

⇒ Chromosomal Basis of Inheritance

Mendel contribution in 1866

Monohybrid & Dihybrid cross

- law of dominance
- law of segregation
- law of independent assortment

But, his work on inheritance remain unchanged due to following reasons:

1. Communication was not easy.
2. His thought on factors (now called alleles) that control the expression of traits (characters) not accepted by his contemporaries.
3. Use of statistics based analysis to explain biological phenomena was totally new in those days.
4. Could not provide any physical proof for existence of factors. The location of these factors (chromosome locus point) was unknown to him.
5. In those days, role of nucleus in reproduction & existence of chromosomes in nucleus was not known.

In 1900, advanced highly magnified microscopes were developed by which scientist were able to carefully observe meiotic cell division.

In 1900, three scientists (de Vries, Correns and von Tschermak) independently rediscovered Mendel's results on the inheritance of characters.

⇒ Chromosomal Theory of Inheritance

- ↳ Chromosomal theory of inheritance was proposed by Walter Sutton & Theodore Boveri in 1902.
- ↳ It was experimentally proved by Morgan and his colleagues.
- ↳ The chromosomal theory of inheritance states that genes are located at specific loci on the chromosomes & it is the chromosomes which segregate (separate) & assort (distribute into groups of same kind) independently during meiosis & recombine at the time of fertilization in the zygote.

Salient features of chromosomal theory of inheritance :

1. Gametes (i.e. sperms & ova) constitute bridge betⁿ one generation & the next generation.
2. Both the sperm & egg contribute equally in the heredity of the offspring. The sperm provides only nuclear part to the zygote. There is fusion of egg nuclei & sperm during fertilisation.
3. Nucleus contains chromosomes. Therefore, chromosomes must carry the hereditary traits.
4. Every chromosome or chromosome pair has a definite role in the development of an individual.
5. Loss of a complete or part of the chromosome produces structural & functional deficiency in the organism.
6. Like the hereditary traits the chromosomes retain their number, structure & individuality throughout the life of an organism & from generation to generation.
7. Both chromosomes as well as genes occur in pairs in diploid cells.

8. The gamete contains only one chromosome of a type & only one of the two alleles of a character.
9. The paired condition of both chromosomes as well as genes is restored during fertilisation.
10. Genetic homogeneity & heterogeneity, dominance & recessiveness can be suggested by chromosomal type and behaviour.
11. In many organisms, sex of an individual is determined by specific chromosomes called sex chromosomes.

* Parallelism betⁿ Genes & Chromosomes

1. Both genes & chromosomes are transferred from generation to generation without any change.
2. In diploid cells, chromosomes occur in homologous pairs.
 - a. Genes also occur in allelic pairs.
 - b. One member of a pair is obtained from maternal parent & the other from the paternal parent.
3. Prior to cell division both chromosome & an allele of a gene get replicated.
 - a. During mitosis the replicated chromosome and replicated allele split which pass into the two daughter cells.
 - b. The process of replication & distribution maintains similarity in the genetic composition of the cells of a multicellular organism.
4. Both segregate (separate) during gamete formation (meiosis) so that a gamete receives only one chromosome & one allele of each pair.

5. Fusion of two haploid gametes restores the diploid chromosome no. & allelic pairs in the offspring.
6. Both chromosomes & alleles follow law of segregation.
7. Both genes & chromosomes show law of independent segregation.

⇒ Drosophila as Experimental material for Genetic Studies

Thomas Hunt Morgan (the father of experimental genetics) selected fruitfly *Drosophila melanogaster* (the Jackpot of Genetics) as experimental materials though it is small sized (2mm size) because of the following advantages in *Drosophila* over pea.

- 1] The flies can be reared inside bottles having yeast culture over synthetic medium containing cream of wheat, molasses & agar.
- 2] A new generation can be raised within 2 weeks with single mating producing hundreds of individuals.
- 3] There was a clear differentiation of the sexes - i.e. the male & female flies are easily distinguishable.
- 4] It has many types of hereditary variations that can be seen with low power microscopes.
- 5] These can be temporarily inactivated with ether & examined by hand lens / dissection microscope.
- 6] Breeding *Drosophila* is quite cheap. Further, it can be done throughout the year.

⇒ Contribution of Morgan in Genetics

Thomas Hunt Morgan, an American geneticist & Noble Prize winner of 1933, is considered as Father of Experimental Genetics for his work.

- Discovery of linkage
- Crossing over
- Sex linkage
- Criss cross inheritance
- Linkage maps
- Mutability of genes

He is called fly man of genetics because of selecting fruit fly (*Drosophila melanogaster*) as research material in experimental genetics.

It was largely due to his book, "The Theory of Gene" that genetics was accepted as a distinct branch of biology.

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LINKAGE

→ Linkage is the tendency of genes to stay together during inheritance through generations without any change or separation due to their being present on the same chromosome.

→ The genes located in the same chromosome are called linked genes and those present in different chromosomes are termed unlinked genes.

⇒ Discovery of Linkage

- ↳ Linkage was first discovered by Bateson and Punnett in 1906 in sweet pea (Lathyrus edaratus).
- ↳ However, it was Morgan (1910) who clearly proved and defined linkage on the basis of his breeding experiments in fruitfly Drosophila melanogaster.
- ↳ The term linkage was coined by Morgan.

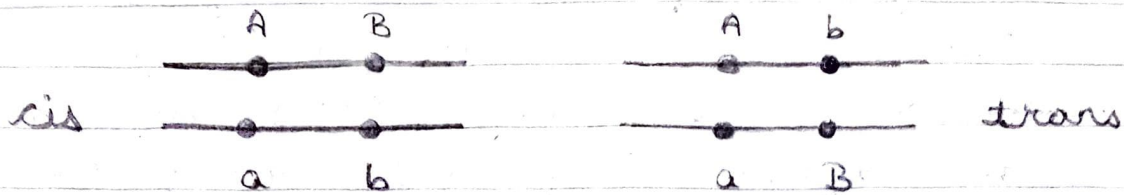
- Linkage is the tendency of genes to stay together during inheritance.
- Morgan defined linkage as physical association of genes.

⇒ Linkage Group

- A linkage group is a linearly arranged group of linked genes.
- The number of linkage groups in a given organism are equal to number of haploid sets of chromosomes.
- But in XX-XY type of organisms, number of linkage groups will be one more in male than in the female as in male X and Y both are different chromosomes.
- Eg. Pisum sativum has 7 linkage groups
 (7 chromosome pairs)

1. Fruitfly ~~ma~~ → 4 linkage groups
2. Human beings → 23 linkage groups
3. Neurospora → 7 linkage groups
4. Mucor → 2 linkage groups
5. Escherichia coli → 1 linkage group
6. Maize → 10 linkage groups

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Arrangement of linked genes

1. Cis arrangement - If dominant alleles of linked genes are present on one chromosome and recessive alleles on its homologous chromosome. In cis arrangement or coupling condition the incomplete linkage ratio will be $7:1:1:7$ (14 parental, 2 recombinants).
2. Trans arrangement - If dominant allele of one pair and recessive allele of second pair are present on one chromosome. In trans arrangement or repulsion case the ratio will be $1:7:7:1$ (2 parental, 14 recombinants).

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Types of Linkage

- a. Complete linkage - When genes remain together on the same chromosome for two or more generations, linkage is said to be complete. It is rare in nature.
Eg. eye colour & wing shape in male *Drosophila*.
- b. Incomplete linkage - When the genes present on same chromosome do not remain linked & separate due to crossing over, linkage is said to be incomplete. It is common in nature. Incompletely linked genes undergoes crossing over and produce recombinants.
Eg. eye colour & wing shape in female *Drosophila*.

Linkage & Recombination

- According to Mendel's law of independent assortment the gene controlling different characters gets assorted independent to each other.
- It is correct if the genes are present on two different chromosomes, but if these are present on same chromosome they may or may not show independent assortment.
- If crossing over takes place between these two genes then the genes get segregated and they will assort independent to each other.
- But if there is no crossing over between these two genes there is no segregation, hence only parental combination will be found in gametes.
- Morgan carried out several dihybrid crosses in *Drosophila* to study genes that were X-linked.
- The crosses were similar to the dihybrid crosses carried out by Mendel in peas.

Dihybrid crosses conducted by Morgan

- At first (cross A) he crossed yellow-bodied (y) and white-eyed (w) female with brown-bodied (y^+) and red-eyed (w^+) male.
- In the F_1 generation, he got brown-bodied red-eyed female and yellow-bodied white-eyed male.
- In F_2 generation, obtained by intercrossing of F_1 hybrids, the ratio deviated significantly from expected.
- He found 98.7% to be parental & 1.3% as recombinants.
- In a second cross (B) between white-eyed and miniature-winged female ($w w m m$) with wild red-eyed (w^+) normal-winged male (m^+) the F_1 generation included red-eyed normal-winged female & white-eyed miniature-winged male.

→ After intercrossing the F_1 progeny was found to be 62.8% parental and 37.2% recombinant type.

CHARACTER	Dominant trait/ Wild type	Recessive trait
Body colour	Brown body (y^+)	Yellow body (y)
Eye colour	Red eye (w^+)	White eye (w)
Wings	Normal (m^+)	Miniature (m)

→ In both of the crosses (A and B), he observed that the two genes did not segregate independently of each other and F_2 generation's ratio deviated very significantly from the 9:3:3:1 ratio.

→ Phenotypic ratio as 9:3:3:1 in F_2 generation is obtained in dihybrid cross if both genes are showing independent assortment.

→ Morgan and his group knew that the genes in both crosses were located on the X-chromosome (i.e. same chromosome).

→ In both crosses, Morgan found out that proportion of parental gene combination was much higher than the non-parental gene combinations.

F_2 generation	Cross A	Cross B
Parent type	98.7%	62.8%
Recombinant type (Non-parental type)	1.3%	37.2%

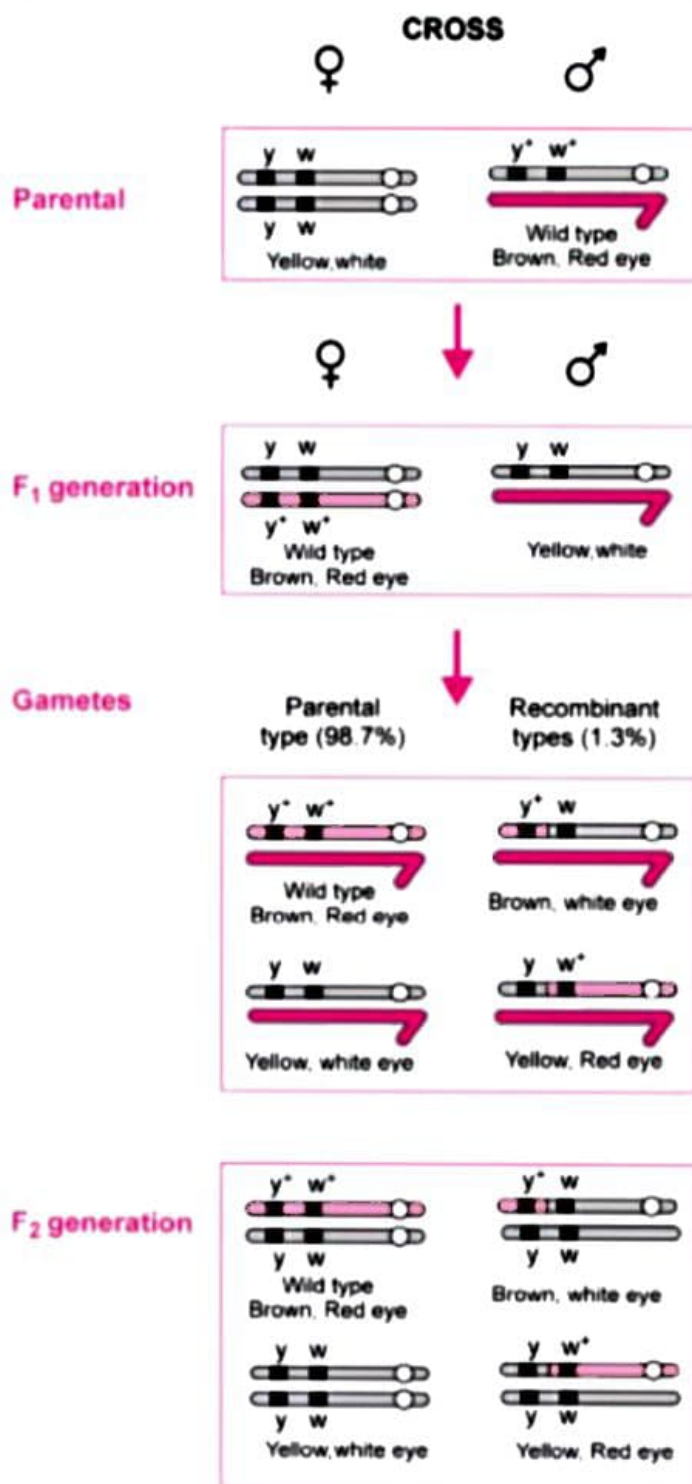


Fig. 5.33. Incomplete linkage in *Drosophila* showing recombination of genes for body colour and eye colour. Results of a dihybrid cross conducted by Morgan, showing cross between gene *y* and *w*. Here dominant wild type alleles are represented with (+) sign in superscript.

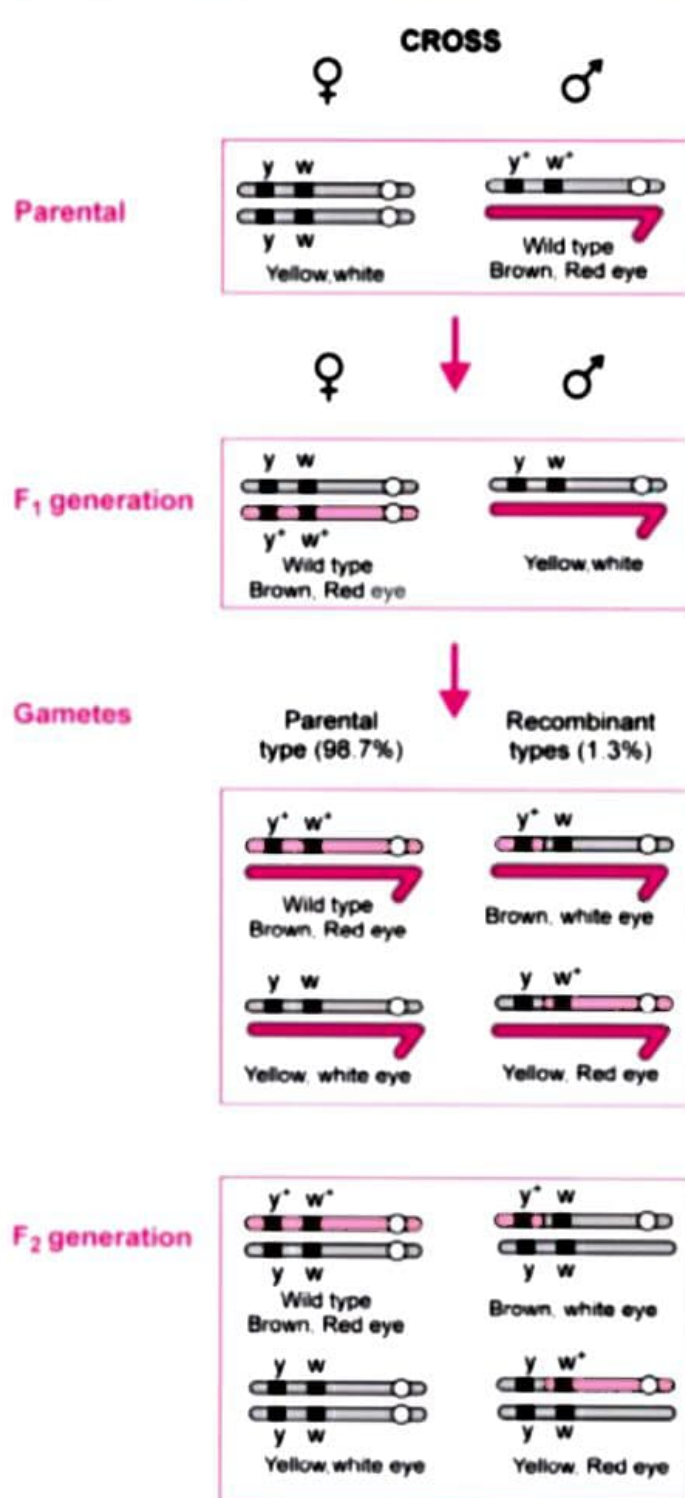


Fig. 5.34. Incomplete linkage in *Drosophila* showing recombination of genes for eye colour and wing size. Results of a dihybrid cross conducted by Morgan showing cross between gene *w* and *m*. Here dominant wild type alleles are represented with (+) sign in superscript.

The strength of linkage between *y* and *w* is higher than *w* and *m*.

→ Morgan attributed this due to the physical association of the two genes & coined the term linkage to describe this physical association of genes on same chromosome & the term recombination to describe the generation of non-parental gene combinations.

Cross A → low recombination (1.3%)
→ genes for white eye & yellow body were tightly linked

Cross B → high recombination (37.2%)
→ genes for white eye & miniature wing were loosely linked.

- Alfred Sturtevant (student of Morgan) used the frequency of recombination between gene pairs on the same chromosome as a measure of the distance between genes & mapped their position on the chromosome.
- Two genes show higher frequency of crossing over if the distance between them is higher and lower frequency if the distance is small.
- Today genetic maps are extensively used as a starting point in the sequencing of whole genome as was done in case of the Human Genome Sequencing Project.