Chapter 5

Principles of Inheritance and Variation

Introduction: Principles of Inheritance & Variation

What do we mean by Heredity?

Do you remember your grandparents telling you that you are just like your father or mother? That is the concept of heredity, the most puzzling and mysterious phenomenon of nature.
No matter how unique we call ourselves, we happen to be an accumulation of all the traits we have inherited. Therefore, our bloodline matters and those traits travel through you till the end of time. Before we understand the importance of inheritance and variation, we need to understand the following terms:

- **Genetics**

  Genetics is the study of principles and mechanisms of heredity and variation. Genetics term was given by W. Bateson (Father of Modern Genetics).

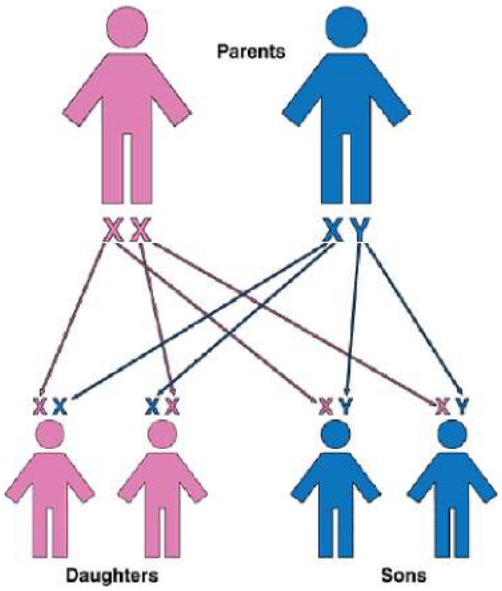
- **Heredity**

  It is a process of transmission of parents' traits to their offspring either via asexual reproduction or sexual reproduction. These characteristics or traits are located on the chromosomes in the form of genes.

- **Variation**

  It is the degree to which progeny differ from their parents. Variation may be in terms of **morphology**, **physiology**, **cytology**, and **behavioristic** traits of individual belonging to the same

species. **Variation arises from** Reshuffling of gene/chromosomes, Crossing over or recombination, mutation, and the environment's effect.



How heredity occurs in human beings

History of Researchers in Genetics

- **Muller:** Father of **Actinobiology**. Actinobiology is the study of the effects of radiation on living organisms.
- **Morgan:** Father of Experimental genetics. He did experiments on Drosophila & proposed various concepts.
- **Gene Theory:** Gene Theory is one of the basic principles of biology. The main concept of this theory is that traits are passed from parents to offspring through gene transmission. Genes are located on chromosomes and consist of DNA. They are passed from parent to offspring through reproduction.
- **Garrod:** Father of human genetics & Biochemical genetics. Garrod discovered the first human Metabolic, genetic disorder called **alkaptonuria**(black urine disease). In this disease enzyme, homogentisic acid oxidase is deficient. Gave the concept 'One mutant gene one metabolic block.

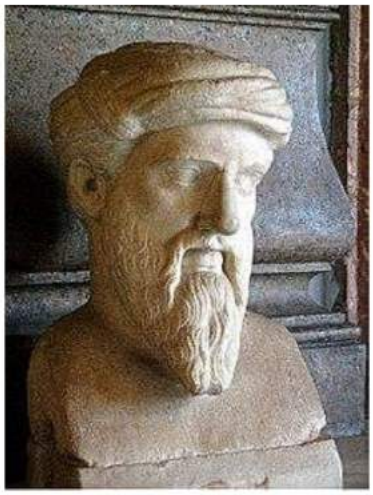
Pre-Mendelian Theories

To explain the like begets (offsprings are similar to their parents), several theories were given. They are collectively known as **theories of Blending**

Inheritance as they believed that characters of the parents blended or got mixed during their transmission to the offspring.
Some of them are as follows:

1. Vapour Fluid Theory

- Greek philosopher **Pythagoras** [500B.C.] proposed this theory. According to this theory, at the time of coitus of male and female, moist vapour secretes from the brain, and due to this, offsprings are similar to their parents.



Pythagoras

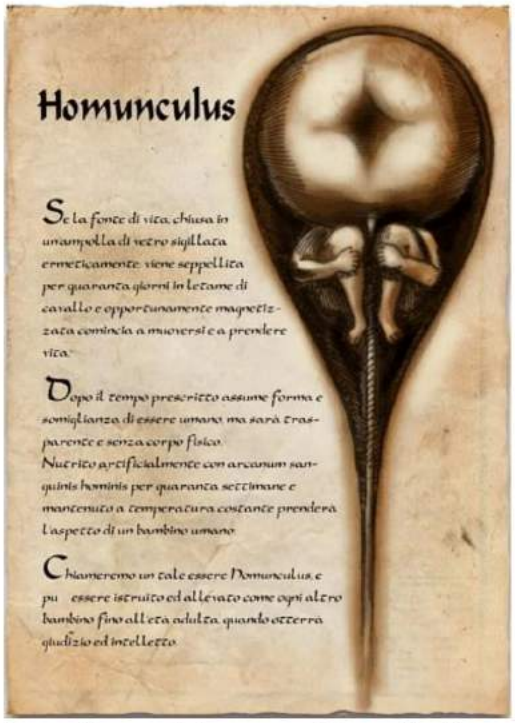
2. Semen Theory

- This theory has given by **Empedocles**. In his view, the semen of males and females is mixed during coitus. Characters of parents appear in the offsprings due to the mixture.
- According to **Aristotle, the** semen of a male is considered **"highly purified blood"** with the power of life, and the semen of a female nourishes it.

3. Preformation Theory

- The theory of preformation believes that the organism is already present, which is performed in the sperm or egg in a miniature form called **homunculus** (Fig. 5.1). Fertilization is required to stimulate its growth. Sperms were observed for the first time by Leeuwenhoek, in 1672.

- Preformation theory was given by **Swammerdam** (1679) and advocated by **Malpighi** (1673). It was believed by a number of workers of that period like Hartosoeker (1694) and Dalepatius (1694). It was supported by Roux as late as 1888 but discarded by Wolff who suggested that organs are formed step by step (theory of epigenesis).



Homunculus - Spermist conception of a human sperm

5. Encasement Theory

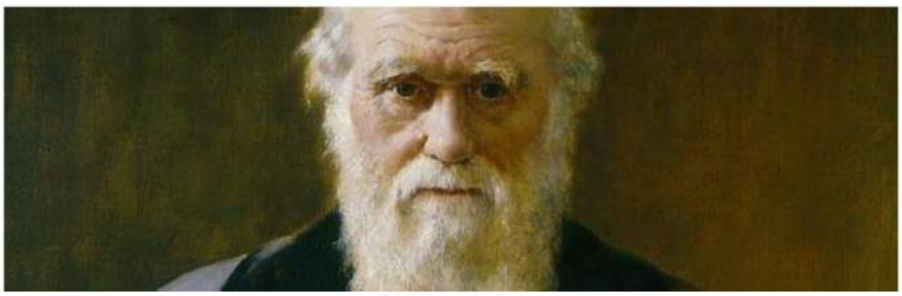
- Charles Bonnet and his supporters presumed that every female contains within her body miniature prototypes of all the creatures which would descend from her, one generation within the other, somewhat like a series of Chinese boxes. This was named encasement theory.

6. Epigenesis Theory

- Wolff proposed that the germ cells contain definite but undifferentiated substances, which, after fertilization, become organized into various complex body organs that form the adult. This idea was referred to as epigenesis.

7. Pangenesis Theory

- The theory of pangenesis was described by **C.Darwin**. This theory postulated that all parts of a living body [tissues] synthesize **"micro molecules."** These micro molecules are known as **Pantene** or **Gemmules**.



C. Darwin

- The male and female pangenes fuse together during fertilization. These are, further again distributed in the various organs of the body at the time of development.

8. Germplasm Theory

- This theory, advocated by **August Weismann** (1889), a German biologist, states that body tissues are of two types, viz., germplasm and Somatoplasm. The germplasm refers to the reproductive tissues or cells which produce gametes.
- The Somatoplasm includes all other body tissues which are not related to sexual reproduction. Thus, the transmission of characters from one generation to another takes place only through germplasm. Any change in the germplasm will lead to change in the next generation. This theory is accepted in a broad sense.

Key Terms

Term	Meaning
Genetics	The study of biological inheritance
Trait	A specific characteristic of an individual
Gene	A unit of heredity that is passed from parent to offspring
Allele	One of different forms of a gene
Genotype	The genetic makeup of an organism (ex: TT)
Phenotype	The physical characteristics of an organism (ex: tall)
Dominant allele	Allele that is phenotypically expressed over another allele
Recessive allele	Allele that is only expressed in absence of a dominant allele
Homozygous	Having two identical alleles for a particular gene
Heterozygous	Having two different alleles for a particular gene
Punnett square	Diagram that can be used to predict the genotypes and phenotypes resulting from a genetic cross

Inheritance of One Gene

Incomplete Dominance Definition

"Incomplete dominance is a form of intermediate inheritance in which one allele for a particular trait is not expressed completely over its paired allele."

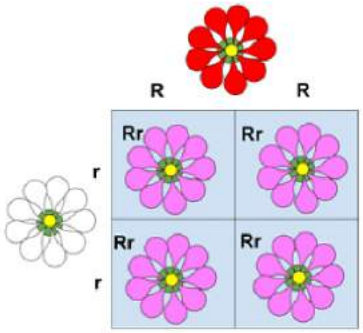
What is Incomplete Dominance?

Incomplete dominance is a form of Gene interaction in which both alleles of a gene at a locus are partially expressed, often resulting in an intermediate or different phenotype. It is also known as **partial dominance**.
For eg., in roses, the allele for red colour is dominant over the allele for white colour. But, the heterozygous flowers with both the alleles are pink in colour.

Mechanism of Incomplete Dominance

Incomplete dominance occurs because neither of the two alleles is completely dominant over the other. This results in a phenotype that is a combination of both. Gregor Mendel conducted experiments on pea plants. He studied on seven characters with contrasting traits and all of them showed a similar pattern of inheritance. Based on this, he generalized the law of inheritance.
Later, researchers repeated Mendel's experiment on other plants. Shockingly, they

noted that the F1 Generation showed variation from the usual pattern of inheritance. The monohybrid cross resulted in F1 Progeny which didn't show any resemblance to either of the parents, but an intermediate progeny.
Let's understand the incomplete dominance with the example of Snapdragon flower (Antirrhinum sp).



Monohybrid cross was done between the red and white coloured flowers of Snapdragon plant. Consider, pure breed of the red flower has RR pair of alleles and that for the white flower is rr.
Firstly, true-breeding red (RR) and white (rr) coloured flowers of snapdragon were crossed. The F1 generation produced a pink coloured flower with Rr pair of alleles. Then the F1 progeny was self-pollinated. This resulted in red (RR), pink (Rr) and white (rr) flowers in the ratio of 1:2:1.
Recollect that the genotype ratio of F2 generation in the monohybrid cross by Mendel also gave the same ratio of 1:2:1. However, the phenotype ratio has changed from 3:1 to 1:2:1. The reason for this variation is the incomplete dominance of the allele R over the allele r. This led to the blending of colour in flowers.

Concept of Dominance

In genetics, Dominance is a relationship between alleles of one gene. In order to understand the concept of the dominance of alleles, we need to know more about genes.
So far we know that genes are a hereditary unit in organisms which exist as a pair of alleles in diploid organisms. These pair of alleles may or may not be similar. That is, a heterozygous gene has two dissimilar pairs of alleles while homozygous have identical ones.
Heterozygous alleles carry different information on traits. When we say one trait is dominant over the other, there can be two reasons:

- either it is non-functional, or
- is less active than the normal allele

Incomplete Dominance and Codominance

Incomplete dominance and codominance are different from each other.
In codominance, both the alleles present on a gene are expressed in the phenotype. A flower showing codominance will have patches of red and white instead of a uniformly pink flower.
In incomplete dominance, the F2 generation from heterozygous plants will have a ratio of 1:2:1 with the phenotypes red, white and spotted flowers.
The humans with AB blood type also show codominance where the alleles for both blood types A and B are expressed.

Examples of Incomplete Dominance

Examples of incomplete dominance are mentioned below:

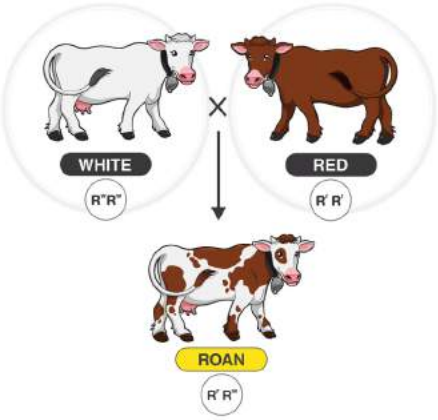
In Humans

The child of parents each with curly hair and straight hair will always have wavy hair. Carriers of Tay-Sachs disease exhibit incomplete dominance.

In Other Animals

The Andalusian chicken shows incomplete dominance in its feather colour. When the rabbits with long and short furs are bred, the offsprings produced will have medium fur length.

Co-Dominance and Multiple Alleles



Dominance is a relationship between two alleles of one gene that affect the phenotype of one allele and masks the contribution of another allele.
The trait which is expressed in a phenotype is called the dominant trait and the suppressed one is called a recessive trait. Incomplete dominance is a type of dominance where a trait incompletely dominates over the other and results in an intermediate progeny.

Co-dominance

Co-dominance is the type of dominance where the offspring show similarity to both the parents and it is due to the blending of alleles.
Let us learn more about codominance in the coming lines.
When the F1 generation exhibits both the parental characters, this is called codominance. The offspring will be a combination of both the parent. The ABO blood group system is one of the best examples of codominance.
There are different types of red blood cells such as A, B, AB and O with or without the Rh factor. The difference is in the antigen present on the red blood cell surface which determines the specific blood group in an organism.
For example: If a person is blood group A, it means the RBC surface consists of antigen-A. But this is decided by the gene I. The gene I have three types of alleles namely, IA, IB and i. The alleles IA and IB produce two different antigens while the allele-i do not produce any antigen. Hence, alleles IA and IB are dominant over the allele i.
As we know, each diploid organism bears two pairs of alleles. Hence, in humans, there are two types of alleles of any combination. Depending on the combination and dominance of allele blood type of an individual could be determined. The different combination of alleles and their type of blood groups are given below.

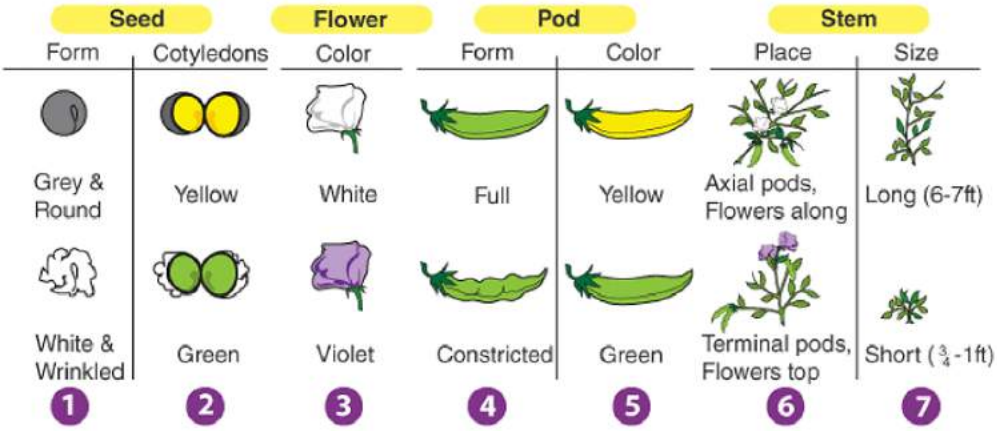
Genotype	Blood type
$I_A I_A$	A
$I_A I_B$	AB
$I_A i$	A
$I_B I_B$	B
$I_B i$	B
ii	O

In the above example, A person with blood group A indicates that he has an IA and i pair of alleles. This is because the allele i is recessive in character and no antigen is produced. However, a person who possess both the alleles IA and IB, they have blood group AB. This is because of alleles IA and IB are codominant. Both the gene will produce their type of antigen.

Mendel's Laws of Inheritance

Inheritance can be defined as the process of how a child receives genetic information from the parent. The whole process of heredity is dependent upon inheritance and it is the reason that the offsprings are similar to the parents. This simply means that due to inheritance, the members of the same family possess similar characteristics.
It was only during the mid 19th century that people started to understand inheritance in a proper way. This understanding of inheritance was made possible by a scientist named Gregor Mendel, who formulated certain laws to understand inheritance known as Mendel's laws of inheritance.

Mendel's Laws of Inheritance



Between 1856-1863, Mendel conducted the hybridization experiments on the garden peas. During that period, he chose some distinct characteristics of the peas and conducted some cross-pollination/ artificial pollination on the pea lines that showed stable trait inheritance and underwent continuous self-pollination. Such pea lines are called true-breeding pea lines.

Why was Pea Plant Selected for Mendel's Experiments?

He selected a pea plant for his experiments:

- The pea plant can be easily grown and maintained.
- They are naturally self-pollinating but can also be cross-pollinated.
- It is an annual plant, therefore, many generations can be studied within a short period of time.
- It has several contrasting characters.

Mendel conducted 2 main experiments to determine the laws of inheritance. These experiments were:

- Monohybrid Cross Experiment
- Dihybrid Cross Experiment

While experimenting, Mendel found that certain factors were always being transferred down to the offspring in a stable way. Those factors are now called genes i.e. genes can be called the units of inheritance.

Mendel's Experiments

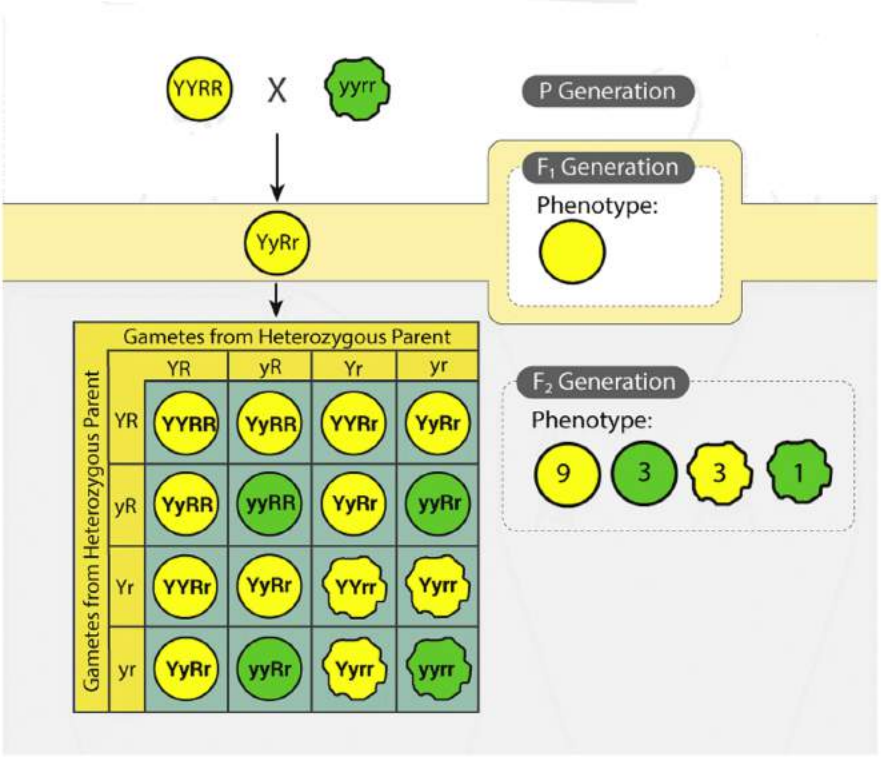
Mendel experimented on a pea plant and considered 7 main contrasting traits in the plants. Then, he conducted both the experiments to determine the aforementioned inheritance laws. A brief explanation of the two experiments is given below.

Monohybrid Cross

In this experiment, Mendel took two pea plants of opposite traits (one short and one tall) and crossed them. He found the first generation offsprings were tall and called it F1 progeny. Then he crossed F1 progeny and obtained both tall and short plants in the ratio 3:1. To know more about this experiment, visit Monohybrid Cross – Inheritance Of One Gene.
Mendel even conducted this experiment with other contrasting traits like green peas vs yellow peas, round vs wrinkled, etc. In all the cases, he found that the results were similar. From this, he formulated the laws of Segregation And Dominance.

Dihybrid Cross

In a dihybrid cross experiment, Mendel considered two traits, each having two alleles. He crossed wrinkled-green seed and round-yellow seeds and observed that all the first generation progeny (F1 progeny) were round-yellow. This meant that dominant traits were the round shape and yellow colour.
He then self-pollinated the F1 progeny and obtained 4 different traits wrinkled-yellow, round-yellow, wrinkled-green seeds and round-green in the ratio 9:3:3:1. Check Dihybrid Cross and Inheritance of Two Genes to know more about this cross.



After conducting for other traits, the results were found to be similar. From this experiment, Mendel formulated his second law of inheritance i.e law of Independent Assortment.

Conclusions from Mendel's Experiments

- The genetic makeup of the plant is known as the genotype. On the contrary, the physical appearance of the plant is known as phenotype
- The genes are transferred from parents to the offsprings in pairs known as allele.
- During gametogenesis when the chromosomes are halved, there is a 50% chance of one of the two alleles to fuse with the other parent.
- When the alleles are the same, they are known as homozygous alleles and when the alleles are different they are known as heterozygous alleles.

Mendel's laws

The two experiments lead to the formulation of Mendel's laws known as laws of inheritance which are:

- Law of Dominance
- Law of Segregation
- Law of Independent Assortment

Law of Dominance

This is also called Mendel's first law of inheritance. According to the law of dominance, hybrid offsprings will only inherit the dominant trait in the phenotype. The alleles that are suppressed are called as the recessive traits while the alleles that determine the trait are known as the dormant traits.

Law of Segregation

The law of segregation states that during the production of gametes, two copies of each hereditary factor segregate so that offspring acquire one factor from each parent. In other words, allele (alternative form of the gene) pairs segregate during the formation of gamete and re-unite randomly during fertilization. This is also known as Mendel's third law of inheritance.

Law of Independent Assortment

Also known as Mendel's second law of inheritance, the law of independent assortment states that a pair of trait segregates independently of another pair during gamete formation. As the individual heredity factors assort independently, different traits get equal opportunity to occur together.

Key Points on Mendel's Laws

- The law of inheritance was proposed by Gregor Mendel after conducting experiments on pea plants for seven years.
- The Mendel's laws of inheritance include law of dominance, law of segregation and law of independent assortment.
- The law of segregation states that every individual possesses two alleles and only one allele is passed on to the offspring.
- The law of independent assortment states that the inheritance of one pair of genes is independent of inheritance of another pair.

Frequently Asked Questions

What are the three laws of inheritance proposed by Mendel?

The three laws of inheritance proposed by Mendel include:

- Law of Dominance
- Law of Segregation
- Law of Independent Assortment

Which is the universally accepted law of inheritance?

Law of segregation is the universally accepted law of inheritance. It is the only law without any exceptions. It states that each trait consists of two alleles which segregate during the formation of gametes and one allele from each parent combines during fertilization.

Why is the law of segregation known as the law of purity of gametes?

The law of segregation is known as the law of purity of gametes because a gamete carries only a recessive or a dominant allele but not both the alleles.

Why was the pea plant used in Mendel's experiments?

Mendel picked pea plant in his experiments because the pea plant has different observable traits. It can be grown easily in large numbers and its reproduction can be manipulated. Also, pea has both male and female reproductive organs, so they can self-pollinate as well as cross-pollinate.

What was the main aim of Mendel's experiments?

The main aim of Mendel's experiments was:

- To determine whether the traits would always be recessive.
- Whether traits affect each other as they are inherited.
- Whether traits could be transformed by DNA.

Inheritance of Two Genes

Introduction: Inheritance of Two Genes

Mendel worked with and crossed pea plants that differed in two characters, as is seen in the cross between a pea plant that has seeds of yellow colour and round shape and one that had seeds of green colour and wrinkled shape. Mendel found that the seeds resulting from the crossing of the parents had yellow coloured and round shaped seeds. Here can you tell which of the characters in the pairs yellow/ green colour and round/wrinkled shape was dominant?
Thus, the yellow colour was dominant over the 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.

Law of Independent Assortment

"The law of independent assortment states that the allels of different genes are inherited independently within the organisms that reproduce sexually."

What is the Law of Independent Assortment?

According to the law of independent assortment, the alleles of two more genes get sorted into gametes independent of each other. The allele received for one gene does not influence the allele received for another gene.
Mendel's experiment always portrayed that the combinations of traits of the progeny are always different from their parental traits. Based on this, he formulated the Law of Independent Assortment.

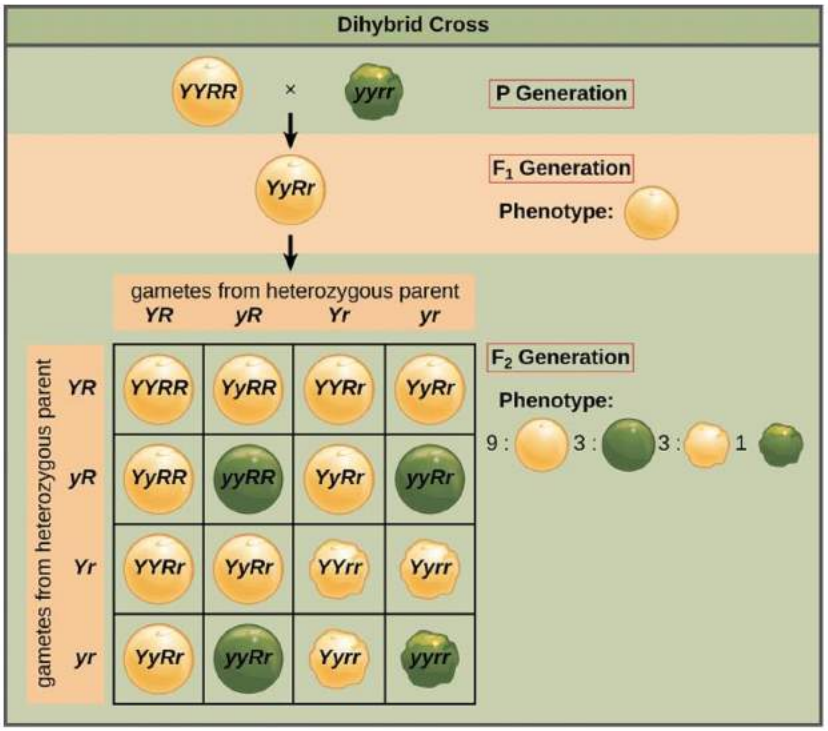
Reasons for Independent Assortment

Independent assortment takes place during the process of meiosis. In this process, the chromosomes are halved and are known as haploid.
To understand the law of independent assortment, it is very important to understand the law of segregation. In this, two different genes are sorted into different gamete cells. On the other hand, the law of independent assortment occurs when the maternal and paternal genes are divided randomly.

Mendel's Experiment on the Law of Independent Assortment

The Law of Independent Assortment states that during a dihybrid cross (crossing of two pairs of traits), an assortment of each pair of traits is independent of the other. In other words, during gamete formation, one pair of trait segregates from another pair of traits independently. This gives each pair of characters a chance of expression.
In the dihybrid cross, he chose round-yellow seed and wrinkled green seed and crossed them. He obtained only round yellow seeds in the F_1 generation. Later, self-pollination of F_1 progeny gave four different combinations of seeds in the F_2 generation. He obtained round-yellow, wrinkled-yellow, round green and wrinkled green seeds in the phenotypic ratio 9:3:3:1.
The phenotypic ratio 3:1 of yellow: green colour and the ratio 3:1 of the round: wrinkled seed shape during monohybrid cross was retained in the dihybrid cross as well. Thus, he concluded that characters are distributed independently and inherited independently. Based on this observation, he developed his third law – Law of Independent Assortment.
The dihybrid crosses between the parental genotype RRYY (round yellow seeds) and rryy (green wrinkled seeds) explains the law. Here the chances of formation of

gametes with the gene R and the gene r are 50:50. Also, the chances of formation of gametes with the gene Y and the gene y are 50:50. Thus, each gamete should have either R or r and Y or y.
The Law of Independent Assortment states that the segregation of R and r is independent of the segregation of Y and y. This results in four types of gametes RY, Ry, rY, and ry. These combinations of alleles are different from their parental combination (RR, YY, rr and yy).



Example of Law of Independent Assortment

Let us consider an example of rabbits with two visible traits:

- fur colour (black or white)
- eye colour (green or red)

Two-hybrid rabbits are crossed. Both the rabbits have a genotype BbGg. Before breeding each rabbit produced gametes. During this, the alleles are separated and the copy of each chromosome is assigned to different gamete. That means, regardless of the parental phenotype, the baby rabbits inherit different combinations of the traits. Alternatively, a baby rabbit can have a genotype Bbgg.

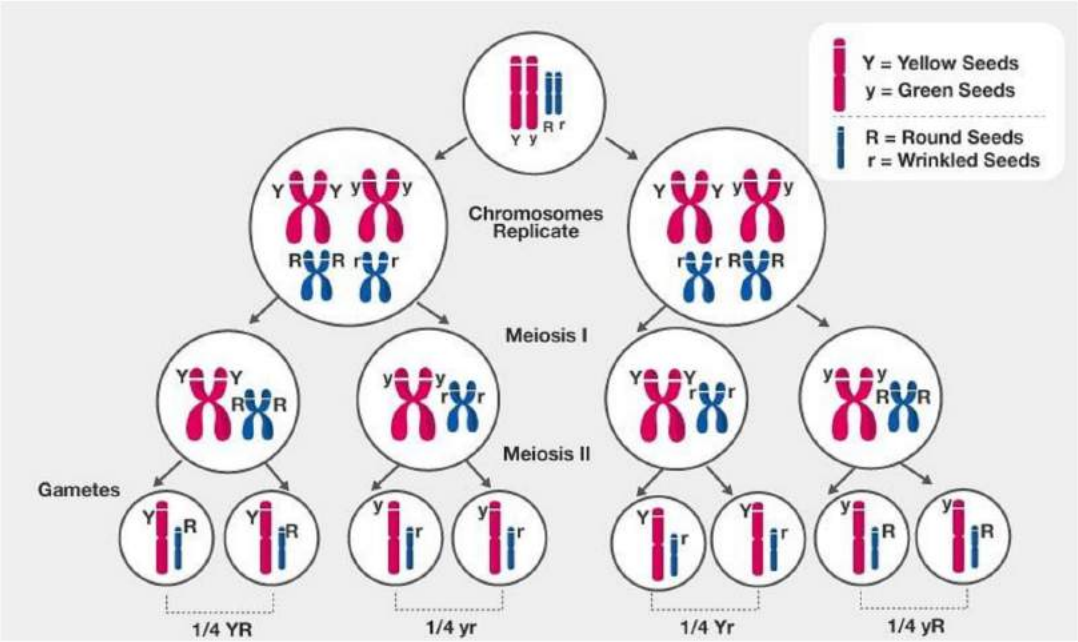
CHROMOSOMAL THEORY OF INHERITANCE

This theory was proposed by **Walter Sutton** and **Theodor Boveri** (1902). Following are the main points of this theory

1. Gametes serve as the **bridge** between two successive generations.
2. Male and Female gametes play an **equal** role in contributing hereditary components of future generation.
3. Only the nucleus of sperm combines with ovum. Thus, the hereditary information is contained in the **nucleus**.
4. Chromatin in the nucleus is associated with the cell division in the form of chromosomes.
5. Any type of deletion or addition in the chromosomes can cause structural and functional changes in living beings.
6. A sort of **parallelism** is observed between Mendelian factors and chromosomes.
7. A number of genes or Mendelian factors are found in each chromosome.
8. Determination of sex in most of the animals and plants is affected by specific chromosomes. These chromosomes are called sex chromosomes.

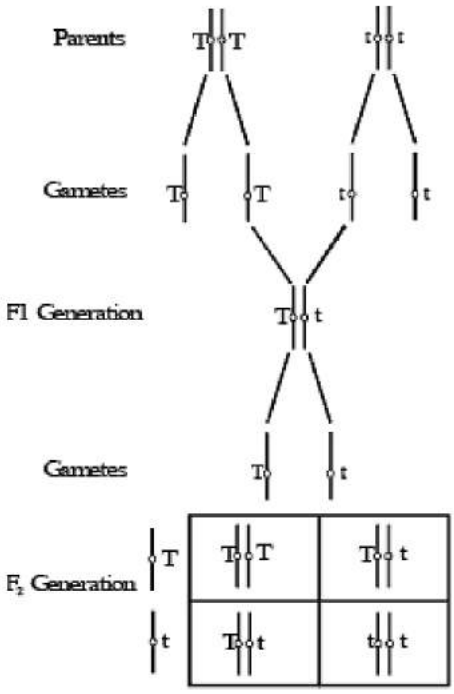
Parallelism Between Gene and Chromosomes

1. Chromosomes are also **transferred** from one generation to the next as in the case of genes (Mendelian factors).
2. The number of chromosomes is **fixed** in each living species.These are found as homologous pairs in diploid cells. One chromosome from father and the other contributed by the mother constitute a homologous pair.
3. Before cell division, each chromosome as a whole and the alleles of genes get **replicated** and are separated during mitotic division.
4. Meiosis takes place during **gamete formation**. Homologous chromosomes form synapses during prophase-I stage which in later course get separated and transferred to daughter cells. Each gamete or a haploid cell has only one allele of each gene present in the chromosome.
5. A characteristic diploid number is again established by the **union** of the two haploid gametes.
6. Both chromosomes and the alleles (Mendelian factors) behave in **accordance to Mendel's law** of **segregation**.



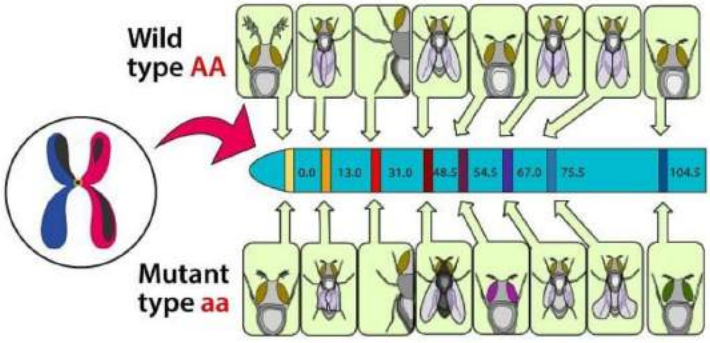
In the homologus chromosomes of a pure tall plant, allele (T) is found for tallness in each chromosome. Likewise, in a pure dwarf plant (tt), allele (t) is present in each chromosome.

These homologous chromosomes get separated during meiotic division. Hence, each gamete possesses only one chromosome of an each pair. Accordingly, all the gametes of tall plants possess a chromosome with an allele of tallness (T), while the gametes of dwarf plants possess a chromosome with an allele for dwarfness (t). Their cross to produce F_1 generation will yield tall hybrid plants with homologous chromosomal pair containing Tt allelic pair. In this generation two kinds of gamete will be formed during **gameto -genesis**, 50% with the allele (T) for tallness and 50% with the allele for dwarfness (t).**Random combination** of these gametes will produce offsprings in F2 generation in the ratio of 25% pure tall (TT), 50% hybrid tall (Tt) and 25% dwarf (tt)



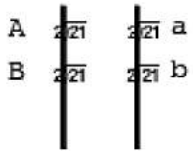
LINKAGE

Collective inheritance of character is called linkage. Linkage first time seen by **Bateson** and **Punnett** in *Lathyrus odoratus* and gave **coupling and repulsion phenomenon**. But they did not explain the phenomenon of linkage. Sex linkage was first discovered by **Morgan** in Drosophila & coined the term linkage. He proposed the theory of linkage.



Linkage and Recombination

Linkage and independent assortment can be represented in dihybrid plant, as –
In case of linkage in dihybrid AaBb



It produces two types of gamete

AB : ab

In case of independent assortment in dihybrid AaBb

It produces four types of gamete

AB : ab : aB : Ab

Theory of linkage

1. Linked genes are linearly located on same chromosome. They get separated if exchange (crossing over), takes place between them.
2. Strength of linkage α1/ distance between the genes . It means, if the distance between two genes is increased then strength of linkage is reduced and it proves that greater is the distance between genes, the greater is the probability of their crossing over. Crossing over obviously disturbs or degenerates linkage. Linked genes can be separated by crossing over.

Factors affecting crossing over (C.O) :-

(1) Distance ↑ = C.O. ↑

(2) Temperature ↑ = C.O. ↑

(3) X-Ray ↑ = C.O. ↑

(4) Age ↑ = C.O.↓

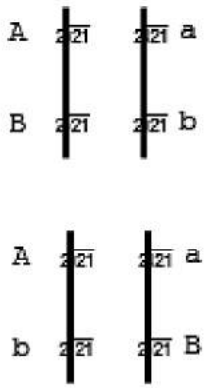
(5) Sex - Male C.O.↓ (Crossing over totally absent in male Drosophila.)

Arrangement of linked Genes on Chromosomes :-The arrangement of linked genes in any dihybrid plant is two types.

[a] Cis - Arrangement :- When, two dominant genes located on one chromosome and both recessive genes located on another chromosome, such type of arrangement is termed as cis-arrangement. Cis-arrangement is an original arrangement.

- Two types of gamete can be produced in cis-arrangement → (AB) and (ab).

[b] Trans-arrangement :- When a chromosome bears one dominant and one recessive gene, and another chromosome also possess one dominant and one recessive gene, such type of arrangement is called trans-arrangement.Trans-arrangement is not an original form. It is due to crossing over. Two types of gamete also formed in trans-arrangement but it is different from cis-arrangement (Ab) and (aB).



Types of Linkage :- There are two types of linkage –

1 COMPLETE LINKAGE :- Linkage in which genes always show parental combination. It never forms new combination. Crossing over is absent in it. Such genes are located very close on the chromosomes. Such type of linkage very rare in nature. e.g. male Drosophila, female silk moth.

2. INCOMPLETE LINKAGE :- When new combinations also appear along with parental combination in off-springs, this type of linkage is called incomplete linkage, the new combinations form due to crossing over. The percentage of new combination is equal to the percentage of crossing over.(<50%)

Linkage group :- All the genes which are located on one pair of homologous chromosome form one linkage group. Genes which are located on homologous chromosomes inherit together so we consider one linkage group.

- No. of Linkage group = haploid no. of homologous chromosomes.

	2n	n	Pair	Linkage group
Pea	14	7	7	7
Maize	20	10	10	10
Drosophila	8	4	4	4
Barley	14	7	7	7
Mouse	42	21	21	21

Application of Linkage :-

Distance can be identified by the incomplete linkage. It's unit is centi Morgan.

$$\text{Strength of linkage} \propto \frac{1}{\text{Distance b/ w linked gene}} \propto \frac{1}{\text{Crossing Over}}$$

Genetic map/Linkage map/chromosome map - In genetic map different genes are linearly arranged according to % of crossing over (μ Distance) between them. With the help of genetic map we can find out the position of a particular gene on chromosome. Genetic map is helpful in the study of genome.

Polygenic Inheritance & Pleiotropy

What is Polygenic Inheritance?

Polygenic inheritance is defined as quantitative inheritance, where multiple independent genes have an additive or similar effect on a single quantitative trait.

Polygenic inheritance is also known as multiple gene inheritance or multiple factor inheritance.

Characteristics of Polygenic Inheritance

- Polygene refers to a gene that exerts a slight effect on a phenotype along with other genes
- The effect of a single gene is too small, so it is difficult to detect

- Multiple genes produce an equal effect
- Each allele has a cumulative or additive effect
- Polygenic inheritance differs from multiple alleles, as in multiple alleles, three or more alleles are present in the same locus of which any two alleles are present in an organism, e.g. ABO blood group system, which is controlled by three alleles
- There is no epistasis involved, i.e. masking of the expression of an allele of the different locus
- There is no linkage or dominance, rather there exist contributing and non-contributing alleles, which are known as active or null alleles respectively
- Polygenic inheritance is characterised by the continuous variation of the phenotype of a trait
- The polygenic inheritance pattern is complex. It is difficult to predict phenotype
- The statistical analysis can give the estimate of population parameters

Polygenic Inheritance in Humans

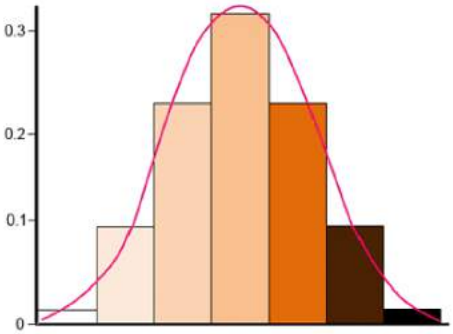
There are many traits in humans, which show polygenic inheritance, e.g. skin and hair colour, height, eye colour, the risk for diseases and resistance, intelligence, blood pressure, bipolar disorder, autism, longevity, etc.

Brief description of some of the traits:

Skin pigmentation:

Inheritance of skin pigmentation is polygenic inheritance. Around 60 loci contribute to the inheritance of a single trait. If we take an example of a pair of alleles of three different and unlinked loci as A and a, B and b, C and c. The capital letters represent the incompletely dominant allele for dark skin colour. The more capital letters show skin colour towards the darker range and small letters towards the lighter colour of the skin. Parents having genotype AABBCC and aabbcc will produce offspring of intermediate colour in the F1 generation, i.e. AaBbCc genotype. In the F2 generation of two triple heterozygotes (AaBbCc x AaBbCc) mate, they will give rise to varying phenotypes ranging from very dark to very light in the ratio 1:6:15:20:15:6:1.

	ABC	*ABc*	*AbC*	*aBC*	*Abc*	*aBc*	*abC*	*abc*
ABC	6	5	5	5	4	4	4	3
ABc	5	4	4	4	3	3	3	2
AbC	5	4	4	4	3	3	3	2
aBC	5	4	4	4	3	3	3	2
Abc	4	3	3	3	2	2	2	1
aBc	4	3	3	3	2	2	2	1
abC	4	3	3	3	2	2	2	1
abc	3	2	2	2	1	1	1	0



From light to dark:

1. **Height:** There are around 400 genes responsible for the phenotype and the environment greatly influences the expression of genes.
2. **Eye colour:** The colour of the eye is determined by polygenes. At least 9 colours of eye colour are recognised in humans. There are two major eye colour genes and 14 more genes that determine the expression of the phenotype. A different number of alleles contribute to each colour. These are found to be X-linked.

Polygenic Inheritance in Plants

Polygenic inheritance in plants includes the colour and shape of the stem, pollen, flower, yield, oil content, size of a seed, time to mature or flower, etc.
Brief description of some of the traits:

Kernel colour of the wheat: The three independent pairs of alleles are involved in the expression of kernel colour of wheat. They show independent assortment. When dark red wheat kernel (AABBCC) is crossed with the white wheat kernel (aabbcc) the F1 generation has an intermediate red colour kernel (AaBbCc). When F1 generation is crossbred, F2 generation has 63 red kernel plants having different shades of red and 1 white kernel.

1	6	15	20	15	6	1
Dark red	Moderate Red	Red	Intermediate red	Light red	Very light red	White

Effect of environment on Polygenic Inheritance

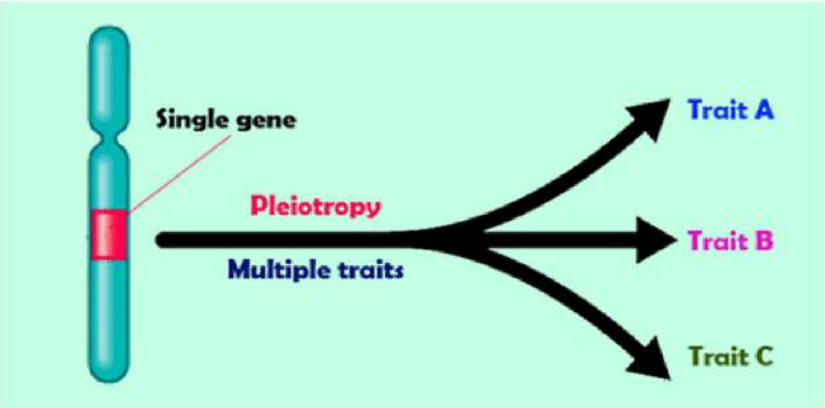
- The expression of polygenesis greatly influenced by environmental conditions. The genotype sets the range for a quantitative trait, but the environmental conditions decide the phenotype within its genetic limits. Genes function differently in different environmental conditions. Environment regulates the activity of certain genes and sets them on or off.
- The range of phenotype possible under the different environmental conditions from the same genotype is termed as 'norm of reaction'. The norm of the reaction is narrow for certain genotypes and broad for some genotypes, e.g. genotypes involved in human height have a very broad norm of reaction.
- Identical twins raised in two different environments show that individuals may have genetic potential or vulnerability, but environmental conditions influence the expression of genotype. Human characters such as intelligence, depression, height, skin colour, schizophrenia show the effect of the environment on gene expression. Phenotypic expression is dependent on both nature and nurture.

Examples:

1. Diet and general health greatly influences height
2. Flower, the colour of a shrub, Hydrangeas, depends on the level of aluminium present in the soil
3. Effect of temperature on the skin of Himalayan rabbits.

What is Pleiotropy in Genetics?

In genetics, Pleiotropy is defined as the expression of multiple traits by a single gene. Pleiotropy is derived from a Greek word meaning more ways.
A simple example of a Pleiotropy is phenylketonuria is a disease. It is a genetic disorder caused by the low metabolism of the amino acid phenylalanine in the body cells.



Pleiotropy

Gregor Mendel, the father of genetics made various interesting observations during his study of inheritance regarding the colour of different plant components. Significantly, Mendel also observed that the plants with coloured seed coats had coloured leaf axils (a part that connects leaves to stems) and coloured flowers. Mendel also noticed that pea plants had colourless seed coats with no pigmentation on their axils and white-coloured flowers. The colour of the seed coat was always concerned with specific axil and flower colour.

Today we come to the conclusion that Mendel's observations were based on the result of pleiotropy which is the phenomenon wherein an individual gene plays its role in multiple phenotypic traits. Here, the gene of seed coat colour was not the only one responsible for its colour but also for the axil pigmentation and flower.

A human genetic disorder known as the Marfan syndrome is caused due to the mutation in a single gene yet it affects various aspects of growth and development that include vision, height, and heart functioning. All these are examples of pleiotropy or a gene that affects multiple characteristics.

Gene Pleiotropy

The gene which focuses on the number of functions of a particular gene is termed as the Gene pleiotropy. It is also referred to as molecular-gene pleiotropy.

When we talk about Mendel's experiments with white-coloured flower and purple coloured plants, we do not think about phenotypes concerned with the colours of two flowers. However, Mendel observed that the colours were always related to two different features: the seed coat colour and the colour of axils.

A plant bearing white-coloured flowers consist of colourless axils and seed coats, whereas plants with purple flowers have brown-grey coloured seed coats with reddish axils. Hence, instead of affecting only one characteristic, the colour gene affects three.

Genes of this kind that control multiple and unrelated features are called pleiotropic where the term pleio refers to many and tropic indicates effects. In this manner, the discrete phenotypes could be identified back to a defect in one gene with different jobs.
Moreover, the alleles of pleiotropic genes are transferred in a similar way as alleles of genes affect the single traits. Although a phenotype has various elements, these elements are expressed as a package and the recessive and dominant versions of the package would be visible in the offspring of two heterozygotes in a 3:1 ratio.

Human Genetic Disorders

The genes which are affected by human genetic disorders are mostly pleiotropic. For example, a person with a hereditary disorder known as Marfan syndrome could have a set of unrelated symptoms that involve the following:

- Abnormal tall height.
- Dislocation of the eye lens.
- Lean fingers and toes.
- Heart problems that include the aorta, large blood vessels that carry blood away from the heart, ruptures.

The above symptoms do not seem relevant but as it turns out, it could be traced back to the mutation of an individual gene. This gene encodes a protein into chains and makes fibrils that provide flexibility and strength to the body's connective tissues. Mutations that are responsible for Marfan syndrome minimize the amount of functional protein formed by the body and results in lesser fibrils.

Sex Determination

What is Sex Determination?

Establishment of sex through differential development in an individual at an early stage of life, is called sex determination. There are different methods for sex determination in organisms:
1. Environmental Determination of Sex
2. Allosomic Sex determination
3. Haploid - Diploid Mechanism
4. Sex Determination by Hormone

Sex determination can also be done on the basis of fertilization and is classified in 3 categories:

1. Progamic – Sex is determined before fertilization.
eg. - drone in honey bee
2. Syngamic - Sex is determined during fertilization.
eg. - most of plants & animals
3. Epigamic - Sex is determined after fertilization.
eg. - Female in honey bee.

Environmental Determination of Sex

It is non-genetic determination of sex which is based purely on environmental conditions. The organisms are potentially hermaphrodite and capable of expressing any of the two sexes.

1. In marine worm **Bonellia,** larva develops into female if it settles down alone in an isolated place. Any larva coming in contact with the already grown female, it changes into male, and lives as a parasite in the uterus of female.
2. **Crepidula** (marine mollusca) where larva develops into male in the company of female and develops into female if left alone.
3. In **crocodiles** low temperature induces femaleness and high temperature maleness.
4. In **turtles** temperature **below 28°C induces maleness, above 33°C femaleness** while between 28 - 33°C equal number of male and female animals are formed.
5. In marine fish **Medusa** sex changes according to environmental condition, becoming male in cold water and female in warm water.

Allosomic Determination of Sex

Chromosomes are of two types -
(a) Autosomes or somatic chromosomes -
These regulate somatic characters.
(b) Allosomes or Heterosomes or Sex chromosomes -
These chromosomes are associated with sex determination. Term "**Allosome**" & "**Heterosome**" were given by **Montgomery.**
Sex chromosomes first discovered by "**Mc Clung**" in grass hopper X- Chromosome discovered by "**Henking**" and called '**x-body**'.
Wilson & Stevens proposed chromosomal theory for sex determination.
(1) XX - XY type or Lygaeus type :- This type of sex determination first observed by Wilson & Stevens in Lygaeus insect. Two types–

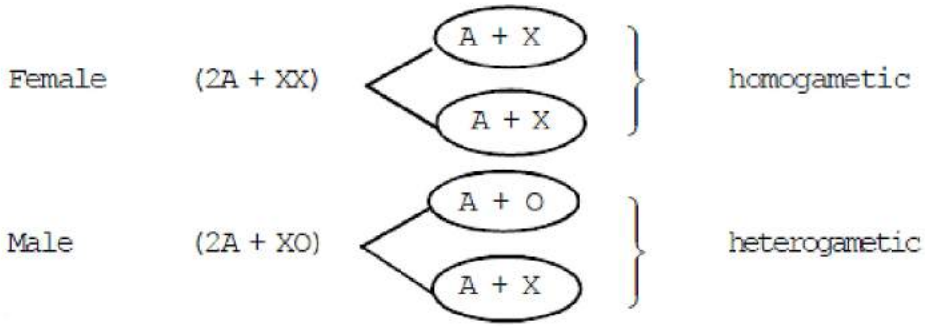
(a) XX female and XY male :- In this type of sex determination female is Homogametic i.e produces only one type of gamete

- Male is heterogametic (male produces two types of gamete)

In male X-chromosome containing gametes is called "**Gynosperm**" and Y-chromosome containing gamete is called "**Androsperm**". **eg**. Man and dioecious plants like Coccinia, Melandrium

(b) XY female and XX male or ZW female and ZZ male :- In this type of sex determination female is Heterogametic i.e produces two types of gamete and male individual is homogametic i.e produces one type of gamete.
It is found in some insects like butter flies, moths and vertebrates like birds, fishes and reptiles.
In plant kingdom this type of sex determination is found in Fragaria elatior.

(2) XX female and XO male :- or "Protenor type" :- In this type of sex determination deficiency of one chromosome in male. In this type, female is homogametic and male is heterogametic.



Example :–

– Grass hopper
– Squash bug Anasa
– Cockroach
– Ascaris and in plants like - Dioscorea sinuta & Vallisneria spiralis

Genic balance theory :- C.B. Bridges proposed genic balance theory for sex determination in Drosophila.
– According to Bridges in Drosophila Y-chromosome is heterochromatic so it is not active in sex determination
In Drosophila sex determination takes place by sex index ratio.

$$\text{Sex index ratio} = \frac{\text{No. of x chromosomes}}{\text{No. of set of Autosomes}} = \frac{X}{A}$$

In Drosophila gene of femaleness (Sxl- gene) (Sxl=Sex lethal gene) is located on x-chromosome and gene of maleness is located on autosome
Gene of male fertility is located on y-chromosome and in Drosophila, y-chromosome plays additional role in spermato genesis and development of male reproductive organ, so y-chromosome is essential for the production of fertile male.

Sex index ratio

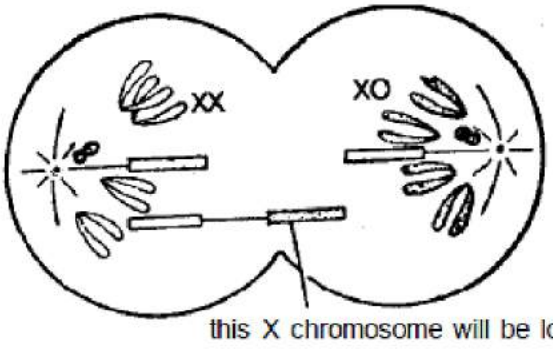
(a) $\frac{X}{A} = 1 \rightarrow$ female (2A + XX), (3A + XXX)

(b) $\frac{X}{A} = 0.5 \rightarrow$ male → (2A + XY) = Fertile male; (2A + XO) = Sterile male

(c) X/A = 1.5 → Super female or meta female (sterile) (2A + XXX)
(d) X/A = less than 0.5 → Super male or meta male (Sterile) (3A + XY)
(e) X/A = = In between 0.5 and 1 → Intersex (Sterile) (3A+XX)

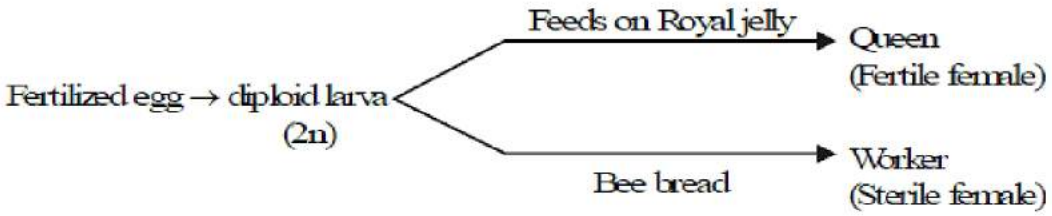
Gynandromorph

Body of some Drosophila has some cells with male genotype (X0) and some cells with female genotype (XX).
Body of such type of Drosophila has half lateral part of male and half lateral part of female and it is called bilateral gynandromorph. It is formed due to loss of one x-chromosome at metaphase plate during first zygotic division. Formation of gynandromorph is the best evidence that y-chromosome does not play any role in sex differentiation.



Haploid-Diploid Mechanism

In insects of order Hymenoptera which includes ants,honey bees, wasps etc.
Sex determination takes place by sets of chromosomes.
Diploid (two sets) → Female
Haploid (One set) → Male
In honey bee, male individual (Drone) develops from unfertilized eggs (Haploid).
Male is always parthenote.
Queen and worker bees develop from diploid eggs i.e. fertilized egg.



Sex determination by Hormone

Dizygotic twins are common in cattle like cow, sheep, goat etc. Some times the placentae of the two dizygotic twins fuse forming blood vascular connections between two developing foetus. If twins are dizygotic, one foetus may be male and the other female.

- **Male hormone produced before female** hormone by male twins which suppresses the differentiation of female internal sex organ. Such a sterile female with Under developed ovaries, oviducts, Uterous etc. is called **free martin**. In free martin conditions, female is sterile & male is normal.

Cytological basis of sex determination – Barr body technique or **Lyon's hypothesis –**

Interphasic nucleus of human female contains two X- chromosomes. Out of two, one X- chromosome becomes heterochromatin and other X- chromosome is euchromatin. By staining X- heterochromatin, it appears as a dense body which is called Barr body. (Facultative hetrochromatin)
No. of Barr body ⇒ (No. of X chromosomes – 1)
So in a Normal female (2A + XX) → One Barr body
Normal male (2A + XY) → Barr body absent
Turner syndrome (Sterile female) (2A + XO) → No. Barr body
Klinefelter syndrome (Sterile male)(2A + XXY) → One Barr body
Drum stick which occurs in blood of female of mammals, is also a type of barr body.
Drum stick is absent in neutrophils of Male.

Sex determination in Humans

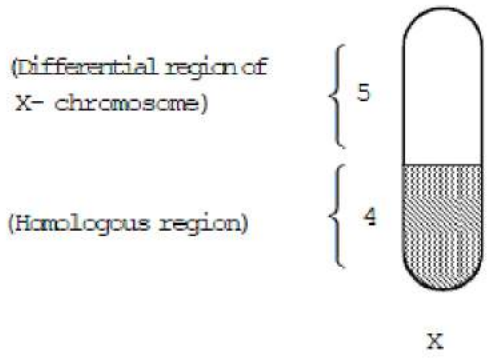
There occur a special gene on differential region of Y-chromosome of human, called Sry - gene (Sex determine region on y chromosome). This gene forms a proteinaceous factor called TDF (testes determining factor). TDF responsible for the development of male reproductive organs. So presence and absence of Y-chromosome determines sex.

Sex determination in Plant

H.E. Warmke discovered sex determination in Melandrium plant.
In Melandrium Y- chromosome is long as compare to X- chromosome.
In plant sex chromosomes are found only in unisexual plant.
Pro. R.P. Roy gave the importance of Y-chromosome in plant.
He discovered sex determination in **Coccinea indica** (Family- cucurbitaceae)
Y- chromosome contains four regions and X- chromosome contains two regions.
Different functions of these regions-

1. Ist region - (Female suppressor region) :- This region suppresses the development of female reproductive structures.
2. IInd region (Male promoter region) :- This region initiates or start the development of Anther
3. IIIrd region (Male fertility region) :- This region induces the further development of Anther.
4. IVth region (Homologous region) :- This region helps in the dis-junction & Pairing of X and Y chromosome during meiosis.
5. Vth region (Differential region of X-chromosome) :- This region induces the development of female gonads

So when one or more than one Y- chromosome present then plant is male and in female plant Y chromosome is absent.



Special Case

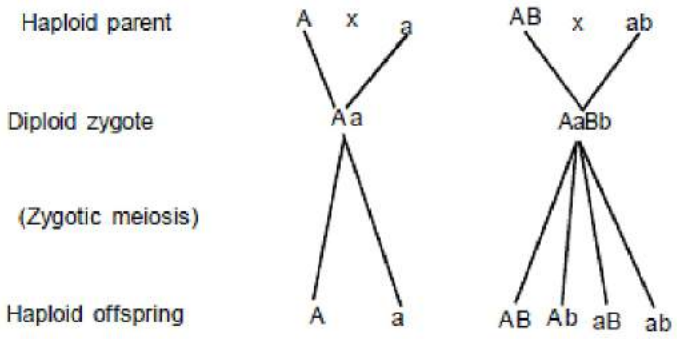
- If Ist region of Y chromosome is removed then plant becomes bisexual (XY).
- If IInd region of Y chromosome is removed then plant becomes female due to absence of IInd region, Ist region of Y chromosome does not suppress the Vth region of X-chromosome.

- If IIIrd region of Y chromosome is removed then plant become sterile male due to absence of IIIrd region so further development of anther does not take place.

Phenotypic Expression in Haploid Organisms (Neurospora Genetics)

Diploid organisms such as pea and Drosophila, have two alleles for each gene on each chromosome (the exceptions are for the X linked genes in XY or XO males). With the result, the recessive allele is not expressed in the phenotype in presence of the dominant one. However, this is not so in the case of haploid organisms. Contrary to diploid organisms, the genetics of haploid organisms exhibit the following features:

1. Haploid organisms contain only one allele of a gene, so there is no complication of dominance. All the genes, whether dominant or recessive, expresses itself in the off springs.
2. In absence of dominance, any new mutation is immediately expressed in the phenotype, in haploid organisms.
3. Study of inheritance of the mutated gene, its linkage, crossing over and biochemical consequence of a mutation can easily be studied in haploid.



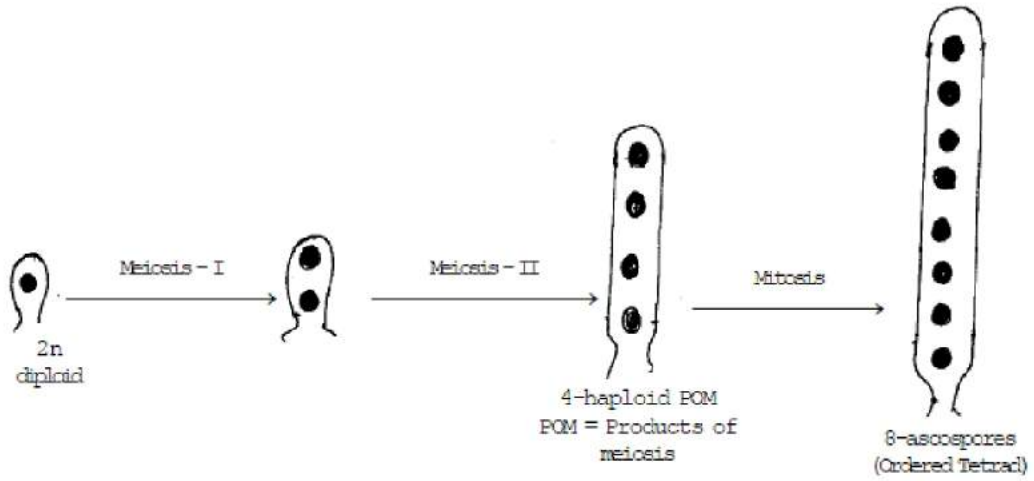
Linkage And Recombination in Neurospora (Drosophila of plant kindgom)

Detection of linkage and recombination of genes in haploid organisms as in fungi, bacteria etc. is comparatively simple. Fungus **Neurospora** is one of the favourite material with geneticists, because :-

1. The life cycle of **Neurospora** is the product of a single meiosis.
2. The life cycle is of a **short** duration.
3. The meiotic products are **linearly arranged** in ascus as 8 ascospores as ordered tetrads (i.e, the eight ascospores are arranged in the same order in which chromatids were on the meiotic metaphase plate).

Tetrad Analysis in Ordered Tetrads:

In **Neurospora**, the nuclei from hyphae of opposite mating type (+) and (–) fuse to form a diploid zygote. The zygote is the only diploid stage in the life cycle of **Neurospora**. The zygote nucleus divides meiotically producing four haploid nuclei, each of which then undergoes mitosis. The eight cells produced this way, form 8 haploid ascospores enclosed in the ascus. The three divisions proceed along the longitudinal axis, so the ascospores are arranged in a line in a specific order that indicates the order of arrangement of chromatids on the meiotic metaphase plate. This is called linear or ordered tetrad. Each of the four products of meiosis can be cultured separately to study their phenotypes and genotypes. This is called tetrad analysis.

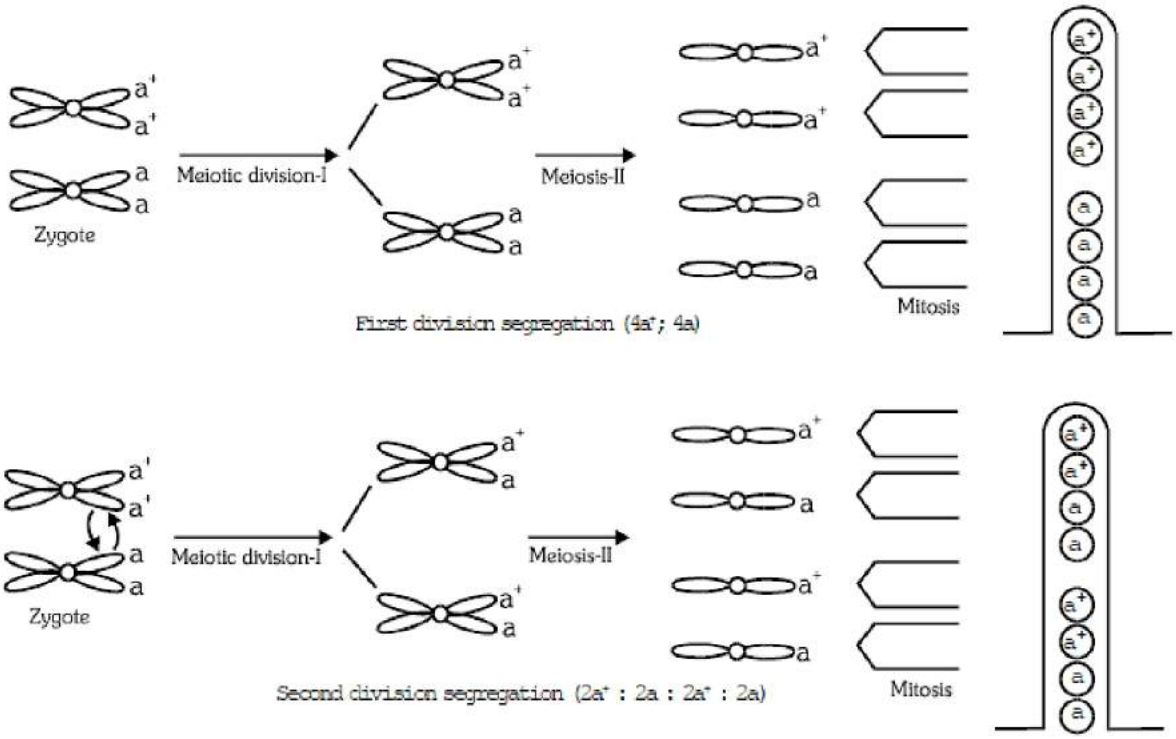


1. First Division Segregation Between Centromere and gene-a.

A cross between two strain of **Neurospora**, one normal (a^+) and other mutant (a) strain produces 8-ascospores, out of which four are normal (a^+) and other four mutants (a). The linear arrangement of ascospores in ascus is $4a^+ : 4a$. It indicates the absence of crossing over between locus-a and centromere. This is described as first division segregation.

2. Second Division Segregation Between Centromere and Gene-a.

In a similar cross if crossing over takes place leading to paired arrangement of ascospores with a particular gene, it is described as **second division crossing over.** The arrangement of ascospores in the sequence (2 : 2: 2 : 2) is as follows:
(i) $a^+ : a^+ : a : a : a : a : a^+ : a^+$
(ii) $a : a : a^+ : a^+ : a^+ : a^+ : a : a$
(iii) $a^+ : a^+ : a : a : a^+ : a^+ : a : a$



Single Gene Mapping in Neurospora

In Neurospora centromere behaves as a gene for mapping gene pair. In such a case distance of gene from the centromere is calculated by calculating the percentage of cross overs between centromere and gene.

Genetic Disorders: Pedigree Analysis &

Mendelian Disorders

Mendel's works on the principle of inheritance in genetics remained a mystery for quite some time. Even though his works were not accepted during his era, later it was rediscovered and gained credibility. Currently, Mendel's work is fundamental for studying inheritance pattern in living organisms. In addition, it helped to discover and predict how genetic disorders function. Let's learn about pedigree analysis and how it helps in predicting genetic disorders.

What is a Pedigree Analysis?

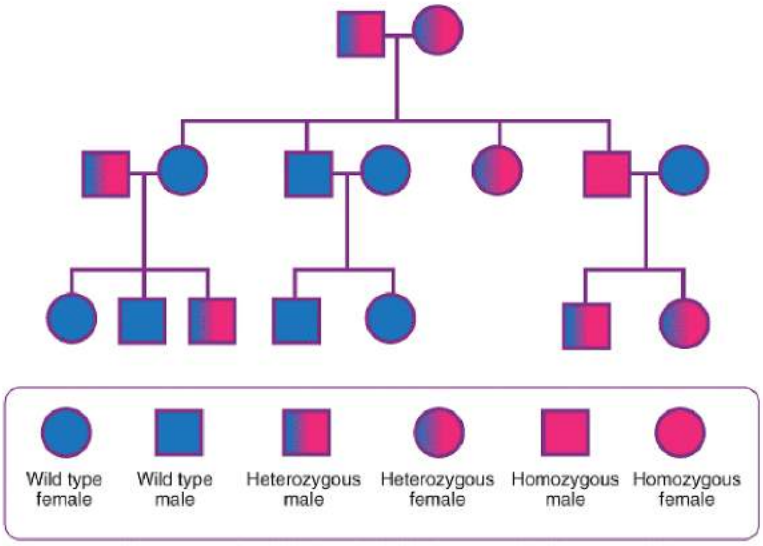
Pedigree analysis is a chart that represents a family tree, which displays the members of the family who are affected by a genetic trait.
Here, the rows represent the generations of a family, squares represent males and

circles represent females. In many cases, including various plant and animal species, scientists use pedigree analysis to analyse the inheritance of phenotypes, or traits, using mating experiments called crosses.

Mendel's experiments revealed that the 'factors', what we know as genes, are responsible for the inheritance of traits. They are also accountable for the disorders prevailing in living organisms. Genes are the hereditary unit of organisms, responsible for structural and functional changes in them. Besides this, it is the cause of variation in organisms which can either result in a good or bad trait. The conclusions we derived were on the basis of controlled crosses on pea plants and other organisms. These controlled experiments can't be performed in the human population due to ethical concerns. The only suggested solution to this limitation was pedigree analysis. i.e., to observe and analyze the pattern of inheritance in humans using their family history.

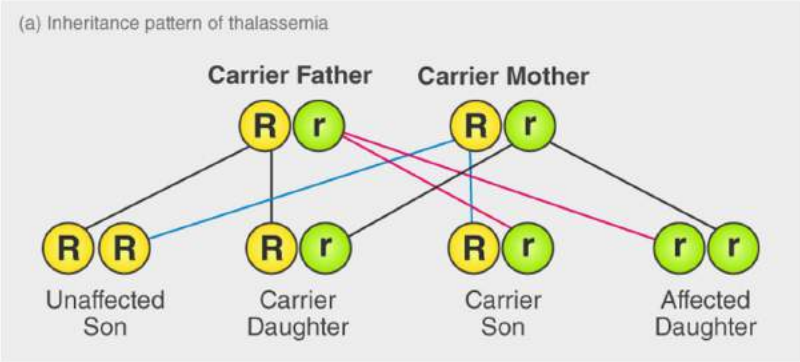
DNA sequences are made up of various, which, in turn, code for a particular protein. Any changes in this sequence, e.g. mistakes during DNA replication may lead to a change in the genetic codes or chromosomal aberrations. This can be transferred from parents to offspring. Inheritance of altered genes causes genetic disorders in offspring. The Mendelian disorders may arise due to change or alteration in one gene. Their genetic inheritance is governed by Mendelian genetics. Mendelian disorders mostly occur in families with a certain pattern reflecting the alteration in a single gene. Prediction of these disorders is based on family history and can be done with the help of a family tree. This process of analysis of a number of generations of a family is called the pedigree analysis. Pedigree analysis is a strong tool in human genetics which helps to predict the pattern of inheritance, even when data is limited.

A family tree can be represented by a pedigree chart with all the members of a family. They may be having a genetic disorder or maybe carrier of the disease. In the pedigree analysis, standard symbols are used to distinguish between different family.



Mendelian Disorder Definition

"Mendelian disorders are the genetic disorders caused at a single genetic locus."



What are Mendelian Disorders?

In humans, Mendelian disorder is a type of genetic disorder primarily resulting due to alterations in one gene or as a result of abnormalities in the genome. Such a condition can be seen since birth and be deduced on the basis of family history using the family tree. The analysis hence carried out is known as pedigree analysis.
These genetic disorders are quite rare and may affect one person in every thousand or a million. Genetic disorders may or may not be inherited. Inheritable genetic disorders usually occur in the germline cells, whereas in non-inheritable genetic disorders the defects are generally caused by new mutations or due to some changes in the DNA. For instance, cancer may either be caused by an inherited

genetic condition, or by a new mutation caused by the environmental causes or otherwise.

Types of Mendelian Genetic disorders

According to Mendel's' laws of inheritance, the different types of Mendelian disorders include:

- Autosomal dominant.
- Autosomal recessive.
- Sex-linked dominant.
- Sex-linked recessive.
- Mitochondrial.

The various types of Mendelian disorders can be identified easily from the pedigree analysis.

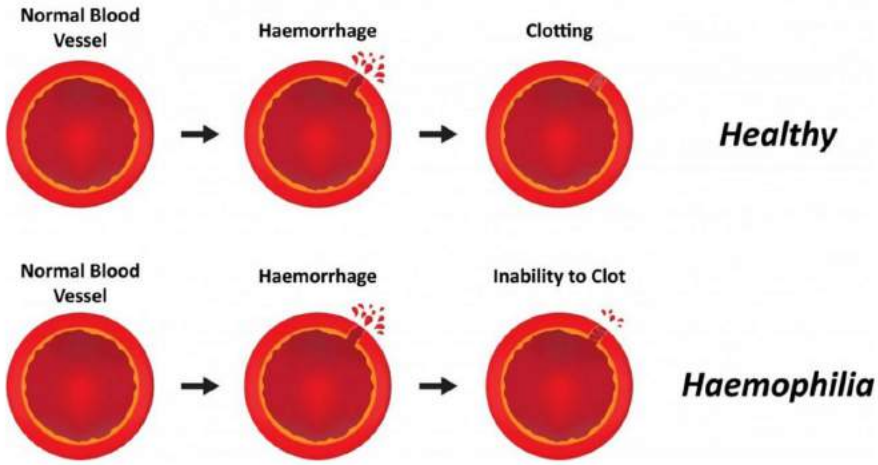
Examples of Mendelian Disorders

Few examples of the Mendelian disorder in humans are

- Sickle cell anaemia
- Muscular dystrophy
- Cystic fibrosis
- Thalassemia
- Phenylketonuria
- Colour blindness
- Skeletal dysplasia
- Haemophilia

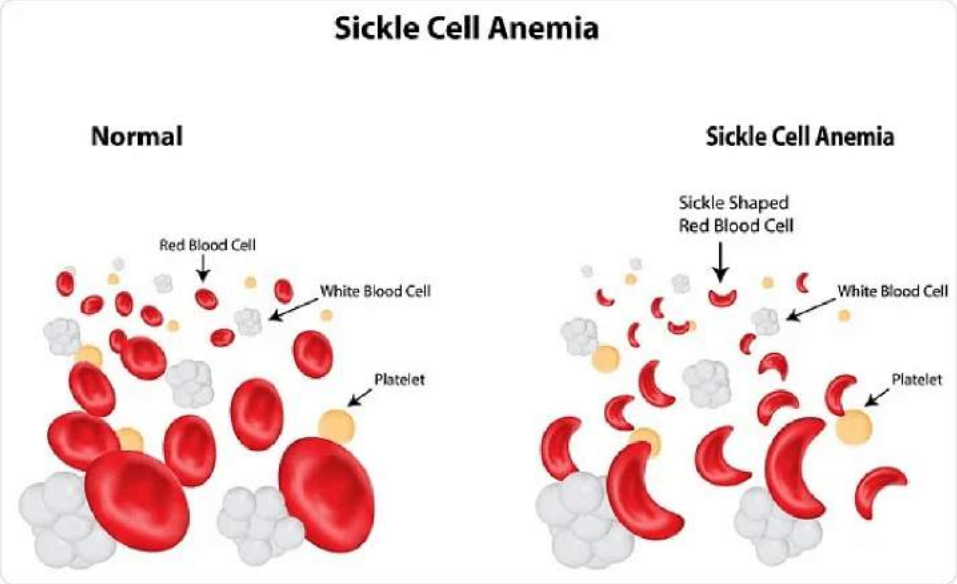
➤ **Haemophilia**

Haemophilia



- This is a type of sex-linked recessive disorders. According to the genetic inheritance pattern, the unaffected carrier mother passes on the haemophilic genes to sons.
- It is a very rare type of disease among females because for a female to get the disease, the mother should either be hemophilic or a carrier but the father should be haemophilic.
- This is a disorder in which blood doesn't clot normally as the protein which helps in clotting of blood is affected. Therefore, a person suffering from this disease usually has symptoms of unexplained and excessive bleeding from cuts or injuries.
- This type of genetic disorder is caused when the affected gene is located on the X chromosomes. Therefore, males are more frequently affected.

➤ **Sickle-cell anaemia**



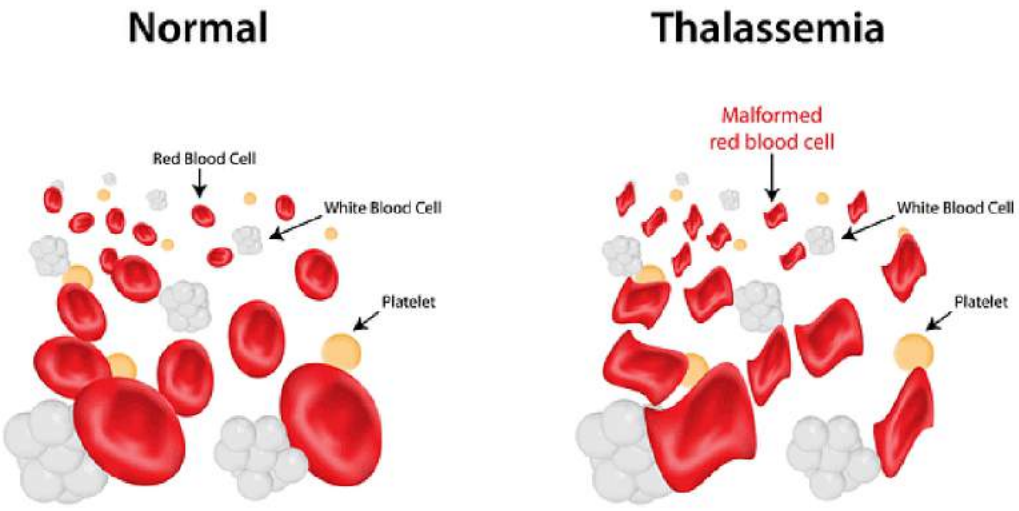
- This is a type of autosomal recessive genetic disorder.
- According to Mendelian genetics, its inheritance pattern follows inheritance from two carrying parents.
- It is caused when the glutamic acid in the sixth position of the beta-globin chain of haemoglobin molecule is replaced by valine. The mutant haemoglobin molecule undergoes a physical change which changes the biconcave shape into the sickle shape.
- This reduces the oxygen-binding capacity of the haemoglobin molecule.

➤ **Phenylketonuria**

- This genetic disorder is autosomal recessive in nature.
- It is an inborn error caused due to the decreased metabolism level of the amino acid phenylalanine.
- In this disorder, the affected person does not have the enzyme that converts phenylalanine to tyrosine. As a result, phenylalanine accumulation takes place in the body and is converted into many derivatives which result in mental retardation.

➤ **Thalassemia**

Thalassemia



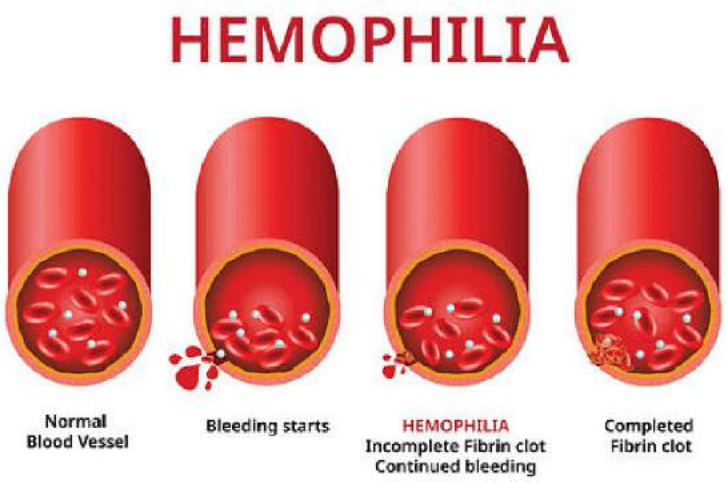
- This is a type of disorder in which the body makes an abnormal amount of hemoglobin. As a result, a large number of red blood cells are destroyed which leads to anemia.
- It is an autosomal recessive disease.
- Facial bone deformities, abdominal swelling, and dark urine are some of the symptoms of thalassemia.
- It is an inherited disease which is mainly caused due to abnormal hemoglobin synthesis. It is transferred by one of the parents who is a carrier of this disease due to either deletion of particular key gene fragments or a genetic mutation.
- There are two types of thalassemia:

  - Alpha-thalassemia – A disorder in which one of the genes of alpha-globin has a mutation or abnormality.
  - Beta-thalassemia – The genes of beta-globin are abnormal.
- It develops when there is some abnormality in any one of the genes that are involved in the production of hemoglobin and this defect is inherited from the parents. If any of the parents have thalassemia, the baby is more likely to develop this disease so-called thalassemia minor. If both the parents suffer from this disease, you are more likely to get the disease.
  There are no symptoms at an early stage but are likely to be a disease carrier. It is the most common disease in people of Asia, Africa, the Middle East, Turkey, and Greece.

➤ **Cystic Fibrosis**

- This is an autosomal recessive disorder.
- This disease affects the lungs and the digestive system and the body produces thick and sticky mucus that blocks the lungs and pancreas.
- People suffering from this disorder have a very short life-span.

What is Hemophilia?



This disorder is characterized by uncontrolled bleeding and the inability of the blood to clot properly. Even a small cut or a minor injury can result in severe bleeding. Haemophilia is one among the many X-linked recessive inherited genetic disorders, where the gene causing the disorder or dysfunction is located on the X-chromosome. It results in massive internal bleeding (known as haemorrhaging) in the joints such as the knees, elbows, ankles, and also in the tissues and muscles. This can lead to considerable consequences, such as swelling and pain in the affected areas. It can even cause permanent damage to the affected body parts. When bleeding happens in a vital organ, especially in the brain, it has the potential to turn fatal.

<u>Types of Hemophilia</u>

Haemophilia exists in two forms:

- **Hemophilia A:** It is caused specifically by a mutation in the Factor VIII gene on the X chromosome.
- **Hemophilia B:** This is caused by a mutation in the Factor IX gene on the X chromosome.

Hemophilia Prevention

Since haemophilia is a hereditary condition, it cannot be prevented; but it can be diagnosed and help the mother understand the risks of having a baby with haemophilia. The female members of the family are the only carriers of this syndrome. If there is a history of haemophilia in a family, it is better to consult a physician and have a blood test to examine the clotting factors and to perform a molecular genetic test to examine the carriers in their genes.
As per the studies conducted on this inherited genetic disorder, the genes from the mother can be transmitted to both her children. Among them, there are 50% chances that her son will have haemophilia A or B and 50% chances that her daughter will be a carrier of this gene.

Symptoms of Hemophilia

The signs and symptoms of haemophilia vary based on the levels of clotting factors present. These clotting factors are substances in the blood affect the process of blood coagulation. If the clotting factors are slightly reduced, then the bleeding is observed only after the surgeries. If the clotting factors are completely reduced, then spontaneous bleeding is observed.

Symptoms of spontaneous bleeding include

- Many large or deep bruises.
- Joint pain and swelling (caused by bleeding)
- Unexplained bruises or bleeding.
- Blood in urine or in stools.
- More bleeding for a normal cut or injury.
- Nosebleeds for no apparent reason.
- Excessive bleeding in tooth gums.
- Unusual bleeding after vaccinations.

Colour blindness

Introduction

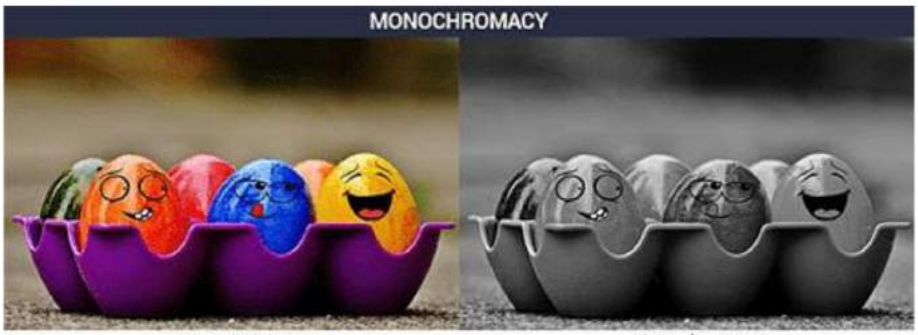
Colour blindness can be simply defined as trouble in seeing or identifying colours like blue, green and red. There are some rare cases where a person cannot see and identify any colours at all. A person with this syndrome also finds difficulties in differentiating the colours with shades. This syndrome is also called a colour vision problem or colour vision deficiency.
Colour blindness was discovered by an English chemist named John Dalton in the

year 1798. During the discovery, he was also suffering from colour blindness. He wrote his first article about colour blindness, which was based on his own experience. Colour blindness is also called as Daltonism, which is named after its discoverer – John Dalton.

Types of Colour Blindness

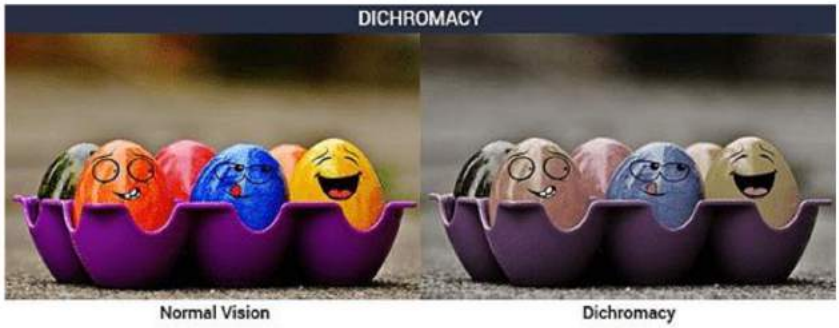
➤ Monochromacy

- This syndrome occurs when two or three-cone pigments (red, blue and green) are absent or damaged. In this type of colourblindness both the colour and lightness vision is reduced to one dimension. This results in total colour blindness.



Dichromacy

- This syndrome occurs when only one of the cone pigments (red, blue and green) is absent or damaged. In this type of colourblindness, only the colour vision is reduced to two dimensions. This results in partial colour blindness.



Causes of Colour Blindness

The healthy human eye retina contains two light-sensitive cells – rod cells and the cone cells.
The rod cells are for low light and the cone cells are for normal and bright light and responsible for colour vision.
Colour blindness is affected when these two light-sensitive cells fail to perform their functions.
There are several factors, which causes a colour vision problem in a person. The factors include:

- Damaged caused to brain or eye or to the nerve cells.
- Genetic disorders.
- Side effects of drugs.
- Use of tobacco and alcohol.

Symptoms of Colour Blindness

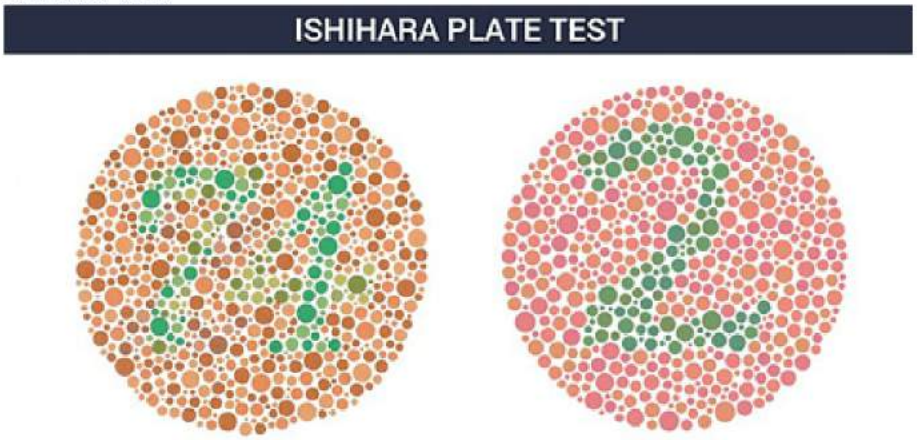
Symptoms of this eye syndrome include:

- Rapid eye movement.
- Sensitivity towards the bright light.
- Trouble in seeing colours and the brightness of colours.
- The problem in identifying the differences between colours shades.

Diagnosis of Colour Blindness

There are certain tests available to diagnosis and to measure colour vision deficiency in a patient. Doctors can easily diagnose colour blindness by using the Ishihara Plate Test.

➤ **Ishihara Plate test**



- A test, which is most commonly used for routine colour vision screening. This is present in all eye clinics and in schools. There are totally 38 plates of circles, which are created by irregular coloured dots using two or more colours. During this diagnosis, patients are asked to identify the number on a plate.

➤ **Screening test**

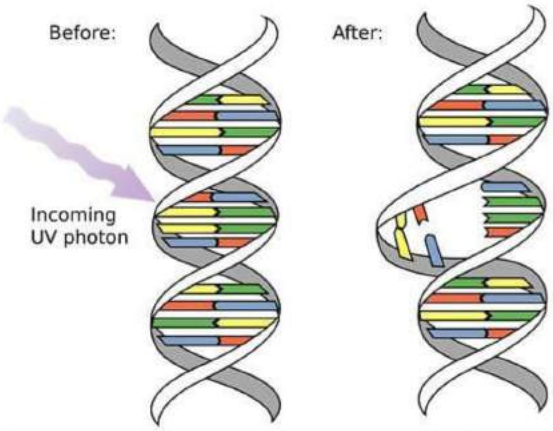
- This test is mainly used to detect and determines the type and severity of the colour blindness.

Treatment for Colour Blindness

Currently, there is no treatment for this syndrome. Photographic frames or filters and eyeglasses with contact lenses can be used to a certain extent to improve the dimension between some colours. A properly balanced diet can be followed to improve the symptoms of colour blindness.
Patients with the colour blind syndrome face many difficulties in their daily life. They may face difficulties in choosing fresh vegetables, fruits, flowers, differentiating the pulses, driving a car, selecting clothes and much more. The most common type of inherited colour blindness is red and green colour blindness. As per the studies and medical records, red and green colour blindness is seen more in men than in women. Blue colour blindness is seen both in men and women.

Mutation and Its Types

What is Mutation?



- Sudden heritable change in genetic material of an organism is called as **Mutation.**
- Mutation are discontinuous source of variation.

- Frequency of mutation at present is 1 × 10–6 (1 cell in : 1 million-cell). But it will increase in future due to pollution and destruction of ozone layer.
- Mutation word was given by **Hugo De Vries**.
- **De Vries** studied mutations in the plant **Oenothera lamarckiana** (evening primrose). It is a hybrid plant.
- De Vries gave (proposed) mutation theory of evolution.
- This theory was given in support of Darwinism because Darwin was unable to explain the source of variations.
- Darwin called variation as **sport**.
- According to De Vries there are two types of variations in evolutions.

1. Continuous variations : These variations are developed in every generation of an organism.

- These variations are developed by crossing over/meiosis/ sexual reproduction.
- Only minor variation are developed by crossing over.

2. Discontinuous variations : These variations are developed by mutations.

- Suddenly appear in any generation.
- Both minor and major type of variations are developed by mutations mostly major type.

3. Seth Right : Mutation was first observed by him.

- He observed some short legged sheep (Ancon) variety in a population of long legged sheep.
- It was an example of dominant germinal of mutation.
- Those mutation are only heritable which occur in **germinal cell** of an organism. While somatic mutations are non heritable.
- **Somatic mutations are also heritable in vegetative propagated plants.**

4. Morgan: Credit of discovery of mutation is given to him. He observed some white eyed male Drosophila in a population of red eyed Drosophila.

- In Drosophila eye colour is a sex linked character. Gene of eye colour is located on X chromosome. Gene of red eye is dominant over the gene of white eye. So in Drosophila genotypes for eye colour are of following types :

Male	Female

X^w Y - Red	X^wX^w = Red
X^w Y - White	X^W X^w = Red
50 - 50% Red & White	X^w X^w = White

Muller :-

* **Discoverer of Induced Mutations.**
* He induced mutations in Drosophila by the help of X-rays.

Mac Farlane Burnitt, Neil Jerne

* Induced mutations in B-lymphocytes of blood to obtain new antibodies.

Beadle and Tatum

* Induced mutations in Neurospora to study nutritional mutation by the help of U. V. rays. or X-rays.

Wild Neurospora $\xrightarrow{\text{U. V. rays}}$ Mutant Neurospora.

(PROTOTROPH) (AUXOTROPH)

- Normal-**Neurospora** can be grown in minimal medium (which lacks some nutrients), because it can make all nutrients for it. This is known as **Prototroph**.
- Mutant Neurospora doesn't has capability to grow in minimal medium because due to mutation it loses those genes which prepare some special nutrients for it. Eg. Vita.–B or Thiamine.
- When Vitamin–B or Thiamine was given to mutant Neurospora then the growth of Neurospora was normal. This form is known as **Auxotroph**.

M.S. Swaminathan :

- He induced mutations in wheat by the help of g-rays to obtain good varieties for eg. Sharbati Sonora
- Swaminathan established **g garden** in IARI-New Delhi (Pusa Institute).
- Largest Institute in the field of Agriculture in Asia.

Main Points :

- Mostly mutations are harmful.
- Sometimes they are lethal which leads to death of organisms.
- But sometimes they are beneficial which are used to obtain good varieties of plants and animals. It is called as **Mutation Breeding**.

- Mostly mutations are recessive and being recessive. They never eliminate from a population it is called as **Hardy-weinberg law**. Which is applicable to large population and random mating.
- Dominant lethal mutation always eliminate from a population either it is large or small.

Forward and Backward Mutation :

Wild gene Forward Backward _____ Mutant gene

Mutator gene and Mutable gene :

- Gene which induce mutation in another gene is called **mutator gene** and gene in which mutation is induced is called as **mutable gene.**

Neutral Mutation\Suppression :

- Mutation in one gene is neutralised by mutation in another gene called as neutral mutation. So it means mutation without effect and in neutralization **two mutations** are required.

Complementation :

- Occur in Heterokaryon or dikaryon cells in which two genetically different nuclei are present in a cell. Mutation effect in one nucleus is neutralised by the another nucleus of heterokaryon. This condition occur in Neurospora during somatogamy.

Hot Spot :

- Place on DNA or gene where frequency of mutation is high.
- In Prokaryotes frequency of mutation is high than eukaryotes due to naked DNA.

Muton (unit of mutation) :

- Smallest part of DNA which undergoes mutation.
- It is one nucleotide.

Types of Mutation

I. Chromosomal Mutation
II. Gene Mutations

Chromosomal Mutations :

- Change in number or structure of chromosome.

Types of chromosomal mutation
(i) Heteroploidy/Genomatic mutation → change in chromosome number.

(ii) Chromosomal aberration → change in structure of chromosome.

Heteroploidy / Genomatic mutation

- Change in number of sets or chromosomes in sets. Two types –

(i) **Euploidy →** Change in number of sets.

(ii) **Aneuploidy →** Change in number of chromosome in set.

Euploidy :

- Change in number of sets/loss or addition of sets of chromosomes.
- In a normal diploid cell two sets of chromosome are present.
- Loss of one set ($2n - n = n$) monoploidy.
- Addition of set called as polyploidy
- Addition of one set called as Triploidy $2n + n = 3n$
- Addition of two sets called as Tetraploidy $2n + 2n = 4n$
- Addition of three sets called as Pentaploidy $2n + 3n = 5n$
- Addition of four sets called as Hexaploidy $2n + 4n = 6n$
- Addition of five sets called as Heptaploidy $2n + 5n = 7n$
- Octaploid plants rarely survive.
- Polyploid plants with even number of sets are always fertile, reproduce sexually and form seeds.
- Polyploid plants with odd number of sets are always sterile don't reproduce by sexual reproduction, They don't produce seeds but they may produce seedless fruits by parthenocarpy. eg. Banana and seedless grapes.

Polyploidy is of two types :

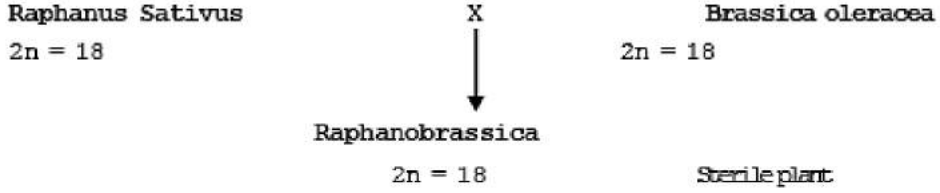
1. Autopolyploidy :

- It is repetition of same set of chromosomes. eg. AAA.
- Cyanodon and Rose → Autortirploid plants
- These are sterile plants.
- Reproduce by vegetative propagation.

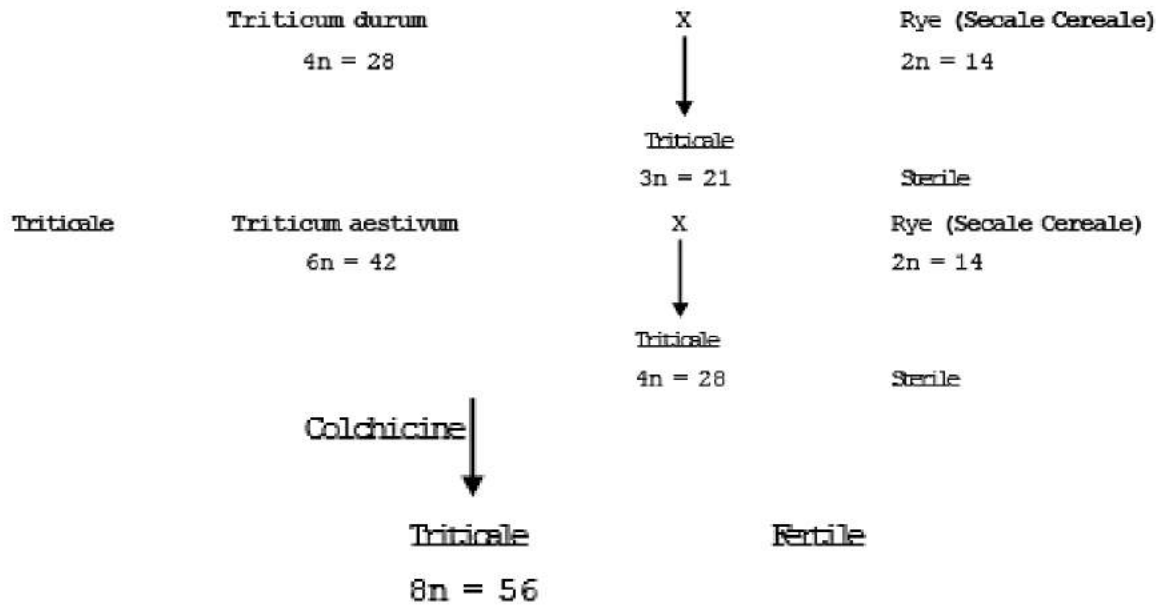
2. Allopolyploidy :

- More than one type of sets are present in these plants eg. AA BB.
- These plants are obtained by intergeneric cross.

e.g Raphanobrassica is obtained by cross between Raddish and cabbage and first time obtained by Russian Scientist Karpechenko.



Triticale :



Aneuploidy : Loss or addition of chromosomes in sets of chromosomes.

Types of Aneuploidy : 1. Hypoaneuploidy (loss)

- 2n – 1 = monosomy :- (loss of one chromosome in one set).
- 2n – 1 – 1 = double monosomy (loss of one chromosome from each set, but these are non homologus.)
- 2n – 2 = Nullisomy (loss of two homologus chromosome)
-

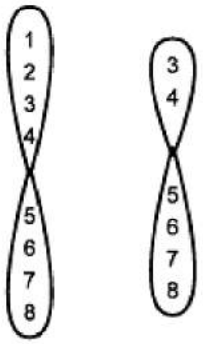
2. Hyperaneuploidy (add.)

- 2n + 1 = Trisomy : addition of one chromosome in one set.
- 2n + 1 + 1 = Double Trisomy : addition of one chromosome in each set.
- 2n + 2 = Tetrasomy : addition of two chromosome in one set.
- Cause of aneuploidy is chromosomal non-disjunction means chromosomes fail to separate during meiosis.
- Chances of aneuploidy are more in higher age female due to less activity of oocyte, so chances of syndrome increase in children who are born from higher age female.

2. Chromosomal Aberrations : Change in structure of chromosome.
(i) Deletion : Loss of a part or segment of chromosome which leads to loss of some gene is called as deletion.

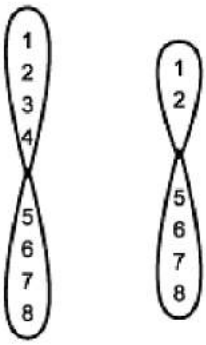
It is of 2 types :-

(i) **Terminal deletion -** Loss of chromosomal segment from one or both ends.



eg. The cry -du-chat syndrome is an example of terminal deletion in short arm of 5th chromosome.

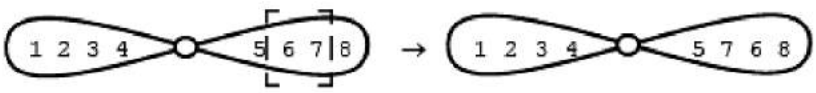
(ii) **Intercalary deletion -** Loss of chromosomal part between the ends.



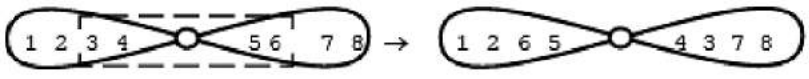
(ii) Inversion : Breakage of chromosomal segment but reunion on same chromosome in reverse orders. It leads to change in distance between genes on chromosome or sequence of genes on chromosome so crossing over is affected.

It is of 2 types :-

(i) **Paracentric -** If inversion occur only in one arm and inverted segment does not include centromere.

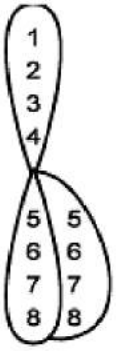


(ii) Pericentric - In this type of inversion inverted segment include centromere.



(iii) Duplication :

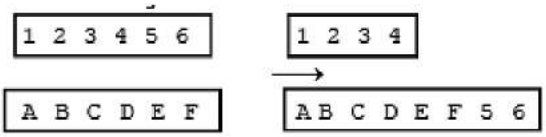
Occurrence of a chromosomal segment twice on a chromosome. If in this segment any recessive gene is present, then it gives it's expression due to homozygous condition. If in this segment any recessive but lethal gene is present, it leads to death of organism.



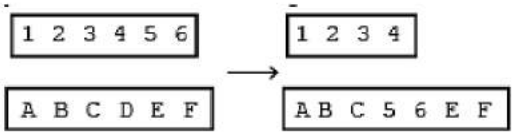
Example : In drosophila **"Bar eye character"** is observed due to duplication in X-chromosome. Bar eye is a character where eyes are narrower as compared to normal eye shape.

IV Translocation : In this, a part of the chromosome is broken and may be joined with non homologous chromosome. This is also known as **illegitimate** crossing over (illegal crossing over) Three types of translocation –

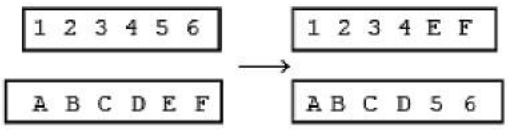
(A) Simple Translocation→ When a chromosomal segment breaks and attached to the terminal end of a non- homologous chromosome.



(B) Interstitial or shift translocation→ If a segment of chromosome breaks and gets inserted in interstitial position of a non homologous chromosome.



c) Reciprocal Translocation→ Exchange of segments between two non-homologous chromosome.



eg. **Chronic myloid leukemia [C M L] is a type of blood cancer. This disease is a result of reciprocal translocation between 22 and 9 chromosome.**
Note : If exchange of segments takes place in between homologous chromosomes then it is called **crossing over**.

Gene Mutation or point mutation

Two types :-
1. **Substitution**
2. **Frame shift mutation.**

A. Substitution : Replacement of one nitrogenous base by another nitrogenous base is called as substitution.

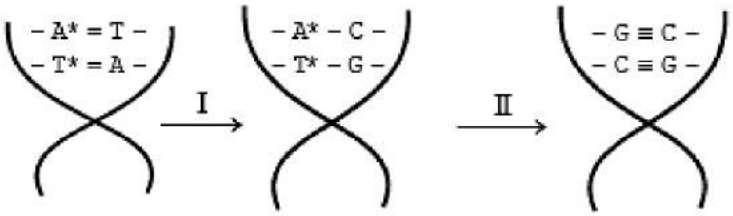
- It causes change in one codon in genetic code which leads to change in one amino acid in structure of protein. eg. Sickle cell anaemia

Main Point :

- **Change may not occur because for one animo acid more than one type of codons are present.**

Substitution is of two types :-1. **Transition** 2. **Transversion.**
1. Transition : Replacement of one purine by another purine or replacement of pyrimidine by another pyrimidine.
Methods of Transition :-

1. By Tautomerization :- By this method transition is induced by HNO_2.
HNO_2 changes normal structure of nitrogenous base and changed nitrogenous base is called as **Tautomer**.



Forbidden pairing

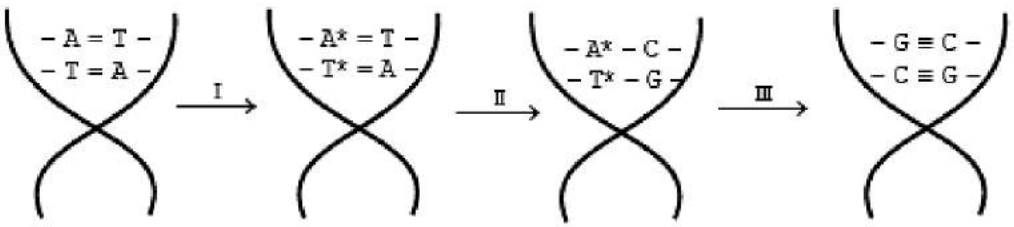
- In structure of **adenine** and **guanine**, amino group is present, HNO_2 changes it into **amino** group.
- In the structure of cytosine and thymine, keto group is present. Which is changed into **enol** group by HNO_2.
- In first DNA replication, Tautomer of adenine pairs with a normal cytosine and Tautomer of thymine pairs with normal guanine.
- It is unusual pairing which is called as **forbidden pairing** so a wrong type of DNA is formed in cell.
- In second DNA replication normal cytosine pairs with normal guanine and normal guanine pairs with normal cytosine.
- It is usual pairing so transition completes in two DNA replication (Tautomers always perform forbidden pairing)

2. By Ionisation :

- By this method transition is induced by ionising radiation like X-ray. These radiations convert nitrogenous bases in their ions and ions perform forbidden pairing. So by this method transition is completed in two DNA replications.

3. By Base Analogues :

- Transition is induced by chemicals which are same as nitrogenous base in function. They are called **base analogues** or **duplicates of nitrogenous base** eg.:- **Aminopurine** is base analogue to Adenine (purine) **5–Bromo uracil** is base analogue to thymine (pyrimidine), **5-Iodo uracil** is base analogue to guanine, **5-Chloro uracil** is base analogue to cytosine.



Forbidden pairing

- In I DNA replication base analogues get establish in normal structure of DNA.
- In II DNA replication they perform forbidden pairing.
- In III DNA replication transition is completed.

Transversion :

- Replacement of **purine** by **pyrimidine** or **pyrimidine** by **purine** is called **transversion**.
- **EMS** r Ethyl methane sulphonate
- **M MS** r Methyl methane sulphonate
- These chemicals causes depurination means they remove one purine from structure of DNA. So a gap is formed.
- If this gap is filled by another purine then it is called as **transition**.
- *But if this gap is filled by pyrimidine then it is called as **transversion**.
- So EMS and MMS may cause both transition and transversion.

Frame shift mutation/Gibberish mutation :

- (1) Acredine (2) proflavin These chemicals causes loss or addition of one or two nitrogenous bases in structure of DNA so complete reading of genetic code is changed. It leads to change in all animo acids in structure of protein so a new protein is formed which is completely different from previous protein.

A TG ACG GAC AGA AAC .....
A TG CGG A CA GAA AC .....

- So frame shift mutations are more harmful as compared to substitution.
- Thalassemia (lethal genetic disorder) Mutagens :
- Mutagens are those substances which cause mutations :-

1. Radiation :- are two types
(i) Ionizing :- a, b, g, X-ray
(ii) Non ionizing :- U. V. rays.

- U. V. rays has less penetration power and skin of higher organisms absorb radiations. So they don't cause any effect in higher animals, but U. V. rays and radiations are effective mutagens in microbes and due to more effect leads to death of microbes. So U. V. rays are used to sterilize operation theater.
- Radiations mainly cause chromosomal aberrations which cause major change in organisms. So chromosomal mutations are more important in evolution.
- U. V. rays and HNO_2 cause deamination of nitrogenous base means they remove amino group from nitrogenous base by deamination of,
  Adenine ¾ → Hypoxanthine Guanine ¾ → Xanthine Cytosine ¾ → Uracil
  U.V. rays do not cause deamination in thymine. By U.V. rays two adjacent thymine bind together and form thymine-dimer.

2. Chemical mutagens:-eg. Mustard gas (first identified Chemical Mutagens) Carbon tetra sulphide, Nitrous acid (HNO_2) Organic peroxide, Ethyl urethane, Pesticides etc. DDT (Dichloro Diphenyl Trichloro Ethane) LSD (Lysergic acid diethylamide)

- Chemical mutagens are more harmful than radiations because body is not protected against chemicals.
- Source of chemical mutagens are food, air and water.
- Effect of radiation is localized, while chemical mutagens spread in complete body through blood circulation and when they reach in gonads they cause germinal mutation.
- Chemicals also cause chromosomal mutations.

Antibiotics : 1. Neomycin 2. Kenamycin 3. Streptomycin
These antibiotics combine with small sub-unit of prokaryotic ribosome and Cause misreading of genetic code or induce error in translation.

Main Point :

- Same effect of puromycin antibiotic in eukaryotes.