1-2: How is hereditary information passed from one generation to the next?

Key Vocabulary

- (Review: allele, gene, chromosome, homologous chromosome, gamete)
- Genetics
- Trait
- Gregor Mendel
- True-breeding
- Offspring
- F1, F2
- Law of segregation
- Dominant allele
- Recessive allele
- Phenotype
- Genotype
- Homozygous
- Heterozygous
- Homozygous dominant
- Homozygous recessive
- Cross
- Monohybrid cross
- Hybrid
- Punnett square
- Phenotypic ratio
- Genotypic ratio
- Codominance
- Incomplete dominance
- Sex-linked trait
- X-linked trait
- Carrier

Topic 1.2: How is hereditary information passed from one generation to the next?

- Genes pass on inherited traits from parent to offspring.
- Punnett squares show the probability of offspring inheriting specific traits.
- Both alleles are expressed in codominance.
- In incomplete dominance, alleles are neither dominant nor recessive.
- Some inherited traits are due to alleles on the sex chromosomes.

Concept 1: Genes pass on inherited traits from parent to offspring.

- **Genetics:** field of biology that studies heredity (how traits are passed from parents to offspring)
- **Trait:** an inherited characteristic
  - E.g. eye colour, hair colour, straight/curly hair

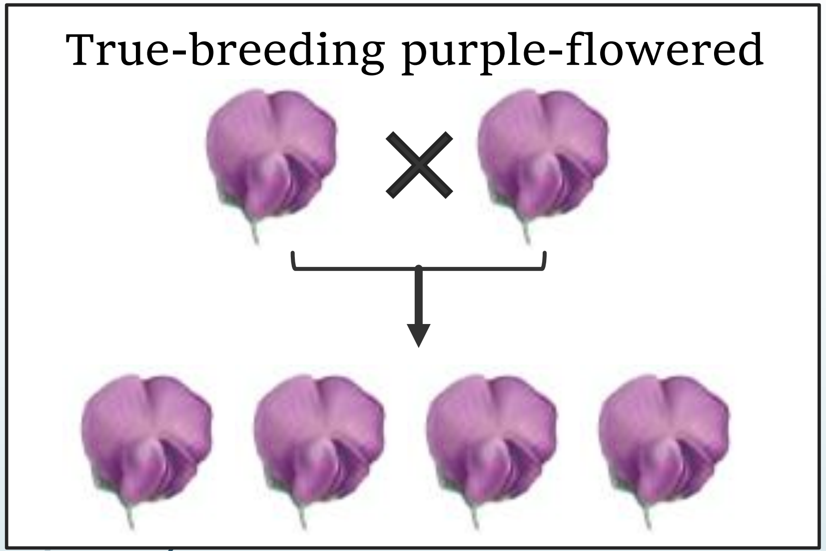
Image: https://www.assignmentpoint.com/science/biology/genetics-inheritance-traits.html

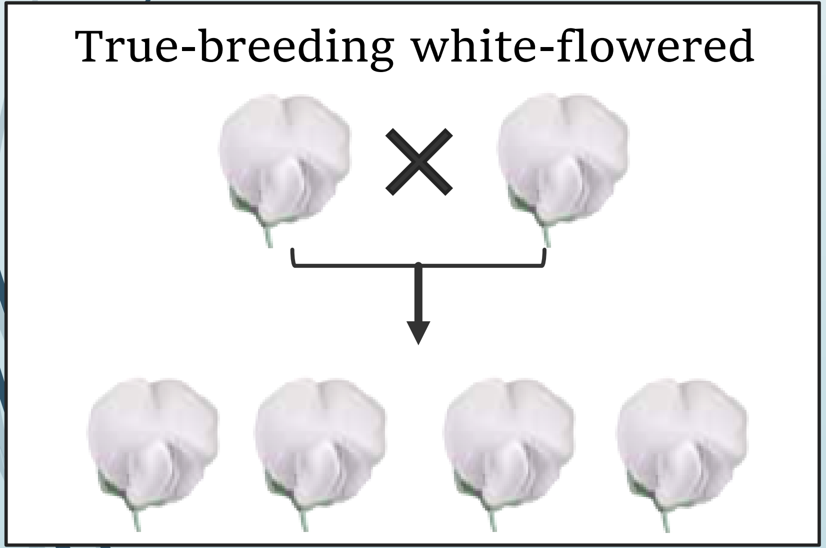
First Modern Experiments in Genetics

- **Gregor Mendel** discovered how traits are inherited by experimenting with pea plants.

Image credits:
https://en.wikipedia.org/wiki/Gregor_Mendel
https://plantsam.com/pisum-sativum/
http://www.flowersinisrael.com/Pisumsativum_page.htm
http://theworldwidevegetables.weebly.com/pisum-sativum-common-pea.html

Mendel's Experiments (cont'd)





- ***True-breeding*** plant: when self-fertilized (or crossed with same type of true-breed), all offspring have the same traits
  - E.g. true-breeding purple-flowered plant self-fertilizes to make all purple-flowered plants
  - E.g. true-breeding wrinkly-seeded plant self-fertilizes to make all wrinkly-seeded plants

Mendel's Experiments

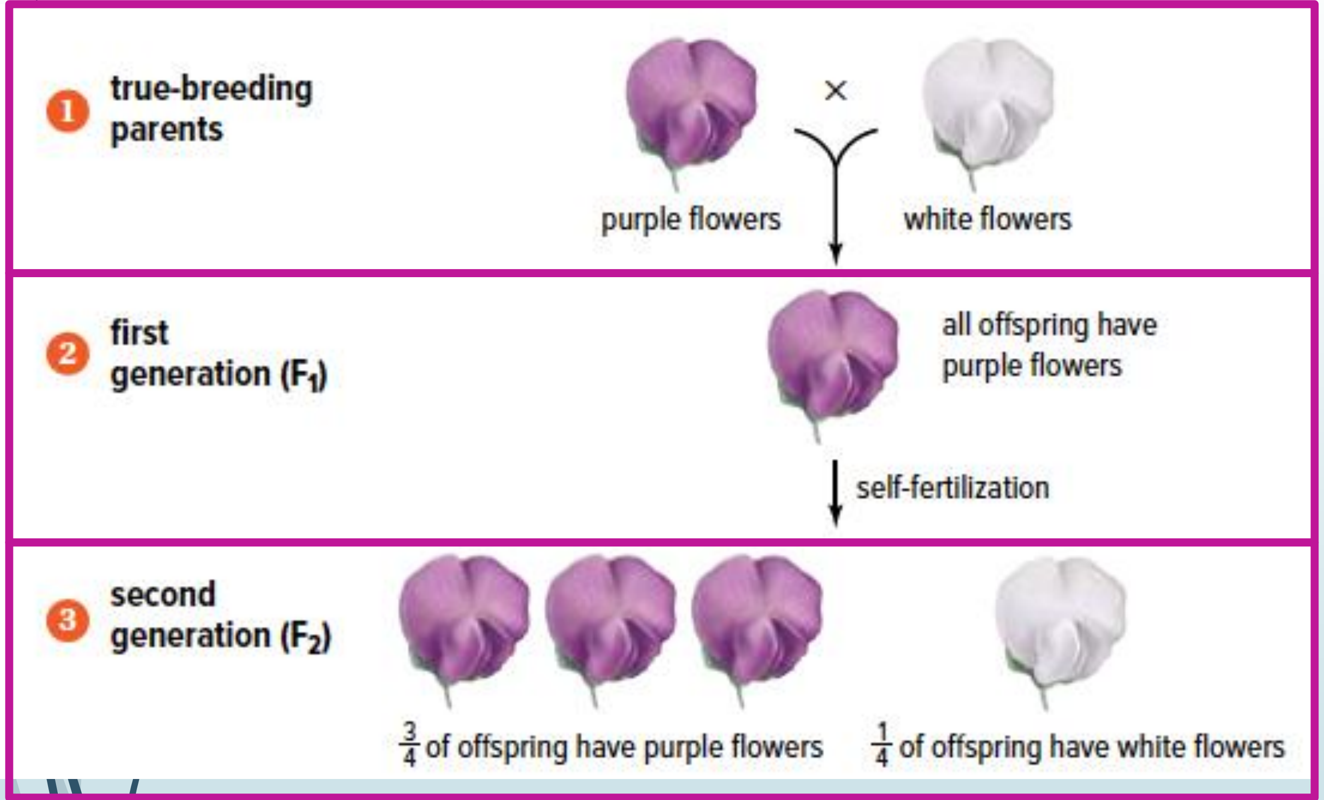


Figure 1.10: These are the results of Mendel's cross involving true-breeding pea plants with purple flowers and true-breeding pea plants with white flowers.

- Mendel used true-breeding pea plants in F_0
- True-breeding parent plants produced new plants called ***offspring*** in the ***first generation*** **(F_1)**
- Plants from the first generation self-fertilized to produce offspring in the ***second generation*** **(F_2)**

Mendel's Experiments (cont'd)

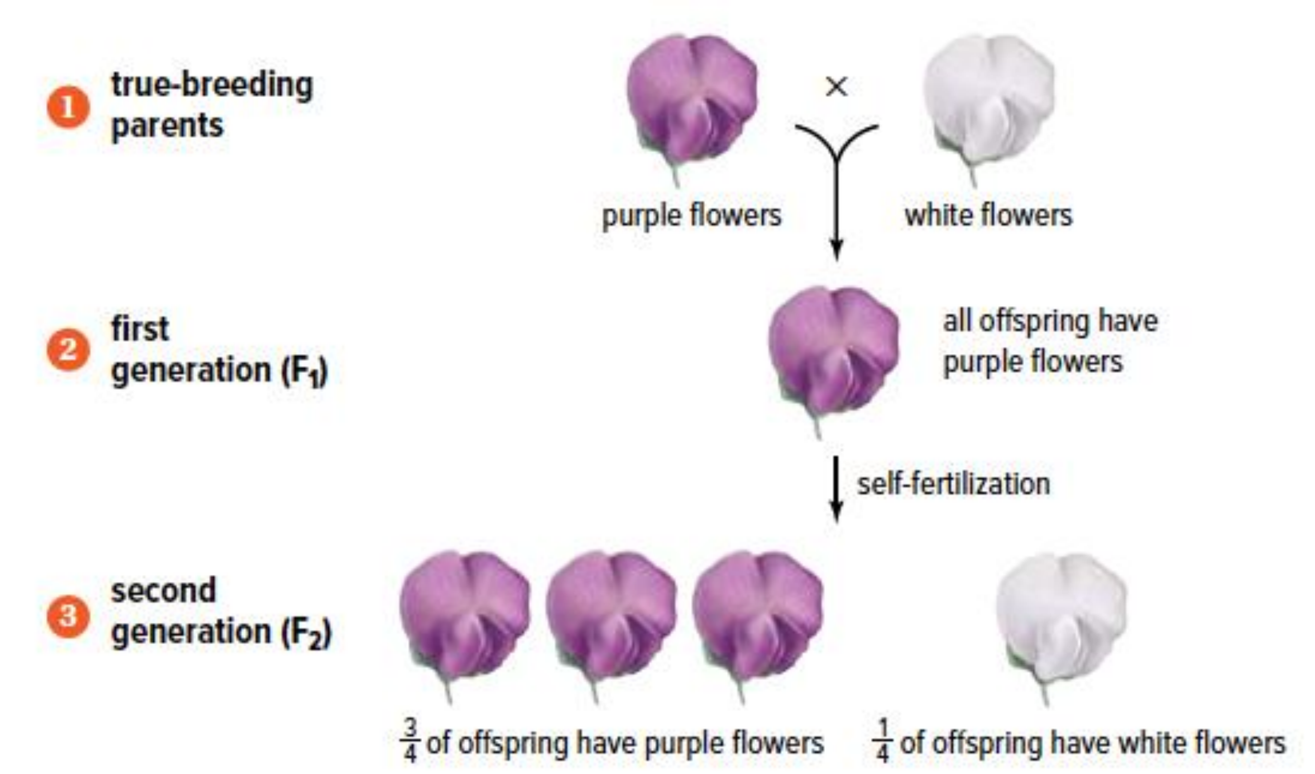


Figure 1.10: These are the results of Mendel's cross involving true-breeding pea plants with purple flowers and true-breeding pea plants with white flowers.

When two different **true-breeding** pea plants are crossed, one trait *disappears* in the F_1 offspring, but *reappears* in the F_2 offspring.

Mendel's Experiments (cont'd)

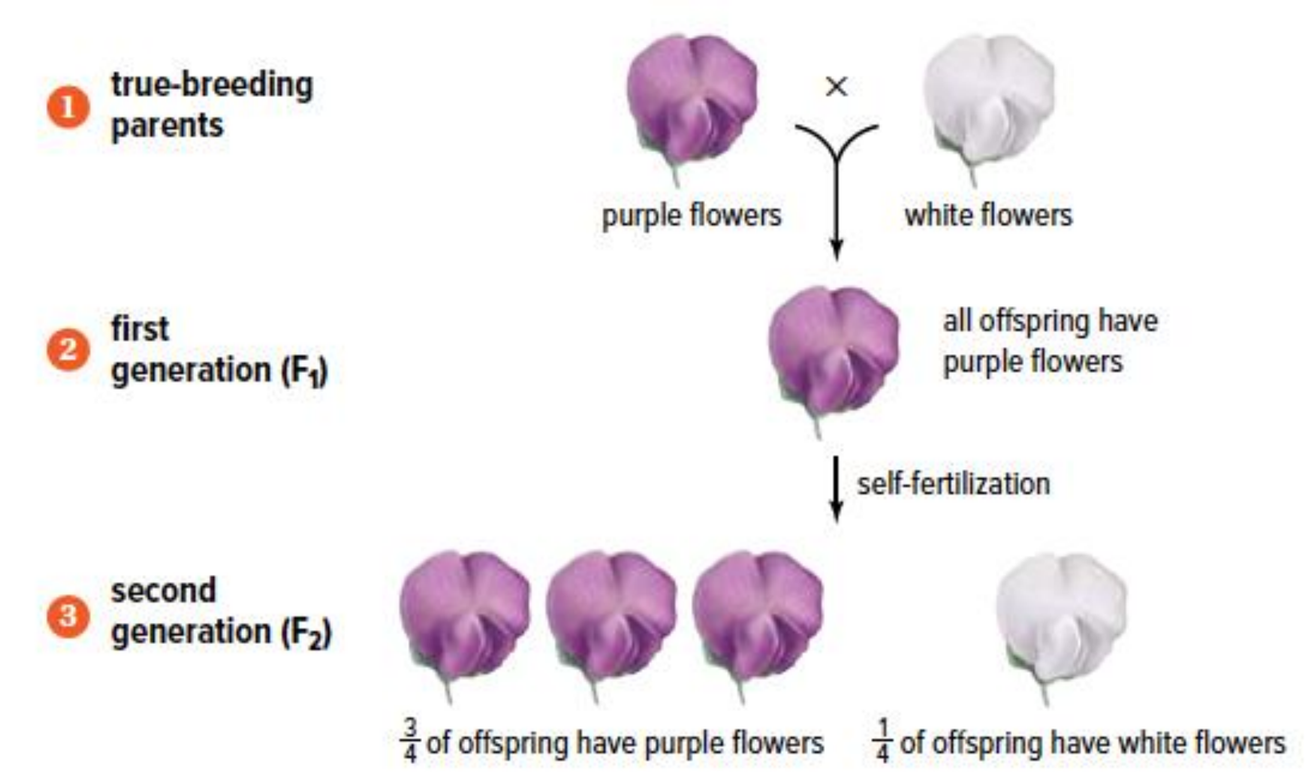
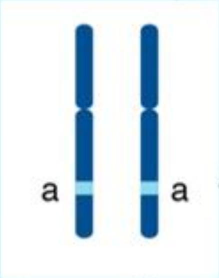
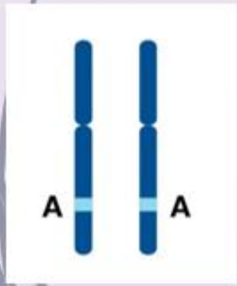


Figure 1.10: These are the results of Mendel's cross involving true-breeding pea plants with purple flowers and true-breeding pea plants with white flowers.

Based on this, Mendel proposed:

- Each plant has two factors for a trait.
- Each parent gives one factor for each trait.
- One factor dominates over the other if present.
- (The "factors" Mendel referred to in his conclusions are now called **alleles**.)

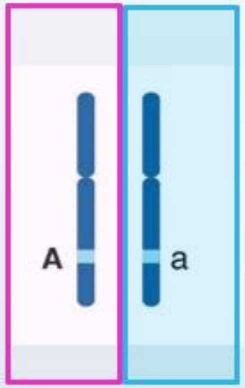
The Law of Segregation

Parental DNA	Meiosis	Gametes
Biological father 	100% chance of allele "*a*"	 
Biological mother 	100% chance of allele "A"	 

Fertilization
(one chromosome from each parent)

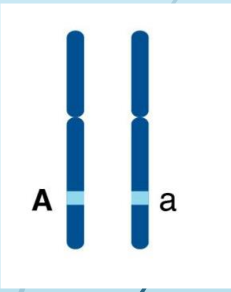
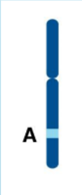
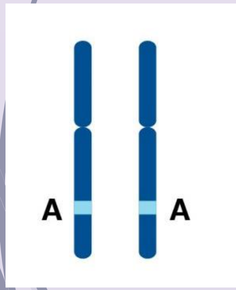
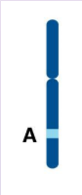
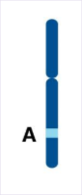
Offspring DNA

100%



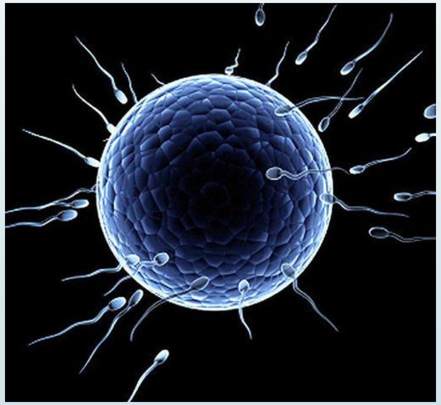
Images: https://www.thoughtco.com/allele-a-genetics-definition-373460; https://www.cbsnews.com/pictures/human-eggs-9-fascinating-facts/

The Law of Segregation

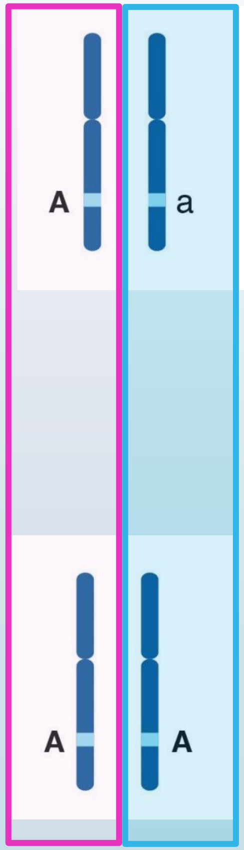
Parental DNA	Meiosis	Gametes
Biological father 	50% chance of allele "A"; 50% of allele "*a*"	 
Biological mother 	100% chance of allele "A"	 

Fertilization

(one chromosome from each parent)



Offspring DNA

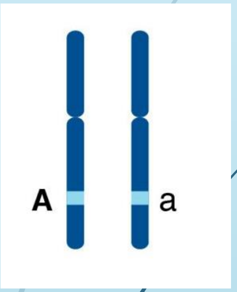
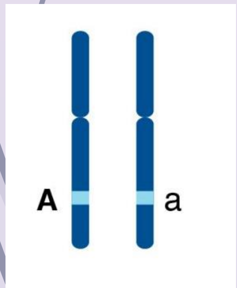
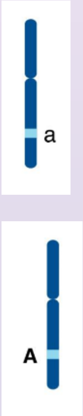


50%

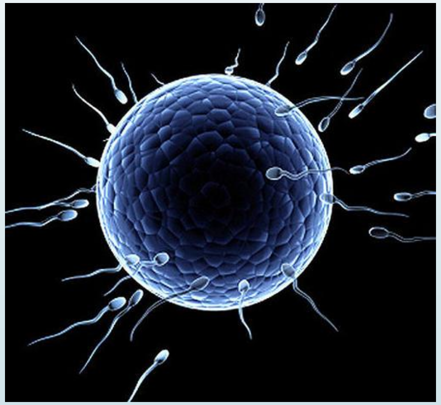
50%

Images: https://www.thoughtco.com/allele-a-genetics-definition-373460; https://www.cbsnews.com/pictures/human-eggs-9-fascinating-facts/

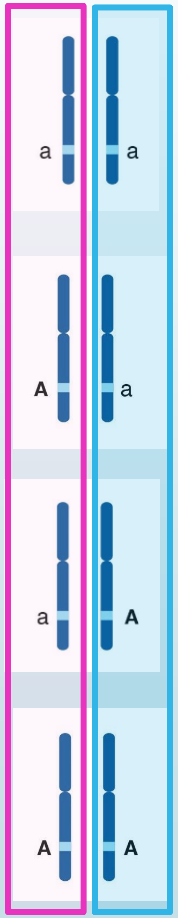
The Law of Segregation

Parental DNA	Meiosis	Gametes
Biological father 	50% chance of allele "A"; 50% of allele "*a*"	
Biological mother 	50% chance of allele "A"; 50% of allele "*a*"	

Fertilization
(one chromosome from each parent)



Offspring DNA



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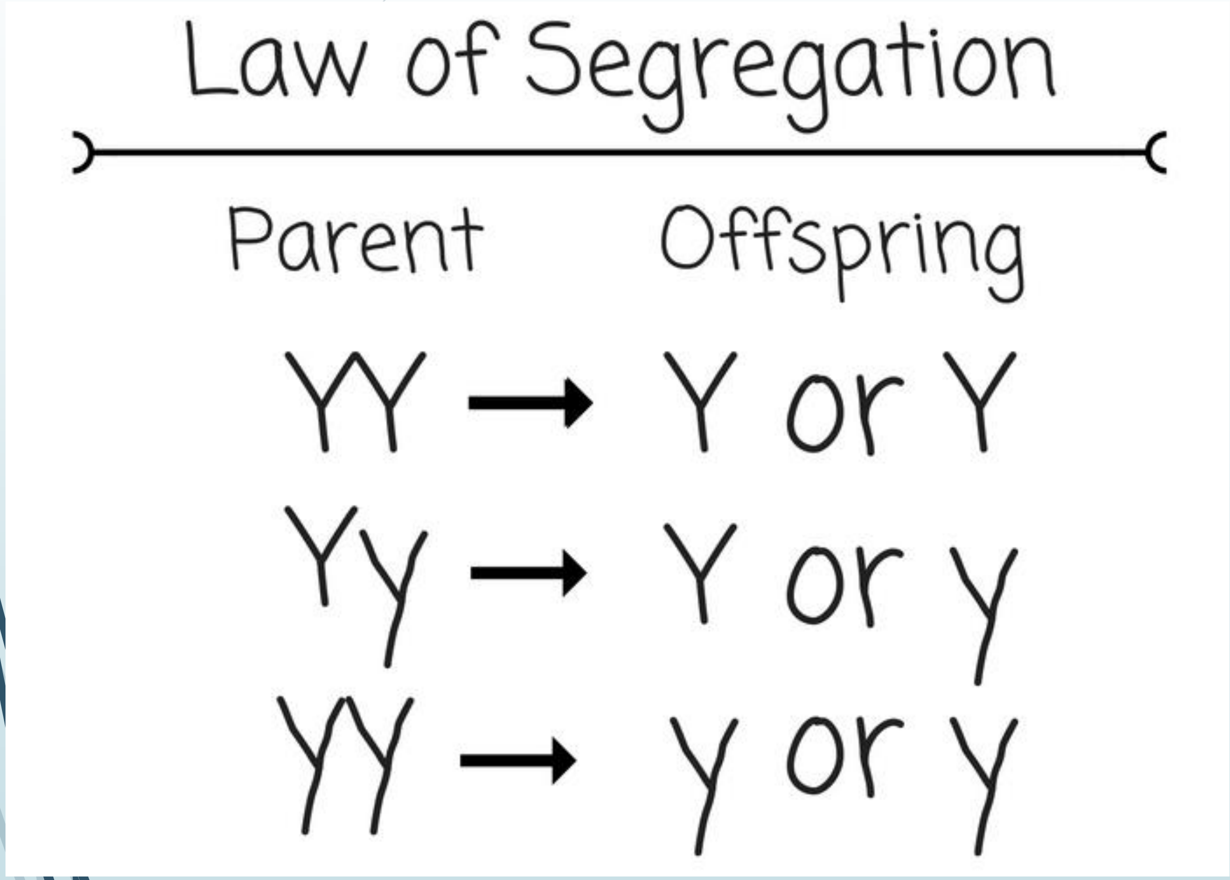
Images: https://www.thoughtco.com/allele-a-genetics-definition-373460; https://www.cbsnews.com/pictures/human-eggs-9-fascinating-facts/

Homologous Chromosomes and Gametes

- Chromosomes may carry different alleles.
- During gamete formation, pairs of homologous chromosomes separate.
- Each gamete receives one member of each pair, so it receives only one allele of each pair.
- During fertilization when the male and female gametes meet, homologous chromosomes and alleles are paired again.

The Law of Segregation



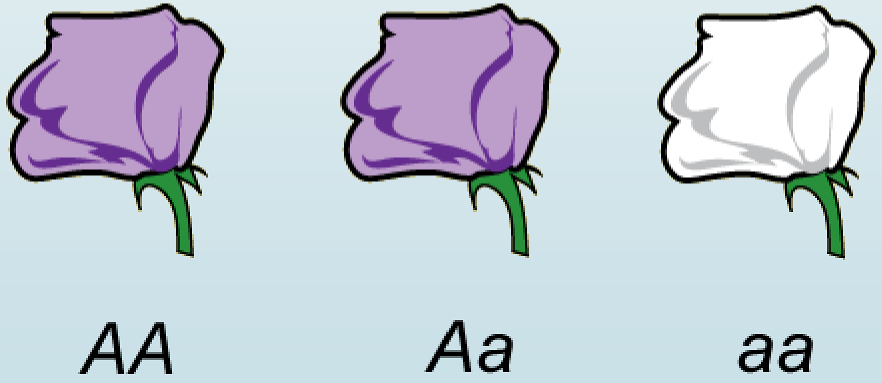
Law of segregation: states that alleles for a trait separate during meiosis

- Each gamete carries one allele for each trait.
- During fertilization, each gamete contributes an allele for each trait.

https://untamedscience.com/biology/genetics/mendelian-genetics/law-of-segregation/

Dominant and Recessive Alleles

- **Dominant alleles** (capital letter) will always be expressed if present.
- **Recessive alleles** (lower-case letter) will be expressed only if there are two recessive alleles.



Images: https://mammothmemory.net/biology/dna-genetics-and-inheritance/genes/dominant-allele-and-recessive-allele.html; https://study.com/academy/lesson/genotypic-frequency-definition-lesson-quiz.html

Dominant and Recessive Alleles (cont.)

Purple flower colour = *BB* or *Bb*

White flower colour = *bb*

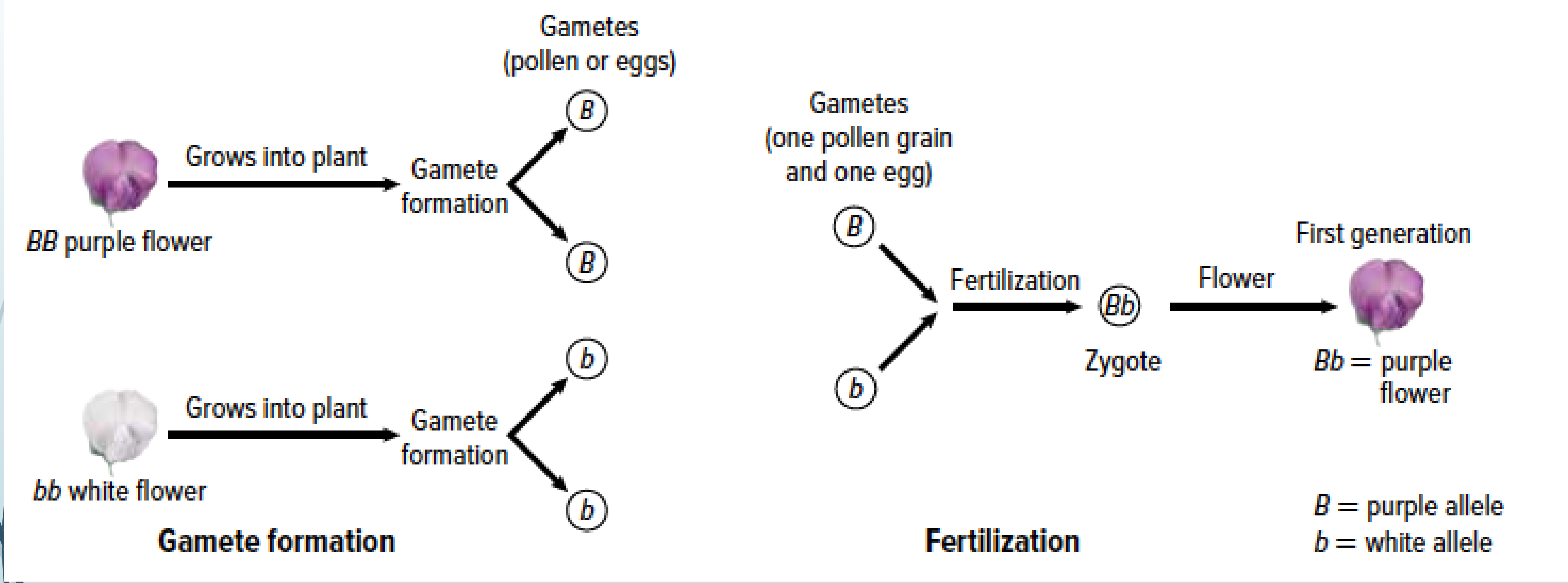


Figure 1.11: These are the results of Mendel's cross involving true-breeding pea plants with purple flowers and pea plants with white flowers.

Genotypes and Phenotypes

Phenotype: the physical *description* of an organism's trait

Examples:

- Purple flowers, white flowers
- Brown eyes, blue eyes
- Has disease, does not have disease

Genotype: the specific *combination of alleles* an organism has for a trait

Examples:

- *AA or aa or Aa*
- *BB or bb or Bb*
- *Multiple genes: AaBB*

Genotypes and Phenotypes

GENOTYPE

GENOTYPE refers to the genetic code of the individual. This is all the information that is found inside the individual's cells.

- Everything that someone inherited from their parents
- Depends on the hereditary information
- Example: There's a person who has brown hair but his cells contain one "brown hair" and one "blonde hair" allele. The genotype includes all of this information, even though this person doesn't have blonde hair.

PHENOTYPE

PHENOTYPE is the expression of the genotype that is visible to other people and can be observed. That is, for example, the color of the person's eyes.

- Can be influenced by the environment
- The phenotype only includes information about brown hair because that's what we observe when we look at this person.

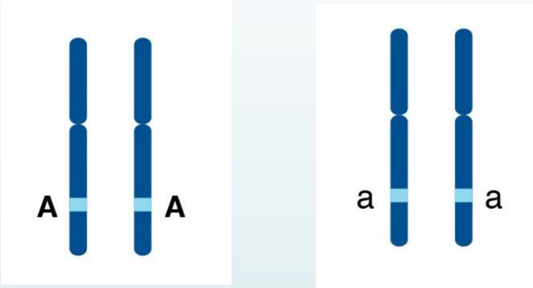
It's interesting that the fact that two people have the same genotypes doesn't necessarily mean that they'll have the same phenotypes. That's happening because the phenotype isn't inherited directly, and environmental factors play an important role when determining it. Thus, even identical twins can have different phenotypes.

https://7esl.com/genotype-vs-phenotype/

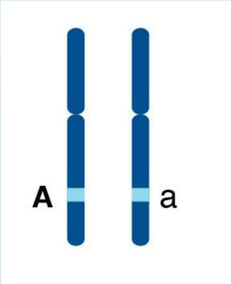
Genotypes and Phenotypes (cont.)

Genotype Vocabulary

- **Homozygous:** an organism with two of the *same alleles* for a particular trait (e.g. *BB*, *bb*, *AA*, *aa*)



- **Heterozygous:** an organism with two *different alleles* for a particular trait (e.g. *Bb*, *Aa*)



Genotypes and Phenotypes (cont.)

Genotype Vocabulary

1) *Homozygous dominant*: two dominant alleles (e.g. *BB*)
2) *Homozygous recessive*: two recessive alleles (e.g. *bb*)
3) *Heterozygous*: one dominant allele and one recessive allele (e.g. *Bb*)

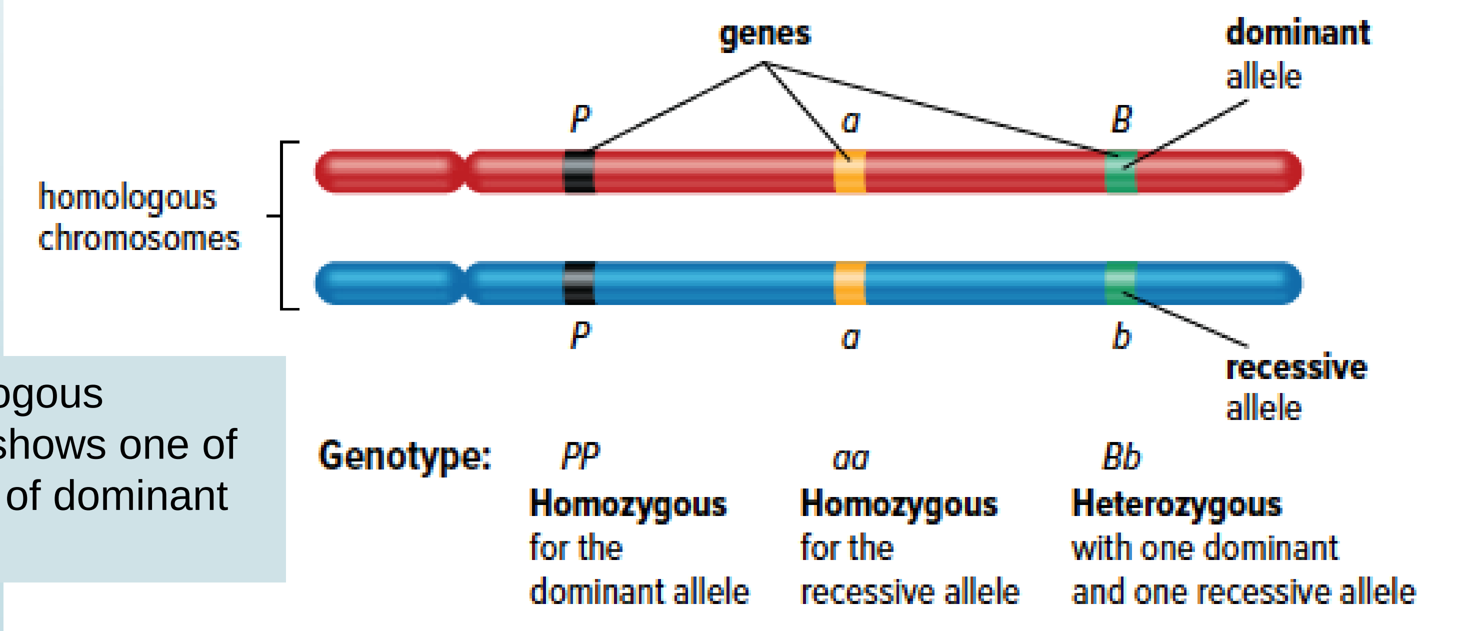


Figure 1.12: Three different genes on homologous chromosomes are indicated. Each example shows one of the three possible combinations (genotypes) of dominant and recessive alleles.

Discussion Questions

1. Write a definition for genetics in your own words.
2. Seed shape in pea plants can either be round or wrinkled. The allele for round shape is indicated by *R*. Is round seed shape dominant or recessive?
3. The allele for freckles is indicated by *F*. What is the genotype of a person who is heterozygous for freckles?
4. What is a "true-breeding plant"? Which of the following would be considered true-breeding? Explain why or why not.
   a) Homozygous recessive
   b) Homozygous dominant
   c) Heterozygous

Concept 2: Punnett squares show the probability of offspring inheriting specific traits.

- Genetic cross is a deliberate mating between a genetic male and a genetic female.
- *Monohybrid cross* considers one trait.
- *Hybrid* is an offspring that has different traits from its parents.

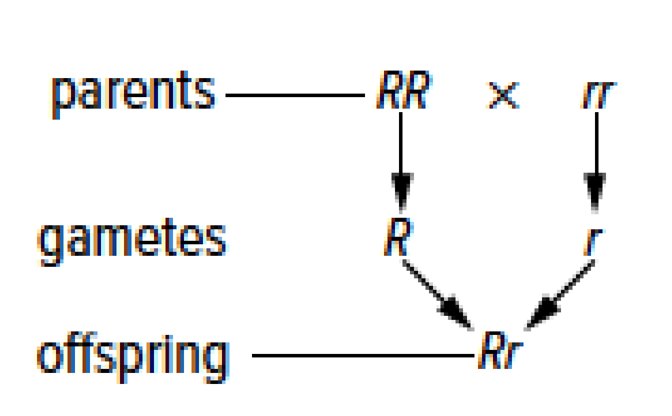


Figure 1.13: A monohybrid cross between a homozygous dominant individual and a homozygous recessive individual. Each parent contributes one type of allele to the offspring. The symbol “ × ” represents the word *cross*.

Punnett Squares

- A **Punnett square** is a tool used to help determine the *probability* of inheriting traits in a monohybrid cross.
- It shows the genotypes of the parents and the offspring.

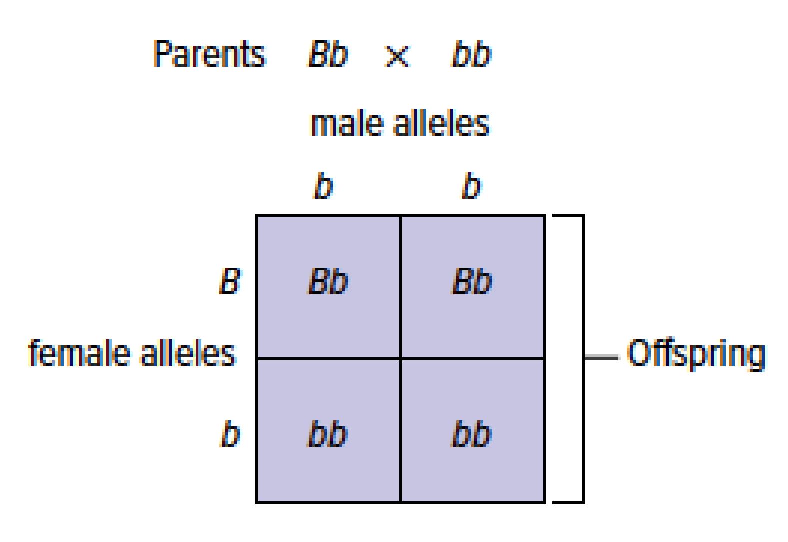


Figure 1.14: In this cross, the female horse can contribute either a *B* allele or a *b* allele to offspring. The male horse can contribute only the *b* allele. The genotypes of the offspring are all possible combinations of alleles that can occur when the gametes combine at fertilization.

Punnett Squares (cont'd)

- *Phenotypic ratio* shows the frequency of the phenotypes in offspring.
  - Example: 3 purple flowers:1 white flower
- *Genotypic ratio* shows the frequency of the genotypes in offspring.
  - Example: 1*BB*:2*Bb*:1*bb*

Discussion Questions

1. A monohybrid cross produces half the offspring with one genotype and half the offspring with another genotype. Express this in the form of a ratio.

2. What do the alleles that are written along the top and beside a Punnett square represent?

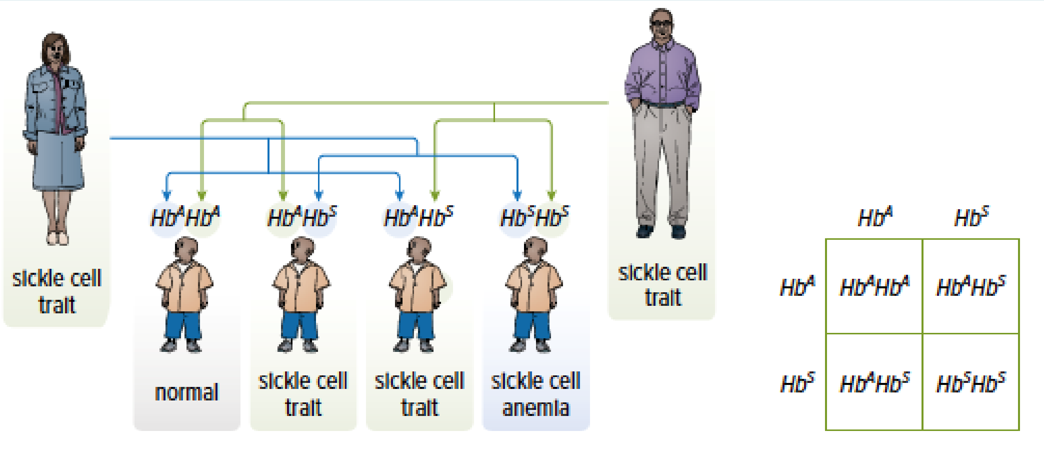
Concept 3: Both alleles are expressed in codominance.

- **Codominance:** the condition in which both alleles for a trait are equally expressed in a heterozygote; both alleles are dominant
- Codominant alleles are represented by capital letters with a superscript for each allele
  - Example: H^RH^W

Sickle Cell Anemia—Another Example of Codominance

- Sickle cell anemia is a genetic disorder where the red blood cell is C-shaped (sickle shape) and therefore cannot transport oxygen effectively.
- People who are heterozygotes with the sickle cell trait are resistant to the life-threatening disease malaria.

Figure 1.18: When a man and a woman are both heterozygous for the sickle cell gene, there is a one in four chance that they will have a child with sickle cell anemia.



Discussion Questions

1. What is codominance? Give three examples of codominance.

2. Hypothesize why the frequency of the sickle cell allele is much higher in Africa than in other areas of the world.

Concept 4: In incomplete dominance, alleles are neither dominant nor recessive.

Incomplete Dominance

- **Incomplete dominance:** a condition in which neither allele for a gene completely conceals the presence of the other; it results in intermediate expression of a trait
- Example: Four o'clock flowers can be red, pink, or white.

Incomplete Dominance

- Use capital letters with superscripts to represent incomplete dominance.

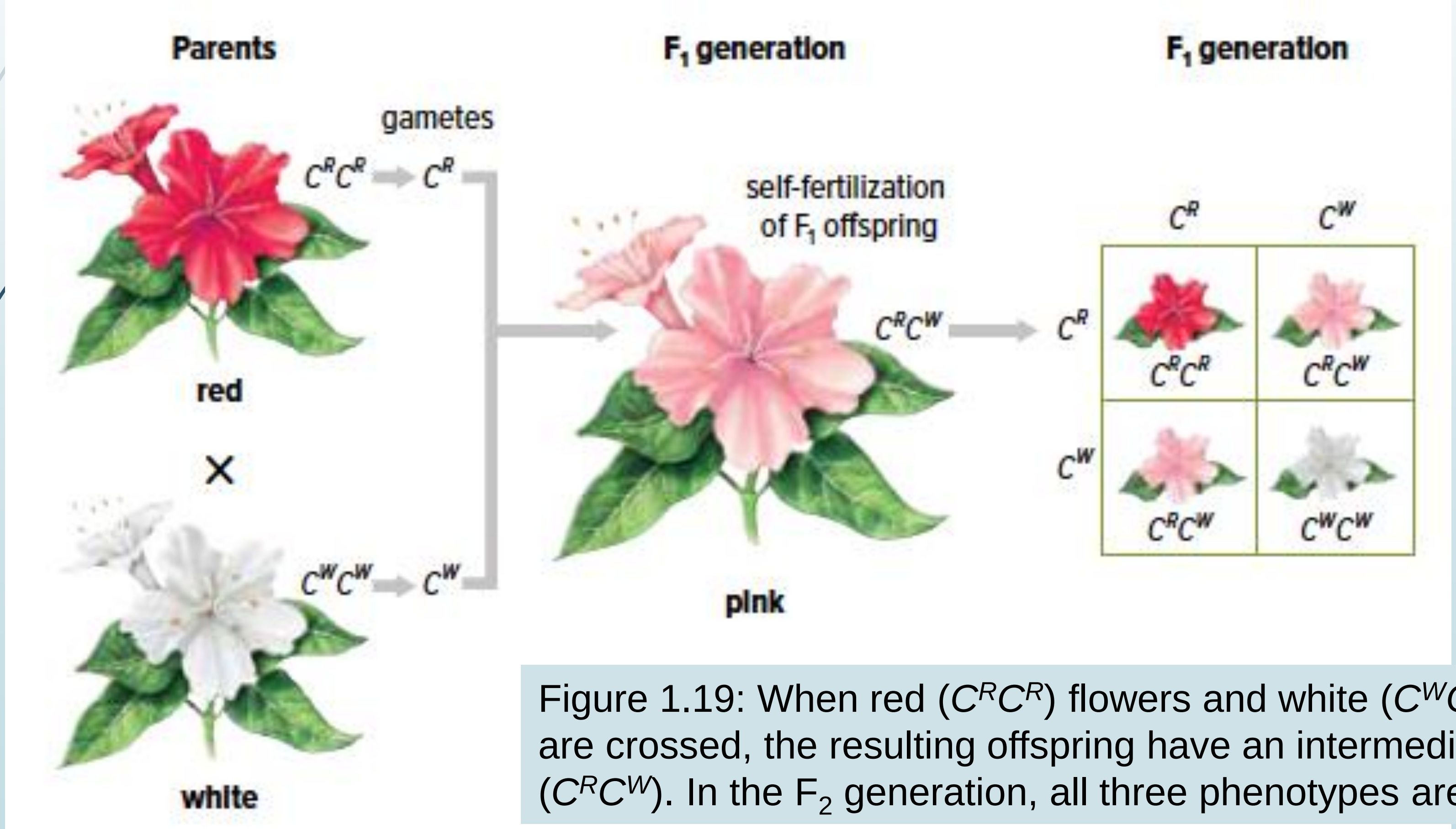


Figure 1.19: When red (C^RC^R) flowers and white (C^WC^W) flowers of the four o'clock are crossed, the resulting offspring have an intermediate phenotype, pink flowers (C^RC^W). In the F_2 generation, all three phenotypes are observed.

Discussion Questions

1. What is the difference between incomplete dominance and codominance?
2. A plant that produces white flowers is crossed with a plant that produces purple flowers. Describe the phenotype of the offspring if the inheritance pattern for flower colour is

   a) incomplete dominance

   b) codominance

Concept 5: Some inherited traits are due to alleles on the sex chromosomes.

- **Sex-linked trait:** a trait controlled by genes on sex chromosomes
- **X-linked trait:** a trait controlled by genes on the X chromosome
- Males are affected by recessive X-linked traits more often because they have only one X chromosome.

Red-Green Colour Vision Deficiency

- Red-green colour vision deficiency is a recessive X-linked trait.
- *Carrier* is a female that has one recessive allele on one of her X chromosomes.

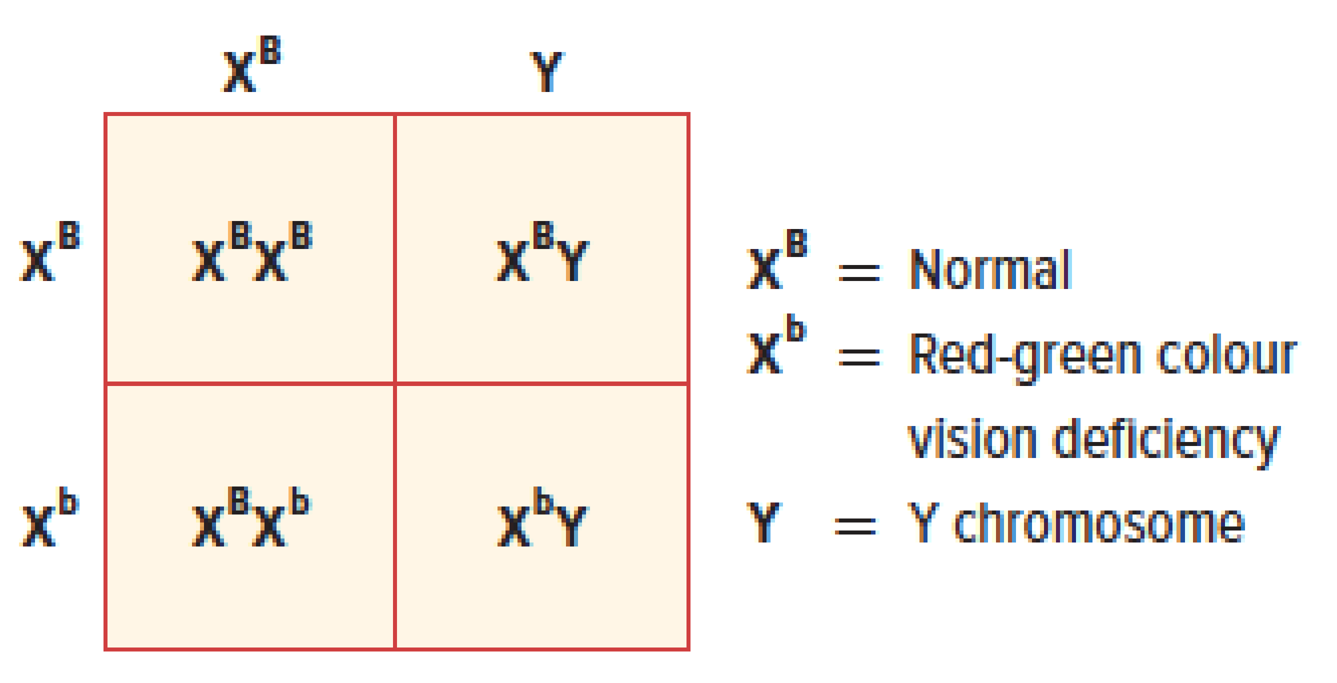


Figure 1.20: The Punnett square shows how the sex-linked trait is inherited.

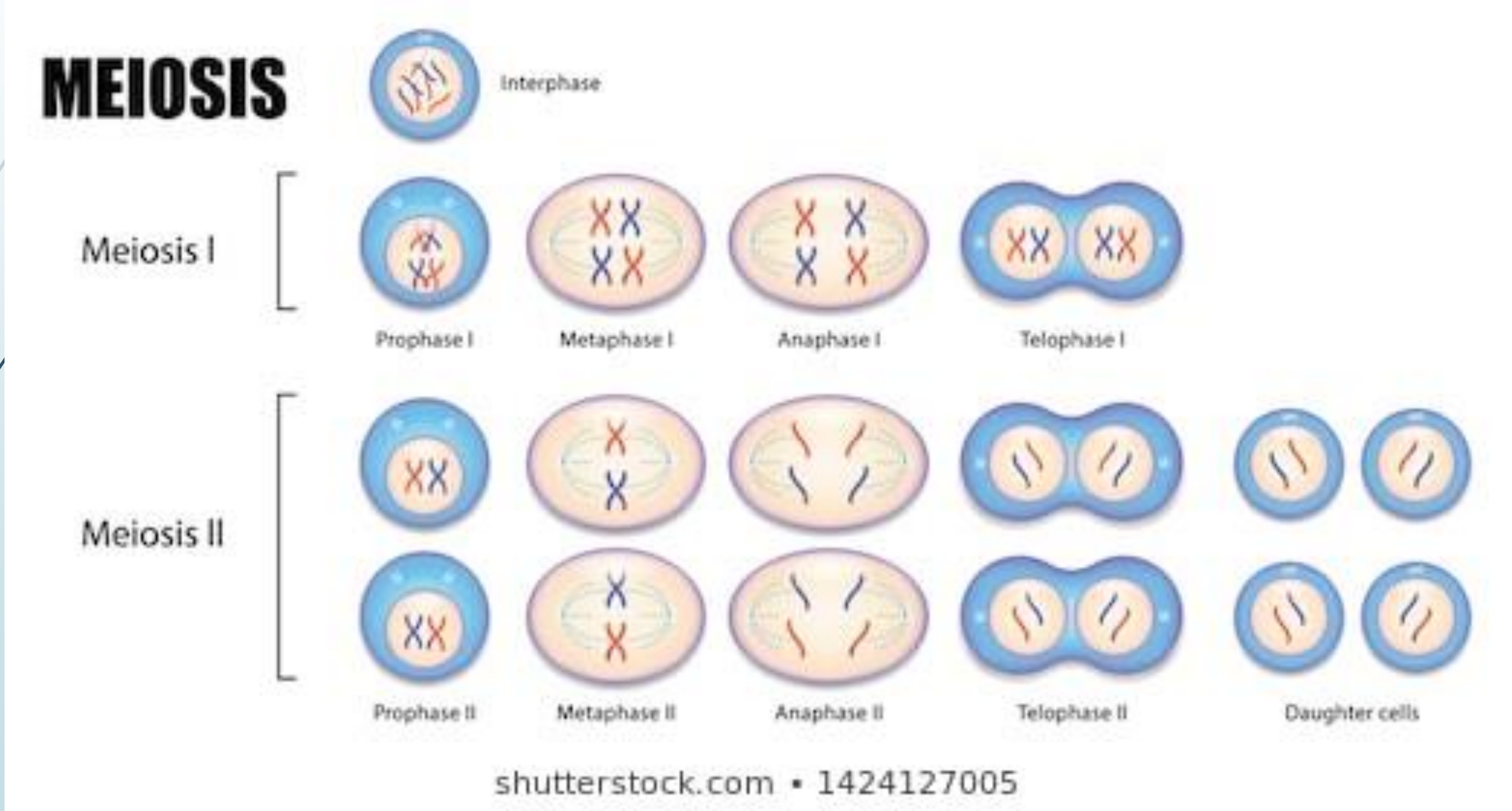
Discussion Questions

1. What are sex-linked traits?

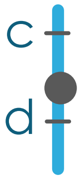
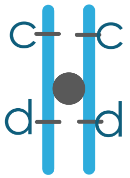
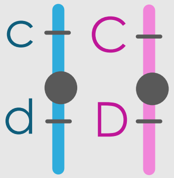
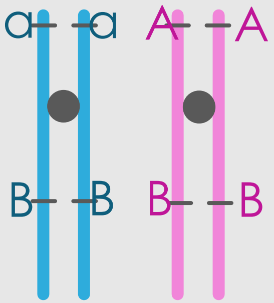
2. Use vocabulary terms to describe the genotype of a male who is red-green colour vision deficient.

End of testable content

Genetic diversity is caused by independent assortment and crossing over during meiosis.



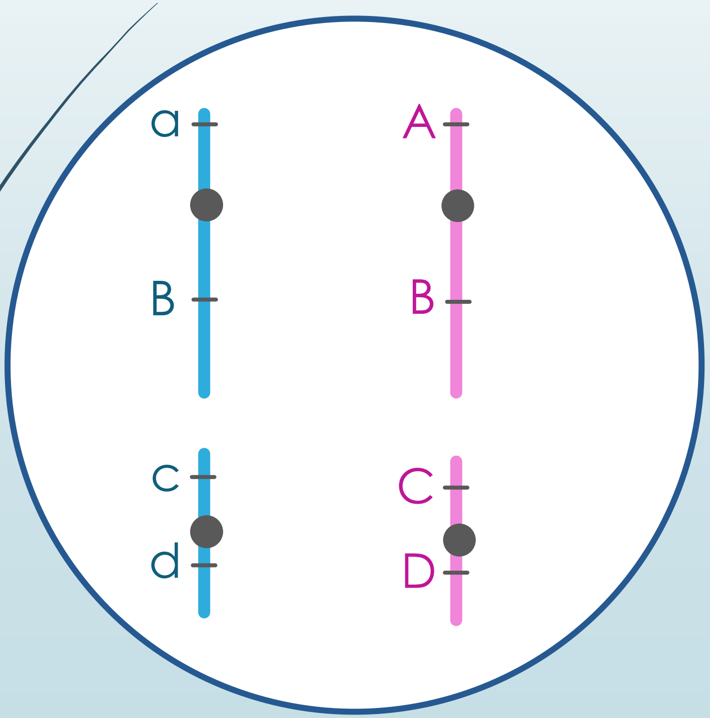
Reference: Interpreting Mitosis and Meiosis Diagrams

Structure	Symbol	Notes
Centromere		1 centromere per chromosome. No exceptions.
Chromosome	 **OR** 	Replication makes an identical copy of the DNA strand of the chromosome. But: this entire structure is still **one chromosome** because it has **one centromere.**
Homologous chromosomes	 **OR** 	Homologous chromosomes have the same: • Centromere placement • Length of DNA strand (vertical line) • Genes (short dashed line) In each pair, one chromosome comes from the **mother**, and one from the **father**. Alleles can be the same or different. Examples: • Left: the chromosomes have different alleles for both genes. • Right: different alleles for "A" gene; same alleles for "B" gene.

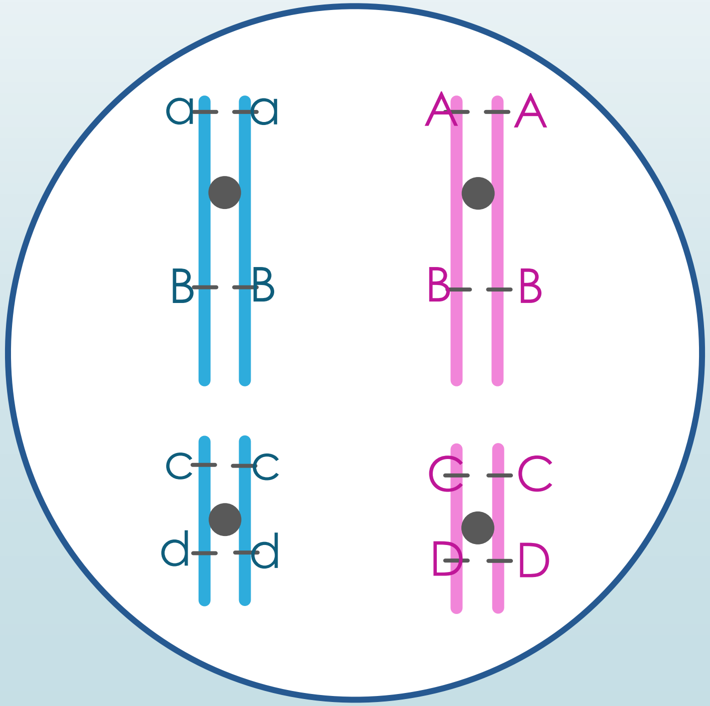
Interphase (review):

During interphase, DNA is replicated. However, the number of chromosomes stays the same.

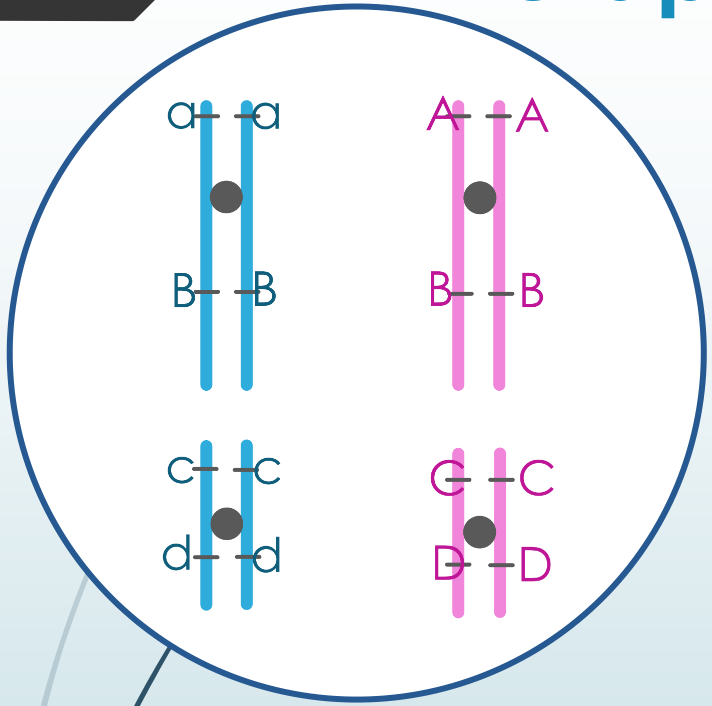
Interphase: **before** replication
(2 homologous pairs: 4 chromosomes)

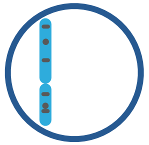
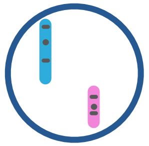
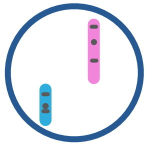
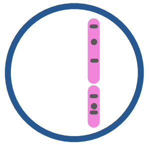


Interphase: **after** replication
(2 homologous pairs: 4 chromosomes)



Metaphase 1: Independent Assortment



	Chromosome 1: **aB** Chromosome 2: **cd**		Chromosome 1: **aB** Chromosome 2: **CD**
	Chromosome 1: **AB** Chromosome 2: **cd**		Chromosome 1: **AB** Chromosome 2: **CD**

In this case with 2 homologous pairs, there are 4 possible gametes that this parent could produce. The number of possible combinations increases exponentially when the number of homologous pairs increases.

Humans have 23 homologous pairs of chromosomes. It is estimated that independent assortment alone leads to 6.3 billion chromosome combinations for any two parents. This is why no two siblings are alike!

https://www.nature.com/scitable/topicpage/mitosis-meiosis-and-inheritance-476/#:~:text=When%20these%20chromosome%20pairs%20are,A%20B%20C

Prophase 1: Crossing Over

Synapsis is where homologous pairs 'buddy up' during Prophase 1 and exchange pieces of DNA between them. This exchange is called **crossing over**.

Prophase 1 (start)	Synapsis	Crossing Over (complete)