Lecture 4

# Genetic linkage and Crossing Over

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# Is independent assortment always the case? No

- Independent assortment states that during gamete formation, the two alleles for one gene segregate or assort independently of the alleles for other genes.

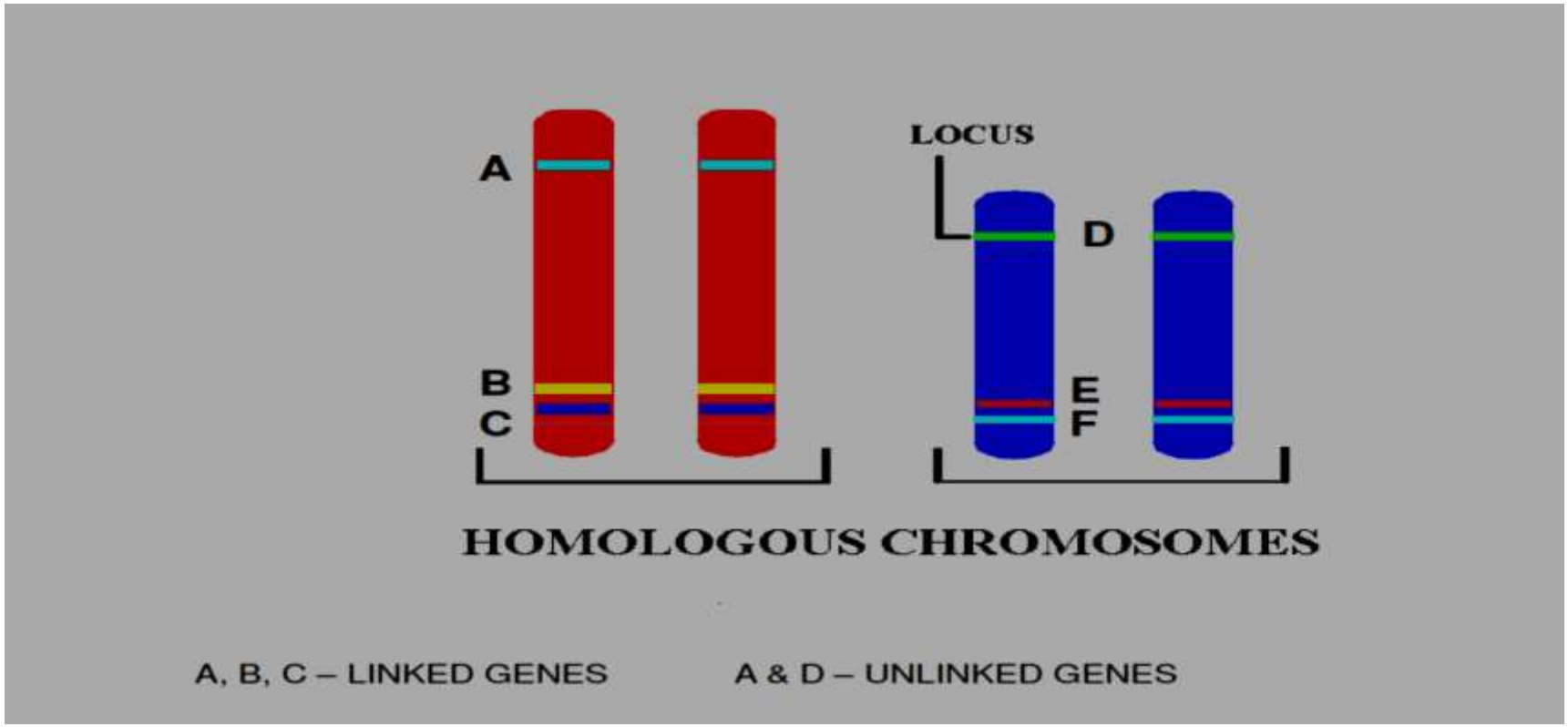
- But if two genes are found on the same chromosome, they will not assort independently, and do not follow Mendelian inheritance patterns.

- Genes that are inherited together are said to be "***linked***."

- Genes **located on different chromosomes are not linked**
  This allows independent assortment – in a **di-hybrid cross** the traits show the classic **9:3:3:1** inheritance pattern.

- Genes that are located **very close** together **on the same chromosome** may show **complete linkage**
  They may be so close to each other that they cannot be separated by **recombination** during meiosis.

**(c)** Genes located **far apart** on the **same chromosome** typically show **incomplete (partial) linkage** because they are easily separated by **recombination.**



# Genetic linkage

- Genetic linkage is the tendency of alleles that are located close together on a chromosome to be inherited together during meiosis.

- Genes whose loci are nearer to each other are less likely to be separated on to different chromatids during chromosomal crossover, and are therefore said to be genetically ***linked*****.**

- In other words, the nearer two genes are on a chromosome, the lower is the chance of a swap occurring between them, and the more likely they are to be inherited together.

# The discovery of genetic linkage

- ***William Bateson*** and ***Reginald Punnett*** completed a study in **1905** that determined the movement of alleles found on the same chromosome.

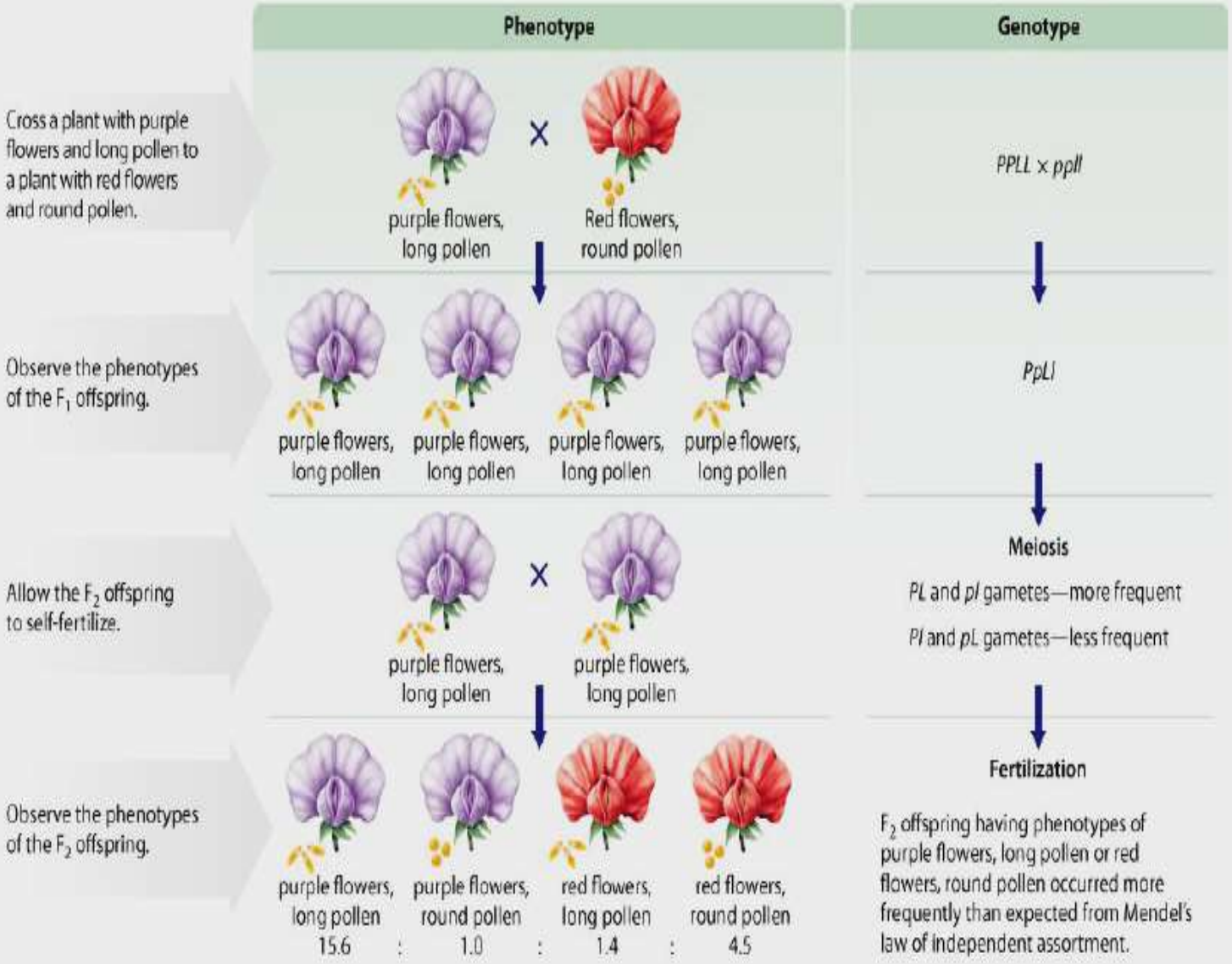
- The study used sweet peas, particularly flower colour and pollen shape, they followed the inheritance pattern.

Reginald Punnett (left) joined William Bateson (right) in 1903

- For flower colour, purple is dominant over red, and for pollen shape long is dominant over round.
- A cross was performed using a true breeding purple/long and red/round.
- The **F1** generation was 100% purple/long.

- Crossing two individuals from the **F1** generation resulted in a **F2** generation with four different phenotypes. (***purple/long, purple/round, red/long and red/round***).

- The alleles that created these combinations did not follow the 9:3:3:1 pattern, but supported the idea that these alleles did not assort independently and therefore must be ***linked***.


Phenotype
Genotype
Cross a plant with purple flowers and long pollen to a plant with red flowers and round pollen.
purple flowers, long pollen
Red flowers, round pollen
PPLL × ppll
Observe the phenotypes of the F1 offspring.
purple flowers, long pollen
purple flowers, long pollen
purple flowers, long pollen
purple flowers, long pollen
PpLl
Meiosis
PL and pl gametes—more frequent
Pl and pL gametes—less frequent
Allow the F2 offspring to self-fertilize.
purple flowers, long pollen
purple flowers, long pollen
Fertilization
Observe the phenotypes of the F2 offspring.
purple flowers, long pollen 15.6
purple flowers, round pollen 1.0
red flowers, long pollen 1.4
red flowers, round pollen 4.5
F2 offspring having phenotypes of purple flowers, long pollen or red flowers, round pollen occurred more frequently than expected from Mendel's law of independent assortment.

# Why Linkage

- Linkage refers to packaging genes onto chromosomes.

- Chromosomes (and therefore linkage) are for organizing genes for their safe coordinated transmission from cell to cell( parent to offspring).

# Types of Linkage

**Depending upon the presence or absence of new combinations or non-parental combinations, linkage can be of two types:**

**(i) Complete Linkage:**

If two or more characters are inherited together and consistently appear in two or more generations in their original or parental combinations, it is called complete linkage. These genes do not produce non-parental combinations.

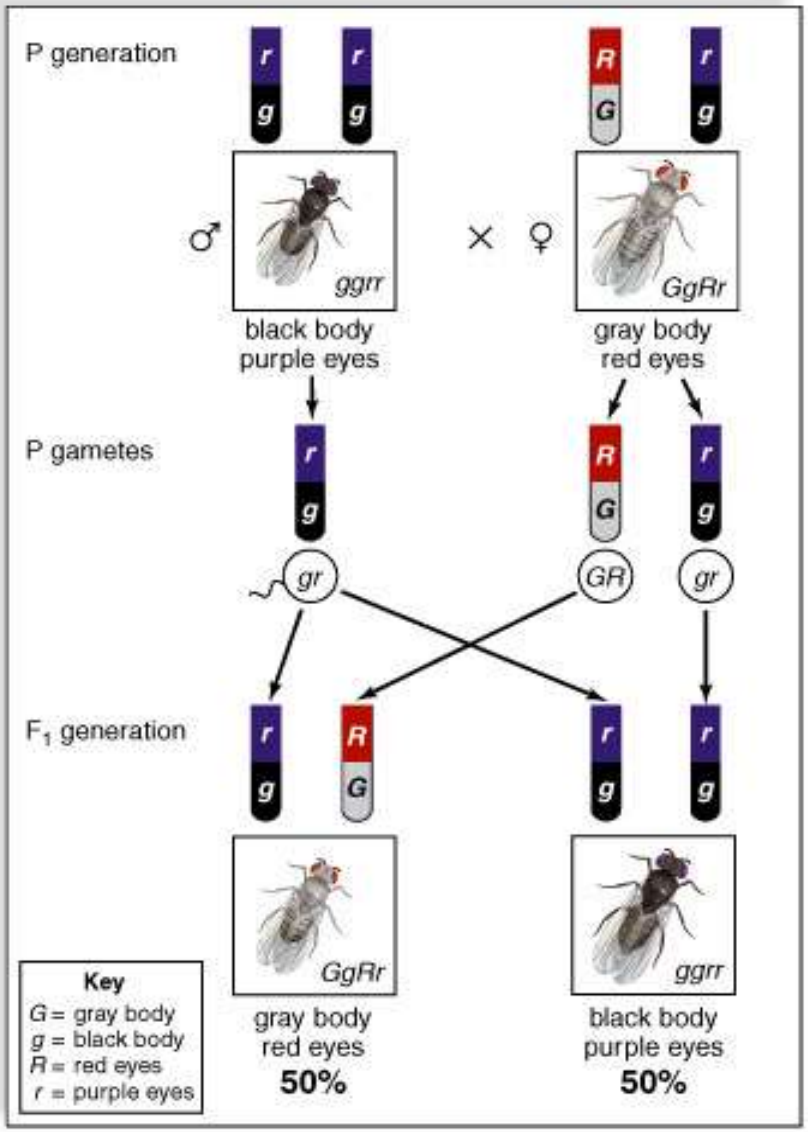
Genes showing complete linkage are closely located in the same chromosome.

**(ii) Incomplete Linkage:**

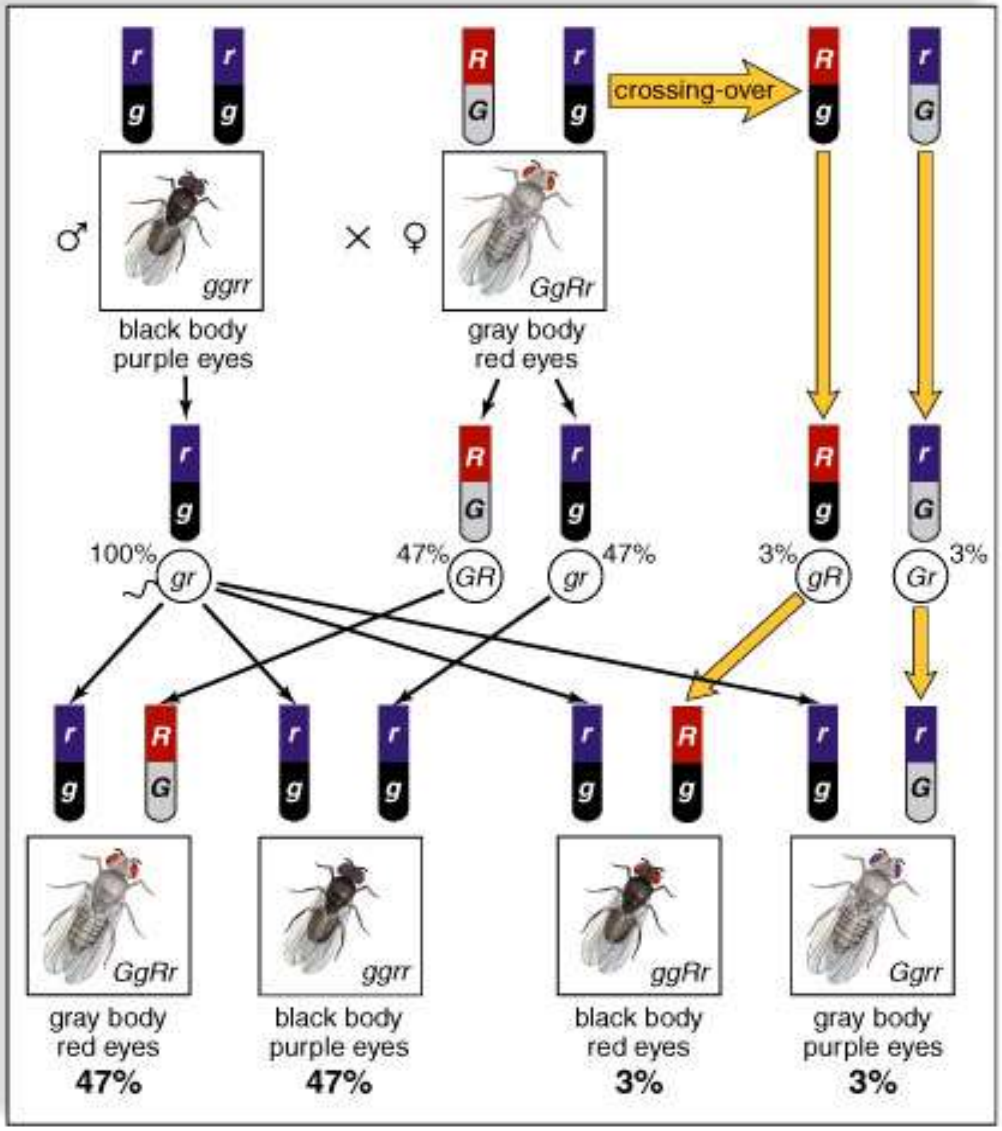
Incomplete linkage is exhibited by those genes which produce some percentage of non-parental combinations. Such genes are located distantly on the chromosome. It is due to accidental or occasional breakage of chromosomal segments during crossing over.

# Complete vs. Incomplete Linkage






a.




b.

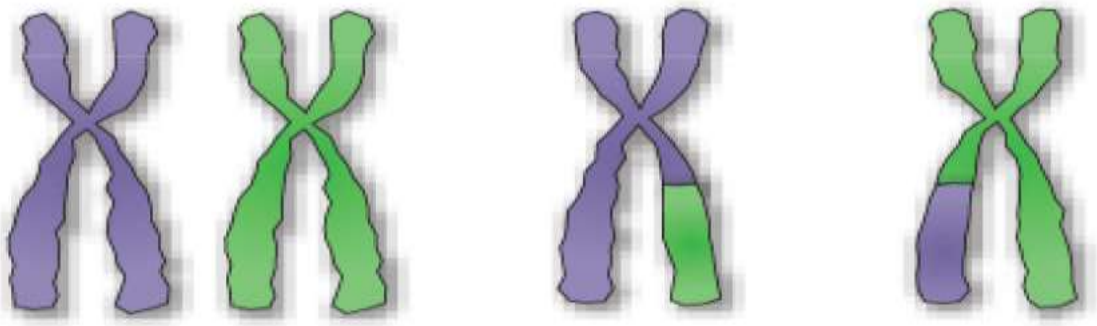
# Significance of Linkage

1. Linkage does not permit the breeders to bring the desirable characters in one variety. For this reason plant and animal breeders find it difficult to combine various characters.

2. Linkage reduces the chance of recombination of genes and thus helps to hold parental characteristics together. It thus helps organism to maintain its parental, racial and other characters.

- **Linked genes are not inherited together every time**

Chromosomes exchange homologous genes during meiosis.

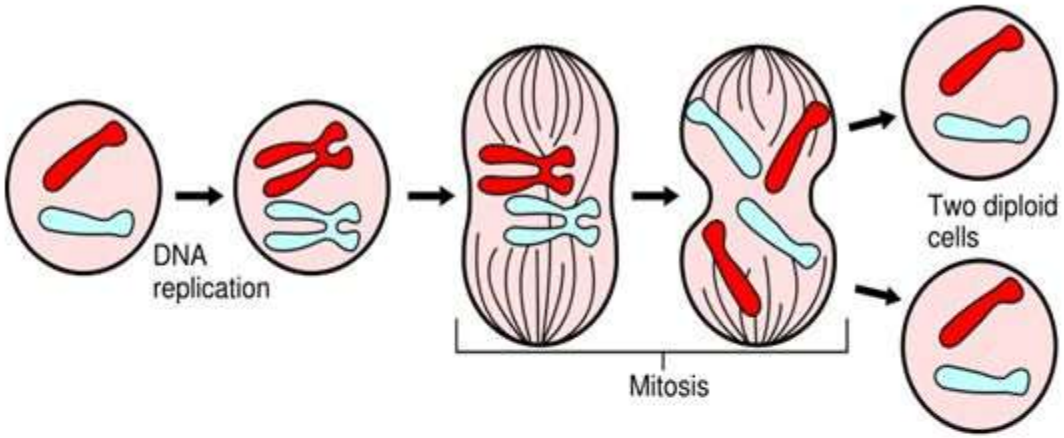


Punjab EDUSAT Society{PES}

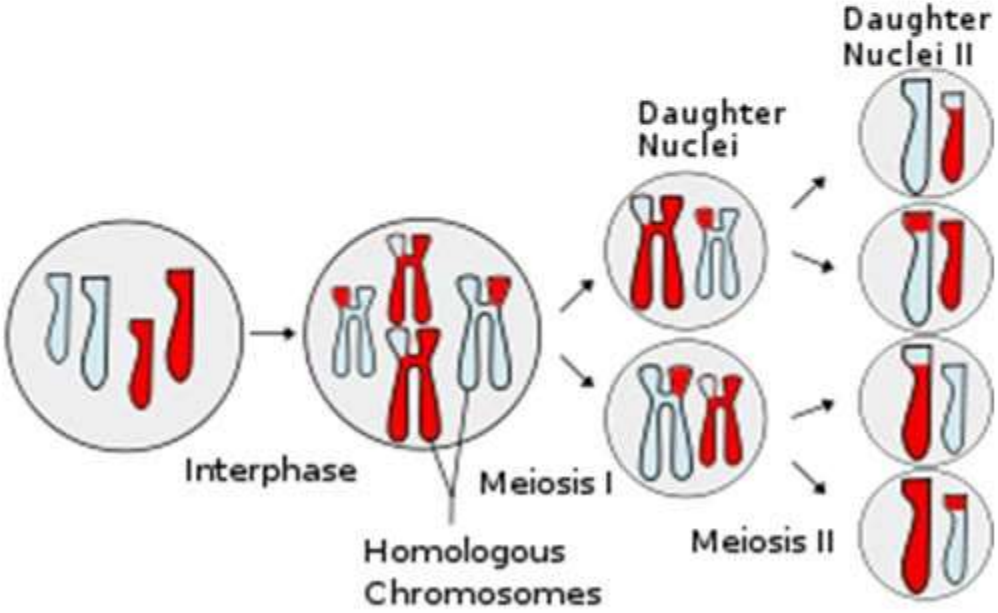
# Crossing Over and the Inheritance of Linked Genes

- Linked genes don't always stay linked.

- These linkage groups can be separated by crossing over during ***prophase I*** of meiosis.




No crossing over – daughter cells are **identical** to parent cells

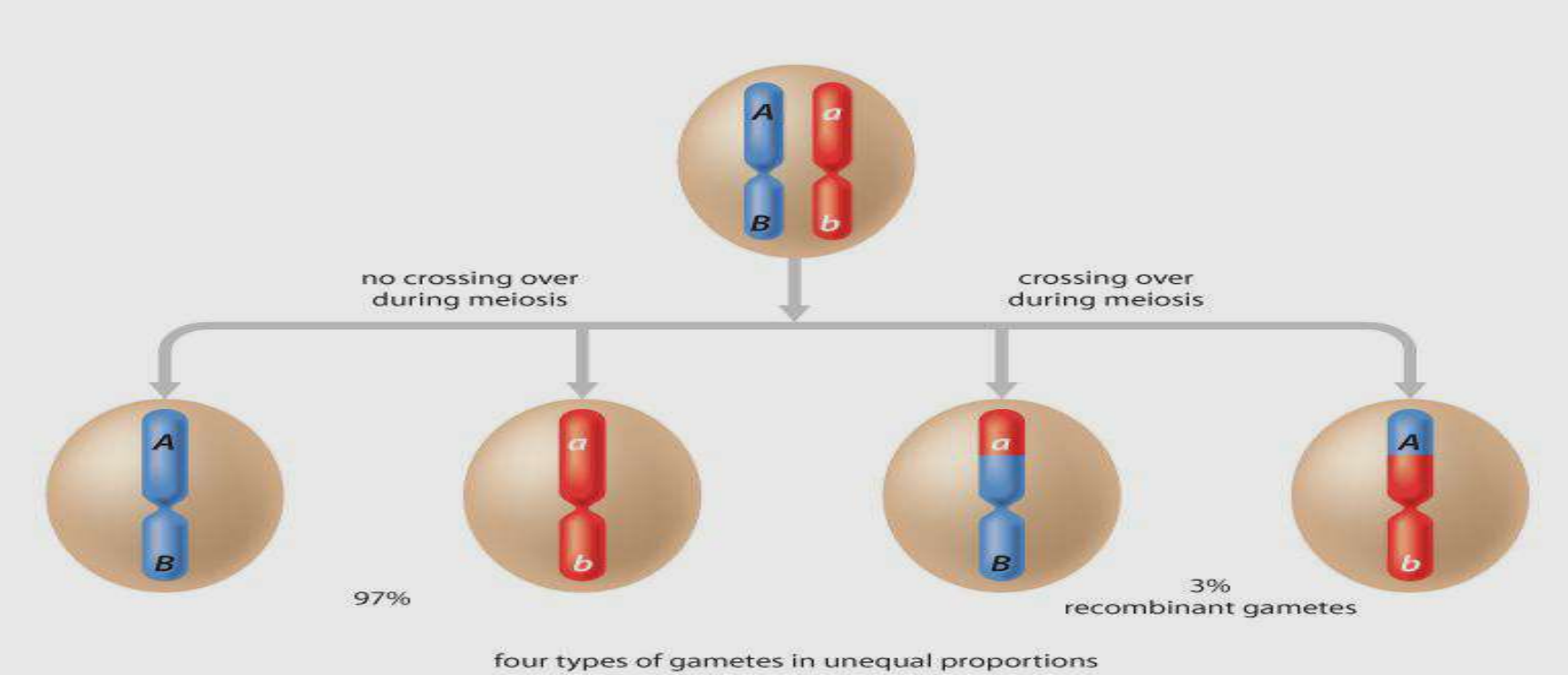



Crossing over occurs –causes **genetic variation**

(Daughter cells are NOT identical to parent cell)

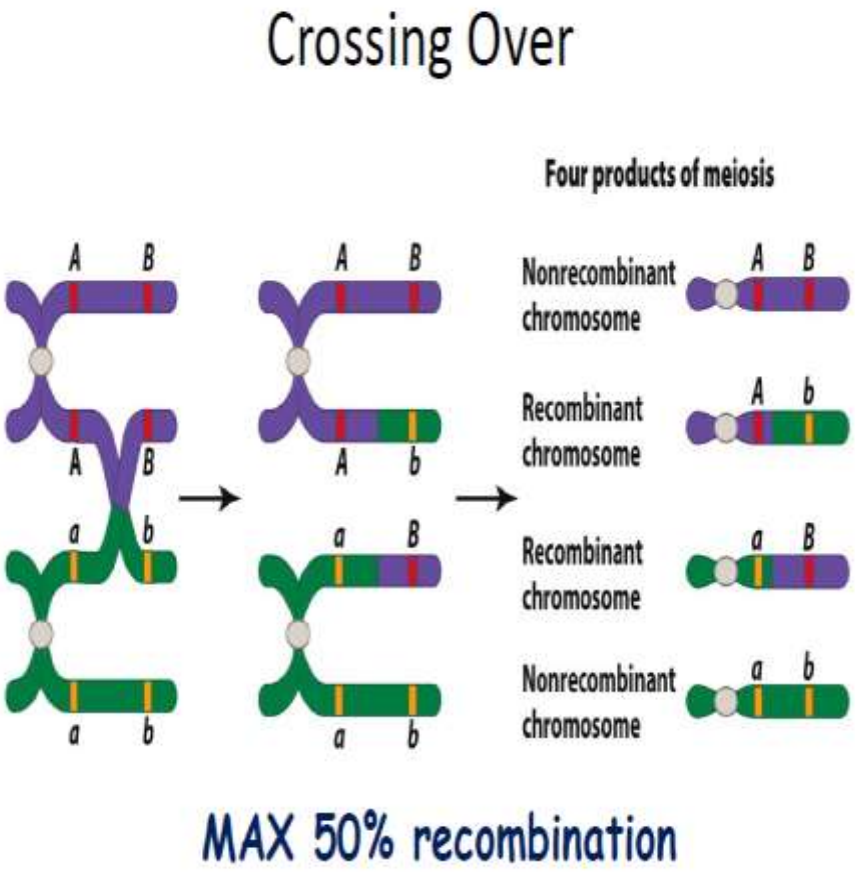
- When crossing over occurs, the genes that were previously linked become unlinked, creating four different types of chromosomes (***gametes***).

- The proportions are not equal because crossing over does not occur in every cell during meiosis.

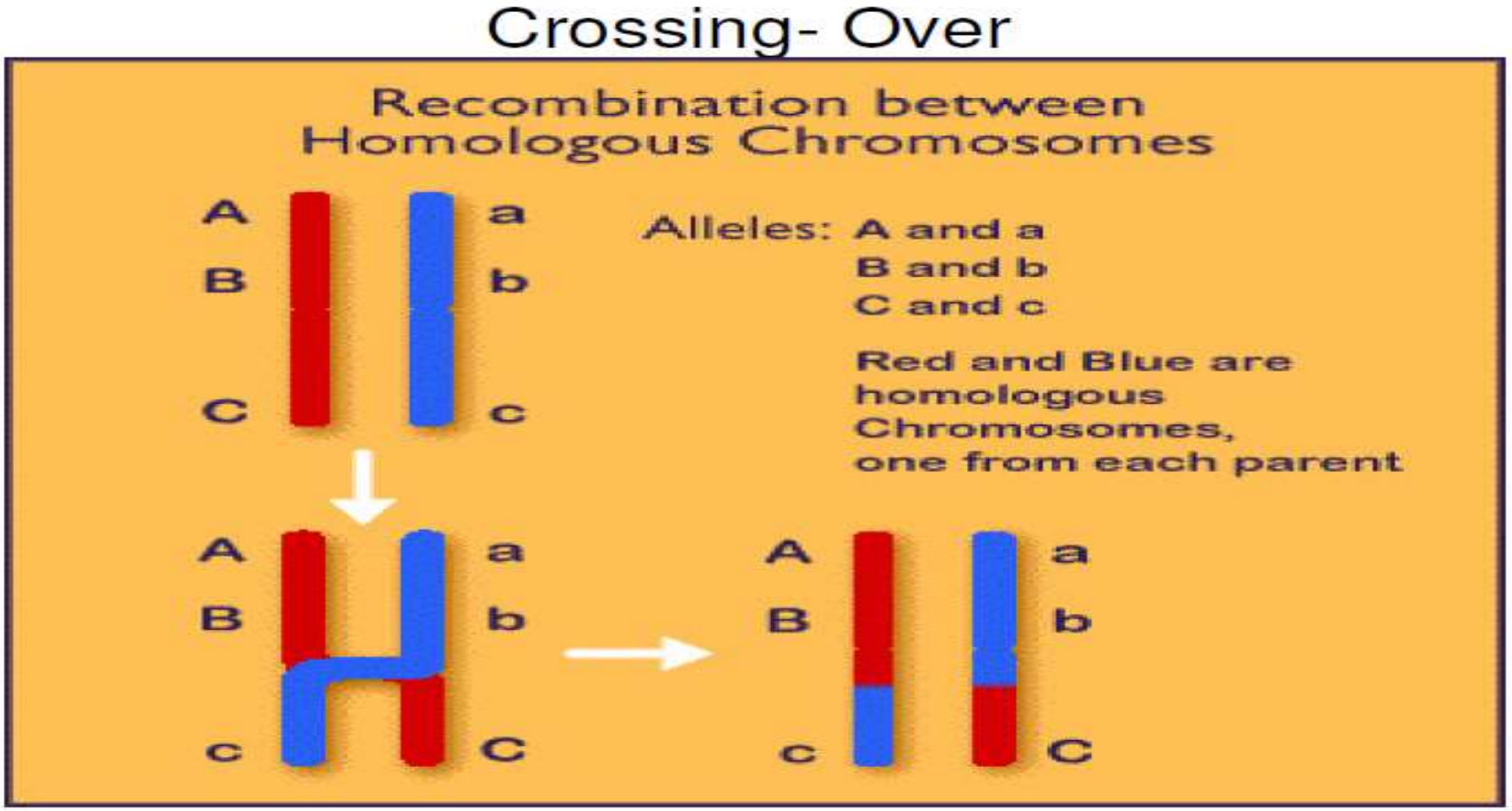


# Crossing Over

- A random exchange of DNA between two non-sister chromatids of homologous chromosomes.
- Results in recombination of genetic material



- Prevalence of recombination is dependent on the distance between linked genes



# FACTORS AFFECTING CROSS OVER

**1. Sex:**

there is a tendency of reduction of crossing over in male mammals.

**2. Mutation:**

mutation reduces crossing over

**3. Temperature:**

high and low temperature variations increase the percentage of crossing over in certain parts of the chromosome.

**4. X-ray Effect:**

X-ray irradiations increase crossing over near centromere.

**5. Age:**

older age increases the rate of crossing over.

# Significance of Crossing-over

1. Produces new combinations of traits.

2. Through crossing over segments of homologous chromosomes are interchanged and hence provide origin of new characters and genetic variations.

3. Crossing over plays a very important role in the field of breeding to improve the varieties of plants and animals.

# Theories of Crossing Over

**(i) Contact First Theory :**

According to this theory the inner two chromatids of the homologous chromosomes undergoing crossing over, first touch each other and then cross over. At the point of contact breakage occurs. The broken segments again unite to form new combinations.

**(ii) The Breakage-First Theory :**

According to this theory the chromatids under-going crossing over, first of all break into two without any crossing over and after that the broken segments reunite to form the new combinations.

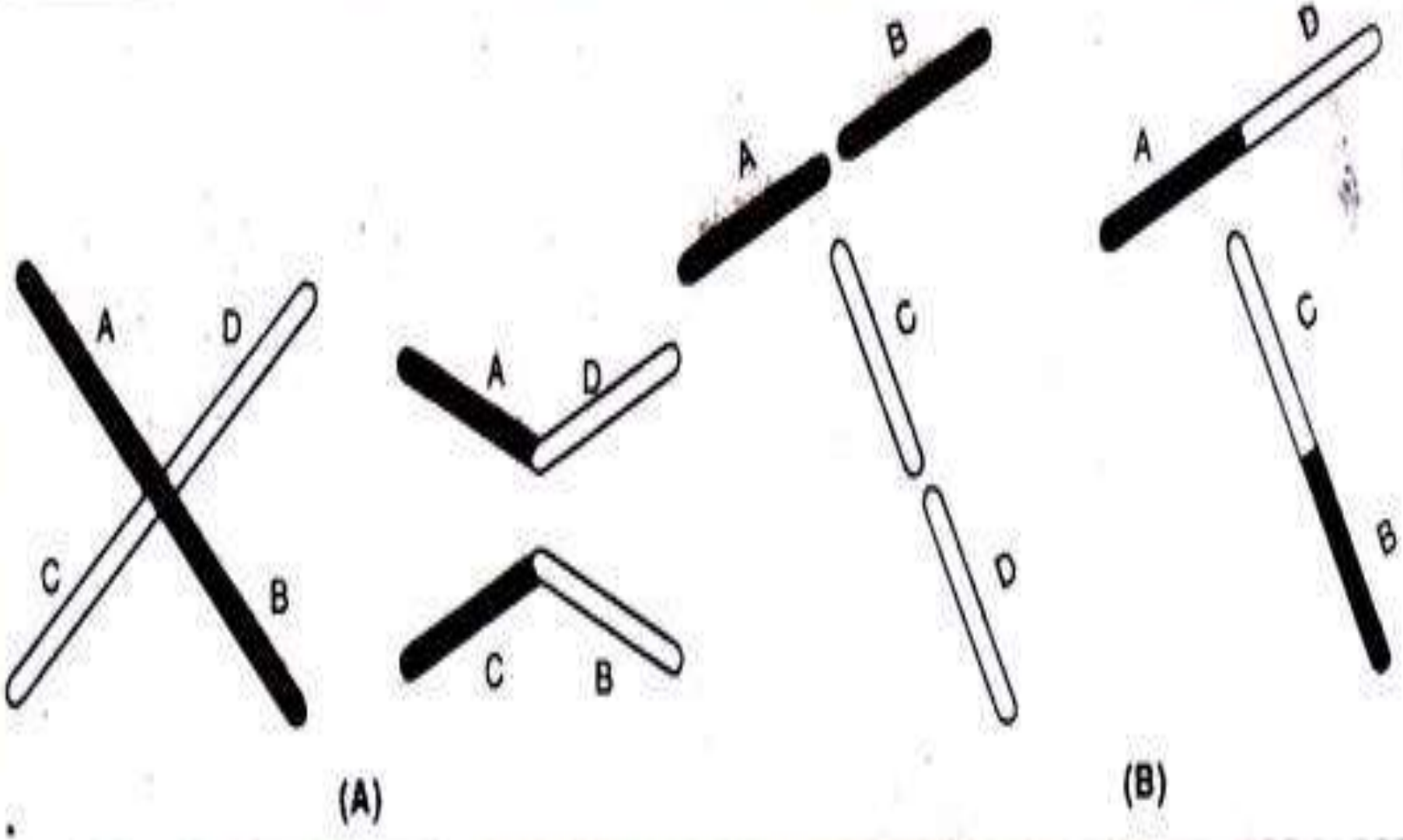



Fig. 5.11 Diagrams showing
A : contact-first theory of crossing over. B : Breakage-first theory of crossing over

# Types of Crossing Over

## (i) Single Crossing Over:

In this type of crossing over only one chiasma is formed (a **chiasma** is the point where two homologous non-sister chromatids exchange genetic material during chromosomal crossover in meiosis ) all along the length of a chromosome pair. Gametes formed by this type of crossing over are called single cross over gametes .

# Types of Crossing Over

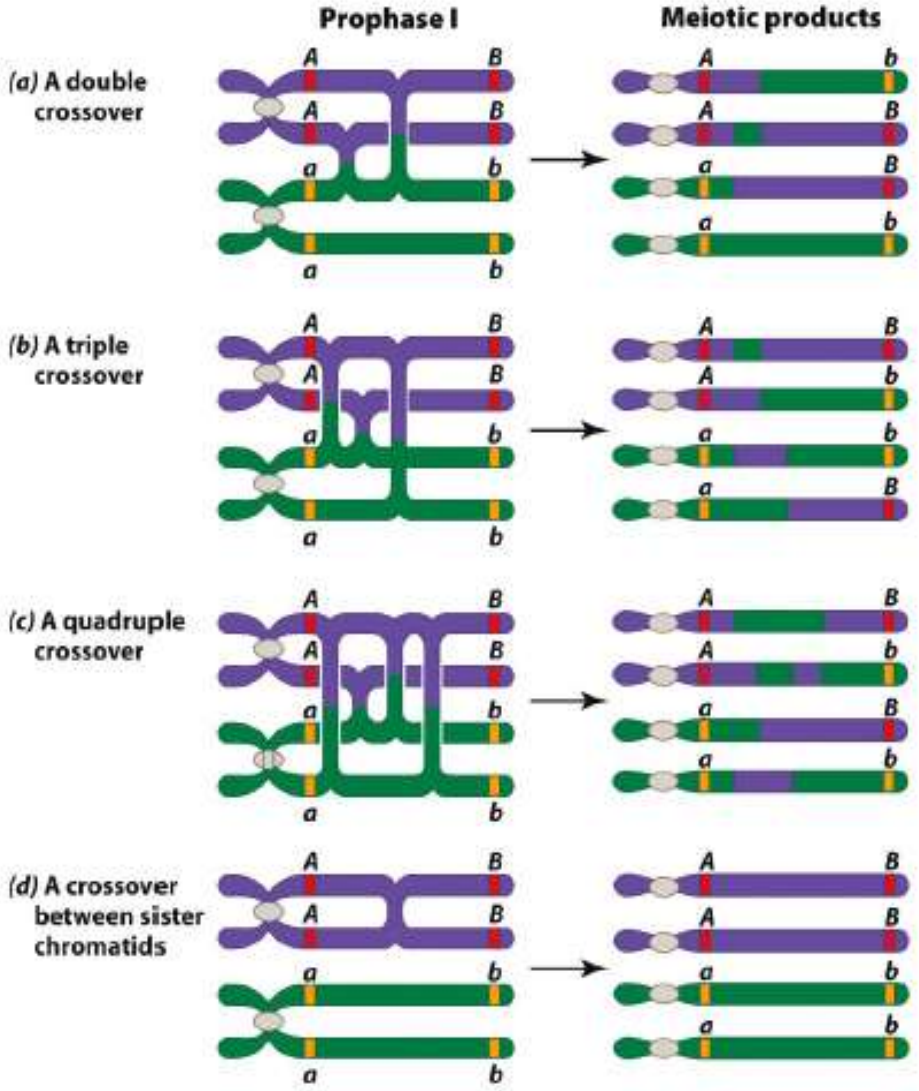
**(ii) Double Crossing Over:**

In this type two chiasmata are formed along the entire length of the chromosome leading to breakage and rejoin of chromatids at two points. The gametes produced are called double cross over gametes.

**(iii) Multiple Crossing Over:**

In this type more than two chiasmata are formed and thus crossing over occurs at more than two points on the same chromosome pair. It is a rare phenomenon.

# Multiple Crossovers



# Difference between linkage and crossing over

## Linkage

1. It is tendency of genes on a chromosome to remain together and passed as such in next generation.
2. It brings more parental types.
3. Strength of linkage between two genes increases if they are closely placed on a chromosome.
4. It helps to maintain a newly improved variety.

# Difference between linkage and crossing over

## Crossing over

1. It is exchange of genes or chromosomal parts to break established linkage and formation of new linkage.
2. It produces recombination.
3. Frequency of crossing over between two genes decreases if they are closely placed .
4. It is the source of variation for producing new varieties.

**In genetic recombination by crossing over, what is the difference between parental gametes and recombinant gametes?**

- Parental gametes are the gametes that maintain the original linkage of genes (alleles) in the chromosome.

- Recombinant gametes are those in which the original linkage is undone due to exchange of chromosomal pieces via crossing over during meiosis.