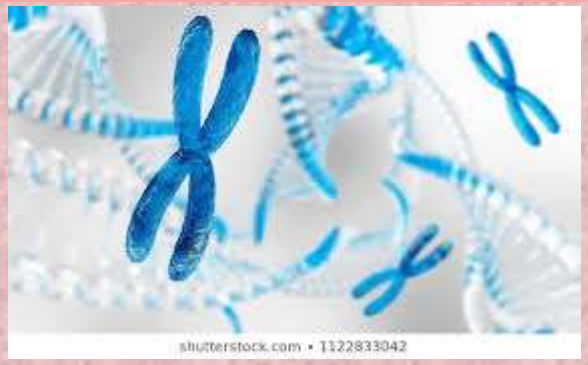
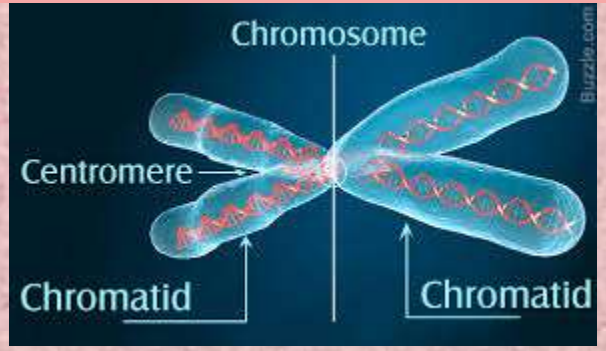




Linkage and crossing over

Dr. TARUNPREET SINGH

LINKAGE

- Discovery of linkage
- Meaning of linkage
- Characteristics of linkage
- Genes in linkage
- Theories
- Kinds of linkage
- Linkage group
- Significance

CROSSING OVER

- Discovery of crossing over
- Meaning of crossing over
- Characteristics of crossing over
- Types crossing over
- Mechanisms
- Factors affecting crossing over
- Significance
- Differences between crossing over and linkage

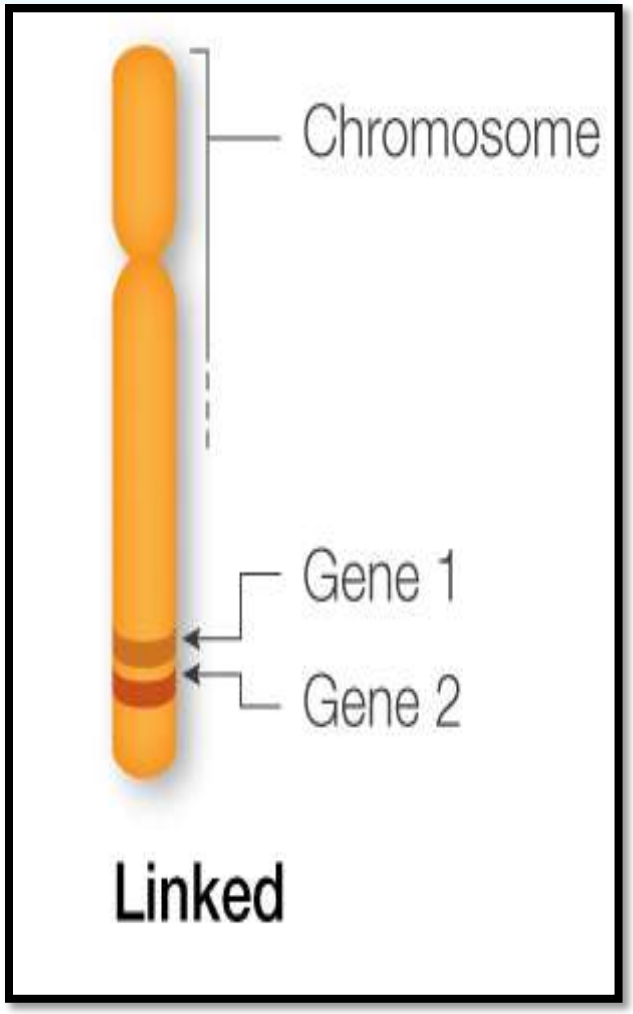
Discovery of Linkage

- The principle of linkage was discovered by English Scientists **William Bateson** and **R.C. Punnet** in 1906 in Sweet Pea (*Lathyrus odoratus*). However, it was put forward as a regular concept by **Morgan** in 1910 from his work on (*Drosophila melanogaster*).

Reginald Crundall Punnett

Meaning of Linkage

- Linkage is the phenomenon of certain genes staying together during inheritance through several generations without any change or separation due to their being present on same chromosomes.



CHARACTERISTICS OF LINKAGE

- Linkage involves two or more genes which are linked in same chromosomes in a linear fashion.
- Linkage reduces variability.
- It may involve either dominant or recessive alleles(coupling phase) or some dominant and some recessive alleles(repulsion phase).
- It usually involves those genes which are located close to each other.
- The strength of linkage depends on the distance between the linked gene.

  Lesser the distance higher the strength of linkage

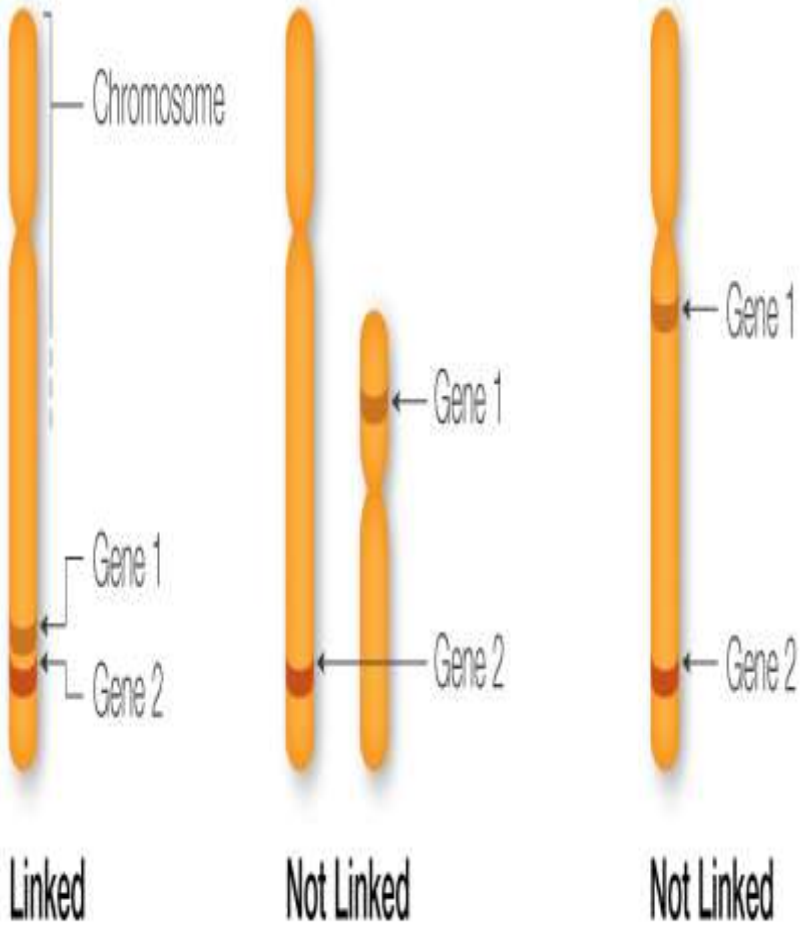
Genes in Linkage

- **LINKED GENE :**

  These genes do not show independent assortment. It occurs in same chromosome.

  Dihybrid ratio of linked gene is 3:1
- **UNLINKED GENE:**

  These gene show independent assortment. Dihybrid ratio is 9:3:3:1.



Theories of Linkage

- DIFFERENTIAL MULTIPLICATION THEORY (**William Bateson**)
- CHROMOSOMAL THEORY (**Thomas Hunt Morgan**)

DIFFERENTIAL MULTIPLICATION THEORY

- This theory was put forward by Bateson in 1930.
- He said that after the segregation of genes during gametogenesis certain genes multiply faster then others.

CHROMOSOME THEORY

- Morgan and Castle associate genes with chromosome and formulated postulates
- The genes which show Linkage are located in same chromosome.
- The distance between linked gene in the chromosome determine the strength of linkage.
- The genes lie in a linear manner in the chromosomes.

KINDS OF LINKAGE

- **ON THE BASIS OF CROSSING OVER**

i. Complete linkage

ii. Incomplete linkage

- **ON THE BASIS OF CHROMOSOME INVOLVED**

i. Autosomal linkage

ii. Allosomal /Sex linkage

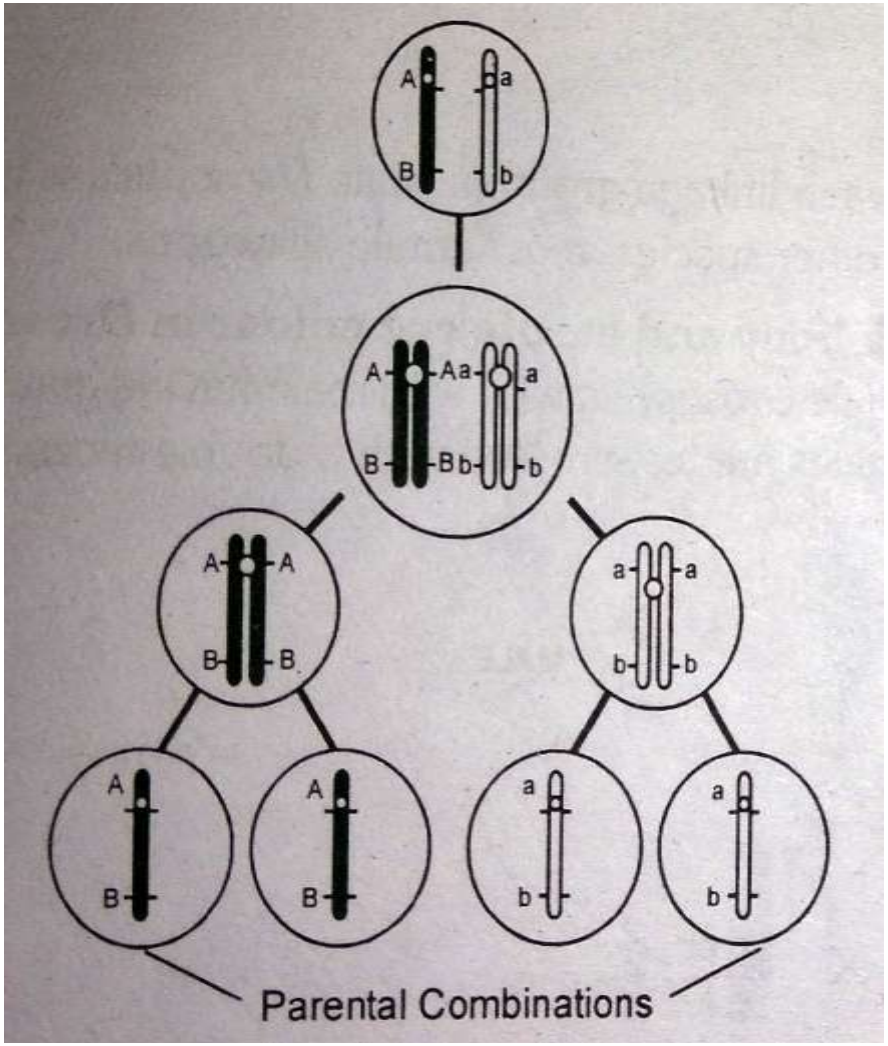
- **ON THE BASIS OF GENE INVOLVED**

i. Coupling phase

ii. Repulsion phase

ON THE BASIS OF CROSSING OVER

- **COMPLETE LINKAGE**
- The genes located in the same chromosome are inherited together over the generations due to absence of crossing over. It is rare but has been reported in male *Drosophila*.



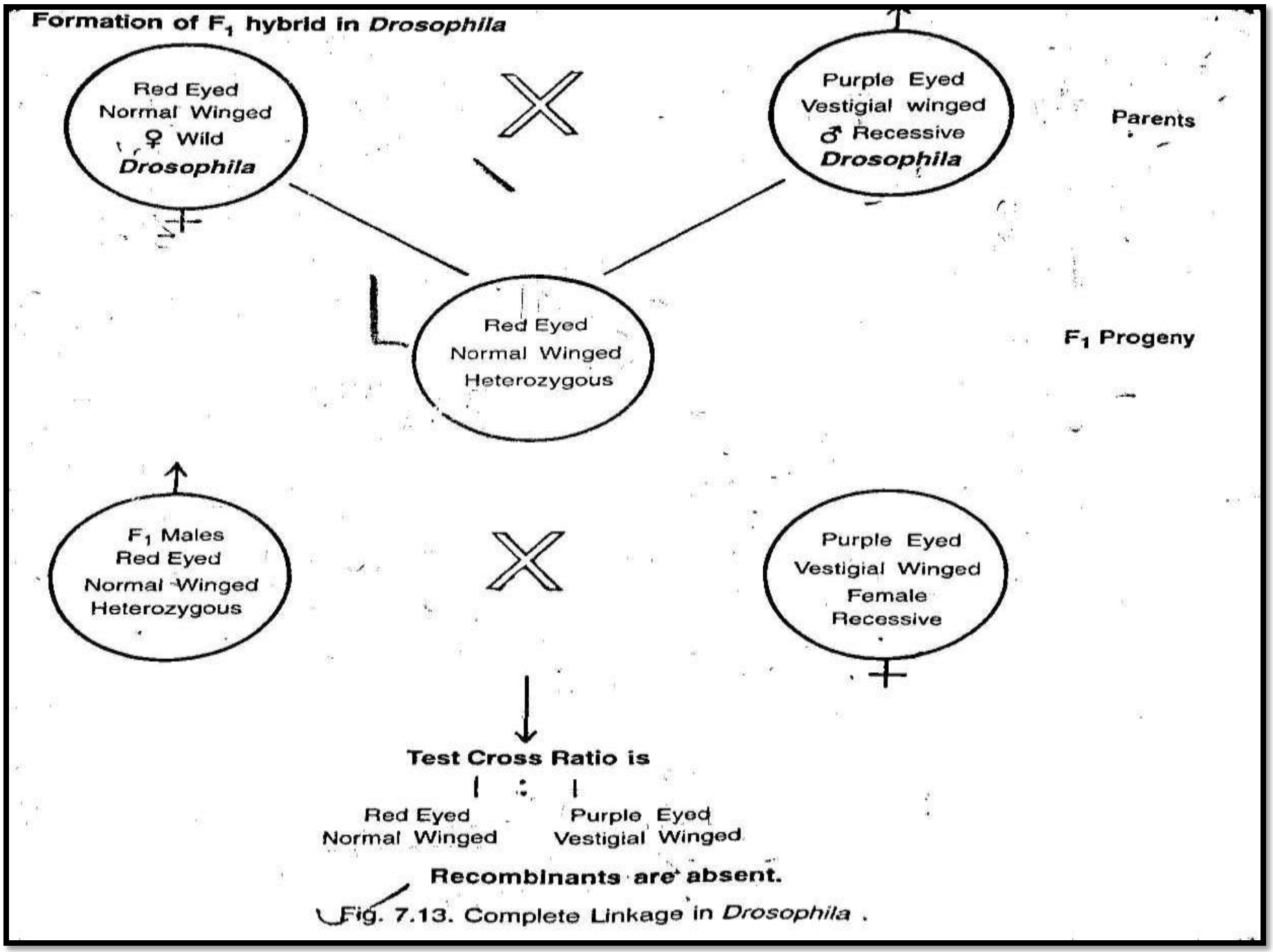
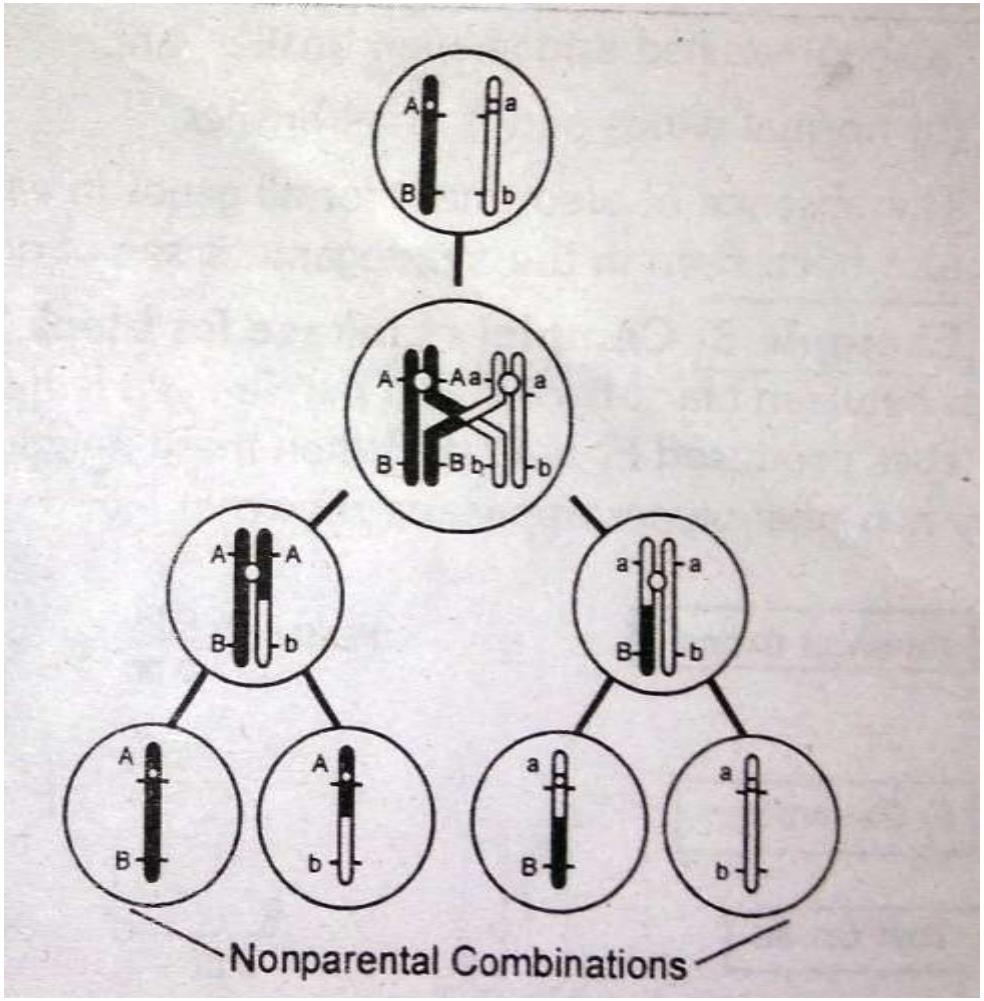


Fig. 7.13. Complete Linkage in *Drosophila* .

INCOMPLETE LINKAGE

- Genes present on the same chromosomes have a tendency to separate due to crossing over. They produce recombinant progeny beside the parental types.



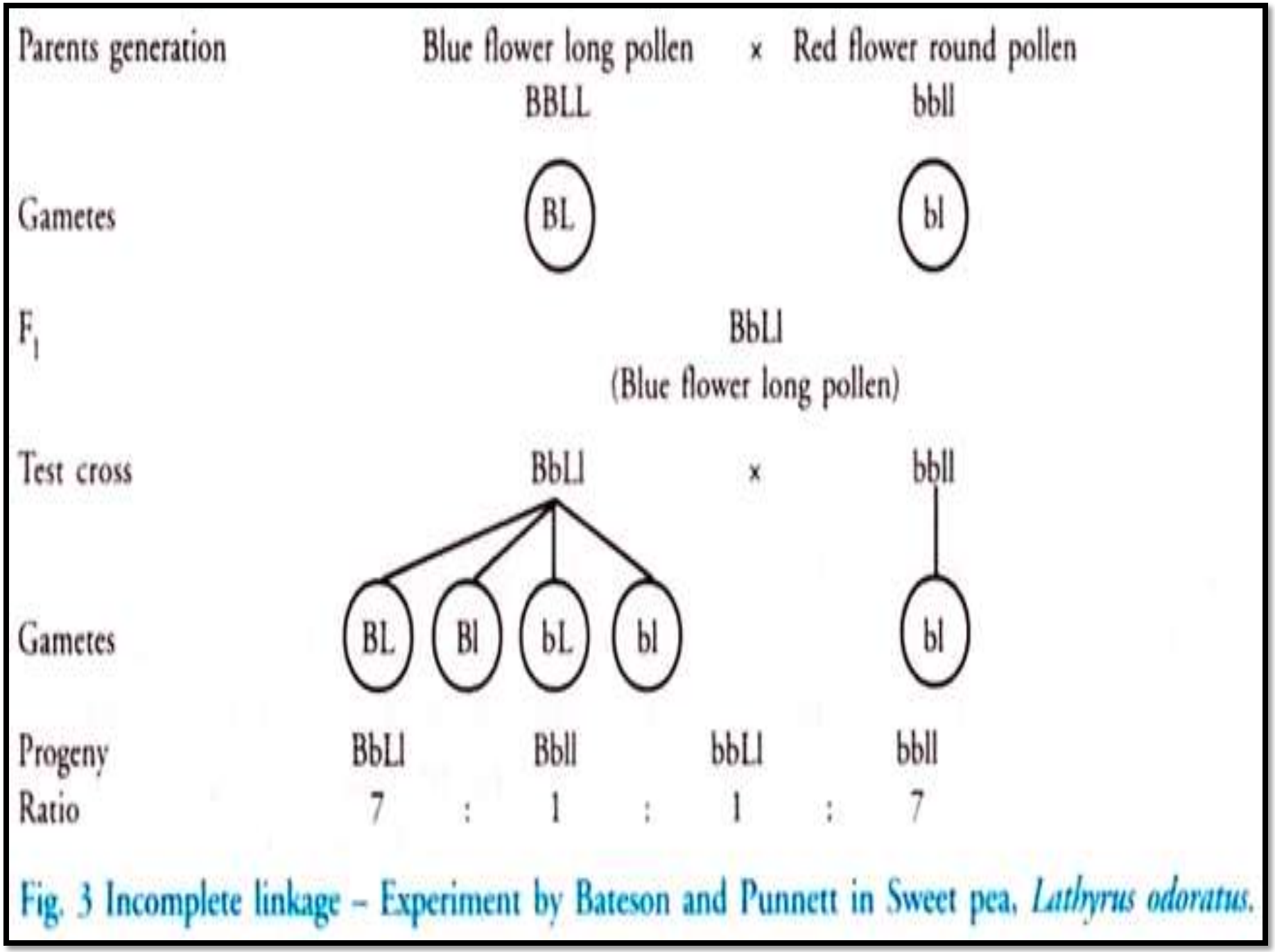


Fig. 3 Incomplete linkage – Experiment by Bateson and Punnett in Sweet pea, *Lathyrus odoratus*.

ON THE BASIS OF CHROMOSOMES INVOLVED

- **Based on the chromosomes involved:-** Based on the location of the genes on the chromosomes, linkage is categorized into:-

i. **Autosomal linkage:-** It refers to linkage of those genes which are located in autosome (other than the sex chromosomes).

ii. **Allosomal linkage:-** It refers to linkage of genes which are located in sex chromosomes i.e. either "X" or "Y".

ON THE BASIS OF GENES INVOLVED

- Depending on whether all dominant or some dominant and recessive alleles are linked together, linkage can be categorized into coupling and repulsion phase:-

i. **Coupling phase:-** Dominant alleles and recessive alleles present on the same chromosomes shows coupling phase.

TR tr

----- ---- **COUPLING PHASE**

TR tr

ii. **Repulsion phase:-** Dominant alleles of same genes are linked with recessive alleles of other genes on same chromosomes shows repulsion phase.

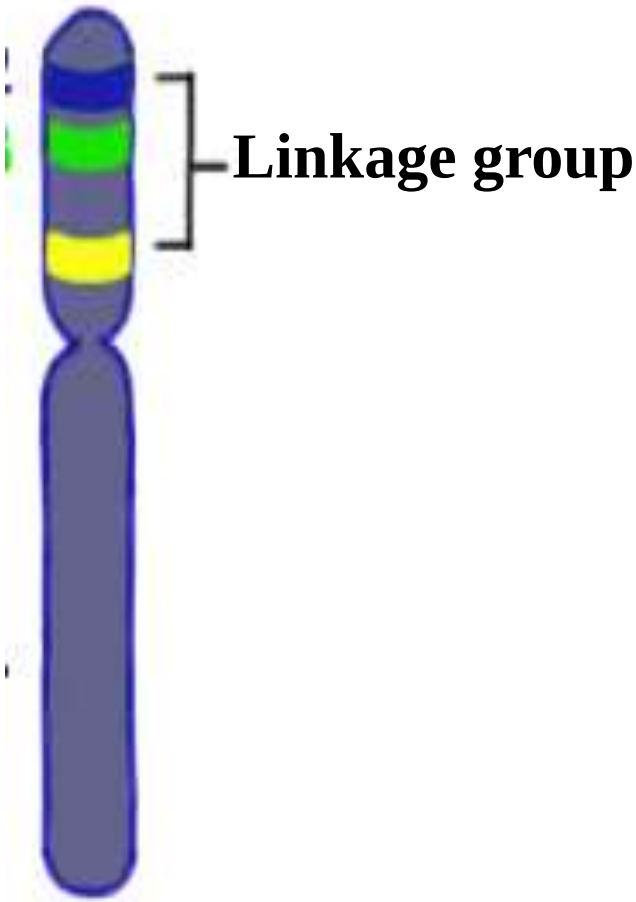
Tr tR

---- ---- **REPULSION PHASE**

Tr tR

Linkage group

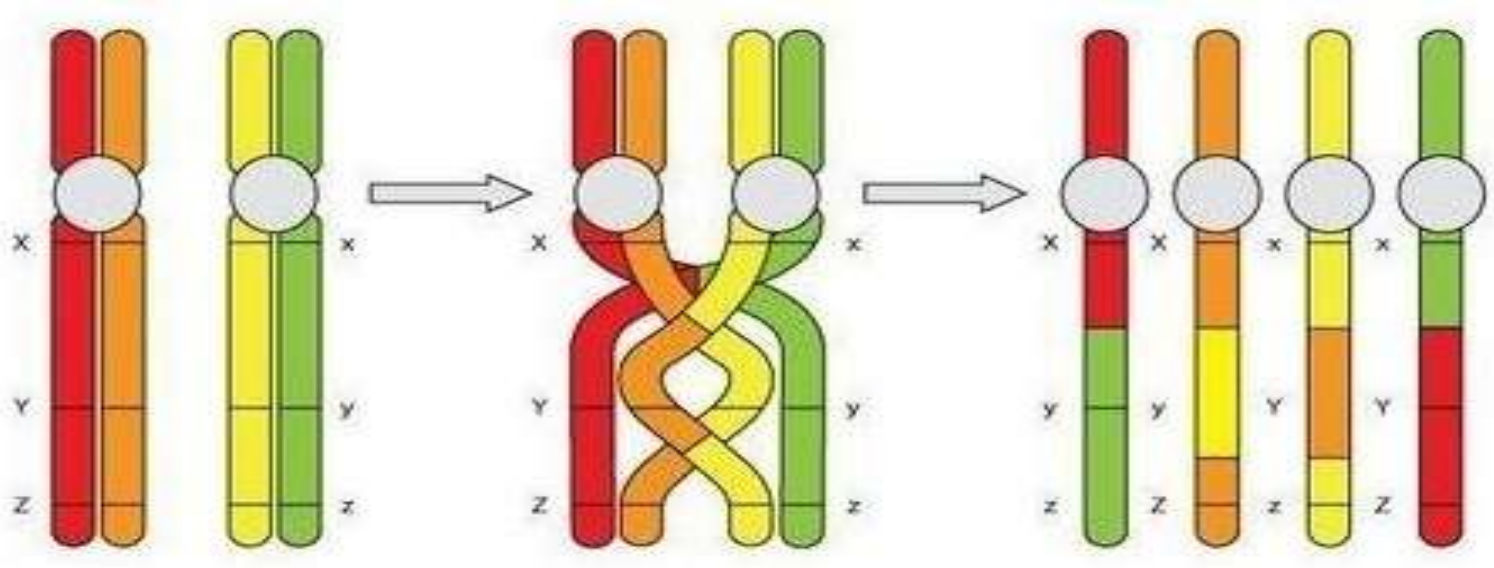
- A linkage group is a linearly arranged group of linked genes which are normally inherited together.
- **Example**:- In a fruit fly *Drosophila melanogaster* has four linkage group (Four pairs of chromosomes).
- In human being 23 linkage group are present (23 pairs of chromosomes).



Significance of linkage

- It reduce the chances of formation of new combinations of genes in gametes.
- It helps keeping the parental, racial and specific traits together.
- It also useful for maintaining the good character of newly developed variety.
- Linkage plays an important role in determining the nature and scope of hybridization.

CROSSING OVER

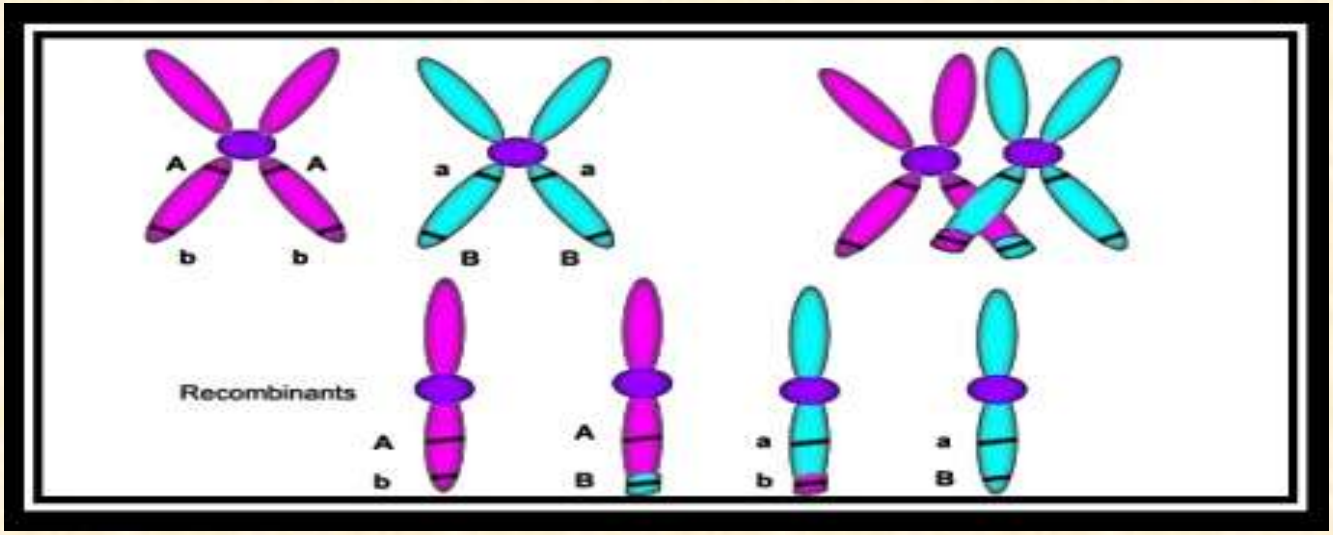


Discovery of crossing over

Frans Alfons Janssens who described the phenomenon of crossing over in 1909. He is observed cross-like arrangements in meiosis and proposed crossing over as a genetic process.

Meaning of Crossing over

- Crossing over or (chromosomal cross over) is the exchange of genetic material between homologous chromosomes that results in recombinant chromosomes.

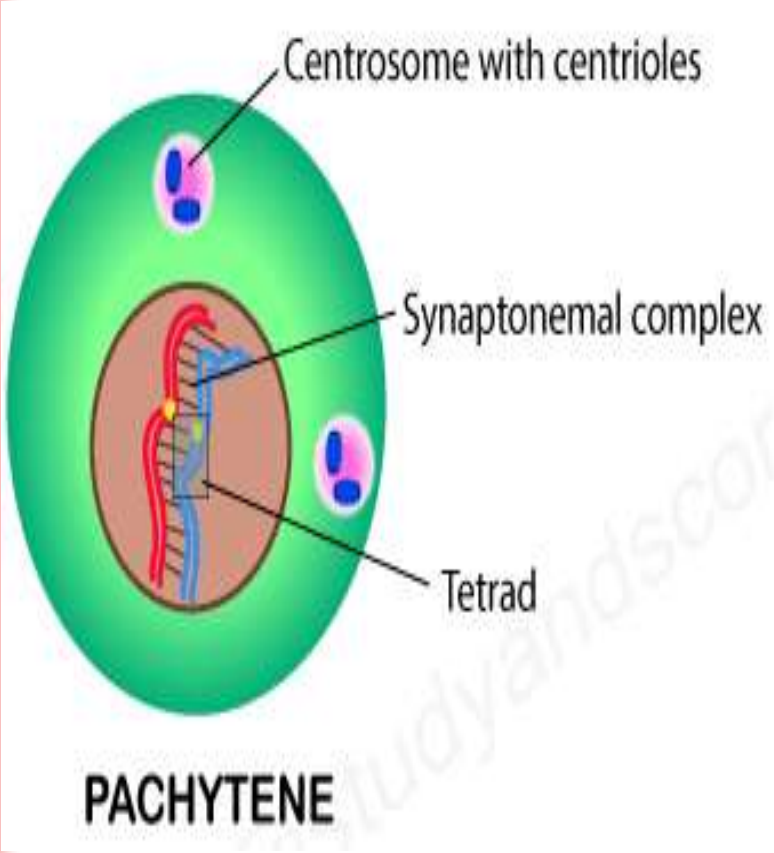


Characteristics of crossing over

- Crossing over occurs between non-sister chromatids. One chromatid from each of the two homologues chromosomes is involved in crossing over.
- Crossing over leads to re-combinations or new combinations between linked genes.
- The value of crossover or recombinants may vary from 0-50%.
- Crossing over generally yields two recombinant types or crossover types and two parental types or non-crossover types.
- Crossing over generally leads to exchange of equal segments or genes and recombination is always reciprocal.

Stage at which crossing over occur

- The meiotic crossing over takes place during the pachytene stage of the prophase of meiosis –I. Pachytene stage is also known as recombination stage. Crossing over occurs when homologus chromosomes are in the four chromatid or tetrad stage in pachytene.



Types of crossing over

- It is mainly two types
- Somatic or mitotic crossing over.
- Germinal or meiotic crossing over. It is further divided into two types
- **Equal crossing over**
- **Unequal crossing over**

Somatic or mitotic crossing over

- This type of crossing over occurs in the somatic cells during mitosis.
- It is rare and has no genetic significance.
- **Example- Curt Stern** reported it in the fruit fly and **Potnecorvo** noted it in the fungus *Aspergillus*

Germinal or meiotic crossing over

- This type of crossing over takes place in the germinal cells during meiosis that produces gametes.
- It is universal and has a great genetic significance.

Kinds of Germinal crossing over

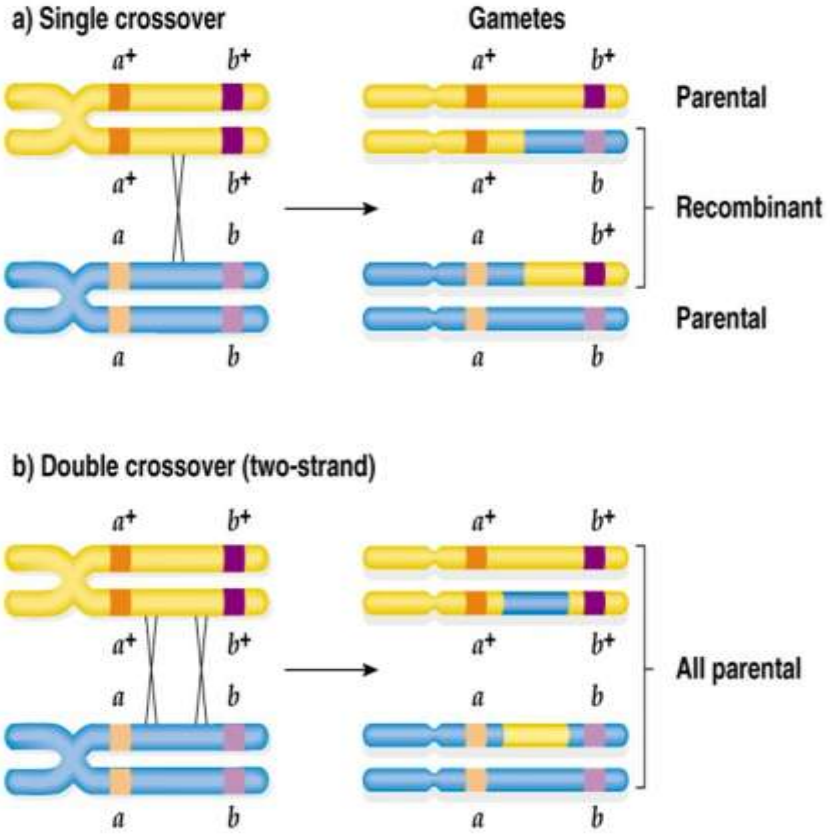
- (A) **Equal crossing over** :- The segments exchanged between the chromosomes are of equal size. It is divided into three types according to the number of points at which it occurs.
  - **Single crossing over**
  - **Double crossing over**
  - **Multiple crossing over**

a) **Single crossing over** In this type of crossing over the chromatids break and reunite at one point only.

b) **Double crossing over** During this type of crossing over the chromatids break and reunite at two points in the same tetrad.

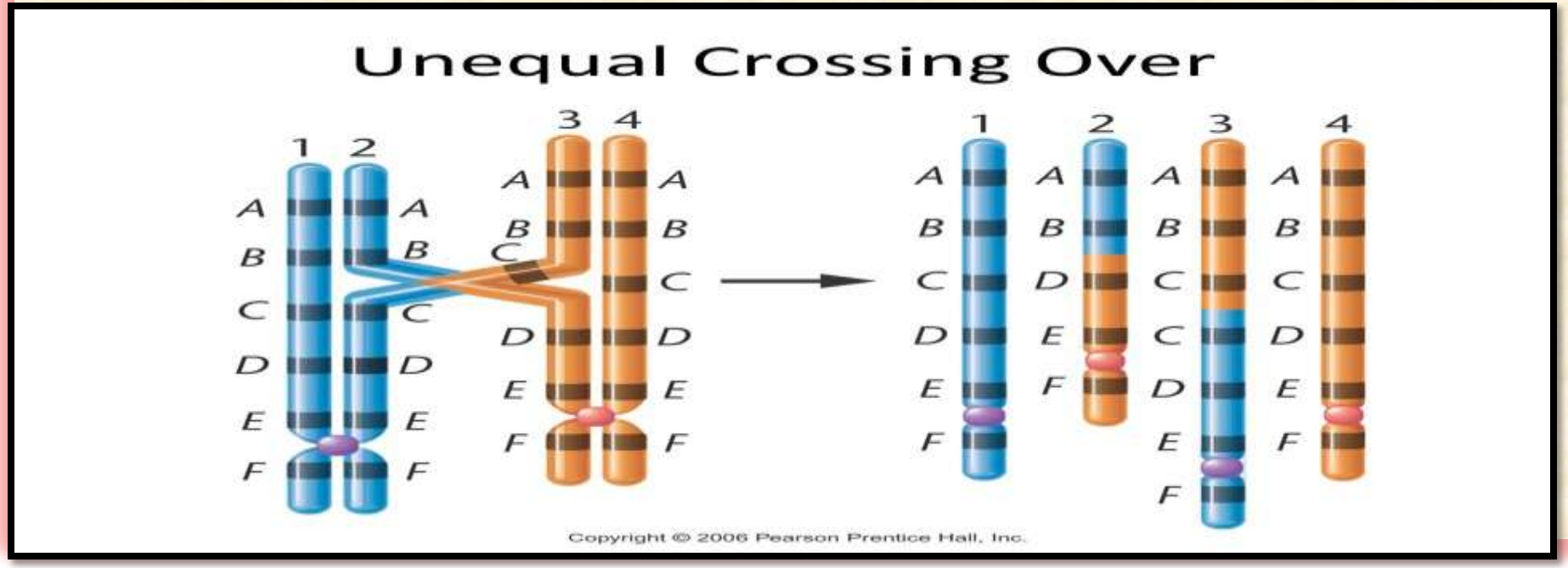
c) **Multiple crossing over**: In multiple crossing over, chromatid break and reunite at many points in the tetrad . It occurs rarely.

Progeny of single and double crossover



Unequal crossing over

- The segments exchange between chromatids are unequal so that one chromosome receives an extra gene, and other gets one gene less.

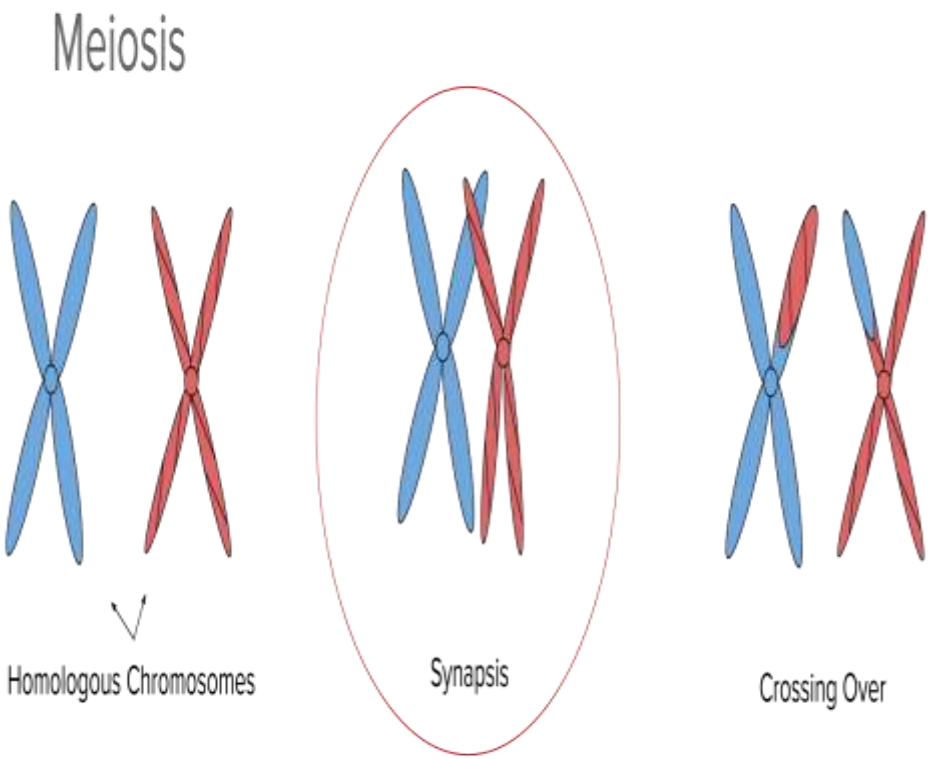


MECHANISM OF CROSSING OVER

I. Synapsis
II. Tetrad formation
III. Exchange of chromatid segments
IV. Terminalization

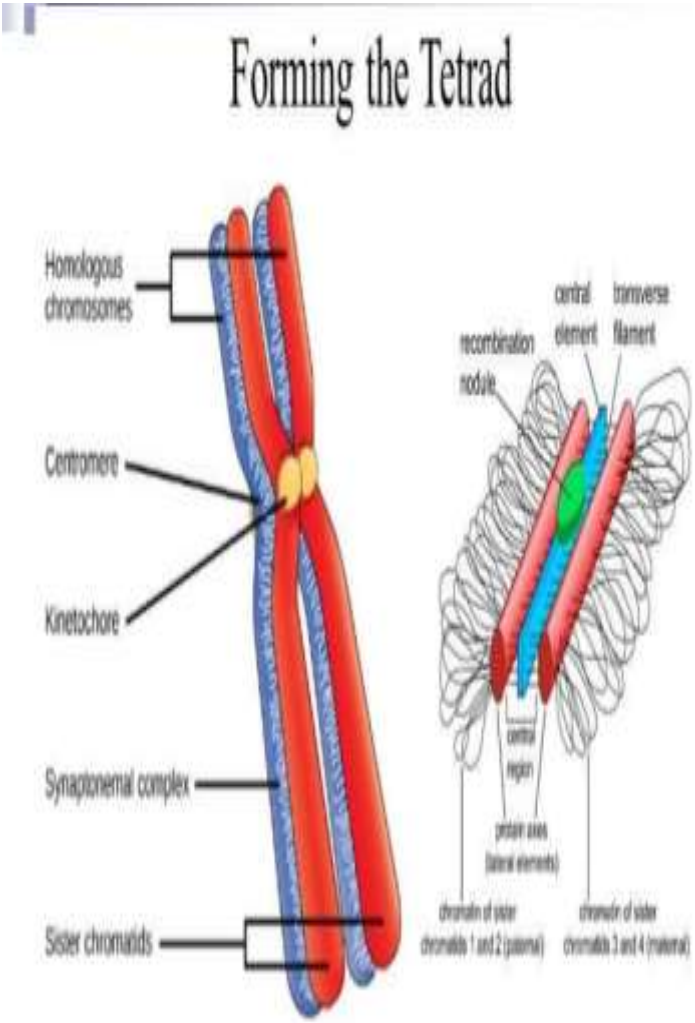
1.Synapsis

- In the **Zygotene** or pairing stage of prophase-I, the homologous chromosome of each pair come together and line up side by side. This pairing of homologous chromosomes is called **synapsis**.



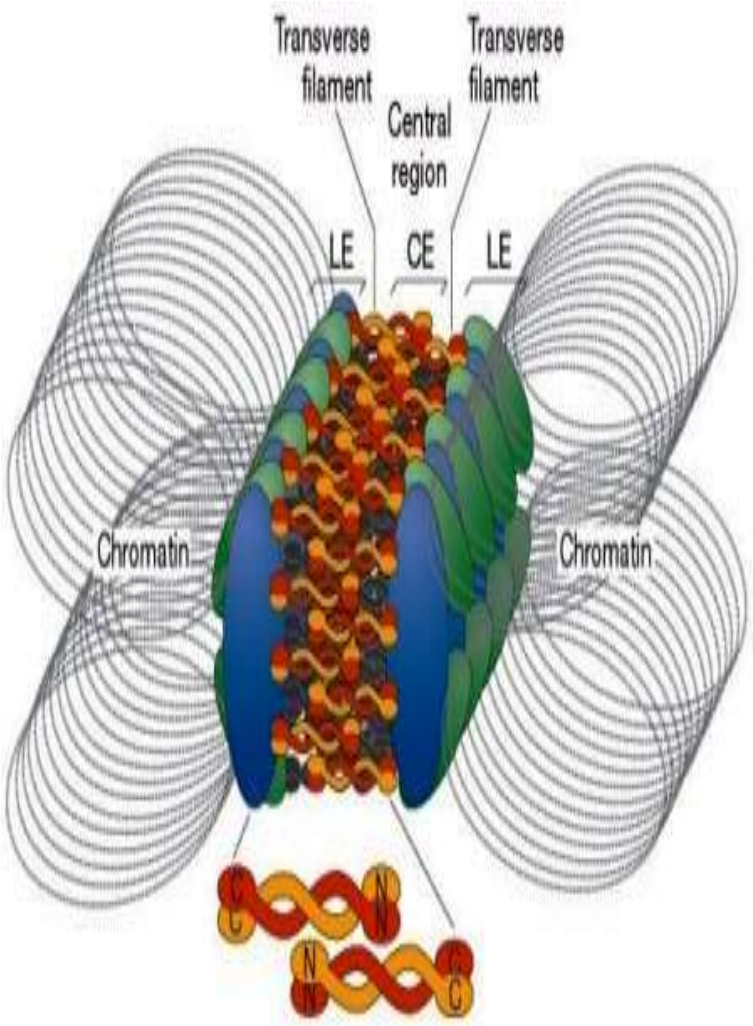
2.Tetrad formation

- The two chromatids of chromosome are referred to as **dyad**. A group of four homologous chromatids (two dyad) of two synapsed homologous chromosome is known as **tetrad**. The two chromatids of same chromosome are called **sister chromatids**. The two chromatids, one of the one chromosome and other of its homologue, are termed **non-sister chromatids.**



Synaptonemal complex

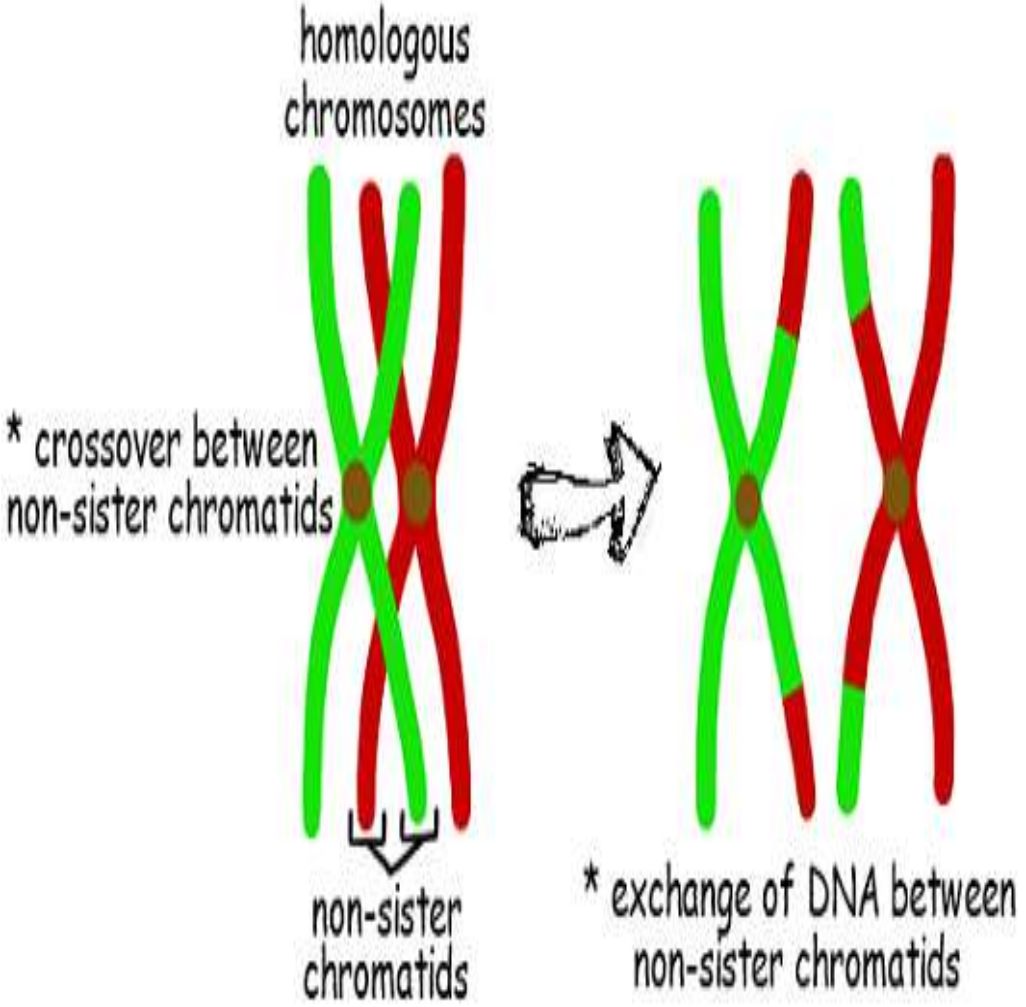
- A highly organized structure of filaments is formed between the paired homologous chromosome at the zygotene and pachytene stages of meiosis-I, the structure is called synaptonemal complex. It helps in crossing over by keeping the homologous chromosome in closely paired state.



3. Exchange of chromatid segments

- Two non sister chromatid in a tetrad break at equivalent locations.
- The broken ends transpose and join the respective broken ends of opposite chromatid.
- This complete the process of crossing over.
- The unchanged chromatids are called parental or non cross overs.
- The changed chromatids are called recombinants.

3. Exchange of chromatid segments



Physical breakage of chromatids into segments

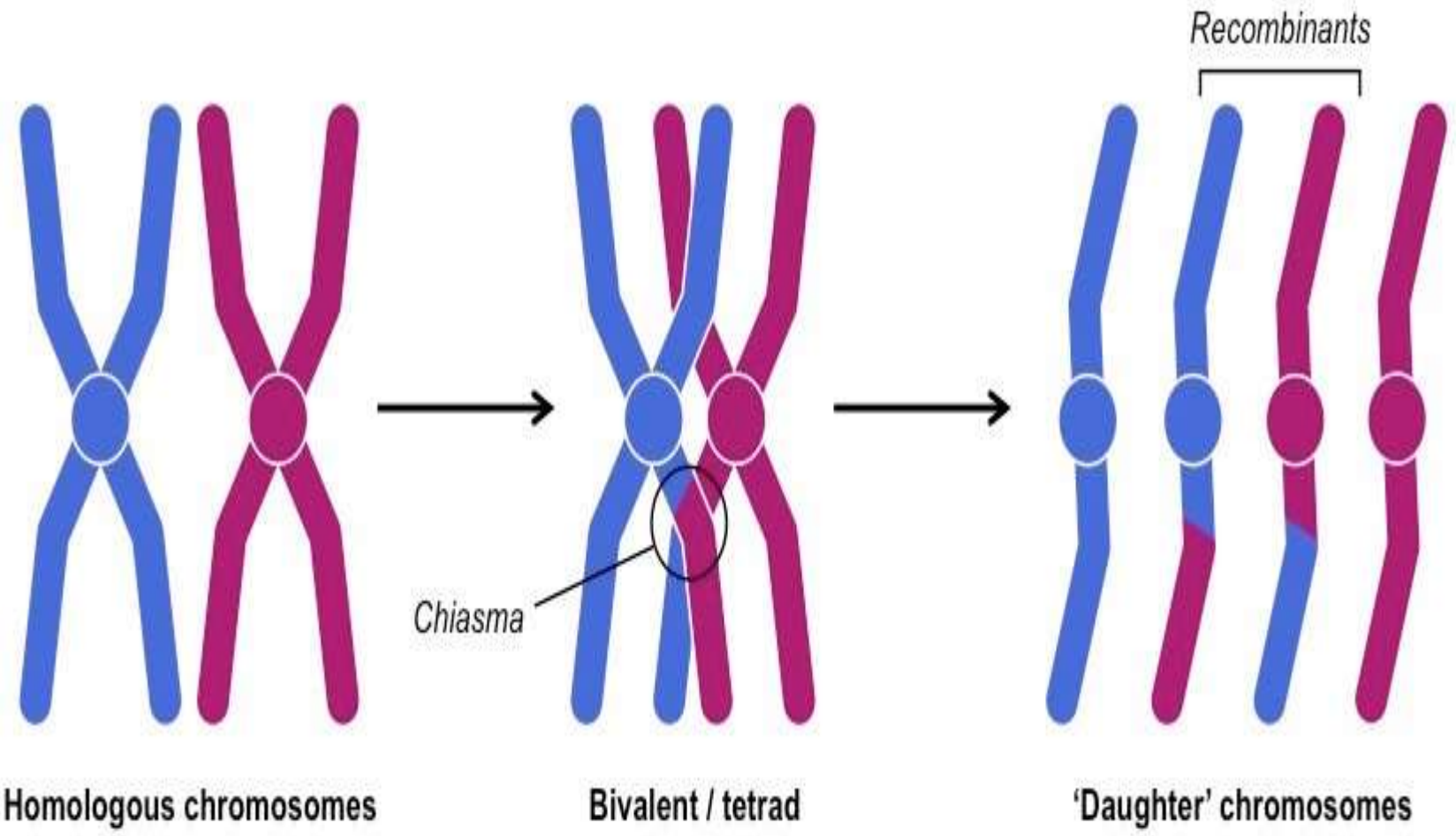
Transposition of segments

Reunion of segments

4.Terminalization

- Completion of crossing over marks the end of pachytene stage and beginning of diplotene stage.
- Synaptic forces end and the homologous chromosomes separate.
- The points at which the separation does not occur is called **chiasmata.**
- The chromatids separate progressively from the centromere towards the chiasma which moves like a zipper towards the end of tetrad.
- The slipping of chiasmata towards the ends of the bivalents is called terminalization.

Terminalization



Factors affecting crossing over

- Maternal age effect
- Temperature
- Nutritional and chemical effect
- Chromosomes effect
- Centromere effect
- Mutation effect
- Sex

Significance of crossing over

- Crossing over has helps in establishing the concept of liner arrangements of genes.
- The frequency of Crossing over helps in mapping of chromosomes i.e. determining the location of genes on the chromosomes.
- It is an important factor in sexual reproduction.
- It increases the variation which is vital for evolution.
- It helps in plant breeding also.

Difference between Linkage and Crossing over

Linkage	Crossing over
1. It keeps the genes together.	1. It leads to separation of linked genes.
2. It involves individual chromosomes.	2. It involves exchange of segments between non-sister chromatids of homologous chromosome.
3. The number of linkage groups can never be more than haploid chromosome number.	3. The frequency of crossing over can never exceed 50%.
4. It reduces variability	4. It increase variability by forming new gene combinations.

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Thank You