PRINCIPLES OF INHERITANCE AND VARIATION

INHERITANCE OF TWO GENES

INHERITANCE OF TWO GENE (DIHYBRID CROSS)

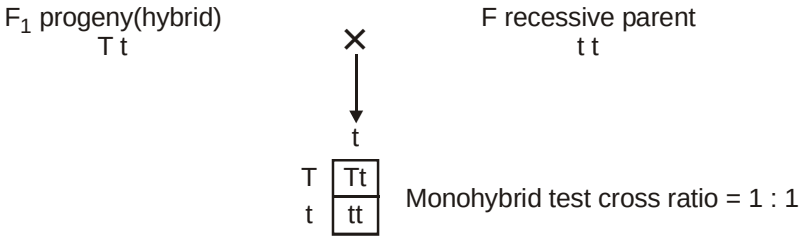
Back Cross :A back cross is a cross in which F_1 individuals are crossed with any of their parents.

When F_1 individual is crossed with dominant parent then it is termed **out cross.** The generation obtained from this cross, all possess dominant character.

Test Cross : When F_1 progency is crossed with recessive parent then it is called test cross. The total generations obtained from this cross, 50% having dominant character and 50% having recessive character. [Monoybrid test cross]. Test cross helps to find out the genotype of dominant individual. Whether it is homozyous or heterozyous for that character

Number of traits hybrid (n)	Experiment	Types of gametes (2^n)	Number of Zygotes / offsprings $(gametes)^2$	Number of Phenotype (2^n)	Number of genotype (3^n)	Phenotypic Ratio	Genotypic Ratio
1	Monohybrid cross (Aa × Aa)	$2^n = 2^1 = 2$	$2^2 = 4$	$2^n = 2^1 = 2$	$3^1 = 3$	3 : 1	1 : 2 : 1
2	Dihybrid cross (AaBb × AaBb)	$2^2 = 4$	$4^2 = 16$	$2^2 = 4$	$3^2 = 9$	$(3 : 1)^2$ = 9 : 3 : 3 : 1	$(1 : 2 : 1)^2$ = 2 : 4 : 2 : 1 : 2 : 1 : 1 : 2 : 1
3	Trihybrid cross [AaBbCc × AaBbCc]	$2^3 = 8$	$8^2 = 64$	$2^3 = 8$	$3^3 = 27$	$(3 : 1)^n$	$(1 : 2 : 1)^3$

Monohybrid Test Cross : The progeny obtained, from the monohybrid test cross are in equal proportion, means 50% is dominant phenotypes and 50% is recessive phenotypes. It can be represented in symbolic forms as follows.



DILHYBRID TEST CROSS :

The progency is obtained from dihybrid test cross are four types and each of them is 25%

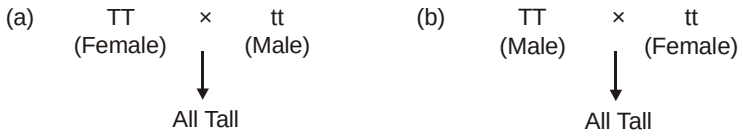
Phenotype or Genotype ratio of Dihybrid test cross = 1:1:1:1

- **Construction :** In test cross phenotypes and genotypes ratio are same.
- **Trihybrid test** cross (phenotype, genotype) ratio = 1 : 1 : 1 : 1 : 1 : 1 : 1 : 1

RECIPROCAL CROSS :

When two parents are used in two experiments in such a way that in one experiment "A" is used as the female parent and "B" is used as the male parent, in the other experiment "A" will be used as the male parent and "B" as the female parent. Such type of a set of two experiments is called Reciprocal cross.

Characters which are controlled by karyogene are not affected by Reciprocal cross. In case of cytoplasmic inheritance result become change by Reciprocal cross.



CYTOPLASMIC INHERITANCE (Correns)

Inheritance of characters which are contorlled by cytogene or cytoplasm is called cytoplosmic inheritance. Genes which are present in cytoplasm called **'Cytogene'** or **'Plasmagene'** or **extra nuclear gene.** Total cytogene present in cytoplasm is called '**Plasmon**'.

A gene which is located in the nucleus is called '**karyogene**'.

- Inheritance of cytogene in higher plants only through the female.
- The male gamete of higher plant is called male nucleus. It has very minute [equivelent to nil] cytoplasm.So male gamete only inherited karyogene.
- Thus, inheritance of cytogene only through female cytoplasm. (also called maternal inheritance)
- If there is a reciprocal cross in this condition, then result will be effected.

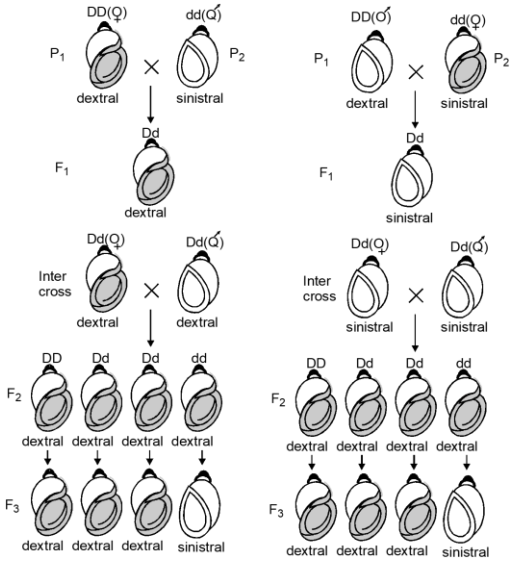
Cytoplasmic inheretance of three types :

- Maternal effect depending indirectly on nuclear genes and involving no known cytoplasmic cytoplasmic hereditary unit called as **predetermination.** maternal effect is determine before fertilization.
- Cytoplasmic inheritance involving dispensable and infective heredetary particle in cytoplasm which may or may not depend on nuclear genes called as **Dauermodification.**
- Cytoplasmic inheritance involving essential organelles like, Chloroplast and mitochondria called as **organellar genetics.**

Example of predetermination

Shell coiling in snail (Limnaea peregra)

In Shell coiling of snail can be dextral (Coiling to the right) or sinistral (coiling to the left). This direction of coiling is genetically the dextral coiling depending upon maternal dominant allele D and sinistral coiling depending upon maternal recessive allele (d).



Above reciprocal cross indicates that phenotype of offspring is decided by genotype of female parent not the phenotype of female parent. If female parent contains only one dominant gene 'D' then phenotype of all offspring will be dextral.

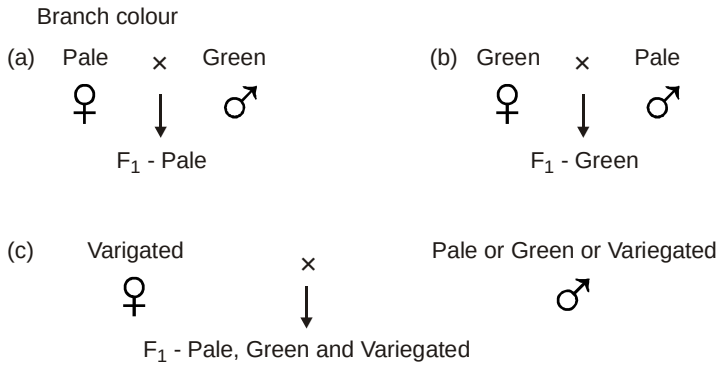
Example of Dauermodification -

- **Sigma particle in Drosophila** these particle are virus like particles which are present in Drosophila and related to CO_2 sensitivity. Inheritance of sigma particle takes place through the egg cytoplasm.
- **Kaapa particle in Paramecium** kappa particles are found in certain ''Killer strains'' of Paramecium and are responsible for production of substance paramecin which is toxic to strain not prossessing Kappa. (Sensitive Strain)

  The minimum number of kappa particlesis 400 to secrete paramecin. Kappa particles are symbiotic bacteria named **"Caedobacter taeniospiralis"**

Example of Organellar Genetics : (True examles of cytoplasmic inheritance)

- **Plastid inheritance in Mirabilis jalapa –** cytoplasmic inheritance first discovered by **Correns** in Mirabilis jalapa.
- In Mirabilis jalapa plastid inheritance i.e. branch colour is example of cytoplasmic inheritance.



Male strelity in maize plant – Gene of male sterelity present in mitochondria. If a normal male plant crossed with a female plant which has genes of male sterelity then all the generation become male sterile because a particular gene was present in female which inherited by female.

- **Albinism in plant :** Gene of albinism is found in chloroplast. Gene of albinism is leathal in plant.
- **Inheritance of Bacterial plasmid.** In bacteria plasmid inheritance is due to conjugation.

- **Petite form in yeast** = (mitochondrial gene) petite is mutant form of yeast. This mutant form is slow growing on culture medium.
- **Iojap inheritance in Maize** Iojap is characterized by contrasting strip of green and white colour of leaves.
- **Poky Neurospora** - (Mitochondrial gene) poky is mutant form of Neurospora. It is slow growing on culture medium.

Exceptions of conclusions of Mendel :

Exceptions of Principle of Dominance and Paired Factors :

1. **Incomplete dominance :**

   Incomplete dominance was discovered by **Carl correns (1903)in Mirabilis jalapa.**

   Incomplete dominance is the phenomenon where none of the two contrasting factor or alleles is dominant.

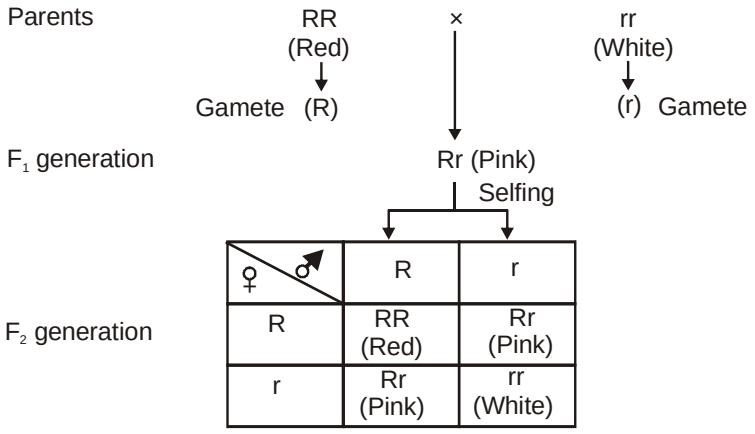
   The expression of the character in a hybrid of F_1 generation is intermediate (partial or mosaic). **Mirabilis jalapa is also known as 4'0' clock plant or Gulbansi**

   In Mirabilis jalapa, there are two types of flower colour in pure state, Red and White.When the two types of plant are crossed. The hybrid of F_1 generation have pink flower. If the latter are selfed, the plants of F_2 generation are of three types- Red, Pink and White flowered in the ratio of 1: 2: I

   The phenotypic and genotypic ratio is similar (1 : 2 : 1) due to incomplete dominance in F_2 generation.

   Analysis : It is cleared that factors of Red and White colour are found in F_1 generation of Mirabilis but the factor of Red colour does not completely express itself in the presence of factor of white colour.

   Thus the pink colour apparently appears due to mixing of Red and White colour in Heterozygous F_1 generation. Incomplete dominance can also be shown by checker board method.



Phenotypic ratio 1 : 2 : 1

Red Pink White

Genotypic ratio 1 : 2 : 1

RR Rr rr

(25%) (50%) (25%)

Incomplete dominance is also found in **colour of flower in Snapdragon or Antirrhinum or Dog flower** and **feather colour in Andulasian fowls**.

Note: Incomplete dominance is not an example of blending inheritance because the parental types reappear in the F_2 generation. Some worker considered it as example of quantitaitve inheritance where single gene pair involved.

2. **Co-dominance :**

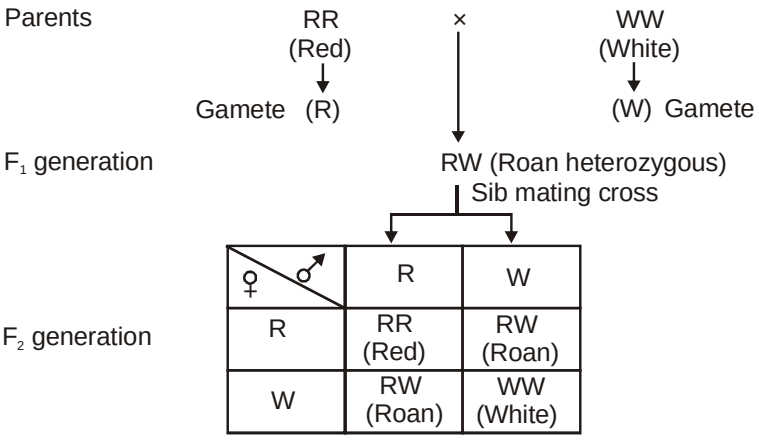
In codominance the alleles are able to express themselves independently in F_1 generation.

Ex :

(i) **Skin colour in Short Horned cattles**.

There are two types of pure cattle, Red and White. On cross-breeding the individuals of F_1 generation are found to have roan colour.Here in a heterozygote of F_1 generation both alleles express themselves independently. The effect is produce due to juxtaposition of small patches of Red and White colour. It is also known as mosaic inheritance. Both the alleles are co-

dominant in F_1 generation. On inbreeding the roan hybrids produce three types of cattle-Red Roan and White in the ratio of 1:2:1.



Phenotypic ratio **1 : 2 : 1**

Red Roan White

1 : 2 : 1

Genotypic ratio **RR RW WW**

Ex:

(ii) Sickle cell Haemoglobin. The allele for sickle cell haemoglobin Hb^S is codominant with allele for normal haemoglobin Hb^A.

Ex:

(iii)AB Blood Group. Alleles of blood group A(I^A) and blood group B (I^B) are codominant & found over the surface of erythrocytes. when they come together in an individual, they produce blood group AB.

Ex:

(iv) MN Blood Group. It is found in humans. The erythrocytes carry two types of native antigens, M and N, and an individual can be MM, MN, NN.

3. **Multiple allele :**

Bernstein (1924) : Discovered multiple alleles.

More than 2 alternative forms of a gene are called as multiple allele. Multiple alleles are located on same locus of homologous chromosome. A diploid individual contains two alleles and gamete contains one allele for a character.

Ex:

(i) **Human Blood group - 3 alleles**

Table: Different aspects of blood group

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

Human beings have four blood groups or blood group phenotypes **– A, B, AB and O.**

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

I^A = dominant

I^B= dominant

I° = recessive

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

If **n** is the number of alleles of a gene then number of different possible genotype =

For **eg-** In human blood group number of alleles or **n** are 3. Thus the number of different possible genotype will be **= 6 genotypes.**

Ex:

(ii) **Coat colour in rabbit**

Four alleles regulate coat colour in rabbit

Wild type = Full coloured = agouti = C.

Himalayan [white with black tip on extremities (like nose, tail and feet)] = c^h

Chinchilla (mixed coloured and white hairs] = c^{ch}

Albino = Colourless = c

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

Possible genotypes -

Coloured = CC, Cc^{ch}, Cc^{h} Cc

Chinchilla = $c^{ch}c^{ch}$, $c^{Ch}c^{h}$, c^{ch}c

Himalayan = $C^{h}C^{h}$, c^{h}c

Albino = cc.

Number of possible genotypes =**genotypes** .

4. **Pleiotropy :**

   A gene regulates multiple phenotypic effect. **Ex: sickle cell anaemia**.

EXCEPTION OF CONCLUSION OF INDEPENDENT ASSORTMENT

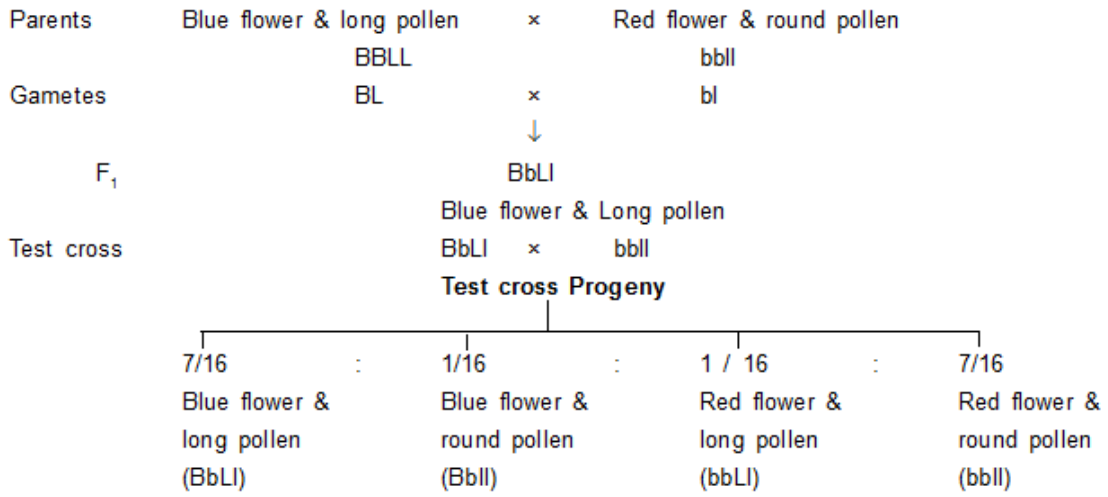
The law of independent assortment is most criticised. Linkage is the exception of this law.

LINKAGE :

collective inheritance of character is called linkage first time seen by **Bateson and Punnett** in **Lathyrus odratus** 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.

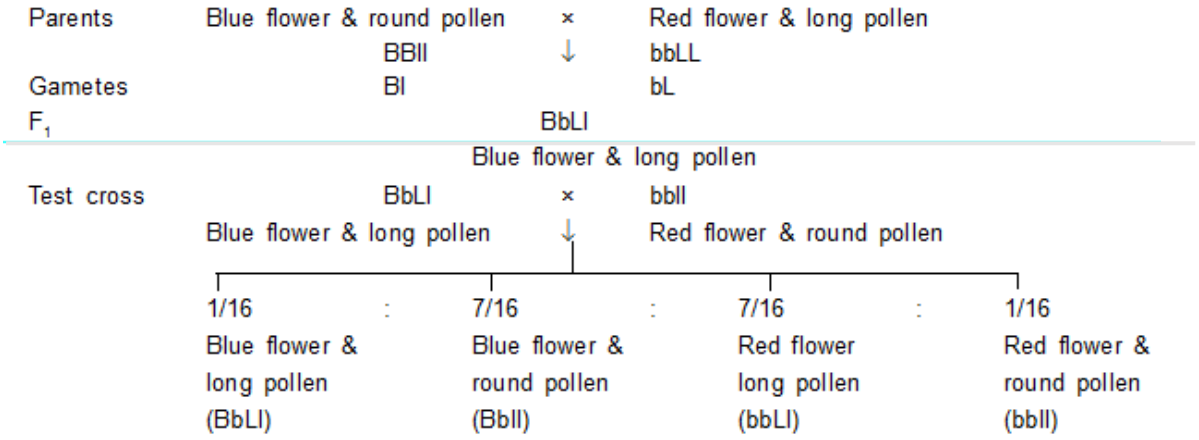
In 1906, **Bateson and Punnet** crossed two varieties of Lathyrus odoratus (sweet pea) and observed that the results do not agree with the mendel's law of independent assortment. They formulated the hypothesis of **coupling and repulsion** to explain the unexpected F_2 results of dihybrid cross between a homozygous sweet pea having dominant alleles for blue flowers (BB) and long grains (LL) with another homozygous double recessive plant with red flowers and round pollen grains (bbll).

Test Cross Ratio of F_1 7 : 1 : 1 : 1 indicated that there was a tendency of the dominant alleles to remain together. Similar was the case with recessive alleles.



It was called **gametic coupling** by bateson and Punnet. The tendency of two dominant genes to remain together in the process of inheritance was called as **coupling.**

In another cross they took a sweet pea plant with blue flowers and round pollens (BBll) and other plant with red flowers and long pollens (bbLL) and obtained the **ratio of 1 : 7 : 7 : 1** by test crossing F_1 generation.



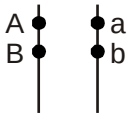
When two dominant or recessive genes comes from different parents, they tend to remain separate hence, this ratio is called repulsion ratio. **T.H. Morgan** in 1910 showed that coupling and repulsion are two aspects of the same phenomenon called linkage. He suggested that the two genes present on the same chromosome, are in **coupling phase** and when present on two different homologous

chromosomes are in **repulsion phase**. Linkage therefore, may be defined as "**The tendency of two genes of the same chromosome to remain together in the process of inheritance"**.

According to Morgan, the degree or the strength of linkage depends upon the distance between the linked genes in the chromosome.

Linkage and independent assortment can be represented in dihybrid plant

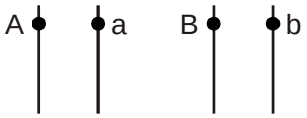
In case of linkage in dihybrid (AaBb)



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 :

- Linkage genes are linearly located on same chromosome. They get separated if exchange (crossing over), takes place between them.
- Strength of linkage α 1 / 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 the probability of their crossing over.
  Crossing over obviously disturbs or degenerates linkage. Linked genes can be separated by crossing over.

Factors effecting crossing over (C.O.) & Linkage

- Distance ↑ = C.O. ↑ Linkage ↓
- Temperature ↑ = C.O. ↑ Linkage ↓
- X-Ray ↑ = C.O. ↑ Linkage ↓
- Age ↑ = C.O. ↓ Linkage ↑
- Sex- Male C.O. ↓ (Crossing over totally absent in male Drosophila) Linkage

Arrangement of linked Genes on Chromosomes :

The arrangement of linked genes in any dihybrid plant is two types.

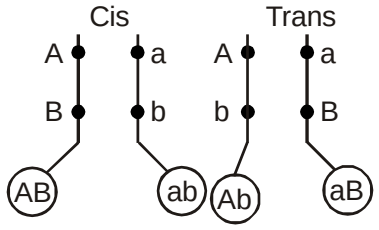
- **Cis - Arrangement :** When, two dominant genes located on one chromosome and both recessive genes located on another chromosome. Such type of arrangement is termed as cis-arrangement. Cis-arrangement is an original arrangement.

  Two type of gomets can be produced in this arrangement → (AB) and (ab)

  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

- **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.

- **INCOMPLETE LINKAGE** : When new combinations also appear along with parental combination in offsprings, 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%)

  Example : In maize incomplete linkage was observed by **Hutchinson.** w.r.t seed coat colour and seed shape.

The results show that parental combination of alleles (CS/CS and cs/cs) appear in about 96% cases. The other two are new combinations (Cs/cs and cS/cs) apear in about 4% cases. Thus in about 4% cases crossing over has occured between linked genes.

Parents	Coloured & full	×	Colourless & shrunken	
	CS / CS		cs / cs	
Gametes	CS	×	cs	
		↓		
F_1		CS / cs		
		Coloured & full		
Test cross		Cs/cs	×	cs / cs
Gametes	cs			
Result :	CS	CS/cs	–	Coloured & full 48.2%
	cs	Cs/cs	–	Coloured & shrunken 1.8%
	cS	cS/cs	–	Colourless & full 1.8%
	cs	cs/cs	–	Colourless & shruken 48.2%

Incomplete Linkage

Another example was demonstrated by Morgan, while working with Drosphila.

(i) Crossing of yellow bodied (Y) and white eyed (W) female with brown bodied (Y^+) red eyed W^+) male produced F_1 to be brown bodied red eyed. In F_2 generation, obtained by selfing of F_1 hybrids, the ratio deviated significantly from expected. He found 98.7% to be parental and 1.3% as recombinants.

(ii) In a second cross between white eyed and miniature winged female (wwmm) wild red eyed normal winged male ($W^+W^+M^+M^+$) all hybrids were found to be wild type. Test cross progency of this hybrid was found to be 62.8% parental and 37.2% recombinant.

Linkag group : All the genes which which are loacated on one pair of homologous chromosome form one linkage group. Genes which are located on homologous chromosomes are allelic so we consider one linkage group.

- Linkage group – haploid no. of homologous chromosomes.

	2n	n	Pair	Linkage group
Human	46	23	23	23
Mouse	42	21	21	21
Frog	26	13	13	13
Maize	20	10	10	10
Pea	14	7	7	7
Drosophila	8	4	4	4
Neurospora	7	7	7	7
Bacteria / B.G.A.	–	–	–	1

Application of Linkage :

Distance can be identified by the incomplete linakage. It's unit is centi Morgan (cM).

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

Genetic map / Linkage map / chromosome map – In genetic map different linked genes are linearly arranged or chromosome according to percentage of crossing over (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.

Sex Linkage

When the genes of vegetative / somatic characters are present on sex-chromosome is termed as sex linked gene and such phenomenon is known as sex-linkage. Two - types of sex linkage :

- **X-linkage :** Genes of sometic characters are found on x-chromosome. the inheritance of x-linked character may be through the males and females.
  e.g. Haemophilia, Colour blindness

- **Y-linkage :** The genes of somatic characters are located on Y-chromosome. The inheritance of such type of character only through the males, such type of character is called Holandric character these characters only found in male.

  e.g. Gene which forms TDF

  Hypertrichosis (excessive hair on ear pinna.)

  Gene which is located on differential region of Y - chromosome is known as Holandric gene.

Example of X- linkage :

- **Eye colour in Drosophila :** Eye colour in Drosophila is controlled by a X-linked gene. If a red eyed colour gene is represented as '+' and white eyed colour represented as 'w', then on basis of this different type of genotypes are found in Drosophila.

  Gene for red eye domainant (+) and white colour of eye is recessive (w)

  Homozygous red eyed female = $X^{+}X^{+}$

  Heterozygous red eyed female = $X^{+}X^{w}$

  Homozygous white eyed female = $X^{w}X^{w}$

  Hemizygous red eyed male = X^{+} Y

  Hemizygous white eyed male = $X^{w}Y$

  It is clear by above different types of genotype that female either homozygous or heterozygous for eye colour. But, for the male eye colour, it is always hemizygous.

Haemophilia : Haemophilia is also called "**bleeder's disease"** and first discovered by **John Otto** (1803). The gene of haemophilia is recessive and x-linked lethal gene.

On the basis of x-linked, following types of genotype are found.

$X^{h}X$ = Carrier female

$X^{h}X^{h}$ = Affected female

$X^{h}Y$ = Affected male

But $X^{h}X^{h}$ type of female dies during embryo stage because in homozygous condition, this gene is lethal and causes death.

Haemophilia - A → due to lack of factor - VIII (Antihaemophilic globulin AHG)

Haemophilia B or Christmas disease - due to lack of factor - IX (plasma thromboplastin component)

- **Haemophila -C -** due to lack of factor XI (plasma thromboplastin anticedent)
- **Colour Blindness :** The inheritance of colour blindness is like as haemophilia, but it is not a lethal disease so it is found in both male and female (discoverd by **Horner**)

  Three types of colour blindness are :

  Protanopia : It is for **red** colour.

  Deuteranopia : It is for **green** colour

  Tritanopia : Blue colour blindness. Colour blindness is cheked by **Ishihara - chart**.

Other examples of X - linkage

- Diabetes insipidus (recessive).
- Duchenne muscular dystrophy (recessive)
- Fragile x syndrome (recessive).
- Pesudoricketes (Dominant)
- Defective enamel of teeth (Dominant)

Types of Inheritance of sex linked characters :

- ❖ **Criss Cross inheritance (Morgan) :** In criss-cross inheritance male or famale parent transfer a X-linked character to grandson or grand daughter through the offspring of opposite sex.
- **Diagenic :** Inheritance in which characters are inherited from father to the daughter and from daughter to grandson.

  Father → Daughter → Grand Son
- **Diandric :** Inheritance in which characters are inherited from mother to the son and from son to grand daughter. Mother → Son → Grand Daughter

- ❖ **Non criss-cross inheritance :** In this inheritance male or female parent transfer sex linked character to grand son or grand daughter through the offspring of same sex.
- **Hologenic :** Mother → Daughter → Grand-daughter (female to female)
- **Holandric :** Father → Son → Grand-son (male to male)

- **Sex-Limited Character :** These characters are expressed in one sex and unexpressed in another sex. But their genes are present on autosome of both the sexes and their expression is depend on sex hormone.

  Example : Secondary sexual characters these genes located on the autosomes and these genes are present in both male and female, but effect of these are depend upon presence or absence of sex-hormones. For example - genes of beard & moustache express their effects only in the presence of male hormone - testosterone.

- **Sex Influenced Characters :** Genes of these characters are also present on autosomes but they are influenced differently in male and female. In heterozygous condition their effect is different in both the sexes. Example : Baldness : Gene of baldness is dominant (B).

Genotype	Male (♂)	Female (♀)
BB	Baldness present	Baldness present
bb	Baldness absent	Baldness absent
Bb	Baldness present	Baldness absent

Gene Bb shows partiality in male and female, Baldness is found in male, but baldness is absent in female with this genotype.

Lethal gene :

It was discovered by **Cuenot** In coat colour of mice Some genes regulate specific characters in the organisms. they cause death of organism if they present in homozygous dominant or homozygous recessive state. If individual dies in embryonic state, it is called **Absolute lethality**

Ex: coat colour in mice.

Yy × Yy
(Heterozygous yellow) (Heterozygous yellow)

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

Thus Monohybrid phenotypic ratio is modified 2 : 1

Yellow Brown

Yellow body colour (Y) was dominant over normal brown colour (y) Gene of yellow body colour is lethal in homozygous state so that in nature homozygous Yellow mice are never occured in population E. Baur discovered lethal gene in Snapdragon (Antirrhinum majus).

Cc (golden or auria) × Cc (golden or auria)

♀ \ ♂	C	c
C	CC died	Cc golden
c	Cc Golden	cc Green

Phenotypic ratio 2 : 1

Golden Green

Homozygous golden are never occured in nature.

If individual dies before reproductive matruity it is called **Sublethality Ex: Sickle cell anaemia.**

If death of individual takes place after sexual maturity it is called **Delayed lethality**.

PLEIOTROPIC GENE :

Gene which controls more than one character is called pleiotropic gene.

This gene shows multiple phenotypic effect.

For example :

In Pea plant : Single gene influences

In Drosophila recessive gene of vestigial wings also influence the some another characters

Structure of reproductive organs

Longevity (Length of Body)

Bristles on wings.

Reduction in egg production.

Example of pleiotropic gene in human.

Sickle cell anaemia- Gene Hb^S provide a classical example of pleiotrophy. It not only causes haemolytic anaemia but also results increased resistance to one type of malaria that caused by the parasite Plasmodium falciparum.

The sickle cell Hb^S allele also has pleiotropic effect on the development of many tissue and organs such as bone, lungs, kidney, spleen, heart.

Cystic fibrosis - Hereditary metabolic disorder that is controlled by a single autosomal recessive gene. The gene specifies an enzyme that produces a unique glycoprotein.

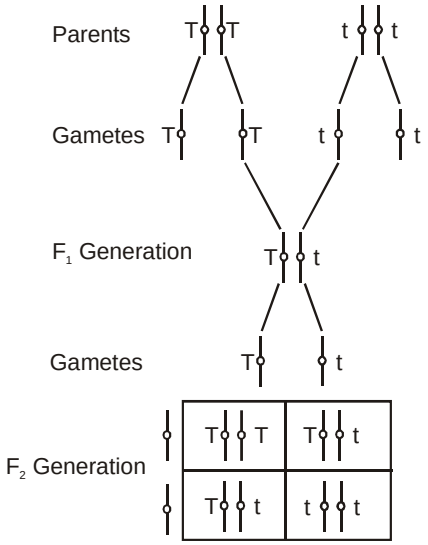
This glycopotien results in the production of mucous.

More mucous interfere with normal functioning of several exocrine glands including those in the skin, lungs liver and pancreas.

CHROMOSOMAL THEORY OF INHERITANCE

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

- Male and Female gemetes play an **equal** role in contributing hereditary components of future generation.
- Gemetes serve as the **bridge** between two successive generations.
- Only the nucleus of sperm combines with ovum. Thus, the hereditary information is contained in the **nucleus**.
- Chromatin in the nucleus is associated with the cell division in the form of chromosomes.



- Any type of deletion or addition in the chromosomes can cause structural and functional changes in living beings.
- A sort of **parallelism** is observed between Mendelian factors and chromosomes.
- A number of genes or Mendelian factors are found on chromosome.
- Determination of sex in most of the animals and plants is affected by specific chromosomes. These chromosomes are called sex chromosomes.

SEX DETERMINATION :

Establishment of sex through differential development in an individual at an early stage of life, is called sex determination. Various methods operate in sex determination like enviromental, non-allosomic genetic determination, allosomic sex determination and haplodiploidy

Sex Determination on the basis of fertilization.

Three types :

- **Progamic :** Sex is determined before fertilization.
  eg. – Drone in honey bee
- **Syngamic –** Sex is determined during fertilization.
  eg. – most of plants & animals
- **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 sexes.

- 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.
- **Crepidula** (marine mollusca) where larva develops into male in the company of female and develops into female if left alone.
- In **Crocodiles** low temperature induces femaleness and high temperature maleness.
- In **turtles** temperature **below 28ºC** induces maleness, above **33ºC** femaleness while between **28 - 33ºC** equal number of male and female animals are formed.

- 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 :

- Autosomes or somatic chromosomes.

  These regulate somatic characters.

- Allosomes or Hetersomes 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**.

XX - XY type or Lygaeus type : This type of sex determination first observed by **Wilson** & **Stevens** in **Lygaeus** insect.

Two types :

XX female and XY male : In this type of sex determination female is Homogametic produces one type of gamete

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

  $2A + XY(Male) \rightarrow$

  In male X-chromosome containing gametes is called **"Gynosperm**" and Y-chromosome containing gamete is called "**Androsperm**"

  eg. Man and dioecious plants like Cocinea, Melandrium

- **XY female and XX male or ZW female and ZZ male** : In this type of sex determination female is hetergametic produces two types of gamete and male individual is homogametic produces one type of gamete.

  It is found in some insects like **butter flies, moths** and **vertebrates** like **birds**, **fishes** and **reptilies.** In plant kingdom this type of sex determination is found in **Fragaria elatior.**

- **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.

  Female

  Male

Example :

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