CHAPTER - 5
PRINCIPLES OF INHERITANCE AND VARIATION

1. INTRODUCTION:

W.Bateson (1906) firstly used the term **'Genetics'.** He is known as **'father of modern genetics' Muller** established '**Cytogenetics**.

Father of genetics – Gregor Johann Mendel

Genetics: It is a branch of biology that deals with the study of heredity and variation.

OR

Genetics is a branch of biology which deals with principles of inheritance and its practices.

Genetics is also defined as study of genes.

Heredity: It is transmission of characters from parents to offspring.

Variations: It means the differences (Morphological, Physiological, and Anatomical) amongst the individuals of the same species and the offspring of the same parents.

- **H**umans knew from as early as 8000-1000 B.C. that one of the causes of variation was hidden in sexual reproduction.
- Human exploited the variations that were naturally present in the wild populations of plants and animals to selectively breed and select for organisms that possessed desirable characters.

  e.g., **Sahiwal** cows in Punjab (well-known Indian breeds) developed through artificial selection and domestication from ancestral wild cows.
- We must recognise that though our ancestors knew about the inheritance of characters and variation, they had very little idea about the scientific basis of these phenomena.
- Progeny resembling the parents in morphological and physiological features has attracted the attention of many biologists. Mendel was the first to study this phenomenon systematically.

2. MENDELISM:

2.1. Introduction of Mendel

Given by Gregor Johann Mendel - known as **'Father of Genetics'**

- Mendel born on 22 July 1822 in **Siflisia** village in **Heinzendorf state (Austria).**
- Mendel dead on 6 January 1884 due to Kidney disorder (Bright disease)
- Mendel passed graduation and joined Augustinian monastry of st. Thomas at Brunn (Then in Austria; Now Brno in Czech) as a **monk (Priest)**.
- Mendel performed **hybridization experiment** for seven years on garden Pea (*Pisum sativum*) from 1856 to 1863 and proposed the laws of inheritance in living organisms.
- Mendel studied 7 contrasting characters of pea and for that he selected 14 true-breeding pea plant varieties, as pairs which were similar except for one character with contrasting traits.
- After 7 years of experimentation he read out the results of his observations of the **Natural history society of Brunn** in 1865.

- The main research paper of **Mendel "Versuche Uber pflanzen Hybriden" or "Experiment on plant-hybridization"** was published in 1866. in **'Natureforschender varien'** magazine of German language.

NOTE: As per NCERT Mendel published his result in 1865.

2.2. Reason for delay in recognition of Mendel's work

- Mendel's work remained unrecognised till 1900 (**34 years)** due to following reasons.

(i) Firstly communication was not easy (as it is now) in those days and his work could not be widely publicised.

(ii) Secondly, his concept of genes (or factors, in Mendel's words) as stable and discrete units that controlled the expression of traits and, of the pair of alleles which did not 'blend' with each other, was not accepted by his contemporaries as an explanation for the apparently continuous variation seen in nature.

(iii) Thirdly, Mendel's approach of using mathematics to explain biological phenomena was totally new and unacceptable to many of the biologists of his time.

(iv) Finally, though Mendel's work suggested that factors (genes) were discrete units, he could not provide any physical proof for the existence of factors or say what they were made of.

(v) The scientific world was being rocked at that time by Darwin's theory of evolution (Origin of Species, 1859)

(vi) Mendel's conclusion about heredity were ahead of his time.

2.3. Reason's for Mendel's Success:

Many scientists worked on inheritance before Mendel **(like Kolreuter work on tobacco, Knight and Goss work on Pea)** but they did not succeed.

But Mendel get success because

(i) Mendel kept a complete record of every cross and used statistical analysis and mathematical logic to analyse number, data and results of experiment.

(ii) Mendel worked on large number of plants for same trait and obtained large number of offsprings thus his experiments had a large sampling size, which gave greater credibility to the data that he collected.

(iii) Mendel analyse results of his initial experiments and draw certain theoretical conclusions and later on the confirmation of his inferences from experiments on successive generations (up to F_3 generation) of his test plants, proved that his results pointed to general rules of inheritance rather than being unsubstantiated ideas.

(iv) Mendel took one or two characters at one time for his breeding experiment. Mendel investigated characters in the garden pea plant that were manifested as two opposing traits, e.g., tall or dwarf plants, yellow or green seeds. This allowed him to set up a basic framework of rules governing inheritance which was expanded on by later scientists to account for all the diverse natural observations and the complexity inherent in them

(v) He used emasculation and bagging techniques to ensure desired pollination.

(vi) Mendel selected the pea plant for experiment because-

(a) Pea plant is herbaceous and annual. It can be grown two or three time in a year so more number of generations can be studied within short time.

(b) It can be easily grown in garden.

(c) Many contrasting characters are found in pea plant. Mendel selected 7 pairs of contrasting traits of pea plant.

(d) Pea flowers are bisexual and naturally self (bud) pollinated so true breeding lines are easily available and Mendel conducted artificial pollination/cross pollination experiments using several true-breeding pea lines.

Note –

- Mendel selected 14 true-breeding pea plant varieties, as pairs which were similar except for one character with contrasting traits.
- A true-breeding line / pure line is one that, having undergone continuous self-pollination, shows the stable trait inheritance and expression for several generations.
- Among 7 contrasting traits of Mendel pod shape and plant height are closely present on 4^{th} chromosome (linked gene).

S.No.	Character	Dominant	Recessive	Chromosome number
1	Plant height	Tall (T)	Dwarf (t)	4
2	Position of flower	Axil (A)	Terminal (a)	4
3	Flower colour	Violet (V)	White (v)	1
4	Shape of pod	Inflated or Full (F)	Constricted (f)	4
5	Pod colour	Green (G)	Yellow (g)	5
6	Seed shape	Round (R)	Wrinkled (r)	7
7	Seed colour	Yellow (Y)	Green (y)	1

2.4. Re-discovery of Mendel's work:

It was in 1900 that three scientists independently rediscovered the principles of heredity already worked out by Mendel. They were **Eric von Tschermak of Austria, Hugo de Vries of Holland and Carl Correns of Germany.**

2.5. Terminology:

2.5.1 Factor:

Based on these observations, Mendel proposed that something was being stably passed down, unchanged, from parent to offspring through the gametes, over successive generations. He called these things as 'factors'.

- Mendel's factor are now called as gene.

  Gene: These are the units of inheritance (functional unit of inheritance). They contain the information that is required to express a particular trait in an organism.
- Gene are segment of DNA which have information of a particular function/enzyme.

2.5.2 Allele or Allelomorph:

Mendel proposed that the 'factors' (later named as genes) regulating the characters are found in pairs known as alleles.

- Genes which code for a pair of contrasting traits are known as alleles, i.e., they are slightly different forms of the same gene.
- Contrasting forms of a gene which are found on the same locus in the two homologous chromosomes & control the expression of a trait are called alleles.
- If we use alphabetical symbols for each gene, then the capital letter is used for the trait expressed at the F_1 stage (dominant trait) and the small alphabet for the other trait (recessive trait).
- For example, in case of the character of height, T is used for the 'Tall' trait and t for the 'dwarf', and T and t are alleles of each other. Hence, in plants the pair of alleles for height would be TT, Tt or tt.
- Alleles can be similar as in the case of homozygotes TT and tt or can be dissimilar as in the case of the heterozygote Tt.

2.5.3 Homozygous and Heterozygous:

Homozygous: It is an individual which contains identical alleles of a gene or factor of a character on its homologous chromosome **Eg: TT and tt.**

- Mendel also proposed that in a true breeding, tall or dwarf pea variety the allelic pair of genes for height are identical or homozygous, TT and tt, respectively.

Heterozygous: It is an individual which contains two different alleles of a gene on its homologous chromosomes. **Eg: Tt**

- The phenotype of the F_1 heterozygote is exactly like the dominant parent.

2.5.4 Phenotype and Genotype:

Phenotype: It represents the expression of external/morphological appearance like colour, shape etc. of an individual.

Eg: Red colour, Tallness or dwarfness etc.

- **Genotype:** It indicates the genetic constitution of an individual. **Eg: Pure tall - TT and Dwarf - tt.**
- TT and tt are called the genotype of the plant while the descriptive terms tall and dwarf are the phenotype.
- The factors (now known as gene) on chromosomes regulating the characters are called the **genotype** and the physical expression of the chraracters is called **phenotype**.
- **Johannsan** (1911) firstly used the term **Gene**, **Phenotype**, **Genotype** and **pure line.**
- **Bateson** coined terms allele, homozygous and heterozygous.

2.5.5 Phenocopy:

When the different genotypes produce the same phenotypes due to different environments, then one is called the phenocopy of the other **Eg: All seeds irrespective of their genotypes, germinating in dark develop yellow leaves.** Phenocopy is not inheritable. The term **phenocopy** was introduced by Goldschmidt in 1935.

2.5.6 Punnett square / Checker Board:

It was firstly developed by Reginald C. Punnett (British Geneticist).

- It is a graphical representation to calculate the probability of all possible genotypes of offspring in a genetic cross.

- The production of gametes by the parents, the formation of the zygotes, the F_1 and F_2 plants can be understood from a diagram called Punnett Square
- The possible gametes are written on two sides, usually the top row and left columns. Female gametes arrange vertically and male gametes arrange horizontally.
- All possible combinations (zygote) are represented in boxes below in the squares, which generates a square output / square tabular form.

3. HYBRIDISATION EXPERIMENT OF MENDEL:

3.1. Monohybrid cross: Inheritance of one gene.

- It is cross/hybridisation experiment between two organisms of a species that are different in a pair of contrasting traits of a character. **Eg: Height of pea plant.**

3.1.1 Steps in making a cross in pea

- Firstly Mendel selected true breeding tall (TT) and true breeding dwarf (tt) plants of garden pea as parent plant (P_1 and P_2)
- Mendel removed stamen from the flowers **(Emasculation)** of one plant (P_1) in bud condition to prevent self-pollination. A bag was then tied over the flowers to prevent undesirable cross -pollination **(Bagging).**
- On dehiscence or maturity, the pollen grains of P_2 plant were sprayed over the stigma of P_1 plant (cross pollination) and It was again covered with bag.
- He collected the seeds produced as a result of this cross and grew them to generate plants of the first hybrid generation.
  This generation is also called the **Filial$_1$ progeny** or the **F_1**.

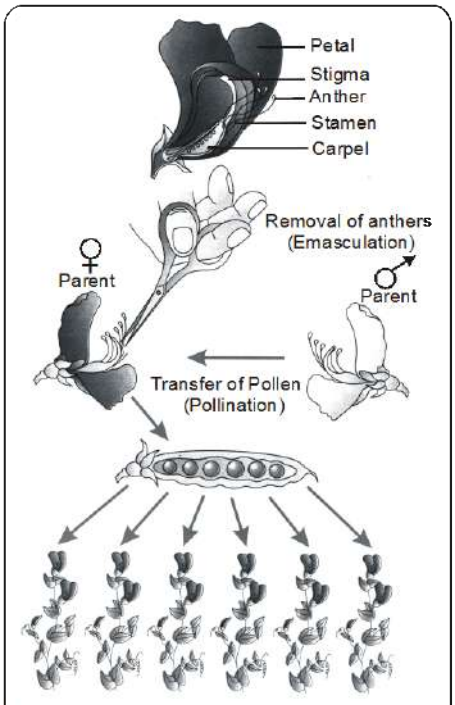


Fig : Steps in making a cross in pea

3.1.2 Mendel's observation

- Mendel observed that all the F_1 progeny plants were tall, like one of its parents; none were dwarf.
- He made similar observations for the other pairs of traits – he found that the F_1 always resembled either one of the parents, and that the trait of the other parent was not seen in them.

- Mendel then self-pollinated the tall F_1 plants and to his surprise found that in the Filial$_2$ generation some of the offspring were 'dwarf'; the character that was not seen in the F_1 generation was now expressed.
- The proportion of plants that were dwarf were 1/4th of the F_2 plants while 3/4th of the F_2 plants were tall.
- Similar results were obtained with the other traits that he studied: only one of the parental traits was expressed in the F_1 generation while at the F_2 stage both the traits were expressed in the proportion 3:1.
- The tall and dwarf traits were identical to their parental type and **did not show any blending**, that is all the offspring were either tall or dwarf, none were of in between height. The contrasting traits did not show any blending at either F_1 or F_2 stage.

3.1.3 Concept of segregation:

- From the observation that the recessive parental trait is expressed without any blending in the F_2 generation, we can infer that, when the tall and dwarf plant produce gametes, by the process of meiosis, the alleles of the parental pair separate or segregate from each other and only one allele is transmitted to a gamete.
- The results are so because each diploid individual contains two copies of every gene - one copy on each of the two homologous chromosomes.
- These homologous pair segregate at the time of meiosis so gametes have only one allele.
- This segregation of alleles is a random process and so there is a 50 per cent chance of a gamete containing either allele, as has been verified by the results of the crossings. In this way the gametes of the tall **TT** plants have the allele **T** and the gametes of the dwarf **tt** plants have the allele **t**.
- During fertilisation the two alleles, **T** from one parent say, through the pollen, and t from the other parent, then through the egg, are united to produce zygotes that have one T allele and one t allele.
- In other words the hybrids have **Tt**. Since these hybrids contain alleles which express contrasting traits, the plants are heterozygous.
- Pureline / homozygous ones contributed only one copy of their gene (as a result of meiosis) to their F_1 progeny to restore its diploid nature with genotype Tt (heterozygous).

3.1.4 Punnett square of monohybrid cross :

- The Punnett Square shows the parental tall **TT** (male) and dwarf **tt** (female) plants, the gametes produced by them and, the F_1 **Tt** progeny. The F_1 plants of genotype **Tt** are self-pollinated.
- The symbols ♀ and ♂ are used to denote the female (eggs) and male (pollen) of the F_1 generation, respectively.
- The F_1 plant of the genotype **Tt** when self-pollinated, produces gametes of the genotype **T** and **t** in equal proportion.
- When fertilisation takes place, the pollen grains of genotype **T** have a 50 per cent chance to pollinate eggs of the genotype **T**, as well as of genotype **t**. Also pollen grains of genotype **t** have a 50 per cent chance of pollinating eggs of genotype **T**, as well as of genotype **t**. As a result of random fertilisation, the resultant zygotes can be of the genotypes **TT**, **Tt** or **tt.**
- From the Punnet square it is easily seen that $1/4^{th}$ of the random fertilisations lead to **TT**, 1/2 lead to **Tt** and $1/4^{th}$ to **tt**.

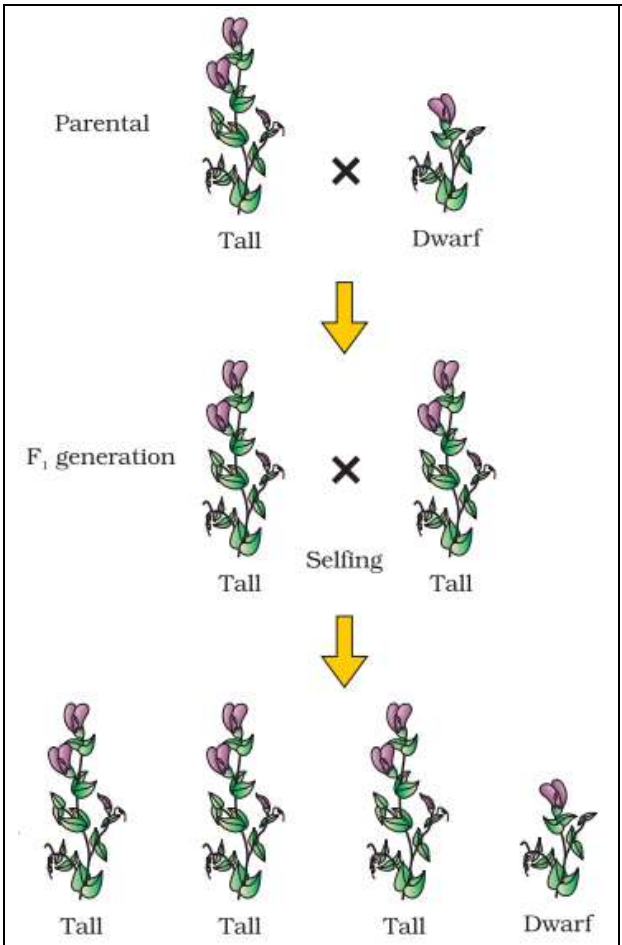


Fig. : Diagramatic representation of monohybrid cross

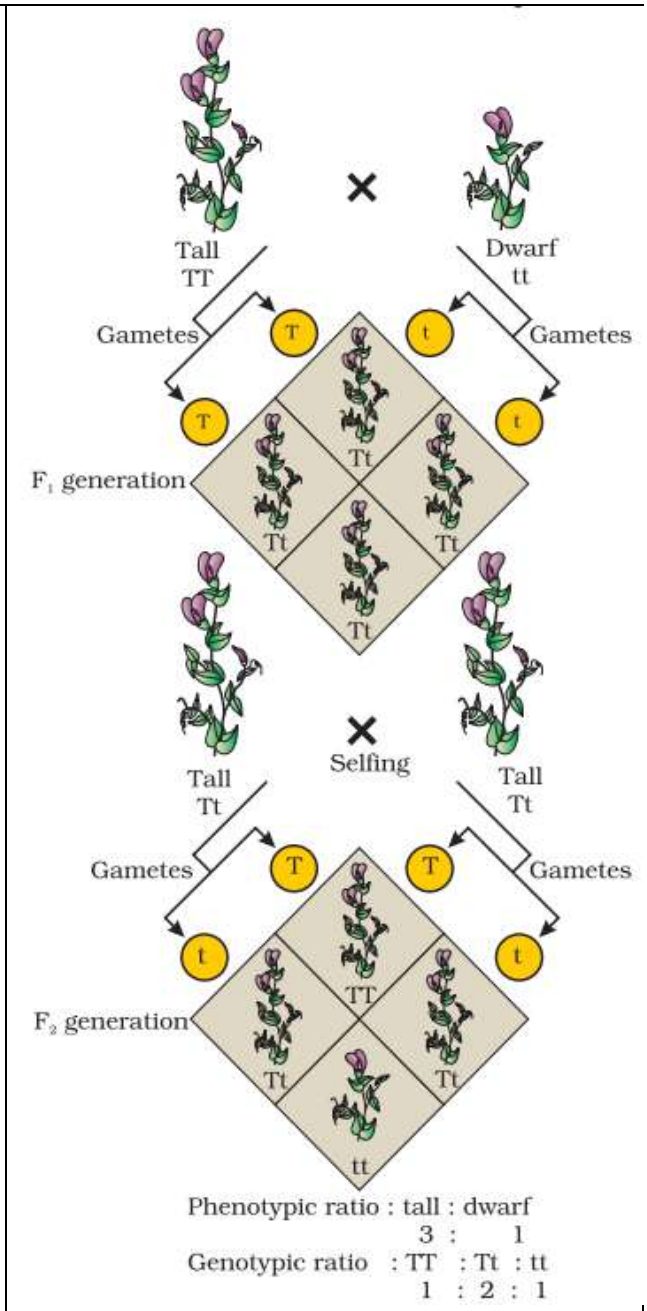


Figure : A Punnett square of monohybrid cross

- Though the F_1 have a genotype of **Tt**, but the phenotypic character seen is 'tall'. At F_2, $3/4^{th}$ of the plants are tall, where some of them are **TT** while others are **Tt**. Externally it is not possible to distinguish between the plants with the genotypes **TT** and **Tt**.
- Hence, within the genotypic pair **Tt** only one character '**T**' tall is expressed. Hence the character T or 'tall' is said to dominate over the other allele **t** or 'dwarf' character. It is thus due to this dominance of one character over the other that all the F_1 are tall (though the genotype is **Tt**) and in the F_2 $3/4^{th}$ of the plants are tall (though genotypically 1/2 are **Tt** and only 1/4th are **TT**).
- This leads to a phenotypic ratio of $3/4^{th}$ tall (1/4 TT + 1/2 **Tt**) and $1/4^{th}$ **tt, i.e., a 3:1 or 75% : 25% ratio, but a genotypic ratio of 1:2:1.**

- The 1/4 : 1/2 : 1/4 ratio of **TT**: **Tt**: **tt** is mathematically condensable to the form of the binomial expression $(ax + by)^2$, that has the gametes bearing genes **T** or **t** in equal frequency of ½. The expression is expanded as given below :

  $(1/2T + 1/2\ t)^2 = (1/2T + 1/2t)\ X\ (1/2T + 1/2t) = 1/4\ TT + 1/2\ Tt + 1/4\ tt$

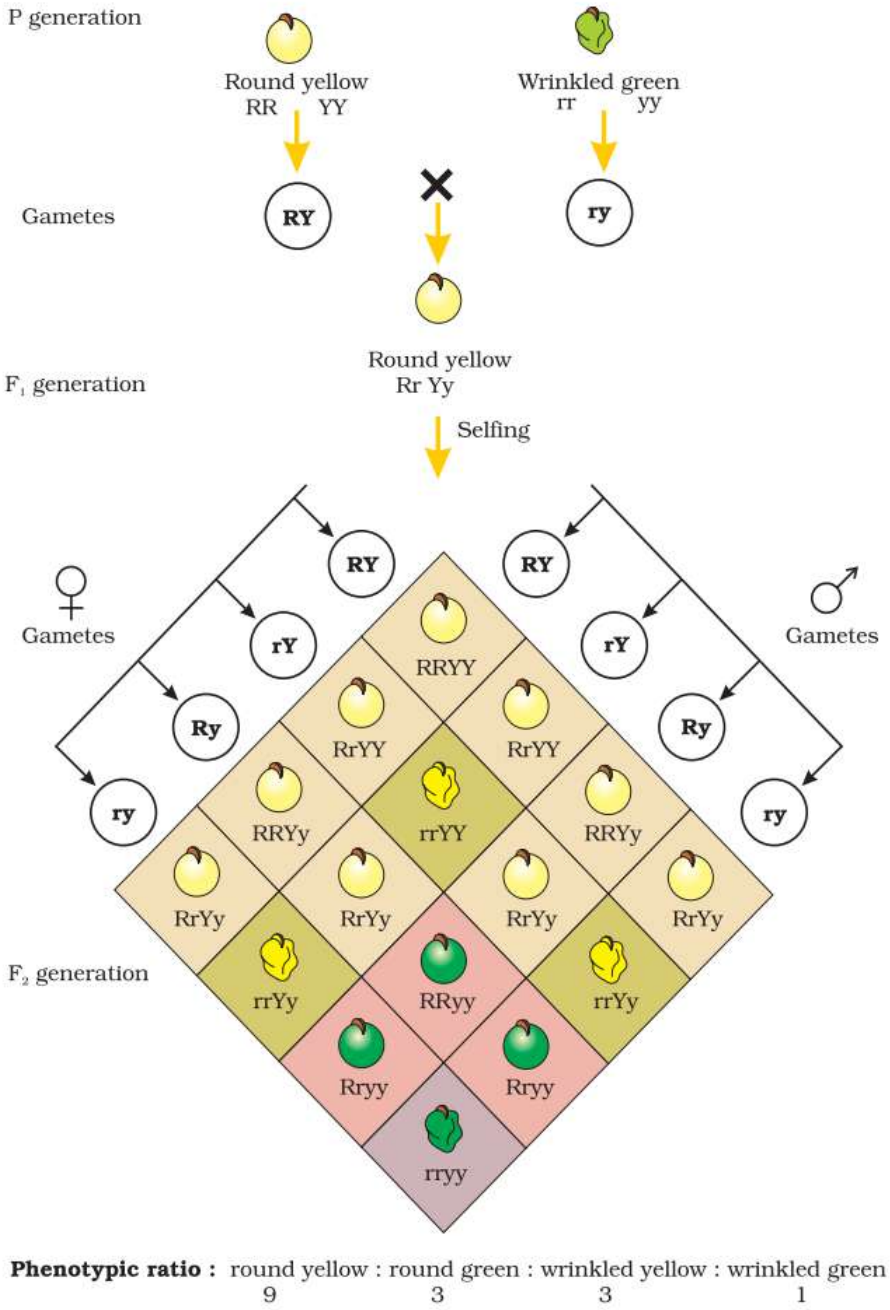
  Mendel self-pollinated the F_2 plants and found that dwarf F_2 plants continued to generate dwarf plants in F_3 and F_4 generations. He concluded that the genotype of the dwarfs was homozygous – **tt**.

3.1.5 Conclusion of monohybrid cross:

- Based on his observations on monohybrid crosses Mendel proposed two general rules to consolidate his understanding of inheritance in monohybrid crosses.
- Today these rules are called the **Principles or Laws of Inheritance:** the First Law or **Law of Dominance** and the Second Law or **Law of Segregation**.

3.2. Dihybrid cross:

- Mendel also worked with and crossed pea plants that differed in two characters (seed shape / seed colour), as is seen in the cross between a pea plant that has seeds with yellow colour and round shape **(RRYY)** and one that had seeds of green colour and wrinkled shape **(rryy)**.
- The gametes **RY** and **ry** unite on fertilisation to produce the F_1 hybrid **RrYy**.
- Mendel found that the seeds (F_1) resulting from the crossing of the parents, had yellow coloured and round shaped seeds.
- Thus, yellow colour was dominant over green and round shape dominant over wrinkled.
- These results were identical to those that he got when he made separate monohybrid crosses between yellow and green seeded plants and between round and wrinkled seeded plants.
- When Mendel self-hybridised the F1 plants he found that 3/4th of F_2 plants had yellow seeds and 1/4th had green. The yellow and green colour segregated in a 3:1 ratio. Round and wrinkled seed shape also segregated in a 3:1 ratio; just like in a monohybrid cross.
- In the dihybrid cross, the phenotypes round, yellow; wrinkled, yellow; round, green and wrinkled, green appeared in the ratio 9:3:3:1. Such a ratio was observed for several pairs of characters that Mendel studied.
- The ratio of 9:3:3:1 can be derived as a combination series of 3 yellow: 1 green, with 3 round: 1 wrinkled. This derivation can be written as follows: (3 Round : 1 Wrinkled) (3 Yellow : 1 Green) = 9 Round, Yellow : 3 Wrinkled, Yellow: 3 Round, Green : 1 Wrinkled, Green



Phenotypic ratio : round yellow : round green : wrinkled yellow : wrinkled green
9 3 3 1

Genotypic ratio	1	:	2	:	2	:	4	:	1	:	2	:	1	:	2	:	1
	YYRR		YYRr		YyRR		YyRr		YYrr		Yyrr		yyRR		yyRr		yyrr

Fig. Dihybrid cross

4. LAWS OF MENDEL

4.1. Law of Dominance

(i) Characters are controlled by discrete units called factors.

(ii) Factors occur in pairs.

(iii) In a dissimilar pair of factors one member of the pair dominates (dominant) the other (recessive).

- In heterozygous (Tt) where only one form (allele) is expressed (dominant) and the other form (allele) is not expressed (recessive). This is the phenomenon of Dominance
- **The law of dominance is used to explain the expression of only one of the parental characters in a monohybrid cross in the F_1 and the expression of both in the F_2. It also explains the proportion of 3:1 obtained at the F_2.**

4.2. Law of Segregation

- Though the parents contain two alleles during gamete formation, the factors or alleles of a pair segregate from each other such that a gamete receives only one of the two factors.
- Of course, a homozygous parent produces all gametes that are similar while a heterozygous one (F_1) produces two kinds of gametes each having one allele with equal proportion. 50% having dominant allele, and the remaining 50% having recessive allele.
- These gametes undergo random fusion during fertilisation to produce the F_2 generation.
- This law is based on the fact that the alleles do not show any blending and that both the characters are reappeared / recovered as such in the F_2 generation though one of these is not seen at the F_1 stage.

Note :-

- Reappearance of recessive phenotype (dwarf trait) in F_2 generation verifies the law of segregation.
- It is commonly define as -
- The allele of a gene pair separate / segregate from each other at the time of gamete formation.

OR

- When alleles present together they do not contaminant each other i.e. they do not change the expression each other.
- Due to this, the gametes are always pure for their expression so this law is also called as law of purity of gametes.
- This ratio of 3:1 in the F_2 suggests that in the F_1 heterozygotes, the recessive allele does not get destroyed and remains only in the recessive (dormant) state to get an opportunity to express itself when it has separated from the influence of the dominant allele (Y). This is called Law of Segregation of the alleles.

4.3. Law of Independent Assortment

- Mendel studied the inheritance of two characters together and based upon his observations on **dihybrid crosses** (crosses between plants differing in two traits) Mendel found that the factors independently assort and combine in all permutations and combinations (commonly called as Law of Independent Assortment).
- The law states that 'when two pairs of traits are combined in a hybrid, segregation of one pair of characters is independent of the other pair of characters'. It means that genes of two different traits assort

independently to give a probability ratio equal to segregation probability ratio of the allele pair X segregation probability ratio of other allele pair, which comes to, (3:1) X (3:1) = 9 : 3 : 3 : 1.

1 Dihybrid cross = 2 Monohybrid crosses

- The Punnett square can be effectively used to understand the independent segregation of the two pairs of genes during meiosis and the production of eggs and pollen in the F_1 **RrYy** plant.
- Consider the segregation of one pair of genes **R** and **r**. Fifty per cent of the gametes have the gene **R** and the other 50 per cent have **r**. Now besides each gamete having either **R** or **r**, it should also have the allele **Y** or **y**.
- The important thing to remember here is that segregation of 50 per cent **R** and 50 per cent *r* is *independent* from the segregation of 50 per cent **Y** and 50 per cent **y**. Therefore, 50 per cent of the **r** bearing gamete has **Y** and the other 50 per cent has **y**. Similarly, 50 per cent of the **R** bearing gamete has *Y* and the other 50 per cent has **y**.
- Thus there are four genotypes of gametes (four types of pollen and four types of eggs). The four types are **RY**, **Ry**, *rY* and **ry** each with a frequency of 25 per cent or ¼th of the total gametes produced.
- When you write down the four types of eggs and pollen on the two sides of a Punnett square it is very easy to derive the composition of the zygotes that give rise to the F_2 plants.

Note:-

- This Law of Independent Assortment was later found to be true only for traits present on two different homologous pair of chromosomes, that is, the two are not linked together. The linked traits do not assort independently, rather they are inherited together (linked) except when crossing over separates them.
- It is quite likely that you may not find your data exactly in the expected ratio, instead almost approximate to it. The statistical significance of this deviation from the exact expected ratio due to probability can be checked using chi-square (χ^2) test.
- The occurence of four types of plants in the F_2 generation of dihybrid cross shows that the inheritance of seed colour (cotyledon colour) assorts independent to the inheritance of seed shape. This law is applicable to only those factors or genes which are either situated distantly on the same chromosome or occur on different chromosomes.

1. Find in correct statement

(1) Variation is the degree by which progeny differ from their parents.

(2) True breeding lines show stable trait inheritance.

(3) Mendel was the first to study heredity systematically.

(4) non-Homologus pair segregate at the time of meiosis so gametes have only one allele.

2. Complete the sentences –

(a) Mendel selected _____ true-breeding pea plant varieties, as pairs which were similar except for one character with contrasting traits.

(b) Genes which code for a pair of contrasting traits are known as _____.

(c) The segregation of alleles is a random process and so there is a _____chance of a gamete containing either allele.

(d) Characters are controlled by discrete units called _____.

3. Suggest one word for the following

(a) Unit of inheritance

(b) Different form of a gene

(c) Artificially selected Indian cow breed

(d) Square tabular form of possible combinations.

4. Which of the following is not a reason for mendel's success:

(1) Large sampling size

(2) Selection of pea plant

(3) Simultaneous study of all character

(4) Use of mathematics & statistics

5. Which cross produce highest number of dwarf plants

(1) TT x Tt (2) TT x tt (3) Tt x Tt (4) Tt x tt

Ans. 1. (4)

2. (a) 14, (b) Allele, (c) 50 per cent, (d) Factor

3. (a) Gene, (b) Allele, (c) Sahiwal, (d) Punnett square

4. (3) **5.** (4)

Ans. 1. (4)

2. (a) 14, (b) Allele, (c) 50 per cent, (d) Factor

3. (a) Gene, (b) Allele, (c) Sahiwal, (d) Punnett square

4. (3) **5.** (4)

5. EXCEPTIONS OF PRINCIPLES OF DOMINANCE AND PAIRED FACTORS:

Not all characters show true dominance. Some characters show incomplete, and some show co-dominance.

5.1. Incomplete dominance:

- Incomplete dominance was discovered by **Carl Correns in *Mirabilis jalapa* (also known as 4 O'clock plant or Gulbansi)**
- When experiments on peas were repeated using other traits in other plants, it was found that sometimes the F_1 had a phenotype that did not resemble either of the two parents and was in between the two.
- The inheritance of flower colour in the dog flower (snapdragon or *Antirrhinum sp.*) is a good example to understand incomplete dominance.

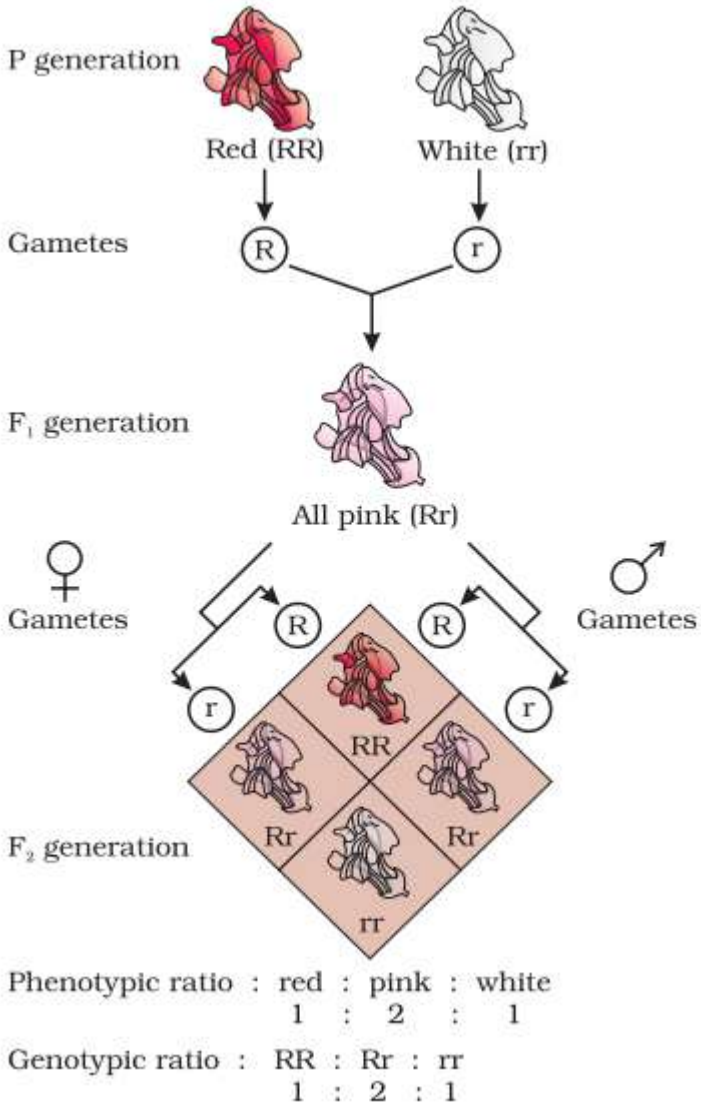


Fig. Incomplete dominance in snapdragon

- In a cross between true-breeding red-flowered **(RR)** and truebreeding white-flowered plants **(rr)**, the F_1 **(Rr)** was pink (new phenotype obtained).
- When the F_1 was self-pollinated the F_2 resulted in the following ratio –

Phenotype and Genotype ratio - 1 (RR) Red: 2 (Rr) Pink: 1 (rr) White

- Here the genotype ratios were exactly as we would expect in any Mendelian monohybrid cross, but the phenotype ratios had changed from the 3:1 dominant : recessive ratio.
- Different phenotype ratio obtained because R was not completely dominant over r and this made it possible to distinguish Rr as pink from RR (red) and rr (white).
- **The phenotypic and genotypic ratio is similar (1 : 2 : 1) due to incomplete dominance in F_2 generation.**
- Other examples of incomplete dominance - **feather colour in Andulasian fowls**, Flower colour in ***Mirabilis jalapa.***

5.2. Co-dominance:

- Till now we were discussing crosses where the F_1 resembled either of the two parents (dominance) or was in-between (incomplete dominance). But, in the case of co-dominance the F_1 generation resembles both parents.

AB blood group :

- A good example is different types of red blood cells that determine ABO blood grouping in human beings. ABO blood groups are controlled by the gene *I*.
- The plasma membrane of the red blood cells has sugar polymers that protrude from its surface and the kind of sugar is controlled by the gene (*I*).
- The gene (*I*) has three alleles I^A, I^B and *i*. The alleles I^A and I^B produce a slightly different form of the sugar while allele *i* does not produce any sugar.
- Because humans are diploid organisms, each person possesses any two of the three *I* gene alleles. I^A and I^B are completely dominant over *i*, in other words when I^A and *i* are present only I^A expresses (because *I* does not produce any sugar), and when I^B and *i* are present I^B expresses. But when I^A and I^B are present together they both express their own types of sugars : this is because of co-dominance.
- Hence red blood cells have both A and B types of sugars.

Other examples of co-dominance - Sickle cell Haemoglobin, **Skin colour in Short Horned cattles**.

MN Blood Group.

Concept of dominance:

- Every gene, as you know by now, contains the information to express a particular trait.
- In diploid heterozygotic organism, the two alleles need not always be identical as some changes (mutation) modifies information that particular allele contains.
- Let's take an example of a gene that contains the information for producing an enzyme. Now there are two copies of this gene, the two allelic forms.

- More commonly the normal allele produce normal enzyme that is needed for for the transformation of a substrate (S) into product.
- Modified allele (mutant allele) could be responsible for production of

  (i) The normal/less efficient enzyme –

  - The modified allele is equivalent to the unmodified allele, i.e., it will produce the **same phenotype** or trait, i.e., result in the transformation of substrate S.
  - Such equivalent allele pairs are very common.

  (ii) a non-functional enzyme – Non-functional enzyme production.

  (iii) no enzyme at all – No enzyme production.
- But, if the allele produces a non-functional enzyme (ii) or no enzyme (iii), the phenotype may be affected. The phenotype/trait will only be dependent on the functioning of the unmodified allele.
- The unmodified (functioning) allele, which represents the original phenotype is the **dominant allele** and the modified allele is generally the **recessive allele** (mutant allele). Hence, in the example above the recessive / mutant trait is seen due to **non-functional enzyme (incomplete dominance)** or because **no enzyme (complete dominance)** is produced.

5.3. Pleiotropy:

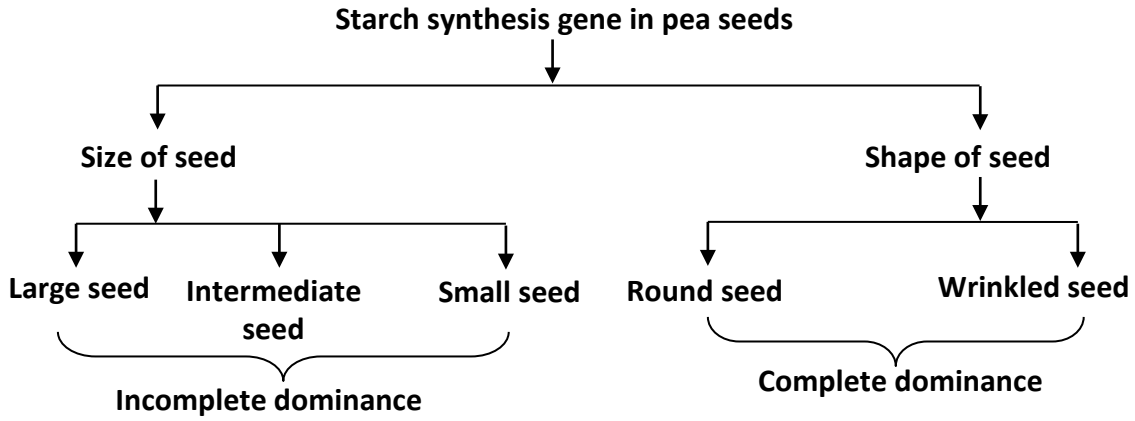
- Occasionally, a single gene product may produce more than one effect / phenotypic expressions such a gene is called a pleiotropic gene. **e.g.:** Phenylketonuria, Starch synthesis in pea seeds and Sickle cell anaemia.
- The underlying mechanism of pleiotropy in most cases is the effect of a gene on metabolic pathways which contribute towards different phenotypes.

Phenylketonuria:

- Deficiency of enzyme "phenyl alanine hydroxylase" (single gene mutation) produce multiple phenotypes like mental retardation, reduction in hair and skin pigmentation.

Starch synthesis gene:

- Starch synthesis in pea seeds is controlled by one gene. It has two alleles (B and b).
- Starch is synthesised effectively by BB homozygotes and therefore, large starch grains are produced. In contrast, bb homozygotes have lesser efficiency in starch synthesis and produce smaller starch grains.
- After maturation of the seeds, BB seeds are round and the bb seeds are wrinkled.
- Heterozygotes produce round seeds, and so B seems to be the dominant allele. But, the starch grains produced are of intermediate size in Bb seeds. So if starch grain size is considered as the phenotype, then from this angle, the alleles show incomplete dominance.



- Therefore, **dominance is not an autonomous feature of a gene** or the product that it has information for. It depends as much on the gene product and the production of a particular phenotype from this product as it does on the particular phenotype that we choose to examine, in case more than one phenotype is influenced by the same gene.

5.4. Multiple allele:

- In multiple allelism more than two, i.e., three (or more than three) alleles, governing the same character.
- Since in an individual only two alleles can be present, multiple alleles can be found only when population studies are made.
- Multiple alleles are located on same locus of homologous chromosome.

Eg: (i) Human Blood group - 3 alleles.

Table: Different aspects of blood group

Blood group	Antigen on surface of RBC	Antibody in Plasma	Genotype
A	A	b	$I^A I^A$, $I^A I^O$
B	B	a	$I^B I^B$, $I^B I^O$
AB	A, B both	Nill	$I^A I^B$
O	Nill	a, b both	$I^O I^O$

- A,B,O blood group are determined by allele I^A, allele I^B, allele I° respectively

  I^A = dominant I^B= dominant I° = recessive

  I^A and I^B are **codominant**.

- Since there are three different alleles, there are six different combinations of these three alleles that are possible, and therefore, a total of six different genotypes and four phenotypes of the human ABO blood types.
- In multiple allele the number of possible genotype = $\frac{n(n+1)}{2}$ (n – Number of alleles).

e.g. In human blood group number of alleles or **n** are 3. Thus the number of different possible genotype will be **=** $\frac{3(3+1)}{2} = \frac{3\times 4}{2}$ **6 genotypes.**

e.g. (ii) Coat colour in rabbit – Four alleles regulate coat colour in rabbit

Phenotype	Genotype	Allele type
Wild (Full colour or agouti)	CC', Cc^{ch}, Cc^{h} Cc	C
Chinchilla	$c^{ch}c^{ch}$, $c^{Ch}c^{h}$, $c^{ch}c$	c^{ch}
Himalayan	$C^{h}C^{h}$, $c^{h}c$	C^{h}
Albino	cc	c

Note: These alleles show a gradient in dominance C > c^{ch}> c^{h} > c

Number of possible genotypes = $\frac{4(4+1)}{2} = \frac{4\times5}{2} = 10$ genotypes.

1. A child has blood group O. If the father has blood group A and mother blood group B, work out the genotypes of the parents and the possible genotypes of the other offsprings.
2. Find odd comparison about flower colour inheritance of pea and antirrhinum.

   (1) Inheritance of flower colour in pea produce two phenotype in F_2 generation while inheritance of flower colour in Antirrhinum produce 3 phenotype in F_2 generation.

   (2) F_1 resemble one parent in pea & but F_1 of antirrhinum do not resemble to either parent.

   (3) In F_2 generation comparison of Pea plant and Antirrhinum, pea produce more dominant phenotype than antirrhinum but both produce equal recessive phenotype.

   (4) F_1 of pea do not show blending but F_1 of Antirrhinum show blending of character.

3. find incorrect statements-

   (a) Dominance is an autonomous feature of gene

   (b) In an individual only two allele can be present, multiple allele can be found only when population studies are made.

   (c) During inheritance of two genes, each gene segregate in 3:1 ratio.

   (d) Starch synthesis in pea seed is controlled by single gene but it produce seeds in three sizes large , intermediate & small due to presence of multiple allele

   (1) a & b (2) c & d (3*) a & d (4) a & c

4. If blood group of male is A and blood group of female is B and their first child is of O blood group then

   A. What is probability that their second child will have AB blood group.

   B. Which blood group is not possible in progeny of this couple.

   C. Presence of which blood group in children confirms the heterozygous nature of both parents.

5. What will be number of classes of phenotypes in the F_2 generation of a cross between -

   A. Dihybrid involving both the genes with incomplete dominance.

   B. Dihybrid involving both the genes with complete dominance.

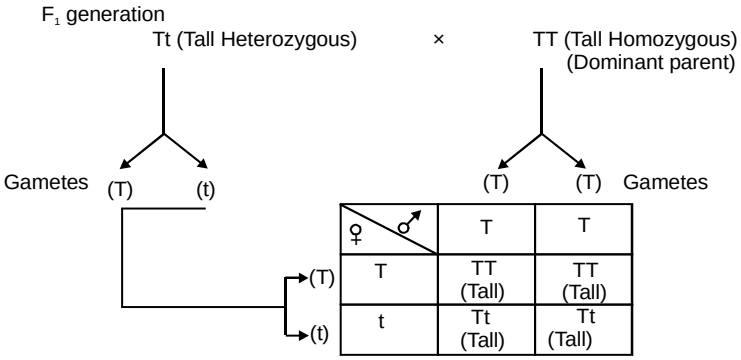
Ans. 1. Genotype of parent – $I^A I^O$ and $I^B I^O$ Genotype of offsprings - $I^A I^B$, $I^A I^O$, $I^B I^O$, $I^O I^O$

2. (4) **3.** (3) **4.** A -25%, B – None, C- O **5.** A- 9, B - 4

5.5. Back cross and Test cross:

5.5.1 Back cross

- It is a cross which is performed between F_1 hybrid and one of its parents.
- If cross is performed between F_1 hybrid and dominant parent then it is called **'Out cross'** All the offsprings obtain from this cross have dominant characters. Thus F_1 generation can be analized through this cross.



(i) Phenotypic ratio = 100% (Tall plants)

(ii) Genotypic ratio = 1 : 1

TT Tt

(Homozygous Tall) (Heterozygous Tall)

5.5.2 Test cross:

- Cross is performed between F_1 hybrid and recessive parent. It is a cross to know whether an individual is homozygous or heterozygous for dominant character.
- As the genotypic ratios can be calculated using mathematical probability, by simply looking at the phenotype of a dominant trait, it is not possible to know the genotypic composition.
- That is, for example, whether a tall plant from F_1 or F_2 has TT or Tt composition, cannot be predicted. Therefore, to determine the genotype of a tall plant at F_2, Mendel crossed the tall plant from F_2 with a dwarf plant. This he called a test cross.
- In a typical test cross an organism (pea plants here) showing a dominant phenotype (and whose genotype is to be determined) is crossed with the recessive parent instead of self-crossing.
- The progenies of such a cross can easily be analysed to predict the genotype of the test organism.

(i) Monohybrid test cross:

Fig shows the results of typical test cross where violet colour flower (W) is dominant over white colour flower (w).

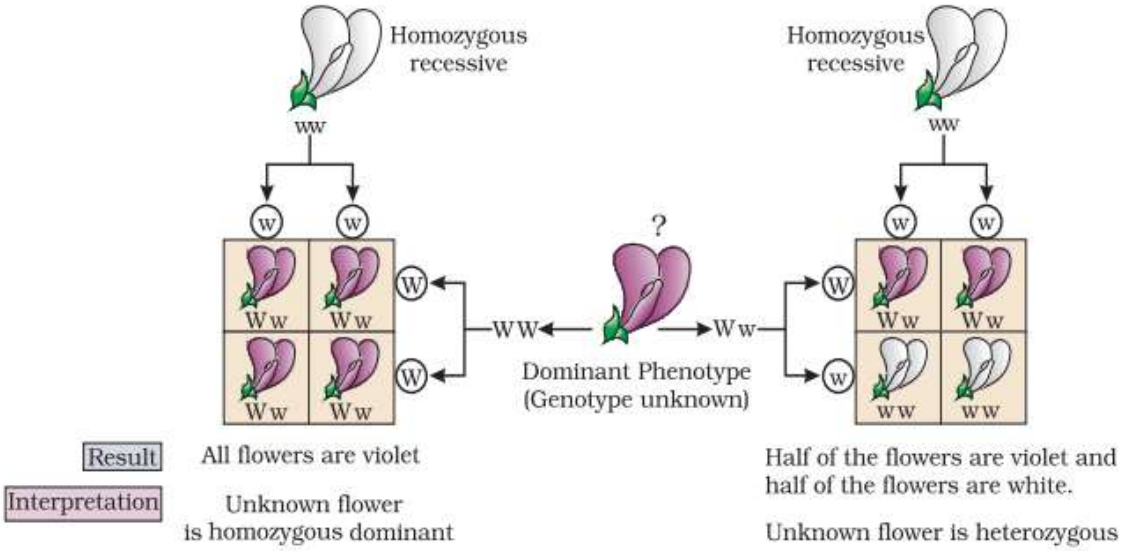
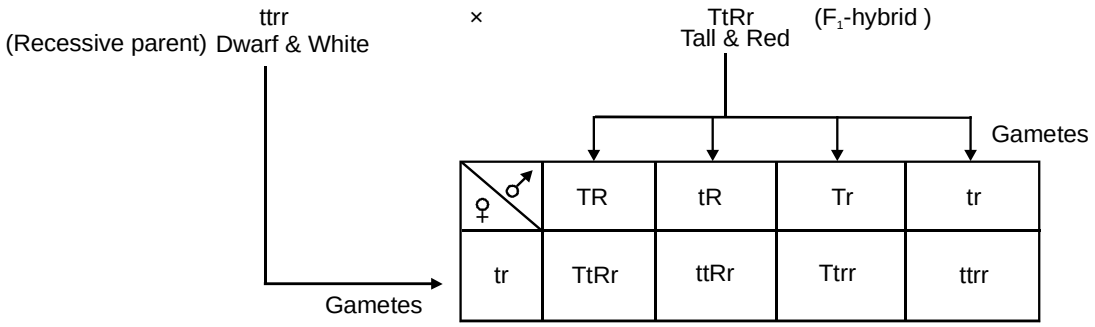


Fig. Diagrammatic representation of a test cross

(i) Phenotypic ratio 1 : 1
Violet White

(ii) Genotypic ratio 1 : 1
Ww ww

(ii) Dihybrid test cross:



(i) Phenotypic ratio 1 : 1 : 1 : 1
Tall & Red / Dwarf &Red / Tall & White / Dwarf & White

(ii) Genotypic ratio 1 : 1 : 1 : 1
TtRr ttRr Ttrr ttrr

1. A diploid organism is heterozygous for 4 loci, how many types of gametes can be produced?
2. When a cross in made between tall plant with yellow seeds (TtYy) and tall plant with green seed (Ttyy), what proportions of phenotype in the offspring could be expected to be
   (a) tall and green.
   (b) dwarf and green.
3. Find the phenotype ratio in following crosses
   (a) AaBB x AaBB
   (b) Aabb x aaBb
   (c) AaBbdd x AaBbdd
   (d) AaBb x aaBb
   (e) AaBb x AaBb (Incomplete dominance in B-gene)
4. Find the ration of following in F_2 generation of dihybrid cross
   (a) Parental : Recombinant genotype
   (b) Pure homozygous : Pure heterozygous
   (c) Homozygous dominant for one pair and Homozygous recessive for other pair
   (d) Genotype with at least one heterozygous pair
   (e) Homozygous for one pair and heterozygous for other pair
5. Suppose you want to verify law of independent assortment experimentally using 64 plastic beads each of yellow, green, red and white to represent, yellow and green colour of seed coat and red and white flowers respectively and if you repeat the experiment six times then guess the expected result and fill the following-

   F_1 Generation

   (a) Total number of individuals, Number of Phenotype (s) & Genotype (s): ___, ___ & ___

   F_2 Generation

   (b) Total number of individuals, Number of Phenotypes & Genotypes: ____, _____ & ____

   (c) Phenotype ratio & Number of individuals in each phenotypic class: _ _ _ _ & _ _ _ _ _

Ans. **(1)** $(2)^4 \Rightarrow 16$

(2) (a) 3/8 (b) 1/8

(3) (a) 3 : 1 (b) 1 : 1 : 1 : 1 (c) 9 : 3 : 3 : 1 (d) 3 : 3 : 1 : 1

(e) 6 : 3 : 3 : 2 : 1 : 1

(4) (a) 1 : 7 (b) 1 : 2 (c) 1/8 (d) 3/4 (e) ½

(5) (a) 64 × 6, 1 & 1 (b) 64 × 6, 4 & 9 (c) 9 : 3 : 3 : 1 & 36×6, 12×6, 12×6, 4×6

6. POST MENDELIAN INHERITANCE:

It involves effect of alleles & non alleles on the normal phenotypic expression of genes. it is of two types

1. Intragenic, 2. Intergenic

6.1. Intragenic:

It takes place between two alleles of a gene. eg: Incomplete dominance, Codominance, Pleiotropy Multiple alleles etc. It is interallelic.

Lethal gene:

- It was discovered by Cuenot In coat colour of mice. Some genes regulate specific characters in the organisms.
- They cause death of organism if they present in homozygous dominant or homozygous recessive state.
- If individual dies in embryonic state, it is called **Absolute lethality.**
- If individual dies before reproductive maturity it is called **Sub-lethality e.g:** Sickle cell anaemia.
- If death of individual takes place after sexual maturity it is called **Delayed lethality**.

Eg 1: coat colour in mice.

Yy (Heterozygous yellow) × Yy (Heterozygous yellow)

♀ \ ♂	Y	y
Y	YY Died	Yy Yellow
y	Yy Yellow	yy Brown

Thus Monohybrid phenotypic ratio is modified

2 : 1

Yellow Brown

Yellow body colour (Y) was dominant over normal brown colour (y) Gene of yellow body colour is lethal in homozygous state so that in nature homozygous Yellow mice are never occured in population

6.2. Intergenic:

It is nonallelic interaction in which two or more independent genes (controlling a single phenotype) present on same or different chromosomes interact to produce a different expression. It involves following types

6.2.1 Epistasis:

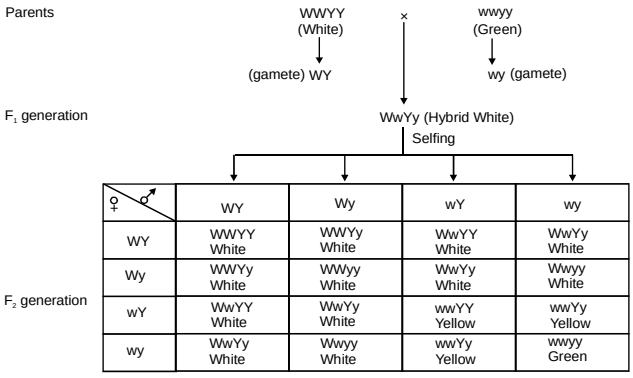
In this type of interaction one gene suppresses the expression of another nonallelic gene. The former is called epistatic gene whereas the latter is called hypostatic gene.

Epistasis comprises three types.

(a) **Dominant epistasis:** In this type dominant gene of one locus suppresses the expression of another gene of different locus.

Eg: Fruit Colour in *Cucurbita pepo* (Summer squash) - A cross between a pure breeding white summer squash (WWYY) with a pure breeding green summer squash wwyy produce white fruits in the F_1 generation.

Dominant gene W is epistatic over Y & w & y genes so that phenotypic ratio of F_2 generation comes to have 12 white fruit, 3 yellow fruit, 1 green fruit.



♀ ♂	WY	Wy	wY	wy
WY	WWYY White	WWYy White	WwYY White	WwYy White
Wy	WWYy White	WWyy White	WwYy White	Wwyy White
wY	WwYY White	WwYy White	wwYY Yellow	wwYy Yellow
wy	WwYy White	Wwyy White	wwYy Yellow	wwyy Green

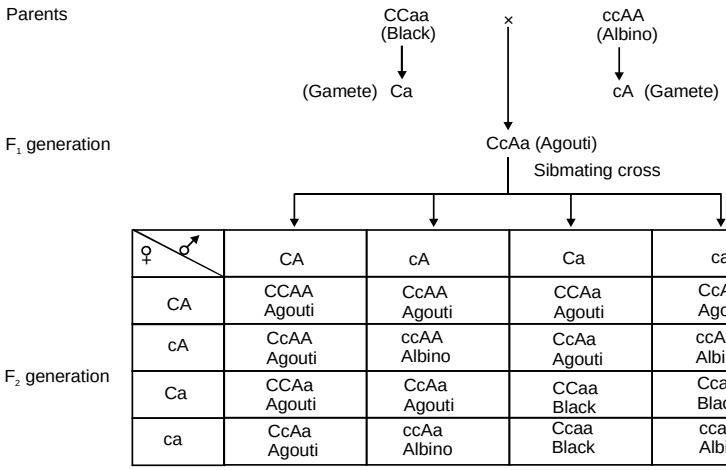
Fig. Dominant epistasis : Inheritance of fruit colour in *Cucurbita pepo*

Phenotypic ratio 12 : 3 : 1

White Yellow green

Other e.g. Coat colour in Dogs (12 white : 3 Black : 1 Brown) and Grain colour in cholam (*Sorghum caudatum*-12 Red : 3 Pearly : 1 Chalky).

(b) Recessive epistasis: In this type recessive homozygous genes of one locus suppresses the expression of another nonallelic gene. **Eg: *Coat Colour in Mice*.**



♀ ♂	CA	cA	Ca	ca
CA	CCAA Agouti	CcAA Agouti	CCAa Agouti	CcAa Agouti
cA	CcAA Agouti	ccAA Albino	CcAa Agouti	ccAa Albino
Ca	CCAa Agouti	CcAa Agouti	CCaa Black	Ccaa Black
ca	CcAa Agouti	ccAa Albino	Ccaa Black	ccaa Albino

Fig. Recessive epistasis with supplementary gene effect in inheritance of coat colour in mice

Phenotypic ratio - 9 : 3 : 4

Agouti Black Albino

Agouti colour is formed by the occurence of Both C and A gene in either Homozygous or Heterozygous condition. A nonallelic gene c is epistatic in homozygous state (cc) & suppresses the expression of A gene thus albino mice are produced. Other Eg: Pigmentation in Onion Bulb. – 9 Red : 3 yellow : 4 White.

(c) Dominant Recessive Epistasis (Inhibitory gene interaction) : Here the dominant allele at one locus (I) and recessive allele at another locus (cc) give rise to the same effect (I - C, I - cc, iicc). Eg : Plumage Colour in Poultry :

Phenotypic ratio - 13 : 3

White Coloured

In the above cross recessive epistatic gene also produces the same phenotype as the dominant epistatic gene.

6.2.2 Complementary Genes:

In this type. Both nonallelic genes independently produce similar effect when they come together in the dominant form they form a new trait.

Eg: Flower colour of Sweet Pea (*Lathyrus odoratus*) - Flower colour is purple if dominant alleles of two nonallelic genes (C – P –) are present together. The colour of flower is white if the double dominant condition is absent (ccP –, C– pp, ccpp).

Purple colour formation is two step reaction and the two genes cooperate to form the ultimate product.

$$\text{Raw material A} \xrightarrow{\text{Gene C – Enz}} \text{Chromagen} \xrightarrow{\text{Gene P – Oxidase}} \text{Anthocyanin}$$

Parents: CCpp (White) × ccPP (White)

(Gamete) Cp, cP (Gamete)

F_1 generation: CcPp (Purple)

Selfing

F_2 generation

♀ \ ♂	CP	Cp	cP	cp
CP	CCPP Purple	CCPp Purple	CcPP Purple	CcPp Purple
Cp	CCPp Purple	CCpp White	CcPp Purple	Ccpp White
cP	CcPP Purple	CcPp Purple	ccPP White	ccPp White
cp	CcPp Purple	Ccpp White	ccPp White	ccpp White

Fig. Complementary gene-Inheritance of purple colour in sweet pea

Phenotypic ratio - 9 : 7

Purple White

6.2.3 Supplementary Genes:

In this type Dominant allele of one gene produces its effect independently where as dominant allele of the second gene is without any independent phenotypic effect but is able to modify the expression of the first gene & produce a new trait. Eg: Seed coat colour in Lablab.

Phenotype ratio - 9 : 3 : 4

Chocolate Khaki Buff

In above example dominant K independently produces Khaki colour. The supplementary gene (L–) changes the expression of pigment forming gene (K) therefore chocolate colour forms.

Other Eg**:** Coat colour in mice - 9 agouti : 3 black : 4 albino

6.2.4 Duplicate Genes:

Two or more independent genes lie on different chromosomes produce same phenotype therefore either they can form the same phenotype in homozygous or heterozygous state.

Independent genes do not form cumulative effect. Eg: Fruit shape in *Capsella bursapestoris*.

Phenotype ratio 15 : 1

Triangular Ovoid - Oblong (Top shape)

6.2.5 Polymeric or Additive Genes:

In this type two independent dominant genes form same phenotypic effect in homozygous or heterozygous condition. When they come together then they produce a cumulative effect. Eg: Fruit Shape in Summer Squash (*Cucurbita pepo*).

Phenotype ratio 9 : 6 : 1

Disc Spherical Long

6.2.6 Collaborative Genes:

Two nonallelic genes produce their own phenotypic effect independently when present in the dominant state but can also interact to form a new trait. Eg: Comb types in poultry.

Phenotypic ratio 9 : 3 : 3 : 1

Walnut pea Rose Single

P gene independently produces Pea comb. R gene independently produces rose comb. Both P and R jointly form walnut comb. When none of these genes is present in the dominant state (pprr), single comb is formed.

Table

S.No.	Type of Gene interaction	Phenotypic ratio	e.g.
1.	Dominant Epistasis	12 : 3 : 1	Fruit colour in summer squash
2.	Recessive epistasis	9 : 3 : 4	Mouse coat colour
3.	Complementary gene	9 : 7	Sweet pea flower colour
4.	Polymeric gene	9 : 6 : 1	Fruit shape in summer squash
5.	Duplicate dominant gene	15 : 1	Seed capsule of Shepherd's purse
6.	Collaborative supplementary gene	9 : 3 : 3 : 1	Feather colour of fowl

6.3. Qualitative and Quantitative Inheritance:

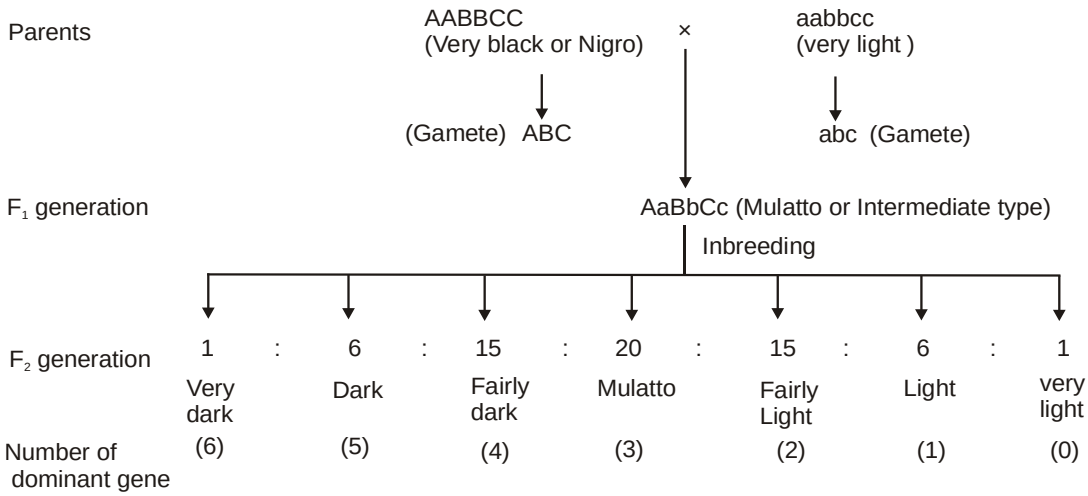
(a) Qualitative or Monogenic Inheritance: In this types single gene influences a complete trait. These genes are called monogenes, **Eg:** Mendellian traits show qualitative inheritances.

(b) Quantitative Inheritance or Polygenic inheritance:

- There are many traits which are not distinct in occurrence and are spread across a gradient e.g. Humans have whole range of possible heights instead of two distinct tall and dwarf alternative. Such traits are generally controlled by two or more genes called as polygenes or multiple genes and their inheritance is called polygenic inheritance.
- In polygenic inheritance the phenotype depends on number of dominant genes (independent of type of dominant gene) and each dominant allele (contributing alleles) of a gene produces a part of trait.
- The full expression of trait takes place in the presence of all the dominant alleles of genes. It is called cumulative effect.
- It was firstly studied by kolreuter in Tobacco. Francis Galton studied polygenic inheritance of human skin colour.
- Nilson Ehle firstly gave the experimental proof of polygenic inheritance. They studied kernal coour of wheat

Eg : 1. Kernal colour of wheat – controlled by two gene pair (Phenotype ratio – 1 : 4 : 6 : 4 : 1).

Eg : 2. Skin colour of Human (Devenport, 1913)



A Histogram of above cross

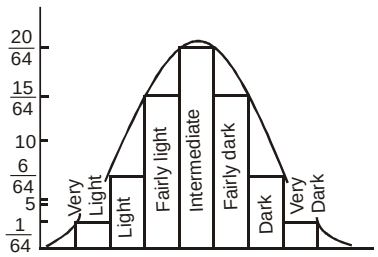


Fig . A histogram prepared from the frequencies of various phenotypes in F_2 generation after a cross between black and white individuals shows a bell shape curve

e.g. If phenotypic categories for 3 different character are 5,7 & 9 then find the number of genes involved in regulation of these characters?

Ans. 2, 3 & 4 respectively.

7. CHROMOSOMAL BASIS OF INHERITANCE

7.1. Chromosomal Theory of Inheritance:

- When Mendel published is results, scientist had no idea about chromosome, their behaviour and role in inheritance of characters.
- But during the rediscovery of Mendellism in 1900 scientist were familiar with chromosome and its behaviour during cell division due to advancement in microscopy.
- Chromosomes (*colored bodies*, as they were visualised by staining) appeared to double and divide just before each cell division.
- By 1902, the chromosome movement during meiosis had been worked out. (by **Sutton and Boveri** independently in **1902**)
- Walter Sutton and Theodore Boveri noted that the behaviour of chromosomes was parallel to the behaviour of genes and used chromosome movement to explain Mendel's laws.
- Chromosomes as well as genes occur in pairs. The two alleles of a gene pair are located on homologous sites on homologous chromosomes.
- After knowing that the genes are located on the chromosomes, a good correlation was drawn between Mendel's laws: segregation and assortment of chromosomes during meiosis. The Mendel's laws were
  extended in the form of 'Chromosomal Theory of Inheritance'.

7.2. Features -

- Main features of chromosomal theory of inheritance are as follows

(1) Sperm and ovum are bridge between two generations.

(2) Both sperm and ovum contribute equally in heredity of offspring the sperm provides only nuclear part to the zygote.

(3) Nucleus contains chromosomes therefore, chromosomes carry the hereditary characters.

(4) Each chromosome or chromosome pair plays definite role in the development of an individual. Loss of a part / complete chromosome causes structural and functional deficiency in the organism.

(5) Both chromosomes appear in pair in the somatic or diploid cells.

(6) A gamete has only one chromosome as well as one Mendelian factor out of homologous pair.

(7) Synapsis and random independent separation of chromosomes form the quantitative basis of independent assortment of Mendelian factors.

(8) Paired condition of chromosomes is retained during fertilization.

(9) Sex of certain organisms is determined by specific chromosomes called sex chromosomes.

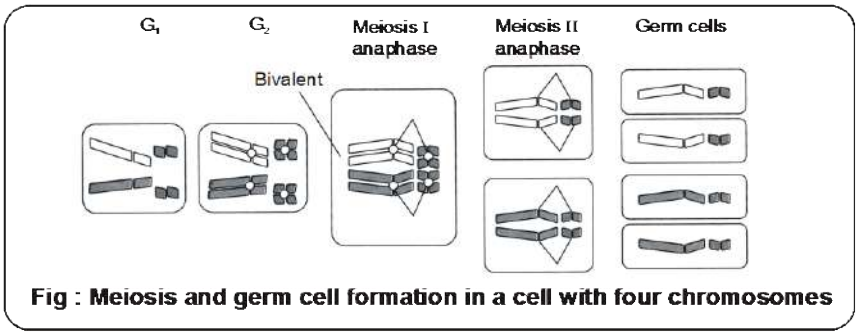


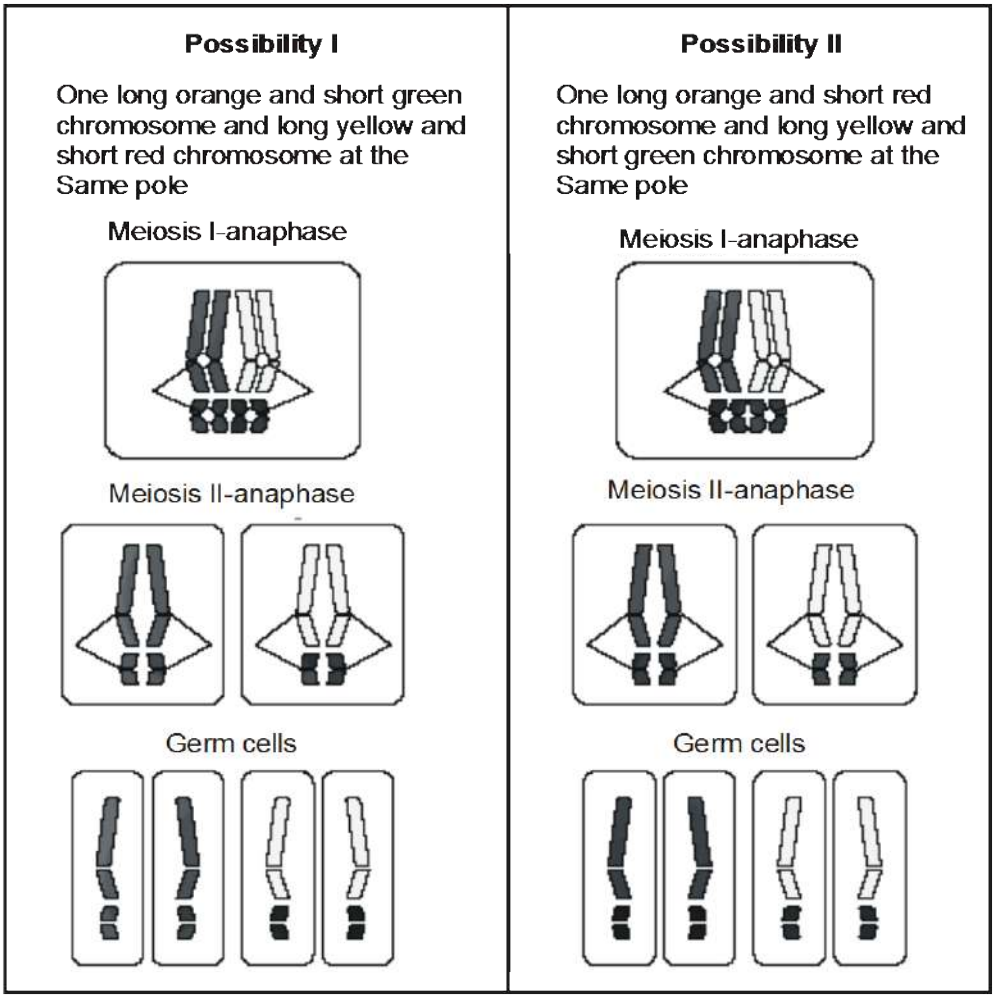
Fig : Meiosis and germ cell formation in a cell with four chromosomes

A Comparison between the behaviour of chromosomes and genes

A	B
Occur in pairs	**Occur in pairs**
Segregate at the time of gamete formation such that only one of each pair is transmitted to a gamete	Segregate at gamete formation and only one of each pair is transmited to a gamete
Independent pairs segregate independently of each other	One pair segregates independently of another pair

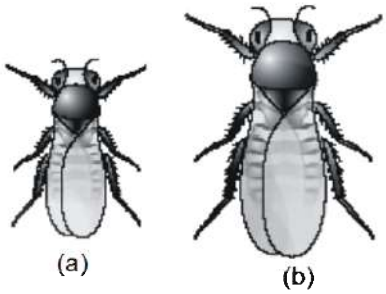
7.3. Chromosomal basis of Independent Assortment

- During Anaphase of meiosis I, the two chromosome pairs can align at the metaphase plate independently of each other.
- To understand this, compare the chromosomes of four different colour in the left and right columns. In the left column (Possibility I) orange and green is segregating together. But in the right hand column (Possibility II) the orange chromosome is segregating with the red chromosomes.



Independent Assortment of Chromosomes

- Sutton and Boveri argued that the pairing and separation of a pair of chromosomes would lead to the segregation of a pair of factors they carried. Sutton united the knowledge of chromosomal segregation with Mendelian principles and called it the **chromosomal theory of inheritance**.
- Following this synthesis of ideas, experimental verification of the chromosomal theory of inheritance by Thomas Hunt Morgan and his colleagues, led to discovering the basis for the variation that sexual reproduction produced.
- Morgan worked with the tiny fruit files, ***Drosophila melanogaster,*** which were found very suitable for such studies. Because.
  1. They could be grown on simple synthetic medium in the laboratory.
  2. They complete their life cycle in about two weeks,
  3. Single mating could produce a large number of progeny flies.
  4. There was a clear differentiation of the sexes – the male and female flies are easily distinguisable.
  5. It has many types of hereditary variations that can be seen with low power microscopes.



Drosophila melanogaster (a) Male (b) Female

8. SEX DETERMINATION:

- The mechanism of sex determination has always been a puzzle before the geneticists.
- On the basis of fertilization, Sex Determination is of three types.
  - **(i) Progamic:** Sex is determined before fertlization **Eg: drone in honey bee.**
  - **(ii) Syngamic:** Determination of sex takes place during fertilization **Eg: most of the animals and plants.**
  - **(iii) Epigamic:** Sex determination takes place after fertilization **Eg: Female in honey bee.**

8.2. Chromosomal / Genetic basis of sex determination.

- The initial clue about the genetic/chromosomal mechanism of sex determination can be traced back to some of the experiments carried out in insects.
- In fact, the cytological observations made in a number of insects led to the development of the concept of genetic/chromosomal basis of sex-determination.
- **Wilson and Stevens** (1905) proposed **chromosomal theory of sex determination**.
- Chromosomes are of two types.
  1. **Autosomes or somatic chromosomes:** They control inheritance of somatic characters and are common in two sexes (male and female).
  2. **Sex chromosomes or Allosomes or Heterosomes:** Involvement in sex determination and are different in two sexes. **e.g.** X and Y chromosome.
- **X-chromosome or X-body** discovered by **Henking** in the **testes of male bug**.
- Henking (1891) could trace a specific nuclear structure all through spermatogenesis in a few insects, and it was also observed by him that 50 per cent of the sperm received this structure after spermatogenesis, whereas the other 50 per cent sperm did not receive it.
- Henking gave a name to this structure as the X body but he could not explain its significance.
- Further investigations by other scientists led to the conclusion that the 'X body' of Henking was in fact a chromosome and that is why it was given the name X-chromosome.

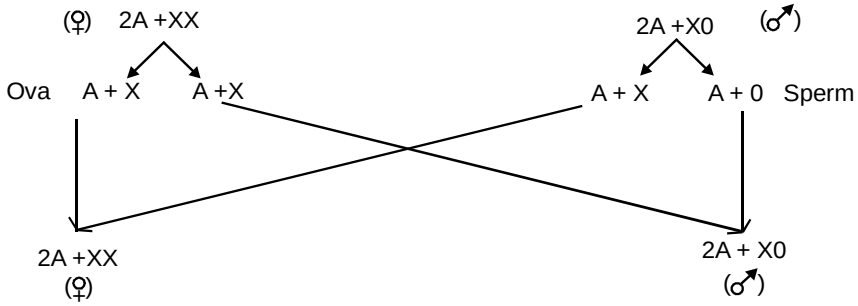
Allosomic determination of sex involves following types.

8.2.1 X0 type or XX — X 0 type or Protenor type:

- In a large number of insects the mechanism of sex determination is of the XO type, i.e., all eggs bear an additional X-chromosome besides the other chromosomes (autosomes).
- On the other hand, some of the sperms bear the X-chromosome whereas some do not.
- Eggs fertilised by sperm having an X-chromosome become females and, those fertilised by sperms that do not have an X-chromosome become males.

- In XO type of sex determination in which the males have only one X-chromosome besides the autosomes, whereas females have a pair of X-chromosomes. Number of chromosomes in the male and female are not equal.
- Female is homogametic and male is heterogametic**.**

  e.g : Large number of insects like Grasshopper, Squash bug - Anasa, Cockroach, Ascaris and plants like *Dioscorea sinuta* & *Vallisneria spiralis*.



8.2.2 XY TYPE or XX—XY type or Lygaeus type:

- It was firstly described by **Wilson & Stevens in Lygaeus insect.**
- XY type of sex determination is seen where both male and female have same number of chromosomes. Among the males an X-chromosome is present but its counter part is distinctly smaller and called the Y-chromosome.
- **Stevens** discovered **Y-chromosome.**
- Females, however, have a pair of X chromosomes. Both males and females bear same number of autosomes.
- Hence, the males have autosomes plus XY, while female have autosomes plus XX.
- In human beings and in *Drosophila* the males have one X and one Y chromosome, whereas females have a pair of X-chromosomes besides autosomes.
- In this types **female** is **homogametic** and forms only one type of gamete whereas **male** is **heterogametic** and produces two types of gametes

  e.g.: Mammals including human and some insect like Drosophila, dioecious plant like Coccinea, Melandrium.

Note –

Male heterogamety

- In the above description you have studied about two types of sex determining mechanisms, i.e., XO type and XY type. But in both cases males produce two different types of gametes, (a) either with or without X-chromosome or (b) some gametes with X-chromosome and some with Y-chromosome. Such types of sex determination mechanism is designated to be the example of male heterogamety.

8.2.3 Sex Determination in Humans

- It has already been mentioned that the sex determining mechanism in case of humans is XY type. Out of 23 pairs of chromosomes present, 22 pairs are exactly same in both males and females; these are the autosomes.

- A pair of X-chromosomes are present in the female, whereas the presence of an X and Y chromosome are determinant of the male characteristic.
- During spermatogenesis among males, two types of gametes are produced.
- 50 per cent of the total sperm produced carry the X-chromosome and the rest 50 per cent has Y-chromosome besides the autosomes.
- Females, however, produce only one type of ovum with an X-chromosome.
- There is an equal probability of fertilisation of the ovum with the sperm carrying either X or Y chromosome.
- In case the ovum fertilises with a sperm carrying X- chromosome the zygote develops into a female (XX) and the fertilisation of ovum with Y-chromosome carrying sperm results into a male offspring.
- Thus, it is evident that it is the genetic makeup of the sperm that determines the sex of the child. It is also evident that in each pregnancy there is always 50 per cent probability of either a male or a female child. It is unfortunate that in our society women are blamed for giving birth to female children and have been ostracised and ill-treated because of this false notion.

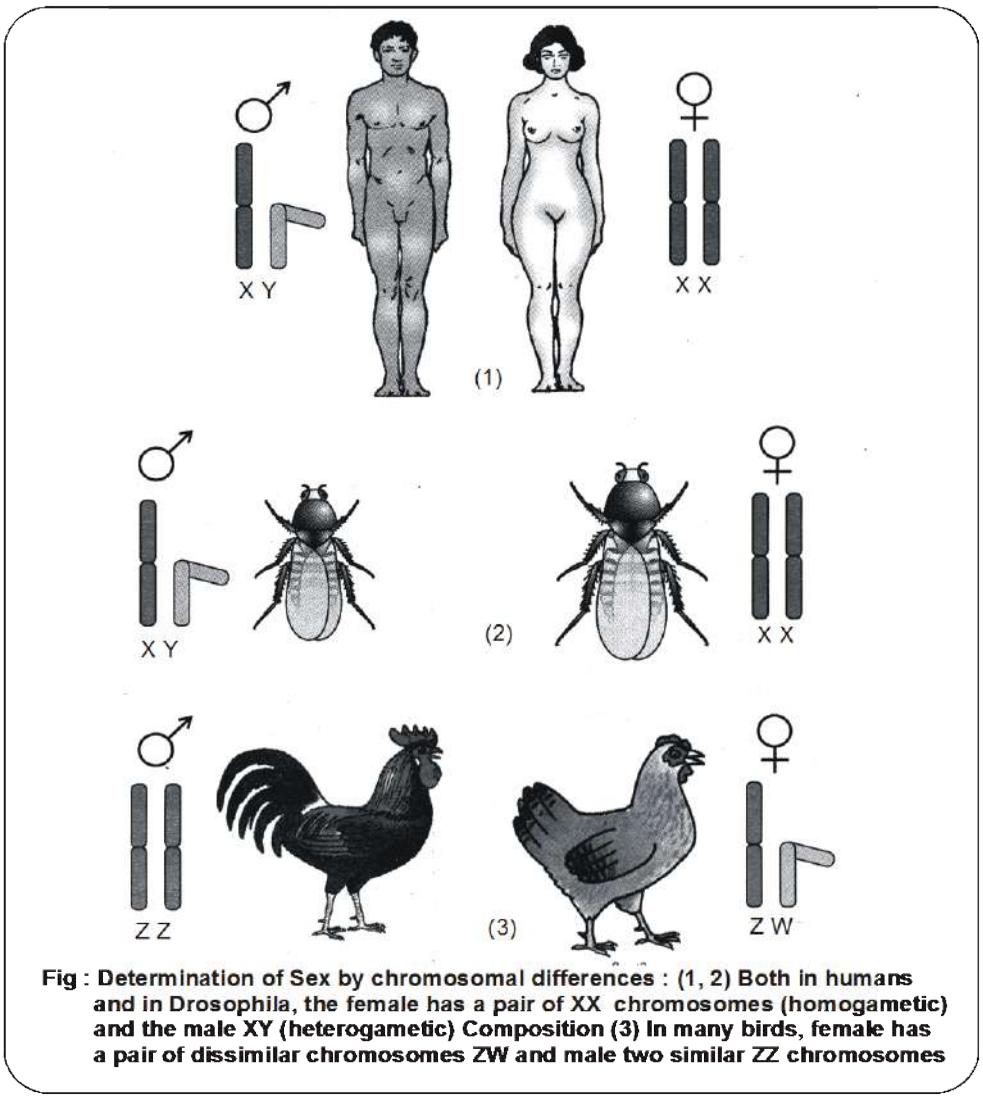


Fig : Determination of Sex by chromosomal differences : (1, 2) Both in humans and in Drosophila, the female has a pair of XX chromosomes (homogametic) and the male XY (heterogametic) Composition (3) In many birds, female has a pair of dissimilar chromosomes ZW and male two similar ZZ chromosomes

8.2.4 ZW (♀) – ZZ (♂) type:

- In order to have a distinction with the mechanism of sex determination described earlier, the two different sex chromosomes of a female bird has been designated to be the Z and W chromosomes. In these organisms the females have one Z and one W chromosome, whereas males have a pair of

Z-chromosomes besides the autosomes. This is how the sex-determination mechanism different in the birds.

- In birds, a different mechanism of sex determination is observed. In this case the total number of chromosome is same in both males and females. But two different types of gametes in terms of the sex chromosomes, are produced by females, i.e., female heterogamety (The egg is responsible for the sex of the chicks).

Eg : Birds, Reptiles, Some fishes, Hen, Plant Fragaria eletier.

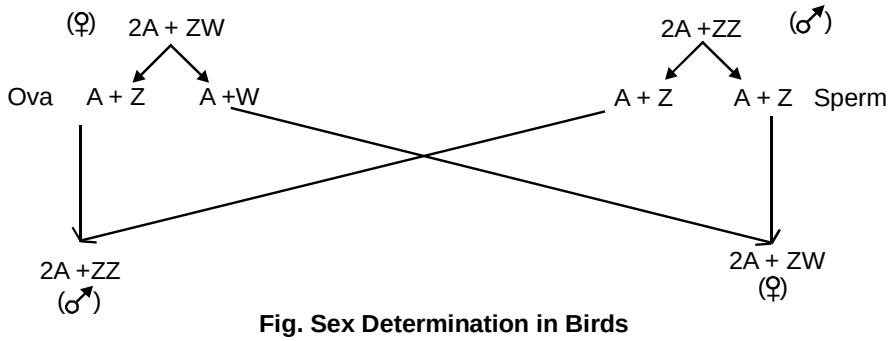
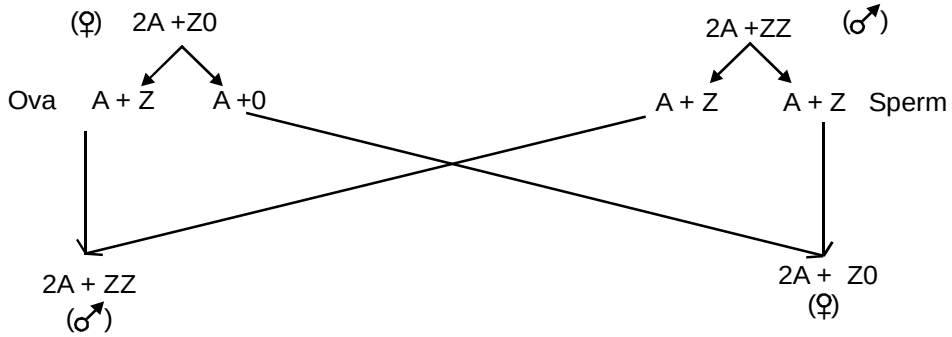


Fig. Sex Determination in Birds

8.2.5 Z0 ♀ – ZZ ♂ type:

- Female is heterogametic in which one sex chromosome is missed Male is homogametic. **Eg: some Moths and Butterflies.**



8.2.6 Haplo-diploidy type:

- The sex determination in honey bee is based on the number of sets of chromosomes an individual receives.
- An offspring formed from the union of a sperm and an egg develops as a female (queen or worker), and an unfertilised egg develops as a male (drone) by means of parthenogenesis.
- This means that the males (N) have half the number of chromosomes than that of a female (2N).
- The females are diploid having 32 chromosomes and males are haploid, i.e., having 16 chromosomes. This is called as haplodiploid sex-determination system.
- The males produce sperms by mitosis, they do not have father and thus cannot have sons, but have a grandfather and can have grandsons.

Gynandromorphs:

- Some Drosophila individuals were found to possess half of the body of male and half of female they are called Gynandromorphs.
- It is formed by loss of one X-chromosome at metaphase plate during first zygotic division.

8.2.7 Genic balance theory:

- It was proposed by **Calvin Bridges** (1926). He stated that sex is determined by the genic balance or **ratio** between **X-chromosomes** and **autosomes**.
- It is applicable for **Drosophila melanogaster** in which **expression of maleness is not controlled by Y-chromosome.**

S. NO.	Chromosome Constitution	X/A ratio	Individual (sex)
(i)	2A + XX	2/2 = 1·0	Diploid female
(ii)	2A + XXY	2/2 = 1·0	Diploid female
(iii)	3A + XX	2/3 = 0· 67	Intersex
(iv)	2A + XY	½ = 0·5	Diploid male
(v)	2A + XXX	3/2 = 1·5	Super female
(vi)	3A + XY	1/3 0·34	Super male

1. Complete the sentences.

(a) The behaviour of chromosomes was _____to the behaviour of genes and used chromosome movement to explain Mendel's laws

(b) Chromosomal theory of inheritance was based on mendellian principles as well as chromosomal segregation during_____.

(c) Chromosomal theory of inheritance was verified by_____.

(d) Linkage is _____associationof genes on a chromosome.

2. Mechanism of sex determination and chromosomal basis of sex determination was initially found in-

(1) Human (2) Plants (3) Birds (4*) Insect

3. **Find correct statements –**

(1*) The number of chromosome are equal in male and females of grasshopper and human.

(2) X-body of Henking was X-chromosome

(3) The autosome are equal in male and females of grasshopper and human.

(4) Total number of chromosome are equal in male and females of birds.

4. Sex determination in insect can be-

(1) XO type (2) XY type (3) Haplodiploid (4*) All the above

5. Male honeybee do not have -

(1) Father (2) Son

(3*) Both Father and Son (4) Grandfather

Ans. **1.** (a) Parallel (b) Meiosis (c) Morgan (d) Physical

2. (4), **3.** (1), **4.** (4) **5** (3)

9. LINKAGE:

9.1. Introduction

- **Sutten and Bovari** firstly stated about linkage in chromosomal theory of inheritance.
- **According to T.H. Morgan (Father of experimental genetics):** The genes of a chromosome have tendency to inherit together and maintains the parental combination in successive generations these genes are called **linked genes** and this phenomenon is called **Linkage**.
- It was found that Mendel's law of independent assortment does not hold true for the genes that were located on the same chromosomes. These genes were called as 'linked genes'.

9.2. Experiment of Morgan on Drosophila:

- Morgan carried out several dihybrid crosses in *Drosophila* to study genes that were sex-linked. The crosses were similar to the dihybrid crosses carried out by Mendel in peas.
- **Cross A :** Morgan hybridised yellow-bodied, white-eyed females to brown-bodied, red-eyed males and intercrossed their F_1 progeny.
- **Cross B :** Morgan hybridised miniature winged, white-eyed females to normal winged, red-eyed males and intercrossed their F_1 progeny.
- He observed that the two genes did not segregate independently of each other and the F_2 ratio deviated very significantly from the 9:3:3:1 ratio (expected when the two genes are independent).
- Morgan and his group knew that the genes were located on the X chromosome and saw quickly that when the two genes in a dihybrid cross were situated on the same chromosome, the proportion of parental gene combinations were much higher than the non-parental type.
- Morgan attributed this due to the **physical association** or linkage of the two genes and coined the term **linkage** to describe this physical association of genes on a chromosome and the term **recombination** to describe the generation of non-parental gene combinations.
- Morgan and his group also found that even when genes were grouped on the same chromosome, some genes were very tightly linked (showed very low recombination) **Figure (i)** while others were loosely linked (showed higher recombination) **Figure (ii)**.
- He found that the genes white and yellow were very tightly linked and showed only 1.3 per cent recombination (98.7 % are parental type) while white and miniature wing showed 37.2 per cent recombination (62.8% are parental type).

9.3. Morgan & Casttle (1911) proposed chromosomal theory of linkage.

(i) Linked genes appear in the same chromosome.

(ii) Genes arrange in Linear fashion on chromosome.

(iii) The strength of linkage is inversely proportional to the distance between two genes. Closely located genes assorted together, and distantly located genes, due to recombination, assorted independently.

(iv) Genes present on same chromosomes have tendency to maintain parental combinations except for occasional crossovers.

(v) Types of gametes reduced in linkage.

(vi) F_2 generation show more parental type and less recombinants.

9.4. Types of linkage:

(1) Complete Linkage **(2) Incomplete Linkage**

9.4.1 Complete Linkage:

- The gene situated on the same chromosome do not separate and are inherited together over the generations due to the absence of crossing over. It is rare. Dihybrid cross of completely linked behave as a monohybrid cross producing 3:1 ratio in F_2 generation and 1:1 ratio in test cross. **Ex: Male Drosophila**.

9.4.2 Incomplete Linkage:

- The linked genes do not always stay together because crossing over may occur.

Eg : Eye colour and body colour ; eye colour and size of wings.

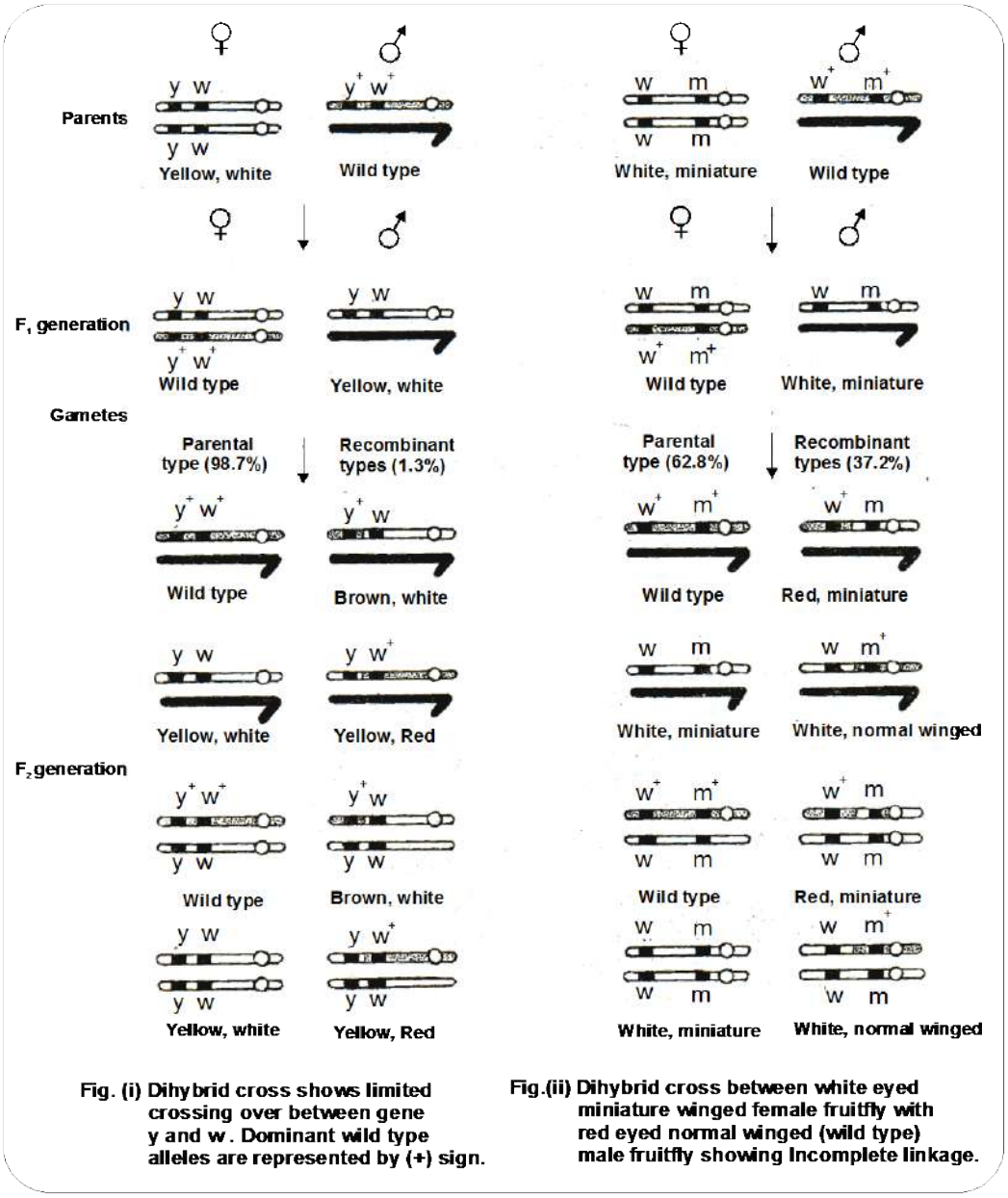


Fig. (i) Dihybrid cross shows limited crossing over between gene y and w. Dominant wild type alleles are represented by (+) sign.

Fig.(ii) Dihybrid cross between white eyed miniature winged female fruitfly with red eyed normal winged (wild type) male fruitfly showing Incomplete linkage.

9.5. Chromosome map / Genetic map / Linkage map

- The graphic representation of sequence and relative distance between genes in a chromosome is called Linkage map.
- The first linkage map was developed by Morgan's student Alfred Sturtevant for **Drosophila**.
- He used the frequency of recombination between gene pairs on the same chromosome as a measure of the distance between genes and 'mapped' their position on the chromosome.
- Distance between genes is directly proportional to recombination frequency between gene pairs. Linkage maps, therefore, corresponded to arrangement of genes on a chromosome.
- Today genetic maps are extensively used as a starting point in the sequencing of whole genomes as was done in the case of the Human Genome Sequencing project.

Recombination frequency or **Cross-over value (COV)** is measured by test cross.

1% crossing over between two linked genes is known as 1 map unit or 1 centimorgan (cM).

$$\textbf{Recombination frequency} = \frac{\textbf{Number of recombinants}}{\textbf{Total number of offsprings}} \times 100$$

Eg: 1 An individual with cd genes crossed with wild type + + On test crossing F_1, the progeny was + c 105, + d 115, cd 880 and + + 900. Distance between cd genes is?

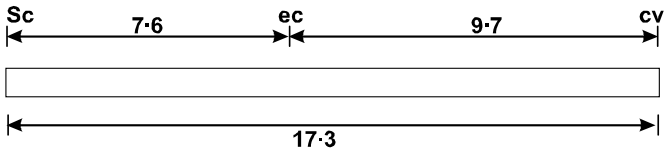
Ans: % cross over value = $\frac{220}{2000} \times 100 = 11$ map unit

Eg: 2. The frequency of crossing over or recombination of three sex linked genes was found to be

(a) Sc and ec = 7·6% (sc = scute or certain bristles missing)

(b) ec and cv = 9·7% (ec = echinus or rough eyes)

(c) sc and cv = 17·3% (cv = cross veinless or absence of cross veins or wings)



Ans: sequence sc–ec–cv

Crossing over:

- Exchange of segments of non sister chromatids between homologous chromosomes is called crossing over.
- The term crossing over was coined by **Morgan**. It occurs in the **pachytene stage**, of **meiosis - I**
- The non sister chromatids in which exchange of segments have occurred are called recombinants or cross-overs while the other chromatids in which crossing over has not taken place are called non cross-overs (parental chromatids).

Factor affecting crossing over:

(i) **Age:** The frequency of crossing over is decreased due to increasing the age.

(ii) **Distance:** If the two genes locate at quite distance. The possibility of crossing over is increased.

(iii) **Temperature:** If temperature increases the possibility of crossing over also increases.

(iv) **X-rays:** The treatment of X- rays also increases the possibility of crossing over.

(v) **Heterochromatin:** Occurrence of centromere and heterochromatic areas decrease the rate of crossing over.

(vi) **Chemicals:** The degree of crossing over in animals is changed by chemicals of food.

(vii) **Sex:** Little crossing over is observed in male Drosophila.

Linkage Groups:

It is linearly arranged groups of linked genes which are normally inherited together except crossing over or haploid no of homologous chromosomes.

Table

S.No.	Organism	Diploid no. of chromosomes (2n)	no. of linkage group
1	Human beings	46	23 (female), 24 (male)
2	Maize	20	10
3	Pea	14	7
4	Drosophila	8	4

Neurospora is haploid. It has **7 linkage groups** (7 chromosomes), **Mucor** has **2 linkage groups** (2 chromosomes).

9.6. Sex Linkage or Sex-Linked Inheritance:

- Sex linkage discovered by **Morgan**.
- Inheritance of some traits is controlled by genes of sex chromosomes. These are called **sex linked traits**.

Types of Sex Linked Inheritance: It is of following types.

(i) **Criss Cross Inheritance:** It is a type of sex linked inheritance where a parent passes the traits to the grand child of the same sex through offspring of the opposite sex. **e.g.** Eye colour in drosophila.

It is of two types

(a) **Diagynic (Diagenic):** Father to grandsons through daughter.

(b) **Diandric:** Mother to grand-daughter through son.

(ii) **Non Criss Cross Inheritance:** It involves two types.

(a) **Holandric/Y-linked:** Direct from father to son or male to male.

(b) **Hologynic:** Direct from mother to daughter or female to female.

(1) **Sex Limited Traits:** These traits are expressed in a particular sex although their genes also occur in the other sex. **Eg: moustaches and beards human males, breast in human females, milk secretion in human females**.

(2) **Sex Influenced Traits:** These traits are controlled by autosomal genes & the expression of these genes in a particular sex depends upon favourable conditions. For example the gene of **Pattern baldness** acts as a dominant one in human males because it can express itself due to availability of male hormones.

Genotype	Male	Female
BB	Baldness	Baldness
Bb	Baldness	Baldness Absent
bb	Baldness Absent	Baldness Absent

(3) X-linked genes: In humans X-chromosome carries alleles of a number of dominant and recessive human sex-linked disorders.

X-linked dominant traits – Duchene Muscular Dystrophy

X-linked recessive traits – Red-Green colour blindness, haemophilia, glucose-6-phosphate dehydrogenase deficiency syndrome.

(4) Y-linked gene – e.g. Hypertrichosis of ear (excessive hairs on ear pinna), TDF (testis determining factor), keratoderma dissipatum (thickened skin of extremities), porcupine skin, webbed toes in humans

1. In a cross if phenotype of dominant parent appear in 75% progeny then it represent :

(1) Test cross (2) F_2 generation of monohybroid cross

(3) complete linkage (4) Both 2 & 3

2. Mendel did not get

(1) Intermediate phenotype (2) Linkage

(3) Blending (4) All the above

3. A test cross of F_1 flies +a/+ b produces the following number of offsprings

++/ab	9
ab/ab	9
+b/ab	41
a+/ab	41

What will be the distance between two genes?

(1) 82 cM (cis) (2) 18 cM (cis) (3*) 18 cM (trans) (4) 20 cM (cis)

4. The distances between genes W, X, Y and Z on a chromosome are as follows: W-Y is 18 units, W-X is 26 units, W-Z is 40 units, X-Y is 8 units and X-Z is 14 units. The sequence of these genes would be:

(1) W, X, Y, Z (2*) W, Y, X, Z (3) X, Y, W, Z (4) Y, W, X, Z

5. Two heterozygous parents are crossed. If the two loci are linked what would be the distribution of phenotypic features in F_1 generation for a dihybrid cross?

Ans. **1.** (4) **2.** (4) **3.** (3) **4.** (2) **5.** 3:1

10. MUTATION:

10.1. Introduction

- Sudden / random permanent genetic / inheritable change in the genetic material of an organism is called mutation.
- **Darwin** coined the term **sports** and **Hugo de vries** coined the term **saltation** for them.
- **Mutation** was discovered by **Hugo de vries** in ***Oenothera lamarckiana*** **(Evening primerose).** Later workers found that 'mutations' observed by De Vries were actually **chromosome aberration and polyploids**.
- As we all know, each and every feature in any organism is controlled by one or the other gene located on the DNA present in the chromosome. DNA is the carrier of genetic information. It is hence transmitted from one generation to the other without any change or alteration. However, changes or alteration do take place occasionally. Such an alteration or change in the genetic material is referred to as mutation.
- Mutation is a phenomenon which results in alteration of DNA sequences and consequently results in changes in the genotype and the phenotype of an organism. In addition to recombination, mutation is another phenomenon that leads to variation in DNA.
- A number of disorders in human beings have been found to be associated with the inheritance of changed or altered genes (e.g. Sickle cell anemia) or chromosomes (Cry du chat syndrome).

10.2. Types of mutations:

(I) On the basis of direction, mutation involves two types

(1) Forward mutation: Wild type – Mutant type

(2) Backward mutation: Mutant type – wild type.

(II) On the basis of dominance or recessiveness.

(1) Dominant mutation

(2) Recessive mutaiton

(III) On the basis of tissue:

(1) Somatic: It takes place in somatic cell or Vegetative cell. It does not inherit in the next generation but in plants, It can transmit next generation through vegetative propagation.

(2) Germinal: It occurs in germinal cell or reproductive cell. It transmits or inherits from generation to generation.

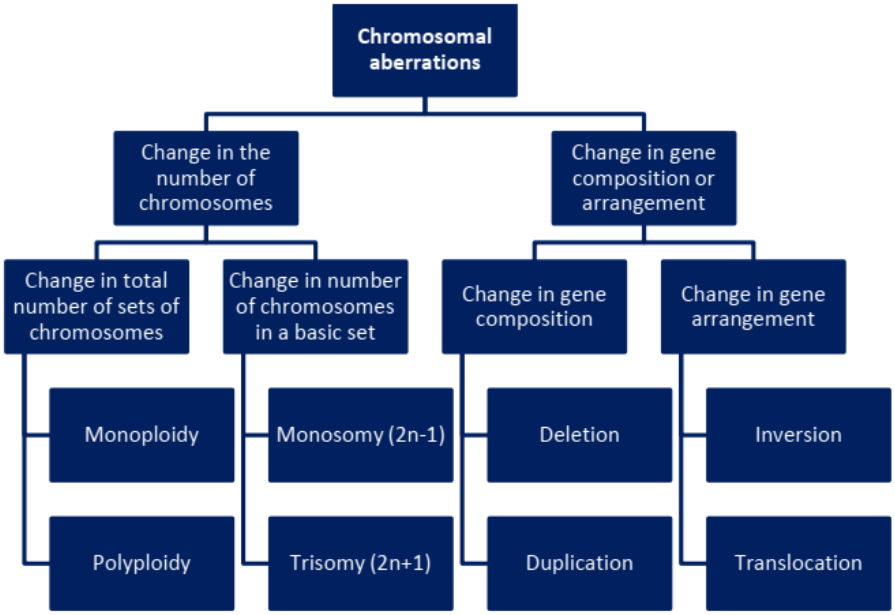
(IV) On the basis of occurrence in nature.

(1) Spontaneous Mutations: They occur naturally in the nature due to internal factors such as background radiations, tautomers, copy error, deamination of Cytosine.

(2) Induced Mutations: they are produced by the application of external factors and chemicals. The first induced mutation produced by **Muller (1927)** in **Drosophila** through the use of **X-rays**.

(V) On the basis of cytology mutation involves following types.

(A) Genomatic Mutation (B) Chromosomal Mutation (C) Gene Mutation



10.2.2 Genomatic Mutation:

Changes in chromosomal Number. It involves **Euploidy and aneuploidy.**

(1) Euploidy : Change in the number of basic sets of chromosomes.

Monoploidy: Presence of only one set of chromosomes.

Polyploidy: Presence of more than two sets of chromosomes.

- If an organism has more than two sets of chromosomes then it is called Polyploid.
- Failure of cytokinesis after telophase stage of cell division results in an increase in a whole set of chromosomes in an organism and this phenomenon is known as **polyploidy**. This condition is often seen in plants
- In nature, polyploidy appears due to the failure of chromosomes to separate at the time of **anaphase** either due to **nondisuction** or due to **absence of spindle**.
- Polyploidy is lethal in animals but used by plant breeders to increase productivity in plants.
- On the basis of occurence of number of genome, polyploid is called **triploid (3n), tetraploid (4n), Pentaplaoid (5n), Hexaploid (6n)** etc**.**

  Polyploids with odd number of genomes **(Eg: triploids, pentaploids)** are sexually sterile. So that they perform reproduction by vegetative propagation **Eg: Banana, Pineapple.**

(2) Aneuploidy: Change in the number of chromosome in one set

- Failure of segregation of chromatids during cell division cycle results in the gain or loss of a chromosome(s), called **aneuploidy**.
- Aneuploidy is caused due to **nondisjunction** i.e**.** failure of separation of paired homologus chromosome during anaphase I, or sister chromatids during anaphase II.

- Nondisjunction disrupts the normal distribution of chromosomes into gametes and leads to formation of gametes with the n+1 (trisomic) and n-1 (monosomic) chromosome composition instead of normal gametes (disomic).
- In which one or few chromosomes are either deficient or in excess in a species.

  It is of two types.

  (a) **Hypoploidy:** In which either one or few chromosomes are deficient. It involves two types.

  (i) **Monosomic (2 n – 1):** Deletion of a chromosome in a set (2n-1).

  Eg: Turner's syndrome (44 + X 0).

  (ii) **Nullisomic (2n – 2):** A pair of chromosome is deficient.

  (b) **Hyperploidy:** In which one or few chromosomes are in excess. It is of two types.

  (i) **Trisomy (2n + 1) :** Addition of extra chromosome in a set (2n+1).

  Eg: 21st Trisomy - Down's syndrome (47, 21+)

  18th Trisomy - Edward syndrome (47, 18+)

  13th trisomy - Patau syndrome (47, 13+)

  Double trisomic has two different chromosomes in triplicate **(2n + 1 + 1)**.

  (ii) **Tetrasomic (2n + 2):** A pair of chromosome is additional or a chromosome is found four times.

  Eg : Super female 44 + XXXX, Double tetrasomic (2n + 2 + 2).

10.2.3 Chromosomal mutation:

Change in gene composition or arrangement.

- One DNA helix runs continuously from one end to the other in each chromatid, in a highly supercoiled form. Therefore loss (deletions) or gain (insertion/duplication) of a segment of DNA, result in alteration in chromosomes (Structural changes). Since genes are known to be located on chromosomes, alteration in chromosomes results in abnormalities or aberrations.
- Chromosomal aberrations are commonly observed in cancer cells.

Structural changes of chromosomes involve following types.

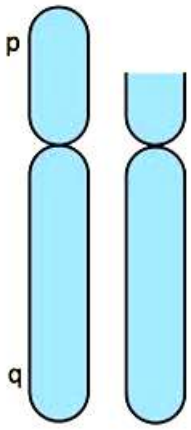
(a) **Intrachromosomal type:**

(1) **Deletion:** A part of chromosome is lost from terminal part (Terminal deletion) or from intercalary part (Intercalary deletion).

Eg:

(i) **Terminal deletion of a segment of short arm of 5th pair of chromosome (5p) in human causes Cri du chat syndrome (cat cry syndrome)** in child

(ii) **Notched wing in Drosophila.**



Terminal deletion 5p (Cri-du-chat syndrome)

(2) Inversion: A segment of a chromosome is turned around 180 degrees within a chromosome. Inversion does not involve loss or gain of genetic information but rearranges the gene sequence in a chromosome. It is of two types.

(i) Paracentric inversion: Inversion without centromere.

(ii) Pericentric inversion: Inversion with centromere.

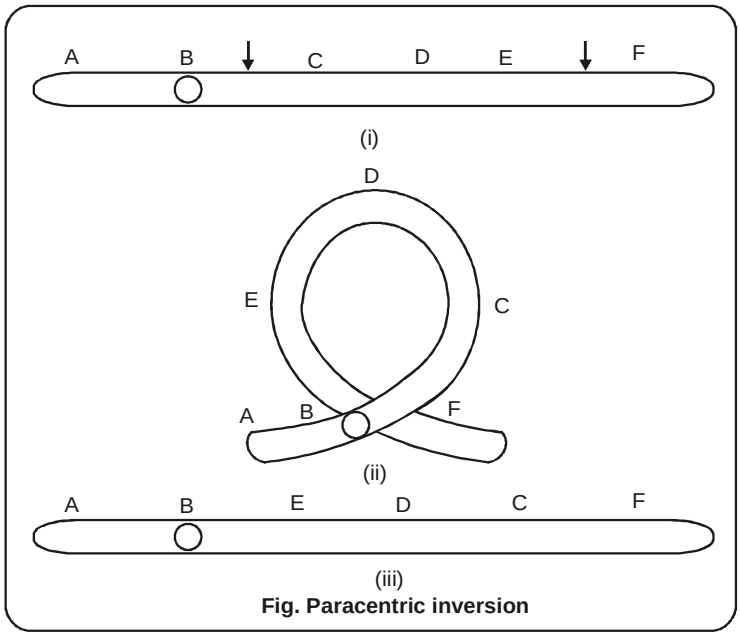


Fig. Paracentric inversion

(b) Interchromosomal type:

(1) Duplication:

It occurs due to addition of a part of chromosome.

Eg: Development of Bar eye in Drosophila by X-ray radiation.

It involves following types.

(i) Tendem duplication: When a chromosomal segement appears two time in a chromosome it is called Tendem duplication.

(ii) Reverse tendem duplication: If the sequence of duplicate part is reverse (180^{o} rotation) it is called Reverse tendem duplication.

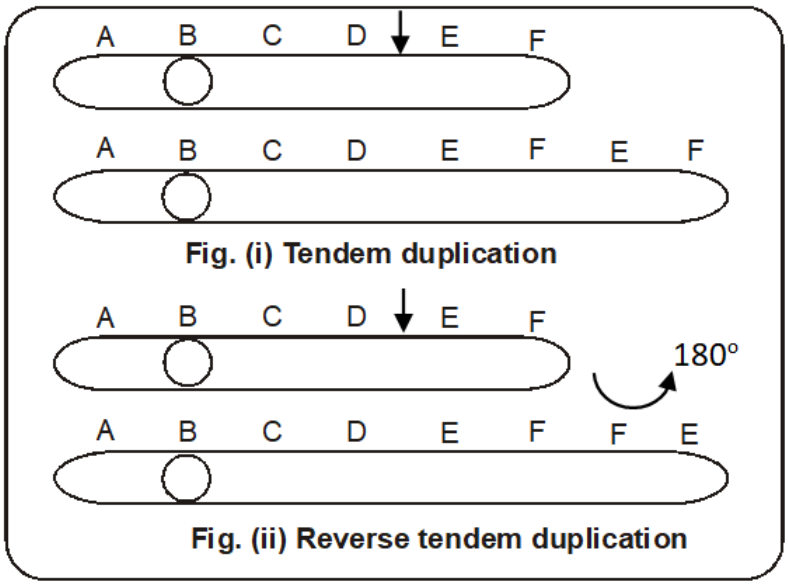


Fig. (i) Tendem duplication

Fig. (ii) Reverse tendem duplication

(2) Translocation:

When the exchange of segments occur between two non-homologous chromosomes. It is called translocation.

It is of two types.

(a) Simple translocation: In which a segment of a chromosome transfers to another nonhomologous chromosome.

(b) Reciprocal translocation / Segmental exchange : In which a mutual exchange of chromosomal segments between two non homologous chromosomes.

Note : It is not a true crossing over as exchange occur between non homologous pair of chromosomes.

Eg: Philadelphia syndrome / Chronic Myeloid Leukemia (CML) is due to reciprocal translocation of long arm in between 9th (9q) and 22nd (22q) chromosomes. Chromosome number 22 is shortened translocated chromosome, also called as Philadelphia chromosome.

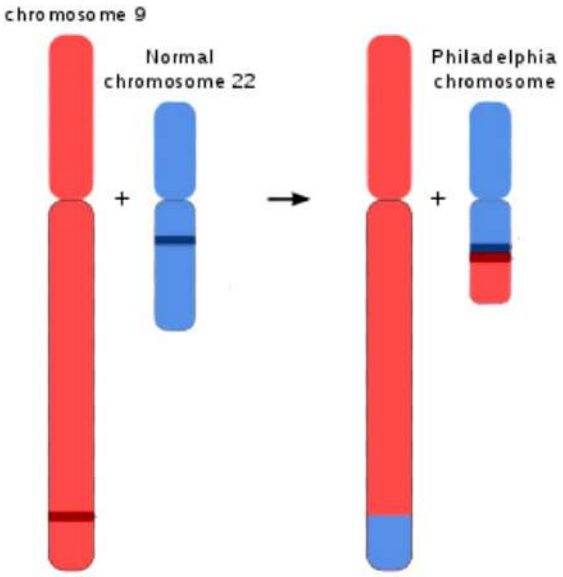


Fig. Reciprocal translocation

10.2.4 Gene Mutations:

- Sudden stable changes in the structure of gene or cistron due to change in nucleotide sequence and nucleotide type are called gene Mutations.
- Most of the gene mutations arise due to change in single nucleotide or single base pair of DNA. These are called **point mutations**. Usually Gene mutations appear during replication of DNA therefore it is called **copy error mutation.** e.g. Sickle Cell Anaemia.

Type of gene mutations: Gene mutations involve three types

(i) **Substitution:** It includes replacement of one type of nitrogenonus base by other. It is of two types

(a) **Transition:** In this type, one purine is replaced by another purine while one pyrimidine by another pyrimidine.

(b) **Transversion:** Purine base is replaced by a pyrimidine base or vice versa.

(i) **Inversion:** A deterioration of DNA by mutagen can change the base sequence of a cistron in the reverse order.

(ii) **Frame-shift Mutations:** In this types the entire reading frame of base sequence shifts laterally either in the forward direction due to insertion of one or more nucleotides or in the backward direction due to deletion of one or more nucleotides. It is also called **gibberish mutations.** It is of two types.

1. **Deletion:** One more nucleotides are eliminated from segment of DNA or gene.
2. **Insertion:** Addition of one or more nucleotides in the segment of DNA or gene.

10.3. Mutagens:

Any type of physical or chemical factor that is used in the induction of mutation are called mutagens. The latter are of two types.

(i) **Physical mutagens:**

(a) **High Energy Radiations:** These are of two types

(1) **Ionizing radiations: Eg: X-rays, gamma rays and cosmic rays, α–rays, β– rays**. Ionizing radiations cause breaks in the chromosome. It causes abnormal cell divsions. Different types of cancers are the result of radiations.

(2) **Non-ionizing radiations: Eg: Ultra-violet light**. Thymine (pyrimidine) dimers show a major mutagenic effect of UV rays that disturbs DNA double helix and thus DNA replication.

(i) **Chemical Mutagens:** They are of several types.

(a) **Base Analogues:** They resemble the normal bases of DNA and, therefore, get incorporated into DNA in place of them. **e.g. 5-bromouracil** is a structural analogue of thymine. It gets incorporated into the newly replicated DNA in place of thymine (T).

e.g. **2- Aminopurine** is an artificial base analogue of adenine and it can also pair with cytosine (C).

(b) **Alkylating Agents:** Nitrogen mustards **Eg: RN (CH_2Cl_2) diethyl sulphate (DES), dimethyl nitrosamine (DMN) and other alkylating agents** cause methylation or ethylation of nitrogen bases.

(c) **Nitrous Acid:** It is a deaminating agent (oxidative deamination). It disturbs replication (Mutagenic to both replicating and non-replicating DNA) and transcription.

e.g. Adenine (A) is deaminated to hypoxanthine which is complementary to cytosine (C).

Guanine (G) is deaminated to xanthine which is complementary to cytosine (C).

Cytosine (C) is deaminated to Uracil (U) which is complementary to Adenine (A).

(d) **Acridines:** They are derived heteroaromatic molecules from which a number of dyes and pharmaceuticals are prepared.

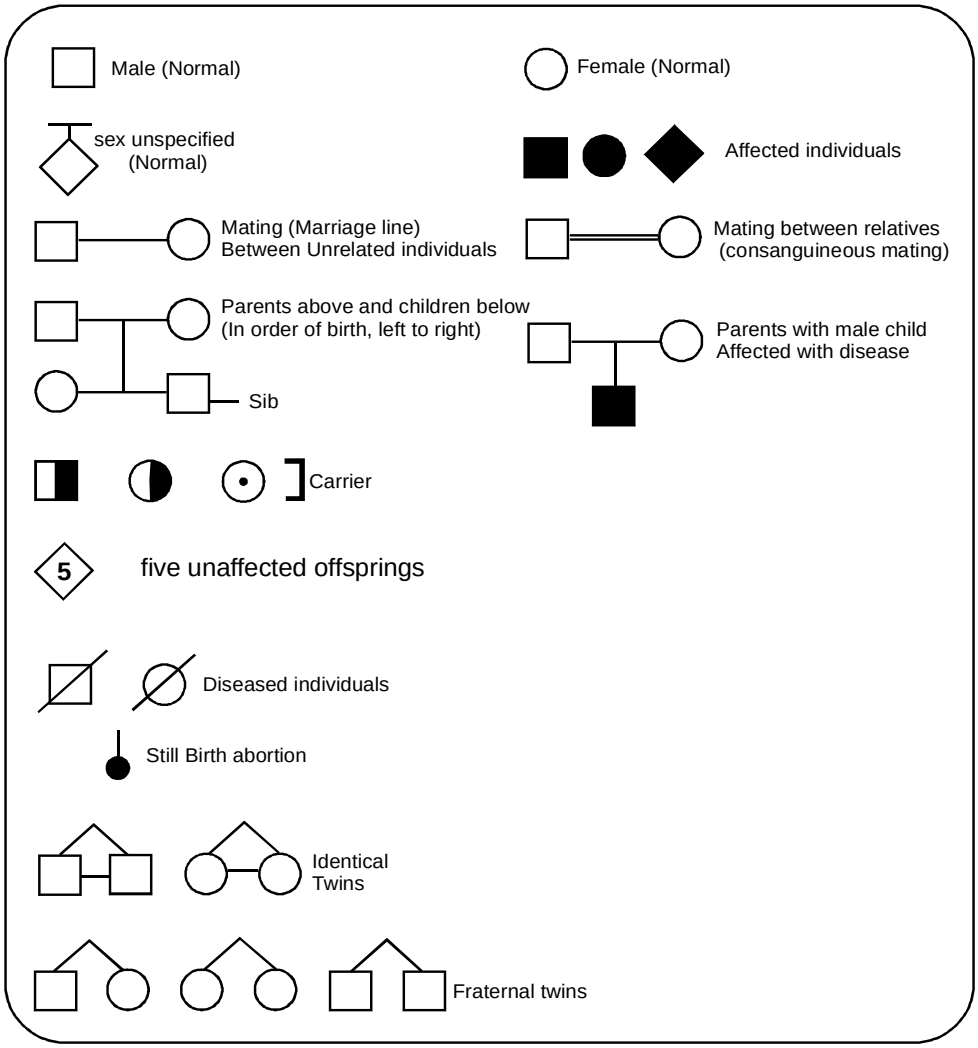
Acridines intercalate between base pairs in DNA and interfere DNA replication causing frameshift mutation.

e.g. Acriflavine, proflavine, acridine orange.

11. HUMAN GENETICS: PEDIGREE ANALYSIS

- The idea that disorders are inherited has been prevailing in the human society since long. This was based on the heritability of certain characteristic features in families.
- The practice of analysing inheritance pattern of traits in human beings began after the rediscovery of Mendel's work.
- Human traits also follow Mendelian inheritance like pea plant and some other organisms but common Mendelian experiment cannot be performed on human traits to study inheritance pattern in successive generations because controlled crosses are **not** possible in humans.
- To study the inheritance pattern of a particular trait of human an alternative method is pedigree analysis.
- Inheritable mutations can be studied by generating a pedigree of a family.
- Pedigree analysis is study of family history of traits in a severals of generations of a family.
- In the pedigree analysis the inheritance of a particular trait is represented in the family tree over generations.
- In human genetics, pedigree study provides a strong tool, which is utilised to trace the inheritance of a specific trait, abnormality or disease.

- It is useful for the genetic counsellors to advice intending couples about the possibility of having children with genetic defects like haemophilia, colourblindness, alkaptonuria, phenylketonuria, thalassemia, sickle cell anaemia, polydactyly & syndactyly.
- Pedigree can be used for analysis of inheritance of the monogenic traits such as tongue rolling, widow's peak, blood group's, red-green colour blindness, dimple in the cheek, hypertrichosis of ear, hitch-hiker's thumb, etc.
- A careful examination of the pedigree chart would suggest whether the gene for the character is autosomelinked dominant or recessive, X - chromosome linked dominant or recessive, Y- chromosome linked or not.



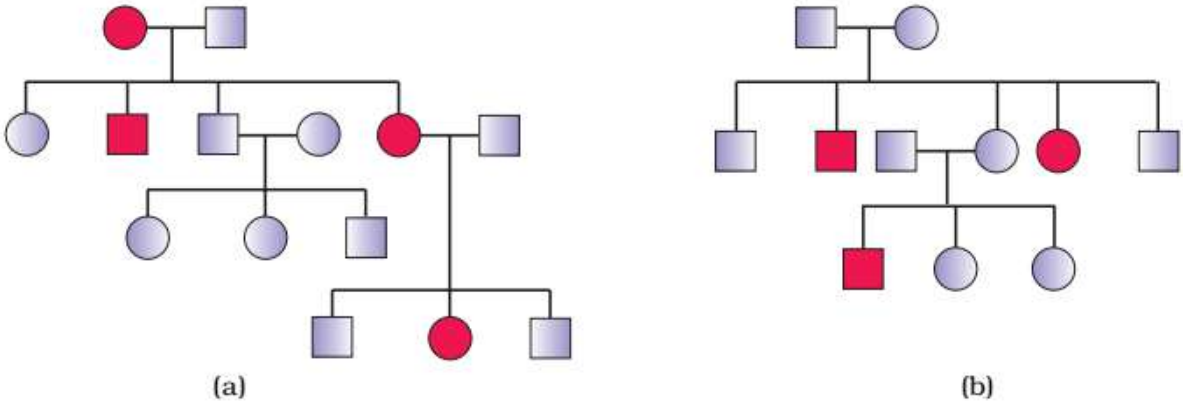
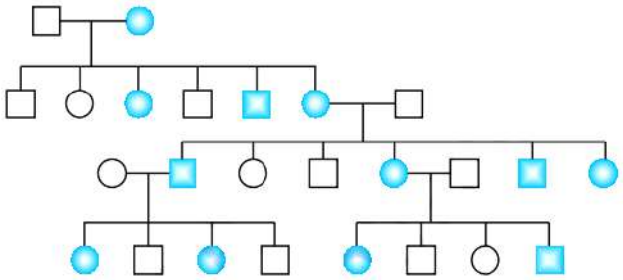


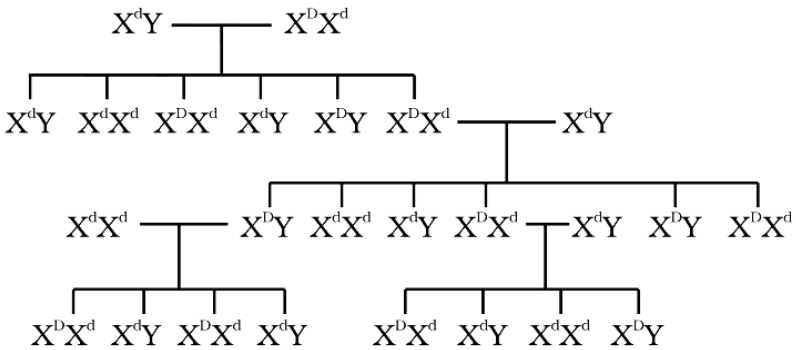
Fig. Representative pedigree analysis of (a) Autosomal dominant trait (for example: Myotonic dystrophy) (b) Autosomal recessive trait (for example: Sickle-cell anaemia)

e.g.



The above pedigree chart shows the inheritance of X-linked dominant trait. Find possible genotype of each organism?

Sol.



12. HUMAN GENETIC DISORDERS:

Genetic disorders: These are the diseases caused by abnormality in the genome. Many times these diseases are inherited from parents to progeny.

Genetic disorders can be:

Mendelian disorders - Arise due to gene mutation.

Chromosomal disorders - Arise due to chromosomal mutation

12.1. Mendelian disorder

- Mendelian disorders are mainly caused by alteration or mutation in the single gene. The mutant form of the gene is responsible for the disease phenotype.
- These disorders are transmitted from parent to progeny based on Mendelian principles of inheritance. The pattern of inheritance of such disorders can be traced in a family by the pedigree analysis.
- Haemophilia, cystic fibrosis, sickle cell anaemia, colour blindness, phenylketonuria are some of the common mendelian disorders.

Classification of Mendelian Disorders

12.1.1 Autosomal dominant disorders:

- These are the traits whose encoding gene is present on any one of the autosomes, and the wild-type allele is recessive to its mutant allele, i.e., the mutant allele is dominant.
- Autosomal dominant disorders appear in both sexes with equal frequency.
- An affected person must have at least one affected parent.
- The trait does not skip generations (The pedigree is vertical, i.e., the trait is marked to be present in each of the generations.)
- Unaffected persons do not transmit the trait.

  Examples: Familial hypercholesterolemia, Huntington disease, Myotonic dystrophy, Brachydactyly (short finger), Polydactyly (extra finger/toes), Achondroplasia (dwarfism), PTC (Phenylthiocarbamine) tasting, Dimple in cheeks, Tongue rolling, Widow's peak (V-shaped hairline).

Huntington's chorea: It is due to **dominant autosomal gene** situated on **chromosome 4,** in which muscle and mental deterioration occurs. Gradual loss of motor control resulting in uncontrollable shaking and dance like movements, slurring of speech, loss of memory and hallucinations after shrinks of brain between 20–30% size. Disease may start at the age of 15– 40 yrs.

12.1.2 Autosomal recessive disorders:

- These are the traits whose mutant allele is recessive to its wild type allele.
- Autosomal recessive disorders appear with equal frequency in both the males and the females.
- Affected children are commonly born to unaffected parents who are carriers.
- The trait tends to skip generations.
- Recessive traits appear more frequently among the offspring of consanguine marriages (marriage between man and woman genetically related to each other, such as cousins)

  Example: cystic fibrosis, phenylketonuria, sickle cell anaemia, Albinism, Thalassemia, attached ear lobe and hitch hiker's thumb

Sickle Cell Anaemia:

- It occurs due to autosomal co-dominant (formerly considered **autosomal recessive**) allele Hb^s present on **chromosome 11**.
- The disease is caused due to **point mutation** in haemoglobin.
- The mutant haemoglobin molecule **undergoes polymerization under low oxygen tension.** This causes the change in the shape of the RBC from biconcave disc to elongated sickle like, which results in anemia and other pleiotrophic effects.
- In human haemoglobin is made up of 2 α and 2 β- globin chains.
- In sickle cell anemia **Glutamic acid** (Glu) at the **sixth position** of the β- globin chain of the haemoglobin molecule is substituted by **Valine** (Val).
- The normal allele for beta globin gene is HbA. The mutant allele responsible for sickle cell anemia is HbS. The allele HbS arises as a result of **single base substitution (transversion) at the sixth codon of the normal β- globin gene from GAG to GUG.**

Normal β-globin DNA:	**TGA GGA CTC CTC.**
mRNA :	**ACU CCU GAG GAG..**
Amino acid	**Glu**
Mutant β-globin DNA. .	**TGA GGA CAC CTC...**
mRNA	**ACU CCU GUG GAG...**
Amino acid	**Val**

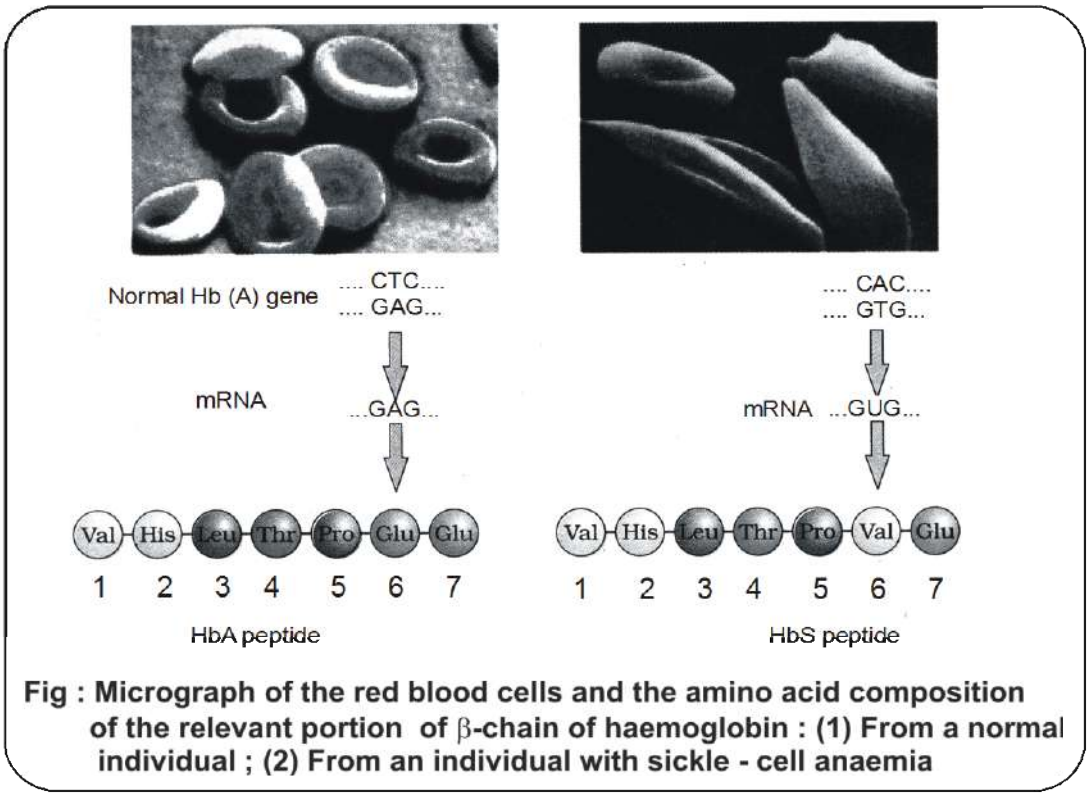


Fig : Micrograph of the red blood cells and the amino acid composition of the relevant portion of β-chain of haemoglobin : (1) From a normal individual ; (2) From an individual with sickle - cell anaemia

- Trait that can be transmitted from parents to the offspring when both the partners are carrier for the gene (or heterozygous). The homozygotes having only haemoglobin-S (Hb^sHb^s) usually die before reaching maturity due to erythrocyte distortion but Hb^AHb^s individuals survive.
- The disease is controlled by a single pair of allele, Hb^A and Hb^S.
- Out of the three possible genotypes (Hb^A Hb^A, Hb^A Hb^S, and Hb^S Hb^S) only homozygous individuals for Hb^S (Hb^SHb^S) show the diseased phenotype. Heterozygous (Hb^AHb^S) individuals appear apparently unaffected but they are carrier of the disease as there is 50 per cent probability of transmission of the mutant gene to the progeny, thus exhibiting sickle-cell trait.

Thalassemia :

- This is also an **autosome-linked recessive** blood disease transmitted from parents to the offspring when both the partners are unaffected carrier for the gene (or heterozygous).
- The defect could be due to either mutation or deletion which ultimately results in reduced rate of synthesis of one of the globin chains (α and β chains) that make up haemoglobin. This causes the formation of abnormal haemoglobin molecules resulting into anaemia which is characteristic of the disease.
- Thalassemia can be classified according to which chain of the haemoglobin molecule is affected. In α Thalassemia, production of α globin chain is affected while in β- Thalassemia, production of β globin chain is affected.
- Thalassemia differs from sickle-cell anaemia in that the former is a quantitative problem of synthesising too few globin molecules while the latter is a qualitative problem of synthesising an incorrectly functioning globin.

Thalassemia	– Quantitative disorder
Sickle cell anaemia	– Qualitative disorder

	α–Thalassemia		**β–Thalassemia**
1.	Gene present on chromosome -16	1.	Gene present on chromosome -11
2.	Controlled by two closely linked genes HBA1 and HBA2	2.	Controlled by a single gene HBB
3.	Caused due to mutation or deletion (16p – short arm) of one or more of the four genes (Alleles)	3.	Caused due to mutation of 1 or both the genes (Alleles).
4.	The more genes affected, the less alpha globin molecules produced (Quantitative effect).	4.	If both Allele affected – no Beta globin synthesis (β–Thalassemia Major) If one allele affected – some Beta globin form (β-Thalassemia Minor/intermedia).
5.	In deficiency of α–globin, β- globin are synthesised in excess which form tetramer (abnormal oxygen dissociation curve).	5.	In deficiency of β–globin, α-globin are synthesised in excess (Toxic aggregate formed) which bind with RBC membrane and damage it. Tetramer formation absent.

Cystic Fibrosis:

- The disease is common in Caucasian population. It occurs due to recessive allele of **chromosome number 7**.
- Symptoms of this disease are the **failure of chloride ion transport mechanism** followed by elevated levels of sodium and chloride in the sweat. Thick mucus accumulates in lungs and respiratory path. It causes blockage and secondary infection. There is impairment of pancreatic and liver functions in most of the cases of cystic fibrosis. Cardiac failure may occur.
- This disorder was formerly called **mucoviscoides**.

Inborn errors of metabolism :

- Metabolic disorder are the genetic diseases involving congenital disorders of metabolism. The majority are due to defects in a single gene that codes for enzyme that facilitates conversion of substrates into products in a metabolic pathway. Some of the common examples of 'inborn errors of metabolism' are phenylketonuria, alkaptonuria, albinism.
- In most of the disorders, problems arise due to accumulation of substances which are toxic or interfere with normal functions. In the absence of enzyme synthesis of essential molecules may also get hampered.

Alkaptonuria:

- **Archibald Garrod,** firsty studied human genetics. He studied black urine disease alkaptonuria and stated that it is inherited by recessive gene. **Garrod was the first to propose that the diseases like Alkaptonuria are due to inborn error of metabolism**.and biochemical genetics, hence Garrod is also known as **"Father of human genetics" or "Father of biochemical genetics".**
- It is an autosomal recessive, metabolic disorder.
- **Deficiency** of an **alkapton oxidase/homogentisate oxidase enzyme** of liver is responsible for it, as a result **homogentisic acid/Alkapton** accumulates in the tissues and is also excreted in the urine.
- Urine turns black in the air due to oxidation of homogentisic acid that's why it is also called as **black urine disease**. Other symptoms are arthritis, bronz pigmentation.

Phenylketonuria (PKU):

- This inborn error of metabolism is also inherited as the **autosomal recessive** trait (chromosome-12).
- The affected individual lacks an liver enzyme **(phenylalanine hydroxylase)** that converts the amino acid phenylalanine into tyrosine. As a result of this phenylalanine is accumulated and converted into phenylpyruvic acid and other derivatives. Accumulation of these in brain results in **mental retardation**.
- These are also excreted through urine because of its poor absorption by kidney.

Albinism:

- Albinos lack dark pigment **melanin** in the **skin, hair** and **iris**.
- It is an **autosomal, recessive genetic disorder**.
- Synthesis of melanin pigment from dihydroxyphenyalanine (DOPA) is absent due to **lack of enzyme tyrosinase**.
- It is due to recessive allele of **long arm of chromosome 11** but may also be caused by another recessive allele of **P- gene** on long arm of **chromosome 15**.

12.1.3 X- Linked dominant disorders:

- These are the traits whose encoding gene is present on the X- chromosome, and the mutant allele of which is dominant over its wild-type allele.
- Such traits are very rare, and are almost difficult to find in the population.
- X-linked dominant traits are seen in both males and females, although they are more common in females than males.
- Daughter affected with an X-linked dominant trait must have an affected parent.
- Father does not inherit the disorder to the sons.

  Example: Duchene Muscular Dystrophy (Oral –facial-digital syndrome) - absence of teeth, cleft (bifid) tongue associated with mental retardation.

12.1.4 X- Linked recessive disorders:

- These are the traits whose encoding gene is present on the X-chromosome and its mutant allele is recessive to its wild-type allele.
- These traits appear more frequently in males than in females.
- These traits are not passed from father to son.
- Affected sons are usually born to unaffected mothers who are carriers.
- If daughters are affected the father would certainly be effected and mother would be at least a carrier.
- X-linked recessive traits tend to skip generations.
- Criss cross inheritance: The trait move from affected father to the daughters who are carrier and expresses in the grandson.
  Example: Haemophilia, colour blindness

Colour blindness:

- It is recessive sex-linked trait in which patient is unable to distinguish red or green or blue colours. The gene for the normal vision is dominant whereas Colour blindness is recessive to normal vision.
- **Type of colour blindness -**

  Red colour blindness - **protonopia**

  Green colour blindness - **deuteronopia**,

  Blue colour blindness - **Tritonopia**
- Colour blindness can be checked by **ishihara card**.
- Colour blindness shows criss-cross inheritance.
- The normal gene and its recessive allele are carried by X-chromosomes. In man Colour Blindness appears in the presence of a single recessive gene (X^cY) whereas in woman colour blindness occurs only when both the sex chromosomes carry the recessive gene ($X^c X^c$).

Condition -1 Normal female (having diseased father) and male Normal.

Parents: XX^C Carrier ♀ × XY Normal ♂

Gametes: XX^C Ova; XY Sperms

Offspring

♀ \ ♂	X	Y
X	XX Normal Girl	XY Normal Boy
X^C	XX^C Carrier Girl	X^C Y Colour Blind Boy

Results : (i) All the Girls are normal (50% normal and carrier whereas 50% normal).

(ii) 50% Boy colour blind and 50% boy have normal vision.

Condition : 2 Carrier female and Colour blind male

Parents: XX^C Carrier ♀ × X^C Y Colour Blind ♂

Gametes: X X^C Ova; X^C Y Sperms

Offspring

♀ \ ♂	X^C	Y
X	XX^C Carrier Girl	XY Normal Boy
X^C	X^CX^C Colour Blind Girl	X^C Y Colour Blind Boy

Results : (i) 50% Girls are Colour blind & 50% normal and carrier Girls.

(ii) 50% Boy colour blind and 50% boy have normal vision.

Condition - 3 Colour blind female and normal male

Parents: X^cX^c Colour Blind ♀ × XY Normal ♂

Gametes: X^c X^c Ova; X Y Sperms

Offspring

♀ \ ♂	X	Y
X^c	XX^c Carrier Girl	X^cY Colour Blind Boy
X^c	XX^c Carrier Girl	X^cY Colour Blind Boy

Results: (i) All the Girls are normal and carrier.

(ii) All the Boys are colour blind.

Condition - 4 Normal female and Colour blind male

Parents: XX Normal ♀ × X^cY Colour Blind ♂

Gametes: X X Ova; X^c Y Sperms

Offspring

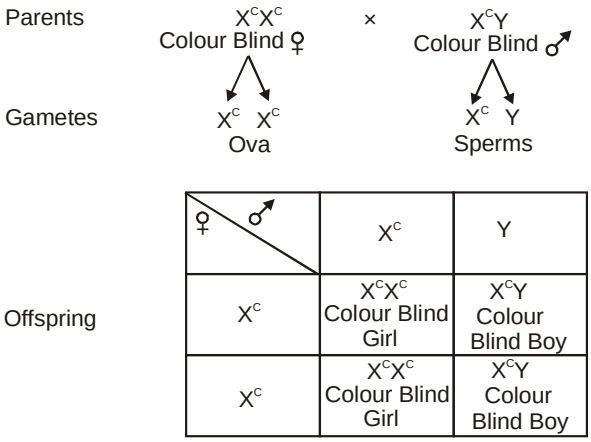
♀ \ ♂	X^c	Y
X	XX^c Carrier Girl	XY Normal Boy
X	XX^c Carrier Girl	XY Normal Boy

Results: (i) All the Girls are normal and carrier.

(ii) All the Boys are normal.

(iii) Occurence of Colour blindness is 0% in the offsprings.

Condition - 5 Colour blind female and Colour blind male.



Results: (i) All Girls & Boys are Colour blind.

Haemophilia (Bleeder's disease) : It was discovered by **John Otto.**

- This sex linked (x-linked) recessive disease, which shows its transmission from unaffected carrier female to some of the male progeny has been widely studied.
- In this disease, a single protein that is a part of the cascade of proteins involved in the clotting of blood is affected. Due to this, in an affected individual a simple cut will result in non-stop bleeding hence it is called bleeder's disease.
- The heterozygous female (carrier) for haemophilia may transmit the disease to sons and it is more common in male because male is hemizygous for X-chromosome.
- The possibility of a female becoming a haemophilic is extremely rare because mother of such a female has to be at least carrier and the father should be haemophilic (unviable in the later stage of life).
- The family pedigree of Queen Victoria shows a number of haemophilic descendents as she was a carrier of the disease hence it is called Royal disease.

  It is of two types.

  (i) Haemophilia – A: Deficiency of clotting **factor VIII (AHG/AHF or Anti Hemophiliac Globulin/Factor).**

  (ii) Haemophilia – B: Deficiency of **clotting factor IX (Plasma thromboplastin factor/Christmas factor).**

Note :-

Inheritance pattern of haemophilia is similar to colour blindness as both are X-linked recessive disease.

12.2. Chromosmal Disorders:

The chromosomal disorders on the other hand are caused due to absence or excess or abnormal arrangement of one or more chromosomes.

Chromosomal disorder can be easily studied by analysis of Karyotypes.

Note:- Karyotyping is a technique to identify and evaluate the size, shape, and number of chromosomes. A karyotype test is done on blood sample taken from vein, sample of amniotic fluid or chorionic villi or cells from bone marrow.

12.2.1 Sex Chromosomal Disorders: These are as follows.

(1) Klinefelter's Syndrome:

- It is found in men but individuals are sterile.
- This genetic disorder is also caused due to the presence of an additional copy of X-chromosome (Trisomy of X chromosome) resulting into a karyotype of **47, XXY**.
- The karyotypes 48, XXXY; 48, XXYY; 49, XXXXY and 49, XXXYY are phenotypically similar to 47, XXY.

Such an individual has overall masculine development, however, the feminine development (development of breast, i.e., **Gynaecomastia**) is also expressed (due to the presence of additional X-chromosome). Other symptoms include undeveloped testes, sparse body hair, mental retardation.

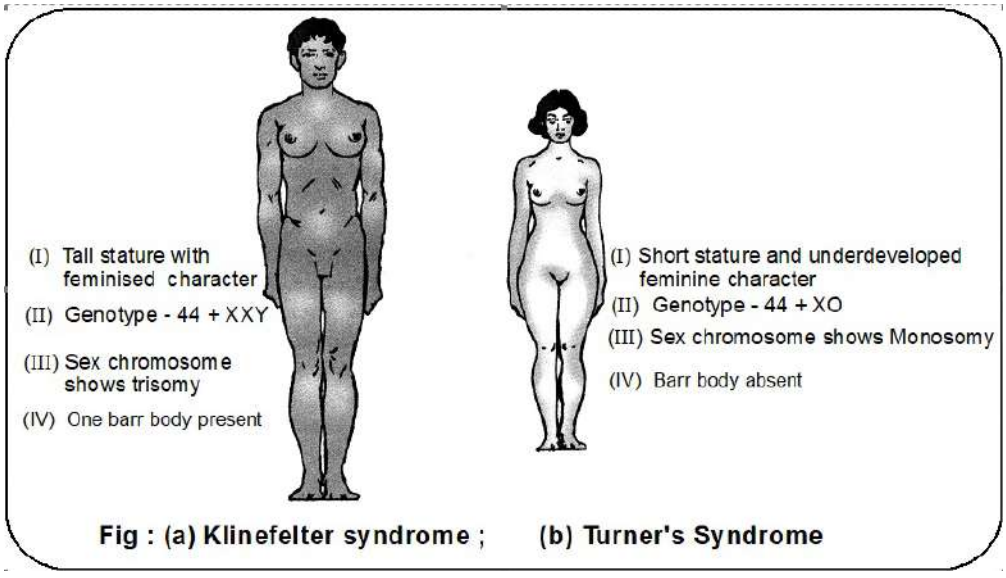


Fig : (a) Klinefelter syndrome ; (b) Turner's Syndrome

(2) Turner's Syndrome:

- It is found in female and are sterile.
- Such a disorder is caused due to the absence of one of the X chromosomes, i.e., **45 with X0**,
- **Symptoms : ovaries are rudimentary,** lack of other secondary sexual characters, menstrual cycle is abnormal or absent, small uterus, short stature, abnormal intelligence (Cognitive impairment), Skin folds on the back of the neck (webbed neck).

(3) Supermales (Jacob's syndrome or criminal syndrome):

- The genotype of supermale is **44 + XYY** & total number of chromosomes are 47 instead of 46. These males are characterised by abnormal height, mental retardation and criminal bent of mind **(Jacob's syndromes)** super males are more aggressive than normal males due to over secretion of male sex hormones.

(4) Super female:

- The genotype of super female is either **44 + XXX (47 chromosomes) or 44 + XXXX (48 chromosomes) or 44 + XXXXX (49 chromosomes).** They have abnormal sexual development and mental retardation.

12.2.2 Autosomal Disorders: These are as follows.

(1) Down's Syndrome (Mongolian Idiocy):

- This disorder was first described by Langdon Down (1866). The cause of this genetic disorder is the presence of an additional copy of the chromosome number 21 (trisomy of 21).
- The most common autosomal aneuploidy in humans.
- The incidence of Down's syndrome increases among children born to older mothers (more than 35 year).
- It is caused by nondisjunction of 21st chromosome pair during anaphase. Thus the total number of chromosomes are 47 instead of 46 & genotype is 45 + XY in male & 45 + XX in female.
- **Symptoms -** Short statured with small round head, Flat back of head, broad flat face, Mongolian type eye lid fold, vertical fold epicanthus on either side of nose, furrowed tongue (Protruding big and wrinkled tongue) causes the mouth to remain partially open, Palm is broad with characteristic palm crease (Simian crease), stubby fingers, many 'loops' on finger tips and congenital heart disease. Physical, psychomotor and mental development is retarded.

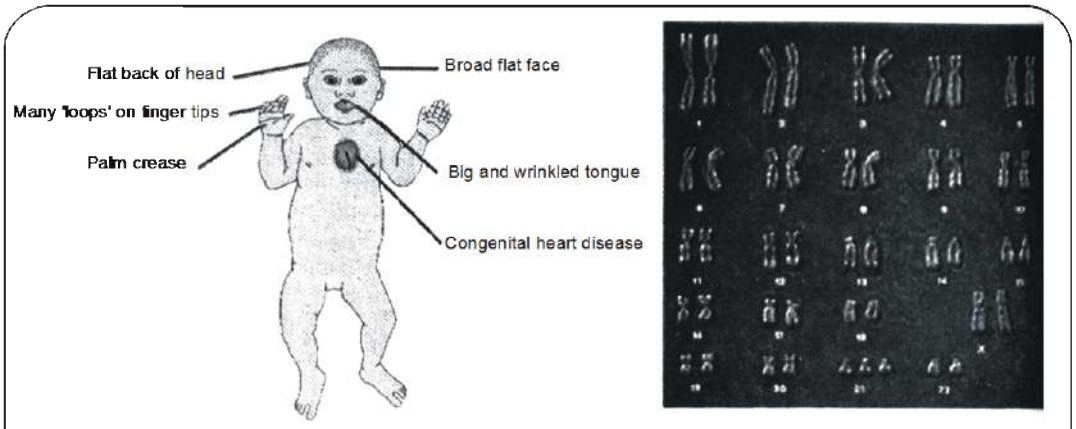


Fig : A representative figure showing an individual infected with Down's syndrome and the corresponding chromosomes of the individual

1. Find correct statement –

(1) Chromosomal aberrations are always observed in cancer cells

(2*)Chromosomal disorders are transmitted to the offspring on the same lines as Mendellian inheritance.

(3) Colourblindness occurs in about 8 per cent of female and only about 0.4 per cent of male.

(4) Mendellian disorder are recessive only

2. How many statements are correct?

a. In human genetics, pedigree study are utilised to trace the inheritance of a specific trait, abnormality or disease.

b. Practice of analysing inheritance pattern of traits are not possible in case of human beings because controlled crosses are not possible like Mendel performed in pea plant.

c. Son affected with an X-linked dominant trait can have unaffected parents.

d. The practice of analysing inheritance pattern of traits in human beings began before the rediscovery of Mendel's work.

(1*) 1 (2) 4 (3) 2 (4) 3

3. How many character are associated with down syndrome –

Feminine character, gynaecomastia, anaemia, mental retardness, sickle shaped RBC, congenital heart disease, Palm crease, furrowed tongue, tall stature.

(1) 8 (2) 6 (3*) 4 (4) 5

4. How many disease causes mental retardness ?

Down syndrome, Phenylketonuria, Klinefelter syndrome, Super female, Sickle cell anaemia, Thalassemia, Haemophilia

(1) 5 (2*) 4 (3) 3 (4) 2

5. Which of the statements are true –

a. The α-thallasemia can be caused due to mutation as well as deletion of one or more genes on chromosome -16 but β-thallasemia is caused due to mutation of one or both genes on chromosome-11

b. Incorrectly functioning globin protein is found in sickle cell anaemia as well as thallasemia.

c. Abnormal haemoglobin is formed in sickle cell anaemia as well as thallasemia.

(1) a & b (2) b & c (3*) a & c (4) a, b & c

Ans. 1. (2) **2.** (1) **3.** (3) **4.** (2) **5.** (3)

13. CYTOPLASMIC INHERITANCE:

- Some self-replicating genes (DNA) are present in the cytoplasm (mitochondrial DNA and chloroplast DNA) also. These are called plasmagenes and all the plasmagenes together constitute plasmon (like genome).
- The inheritance of characters by plasmagenes is called extra nuclear or extra chromosomal inheritance. E.g. Kappa particles and sigma particles.

Certain most important examples of extranuclear inheritance in eukaryotes are following:

Maternal inheritance / Pre-determination: The amount of nuclear hereditary material contributed by the two sexes is almost equal but the cytoplasm in egg is always much more than that of the sperm. So, in extranuclear inheritance, contribution of female parent is more. This is called maternal inheritance. The evidence of maternal inheritance is the coiling of shell in snails.

Organelle inheritance: The DNA is present in mitochondria and chloroplast which controls the inheritance of some characters.

Mitochondrial inheritance: Cytoplasmic male sterility in maize, inheritance of poky (imbalance in the mitochondrial physiology) in the fungus *Neurospora crassa* and Petite in yeast.

Plastid inheritance: A well-known example of plastid inheritance in *Mirabilis jalapa* (4 O'clock plant), discovered by **Correns.** Inheritance are iojap inheritance in maize.

1. The term **'Factor'** was fIrstly used by **Correns.** Which was called **determinor** or **element** by **Mendel**.
2. **Barr Body:** It was discovered by **Barr & Bertman** in interphase stage of nerve cell of female cats. According to Mary Lyon (1962) one of the two X-chromosomes of a normal female becomes heterochromaticand appears as Barr body. It appears as **drum stick** (these are sex chromatin present in the neutrophil of 3 to 5% cells of females and absent in the neutrophils of males) in leucocytes of females. This inactivation of one of the two X-chromosomes of a normal female is called as dosage compensation or '**Lyon's hypothesis**'. The number of Barr bodies is always less than the number of X-chromosome or X – 1.

Table

S.No	Organism	No. of X – Chromosome	No. of Barr body (X – 1)
1	Normal female	XX	2–1= 1 (1 barr body)
2	Normal male	XY	1 –1 = 0 (No barr body)
3	Super female	XXX	3 – 1 = 2 (two barr body)
4	Klinfelter syndrome	XXY	2 –1 = 1 (1 barr body)
5	Turner syndrome	XO	1 –1 = 0 (No barr body)
6	Super male	XYY	1 –1 = 0 (No barr body)

3. Mutation :-

- **Pleiotropic mutation:** Mutation in a gene which has more than one phenotypic expression will affect a variety of characters, such mutation is called pleiotropic mutation **Eg : In sweet pea a single** point mutation cause changes in seed coat colour from Grey to white and flower colour from red to white.
- **Homeotic Mutation:** A mutation that causes part to form another structure instead of forming its normal structure.
- **Polyploidy can be artificially induced by application of colchicine and granosan**.
- **Seth Wright** (1791) firstly recorded point mutation. He observed **short legged lamb (ancon sheep).**
- Scientifically **Thomas Hunt Morgan** observed actual mutation (gene mutation) when he found white eyed mutant of male Drosophila among wild type red eyed Drosophila.

Type of mutation

- **Same-sense mutation or silent mutation:** In this type the codon is changed but the It does not alter the amino acid specificity **Eg : (CCA CCC , GCC GCG)**
- **Mis-sense mutation:** When the meaning of codon changes from one amino acid to another it is called missense mutation Eg : Sickle cell anaemia.
- **Non sense mutation:** In this types polypeptide synthesis is stopped due to formation of a stop / terminating or nonsense codon, such as UAA, UAG, UGA.

Chromosomal mutation

- **Double monosomic:** In double monosomic one chromosome is deficient in each chromosome of a pair. It represents as **2n – 1 – 1**.
- **Mixed Aneuploids:** In which both hypoploidy and hyperploidy occur in two different pair of chromosome. **Eg: 2n + 1 A – 1B**.
- **Euploidy:** In which chromosome number is exact multiple of genome **Eg: Monploidy, diploidy, polyploidy.**

4. Genetic disorder

- **Deficiency of G-6PD:**

The enzyme glucose 6- phosphate dehydrogenase is present in RBC for minor glycolysis. The absence of this enzyme is a sex linked recessive trait. The persons deficient in this enzyme cannot have plasmodium in their RBC and hence cannot suffer from malaria. But if such person are given antimalarial drugs, the RBCs, being fragile, can rupture and cause severe anaemia.

- **Tay-Sach's Disease (TSD) / Infantile Amourotic Idiocy:**

It is recessive autosomal disorder that occurs due to **deficiency** of **enzyme β-D-N-acetyl hexosaminidase** after birth. Symptoms of this disease involve damaging brain and spinal cord. Mental retardation and paralysis due to **accumulation of lipid GM_2 or Tay-Sach's ganglioside**. The child is dead at the age of 3–4 yrs.

- **Edward's Syndrome:**

It is due to **trisomy** in **18th pair of chromosomes**.The affected person keeps the fingers tightly clenched against the palm of the hand. Other symptoms are small jaws, deformed ears, small mouth, nose and fingers, small sternum and pelvis. The patient is mentally retarted and dies within 6 months after birth.

- **Patau's Syndrome :**

It occurs due to **trisomy** in **13th pair of chromosomes**. It is characterised by small head, abnormalities of the face, eyes and forebrain, cleft lip and palate, deformed ears, small chin and the hands are often clenched as Edward's syndrome. The average life span of the affected person is about 4 months.

- **Cri du chat Syndrome or Cat Cry Syndrome :**

It is due to **deletion** of half part in the **short arm of the chromosome number 5 (5p).**

The affected newborn cries like mewing of a cat hence it named Cri du chat (Cat Cry). Its other symptoms are moon like face, widely spaced eyes, small head, receding chin, congenital heart disease.

- **Alzheimer's Disease:**

It is **neuro-degenerative disease of brain** that occurs due to accumulation of **amyloid protein plaques (amyloid-b peptide protein)** resulting degeneration of neurons takes place in patient. Two defective autosomal alleles,(one on the **chromosome 21** and other on **chromosome 19**) are involved. They produce disease after the age of 40. **Symptoms** involve **changes in personality, memory loss, trembling of hands followed by progressive increase in dementia over next 5–10 yrs.**

5. **Branches of applied genetics –**

- **Eugenics:** Improvement of human race by the application of genetics is called Eugenics. **Francis Galton** is called the '**Father of eugenics**'.
- **Euthenics:** Improvement of the human race by improving the environmental conditions is called Euthenics.
- **Euphenics:** The symptomatic treatment of genetic diseases of man is called euphenics.

6. **Bateson and Punnet** worked on **sweet pea** (***Lathyrus odoratus***) and proposed **coupling and repulsion hypothesis**. They found that the factors for certain characters do not show independent assortment thus **linkage** is **exception of independent assortment**. Therefore the **dihybrid ratio is only 3 : 1 and a test cross ratio of 1 : 1.**

7. **Study of Twins:** Birth of two babies simultaneously by woman. Twins are of following types.

- **Dizygotic twins or fraternal twins:** If twins develop from two separate fertilized eggs, they are called dizygotic or fraternal twins.
- **Monzygote twins:** Twins develop from the same fertilized egg (zygote) due to splitting of zygote in to two blastomeres. The former also called identical twins because they are genetically similar except occasional mutation.
- **Siamese twins:** Sometime breaking of young embryo is incomplete so that monzygotic twins are joined in various regions.

8. **Sex chromosome** discovered by "**Mc Clung**" in **Grasshopper**.

- Homologous part of Y- chromosome (the part that synapses with X-chromosome) bears some similar genes of X-chromosoeme. These are called X-Y linked genes, Eg: Xeroderma pigmentosum (skin cancer), epidermolysis bullosa (blistered skin) in humans.
- XO- Chromosomal abnormality in human beings causes turner's syndrome. While in some insects like grasshopper, XO type of sex chromosome determines male sex.

9. **Fairchild:** It is first successful plant hybrid (fairchild's Mule) that is formed by cross between Dianthus (carnation) and centuria (Sweet William).

10. **IQ (Intelligent Quotient):** It is the measurement of intelligence. It is governed by 11 sets of genes. IQ is calculated as.

$$\textbf{IQ} = \frac{\textbf{Mental age}}{\textbf{Actual age}} \times 100$$

Suppose a ten year child has mental age 13, his IQ will be $\frac{13}{10} \times 100 = 130$.

11. **Interference and Coincidence:** One cross over decreases the occurrence of frequency of another crossing over. It is called interference. The ratio of observed double cross over and expected double cross over is called coincidence. The latter is small when interference is high.

$$\textbf{Coefficient of coincidence} = \frac{\textbf{\% observed double cross overs}}{\textbf{\% expected double cross overs}}$$

12. **Polyploidy involves three types:**

(i) Autopolyploidy **(ii) Allopolyploidy** **(iii) Autoallopolyploidy**

(i) Autopolyploidy:

- It is a numerical increase of the same genome such as Autotriploidy (AAA) **Eg : Rice, Gram, Maize**.

(ii) Allopolyploidy:

- It is formed by hybridisation between two species followed by doubling of chromosomes such as (AABB) **Eg : Wheat, Tobacco, artificially produced two allopolyploids are Raphanobrassica (4N) and Triticale(6N).**

(iii) Autoallopolyploidy:

- One genome is in more than diploid state such as (AAAABB) **Eg: *Helianthus tuberosus***.