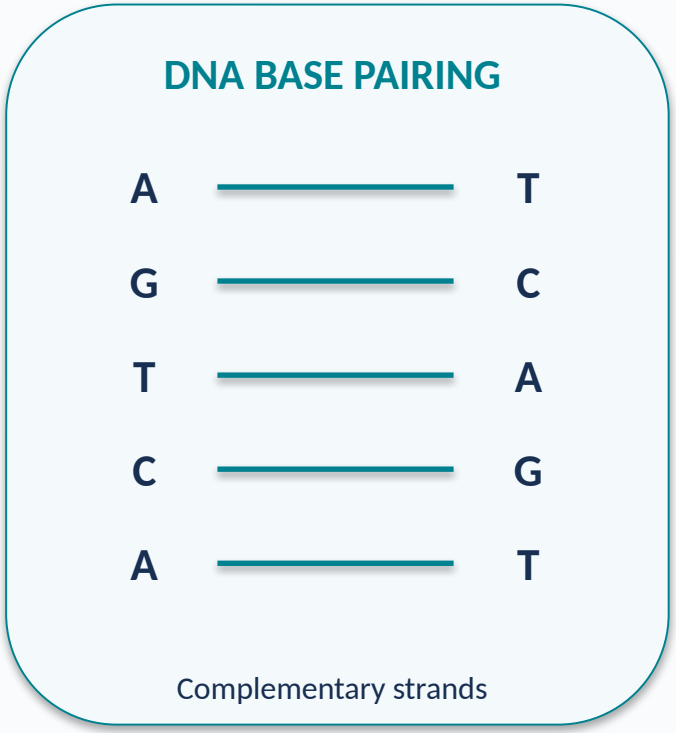
24.2 Which base pairs with adenine in DNA?

A. Guanine

B. Uracil

C. Thymine

D. Cytosine



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Q24 | Practice MCQ 3

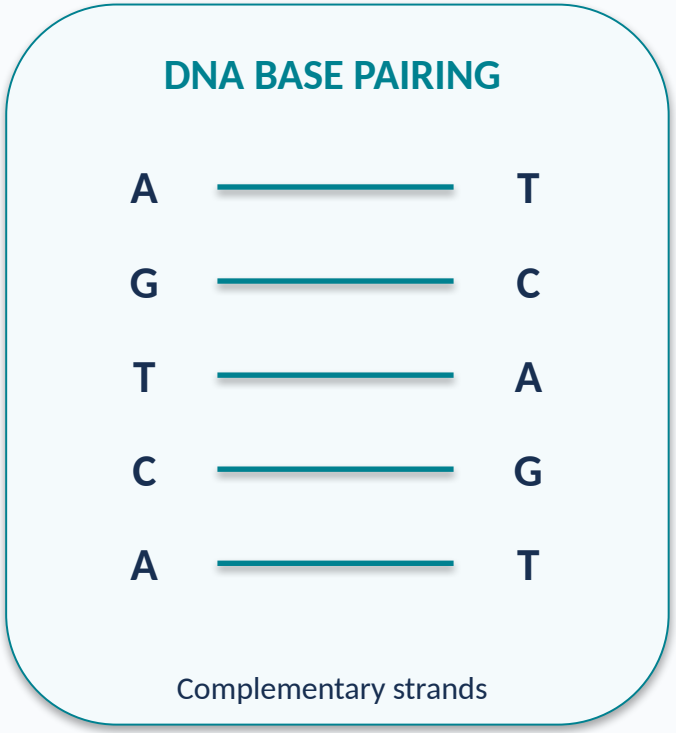
24.3 What sugar is found in DNA?

A. Fructose

B. Deoxyribose

C. Ribose

D. Glucose



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Q24 | Practice MCQ 4

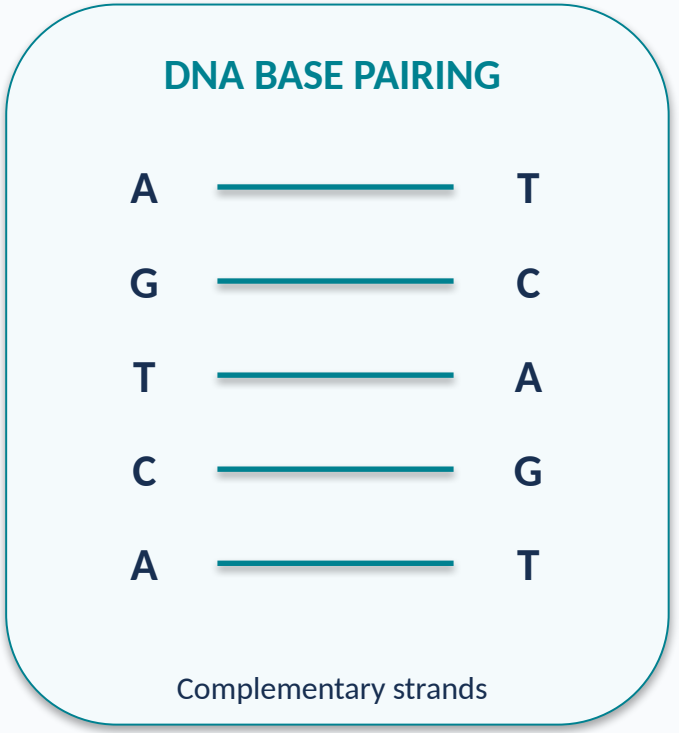
24.4 What forms the sides of the DNA ladder?

A. Alternating sugar and phosphate

B. Paired nitrogenous bases only

C. Amino acids

D. Fatty acids



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Q24 | Practice MCQ 5

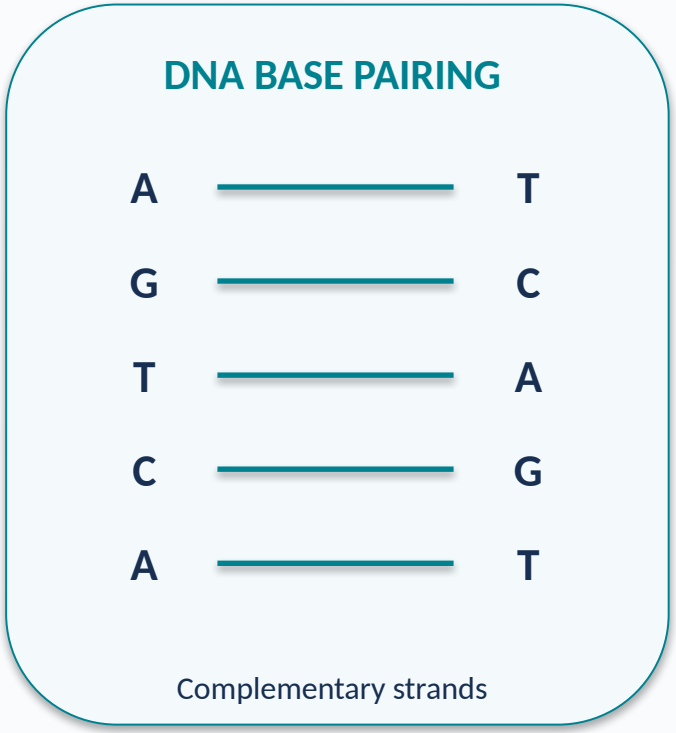
24.5 Which base is a purine?

A. Thymine

B. Cytosine

C. Uracil

D. Guanine



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Q25 | Official learning outcome

BIO.3.3.01.012: Analyze a simulated strand of DNA to determine the genetic code and base pairing of DNA.

EXACT COVERAGE: Q25 | Textbook printed page 42 | Information from text; Figure 3

STUDY TARGET: Complementary DNA bases and hydrogen bonds

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Q25 | Original textbook page

Hershey and Chase

In 1952, Alfred Hershey and Martha Chase published results of experiments that provided definitive evidence that DNA was the transforming factor. These experiments involved a bacteriophage (bak TIHR ee uh fayj), a type of virus that attacks bacteria. Two components made the experiment ideal for confirming that DNA is the genetic material. First, the bacteriophage used in the experiment was made of DNA and protein. Second, viruses cannot replicate themselves. They must inject their genetic material into a living cell in order for replication to take place. Hershey and Chase labeled both parts of the virus to determine which part was injected into the bacteria and, thus, which part was the genetic material.

Radioactive labeling Hershey and Chase used a technique called radioactive labeling to trace the fate of the DNA and protein as the bacteriophages infected bacteria and reproduced. Follow along in **Figure 3,** which illustrates the Hershey-Chase experiment. They labeled one set of bacteriophages with radioactive phosphorus (^{32}P). Proteins do not contain phosphorous, so DNA and not protein in these viruses would be radioactive. Hershey and Chase labeled another set of bacteriophages with radioactive sulfur (^{35}S). Because proteins contain sulfur and DNA does not, proteins and not DNA would be radioactive.

Hershey and Chase infected bacteria with viruses from the two groups. When viruses infect bacteria, they attach to the outside of the bacteria and inject their genetic material. The infected bacteria then were separated from the viruses.

Tracking DNA Hershey and Chase examined Group 1 labeled with ^{32}P and found that the labeled viral DNA had been injected into the bacteria. Viruses later released from the infected bacteria contained ^{32}P, further indicating that DNA was the carrier of genetic information.

When examining Group 2 labeled with ^{35}S, Hershey and Chase observed that the labeled proteins were found outside of the bacterial cells. Viral replication had occurred in the bacterial cells, indicating that the viruses' genetic material had entered the bacteria, but no label (^{35}S) was found.

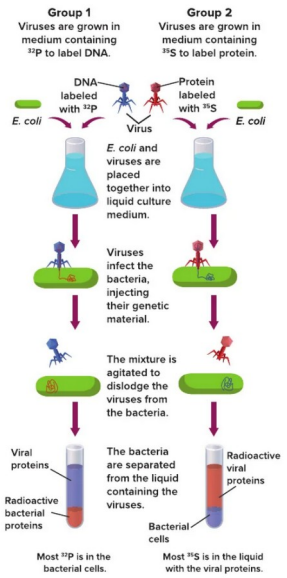

Figure 3 Hershey and Chase used radioactive labeling techniques to demonstrate that DNA is the genetic material in viruses.

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Q25 | Learning outcome explanation (1/3)

Specific textbook focus: DNA strand structure and complementary base pairing; Figure 3.

Key terms (definitions for understanding the learning outcome; not all terms are necessarily examined in this particular reference):

DNA — Deoxyribonucleic acid, the molecule that stores hereditary information.

Nucleotide — The building block of DNA, containing a phosphate, deoxyribose sugar and nitrogenous base.

Complementary base pairing — A pairs with T, and C pairs with G in DNA.

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Q25 | Learning outcome explanation (2/3)

Double helix — The twisted two-stranded structure of DNA.

Antiparallel strands — The two DNA strands run in opposite 5′→3′ directions.

DNA replication — The process by which DNA is copied before cell division.

Semiconservative replication — Each daughter DNA double helix contains one parental strand and one newly synthesized strand.

DNA polymerase — An enzyme that adds complementary DNA nucleotides and can proofread during replication.

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Q25 | Learning outcome explanation (3/3)

DNA helicase — An enzyme that separates the two DNA strands at the replication fork.

DNA ligase — An enzyme that joins DNA fragments by sealing the sugar-phosphate backbone.

DNA reasoning: apply complementary base-pair rules (A–T, C–G) and distinguish the original template strands from newly synthesized strands.

Study focus: Complementary bases and DNA structure. Read the exact cited textbook page and interpret its labeled diagram, table or question. The official coverage description identifies a broader learning outcome; the cited reference narrows the emphasis for this item.

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Q25 | Practice MCQ 1

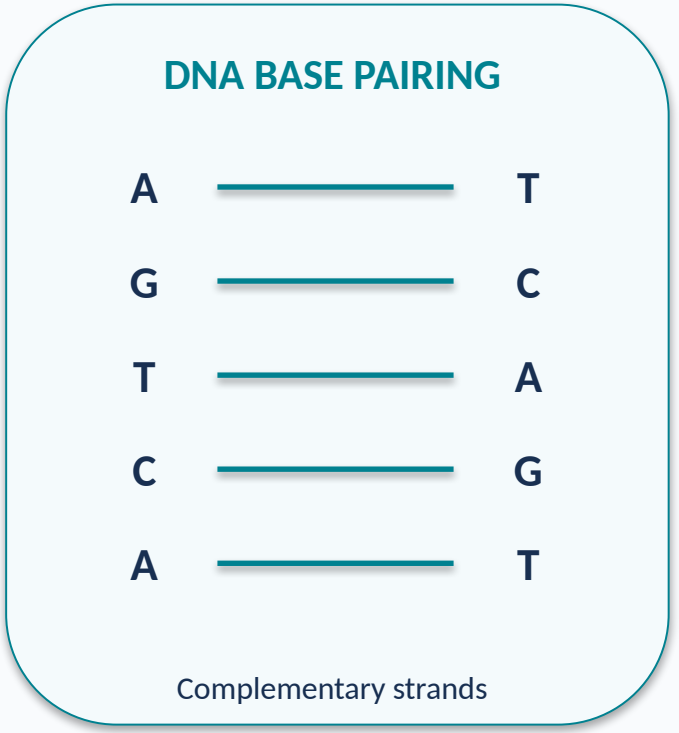
25.1 What is complementary to DNA strand ATGC?

A. UACG

B. GCTA

C. TACG

D. ATGC



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Q25 | Practice MCQ 2

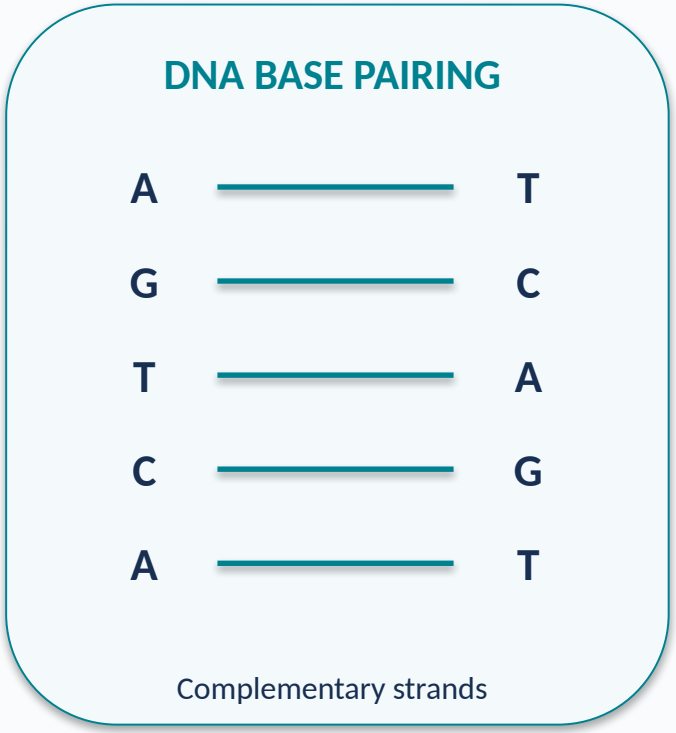
25.2 How many hydrogen bonds normally connect a G–C base pair?

A. 4

B. 3

C. 2

D. 1



Q25 | Practice MCQ 3

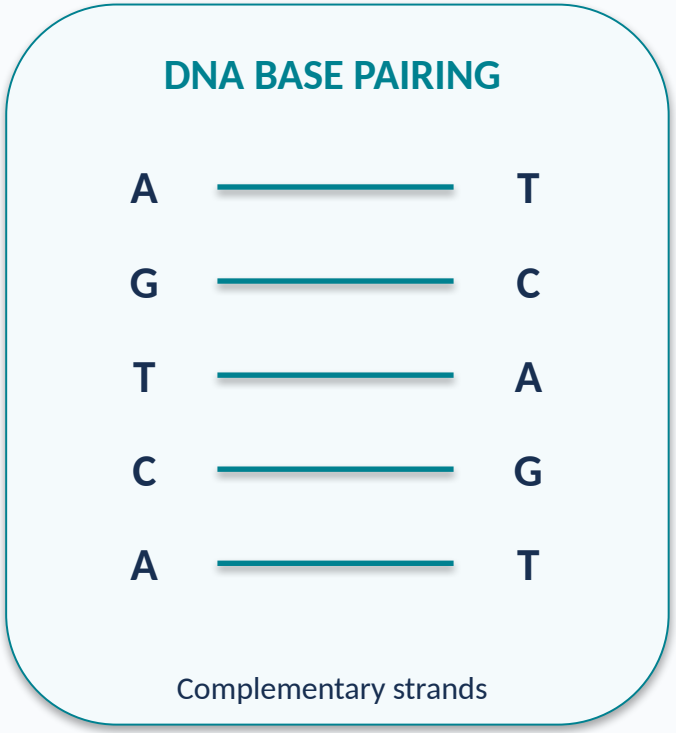
25.3 How many hydrogen bonds normally connect an A–T base pair?

A. 2

B. 3

C. 1

D. 4



Q25 | Practice MCQ 4

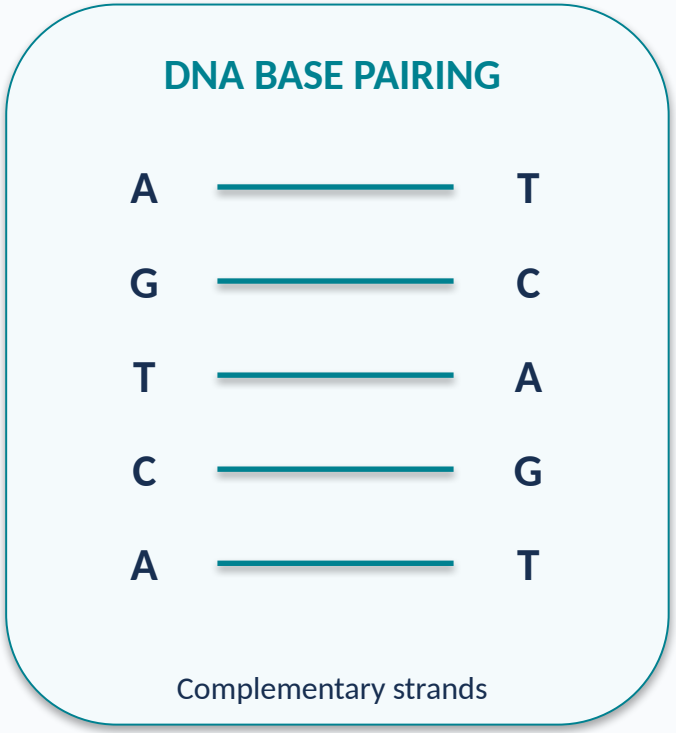
25.4 Which two DNA strands are described as antiparallel?

A. Strands with identical 5′–3′ directions

B. Strands without phosphate

C. Strands made of proteins

D. Strands oriented in opposite 5′–3′ directions



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Q25 | Practice MCQ 5

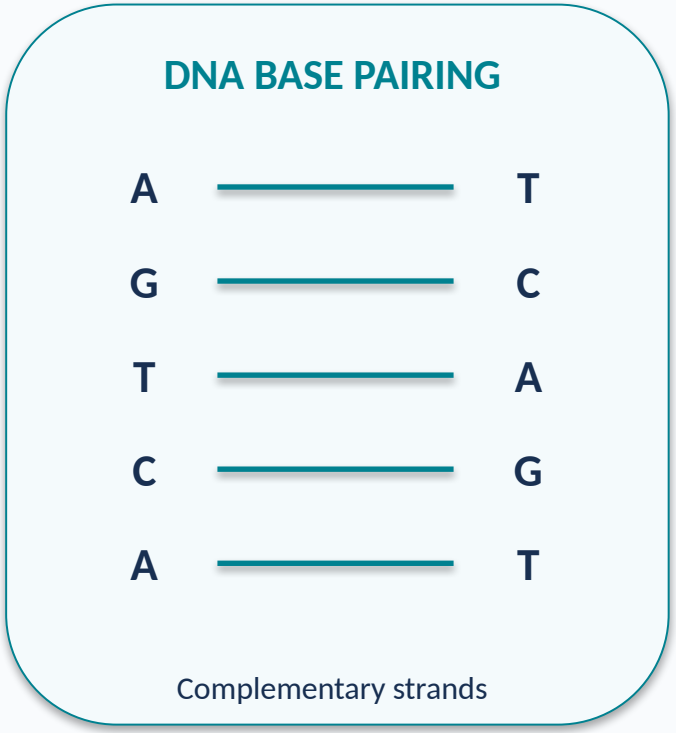
25.5 If a DNA sample has 30% adenine, what percentage is thymine?

A. 40%

B. 70%

C. 30%

D. 20%



Q26 | Official learning outcome

BIO.3.3.01.012: Analyze a simulated strand of DNA to determine the genetic code and base pairing of DNA.

EXACT COVERAGE: Q26 | Textbook printed page 44 | Information from text; Figure 4

STUDY TARGET: Double-helix structure and complementary strands

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Q26 | Original textbook page

Chargaff

Erwin Chargaff analyzed the amount of adenine, guanine, thymine, and cytosine in the DNA of various species. A portion of Chargaff's data, published in 1950, is shown in **Figure 4**. Chargaff found that the amount of guanine nearly equals the amount of cytosine, and the amount of adenine nearly equals the amount of thymine within a species. This finding is known as Chargaff's rule: C = G and T = A.

Chargaff's Data

	Base Composition (Mole Percent)			
Organism	A	T	G	C
Escherichia coli	26.0	23.9	24.9	25.2
Yeast	31.3	32.9	18.7	17.1
Herring	27.8	27.5	22.2	22.6
Rat	28.6	28.4	21.4	21.5
Human	30.9	29.4	19.9	19.8

Figure 4 Chargaff's data showed that though base composition varies from species to species, within a species C = G and A = T.

Franklin and Wilkins

Wilkins was working at King's College in London, England, with a technique called X-ray diffraction, a technique that involved aiming X rays at the DNA molecule. In 1951, Rosalind Franklin joined the staff at King's College. There she took the now famous Photo 51 and collected data eventually used by Watson and Crick. Photo 51, shown in **Figure 5,** indicated that DNA was a **double helix,** or twisted ladder shape, formed by two strands of nucleotides twisted around each other. The specific structure of the DNA double helix was determined later by Watson and Crick when they used Franklin's data and other mathematical data. DNA is the genetic material of all organisms, composed of two complementary, precisely paired strands of nucleotides wound in a double helix.

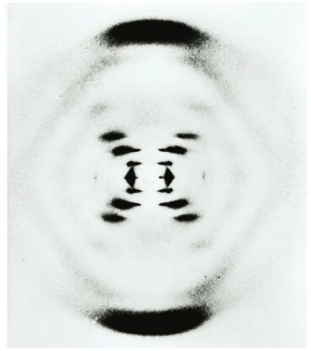

Figure 5 Rosalind Franklin's Photo 51 and X-ray diffraction data helped Watson and Crick solve the structure of DNA. When analyzed and measured carefully, the pattern shows the characteristics of a helical structure.

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Q26 | Learning outcome explanation (1/3)

Specific textbook focus: DNA structure and organization; Figure 4.

Key terms (definitions for understanding the learning outcome; not all terms are necessarily examined in this particular reference):

DNA — Deoxyribonucleic acid, the molecule that stores hereditary information.

Nucleotide — The building block of DNA, containing a phosphate, deoxyribose sugar and nitrogenous base.

Complementary base pairing — A pairs with T, and C pairs with G in DNA.

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Q26 | Learning outcome explanation (2/3)

Double helix — The twisted two-stranded structure of DNA.

Antiparallel strands — The two DNA strands run in opposite 5′→3′ directions.

DNA replication — The process by which DNA is copied before cell division.

Semiconservative replication — Each daughter DNA double helix contains one parental strand and one newly synthesized strand.

DNA polymerase — An enzyme that adds complementary DNA nucleotides and can proofread during replication.

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Q26 | Learning outcome explanation (3/3)

DNA helicase — An enzyme that separates the two DNA strands at the replication fork.

DNA ligase — An enzyme that joins DNA fragments by sealing the sugar-phosphate backbone.

DNA reasoning: apply complementary base-pair rules (A–T, C–G) and distinguish the original template strands from newly synthesized strands.

Study focus: DNA double helix and base pairing. Read the exact cited textbook page and interpret its labeled diagram, table or question. The official coverage description identifies a broader learning outcome; the cited reference narrows the emphasis for this item.

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Q26 | Practice MCQ 1

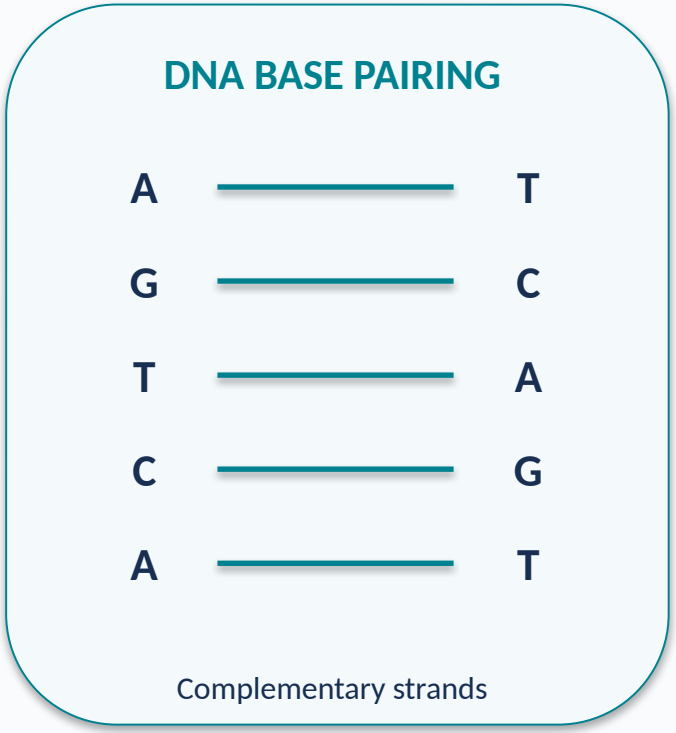
26.1 Which bases pair in DNA?

A. A–C and G–T

B. A–T and G–C

C. A–G and T–C

D. A–U and G–C



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Q26 | Practice MCQ 2

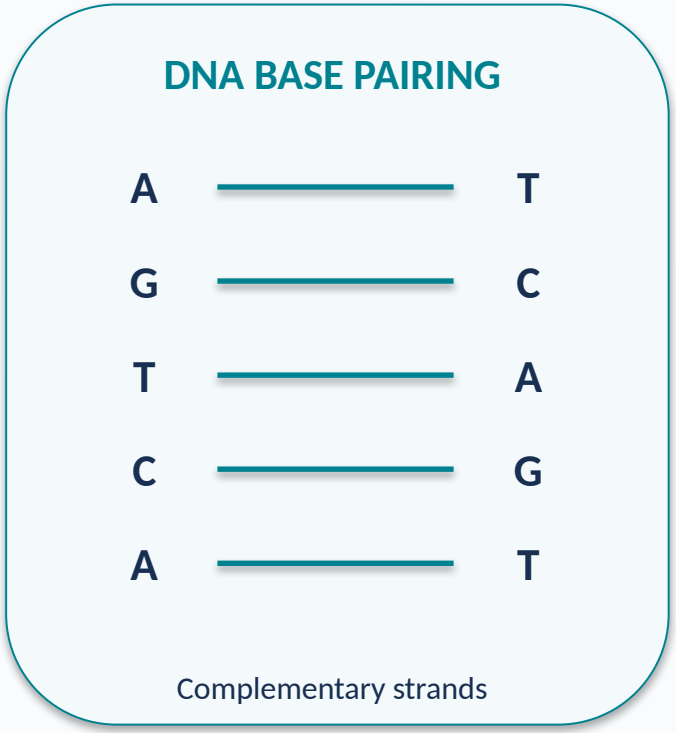
26.2 What holds complementary bases together?

A. Hydrogen bonds

B. Peptide bonds

C. Ionic bonds only

D. Phosphodiester bonds between bases



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Q26 | Practice MCQ 3

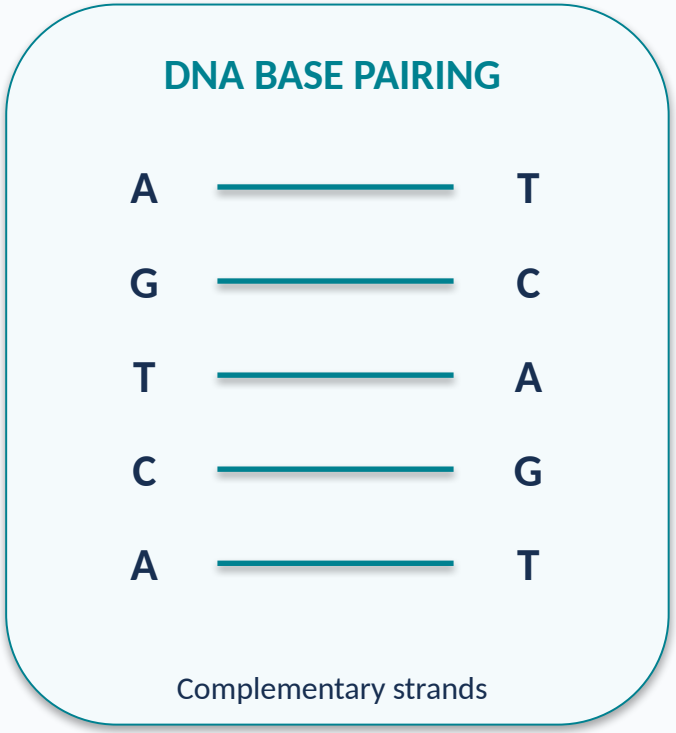
26.3 What is the overall shape of DNA?

A. Single straight chain

B. Triple sheet

C. Circular protein

D. Double helix



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Q26 | Practice MCQ 4

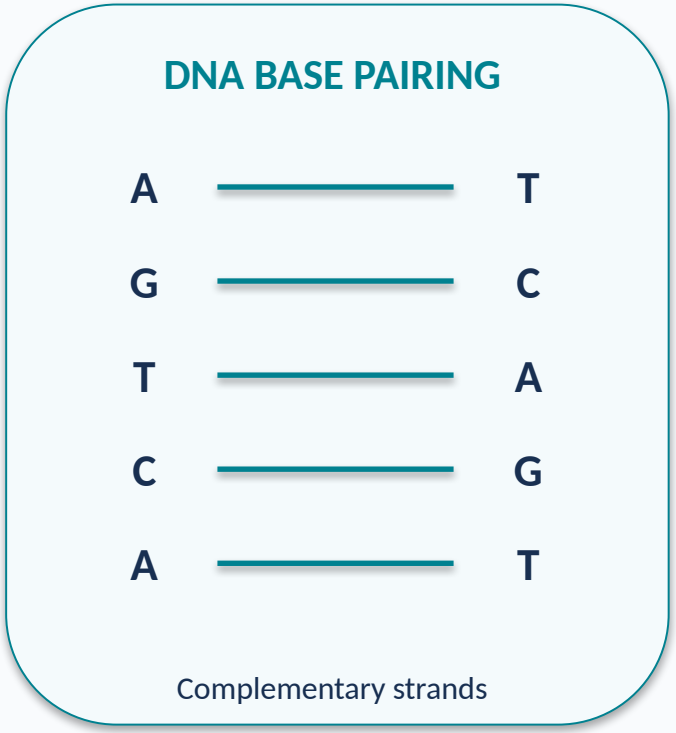
26.4 If one strand reads 5′-GCTA-3′, what is its complementary sequence aligned antiparallel?

A. 3′-CGAU-5′

B. 3′-ATCG-5′

C. 3′-CGAT-5′

D. 3′-GCTA-5′



Q26 | Practice MCQ 5

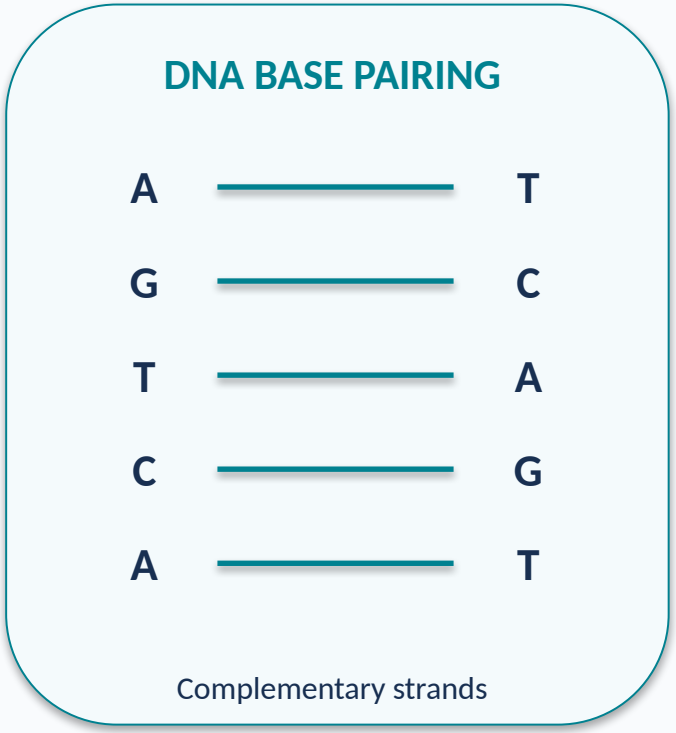
26.5 Which base is a pyrimidine in DNA?

A. Both adenine and guanine

B. Cytosine

C. Adenine

D. Guanine



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Q27 | Official learning outcome

BIO.3.3.01.012: Analyze a simulated strand of DNA to determine the genetic code and base pairing of DNA.

EXACT COVERAGE: Q27 | Textbook printed page 44 | Information from text; Figure 5

STUDY TARGET: DNA strands, nucleotide arrangement and base pairs

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Q27 | Original textbook page

Chargaff

Erwin Chargaff analyzed the amount of adenine, guanine, thymine, and cytosine in the DNA of various species. A portion of Chargaff's data, published in 1950, is shown in **Figure 4**. Chargaff found that the amount of guanine nearly equals the amount of cytosine, and the amount of adenine nearly equals the amount of thymine within a species. This finding is known as Chargaff's rule: C = G and T = A.

Chargaff's Data

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Figure 4 Chargaff's data showed that though base composition varies from species to species, within a species C = G and A = T.

Franklin and Wilkins

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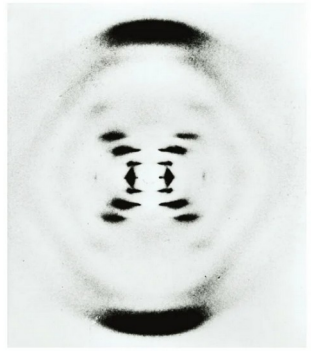

Figure 5 Rosalind Franklin's Photo 51 and X-ray diffraction data helped Watson and Crick solve the structure of DNA. When analyzed and measured carefully, the pattern shows the characteristics of a helical structure.

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Q27 | Learning outcome explanation (1/3)

Specific textbook focus: DNA structure and base pairing; Figure 5.

Key terms (definitions for understanding the learning outcome; not all terms are necessarily examined in this particular reference):

DNA — Deoxyribonucleic acid, the molecule that stores hereditary information.

Nucleotide — The building block of DNA, containing a phosphate, deoxyribose sugar and nitrogenous base.

Complementary base pairing — A pairs with T, and C pairs with G in DNA.

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Q27 | Learning outcome explanation (2/3)

Double helix — The twisted two-stranded structure of DNA.

Antiparallel strands — The two DNA strands run in opposite 5′→3′ directions.

DNA replication — The process by which DNA is copied before cell division.

Semiconservative replication — Each daughter DNA double helix contains one parental strand and one newly synthesized strand.

DNA polymerase — An enzyme that adds complementary DNA nucleotides and can proofread during replication.

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Q27 | Learning outcome explanation (3/3)

DNA helicase — An enzyme that separates the two DNA strands at the replication fork.

DNA ligase — An enzyme that joins DNA fragments by sealing the sugar-phosphate backbone.

DNA reasoning: apply complementary base-pair rules (A–T, C–G) and distinguish the original template strands from newly synthesized strands.

Study focus: DNA structure: nucleotides and strands. Read the exact cited textbook page and interpret its labeled diagram, table or question. The official coverage description identifies a broader learning outcome; the cited reference narrows the emphasis for this item.

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Q27 | Practice MCQ 1

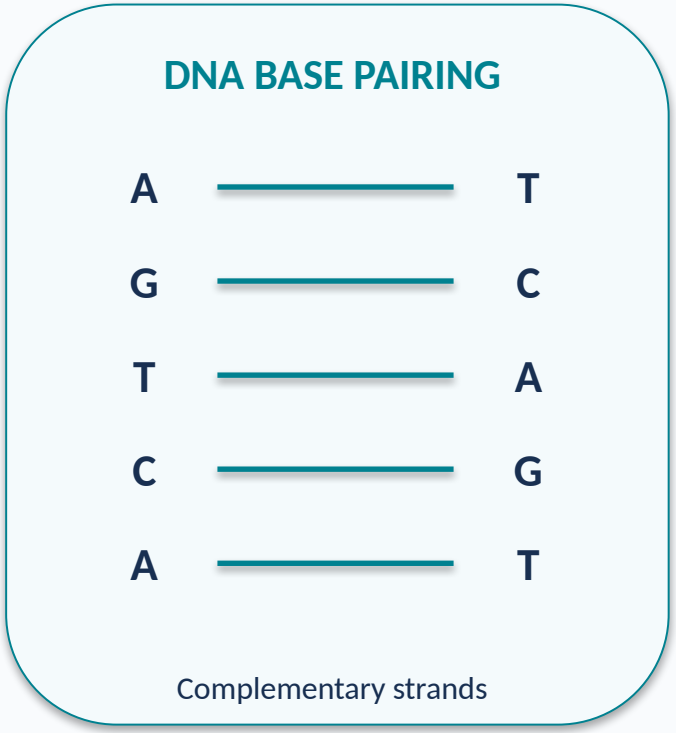
27.1 Which bond joins nucleotides along a single DNA strand?

A. Phosphodiester bond

B. Hydrogen bond between bases

C. Peptide bond

D. Disulfide bond



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Q27 | Practice MCQ 2

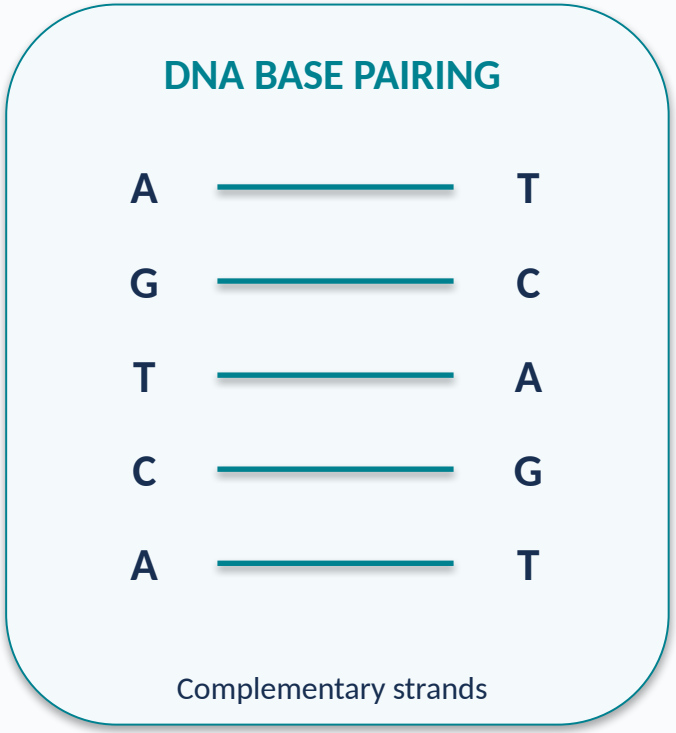
27.2 Which base is absent from DNA?

A. Thymine

B. Adenine

C. Cytosine

D. Uracil



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Q27 | Practice MCQ 3

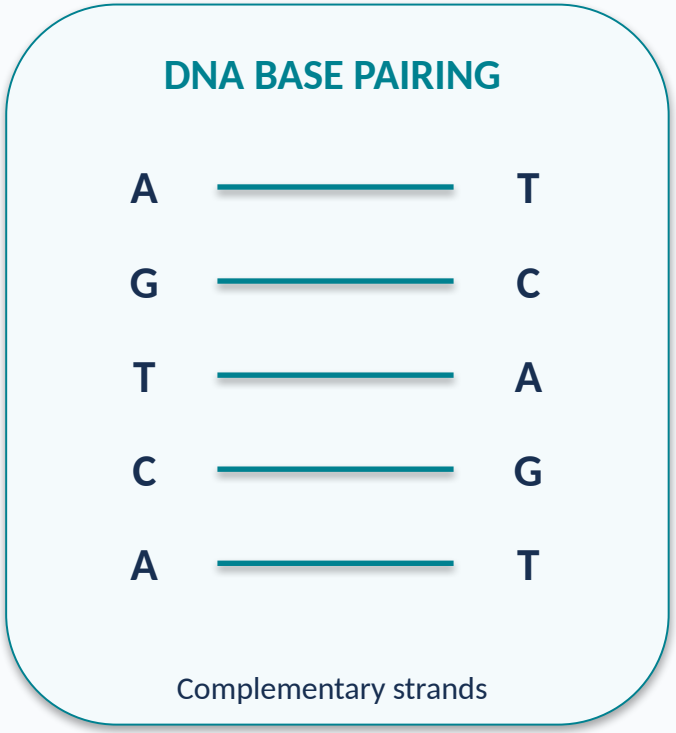
27.3 Which property allows DNA to be copied accurately?

A. Random base pairing

B. Loss of one strand

C. Complementary base pairing

D. Protein translation



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Q27 | Practice MCQ 4

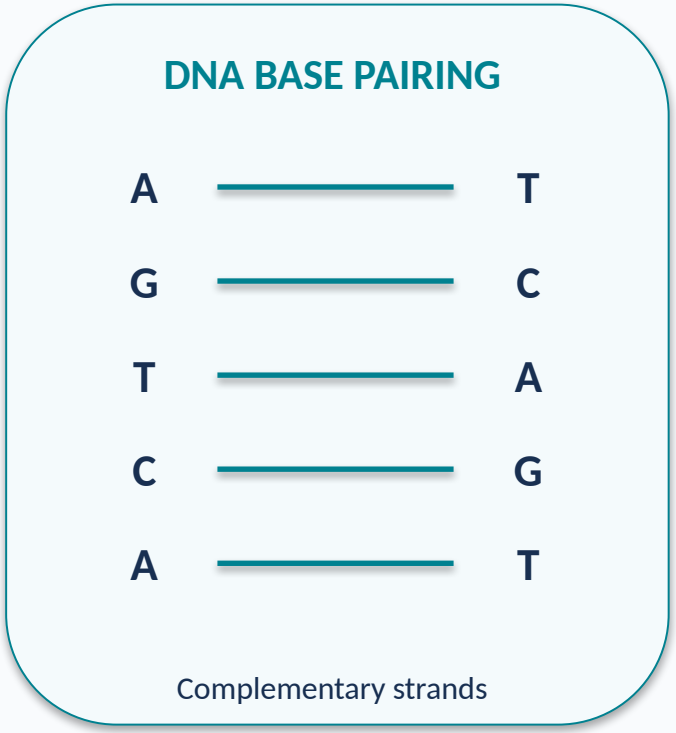
27.4 Which parts of two nucleotides vary among the four DNA types?

A. Number of sugar atoms

B. Nitrogenous bases

C. Deoxyribose sugars

D. Phosphate groups



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Q27 | Practice MCQ 5

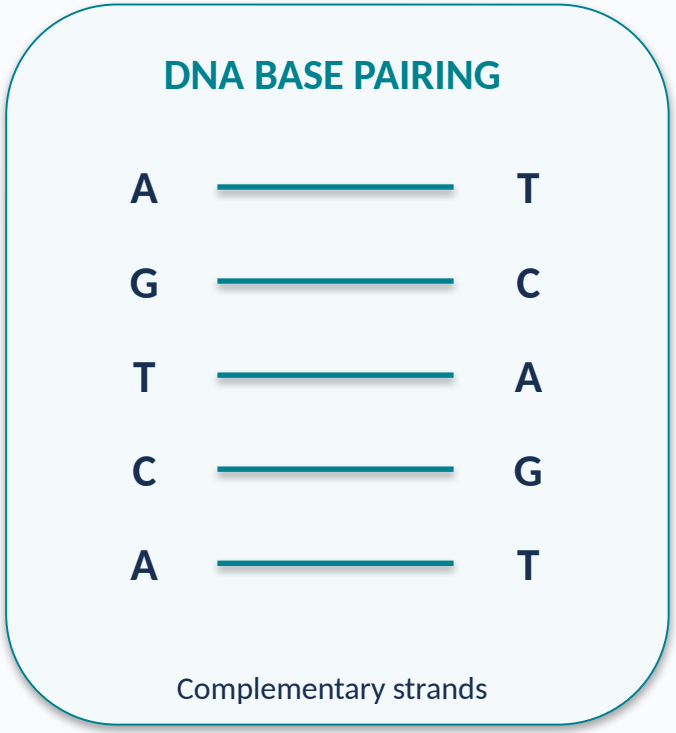
27.5 If 18% of DNA bases are guanine, what percentage is cytosine?

A. 18%

B. 32%

C. 36%

D. 64%



Q28 | Official learning outcome

BIO.3.3.01.012: Analyze a simulated strand of DNA to determine the genetic code and base pairing of DNA.

EXACT COVERAGE: Q28 | Textbook printed page 46 | Information from text; Figure 7

STUDY TARGET: DNA replication process and semi-conservative model

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Q28 | Original textbook page

Nucleotides

In the 1920s, the biochemist P. A. Levene determined the basic structure of nucleotides that make up DNA. Nucleotides are the subunits of nucleic acids and consist of a five-carbon sugar, a phosphate group, and a nitrogenous base. The two nucleic acids found in living cells are DNA and RNA. DNA nucleotides contain the sugar deoxyribose (dee ahk sih RI bos), a phosphate, and one of four nitrogenous bases: adenine (A duh neen), guanine (GWAH neen), cytosine (SI tuh seen), or thymine (THI meen). RNA nucleotides contain the sugar ribose, a phosphate, and one of four nitrogenous bases: adenine, guanine, cytosine, or uracil (YOO ruh sihl). Notice in **Figure 7** that guanine (G) and adenine (A) are double-ringed bases. This type of base is called a purine base. Thymine (T), cytosine (C), and uracil (U) are single-ringed bases called pyrimidine bases.

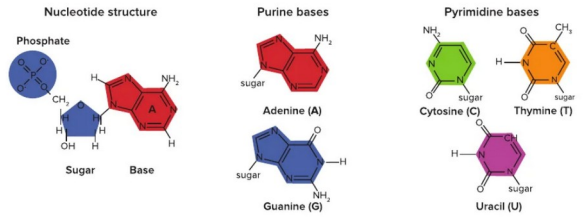

Figure 7 Nucleotides are made of a phosphate, sugar, and a base. There are five different bases found in nucleotide subunits that make up DNA and RNA.

Explain *the structural difference between purine and pyrimidine bases.*

DNA structure

DNA is often compared to a twisted ladder, with the rails of the ladder represented by the alternating deoxyribose and phosphate. The pairs of bases (cytosine–guanine or thymine–adenine) form the steps, or rungs, of the ladder. A purine base always binds to a pyrimidine base, ensuring a consistent distance between the two rails of the ladder. This proposed bonding of the bases also explains Chargaff's data, which suggested that the number of purine bases equaled the number of pyrimidine bases in a sample of DNA. Remember, cytosine and thymine are pyrimidine bases, adenine and guanine are purines, and C = G and A = T. Therefore, C + T = G + A, or purine bases equal pyrimidine bases. Complementary base pairing is used to describe the precise pairing of purine and pyrimidine bases between strands of nucleic acids. It is the characteristic of DNA replication through which the parent strand can determine the sequence of a new strand.

Get It?

Explain why Chargaff's data was an important clue for understanding the structure of DNA.

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Q28 | Learning outcome explanation (1/3)

Specific textbook focus: DNA replication and complementary nucleotides; Figure 7.

Key terms (definitions for understanding the learning outcome; not all terms are necessarily examined in this particular reference):

DNA — Deoxyribonucleic acid, the molecule that stores hereditary information.

Nucleotide — The building block of DNA, containing a phosphate, deoxyribose sugar and nitrogenous base.

Complementary base pairing — A pairs with T, and C pairs with G in DNA.

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Q28 | Learning outcome explanation (2/3)

Double helix — The twisted two-stranded structure of DNA.

Antiparallel strands — The two DNA strands run in opposite 5′→3′ directions.

DNA replication — The process by which DNA is copied before cell division.

Semiconservative replication — Each daughter DNA double helix contains one parental strand and one newly synthesized strand.

DNA polymerase — An enzyme that adds complementary DNA nucleotides and can proofread during replication.

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Q28 | Learning outcome explanation (3/3)

DNA helicase — An enzyme that separates the two DNA strands at the replication fork.

DNA ligase — An enzyme that joins DNA fragments by sealing the sugar-phosphate backbone.

DNA reasoning: apply complementary base-pair rules (A–T, C–G) and distinguish the original template strands from newly synthesized strands.

Study focus: DNA replication model. Read the exact cited textbook page and interpret its labeled diagram, table or question. The official coverage description identifies a broader learning outcome; the cited reference narrows the emphasis for this item.

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Q28 | Practice MCQ 1

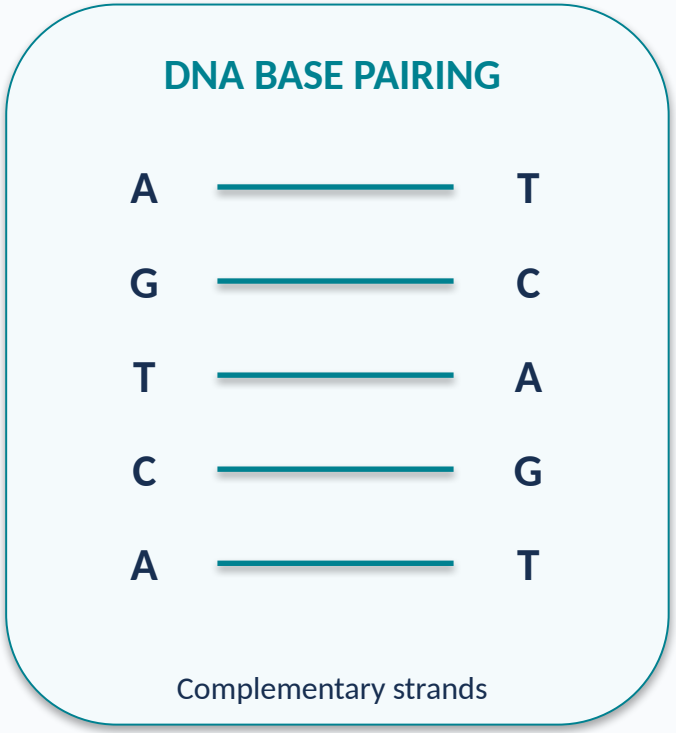
28.1 Why is DNA replication described as semiconservative?

A. Both strands are completely new

B. The original molecule is destroyed

C. Each molecule contains two old strands

D. Each new DNA molecule contains one old and one new strand



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Q28 | Practice MCQ 2

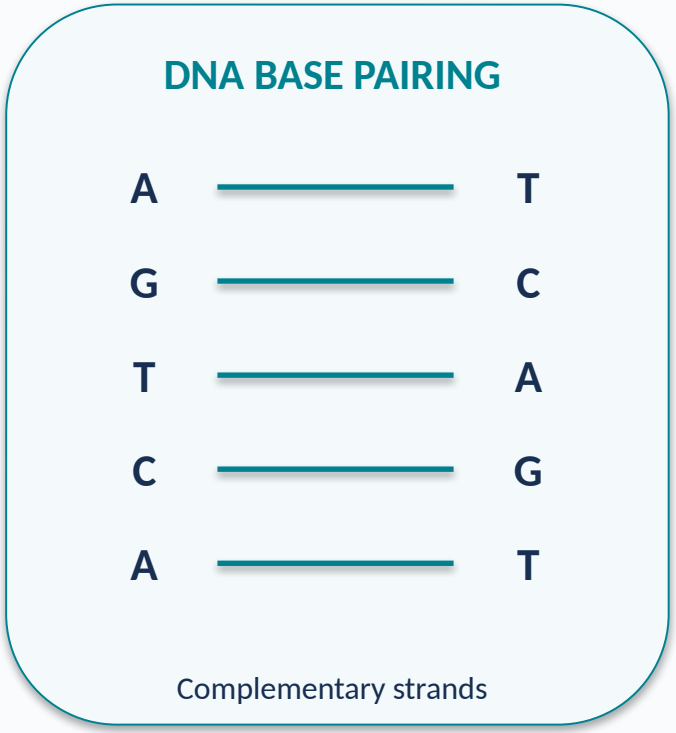
28.2 Which enzyme separates the two DNA strands?

A. RNA polymerase

B. Protease

C. Helicase

D. Ligase



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Q28 | Practice MCQ 3

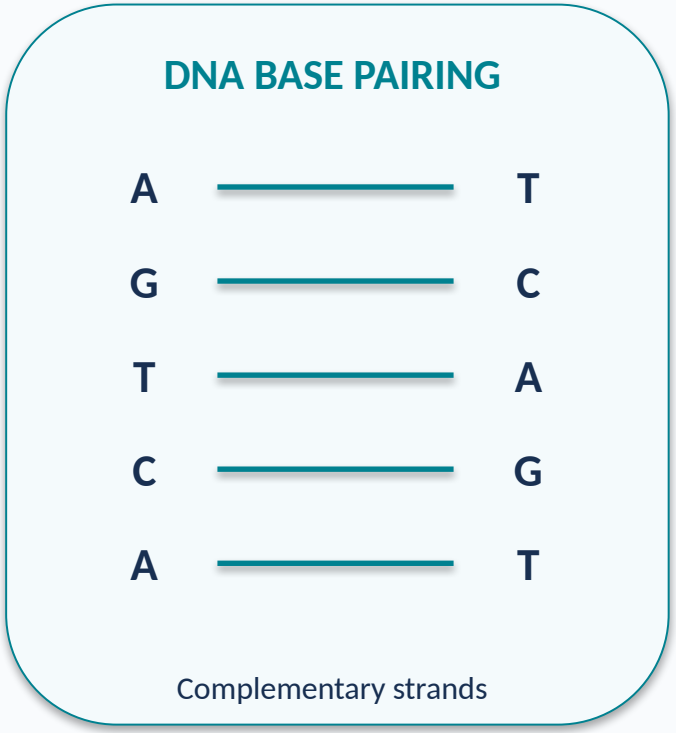
28.3 Which enzyme adds complementary DNA nucleotides?

A. Ribosome

B. DNA polymerase

C. Helicase

D. Amylase



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Q28 | Practice MCQ 4

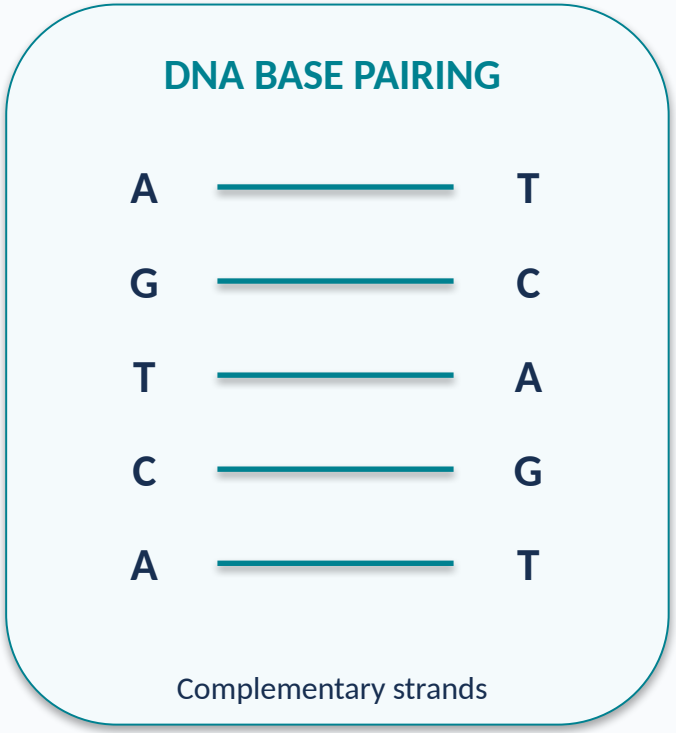
28.4 What serves as a template during replication?

A. Each original DNA strand

B. Only newly synthesized protein

C. A lipid membrane

D. A ribosome



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Q28 | Practice MCQ 5

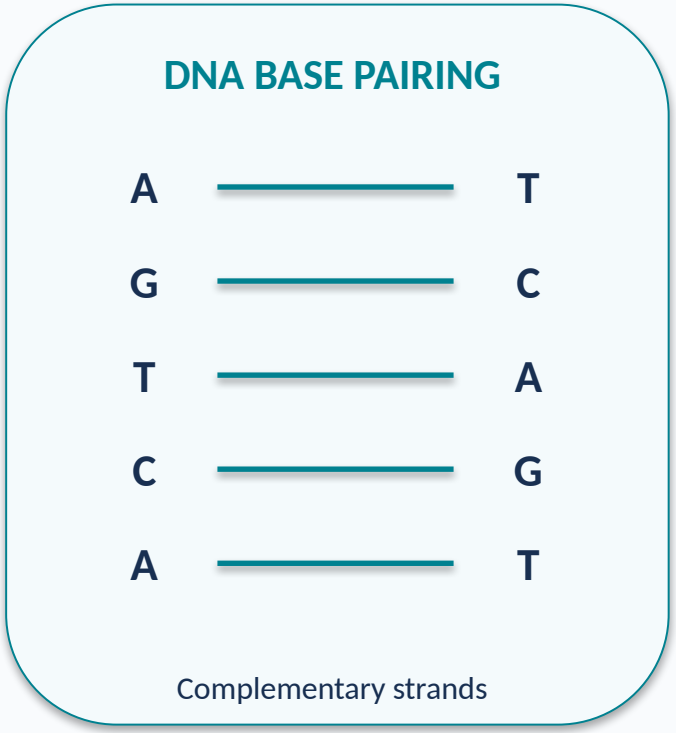
28.5 What results from accurate replication of one DNA double helix?

A. Four unrelated proteins

B. One RNA strand

C. Two molecules without bases

D. Two DNA molecules with matching sequences



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Q29 | Official learning outcome

BIO.3.3.01.016: Explain the current model of DNA replication and describe the different repair mechanisms that can correct mistakes in DNA sequencing including the mechanisms of biotechnology and bioinformatics.

EXACT COVERAGE: Q29 | Textbook printed page 47 | Demonstrate Understanding, Question 2

STUDY TARGET: Replication accuracy and DNA repair (question 2)

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Q29 | Original textbook page

Orientation

Another unique feature of the DNA molecule is the direction, or orientation, of the two strands. Carbon molecules can be numbered in organic molecules. **Figure 8** shows the orientation of the numbered carbons in the sugar molecules on each strand of DNA. On the top rail, the orientation of the sugar has the 5′ (read "five-prime") carbon on the left, and on the end of that rail, the 3′ (read "three-prime") carbon is on the right of the sugar-phosphate chain. The strand is said to be oriented 5′ to 3′. The strand on the bottom runs in the opposite direction and is oriented 3′ to 5′. This orientation of the two strands is called antiparallel. Another way to visualize antiparallel orientation is to take two pencils and position them so that the point of one pencil is next to the eraser of the other.

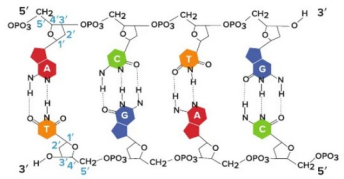

Figure 8 Two strands of DNA running antiparallel make up the DNA helix.

Explain *why the ends of the DNA strands are labeled 3′ and 5′.*

Check Your Progress

Summary

- Griffith's bacterial experiment and Avery's explanation first indicated that DNA is the genetic material.
- The Hershey-Chase experiment provided evidence that DNA is the genetic material of viruses.
- Chargaff's rule states that in DNA the amount of cytosine equals the amount of guanine and the amount of thymine equals the amount of adenine.
- The work of Watson, Crick, Franklin, and Wilkins provided evidence of the double-helix structure of DNA.

Demonstrate Understanding

1. **Summarize** the experiments of Griffith and Avery that indicated that DNA is the genetic material.
2. **Describe** the conclusions drawn by Hershey and Chase about the substance responsible for the transfer of genetic information.
3. **Describe** the data used by Watson and Crick to determine the structure of DNA.

Explain Your Thinking

4. **Describe** two characteristics that DNA needs to fulfill its role as a genetic material.
5. **Explain** what the story of determining the structure of DNA tells us about the nature of science.
6. **Evaluate** Hershey and Chase's decision to use radioactive phosphorus and sulfur for their experiments. Could they have used carbon or oxygen instead? Why or why not?

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Q29 | Learning outcome explanation (1/3)

Specific textbook focus: DNA replication and mechanisms that maintain copying accuracy; Demonstrate Understanding question 2.

Key terms (definitions for understanding the learning outcome; not all terms are necessarily examined in this particular reference):

DNA — Deoxyribonucleic acid, the molecule that stores hereditary information.

Nucleotide — The building block of DNA, containing a phosphate, deoxyribose sugar and nitrogenous base.

Complementary base pairing — A pairs with T, and C pairs with G in DNA.

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Q29 | Learning outcome explanation (2/3)

Double helix — The twisted two-stranded structure of DNA.

Antiparallel strands — The two DNA strands run in opposite 5′→3′ directions.

DNA replication — The process by which DNA is copied before cell division.

Semiconservative replication — Each daughter DNA double helix contains one parental strand and one newly synthesized strand.

DNA polymerase — An enzyme that adds complementary DNA nucleotides and can proofread during replication.

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Q29 | Learning outcome explanation (3/3)

DNA helicase — An enzyme that separates the two DNA strands at the replication fork.

DNA ligase — An enzyme that joins DNA fragments by sealing the sugar-phosphate backbone.

DNA reasoning: apply complementary base-pair rules (A–T, C–G) and distinguish the original template strands from newly synthesized strands.

Study focus: DNA replication accuracy and repair. Read the exact cited textbook page and interpret its labeled diagram, table or question. The official coverage description identifies a broader learning outcome; the cited reference narrows the emphasis for this item.

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Q29 | Practice MCQ 1

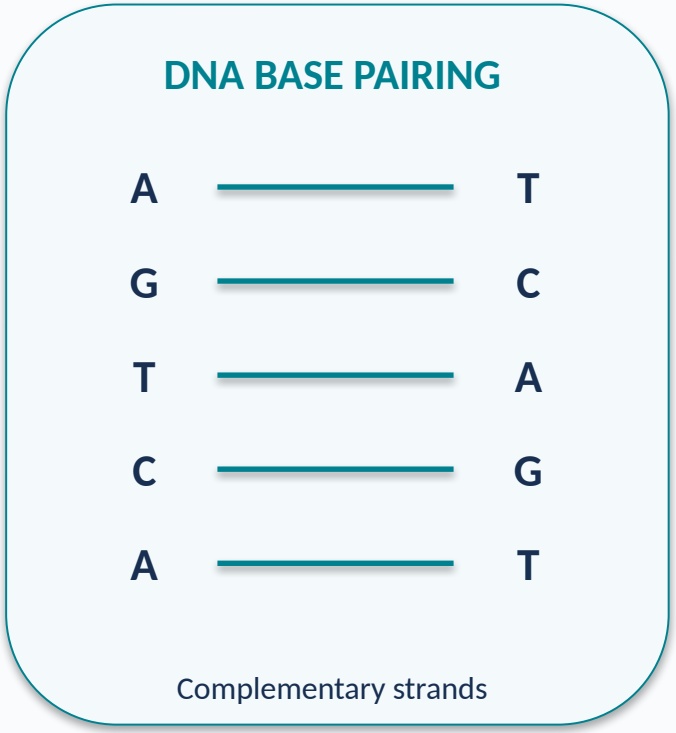
29.1 Which enzyme proofreads newly synthesized DNA during replication?

A. Ribosome

B. ATP synthase

C. DNA polymerase

D. Helicase



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Q29 | Practice MCQ 2

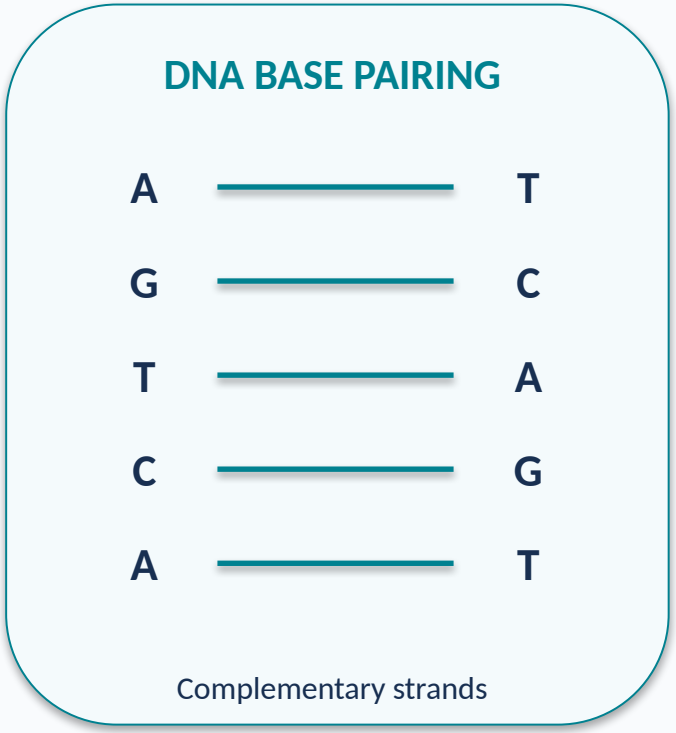
29.2 What is the main benefit of DNA proofreading?

A. Stopping chromosome duplication

B. Reducing copying errors

C. Increasing mutation frequency

D. Breaking every DNA strand



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Q29 | Practice MCQ 3

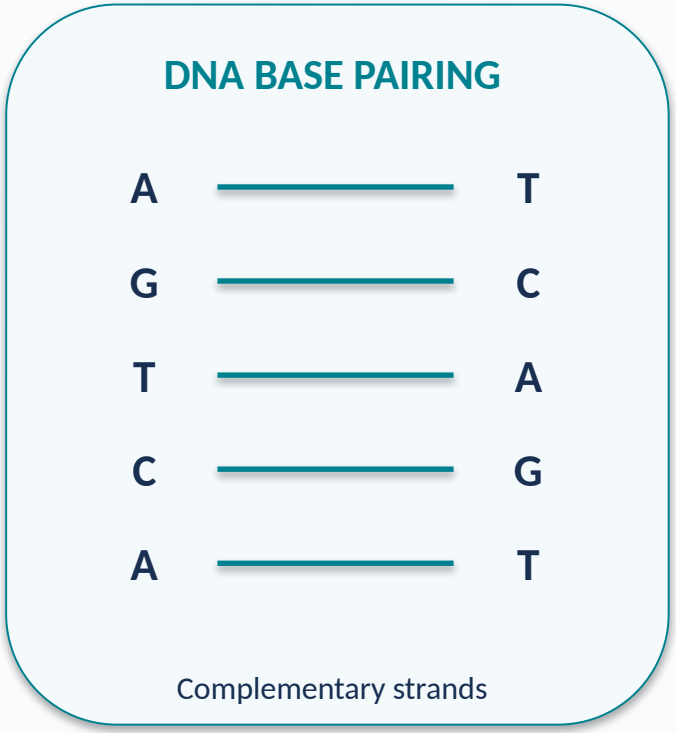
29.3 What can happen if a DNA replication error remains uncorrected?

A. A mutation may be inherited by daughter cells

B. The error always disappears

C. All proteins are destroyed

D. Chromosomes cannot exist



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Q29 | Practice MCQ 4

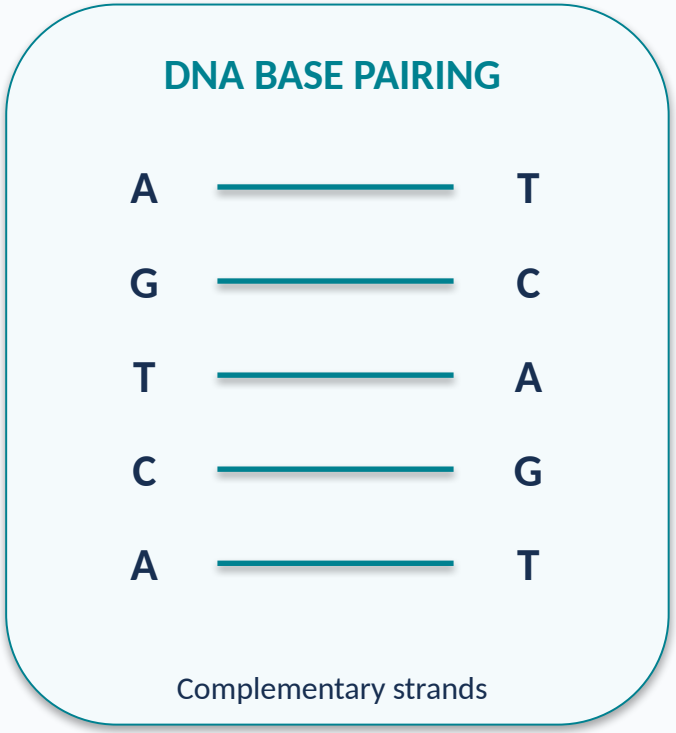
29.4 What does a DNA repair system recognize?

A. Only ribosomes

B. Only cell membranes

C. Only lipids

D. Damaged or incorrectly paired nucleotides



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Q29 | Practice MCQ 5

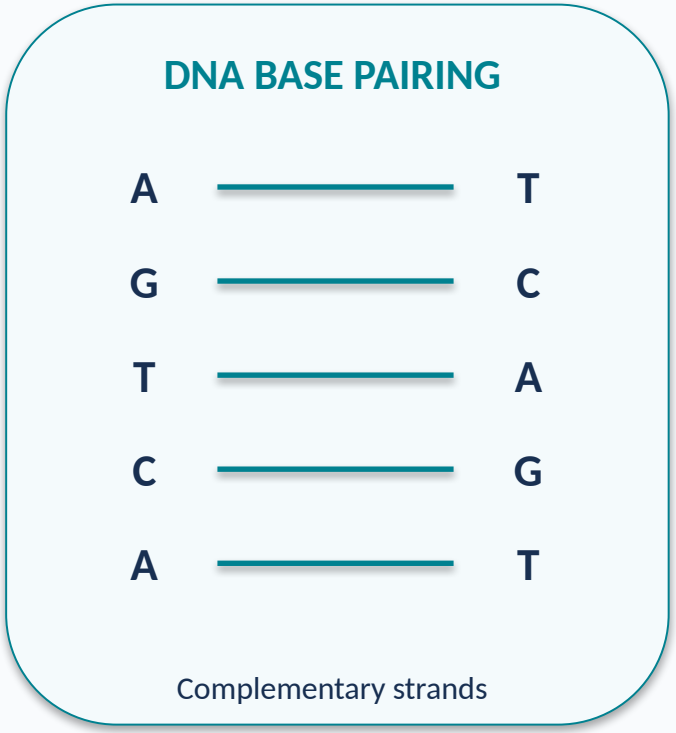
29.5 Which statement best describes replication fidelity?

A. Only one base type is copied

B. Proofreading is unnecessary

C. DNA is copied with high accuracy

D. DNA is copied at random



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Q30 | Official learning outcome

BIO.3.3.01.016: Explain the current model of DNA replication and describe the different repair mechanisms that can correct mistakes in DNA sequencing including the mechanisms of biotechnology and bioinformatics.

EXACT COVERAGE: Q30 | Textbook printed page 47 | Demonstrate Understanding, Question 3

STUDY TARGET: DNA replication and DNA repair (question 3)

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Q30 | Original textbook page

Orientation

Another unique feature of the DNA molecule is the direction, or orientation, of the two strands. Carbon molecules can be numbered in organic molecules. **Figure 8** shows the orientation of the numbered carbons in the sugar molecules on each strand of DNA. On the top rail, the orientation of the sugar has the 5′ (read "five-prime") carbon on the left, and on the end of that rail, the 3′ (read "three-prime") carbon is on the right of the sugar-phosphate chain. The strand is said to be oriented 5′ to 3′. The strand on the bottom runs in the opposite direction and is oriented 3′ to 5′. This orientation of the two strands is called antiparallel. Another way to visualize antiparallel orientation is to take two pencils and position them so that the point of one pencil is next to the eraser of the other.

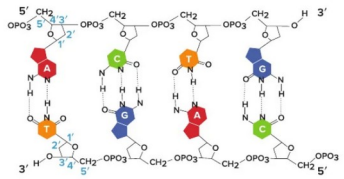

Figure 8 Two strands of DNA running antiparallel make up the DNA helix.

Explain *why the ends of the DNA strands are labeled 3′ and 5′.*

Check Your Progress

Summary

- Griffith's bacterial experiment and Avery's explanation first indicated that DNA is the genetic material.
- The Hershey-Chase experiment provided evidence that DNA is the genetic material of viruses.
- Chargaff's rule states that in DNA the amount of cytosine equals the amount of guanine and the amount of thymine equals the amount of adenine.
- The work of Watson, Crick, Franklin, and Wilkins provided evidence of the double-helix structure of DNA.

Demonstrate Understanding

1. **Summarize** the experiments of Griffith and Avery that indicated that DNA is the genetic material.
2. **Describe** the conclusions drawn by Hershey and Chase about the substance responsible for the transfer of genetic information.
3. **Describe** the data used by Watson and Crick to determine the structure of DNA.

Explain Your Thinking

4. **Describe** two characteristics that DNA needs to fulfill its role as a genetic material.
5. **Explain** what the story of determining the structure of DNA tells us about the nature of science.
6. **Evaluate** Hershey and Chase's decision to use radioactive phosphorus and sulfur for their experiments. Could they have used carbon or oxygen instead? Why or why not?

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Q30 | Learning outcome explanation (1/3)

Specific textbook focus: DNA replication and mechanisms that correct copying errors; Demonstrate Understanding question 3.

Key terms (definitions for understanding the learning outcome; not all terms are necessarily examined in this particular reference):

DNA — Deoxyribonucleic acid, the molecule that stores hereditary information.

Nucleotide — The building block of DNA, containing a phosphate, deoxyribose sugar and nitrogenous base.

Complementary base pairing — A pairs with T, and C pairs with G in DNA.

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Q30 | Learning outcome explanation (2/3)

Double helix — The twisted two-stranded structure of DNA.

Antiparallel strands — The two DNA strands run in opposite 5′→3′ directions.

DNA replication — The process by which DNA is copied before cell division.

Semiconservative replication — Each daughter DNA double helix contains one parental strand and one newly synthesized strand.

DNA polymerase — An enzyme that adds complementary DNA nucleotides and can proofread during replication.

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Q30 | Learning outcome explanation (3/3)

DNA helicase — An enzyme that separates the two DNA strands at the replication fork.

DNA ligase — An enzyme that joins DNA fragments by sealing the sugar-phosphate backbone.

DNA reasoning: apply complementary base-pair rules (A–T, C–G) and distinguish the original template strands from newly synthesized strands.

Study focus: DNA replication and repair mechanisms. Read the exact cited textbook page and interpret its labeled diagram, table or question. The official coverage description identifies a broader learning outcome; the cited reference narrows the emphasis for this item.

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Q30 | Practice MCQ 1

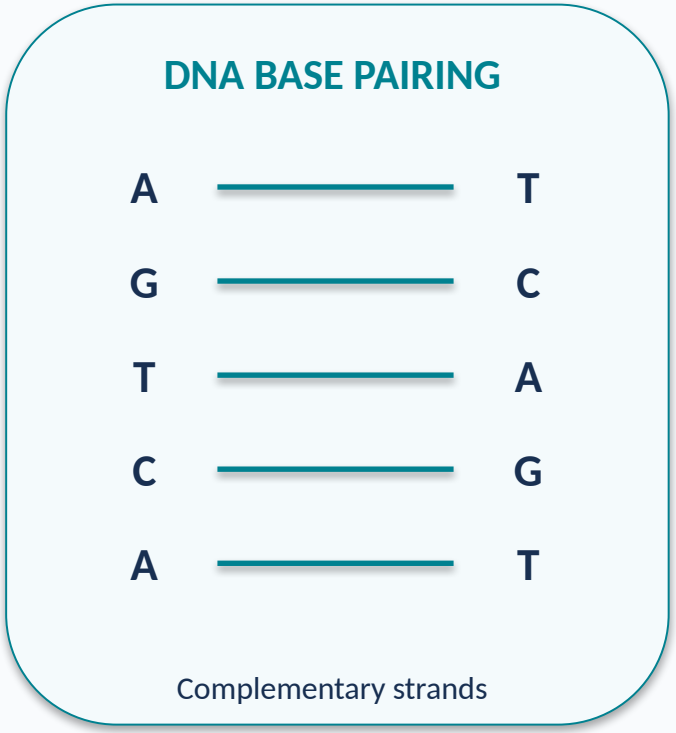
30.1 Which process removes and replaces an incorrect DNA nucleotide?

A. Photosynthesis

B. DNA repair

C. Translation

D. Osmosis



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Q30 | Practice MCQ 2

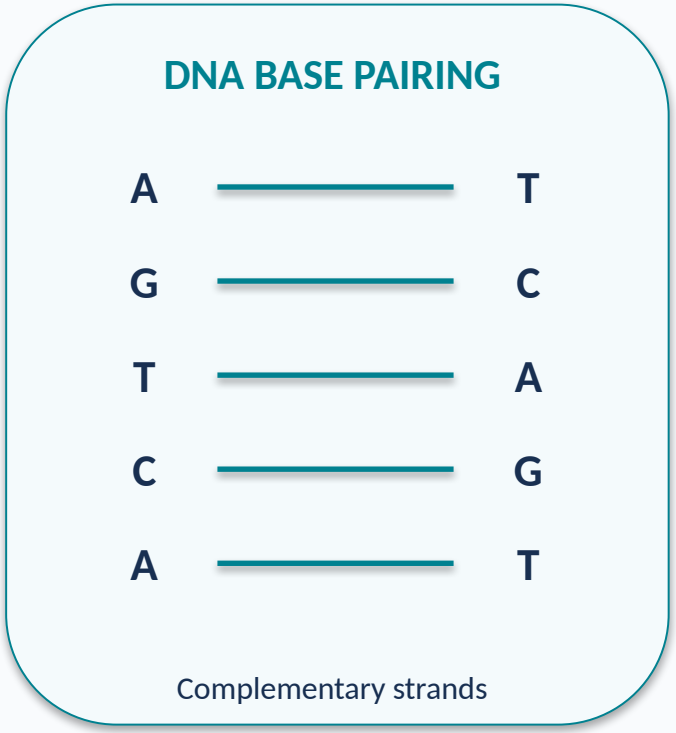
30.2 What does DNA ligase do during DNA repair or replication?

A. Seals breaks in the sugar-phosphate backbone

B. Unwinds DNA at the fork

C. Pairs amino acids

D. Removes all DNA bases



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Q30 | Practice MCQ 3

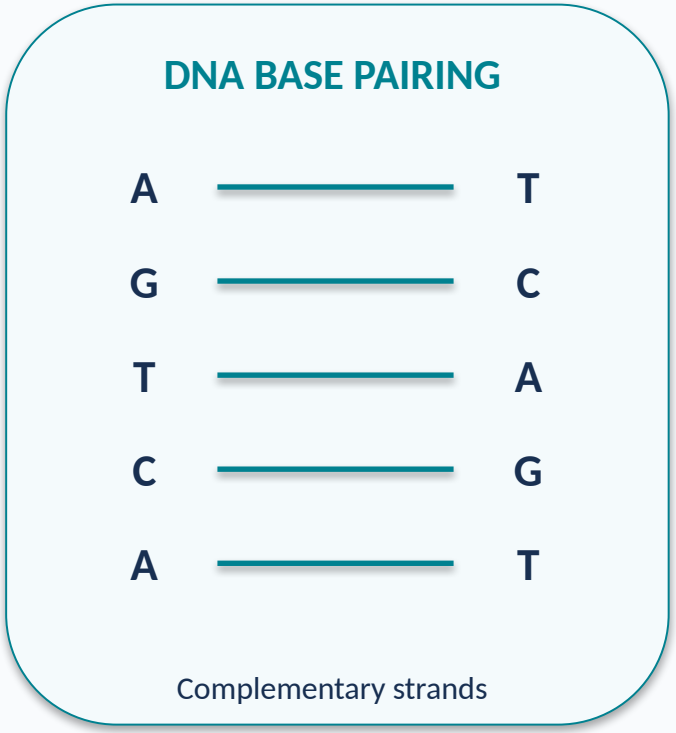
30.3 What happens after a damaged DNA segment is excised during repair?

A. The chromosome is discarded

B. RNA becomes the permanent replacement

C. All DNA replication stops forever

D. DNA polymerase can fill the gap



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Q30 | Practice MCQ 4

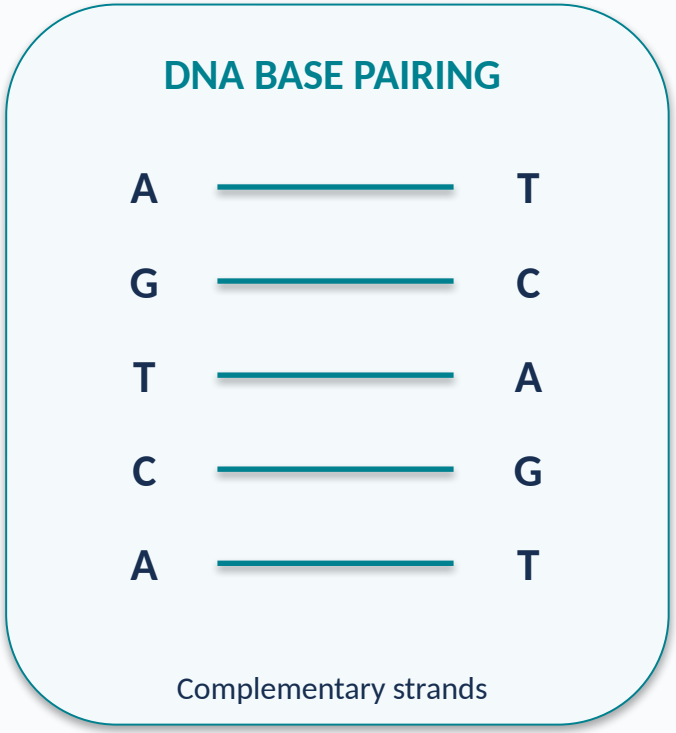
30.4 Which molecule provides the template for replacing an incorrect base?

A. A free amino acid

B. An unrelated protein

C. The undamaged complementary DNA strand

D. A membrane lipid



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Q30 | Practice MCQ 5

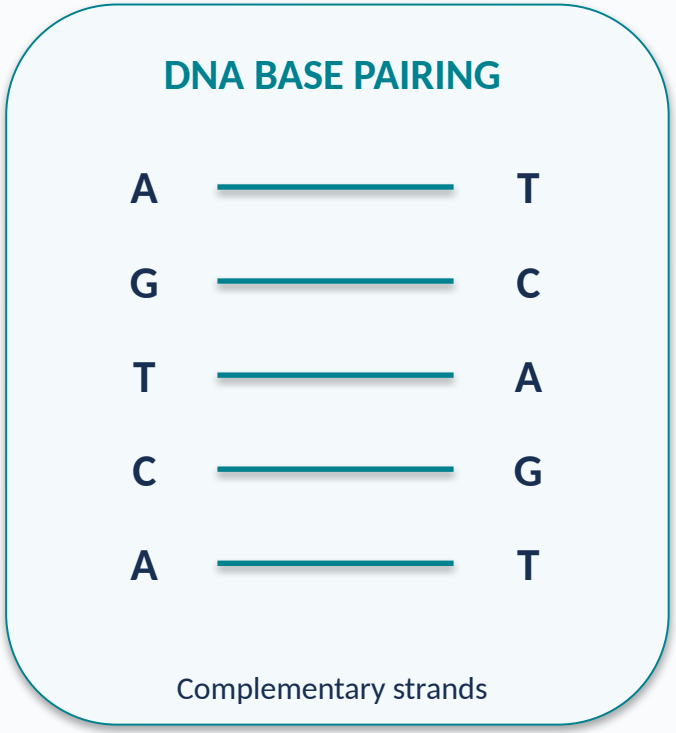
30.5 Why are DNA repair mechanisms biologically important?

A. They prevent all cell division

B. They help maintain genome stability

C. They create every trait without genes

D. They eliminate inheritance



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