UNIT

2

Genetics and Evolution

PRINCIPLES OF INHERITANCE AND VARIATION

- Genetics is a branch of biology that deals with the study of heredity and variations.
- **Heredity** is the study of transmission of characters from parents to offsprings or from one generation to the next. The characters that are passed from one generation to the other are called hereditary characters.
- **Variations** on the other hand may be defined as the differences in characteristics shown by the individuals of a species and also by the offsprings or siblings of the same parents.
- The term genetics was first used by **W. Bateson (1905).**
- **Gregor Johann Mendel** (1822-84) is called the Father of Genetics because he was the first to workout the patterns of heredity by performing experiments on garden pea plant (Pisum Sativum). He laid the foundation of genetic studies. On the other hand, **Archibald Garrod** is considered as the Father of human genetics.

Terms related to heredity

- **Gene** is the inherited factor that determine the biological character of an organism. A pair of contrasting characters is called **allelomorph** or **allele. Dominant allele** is one of the factor of an allelic pair which can express itself whether present in homozygous or heterozygous state, *e.g.*, T (tallness in pea), R (round seed in pea). **Recessive allele** is the factor of an allele pair which is unable to express its effect in the presence of its contrasting factor in a heterozygote, *e.g.*, t in Tt. **Wild allele** is the one which was originally present in the population and is **dominant** and **widespread.**
- In **homozygous condition,** organism have **two similar genes** or alleles for a particular character in a homologous pair of chromosomes, *e.g.*, **TT** or **tt.** Organisms containing **two different alleles** of a gene or individual containing both dominant and recessive alleles of an allelic pair, *e.g.*, **Tt**, is known as **heterozygous** or **hybrid.**
- When only one allelic pair is considered in cross breeding it is called **monohybrid cross.** When two allelic pairs are used for crossing it is called **dihybrid cross. Genotype** is the sum total of heredity or genetic make up. **Phenotype** is the external features of organism. **Punnett square** is a checker board which was devised by **R.C. Punnett** and used to show the result of a cross between two organisms.

MENDELISM

- Mendel was a monk in Austria. Mendel first represented his rules of inheritance based on his hybridization experiments on garden pea in **1865.**
- His laws of heredity were described in his paper "**Experiments on Plant Hybridization**" which was published in the fourth volume of "Annual Proceedings of Natural History Society of Brunn" in 1856.
- At the time Mendel's discoveries were neglected. It was in 1900, that Mendel's laws were rediscovered simultaneously by three great scientists namely **Hugo de Vries, Erich von Tschermak and Carl Correns**. The theory is now known as **Mendelism.**
- Mendel had conducted hybridization experiments on garden pea, *Pisum sativum*. The number of characters studied by Mendel in pea plant was **seven**. The number of chromosomes in *Pisum sativum* is 14 (2**n**). Mendel restricted his experiments to one or few pairs of contrasting traits in each experiment.
- Mendel selected garden pea for his experiment because –
  - It has a number of well defined contrasting characters.
  - It has bisexual flowers.
  - It shows predominantly self fertilization (autogamy) thus pure breeds are easily available.
  - Hybridization or crossing is easy in pea.
  - It has short life span, thus greater number of generations can be studied in a short period.
- Mendel's experiment involved 4 steps as – selection, hybridization, selfing and calculations.
- To carry out hybridization, self fertilization in pea was prevented by removing anthers (emasculation) before pollen grains mature.

Mendel's principles of inheritance

- Mendel's three principles of inheritance are :
  - **Law of dominance**
  - **Law of segregation or law of purity of gametes**
  - **Law of independent assortment.**
- **Law of dominance** states that only one factor expresses itself in F_1 generation. In a hybrid where both the contrasting alleles are present, only one factor/allele called **dominant** is able to express its effect while the other factor

called **recessive** remains suppressed in F_1 generation. This is called law of dominance. F_2 generation expresses both the dominant and the hidden recessive factors in the ratio of 3 : 1 in the monohybrid cross. Exception to principle of dominance are **incomplete dominance** and **codominance**.

- **Principle of segregation** states that, "when a pair of contrasting factors are brought together in a hybrid; these factors do not blend or mix up but simply associate themselves and remain together and separate again at the time of gamete formation". The above law is also known as "**law of purity of gametes**" because each gamete is pure in itself *i.e.*, having either T (*i.e.*, gene for tallness) or t (*i.e.*, gene for dwarfiness).
- **Principle of independent assortment** states that the genes of different characters located in different pairs of chromosomes are independent of one another in their segregation during gamete formation. However it is now known that Independent assortment is not applicable for the genes located on the same chromosome, *i.e.*, linked genes. **Mendelian recombinations** were mainly due to independent assortment.

Back cross and test cross

- A cross of F_1 hybrid with either of the two homozygous parents is known as back cross. When F_1 offsprings are crossed with the dominant parents, all the F_2 offsprings develop dominant character. On the other hand when F_1 hybrids are crossed with recessive parent, individuals with both the phenotypes appear in equal proportions. While both the crosses are known as back cross, the second one is specified as **test cross.**
- It is called so because it can be used to test genotype of a dominant phenotype. If dominant individual is pure (homozygous) it will produce only dominant trait in progeny

GENE INTERACTION

- Gene interaction is the modification of normal phenotypic expression of a gene due to either its alleles or other non-allelic genes. Gene interaction is of two types – **intragenic** and **intergenic**.

Intragenic interaction

- In intragenic interaction, two alleles of a gene which are present on the same gene locus of the two homologous chromosomes, react to produce modified phenotype. *E.g.*, **incomplete dominance, codominance and multiple alleles.**

Incomplete dominance

- It is the phenomenon where dominant allele does not completely express itself. This phenomenon was first studied in flower colour of *Mirabilis jalapa* or four O'clock plant. The phenotypic as well as genotypic monohybrid ratio in F_2 generation in incomplete dominance is 1 : 2 : 1 *i.e.*, pure dominant : hybrid : pure recessive. F_1 generation expresses a phenotype which is intermediate between those of the parent. *E.g.*, pink flowers are obtained when red and white flowered plants are crossed.

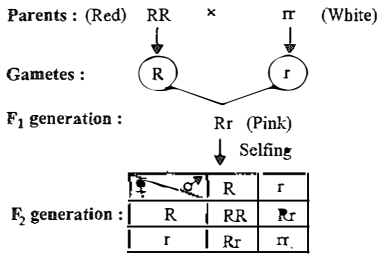


Fig.: Incomplete dominance in *Mirabilis jalapa.*

Codominance

- It is the phenomenon of two alleles lacking dominant-recessive relationship where both of them express themselves together and equally in the organisms. The codominant alleles are able to express themselves independently when present alone.
- The roan coat colour in cattle is an example of codominant allele. If a cattle with black coat is crossed with a cattle with white coat, the F_1 hybrids possess neither black nor white coat colour, but have roan coat colour, where black and white patches appear separately. The effect is produced due to juxtaposition of small patches of black and white colour.
- The codominant alleles are shown with same capital letter but with different superscripts like I^AI^B for allele in human blood group AB and Hb^A Hb^S for normal and sickle celled erythrocytes. The phenotypic ratio is **1 : 2 : 1**.

Table : Differences between incomplete dominance and codominance

	Incomplete dominance	Codominance
1.	Effect of one of the two alleles is more conspicuous.	Effect of both the alleles is equally conspicuous.
2.	It produces a fine mixture of the expression of two alleles.	There is no mixing of the effect of the two alleles.
3.	The effect in hybrid is intermediate of the expression of the two alleles.	Both the alleles produce their effect independently,
4.	Alleles show quantitative effect. One dominant allele produces half and two dominant alleles produce full phenotype.	There is no quantitative effect of the alleles.

Multiple alleles

- More than two alternate forms of a gene, present on the same locus are called multiple alleles. There is absence of crossing over in multiple alleles and the mode of inheritance in case of multiple alleles is called **multiple allelism**.
- The well known example of multiple alleles in humans is blood groups, which also shows codominance. **Karl Landsteiner** discovered the three blood groups in man (A, B and O). Blood group AB was discovered by **de Castello and Steini (1902).**

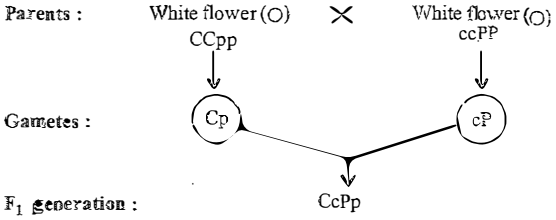
Blood type (phenotype)	Genotype	Antigen	Antibodies
A	I^AI^A or I^AI^O	A	b
B	I^BI^B or I^BI^O	B	a
AB (Universal acceptor)	I^AI^B	Both A and B	Neither a nor b
O (Universal donor)	I^OI^O	Neither A nor B	Both a and b

Intergenic interaction

- Modification of effect of a gene under the influence of a non-allelic gene *i.e.*, a gene at different locus is termed as intergenic interaction. It may be expressed in the form of complementary genes, supplementary genes etc.

Complementary genes

- If two genes present on different loci produce the same effect when present alone but interact to form a new trait when present together are called complementary genes.
- **Bateson and Punnett (1906)** observed complementary gene in sweet pea (*Lathyrus odoratus*). There are two white varieties of sweet pea controlled independently by two different genes C and P. Dominant gene C produces an enzyme that converts the raw material for flower pigmentation into **chromogen**. Dominant gene P produces another enzyme that oxidises chromogen into purple coloured **anthocyanin**. Therefore, the dominant alleles of both the genes are required for expression of flower colour. **Complementary gene ratio is 9 : 7.**



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

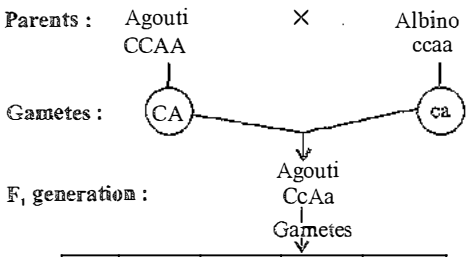
F2 generation :

Purple flower : White flower
9 7

Fig.:Complementary gene action in sweet pea.

Supplementary genes

- Supplementary genes are two non-allelic genes in which one type of gene produces its effect whether the other is present or not and the second (supplementary) gene produces its effect only in the presence of the first, usually forming a new trait.
- In mice, two genes C and A govern the coat colour. In absence of dominant alleles of both genes, albino coat is produced. Gene C, in absence of A produces black coat colour but gene A in absence C cannot express itself and produces albino. Gene C and gene A when present together supplement each other and produce a different type phenotype called 'agouti'.



♀ \ ♂	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

F2 generation: Agouti : Black : Albino
9 : 3 : 4

Fig.: Interaction of supplementary genes in mice for coat colour.

Epistasis

- Epistasis can be defined as the phenomenon of gene interaction whereby one gene interferes with the phenotypic expression of another non allelic gene or genes. The gene or locus which suppresses or masks the action of a gene at another locus is called **epistatic gene**. The gene or locus whose expression is suppressed by an epistatic gene is called **hypostatic gene**.
- A dominant epistatic allele suppresses the expression of a non allelic gene, the latter may be dominant or recessive. The dihybrid ratio for dominant epistasis is **12 : 3 : 1**. In recessive epistasis, epistatic gene suppresses the expression of non-allelic gene only when it is in homozygous recessive state. Recessive epistasis dihybrid ratio is **9 : 3 : 4**. Dominant recessive epistasis ratio is **13 : 3**.
- In *Cucurbita pepo* genes W and Y correspond with fruit colour. Gene W alone expresses white fruit colour and gene Y alone produces yellow fruit colour . Absence of both genes causes green fruit production. But when both W and Y are present, dominant allele W shows epistasis and masks expression of allele Y and produces white fruits. *i.e.*,
  - White fruit : - W – Y –, W – yy
  - Yellow fruit : – wwY –
  - Green fruit : – wwyy

Pleiotropic genes

- When a gene affects many aspects of phenotype or controls several phenotypes, it is said to be **pleiotropic genes** and this phenomenon is called **pleiotropy**.
- When a number of related changes are caused by a pleiotropic gene, the phenomenon is called **syndrome**.
- Pleiotropy is expressed in sickle cell anaemia, haemophilia, etc.

QUANTITATIVE AND QUALITATIVE INHERITANCE

- There are two types of inheritance : qualitative and quantitative. In quantitative inheritance traits are expressed in **continuous fashion. Nilsson-Ehile (1908) was first to experimentally prove quantitative inheritance.**
- In qualitative inheritance traits are expressed in discontinuous fashion.

Inheritance

Qualitative inheritance

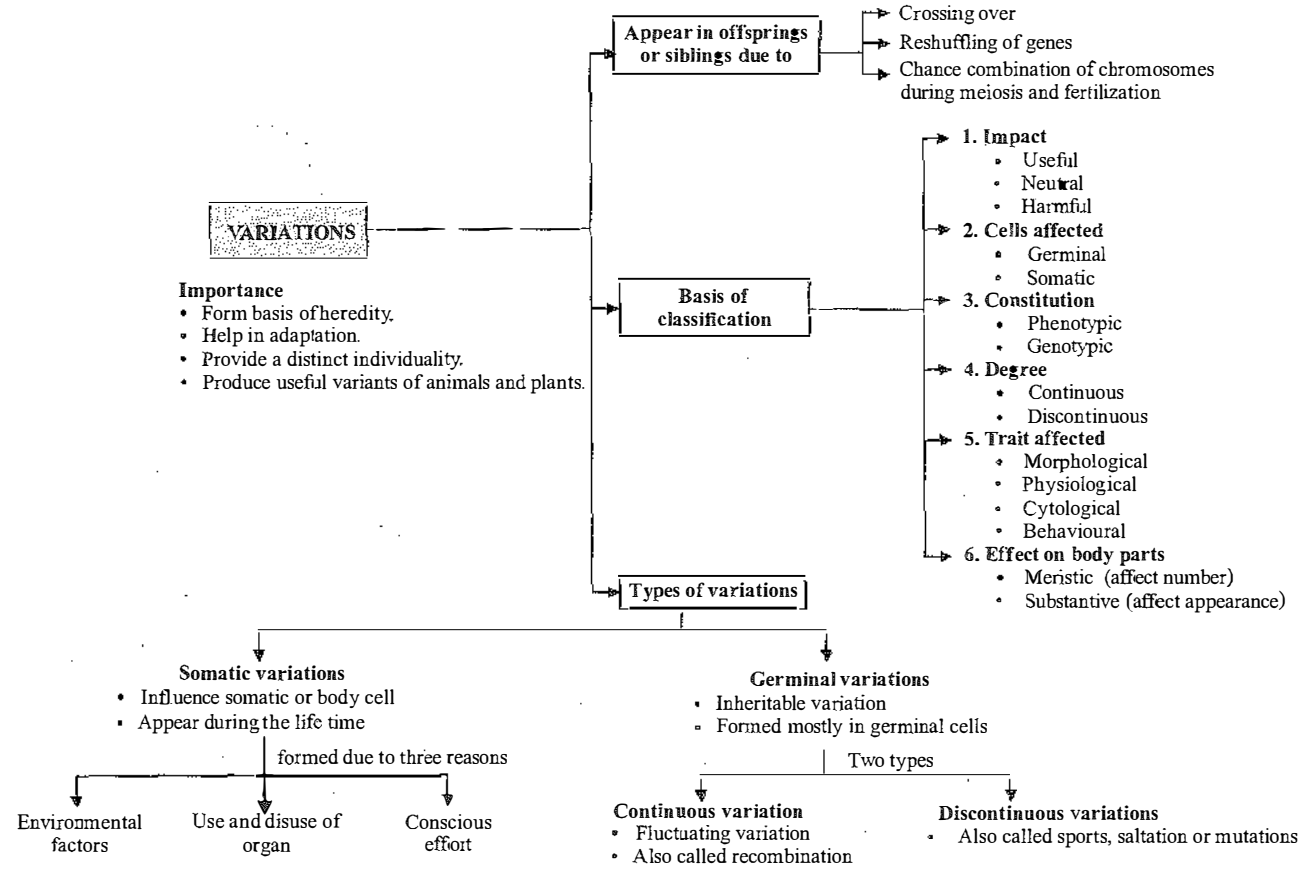
1. A single dominant gene influences a complete trait.
2. Intermediate forms are not produced.
3. Also termed as **monogenic inheritance.**

Quantitative inheritance

1. Full trait is shown when all dominant alleles present.
2. Each dominant allele expresses a part or unit of the trait.
3. Intermediate forms are produced.
4. Also termed as **polygenic inheritance.**

VARIATIONS

- Variations are differences found in morphological, physiological, cytological and behavioural traits of individuals belonging to same species, race and family. **Hereditary variations** are transmitted from generation to generation whereas **environmental variations** are temporary and do not relate with last or next generation.
- Variations are of two types : somatic variations and germinal variations.
- **Somatic variations** affect the somatic or body cells of the organisms and they die with the death of the individual and thus are non-inheritable. Somatic variations are also called modifications or acquired variations because they are acquired by an individual during its life time. They are formed due to three reasons - **environmental factors, use and disuse of organs** and **conscious efforts.**
- **Germinal variations** are inheritable variations formed mostly in germinal cells which are either already present in the ancestors or develop as new due to mutations. They are of two types: **continuous** and **discontinuous**. They are fluctuating variations which oscillate around a mean or average of the race, variety and species.
- **Continuous variations** are also called **recombinations**. They are of two types :
  - **Meristic**, influencing number of parts like number of grains in an ear of wheat, number of tentacles in *Hydra*.
  - **Substantive**, influencing appearance like height, colour, yield of milk or eggs.
- **Discontinuous variations** are mutations which are sudden, unpredictable inheritable variations not connected with the average by any intermediate stages. They are caused by chromosomal aberrations, change in chromosome number and gene mutations.



Flow chart : An overview of variations.

CHROMOSOMAL THEORY OF INHERITANCE

- Mendel held that the traits were transmitted from generation to generation as discrete, stable, particulate units of heredity called factors, now termed genes.
- He did not know the location of the factors (genes) in the cell because the existence of chromosomes in the nucleus, the role of nucleus in reproduction and the processes of mitosis and meiosis were unknown at that time.
- By 1902, the chromosome movement during meiosis had been worked out. **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.**
- This paved the way for the chromosome theory of inheritance (1902). The **chromosome theory of inheritance** states that the Mendelian factors or genes are located at specific loci on the chromosomes, and it is the chromosomes which segregate and assort independently during meiosis and recombine at the time of fertilization in the zygote.
- The **salient features** of chromosome theory of inheritance are as follows :
  - Bridge between one generation and the next is through sperm and ovum. The two must carry all the hereditary characters. Both the sperm and egg contribute equally in the heredity of the offspring. There is fusion of the sperm and egg nuclei during fertilization.
  - As such hereditary characters are governed by nuclear material. Nucleus contains chromosomes. Therefore, chromosomes must carry the hereditary traits.
  - Every chromosome or chromosome pair has a definite role in the development of an individual. Loss of a complete or part of the chromosome produces structural and functional deficiency in the organism.
  - Like the hereditary traits, the chromosomes retain their number, structure and individuality throughout the life of an organism and from generation to generation. The two neither get lost nor mixed up. They behave as units.
  - Both chromosomes as well as genes occur in pairs in the somatic or diploid cells. A gamete contains only one chromosome of a type and only one of the two alleles of a trait. Therefore gamete is always pure/true to its character. The paired condition of both chromosomes as well as Mendelian factors is restored during fertilization.
  - Genetic homogeneity and heterogeneity, dominance and recessiveness can be suggested by chromosomal type and behaviour.
  - Homologous chromosomes synapse during meiosis and then separate or segregate independently into different cells which establishes the quantitative basis for segregation and independent assortment of hereditary factors.

LINKAGE

- Linkage is the phenomenon of certain genes staying together and their ***en block*** **inheritance from generation to generation** without any change or separation due to their being present on the same chromosome. It was **T. H. Morgan (1910)** who clearly proved and defined linkage on the basis of his breeding experiments on fruit-fly *Drosophila melanogaster*.
- Genes are arranged in a **linear fashion** on the chromosome. Some genes situated in close proximity are always inherited together *i.e.*, become linked. Strength of the linkage between two genes is **inversely proportional** to the distance between the two.
- All those genes which are located in the single chromosome, constitute a linkage group. The number of linkage groups in a species corresponds to its haploid number of chromosomes. This principle is known as the **limitation of linkage groups.** For example, there are four linkage groups in *Drosophila*, 23 in man, 7 in sweet pea and 10 in maize and only 1 in *E. coli*.

Types of linkage

- **Complete linkage** is a linkage or grouping of genes on a chromosome which is not altered and is inherited as such from generation to generation without any cross-over. In such cases parental percentage is always 100% and recombinant percentage is zero percent (0%). It is rare but has been reported in certain cases like male *Drosophila*.
- **Incomplete linkage** is the phenomenon of an occasional crossing over between two homologous chromosomes so that one or more alleles present in a linkage group are replaced by other alleles. It produces both **parental** and **recombinant individuals.** The percentage of each parental type is **more than 25%** while that of each recombinant type is **less than 25%**, *i.e.*, parental types are more than 50% of population while recombinant types are less than 50%.

CROSSING OVER (RECOMBINATION)

- **Janssens (1909)** was the first person to discover chiasma formation and related process of crossing over. Crossing over is the recombination of linked genes brought about as a result of interchange of corresponding parts between the **chromatids of a homologous pair of chromosomes**, so as to produce new combinations of old genes.
- The crossing over results basically from an exchange of genetic material between non-sister chromatids by breaking up and subsequent exchange following replication. Recombination formed due to crossing over occurs in **pachytene of meiosis I** which gives rise to a haploid product having a genotype different from the two haploid genotypes present in the parent.
- During crossing over the two homologous chromosomes are held together by a **synaptonemal complex**. The chromatids of each synapsed chromosome slightly separate and become visible in the pachytene stage of prophase I. At this time breakage of chromatid segments, exchange of non-sister chromatid segments and later their fusion in new places occur.
- The synaptonemal complex begins to dissolve except in the region of crossing over. The synaptonemal attachment points between the homologous chromosomes are called **chiasmata**. The crossing over, thus includes the breaking of chromatid segments, their transposition and fusion.

Significance of crossing over

- It brings new combination of genes which are different from parents thus introduces variations. The variations are helpful in **struggle for existence** and **adaptability** to changes in environment.
- It establishes that genes occur in a linear fashion over the chromosomes.
- The rarity or abundance of a particular combination of genes is known from **frequency of crossing over**.
- Useful **recombinations** are picked up by breeders for development of improved varieties.
- The frequency of crossing over is used for building **linkage maps** or **chromosome maps.**

SEX DETERMINATION

- Sex determination is the method by which the distinction between males and females is established in a species. Sex of an individual is determined at the time of fertilisation, when male and females gametes fuse together. In some species it is established by environmental factors while in some it is determined genetically. It is usually under genetic control of specific chromosomes called **sex chromosomes or allosomes.**
- There are five main genetic mechanisms of sex determination:
  - **(i) XY method :** XX – ♀, XY – ♂ *e.g.*, mammals, some insects like *Drosophila.*
  - **(ii) X0 method :** XX – ♀, X0 – ♂ *e.g.*, roundworm, insects.
  - **(iii) ZW method :** ZW – ♀, ZZ – ♂ *e.g.*, birds, reptiles, fishes.
  - **(iv) Z0 method :** Z0 – ♀, ZZ – ♂ *e.g.*, moths, butterfly.
  - **(v) Haploid diploid method.**

XX – XY type

- In this type the female is homogametic (isomorphic) possessing two similar sex chromosome XX and the male is heteromorphic or heterogametic possessing one X-chromosome similar to that of female and in shorter and morphologically different Y-chromosome (humans); however morphology may vary in different organisms.

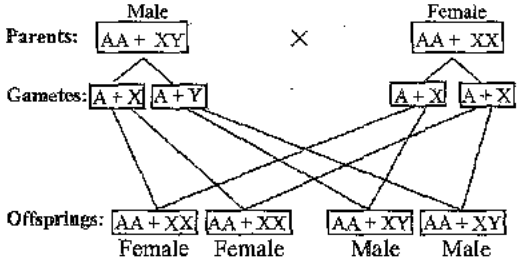


Fig.: XX-XY determination of sex in humans.

- XX – XY type is found in **mammals** and some insects such as *Drosophila.*

XX - X0 type

- In this type the **female** has **two** homomorphic sex chromosomes (XX) and produces similar eggs (**homogametic**) while the **male** has **one** chromosome only and produces two types of sperms (**heterogametic**): gynosperms with X and androsperms without X.

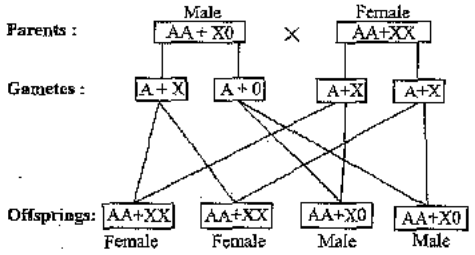


Fig.: XX-X0 determination of sex in cockroach/grasshopper.

ZW - ZZ type

- In this type the male has two **homomorphic sex chromosomes (ZZ)** and is homogametic, and the **female has two heteromorphic sex chromosomes (ZW)** and is heterogametic.
- This mechanism operates in certain insects and invertebrates **(fishes, reptiles and birds).**

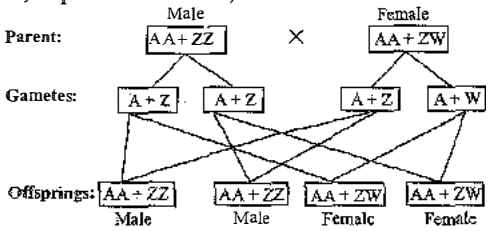


Fig.: ZW-ZZ determination of sex in chicken.

Z0-ZZ type

- In this type the **female** is **heterogametic** while the **male** is **homogametic.**
- This mechanism occurs in certain **butterflies** and **moths.**

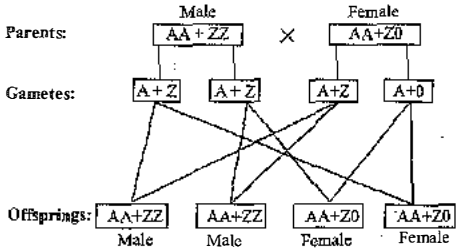


Fig.: Z0-ZZ determination of sex in butterfly

Haploid diploid method

- It is a unique phenomenon in which an unfertilized egg develops into a males and a fertilized egg develops into a female *i.e.*, haploid males and diploid females occur. Eggs are formed by meiosis and sperms by mitosis. Fertilization restores diploidy and produces female. If the egg is not fertilized, it will still develop into a male (**arrhenotoky**).

Sex determination in humans

- 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 characteristics. The genetic makeup of the sperm determines the sex of the child.

- **X chromosome** was discovered by **Henking (1891)**.
- **Y chromosome** was discovered by **Stevens (1902)**.

SEX-LINKED INHERITANCE

- Sex-linked inheritance is the transmission of characters and their determining genes alongwith sex determining genes which are on the sex chromosomes and, therefore, are inherited together from one generation to the next.
- Most sex-linked genes are located on the X chromosome, forming **X-linkage**. A few genes occur on the Y chromosome, forming **Y-linkage.** The Y-linked traits are transmitted only through the male, are X linked and mostly males are affected. Females are usually carriers of these diseases. As they are 'X' linked therefore father never transfers haemophila or colour blindness to their sons. Two important sex-linked human diseases are **haemophilia** and **colour blindness**.
- Besides sex linked inheritance, sex limited genes and sex influences traits have also been observed.
- **Sex limited traits** are those traits which are expressed in a particular sex though their genes also occur in the other sex, *e.g.*, milk secretion in mammalian females.
- **Sex influenced traits** are the traits that are not due to particular genes but are by-products of **sex hormones**, *e.g.*, low pitched voice, beard, moustaches and pattern baldness in males. The gene for baldness behaves as an autosomal dominant in males and autosomal recessive in females (sex linked genes).

Characteristics of sex-linked inheritance

- It is **criss-cross inheritance.** Father does not pass the sex-linked allele of a trait to his son. The same is passed to the daughter, from where it reaches the grandson, *i.e.*, **diagynic inheritance.**
- Mother passes the alleles of a sex-linked traits to both sons and daughters.
- Majority of the sex-linked traits are recessive.
- Sex-linked traits are more apparent in males than in females.
- As many sex-linked traits are harmful, males suffer more from **sex-linked disorders.**
- Females generally function as carriers of sex-linked disorders because recessive genes can express themselves in females only in the homozygous state.
- *E.g.*, colour blindness, haemophilia etc.
- Sex linked non criss-cross inheritance is holandric (if it passes directly from father to son) and hologynic (if it passes directly from mother to daughter).

MUTATION

- Mutation is the sudden inheritable discontinuous variation which appears in an organism due to permanent changes in their genotypes. The term mutation was coined by **Hugo de Vries (1901)**. First scientific study of mutation was made by **T.H. Morgan** (1910 in *Drosphila*). The microorganism which have been used since last 25 years for studies of mutations are *Neurospora* (red mould), *E. coli* and bacteriophages. Mutation are of three types – **chromosomal mutation** (changes in the number and arrangement of gene in the chromosome), **genomic** (changes in number) and **gene mutation** (changes in the form and expression of genes).

Chromosomal mutation

- Chromosomal mutation is the change that occurs in the morphology of chromosome resulting in change in number or sequence of gene without any change of ploidy. They are also called **chromosomal aberration**. They are quite common in cancer cells. Chromosomal aberrations may involve changes in a single chromosome **(intra-chromosomal aberration)** or between two chromosomes **(inter-chromosomal aberrations)**. The intra-chromosomal aberrations are deficiency, deletion and inversion and inter-chromosomal aberrations are duplication and translocation.
- **Deficiency** is the loss of terminal segment of chromosome and is produced by a single break in chromosome. **Deletion** also involves the removal of a section of chromosome and is produced by a double break in chromosomes. In **inversion** the part of chromosome segment gets inverted by 180°. In **duplication**, there is addition of an extra segment/ part of the chromosome so that a gene or set of genes is represented twice in the same chromosome. **Translocation** is the separation of the chromosome segment and its attachment to a non-homologous chromosome.

Genomic mutation

- Genomic mutations are change in the number of chromosomes. Genomic mutation caused by variation in chromosome number are of two types **euploidy** and **aneuploidy**. Euploidy is the condition is which chromosome number is exact multiple of a genome, *e.g.*, monoploidy, diploidy, polyploidy etc.
- Aneuploidy is the phenomenon where there is change in chromosome number due to gain or loss of chromosomes. The organisms showing aneuploidy are known as aneuploids or heteroploids. They are denoted by the number of affected chromosomes with the suffix-somic, *e.g.*, nullisomic, monosomic, trisomic, etc.

Gene mutation

- The sudden stable change in the structure of a gene or cistron due to change in its nucleotide type or nucleotide sequence is called gene mutation. Gene mutations produce new alleles. The first scientific study of gene mutations started with the discovery of white eye trait in Drosophila by Morgan in 1910.
- Gene mutations may occur naturally and automatically due to internal reasons. They are termed as **spontaneous mutations.** Others are produced by external factors or chemicals. They are known as **induced mutations.** Mutation which involves change in single nucleotide is called **point mutation.** Mutation from wild to new type is **forward mutation** and mutated gene to its wild form is **reverse** or **back mutation.**
- **Substitution gene mutation** results when a nitrogenous base of triplet codon of DNA is replaced by another nitrogen base or some derivative of the nitrogen base, changing the codon. Substitution or replacement gene mutation is of two types **transition** and **transversion**.
- In **transition,** one purine is replaced by another purine or one pyrimidine is replaced by another pyrimidine.

This is base pair replacement, *e.g* , adenine ⇌ guanine (purine) and cytosine ⇌ thymine or uracil (pyrimidine). Transition is caused by tautomerization, ionization, base analogues and deamination. In **transversions,** purine is replaced by pyrimidine and *vice-versa*, *e.g*, uracil or thymine with adenine, cytosine with guanine.

- Genetic information in DNA is present in the form of triplet codon (3 letter codon) which constitute reading frame. Sometimes this reading frame is changed due to addition or deletion of a single or more N bases, which is called **frame shift mutation.** Two types of frame shift mutation are insertion and deletion. In **insertion** one or more nucleotides are added in segment of DNA representing a cistron or gene. In **deletion**, one or more nucleotides are lost from a segment of DNA.
- **Induced mutation** is produced artificially by certain mutagenic agents or mutagens. Induced mutation was discovered by **Muller** (1927), who received Noble Prize in 1946. Mutagens are any extra cellular physical or chemical factor which can cause mutations or increase frequency of mutations. **Physical mutagens** are **radiations** and **temperature**. Use of X-rays as mutagenic agent was shown by **H.J. Muller** (1927) in *Drosophila* and later on by **L. J. Stadler (1927)** in maize and barley
- Radiations may be ionizing radiations and non-ionizing radiations. **Ionizing radiations** are X-rays, γ-rays and have high penetrating power. **Non-ionizing radiations** are UV- rays which have low penetrating power. UV-rays were used by **Altenburg** in 1930. X-rays and cosmic rays distort or break DNA duplex and disturb the replication. Chemical mutagens are chemicals inducing mutations, *e.g*., nitrous acid, acridines, 5 bromouracil etc. Some common alkylating agents causing mutations are :
  - Nitrogen mustard
  - Ethyl Methane Sulfonate (EMS)
  - Methyl Methane Sulfonate (MMS)
  - N-methyl-N′-nitro-nitroso-guanidine (NTG).

PEDIGREE ANALYSIS

- Pedigree is a chart showing a record of inheritance of certain traits for two or more ancestral generations of human beings or domesticated animals in the form of a diagram of family tree. Pedigree analysis is a system of analysis by following the movement and distribution of certain genetic traits. This system has following conventions:
  - Females are symbolised by circles (○). Males are symbolied by squares (□).
  - Solid symbol represents the trait being studied (●). Open symbol represents the normal form ○ or □.
  - Parents are joined by the horizontal line, called marriage line ○---□. Offsprings are connected to the horizontal line below the parents called sibling line  .
  - A cross or shade (of any type) in the symbol signifies the carrier of a recessive allele.
- Pedigree analysis is useful in many ways like it helps to find the possible genotypes by knowing the phenotypes only. It helps to study the pattern of inheritance of a dominant or a recessive trait.

GENETIC DISORDERS

- Broadly, genetic disorders may be grouped into two categories– Mendelian disorders and Chromosomal disorders.
- **Mendelian disorders** are mainly determined by alteration or mutation in the single gene. These disorders are transmitted to the offsprings on the same lines as we have studied in the principle of inheritance. The **chromosomal disorder** on the other hand are caused due to absence or excess or abnormal arrangement of one or more chromosomes.

Mendelian disorders

- Mendelian disorders are mainly determined by alteration or mutation in the single gene.
- **Mendelian disorders are transmitted to the offsprings on the same lines as per the principle of inheritance.** The pattern of inheritance of Mendelian disorders can be traced in a family by the pedigree analysis.
- Most common Mendelian disorders are cystic fibrosis, sickle-cell anaemia, colour blindness, haemophilia, phenylketonuria, thalassemia, albinism, muscular dystrophy etc.

Haemophilia

- It is a sex-linked (recessive) disease, which is also known as **bleeder's disease**. It is marked in heterozygous condition.
- A female becomes haemophiliac only when both its X-chromosomes carry the gene (X^hX^h).
- As it is a recessive character, a lady may carry the disease and would transmit the disease to 50% of her sons, even if the father is normal. It can indicate the origin of a trait in the ancestors (*e.g.,* haemophilia). It can indicate the harm a marriage between close relatives may cause.
- **Haemophilia A** is characterized by **antihaemophilic globulin** (factor - VIII). About 4/5th of the haemophiliac cases are of this type.
- **Haemophilia B** is also called '**Christmas disease**'. It results from a defect in plasma thromboplastin component (factor IX).
- Haemophiliadisease (Royal disease) has been quite common in the royal families of Europe. The disease spread to them through the children of **Queen Victoria.**

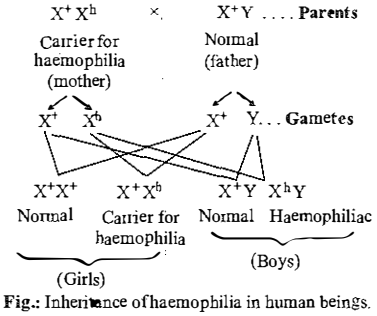


Fig.: Inheritance of haemophilia in human beings.

Colour blindness

- Colour blindness (Daltonism) is a **recessive sex-linked** trait in which the eye fails to distinguish red and green colour The gene for the normal vision is dominant. The normal gene and its recessive allele are carried by X chromosome and therefore men are more likely to show the defect although women may be **carriers.**

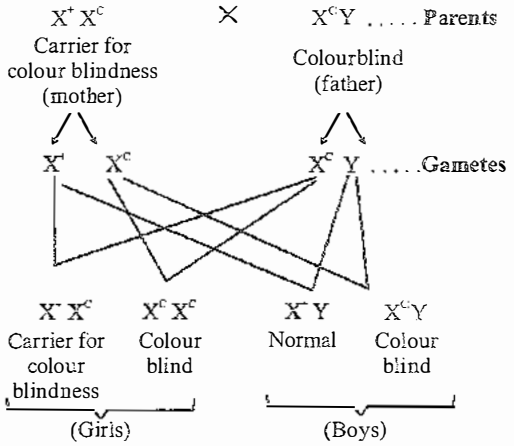


Fig.: Inheritance of sex-linked colour blindness in human beings.

Thalassemia

- It is an autosomal recessive disorder. It is also called **Cooley's anaemia**. Thalassemia is an abnormality in the protein part of the haemoglobin molecule. It appears in the children of two unaffected parents (heterozygous). The defect is due to mutation or deletion of gene controlling formation of globin chains. The affected red cells cannot function normally, leading to anaemia. Depending upon the globin chain affected it is of three types α, β and δ.
- Other symptoms include enlargement of the spleen and abnormalities of the bone marrow. Individuals inheriting it from both parents are severely affected (Thalassemia major) but those inheriting it from only one parent are usually symptom free (being recessive trait).
- Some Mendelian disorders are summarized in the given table:

Table : Mendelian Disorders

	Disorder	Mode of Inheritance	Cause of Disorder	Clinical Description
1.	Alkaptonuria	Autosomal recessive	Lack or inactivity of enzyme homogentisic acid oxidase.	Pigmentation of cartilage and fibrous tissue, with development of arthritis. Darkening of urine due to presence of homogentisic acid.
2.	Cystic fibrosis	Autosomal recessive	Failure of chloride ion transport mechanism.	High level of sweat electrolytes, pulmonary disease, cirrhosis of liver, pancreatic malfunction. Life expectancy 12-16 years. Common in persons of North European ancestory.
3.	Haemophilia	X-linked recessive	Lack of blood coagulant.	Chronic bleeding
4.	Phenylketonuria (PKU)	Autosomal recessive	Deficiency of liver phenylalanine hydroxylase.	Leads to a depression in the levels of other amino acids, mental deficiency.
5.	Red-green colour blindness	X-linked recessive		
	(i) Deutan variety		Due to the absence of green cone pigment.	Unable to distinguish green colour.
	(ii) Protan variety		Due to absence of red cone pigment	Unable to distinguish red colour.
6.	Sickle-cell anaemia	Autosomal recessive (incompletely dominant)	Formation of haemoglobins in RBCs.	Abnormality of red blood cells caused by the presence of an inappropriate amino acid in the β-chain of haemoglobin molecule. Causes extreme distortion of shape (sickling) which leads to the premature destruction of cell.

CHROMOSOMAL DISORDERS

- The chromosomal disorders are caused due to absence or excess or abnormal arrangement of one or more chromosomes. Chromosomal anomalies or disorders arise in various ways that are discussed below.
  - **Non-disjunction** : An error in nuclear division in which a pair of chromosomes fails to separate and is carried to one pole. The resulting daughter cells contain an unequal number of chromosomes, 45 and 47. This numerical abnormality in which the chromosome number is not an exact multiple of the haploid number is called **aneuploidy**. Non-disjunction occurs during gametogenesis or during mitosis. It is more common in sex chromosomes.
  - **Translocation** : Sometimes during nuclear division, a portion of one chromosome breaks away and gets subsequently attached to another which is not homologous to the first. This is called translocation.
  - **Deletion** : A piece of a chromosome may become detached and lost from the karyotype resulting in the loss of one or more genes.
  - **Duplication** : Some genes may appear twice in the same chromosome.
  - **Inversion** : Sometimes a chromosomal segment becomes inverted and then the order of sequence of genes is altered.

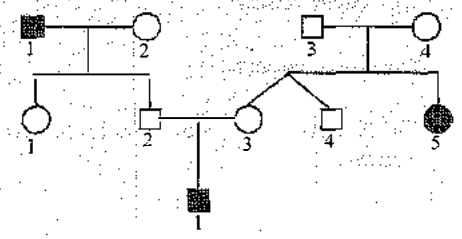
Table: Chromosomal Disorders

	Karyotype	Common name of abnormalities	Clinical Symptoms
1.	Trisomy 13	–	Multiple defects; death by age of 1 month.
2.	Trisomy 15	–	Multiple defects; death by age of 1 to 3 months.
3.	Trisomy 18	–	Ears deformed, heart defects, spasticity and other damages; death by the age of 1 year.
4.	Trisomy 21	Down's syndrome	Earlier known as mongolism; Oriental features. Epicanthus skin fold above the eye, mental retardation (I.Q. usually below 70); short stature, protruding furrowed tongue.
5.	Trisomy 22	–	Similar to Down's syndrome but with more skeletal deformities.
6.	XO	Turner's syndrome (Gonadal dysgenesis)	Short stature, webbed neck. Females with poorly developed breasts and degenerated ovaries and rudimentary sexual characterstics, with slight mental retardation.
7.	XXY	Klinefelter's syndrome	Male with slowly degenerating testes, enlarged breasts.
8.	XYY	–	Usually tall male, heavy acne on skin; Aggressive, and mild mental retardation.
9.	XXX	Triplofemale	Despite three X-chromosomes, the female is usually fertile and fairly normal.
10.	Monosomics Deletion of one short arm of chromosome-5	Cri-du-chat syndrome	Microcephaly; severe mental retardation; in infancy cry resembles mewing of a cat.
11.	Translocation between chromosome 9 and 22	Philadelphia chromosome	Acute myelogenous leukemia

Illustration : What do you know about polygenic inheritance ?

Soln.: Polygenic inheritance or quantitative inheritance is that type of inheritance in which the complete expression of a trait is controlled by two or more genes in which a dominant allele of each gene contributes only a unit fraction of the trait and the total phenotypic expression is the sum total on additive or cumulative effect of all the dominant genes.

Illustration : The following is a pedigree of a fairly common human hereditary trait.



(a) Indicate whether the gene differences causing this effect are dominant or recessive, e.g., 'A' (dominant) or 'a' (recessive).

(b) What would be the genotype of each individual in the pedigree ?

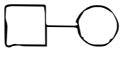
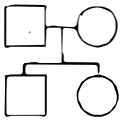
Soln.: (a) The trait can be assumed to be caused by a recessive gene, 'a', since it appears among the offsprings of parents who do not show the trait.

(b) I–1, aa; I–2, AA or Aa; I–3, Aa; I–4, Aa; II–1, Aa; II–2, Aa; II–3, Aa; II–4, AA or Aa; II–5, aa; III–1, aa.

Illustration : What do you understand by discontinuous variation?

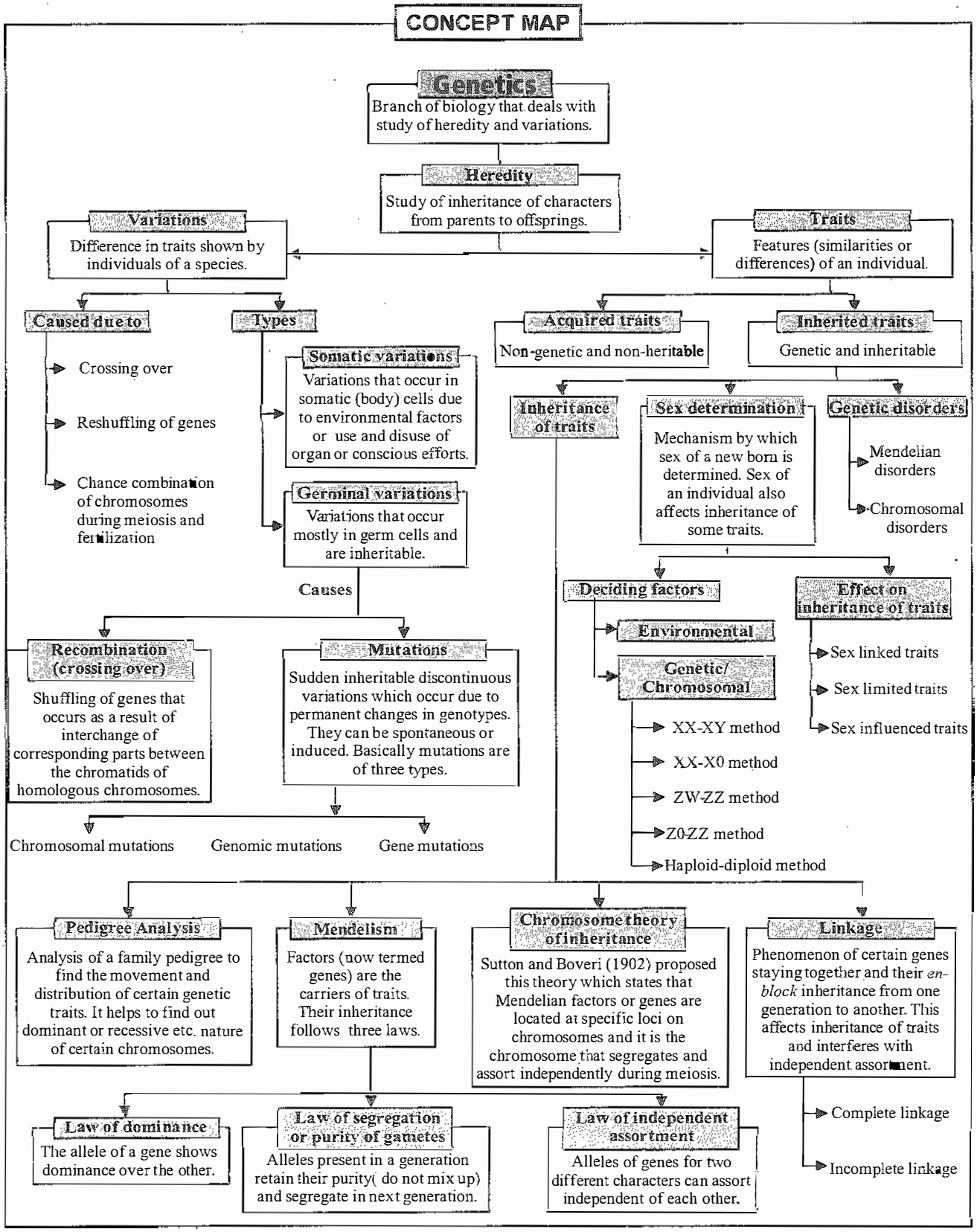
Soln.: Discontinuous variations are mutations which are sudden, unpredictable, inheritable variations not connected with the average by any intermediate stages. Discontinuous variations are caused by chromosomal aberrations, change in chromosome number and gene mutations. They formed the basis of mutation theory of de Vries (1902).

Illustration : Label the symbols and name the analysis in which these symbols are used.

(i)  (ii)  (iii)  (iv)  (v) 

Soln.: (i) Male (ii) Female (iii) Affected individuals (iv) Mating (v) Parent above and children below.

These symbols are used in pedigree analysis in which the record of inheritance of a particular trait for two or more generations is represented in the form of a family tree.


CONCEPT MAP
Genetics
Branch of biology that deals with study of heredity and variations.
Heredity
Study of inheritance of characters from parents to offsprings.
Variations
Difference in traits shown by individuals of a species.
Traits
Features (similarities or differences) of an individual.
Caused due to
Types
Crossing over
Reshuffling of genes
Chance combination of chromosomes during meiosis and fertilization
Somatic variations
Variations that occur in somatic (body) cells due to environmental factors or use and disuse of organ or conscious efforts.
Germinal variations
Variations that occur mostly in germ cells and are inheritable.
Causes
Acquired traits
Non-genetic and non-heritable
Inherited traits
Genetic and inheritable
Inheritance of traits
Sex determination
Mechanism by which sex of a new born is determined. Sex of an individual also affects inheritance of some traits.
Genetic disorders
Mendelian disorders
Chromosomal disorders
Deciding factors
Environmental
Genetic/ Chromosomal
XX-XY method
XX-X0 method
ZW-ZZ method
Z0-ZZ method
Haploid-diploid method
Effect on inheritance of traits
Sex linked traits
Sex limited traits
Sex influenced traits
Recombination (crossing over)
Shuffling of genes that occurs as a result of interchange of corresponding parts between the chromatids of homologous chromosomes.
Mutations
Sudden inheritable discontinuous variations which occur due to permanent changes in genotypes. They can be spontaneous or induced. Basically mutations are of three types.
Chromosomal mutations
Genomic mutations
Gene mutations
Pedigree Analysis
Analysis of a family pedigree to find the movement and distribution of certain genetic traits. It helps to find out dominant or recessive etc. nature of certain chromosomes.
Mendelism
Factors (now termed genes) are the carriers of traits. Their inheritance follows three laws.
Chromosome theory of inheritance
Sutton and Boveri (1902) proposed this theory which states that Mendelian factors or genes are located at specific loci on chromosomes and it is the chromosome that segregates and assort independently during meiosis.
Linkage
Phenomenon of certain genes staying together and their en-block inheritance from one generation to another. This affects inheritance of traits and interferes with independent assortment.
Complete linkage
Incomplete linkage
Law of dominance
The allele of a gene shows dominance over the other.
Law of segregation or purity of gametes
Alleles present in a generation retain their purity(do not mix up) and segregate in next generation.
Law of independent assortment
Alleles of genes for two different characters can assort independent of each other.