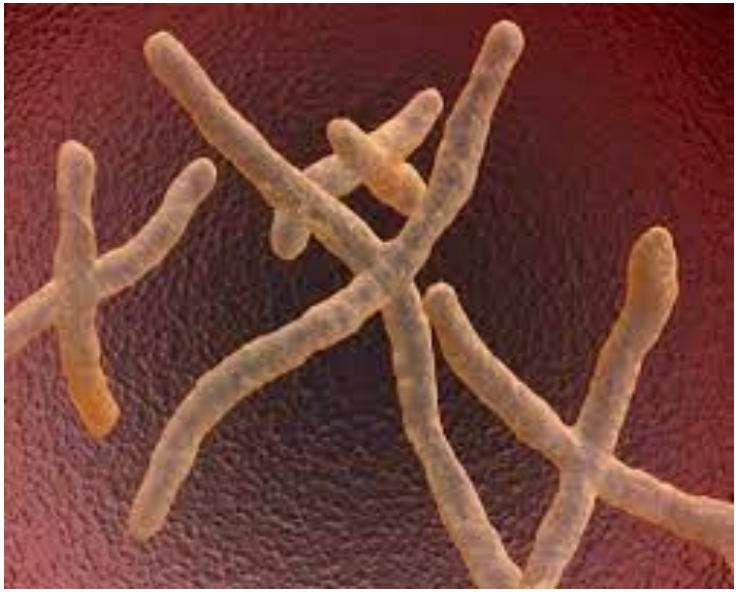
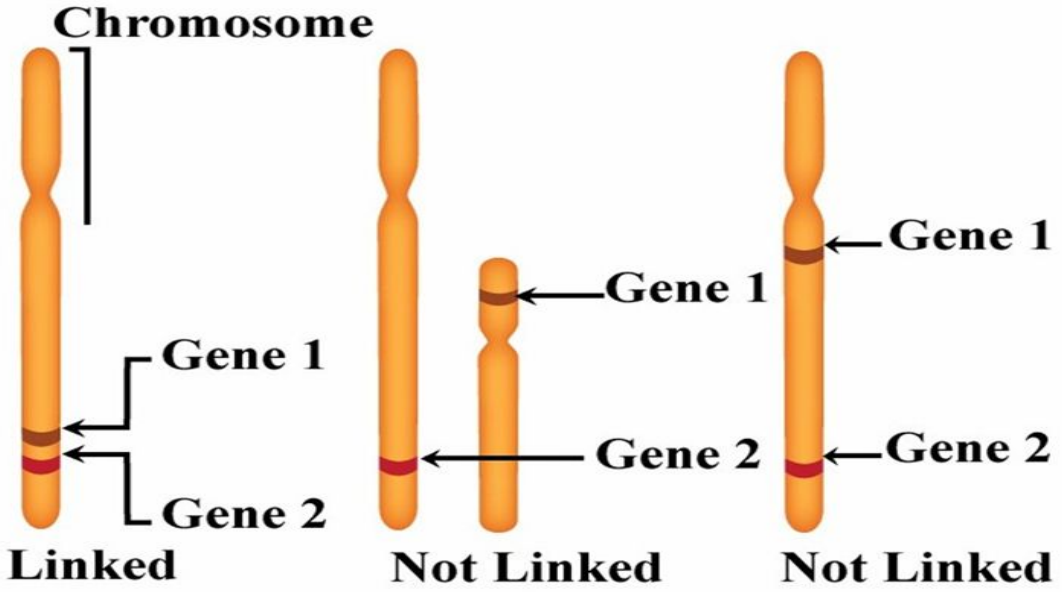
Linkage and Crossing Over



Introduction to Linkage

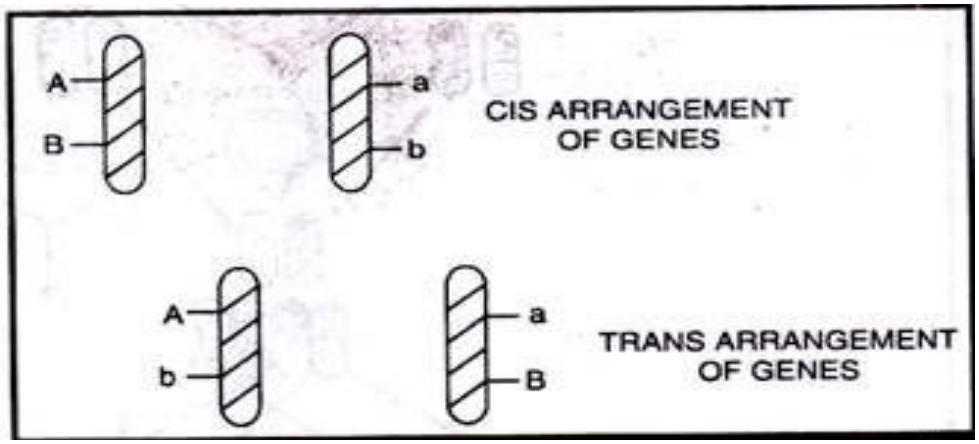
- *"Tendency of genes to remain together in their original combination during inheritance is called **linkage**"*

- The phenomenon of linkage was firstly reported by ***Bateson and Punnet*** in 1906



Characteristics of Linkage

- Genes that show linkage are situated in the same chromosome.
- Genes are arranged in a linear fashion in the chromosome i.e., **linkage of genes is linear.**
- The distance between the linked genes is inversely proportional to the strength of linkage
- The linked genes show two types of arrangement on the chromosome(Cis and trans arrangement).



Types of Linkage

- Linkage is generally classified on the basis of three criteria

(i) Crossing over

(ii) Genes involved and

(iii) Chromosomes involved

Types of Linkage: Based of Crossing over

- **Based on crossing over:** Linkage may be classified into
  (a) complete and (b) incomplete / partial linkage

(a) Complete linkage: It is known in case of males of *Drosophila* and females of silkworms, where there is complete absence of recombinant types due to absence of crossing over.

(b) Incomplete / partial linkage: If some frequency of crossing over also occurs between the linked genes, it is known as incomplete / partial linkage. Incomplete linkage has been observed in maize, pea, *Drosophila* female and several other organisms.

Types of Linkage: Based on genes involved

Based on genes involved : Depending on whether all dominant or some dominant and some recessive alleles are linked together, linkage can be categorized into (a) Coupling phase and (b) Repulsion phase

(a) Coupling phase: Dominant alleles present on the same chromosome and recessive alleles present on same chromosome shows coupling phase

TR	tr	
----	----	Coupling phase
TR	tr	

(b) Repulsion phase: Dominant alleles of some genes are linked with recessive alleles of other genes on same chromosome shows repulsion phase

Tr	tR	
----	----	Repulsion phase
Tr	tR	

Coupling (*cis*)

Repulsion (*trans*)

Types of Linkage: Based on chromosomes involved

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

(a) Autosomal linkage: It refers to linkage of those genes which are located in autosomes (other than sex chromosomes).

(b) Allosomal linkage / sex linkage: It refers to linkage of genes which are located in sex chromosomes i.e. either 'X' or 'Y' (generally 'X')

Linkage group,

Linkage group, in genetics, all of the genes on a single chromosome.

- **Maximum no of linkage group equal to Haploid set of chromosome**
- **In the case of humans, females have 23 linkage groups (22 pairs of autosomes and one pair of homologous sex chromosomes - XX)**

Name of organism	Linkage groups
Mucor	2
Drosophila	4
Sweet pea	7
Neurospora	7
Maize	10

Significance of Linkage:

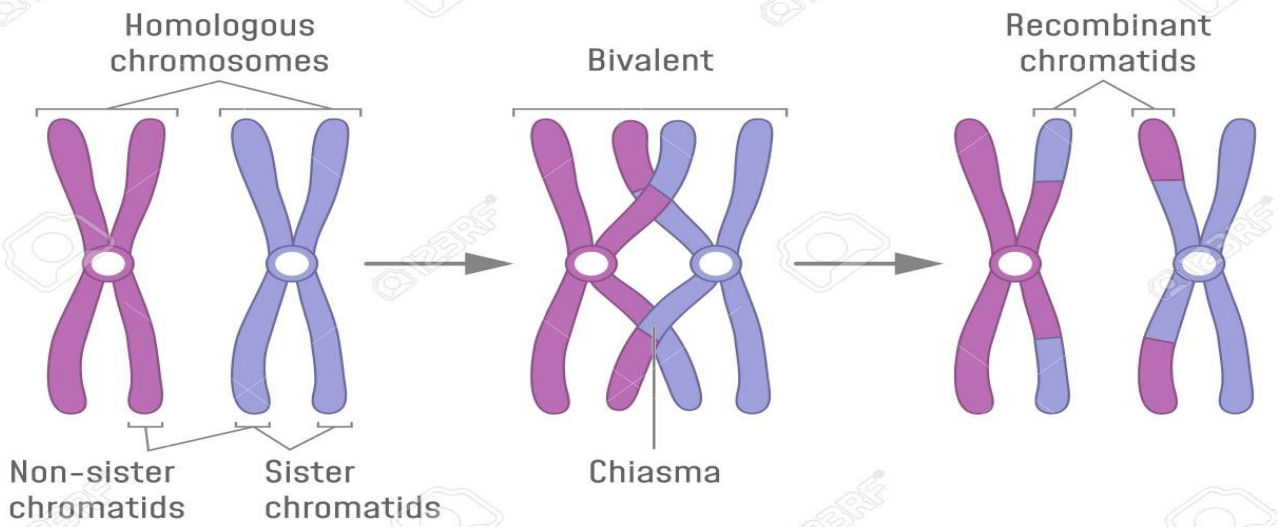
(i) Linkage ensures to keep the genes in a chromosome to inherit together.

(ii) Linkage plays an important role in determining the nature of scope of hybridization and selection programmes.

(iii) 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.

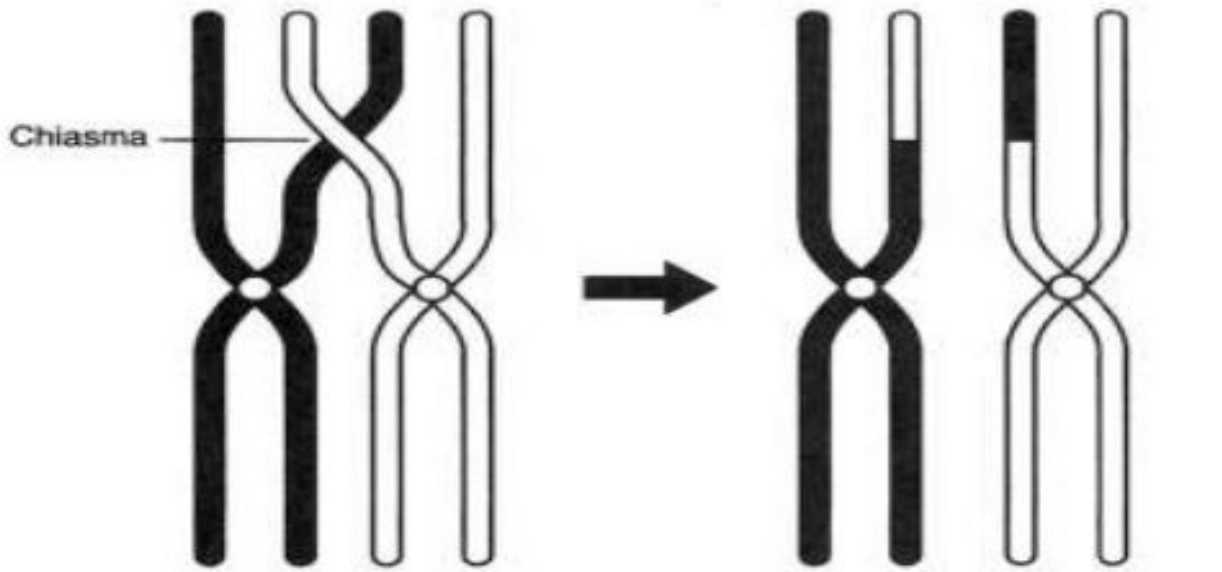
What is Crossing over?

- Crossing over is the exchange of segments between the non-sister chromatids of homologous chromosome.
- The term crossing over was coined by **Morgan.**
- It is the mutual exchange of segments of genetic material between non-sister chromatids of two homologous chromosomes, so as to produce re-combinations or new combinations of genes.
- It occurs in the meiosis-I (pachytene stage)



Chiasmata

- Chiasmata represents the site of crossing over.
- It is the point at which two homologous non-sister chromatids exchange genetic material.



Kinds of Crossing-over:

- **Depending upon the number of chiasmata appeared, kinds of crossing-over of can be**

(i) Single cross-over:

- In this case, only one chiasma is formed which leads to formation of single cross-over gametes. It is most common type of cross-over.

(ii) Double cross-over:

- In double cross-over, two chiasmata develop. These chiasmata may appear between the same chromatids or between different chromatids. This type of crossing over forms double crossing-over gametes.

(iii) Multiple cross-over:

- Here, 'more than two chiasmata are constituted. It may be further classified into triple (3 chiasmata), quadruple (4 chiasmata) and so on. Multiple crossing-over is of rare occurrence.

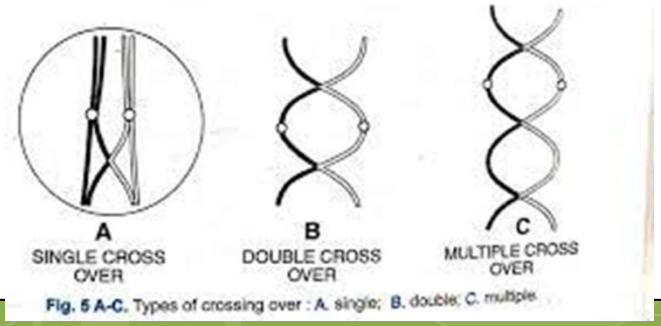
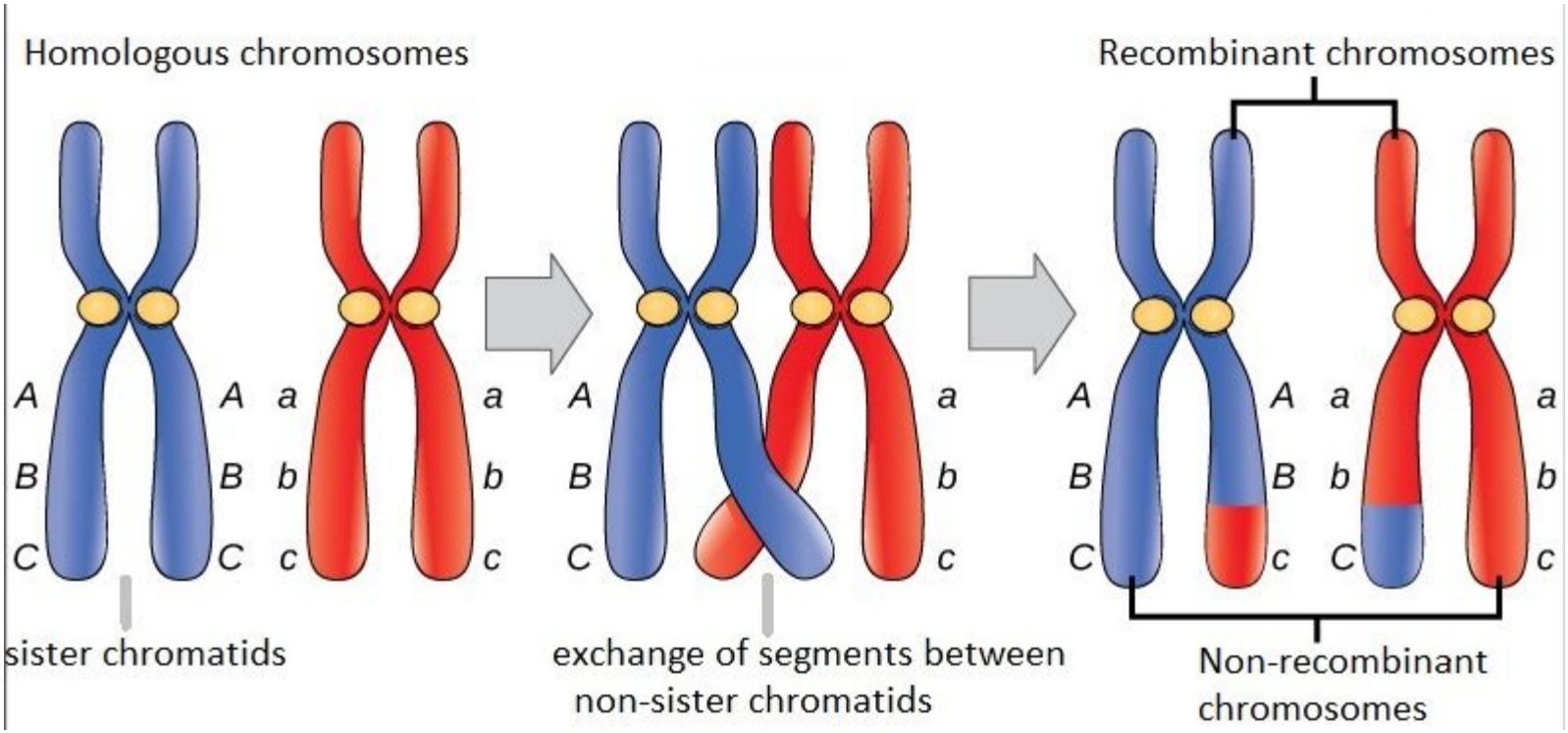


Fig. 5 A-C. Types of crossing over : A. single; B. double; C. multiple

Mechanism of Crossing over (molecular basis)

- **Stern and Hotta,(1969, 1978).** **There is breakage of chromatid segments, exchange of nonsister chromatid segments and later their fusion in new places.**



Cytological basis of crossing over

Cytological Evidence of Crossing Over:

(i) Crossing over occurs between homologous chromosomes. Such chromosomes are alike in appearance and it is not possible to distinguish between them in microscope.

(ii) During crossing over, the four chromatids are intimately coiled around one another.

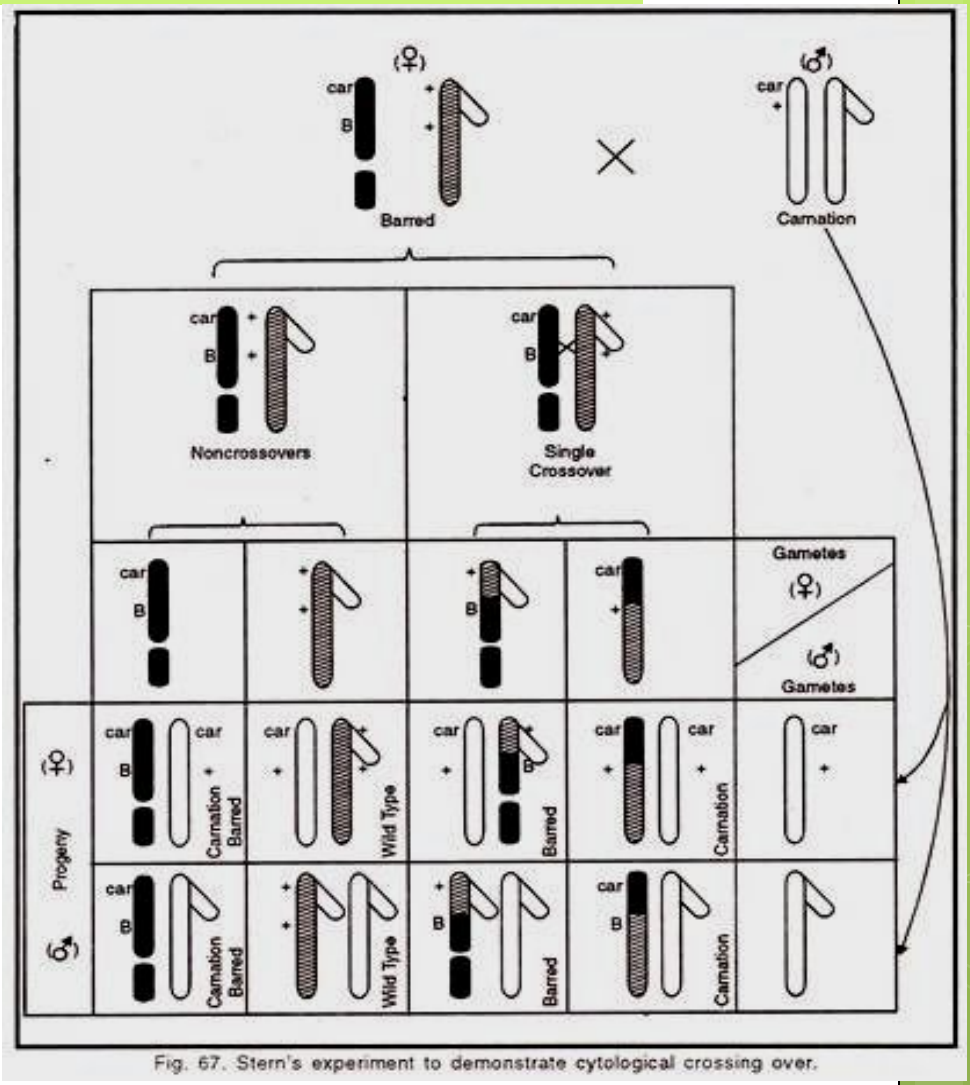


Fig. 67. Stern's experiment to demonstrate cytological crossing over.

Stern's experiment to demonstrate cytological crossing over.

Factors Influencing Crossing Over

- **Distance:** Nearer the genes lesser the recombination
- **Age:** Increase in age decreases the degree of crossing over in most of the cases.
- **Sex:** Male Drosophila shows little crossing over. The phenomenon of crossing over is quite common in the female fly.
- **X-Rays:** Exposure to X-rays increases the incidence of crossing over.
- **Temperature:** Variations in temperature increase the frequency of crossing over.
- **Chemicals:** A number of chemicals present in the food have been found to change the degree of crossing over in animals.

Significances Of Crossing Over

- Crossing over produces a **new combination of genes**
- Crossing over plays an essential role in the **process of evolution**
- Crossing over frequency helps in the **construction of genetic maps**
- Crossing over provides an **inexhaustible store of gene variability** in sexually reproducing organisms
- **Useful recombinations** are used by the plant and animal breeders.
- **Origin of new character**
  - Necessary for Natural selection. It increase the chance of variation

Green revolution has been achieved in India due to this selective picking up of useful re-combinations. Operation flood or white revolution is also being carried out on the similar lines.

Differences between crossing over and linkage

Crossing over	Linkage
It leads to separation of linked genes	It keeps the genes together
It involves exchange of segments between non-sister chromatids of homologous chromosomes	It involves individual chromosomes
The frequency of crossing **over can never exceed 50 %**	The number of linkage groups can never be more than **haploid chromosome number**
It increases variability by forming new gene combinations	It reduces variability
It provides equal frequency of parental and recombinant types in test cross progeny	It produces **higher frequency of parental types** than recombinant types in test cross progeny


Thank You!