Gregor Johann Mendel

Chapter

2

Genetics

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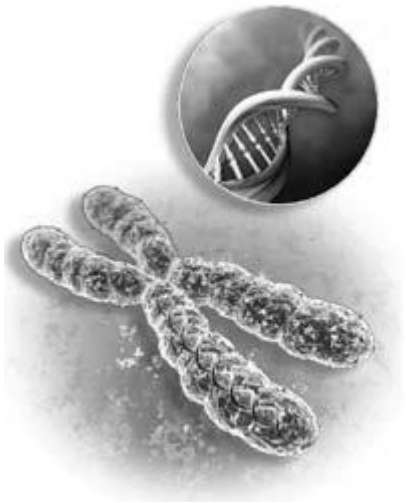


Genetics emerged as a formal discipline of biology only in the early twentieth century. Although its history is rich and dates back to pre-historic times, the observation that characters are passed on from generation to generation must have been made very early. The continuity of life and the variations there in both form the integral components of the process of inheritance. Therefore genetics is the base of continuity of life.

GENETICS

Introduction

The term genetics was coined by *Bateson* (1960). Genetics is the study of principles and mechanism of heredity and variations. The resemblance amongst offspring is never 100% (except in monozygotic twins) due to reshuffling of chromosomes and their genes. Same genetic traits are present in monoparental individuals formed through asexual reproduction or mitosis. Such individuals are called *ramets* while the whole group of similar individuals is called *clone.*

Father of genetics (classical genetics)	*Mendel*
Father of modern genetics/Animal genetics	*Bateson*
Father of experimental genetics/Drosophila genetics	*Morgan*
Father of human & physiological genetics	*Garrod*
Father of quantitative inheritance	*Kolreuter*
Father of Neurospora genetics	*Dodge*
Father of Eugenics	*Francis Galton*
Father of Indian genetics	*M. S. Swaminathan*

2.1 Heredity

Heredity is the study of transmission of characters and variations from one generation to the next.

(1) **Basis of heredity :** Heredity involves the transfer of chromosomes from parents to offspring or one individual to another. Therefore, chromosome is the base of heredity. The physical basis of heredity are genes while chemical basis of heredity is DNA.

(2) **Pre-Mendelian view points**

(i) **Vapour and fluid theory :** Greek philosopher, Pythagoras proposed that some moist vapour is given out from the brain, nerves and all other parts of the body during coitus. On account of these vapours, the offspring exhibits similarities with the male parents.

(ii) **Semen theory :** Empedocles, suggested that both parents produce semen which arises directly from their various body parts. The semen from both the parents gets mixed and produces a new individual.

(iii) **Preformation theory** : Antony von Leeuwenhoek was the first to observe human sperms. This theory believes that one of the sex cells or gametes either sperm or egg, contained within itself the entire organism in perfect miniature form. Miniature form was called as 'homunculus'. The theory was supported by Malpighi, Hartosoeker and Roux.

(iv) **Particulate theory :** Maupertuis proposed that the body of each parent gives rise to minute particles. These particles unite together to form the daughter individual.

(v) **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 chines boxes. This was named as encasement theory.

(vi) **Theory of epigenesis :** Wolgg proposed that the germ cells contain definite but undifferentiated substances, which after fertilization, become organised into various complex body organs that form the adult. This idea was referred to as epigenesis.

(vii) **Pangenesis theory :** This theory was proposed by *Charles Darwin* according to this theory every cell, tissue and organ of animal body produces minute invisible bodies, called gemmules or pangenes. They can produce offsprings.

(viii) **Weismann theory of germplasm :** August Weismann (1889) suggested the theory of continuity of germplasm. He described reproductive cells as germplasm and rest of the body as somatoplasm. The germplasm forms the bridge of life between successive generations and is passed on from one generation to the next.

(3) **Evidences against blending theory :** Thus individual would represent the mixture of both the parents. The prevailing view of in pre-mendelian era was blending theory. The hereditary material was thought of as being analogous to a fluid. Under this concept, the progeny of a black and white animal would be uniformly grey. The further progeny from crossing the hybrids among themselves would be grey, for the black and white hereditary material, once blanded, could never be seperated again. Pattern of inheritance shown by atavism also speaks against blending theory. The traits of sex do not blend in unisexual organisms.

(4) **Basic features of inheritance :** In the middle of 18^{th} century, *Carolus Linnaeous* a Swedish taxonomist and two German plant breeders *Kolreuter* and *Gaertner* performed artificial cross pollination in plants and obtained hybrid offspring. Kolreuter obtained experimental evidence that inherited traits tended to remain discrete, although his observations were similar to mendel but he was not able to interpret them correctly. Mendel's great contribution was to replace the blending theory with particulate theory. Few essential features of inheritance are : –

(i) Traits have two alternative forms.

(ii) Traits are represented in the individual by distinct particles which do not blend or change.

(iii) Traits may remain unexpected for one or more generations and reappear later unchanged.

(iv) Traits may remain together in one generation and separate in a later generation.

(v) One alternative of a trait may express more often then the other.

2.2 Variations

Variations are differences found in morphological, physiological and cytological behaviouristic traits of individuals belonging to same species race and family. They appear in offspring or siblings due to : –

- Reshuffling of genes/chromosomes by chance separation of chromosomes
- Crossing over

- Chance combination of chromosomes during meiosis and fertilization.

Types of variations

(1) **Somatic variations :** These variations influence the somatic or body cells. They appear after birth and are, also called *acquired characters, modifications or acquired variations*. Somatic variations are non-inheritable and usually disappear with the death of the individual. They are formed due to three reasons *i.e.* environmental factors, use and disuse of organs, and conscious efforts.

(i) **Environmental factors :** They have lesser effect on animals as compared to plants. Important environmental factors are as follows:

(a) **Medium :** Amphibious or emergent aquatic plants possess heterophylly, *i.e.* different types of submerged, floating and emerged leaves, e.g. *Ranunculus aquatilis, Limnophila heterophylla* and this meristic activities are due to change in depth and medium of water.

(b) **Light :** Partial shade causes elongation of internodes.

(c) **Temperature :** Plants of hot areas have extensive roots but smaller shoots. Human skin becomes darker with increase in environmental temperature.

(d) **Nutrition :** Honey bee larva feeding on royal jelly develops into queen while the ones obtaining ordinary nourishment (bee bread) grow into workers.

(e) **Water :** Water deficiency leads to several modifications in plants like succulente, spines, reduced leaves, thick bark, hair etc.

(ii) **Use and disuse of organs :** In higher animals and human beings, greater use of an organ leads to its better development as compared to other organs which are less used, e.g., stronger muscular body in a wrestler.

(iii) **Conscious efforts :** Acquired variations due to conscious efforts *include education*, training of pets boring of pinna, bonsai, etc.

(2) **Germinal variations :** They are inheritable variations formed mostly in germinal cells which are either already present in the ancestors or develop a new due to *mutations*. Germinal variations are of two types, continuous and discontinuous

(i) **Continuous variations :** They are *fluctuating variations* and also called *recombinations* because they are formed due to recombination of alleles as found in sexual reproduction. Darwin (1859) based his theory of evolution on continuous variations.

(ii) **Discontinuous variations :** They are *mutations*, which are ultimate source of organic variations. Discontinuous variations are caused by chromosomal aberrations, change in chromosome number and gene mutations. In pea seed coat colour changes gray to white is an example of spontaneous mutation.

Importance of variations

(1) Variations continue to pile up forming new species with time.

(2) They are essential in the struggle for existence.

(3) Adaptability is due to variations.

(4) Variations allow breeders to improve races of plants and animals.

(5) Discontinuous variations introduce new traits.

(6) Inbreeding between closely related organisms reduces variation.

2.3 Important terms used in inheritance studies

(1) **Gene (Mendel called them factor) :** In modern sense an *inherited factor* that determines a biological character of an organism is called gene (functional unit of hereditary material).

(2) **Allelomorphs or alleles :** Alleles, the abbreviated form of term allelomorphs (meaning one form or the other) indicates alternative forms of the same gene. e.g., Tall **TT** and dwarf **tt** are alternation forms of the same gene etc.

(3) **Gene locus :** It is the portion or region on chromosome representing a single gene. The alleles of a gene are present on the same gene locus on the homologous chromosomes.

(4) **Wild and mutant alleles :** An original allele, dominant in expression and wide spread in the population is called wild allele. An allele formed by a mutation in the wild allele, recessive in expression and less common in the population is termed as mutant allele.

(5) **Homozygous :** Both the genes of a character are identical is said to be homozygous or genetically pure for that character. It gives rise to offspring having the same character on self-breeding e.g. **TT** (Homozygous dominant) or **tt** (Homozygous recessive).

(6) **Heterozygous :** Both the genes of a character are unlike is said to be heterozygous or *hybrid.* Such organisms do not breed true on self fertilization e.g. **Tt**

If we know the number of heterozygous pairs we can predict the following:

Number of types of gametes = 2^n

Number of $\mathbf{F_2}$ phenotype = 2^n (Where ***n*** is the number of heterozygous pairs).

Number of $\mathbf{F_2}$ genotype = 3^n

(7) **Genotype :** The genotype is the genetic constitution of an organism. **TT**, **Tt** and **tt** are the genotypes of the organism with reference to these particular pairs of alleles.

(8) **Phenotype :** Expresses the characters of individuals like form, sex, colour and behaviour etc.

(9) **Pure line :** Generations of homozygous individuals which produce offsprings of only one type *i.e.* they breed true for their phenotype and genotype.

(10) **Monohybrid, dihybrid and polyhybrid :** When only one allelic pair is considered in cross breeding, it is called monohybrid cross. Similarly when two allelic pairs are used for crossing, it is called dihybrid cross and more than two allelic pairs in a cross are called polyhybrid cross.

(11) **Reciprocal cross :** The reciprocal crosses involve two crosses concerning the same characteristics, but with reversed sexes.

(12) **Genome :** Total set of genes (DNA instructions) in the haploid set of chromosomes and inherited as unit from parents to offspring is called genome.

(13) **Gene pool :** All the genotypes of all organisms in a population form the gene pool.

(14) **F_1 Generation :** F_1 or first filial generation is the generation of hybrids produced from a cross between the genetically different individuals called parents.

(15) **F_2 Generation (Bateson, 1905) :** F_2 or second filial generation is the generation of individuals which arises as a result of inbreeding or interbreeding amongst individuals of F_1 generation.

(16) **Punnet square :** It is a checker-board used to show the result of a cross between two organisms, it was devised by geneticist, R.C. Punnet (1927). It depicts both genotypes and phenotypes of the progeny.

(17) **Back cross :** It is cross which is performed between hybrid and one of its parents. In plant breeding, back cross is performed a few times in order to increase the traits of that parent.

(18) **Test cross :** It is a cross to know whether an individual is homozygous or heterozygous for dominant character. The individual is crossed with recessive parent. The ratio will be 50% dominant and 50% recessive in case of hybrid or heterozygous individual. In case of double heterozygote (e.g., RrYy) crossed with recessive (rryy) the ratio will be 1:1:1:1 test cross help to find out genotype of parents.

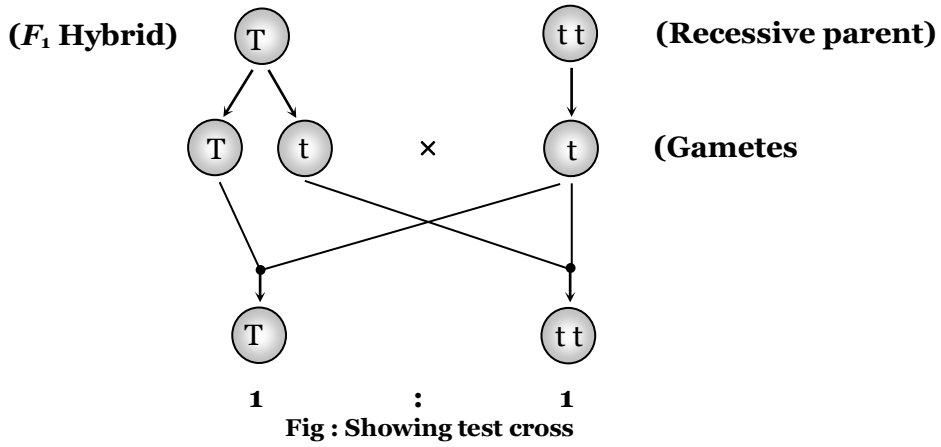


Fig : Showing test cross

(19) **Self cross/selfing :** It is the process of fertilization with pollen or male gametes of the same individual.

(20) **Theory of probability :** (i) Out of the two alternate events, the probability of occurrence of each one of them is 50%.

(ii) Two events are independent if occurrence of one does not affect the probability of occurrences of the other.

(iii) The probability of joint occurrence of two independent events is the product of their individual probabilities.

(iv) For an event, which can happen through two independent pathways, the probability of its occurrence is the sum of separate probabilities.

(21) **Observed Vs expected results :** Experimental results conform to the ones expected through the theory of probability if the size of the sample is small but they tend to approach the latter if the sample size is large.

(22) **Hybrid :** The organism produced after crossing of two genetically different individuals is called hybrid.

(23) **Heredity and variations in sexual and asexual reproduction**

(i) **Sexual reproduction :** Variations are common in animals and plants which reproduce by sexual means. The reason for this is that the sexual reproduction is biparental, involves meiosis and fertilization, and the offspring receives some traits from father and some from mother.

(ii) **Asexual reproduction :** Those organisms which reproduce by asexual means *eq*. bacteria, amoeba, euglena, rose etc. The asexual reproduction is monoparental, involves mitosis and the organism produced by it, inherits all the traits of its single parent. With the result, it is almost a carbon copy of the parent and is known as ramet. A group of ramets is called a clone.

Differences between clone and offsprings

Characters	Clone	Offspring
Type of reproduction	Clone is the product of asexual reproduction	Offspring is the product of sexual reproduction
Number of parents	Clone is monoparental	Offsprings is derived from two parents thus biparental
Cell division	Clone is formed by mitosis. meiosis does not occur.	Meiosis takes place prior to formation of gametes
Resemblance	Clone exactly resembles the parent	Offspring differs from parents.

2.4 Mendel's predecessors

A number of scientists had worked on plant hybridization during the 18^{th} and 19^{th} centuries prior to the mendel. Some of the more notable scientists among them are *Joseph Koelreuter, John Goss, Gaertner, Darwin, Herbert,* and *Naudin Koelreuter* conducted extensive studies on hydridization between various species of Nicotiana (Tabacco) between 1761 and 1767, he noted the uniformity and heterosis in $\mathbf{F_1}$ (First ficial generation) and appearance of increased variations in $\mathbf{F_2}$. Koelreuter also observed that the hybrids were intermediate between their parents and that hybrids from reciprocal crosses were indistinguishable. Knight and goss conducted experiments on edible pea (*Pisum sativum*) much before Mendel but failed to formulate the laws of inheritance.

2.5 Mendelian period

Introduction : *Gregor Johann Mendel* (1822-1884) first "geneticist", also known as *father of genetics* was born in 1822 in Silisian, a village in Heizendorf (Austria). In 1843, he joined Augustinian monastry at Brunn (then in Austria, now Brno Czechoslovakia). In 1856, Mendel got interested in breeding of *Garden pea* (*Pisum sativum*). He selected pure breeding varieties or *pure lines of pea.* Breeding experiments were performed between 1859 – 1864. The results were read out in two meetings of *Natural History Society* of *Brunn* in 1865 and published in 1866 in "Proceedings of Brunn Natural History Society" under the topic *"Experiments in Plant Hybridisation"*. Mendel died in 1884 without getting any recognition during his lifetime.

In 1900, *Hugo de Vries* of Holland, *Carl Correns* of Germany and *Erich von Tshermak* of Austria came to the same findings as were got by Mendel. Hugo de Vries found the paper of Mendel and got it reprinted in *'Flora'* in 1901. *Correns* converted two of the generalisations of Mendel into two laws of heredity. These are law of segregation and law of independent assortment.

(1) **Reasons for Mendel's success :** The reasons of his success can be discussed as follows:

(i) **Method of working :** He maintained the statistical records of all the experiments and analysed them. He selected genetically pure (pure breed line) and purity was tested by self-crossing the progeny for several generations.

(ii) **Selection of material :** Mendel selected garden pea as his experimental material because it has the following advantages.

It was an *annual plant.* Its short life–cycle made it possible to study several generations within a short period and has perfect *bisexual flowers* containing both male and female parts. The flowers are predominantly *self-pollinating* because of self-fertilization, plants are homozygous. It is, therefore, easy to get pure lines for several generations and also easy to cross because pollens from one plant can be introduced to the stigma of another plant by removing anthers (emasculation) and bagging. In addition to that there was one reason more for his success. He studied seven pairs of characters which were present on four different pairs of chromosomes.

(iii) **Selection of traits :** Mendel selected seven pairs of contrasting characters as listed in the table. Luckily all were related as dominant and recessive.

List of seven pairs of contrasting characters in pea plant

S.No.	Character	Dominant	Recessive
(1)	Stem length	Tall	Dwarf
(2)	Flower position	Axial	Terminal
(3)	Pod shape	Inflated	Constricted
(4)	Pod colour	Green	Yellow
(5)	Seed shape	Round	Wrinkled

(6)	Seed colour	Yellow	Green
(7)	Seed coat colour	Grey	White

(2) **Mendel's experiments**

(i) **Monohybrid cross :** Experiments with garden pea for *single pair* of contrasting characters.

(a) **Procedure :** Mendel crossed pure tall and dwarf plants. The plants belonged to $\mathbf{F_1}$ *generation* all tall were self-pollinated. The plants of $\mathbf{F_2}$ *generation* were both tall and dwarf, in approximate 3:1 ratio phenotypically and 1:2:1 genotypically. On, self-pollination, the tall plants of $\mathbf{F_2}$ only 1/3–rd breed true for tallness, the rest 2/3–rd produced tall and dwarf in the ratio of 3:1 **(**$\mathbf{F_3}$ *generation***)**. It means $\mathbf{F_2}$ generation consisted of three types of plants (instead of apparent two types) –

Tall homozygous (Pure)

1 25% **TT**

Tall heterozygous (Hybrid)

2 50% **Tt**

Dwarf homozygous (Pure)

1 25% **tt**

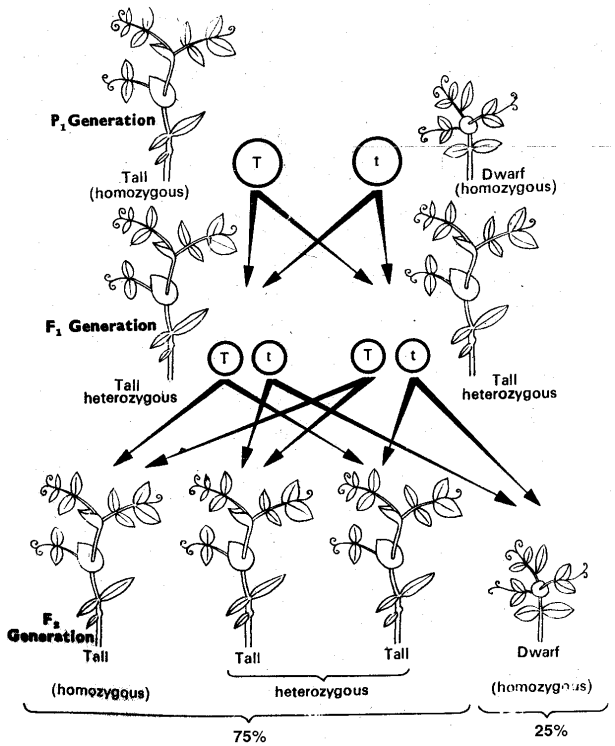


Fig : Mendel's monohybrids crosses between tall and dwarf pea plants

Hence it is to be said that in $\mathbf{F_2}$ generation 50% plants passes parental combination while 50% are new combination.

(b) **Mendel's explanation :** Mendel explained above results by presuming that *Tallness* and *dwarfness* are determined by a pair of contrasting factors or determiners (now these are called genes). A plant is tall because it possesses determiners for tallness (represented by **T**) and a plant is dwarf because it has determiners for dwarfness (represented by **t**). These determiners occur in pairs and are received one from either parent. On the basis of this behaviour the tallness is described as dominant character and dwarfness as recessive (*law of dominance*). The determiners are never contaminated. When gametes are formed, these unit factors segregate so that each gamete gets only one of the two alternative factors. When F_1 hybrids (**Tt**) are self pollinated the two entities separate out and unite independently producing tall and dwarf plants (*law of segregation*).

(ii) **Dihybrid cross** (Crosses involving *two pairs* of contrasting characters)

(a) **Procedure :** Later on Mendel conducted experiments to study the segregation and transmission of two pairs of contrasting characters at a time. Mendel found that a cross between round yellow and wrinkled green seeds **(P_1)** produced only round and yellow seeds in **F_1** generation, but in **F_2** four types of combinations were observed. These are

Round yellow 9 Parental combinations

Round green 3 Non-parental combinations

Wrinkled yellow 3 Non-parental combination

Wrinkled green 1 Parental combination

Thus the offsprings of F_2 generation were produced in the ratio of 9 : 3 : 3 : 1 phenotypically and 1 : 2 : 2 : 4 : 1 : 2 : 1 : 2 : 1 genotypically. This ratio is called *dihybrid ratio*.

The results can be represented as follows:

Mendel represented round character of seed by **R** and wrinkled by **r**. Similarly he designated the yellow character by **Y** and green by **y**. Therefore, it was a cross between **RRYY** and **rryy.**

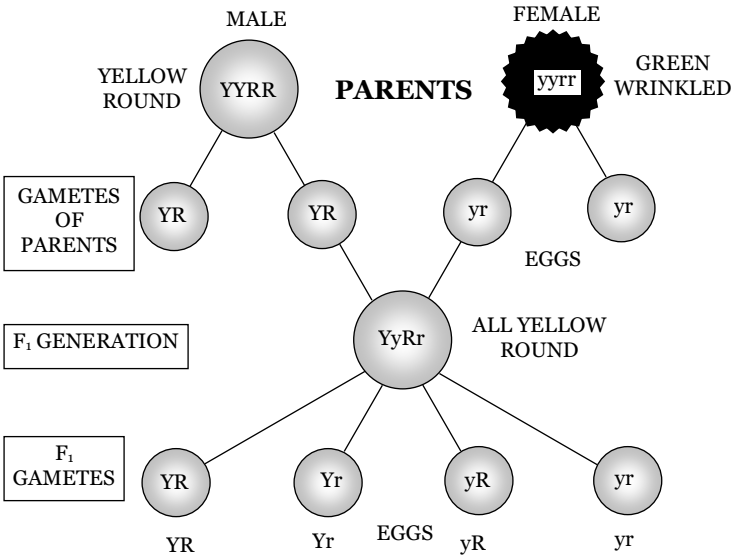
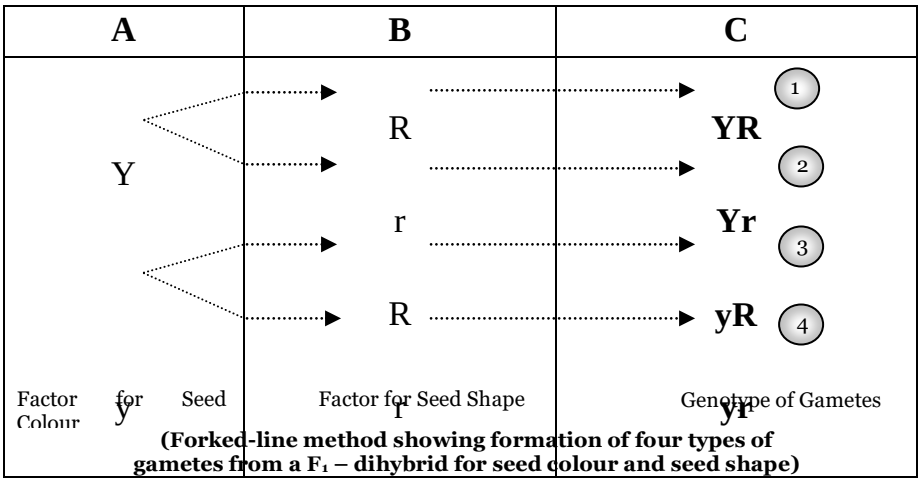


Fig : Mendel's dihybrid-oross between pea plants having yellow round seeds and green wrinkled seeds

(b) **Mendel's explanation :** Mendel explained the results by assuming that the round and yellow characters are dominant over wrinkled and green so that all the **F_1** offsprings are round yellow. In **F_2**-generation since all the four characters were assorted out independent of the others, he said that a pair of alternating or contrasting characters behave independently of the other pair *i.e.*, seed colour is independent of seed coat.

Therefore, at the time of gamete formation genes for round or wrinkled character of seed coat assorted out independently of the yellow or green colour of the seed. As a result four types of gametes with two old and two new combinations *i.e.*, **RY, ry Ry, rY** are formed from the **F_1** hybrid. These four types of gametes on random mating produced four types of offsprings in the ratio of 9:3:3:1 in **F_2** generation (*Law of Independent Assortment*).



(Forked-line method showing formation of four types of gametes from a F_1 – dihybrid for seed colour and seed shape)

(iii) **Trihybrid cross :** The offsprings shows 27 : 9 : 9 : 9 : 3 : 3 : 3 : 1 ratio is found in trihybrid cross. This suggests that a di, tri, or polyhybrid cross is actually a combination of respectively two, three or more monohybrid crosses operating together.

(iv) **Mendel's laws of inheritance :** Mendel's law are still true because these take place in sexually reproducing organisms or parents are of pure breeding. He enunciated two major laws of inheritance *i.e.*, law of segregation and law of independent assortment.

(a) **Law of segregation (Purity of gametes) :** The law of segregation states that when a pair of contrasting factors or genes or allelomorphs are brought together in a heterozygote (hybrid) the two members of the allelic pair remain together without being contaminated and when gametes are formed from the hybrid, the two separate out from each other and only one enters each gamete as seen in monohybrid and dihybrid cross. That is why the law of segregation is also described as law of purity of gametes.

(b) **Law of independent assortment :** If the inheritance of more than one pair of characters (two pairs or more) is studied simultaneously, the factors or genes for each pair of characters assort out independently of the other pairs. Mendel formulated this law from the results of a dihybrid cross.

Important Tips

- ☞ Cytogenetics is Integrated study of cytology and genetics to find cytological basis for various events of genetics. This term was coined by Muller.
- ☞ H.J. Hammerlings proved that nucleus controls the heredity by a experiment on acetabularia (A unicellular green algae)
- ☞ Only sexually derived organisms are called **offspring** or **siblings** (offsprings at different births) e.g., brother and sister.
- ☞ Variations due to environment are known as **ecophenotypes**.
- ☞ Every test cross is **back cross** but every back cross is not a **test cross**.
- ☞ Back cross is used by breeders as a rapid method of making **homozygous**.

- When the two genetic loci produce identical phenotypes in cis and trans position they are considered to be **pseudoalleles**.
- **Somaclonal variations** are produced in tissue culture during differentiation of callus.
- In thalassemia, the β chain of haemoglobin is changed due to **frame shift mutation** as a result, bone marrow is not formed.
- **Bateson** coined the term **Genetics, allele, F_1, F_2, homozygous heterozygous** and **epistasis**. He is also known as **father of animal genetics**.
- The basis of genetic counseling is mendelism.
- In heredity, the genes are obtained from father and mother.
- Nucleus and chromosomes are stained by **hematoxylin**.
- **Johannsen** coined the term **genotype, phenotype, pure line**.
- The term **hybrid vigour (heterosis)** given by **Shull.**
- In mitosis, the daughter cells resemble each other and also the parent cell, in meiosis they differ not only from parent cell in having half the number of chromosomes, but also differ among themselves qualitatively in genetic constitution due to crossing over, independent assortment and segregation.
- Mendelian genetics is also called as **forward genetics**.
- Mendel either avoided the result or could not conduct independent assortment between pod form and stem length.
- Mendel also observed that flower colour and colour of the seed coat may not assort independently.
- Mendel failed to produce same results of his experiments of pea in Hawkweed (Hieracium) and Beans.
- Mendel's typical monohybrid phenotypic ratio was 3 : 1 which was in reality a hidden 1 : 2 : 1 ratio of genotypes.
- Mendelism gave well-defined principles even in early stage in compare to **Darwinism**.
- Mendel did not recognize the linkage phenomenon in his experiments because characters, he studied were located on different chromosomes.
- Mendelian factor are separated during **Anaphase- I in Meiosis- I**.
- If Mendel had studied the seven traits using a plant with 12 chromosomes instead of 14, He would not have discovered the law of independent assortment.
- **Law of filial regression** was postulated by Galton.
- Mendel didn't imagine of linkage.
- Mendel in his experiments on pea considered quantity in relation to quality.
- In bound seeds (RR/Rr) starch branching enzyme (SBE -1) is found but it is absent in wrinkled seeds or in rr seeds.

- ☞ It was thought previously that seven traits in pea studied by Mendel were located on seven different chromosomes but recent studies proves that these are on four chromosomes.
- ☞ The genes for seed form in pea was present on chromosomes no. 7.
- ☞ Independent assortment is shown by the allels present on different loci.

2.6 INTERACTION OF GENES

Genes interaction is the influence of alleles and non-alleles on the normal phenotypic exprssion of genes. It is of two types.

(1) **Inter–allelic or intra–genic gene interaction :** In this case two alleles (located on the same gene locus on two homologous chromosomes) of gene interact in such a fashion to produces phenotypic expression *e.q.* co-dominance, multiple alleles.

(i) **Incomplete dominance (1:2:1 ratio) :** After Mendel, several cases were recorded where F_1 hybrids were not related to either of the parents but exhibited a blending of characters of two parents. This is called incomplete dominance or blending inheritance.

Example : In 4-O'clock plant, (*Mirabilis jalapa*), when plants with red flowers **(RR)** are crossed with plants having white flowers **(rr)** the hybrid F_1 plants **(Rr)** bear pink flowers. When these F_1 plants with pink flowers are self pollinated they develop red **(RR),** pink **(Rr)** and white **(rr)** flowered plants in the ratio of 1:2:1 (F_2 generation).

Example : In Snapdragon or dog flower (*Antirrhinum majus*) the dominant character of leaf (Broadness) and flower (Red) shows incomplete dominance over recessive characters (Narrowness and white) in dihybrid cross.

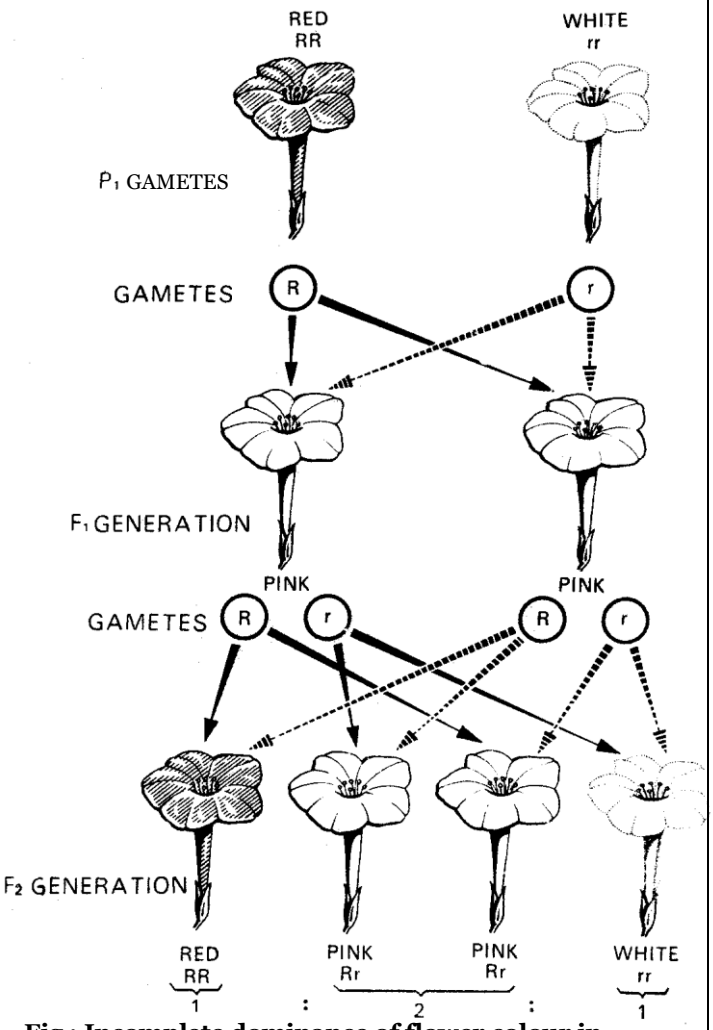


Fig : Incomplete dominance of flower colour in Mirabillis jalapa

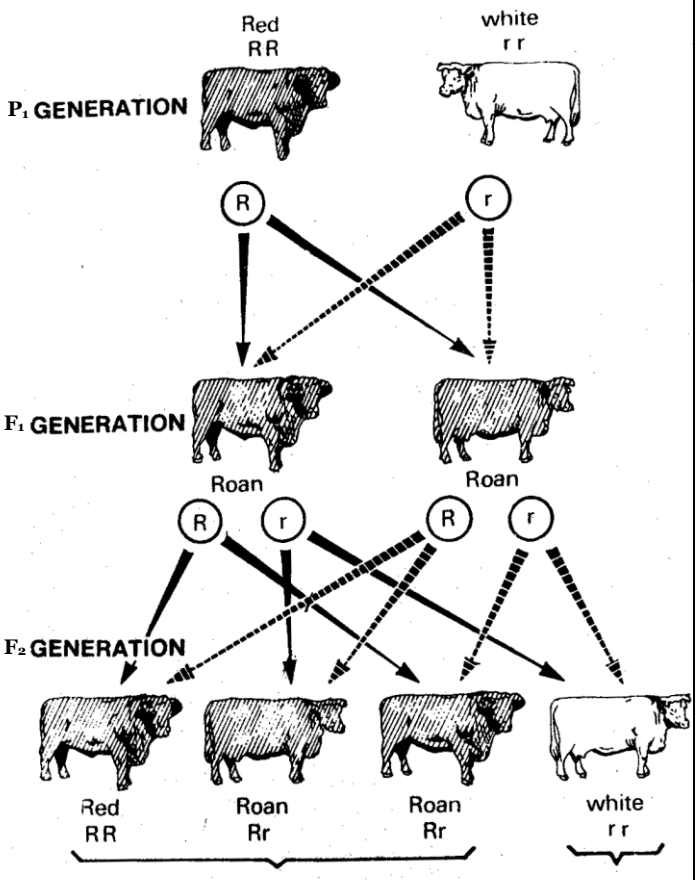


Fig : Inheritance of coat colour in

(ii) **Codominance (1:2:1 ratio) :** In codominance, both the genes of an allelomorphic pair express themselves equally in F_1 hybrids. 1:2:1 ratio both genotypically as well as phenotypically in F_2 generation.

Example : Codominance of coat colour in cattle.

In cattle gene **R** stands for red coat colour and gene **r** stands for white coat colour. When red cattle **(RR)** are crossed with white cattle **(rr),** the F_1 hybrids have roan coloured skin (not the intermediate pink). The roan colour is actually expressed by a mixture of red and white hairs, which develop side by side in the heterozygous F_1 hybrid. In F_2 generation red, roan and white appear in the ratio of 1 : 2 : 1. The phenotypic ratio equal to genotypic ratio **RR, Rr, rr** (1 : 2 : 1).

Example : Codominance in andalusian fowl

In andalusian fowl a cross between pure black and pure white varieties results in blue hybrids.

Example : Codominance of blood alleles in man

(a) **MN** blood type in man is an example of codominance. The persons with **MN** genotype produce both antigen **M** and **N** and not some intermediate product indicating that both the genes are functional at the same time.

(b) In **ABO** blood group system gene **A** and **B** responsible for blood group **A** and **B** are codominant. The hybrid has **AB** blood group.

Differences between incomplete dominance and codominance

Incomplete dominance	Codominance
Effect of one of the two alleles is more conspicuous.	The effect of both the alleles is equally conspicuous.
It produces a fine mixture of the expression of two alleles.	There is no mixing of the effect of the two alleles.
The effect in hybrid is intermediate of the expression of the two alleles.	Both the alleles produce their effect independently, e.g., I^A and I^B, Hb^S and Hb^A.

(2) **Non–allelic or inter-genic gene interaction :** Here two or more independent genes present on same or different chromosomes, interact to produce a new expression *e.g.* epistasis, complementary genes, supplementary genes, duplicate genes, inhibitory genes, lethal genes etc.

(i) **Complementary genes (9 : 7 ratio) :** The complementary genes are two pairs of nonallelic dominant genes (*i.e.* present on separate gene loci), which interact to produce only one phenotypic trait, but neither of them if present alone produces the phenotypic trait in the absence of other.

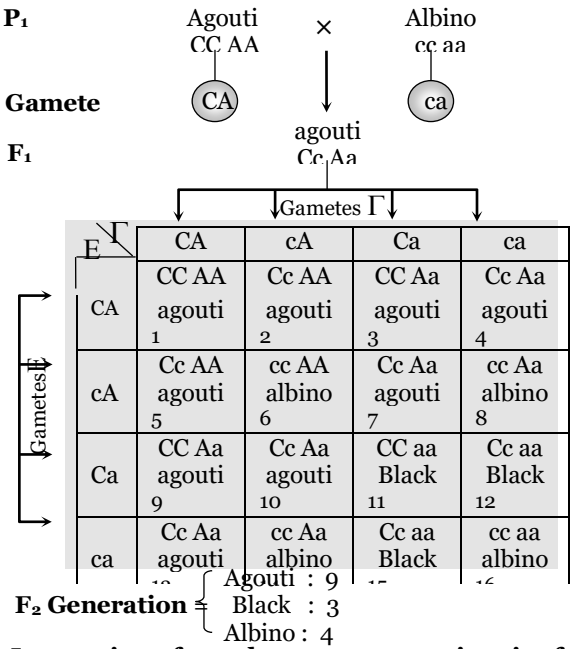


Fig : Interaction of supplementary genes in mice for

Example : Complementary genes for flower colour in sweet pea. In sweet pea (*Lathyrus odoratus*) the purple colour of flowers is dependent on two nonallelic complementary genes ***C*** and ***P***. Gene ***C*** produces an enzyme that catalyzes the formation of colourless chromogen for the formation of anthocyanin pigment. Gene P controls the production of an enzyme, which catalyzes the transformation of this chromogen into anthocyanin. These genes are complementary to each other. It means the pigment anthocyanin is produced by two-biochemical reactions and the end product of first reaction forms the substrate for the other.

If a plant possesses dominant gene ***C*** and ***P,*** it produces purple flowers. But if a plant has a genotype **CCpp,** it produces the raw material but is unable to convert it into anthocyanin. Therefore, it produces white flowers. Similarly, if it possesses dominant gene **P,** but no dominant **C (ccPP),** it produces white flowers because gene **P** can convert colourless chromogen into anthocyanin but cannot form chromogen.

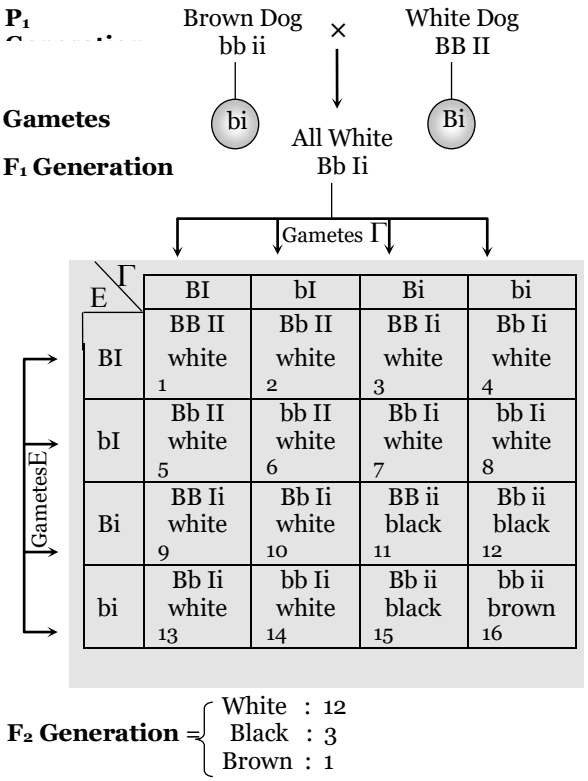


Fig : Interaction of inhibiting genes in dog for coat colour showing dominant

(ii) **Supplementary genes (9 : 3 : 4 ratio) :** Supplementary genes are two independent pairs of dominant genes. Which interact in such a way that one dominant gene will produce its effect whether the other is present or not. The second dominant when added changes the expression of the first one but only in the presence of first one. In rats and guinea pigs coat colour is governed by two dominant genes **A** and **C,** the agouti-coloured guinea pigs have genotype **CCAA**. The black mice possess factor for black colour **C** but not the gene **A** for agouti colour. If gene for black colour is absent agouti is unable to express itself and mice with a genotype **ccAA** are albino. Here presence of gene **C** produced black colour and addition of gene **A** change its expression to agouti colour.

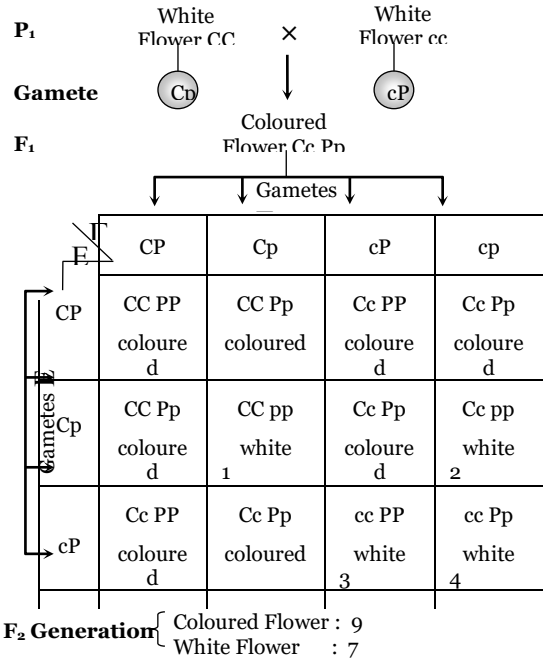


Fig : The results of an experiment to show the operation of complimentary genes in the production of flower colour in sweet

(iii) **Epistasis (Inhibiting genes) :** Epistasis is the interaction between nonallelic genes (Present on separate loci) in which one-gene masks, inhibits or suppresses the expression of other gene. The gene that suppresses the other gene is known as inhibiting or epistatic factor and the one, which is prevented from exhibiting itself, is known as hypostatic. Although, it is similar to dominance and recessiveness but the two factors occupy two different loci. Therefore, while dominance involved intragenic or interallelic gene suppression, the epistasis involves intergenic

suppression. Epistasis can be of the following types – dominant epistasis, recessive epistasis.

(a) **Dominant epistasis (12:3:1 or 13:3 ratio) :** In dominant epistasis out of two pairs of genes the dominant allele, (*i.e.*, gene **A**) of one gene masks the activity of other allelic pair **(Bb)**. Since the dominant epistatic gene **A** exerts its epistatic influence by suppressing the expression of gene **B** or **b**, it is known as dominant epistasis.

Example – Dominant epistasis in dogs : In dogs white coat colour appears to be dominant. It develops due to the action of epistatic gene **I** which prevents the formation of pigment, controlled by hypostatic gene **B**.

The hypostatic gene **B** produces black coat while its hypostatic allele **b** produces brown coat colour only when gene **I** is recessive. The progeny of dominant gene **I** does not allow them to function and results in white colour. When two white coat dogs are crossed, they produce white, black and brown in the ratio of 12 : 3 : 1 The white dogs in this case possess gene for black or brown colour but does not produce the pigment because of the presence of gene **I** in dominant state. Similar phenomena have been seen in *fruit colour in cucurbita as summer squash and coat colour in chickens*.

(b) **Recessive epistasis (9:3:4 ratio) :** Epistasis due to recessive gene is known as recessive epistasis, *i.e.*, out of the two pairs of genes, the recessive epistatic gene masks the activity of the dominant gene of the other gene locus. The dominant **A** expresses itself only when the epistatic locus **C** also has the dominant gene if the epistatic locus has recessive gene **c**, gene **A** fails to express.

Triangular AABB × Top Shaped aabb ------- **Parents**

AaBb × Triangular AaBb ------- F_1

F_2

	AB	**Ab**	**aB**	**ab**
AB	AABB Triangular	AABb Triangular	AaBB Triangular	AaBb Triangular
Ab	AABb Triangular	AAbb Triangular	AaBb Triangular	Aabb Triangular
aB	AaBB Triangular	AaBb Triangular	aaBB Triangular	aaBb Triangular
ab	AaBb Triangular	Aabb Triangular	aaBb Triangular	aabb Top shaped

Example : In mice agouti colour, characterised by banding of hairs is controlled by gene **A**, which is hypostatic to recessive allele **c**. The dominant epistatic gene **C** in absence of **A** gives black coloured mice and in presence of dominant gene **A** gives agouti, but dominant gene **A** is unable to produce agouti colour in absence of gene **c**. Therefore, recessive c gene acts as epistatic gene **A**.

(iv) **Duplicate genes (15 : 1 ratio) :** Sometimes two pairs of genes located on different chromosomes determine the same phenotype. These genes are said to be *duplicate* of each other. The dominant triangular fruit

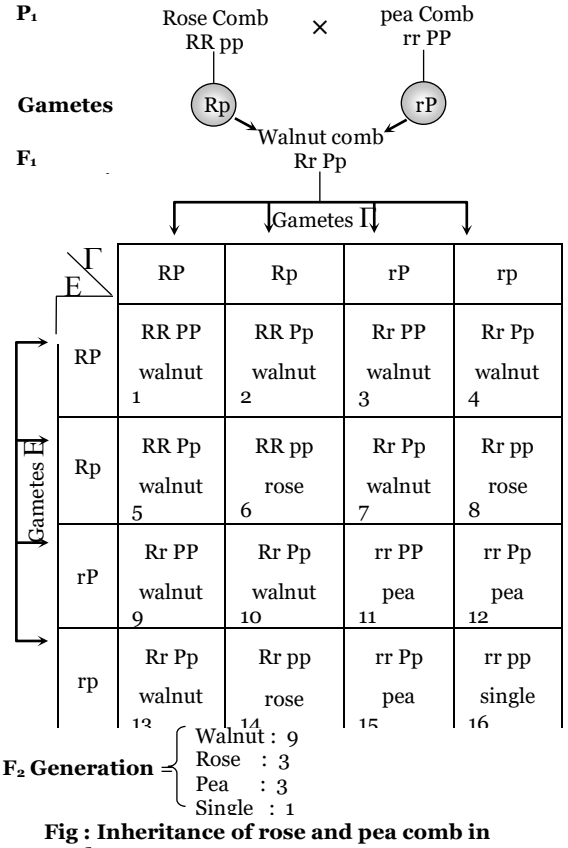


Fig : Inheritance of rose and pea comb in poultry

shape of *Capsella bursa pastoris* (shepherd's purse) is determined by two pairs of genes, say **A** and **B**. If any of these genes is present in dominant form, the fruit shape is triangular. In double recessive forms the fruits are top shaped and thus we get a 15 (triangular) : 1(top shaped) ratio in F_2 generation.

(v) **Collaborator genes :** In collaboration two gene pairs, which are present on separate loci but influence the same trait, interact to produce some totally new trait or phenotype that neither of the genes by itself could produce.

Example : Inheritance of combs in poultry, where two genes control the development of comb.

(a) Gene **R** gives rise to **rose comb**.

(b) Gene **P** produces **pea comb**. Both rose and pea combs are dominant over single comb.

(c) Gene **R** and **P** for rose and pea comb together produce a new phenotype the *walnut comb.*

Wyandotte variety of domestic chicken possesses rose comb, whereas Brahmas have pea comb. Bateson crossed rose-combed Wyandottes and pea–combed Brahmas. The F_1 chickens developed walnut comb, a phenotype not expressed in either parent. When F_1 chickens mated among themselves, the resultant F_2 chickens exhibited the familiar dihybrid ratio 9 : 3 : 3 : 1. These four phenotypes were – walnut comb, rose comb, pea comb and single comb in the ratio of 9 : 3 : 3 : 1. Out of these four phenotypes two phenotypes were different from those expressed in the parents.

The analysis of F_2 results indicates that the presence of two dominant genes **R** and **P** results in the walnut comb. The double recessive **(rrpp)** genotype produces single comb. The rose comb develops when dominant gene for rose comb is present and dominant gene for pea comb is absent **(RRpp)** whereas pea comb develops when gene for rose comb is recessive and gene for pea comb **(P)** is dominant **(rrPP)**.

(vi) **Pleiotropic effect of genes**

(a) **Lethal genes :** Certain genes are known to control the manifestation of some phenotypic trait as well as affect the viability of the organism. Some other genes have no effect on the appearance of the organism but affect the viability alone. These genes are known as lethals or semilethals depending upon their influence. Complete lethal genes in homozygous condition kill all or nearly all homozygous individuals, while in case of semilethal genes some homozygous individuals are able to survive. The lethal genes are always recessive for their lethality and express the lethal effect only in homozygous condition.

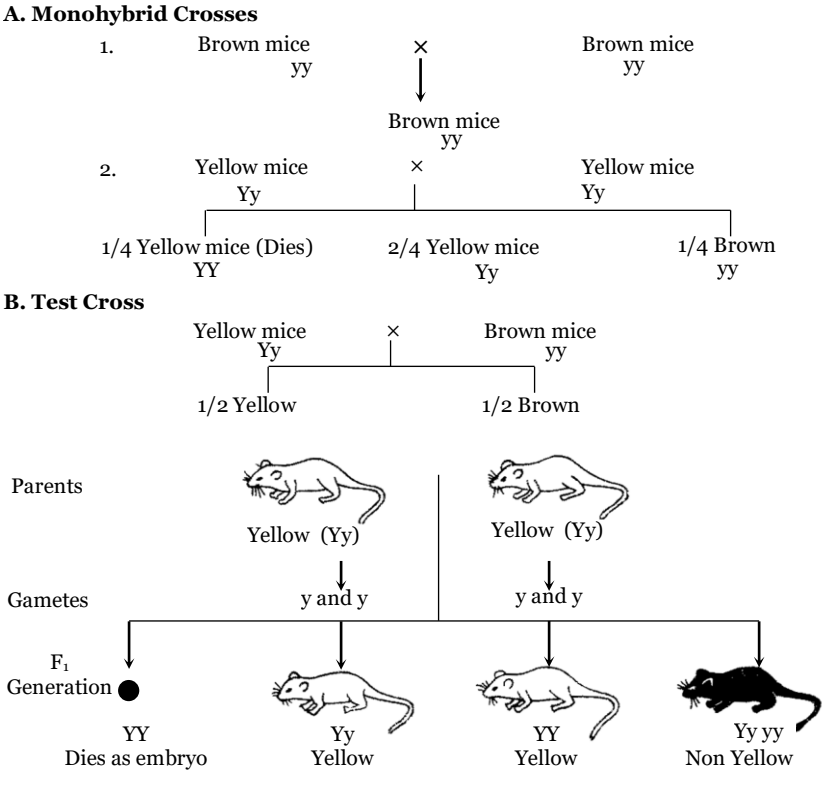


Fig : Inheritance of lethal gene-Y in mice

Dominant lethals : The dominant lethal genes are lethal in homozygous condition and produce some defective or abnormal phenotypes in heterozygous condition. Their most serious effect in heterozygous may also cause death. Following are the examples of dominant lethal genes.

Example – Yellow lethal in mice : A well known example of such lethals is from mice, given by *Cuenot.* He found that the yellow mice never breed true. Whenever the yellow mice were crossed with yellow mice, always yellow and brown were obtained in the ratio of 2:1. A cross between brown and brown mice always produced brown offsprings and a cross between brown and yellow produced yellow and brown in equal proportions.

In 1917, *Stiegleder* concluded that yellow mice are heterozygous. The homozygous yellow ($1/4^{th}$ of the total offsprings) dies in the embryonic condition. When there unborn ones are added to the 2:1 ratio of yellow and brown, these form typical 3:1 ratio. *Cuenot* suggested that gene Y has a multiple effect.

Note : ❑ It controls yellow body colour and has a dominant effect.

❑ It affects viability and acts as a recessive lethal.

Example – Inheritance of sickle cell anaemia in man : The disease sickle cell anaemia is caused by a gene (Hb^S), which is lethal in homozygous condition but has a slight detectable effect in the heterozygous condition. The homozygous for this gene (Hb^s/ Hb^s) generally die of fatal anaemia. The heterozygotes or carriers for Hb^s, (*i.e.*, Hb^A / Hb^s) show signs of mild anaemia as their **R.B.C.** become sickle shaped in oxygen deficiency.

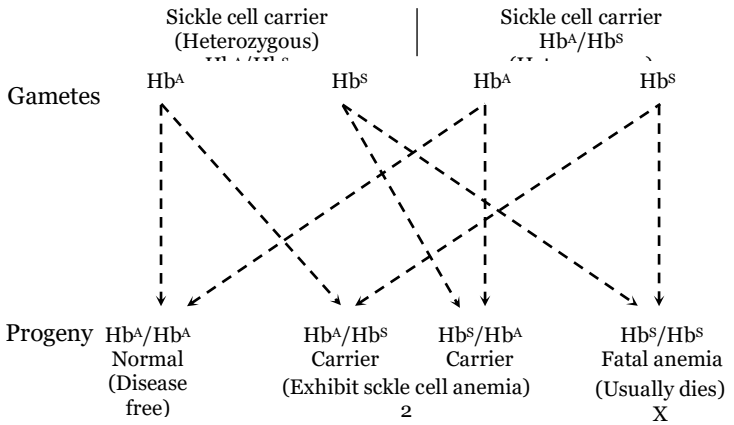


Fig : Diagram depicting inheritance of lethal gene for sickle cell

A marriage between two carriers, therefore, results in carrier and normal offsprings in the ratio of 2:1. The variation in 3:1 ratio is due to the death of homozygous and incomplete dominance of normal gene over recessive gene for sickle cell anaemia in which glutamic acid is substituted by valine in β chain. Which is disorder in Africans that reduce oxygen uptake.

Example – Brachyphalangy : Persons exhibiting brachyphalangy have short fingers apparently having two joints in their fingers, the middle bone being greatly shortened and often fused with one of the other two bones of the finger. Mohr described one case where one child was born without any fingers or toes and did not survive. Two other children showed short fingers and one was normal. This is exact 1 : 2 : 1 ratio.

Example – Huntington's chorea in man : The gene causing Huntington's chorea in man can express itself even when a single dominant allele is present. In both homo and heterozygous condition, the gene expresses itself only at middle–age, usually after forty years. The person suffers from muscular failure, mental retardation and finally death. Thus a dominant gene in heterozygous condition

may also produce lethal effect. The gene is transmitted to next generation only because it expresses itself only after the start of reproductive period.

Recessive lethals : The recessive lethals produce lethal effect only in homozygous condition. Their heterozygotes are normal. Therefore, recessive lethals remain unnoticed in the population but are established in the population because female are carrier for lethal gene. These are detected only when two heterozygous persons get married.

Example – Tay Sach's lethal : The recessive lethal gene for Tay Sach's disease causes death of young children only in homozygotes which are unable to produce enzymes needed for normal fat metabolism. The accumulation of fat in nerve sheaths hampers transmissions of nerve impulse leading to poor muscular control and mental deficiency.

(vii) **Qualitative inheritance :** Qualitative inheritance or monogenic inheritance is that type of inheritance in which one dominant allele influences the complete trait, so that two such allele do not change the phenotype. Here dominant allele is monogene.

(viii) **Quantitative inheritance :** Quantitative inheritance or polygenic inheritance can be defined as, '*two or more different pairs of alleles which have cumulative effect and govern quantitative characters*. The quantitative inheritance is due to incomplete dominance. It has been suggested that the multiple gene inheritance may have following characteristics:

(a) The effects of each contributing gene are cumulative or additive.

(b) Each contributing allele in a series produces an equal effect.

(c) There is no dominance involved.

(d) Epistasis does not exist among genes at different loci.

(e) No linkage is involved in the process.

(f) Effects of environment are absent or may be ignored.

Example – Human skin colour : This character was studied by *Davenport*, 1913 in the marriages between negroes and whites. The F_1 offsprings arising as a result of these marriages are called as mulattoes. The human skin colour is determined by two pairs of genes, P_1 and P_2. A negro having very dark skin with four colour genes *i.e.*, P_1P_1 P_2P_2, when married to a white with no colour gene (p_1p_1 p_2p_2) produce mulattoes with only two colour genes. These mulattoes show intermediate type of skin colour. If this mulatto is married to a similar genotype, the inheritance of pigment forming gene in F_2 offspring shall be as under:

Very dark	–	4 Colour genes	–	One
Intermediates	–	3 Colour genes	–	Four
	–	2 Colour genes	–	Six
	–	1 Colour genes	–	Four
White	–	No colour gene	–	One

If the mulatto is married to a pure white (test cross), the distribution of skin colour shall be as follows:

25% offsprings with two colour genes (P_1 and P_2),

50% offsprings with one colour gene (P_1 or P_2)

25% offsprings with no colour gene

If the mulatto is married to a negro (back cross) the distributions of skin colour shall be as under:

25% offspring with four colour genes

50% offspring with three colour genes

25% offsprings with two colour genes

Example – Ear size in maize : Emerson and East (1913) studied the for the ear length in maize**.** The size difference between two strains of maize is generally due to two or more pairs of genes. If it is due to two pairs of genes, the ratio of different sizes shall be 1 : 4 : 6 : 4 : 1. But, if it is due to three pairs of genes, the size ratio shall be 1 : 6 : 15 : 20 : 15 : 6 : 1.

Example – White spotting in mice : This trait is also polygenic for it is governed by two or more pairs of gene. Depending upon the involvement of the number of gene pairs for determine the trait, the ratios also vary in the manner stated above.

Example – Grain colour in wheat : This character was examined by *Nilsson-Ehile* 1908, which is similar as polygenic gene of skin colour in human. When a red grain was crossed with a white, the F_1 offspring produced light red grains due to incomplete dominance of red over white. The ratio is come out as 1 : 6 : 15 : 20 : 15 : 6 : 1.

(ix) **Multiple alleles :** The multiple alleles can be defined as a set of three, four or more allelomorphic genes or alleles, which have arisen as a result of mutation of the normal gene and which occupy the same locus in the homologous chromosomes. Characters of multiple alleles are following –

(a) Multiple alleles occupy the *same locus* with in the homologous chromosomes. It means only one member of the series is present in a given chromosome.

(b) Since only two chromosomes of each type are present in each diploid cell, only two genes of the multiple series are found in a cell and also in a given individual.

(c) The gametes contain only one chromosome of each types, therefore, only one allele of the multiple series in each gamete.

(d) Crossing over does not occur in the multiple alleles.

(e) Multiple alleles control the same character, but each of them is characterised by different manifestation. *Sturtevent* has summarised it that *they carry the same function but with varying degree of efficiency*.

(f) The multiple alleles of a series are more often related as dominant and recessive. More commonly, the normal gene is dominant to all other mutant alleles. Even the intermediate members of the series may be related as dominant and recessive, or they may exhibit codominance. Therefore, multiple alleles act in some way to control the various steps in a chemical reaction.

Examples : Coat colour in rabbit, blood group in human beings.

(x) **Pedigree analysis :** As man is not a suitable material for genetic research, the human genetics is studied from different point of view. Pedigree analysis is one such method based on Mendelism. It was started by *Galton*.

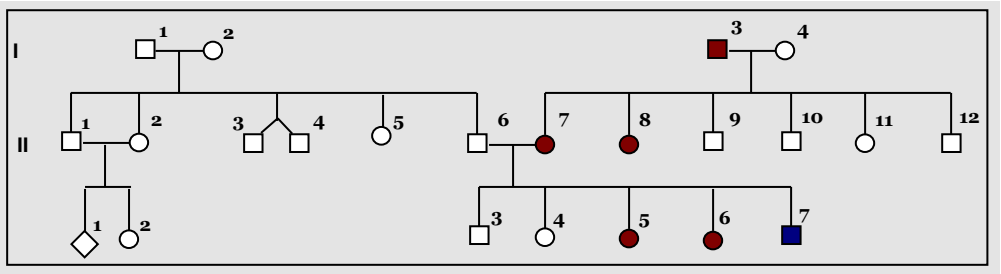


Fig : Pedigree analysis of three

A *pedigree* is a record of inheritance of certain genetic traits for two or more generations presented in the form of a diagram or family tree or case history or genealogy. Pedigree analysis is a system of analysis of pedigree to find out the possibility of absence/presence of a particular trait in the progeny. It is mainly employed in domesticated *animals* and *men* also. The person from whom the case history of a pedigree starts is called *Proband* (called *Propositus* or Prosipitus if it is male and *Proposita* if it is female). The children are called **Sibs**. Empty/open circles and squares represent normal female ( ) and normal male ( ) solid/shaded (● / ■) symbols stand for those which bear the trait under study. ◑ or ⊙ represent carrier normal female having recessive allele of the trait under study identical twins non-identical twins. ◨ This is never used as man can never be a carrier. Horizontal line shows marriage line. All siblings are connected to a horizontal line below parents in order of birth. Only X-linked genes show criss cross inheritance.

Important Tips

- Fair child's sweet William is **hybrid flower**.
- In polygenic inheritance some offsprings may exhibit more extremes than either parent or grandparent. For example, some children are shorter or taller than either parent or any of their more remote ancestors. The same is true with respect to intelligence. These are called **transgressive variations.**
- Formula of number of genotypes in case of multiple allelism is: $\frac{n}{2}(n+1) = n$ alleles .
- In ABO blood group three alleles regulate blood group leading to the formation of six genotypes. **Landsteiner** discovered A, B, O, blood groups.
- During serological test in which antihuman serum is mixed with blood of another animal, blood of chimpanzee gives the thickest precipitate.
- Dominance is a phenomenon and not a low because of the existence of incomplete dominance and codominance.
- Heterosis in plants is obtained by crossing in **unrelated** parents and known as hybrid vigour.
- **Expressivity** is the degree of effect produced by penetrant genotype.

☞ Nilsson-Ehle (1908) was the first scientist to prove quantitative inheritance.

2.7 Cytoplasmic inheritance/Extrachromosomal inheritance

The fact that nucleus contains the units of inheritance was proposed by Oscar Hertwig in 1870's. The mechanism was clearly understood with the development of Mendel's law of inheritance. Further researchers proposed that cytoplasm also contains the hereditary material. The evidence for cytoplasmic inheritance was first presented by Correns in *Mirabilis Jalapa* and by Baur in *Pelargonium zonale* in 1908. Later on Ruth Sager (1954) described cytoplasmic inheritance of streptomycin resistance in chlamydomones in other animals and plants certain characters are inherited independent of the chromosomal genes (Non-chromosomal genes). The cytoplasm in such cases contain self perpetuating hereditary particles formed of DNA. These may be mitochondria, plastids or foreign organism, etc. The total self duplicating hereditary material of cytoplasm is called **plasmon** and the cytoplasmic units of inheritance are described as plasmogenes.

(1) **Criteria for cytoplasmic inheritance :** The cases of cytoplasmic inheritance are found to exibit maternal influence. The reason is very simple. Very little cytoplasm is contained in the sperm cell of an animal. Most of the cytoplasm is contributed to the zygote by the ovum or egg. Hence if there are hereditary units in the cytoplasm, these will be transmitted to the offsprings through the egg. The offspring, therefore will exhibit maternal influence. This could be explained further by following example.

(i) Maternal influence on shell coiling in snail.

(ii) Inheritance of sigma particles in Drosophila.

(iii) Breast tumour in mice.

(iv) Plastid inheritance in Mirabilis (4 O' clock plant).

(v) Plastid inheritance in *Oenothera*.

(vi) Male sterility in plants – *e.q.* maize.

(vii) Inheritance of kappa particles in *Paramecium* : *Sonneborn* and his associates have described the transmission of some cytoplasmic particles known as kappa particles and their relation to nuclear genes in *Paramecium aurelia*. Individuals of particular race of paramecium aurelia called *killer strain* destroy other races of paramecia by secreating some toxic substance into the water in which they live. This substance is known as paramecin. Although kappa particles are cytoplasmic particles and transmitted strictly through the cytoplasm.

2.8 Chromosomes and Genes

CHROMOSOMES

The chromosomes are capable of self–reproduction and maintaining morphological and physiological properties through successive generations. They are capable of transmitting the contained hereditary material to the next generation. Hence these are known as '**hereditary vehicles**'.

(1) **Discovery of chromosomes**

Hofmeister (1848) : First observed chromosomes in microsporocytes (microspore mother cells) of *Tradescantia*.

Flemming (1879) : Observed splitting of chromosomes during cell division and coined the term, 'chromatin'.

Roux (1883) : He believed the chromosomes take part in inheritance.

W.Waldeyer (1888) : He coined the term 'chromosome'.

Benden and Boveri (1887) : They found a fixed number of chromosomes in each species.

(2) **Kinds of chromosomes**

(i) **Viral chromosomes :** In viruses and bacteriophages a single molecule of DNA or RNA represents the viral chromosome.

(ii) **Bacterial chromosomes :** In bacteria and cyanobacteria, the hereditary matter is organized into a single large, circular molecule of double stranded DNA, which is loosely packed in the nuclear zone. It is known as bacterial chromosome or *nucleoid*.

(iii) **Eukaryotic chromosomes :** Chromosomes of eukaryotic cells are specific individualized bodies, formed of deoxyribonucleo proteins (DNA + Proteins).

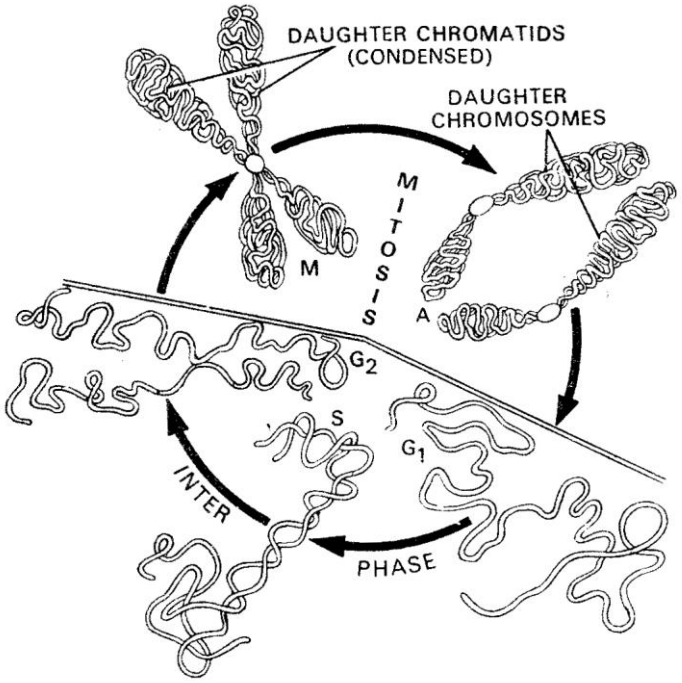


Fig : Diagram showing chromosome cycle : M-Metaphase, A-Anaphase, G-Growth phase I, S-Synthetic phase, G_2 – Growth phase II

(3) **Chromosomal theory of inheritance:** It was proposed independently by *Sutton* and *Boveri* in 1902. The chromosome theory of inheritance proposes that chromosomes are vehicles of hereditary information and expression as Mendelian factors or genes.

(i) Bridge between one generation to the next are sperm and ovum.

(ii) Both sperm and ovum contribute equally in heredity. Sperm provides only nucleus for fertilization. Therefore, heredity must be based in nuclear material.

(iii) Nucleus possesses chromosomes. Therefore, chromosomes must carry hereditary characters.

(iv) Chromosomes, like hereditary factors are particulate structures, which maintain their number, structure and individuality in organisms from generation to generation.

(4) **Chromosomes number :** Chromosome number is $n = 2$ in Mucor hiemalis, $2n=4$ in plant *Haplopappus gracilis*. Chromosome number is 14 ($n=7$) in Pea, 20 in Maize, 46 in human beings. Maximum number of chromosomes is known for Adder's Tongue Fern (*Ophioglossum reticulatum,* $2n = 1262$) and *Aulocantha (*$2n=1600$*)*. Number of chromosomes is not related to complexity or size of

organism *e.g.*, Domestic Fowl and Dog both possess 78 chromosomes. Study of chromosome structure is performed at metaphase and study of chromosome shape at anaphase.

(5) **Chromosome cycle and cell cycle :** Chromosomes exhibit cyclic change in shape and size during cell cycle. In the non-dividing interphase nucleus, the chromosomes form an interwoven network of fine twisted but uncoiled threads of chromatin, and are invisible. During cell division the chromatin threads condense into compact structures by helical coiling.

(6) **Chromosome structure :** Different regions (structures) recognized in chromosomes are as under.

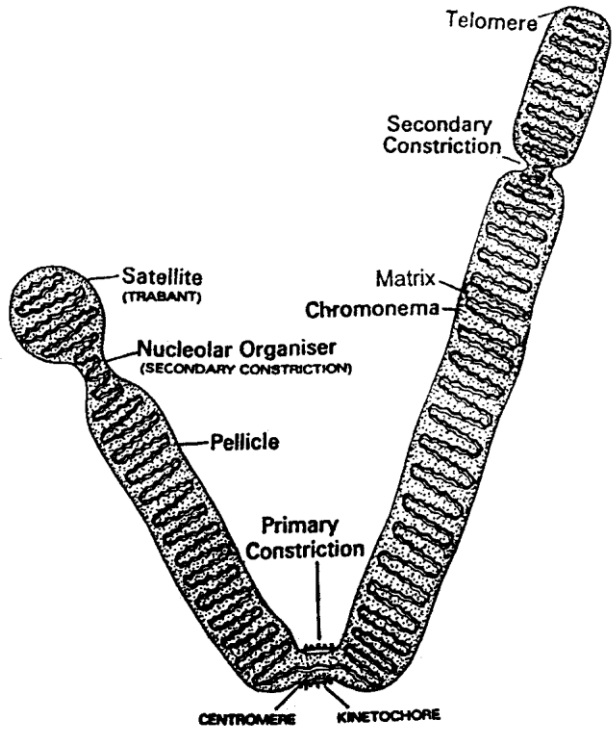


Fig : Structure of chromosome

(i) **Pellicle** : It is the outer thin but doubtful covering or sheath of the chromosome.

(ii) **Matrix :** Matrix or ground substance of the chromosome is made up of proteins, small quantities of RNA and lipid. It has one or two chromonemata (singular - chromonema) depending upon the state of chromosome.

(iii) **Chromonemata :** They are coiled threads which form the bulk of chromosomes. A chromosome may have one (anaphase) or two (prophase and metaphase) chromonemata. There are three view points about the constitution of chromonema and chromosome.

(iv) **A Primary Constriction and Centromere (kinetchore) :** A part of the chromosome is marked by a constriction. It is comparatively narrow than the remaining chromosome. It is known as primary constriction. The primary constriction divides the chromosome into two arms. It shows a faintly positive Feulgen reaction, indicating presence of DNA of repetitive type. This DNA is called centromeric heterochromatin.

(v) **Centromere :** Centromere or kinetochore lies in the region of primary constriction. The microtubules of the chromosomal spindle fibres are attached to the centromere. Therefore, centromere is associated with the chromosomal movement during cell division. Kinetochore is the outermost covering of centromere.

(vi) **Secondary constriction or nucleolar organizer :** Sometimes one or both the arms of a chromosome are marked by a constriction other than the primary constriction. During interphase this area is associated with the nucleolus and is found to participate in the formation of *nucleolus.* It is, therefore, known as nucleolar organizer region or the secondary constriction.

Nucleolar organizer region (NOR) : In certain chromosomes, the secondary constriction is (In human beings 13, 14, 15, 20 and 21 chromosome are nucleolar organizer) intimately associated with the nucleolus during interphase. It contains genes coding for **18S** and **28S** ribosomal **RNA** and is responsible for the formation of nucleolus. Therefore, it is known as *nucleolar organizer region* (*NOR*).

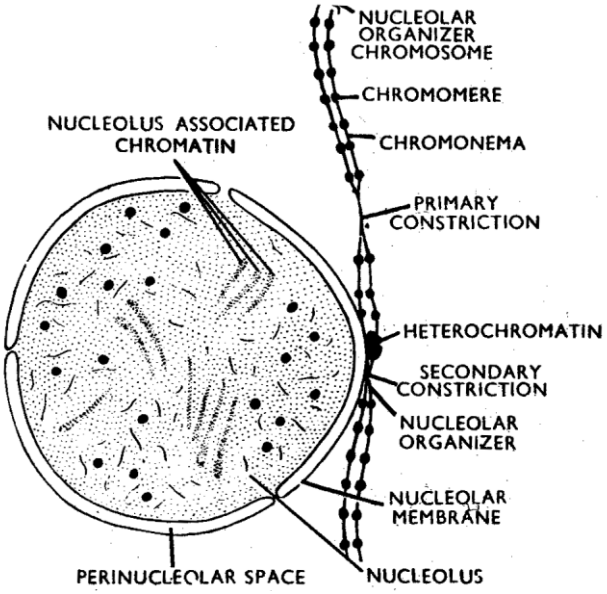


Fig : Nucleolus organizer or secondary constriction and its association with

(vii) **Telomeres :** The tips of the chromosomes are rounded and sealed and are called telomeres which play role in Biological clock. The terminal part of a chromosome beyond secondary constriction is called *satellite*. The chromosome with satellite is known as *sat chromosome*, which have repeated base sequence.

(viii) **Chromatids :** At metaphase stage a chromosome consists of two chromatids joined at the common centromere. In the beginning of anaphase when centromere divides, the two chromatids acquire independent centromere and each one changes into a chromosome.

(7) **Types of chromosomes based on number of centromeres :** Depending upon the number of centromeres, the chromosomes may be:

(i) Monocentric with one centromere.

(ii) Dicentric with two centromeres, one in each chromatid.

(iii) Polycentric with more than two centromeres.

(iv) Acentric without centromere. Such chromosomes represent freshly broken segments of chromosomes, which do not survive for long.

(v) Diffused or non-located with indistinct centromere diffused throughout the length of chromosome. The microtubules of spindle fibres are attached to chromosome arms at many points. The diffused centromeres are found in insects, some algae and some groups of plants (*e.g. Luzula*).

(8) **Types of chromosomes based on position of centromere :** Based on the location of centromere the chromosomes are categorised as follows:

(i) **Telocentric :** These are rod-shaped chromosomes with centromere occupying a terminal position. One arm is very long and the other is absent.

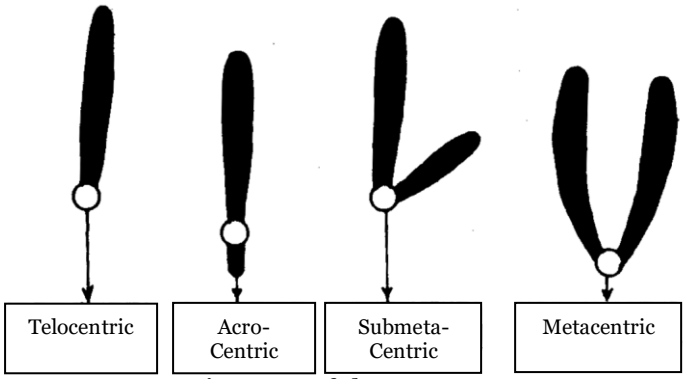


Fig : Types of chromosomes

(ii) **Acrocentric :** These are rod-shaped chromosomes having subterminal centromere. One arm is very long and the other is very small.

(iii) **Submetacentric :** These are **J** or **L** shaped chromosomes with centromere slightly away from the mid-point so that the two arms are unequal.

(iv) **Metacentric :** These are **V**-shaped chromosomes in which centromere lies in the middle of chromosomes so that the two arms are almost equal.

(9) **Molecular organisation of chromosome :** Broadly speaking there are two types of models stating the relative position of DNA and proteins in the chromosomes.

Multiple strand models : According to several workers (Steffensen 1952, Ris 1960) a chromosome is thought to be composed of several DNA protein fibrils, chromatids are made up by several DNA protein fibrils and atleast two chromatids form the chromosome.

Single strand models : According to Taylor, Du prow etc. The chromosome is made up of a single DNA- protein fibril. There are some popular single strand models.

(i) **Folded fiber model :** Chromosomes are made up of very fine fibrils 2 *nm* - 4 *nm* in thickness. As the diameter of DNA molecule is also 2 *nm* (20Å). So it is considered that a single fibril is a DNA molecule. It is also seen that chromosome is about a hundred times ticker than DNA whereas the length of DNA in chromosome is several hundred times that of the length of chromosome. So it is considered that long DNA molecule is present in folding manner which forms a famous model of chromosome called folded fibre model which given by *E.J. Dupraw* (1965).

(ii) **Nucleosome model :** The most accepted model of chromosome or chromatin structure is the 'nucleosome model' proposed by Kornberg and Thomas (1974). Nucleosomes are also called *core particles or Nu-bodies*. The name nucleosome was given by *P. Outdet* etal. The nucleosome is a oblate particle of 55Å height and 110Å diameter. Woodcock (1973) observed the structure of chromatin under electron microscope. He termed each beaded structure on chromosome as nucleosome. Nucleosome is quasicylindrical structure made up of histones and DNA.

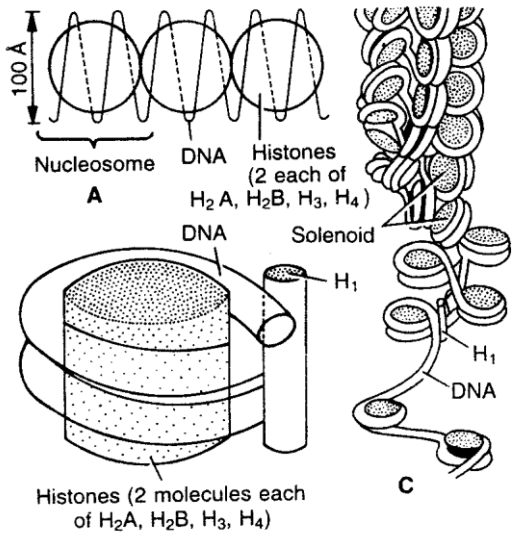


Fig : A-C Nucleosome : A Units of nucleosome, B Nucleosome model C Solenoid model

(a) **Structural proteins (histones) :** Histones are main structural protein found in eukaryotic cells. These are low molecular weight proteins with high proportion of positively charged basic amino acids arginine and lysine.

Types of histones : These are five different types of histones that fall into two categories.

Nucleosomal histones : These are small proteins responsible for coiling DNA into nucleosome. These are H_2A, H_2B, H_3 and H_4 (two molecule of each four histone protein form a octamer structure). These form the inner core of nucleosome.

***H*$_1$-histones or linker histon protein :** These are large (about 200 amino acids) and are tissue specific. These are present once per 200 base pairs. These are loosely associated with DNA. H_1 histones are responsible for packing of nucleosomes into 30 *nm* fiber.

Functions of histones : Histones in eukaryotic chromosomes serve some functions.

- These either serve as structural elements and help in coiling and packing of long DNA molecules.
- Transcription is possible only by dissolution of histones in response to certain molecular signals.

(b) **DNA in nucleosome :** Nucleosome is made of core of eight molecules of histones wrapped by double helical DNA with $1\frac{3}{4}$ turns making a repeating unit. Every $1\frac{3}{4}$ turn of DNA have 146 base pairs. When H_1 protein is added the nucleotide number becomes 200. DNA which joins two nucleosome is called linkar DNA or spacer DNA.

(iii) **Solenoid model :** In this model the nucleosomal bead represents the first degree of coiling of DNA. It is further coiled to form a structure called solenoid (having six nucleosome per turn). It represents the second degree of coiling. The diameter of solenoid is 300Å. The solenoid is further coiled to form a supersolenoid of 2000-4000Å diameter. This represent the third degree of coiling. The supersolenoid is perhaps the unit fiber or chromonema identified under light microscopy. The solenoid model was given by Fincy and Klug 1976. A Klug was awarded by noble prize in 1982 for his work on chromosome.

(iv) **Dangier-String or Radial Loop Model :** (Laemmli, 1977). Each chromosome has one or two interconnected scaffolds made of nonhistone chromosomal proteins. The scaffold bears a large number of lateral loops all over it. Both exit and entry of a lateral loop lie near each other. Each lateral loop is 30 *nm* thick fibre similar to chromatin fibre. It develops through solenoid coiling of nucleosome chain with about six nucleosomes per turn. The loops undergo folding during compaction of chromatin to form chromosome.

(10) **Giant chromosomes :** These chromosomes are of two types.

(i) **Polytene chromosome :** Polytene chromosome was described by *Kollar* (1882) and first reported by *Balbiani* (1881). They are found in salivary glands of insects (*Drosophila*) and called as salivary gland chromosomes. These are reported in endosperm cells of embryosac by *Malik* and *Singh* (1979). Length of this chromosome may be upto 2000μm. The chromosome is formed by somatic pairs between homologous chromosomes and repeated replication or endomitosis of chromonemata. These are

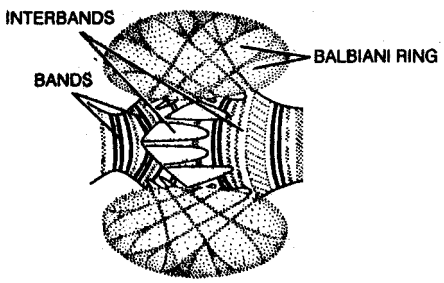


Fig : Polytene chromosome showing balbiani ring

attached to chromocentre. It has pericentromeric heterochromatin. Polytene chromosomes show a large number of various sized intensity bands when stained. The lighter area between dark bands are called interbands. They have puffs bearing *Balbiani rings*. Balbiani rings produce a number of m-RNA, which may remain stored temporarily in the puffs, are temporary structures.

(ii) **Lampbrush chromosomes** : They are very much elongated special type of synapsed or diplotence chromosome bivalents already undergone crossing over and first observed by *Flemming* (1882). The structure of lampbrush chromosome was described by *Ruckert* (1892). They are found in *oocyte, spermatocytes* of many animals. It is also reported in *Acetabularia* (unicellular alga) by *Spring et.al. in* 1975. *In urodele oocyte the length of lampbrush chromosome is upto* 5900μm. These are found in pairs consisting of homologous chromosomes jointed at chiasmata (meiotic prophase–I). The chromosome has double main axis due to two elongated chromatids. Each chromosome has rows of large number of chromatid giving out lateral loops, which are uncoiled parts of chromomere with one–many transcriptional units and are involved in rapid transcription of mRNA meant for synthesis of yolk and other substances required for growth and development of meiocytes. Some mRNA produced by lampbrush chromosome is also stored as informosomes *i.e.*, mRNA coated by protein for producing biochemicals during the early development of embryo. Length of loop may vary between 5-100 μm.

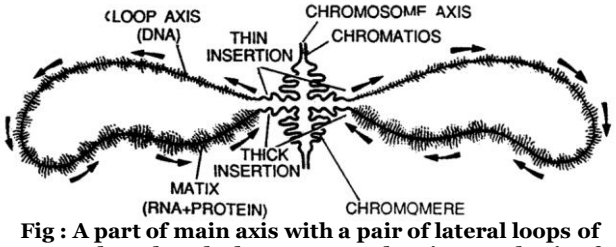


Fig : A part of main axis with a pair of lateral loops of a lampbrush chromosome showing synthesis of RNA

(11) **Other types of eukaryotic chromosomes.**

(i) **B-chromosomes (Wilson, 1905) :** They are supernumerary or extra chromosomes which are mostly heterochromatic, smaller than normal and show slower replication. B-chromosomes may get lost. In excess, they may result in loss of vigour.

(ii) **M-chromosomes :** They are minute but functional chromosomes (0.5μm or less). Which occur is some bryophytes and insects.

(iii) **L-chromosomes :** The chromosomes found only in germ-line cells, which are eliminated during formation of somatic cells**.** In Mainstor 36 chromosomes in female and 42 chromosomes in male are eliminated during development of somatic cells. They are also called E–chromosomes.

(iv) **Sex chromosomes :** Sex chromosomes are those chromosomes whose presence, absence or particular form determines the sex of the individual. Sex chromosomes are also called *idiochromosomes/allosomes*. Besides determining sex, these chromosomes also control a number of morpho-physiological traits called sex-linked characters. Chromosomes other than sex chromosomes are known as autosomes. Autosomes determine morpho-physiological traits of the organisms, which are similar in both the sexes and are not sex-linked.

The two sex chromosomes in an individual may be morphologically similar/homomorphic (e.g. XX) or different/heteromorphic (e.g. XY). The morphologically different chromosome is androsome.

(*e.g.*, Y-chromosome) or male determining in same organisms (e.g., mammals) and gynosome or female determining in others (*e.g.*, W-chromosome in birds). Individuals having homomorphic sex chromosomes produce similar gametes. They are, therefore, *homogametic* (A+X, A+X in human females). Individuals with heteromorphic sex chromosomes produce two types of gametes. They are *heterogametic* (A+X, A+Y in human males). Some sex chromosomes are *heterochromatic* (Y–chromosome in males and one X–chromosome in females) and are called *heterochromosomes/heterosomes*. Other chromosomes are called euchromosomes though the latter term is also applied for autosomes.

(12) **Functions of chromosomes**

(i) Chromosomes are link between parents and offspring.

(ii) They contain genes and hence hereditary information.

(iii) Sex chromosomes determine sex.

(iv) Chromosomes control cell growth, cell division, cell differentiation and cell metabolism through directing synthesis of particular proteins and enzymes.

(v) Haploid and diploid chromosome number determine gametophytic and sporophytic traits.

(vi) Chance separation, crossing over and random coming together of chromosomes bring about variations.

(vii) New species develop due to change in number, form and gene complements of chromosomes.

(13) **Karyotype :** It is chromosome complement of a cell–organism providing description of number, types and characteristics of chromosomes. *Idiogram* is a karyotype consisting of photograph or diagram of all the metaphasic chromosomes arranged in homologous pairs according to decreasing length, thickness, position of centromere, shapes etc, with sex chromosomes placed at the end (but at position I in *Drosophila*).

(i) **Human karyotype :** *Tijo* and *Levan* (1956) of Sweden found that human cells have 23 pairs or 46 chromosomes. 22 pairs or 44 chromosomes are autosomes and the last or 23rd pairs is that of sex chromosomes, XX in females and XY in males.

GENES

Term *'gene'* was given by *Johannsen* (1909) for any particle to which properties of Mendelian factor or determiner can be given. T.H Morgan (1925) defined gene as 'any particle on the chromosome which can be separated from other particles by mutation or recombination is called a gene. In general, gene is the basic unit of inheritance.

According to the recent information a gene is a segment of **DNA** which contains the information for one enzyme or one polypeptide chain coded in the language of nitrogenous bases or the nucleotides. The sequence of nucleotides in a **DNA** molecule representing one gene determines the sequence of amino acids in the polypeptide chain (the *genetic code*). The sequence of three nucleotides reads for one amino acid (*codon*).

(1) **Gene action :** Gene act by producing enzymes. Each gene in an organism produces a specific enzyme, which controls a specific metabolic activity. It means each gene synthesizes a particular protein which acts as enzyme and brings about an appropriate change.

(i) **One gene one enzyme** : This theory was given by Beadle and Tatum (1958), while they were working on red mould or *Neurospora* (ascomycetes fungus). Which is also called *Drosophila of plant kingdom*. Wild type *Neurospora* grows in a minimal medium (containing sucrose, some mineral salts and biotin). The asexual spores *i.e.* conidia were irradiated with x-rays or UV-rays (mutagenic agent) and these were crossed with wild type. After crossing sexual fruiting body is produced having asci and ascospores. The ascospores produced are of 2 types -

(a) The ascospores, which are able to grow on minimal medium called *'prototrophs'*.

(b) Which do not grow on minimal medium but grow on supplemented medium called *'auxotrophs'*.

(2) **Molecular structure of gene :** Gene is chemically DNA but the length of DNA which constitutes a gene, is controversial 3 term *i.e. cistron, muton* and *recon* were given by Seymour Benzer to explain the relation between DNA length and gene.

(i) **Cistron or functional gene or gene in real sense :** Cistron is that particular length of DNA which is capable of producing a protein molecule or polypeptide chain or enzyme molecule.

(ii) **Muton or unit of mutation :** Muton is that length of DNA which is capable of undergoing mutation. Muton is having one or part of nucleotide.

(iii) **Recon :** Recon is that length of DNA which is capable of undergoing crossing over or capable of recombination. Recon is having one or two pairs of nucleotides.

(iv) **Complon :** It is the unit of complementation. It has been used to replace cistron. Certain enzymes are formed of two or more polypeptide chains. Whose active groups are complimentary to each other.

(v) **Operon :** Operon is the combination of operator gene and sequence of structure genes which act together as a unit. Therefore it is composed of several genes. The effect of operator gene may be additive or suppresive.

(vi) **Replicon :** It is the unit of replication. Several replicons constitute a chromosome.

(3) **Some specific terms**

(i) **Transposons or Jumping genes :** The term 'transposon' was first given by *Hedges and Jacob* (1974) for those DNA segments which can join with other DNA segments completely unrelated and thus causing illegitimate pairing. These DNA segments are transposable and may be present on different place on main DNA. The transposons are thus also called Jumping genes. Hedges and Jacob reported them in bacteria. But actual discovery of these was made by *Barbara Mc Clintock* (1940) in maize and she named them as controlling elements in maize or mobile genetic elements in maize. For this work, she was awarded nobel prize in (1983).

(ii) **Retroposons :** The term was given by Rogers (1983) for DNA segments which are formed from RNA or which are formed by reverse transcription under the influence of reverse transcriptase enzyme or RNA dependent DNA polymerase enzyme.

$$\text{RNA} \xrightarrow{\text{Reverse transcriptase}} \text{DNA (Retroposo n)}$$

Note : ❑ About 10% of DNA of genome in primates and rodents is of this type.

(iii) **Split genes or interrupted genes :** Certain genes were reported first in mammalian virus and then in eukaryotes by R. Roberts and P. Sharp in (1977) which break up into pieces or which are made of segments called exons and introns. These are called split genes or interrupted genes.

Split gene = Exons + Introns

In mRNA formed from split gene exons are present and not corresponding to introns. So in split genes, exons carry genetic information or informational pieces of split genes are exons.

(iv) **Pseudogenes or false genes :** DNA sequences presents in multicellular organisms, which are useless to the organism and are considered to be defective copies of functional genes (cistrons) are called pseudogenes or false genes. These have been reported in *Drosophila*, mouse and human beings.

Important Tips

- ☞ Rarely a functional centromere is absent and the whole surface of chromosome functions as such. Such a chromosome is called holocentric.
- ☞ Inheritance is based on particles (genes).
- ☞ Genetically identical progeny is produced when the individual produces identical gametes.
- ☞ **Gene flow** is spread of genes from one breeding population to another by migration.
- ☞ The genes, which enhance the effect of other gene, is also known as extender.
- ☞ **Single copy genes :** Represented only once in the whole genome.
- ☞ **Multigenes :** A group of nearly similar genes.
- ☞ Sutton and Winiweter (1900) expressed that number of chromosome is reduced to half in meiosis and doubled in fertilization.
- ☞ Flemming clarified the chromosomal events involving mitosis and transfer of it from parent to progeny.
- ☞ A human diploid cell has about 100000 genes on its 46 chromosomes, out of which only 5-15% (average 10%) genes are expressed at a time.
- ☞ H_1, H_{2a}, H_{2b} protein of nucleosome rich in lysine amino acid and H_3, H_4 rich in arginine
- ☞ Sometimes two satellites are present in a chromosome these chromosome are called tandem SAT-Chromosomes.
- ☞ SAT Chromosomes are used as marker chromosomes.
- ☞ Deletion is common to acentric chromosomes.

- Lampbrush chromosomes are larger than polytene chromosomes.
- Lampbrush loops and polytene puff are analogous.
- Plasma genes occur in plastids, mitochondria, plasmid, sigma particle & kappa particle.
- Hyper chromism is presence of some chromosome more than one.
- The former gene which have been mutated to such as extent that they can not be transcribed further in m RNA are called **Pseudogenes**.
- Chromosomal theory of inheritance in the present form was modified by **C. B. Bridges**.
- Genes modify the effect of other gene called modifiers.
- Super numerary chromosomes formed due to non-disjunction at the time of meiosis and called planosome.
- 3-11 nucleotide sequence of ribosome recognisition site on mRNA is called SD sequence or shine Dalgrano site.
- The term gene refers to a portion of DNA Gene is formed of polynucleotide. Which can synthesis a single protein.
- Number of genes on a chromosome is infinite.
- In a chromosomes the protein content is trace.
- **Spring** et. al. In 1975 reported lampbrush chromosome in Acetabularia.
- The drug mercaptolethanol when applied early in mitosis, interferes with the centriole apparatus, it therefore affects mitosis by disrupting the spindle formation.
- Genetic drift is the random change in gene frequencies.
- An allele is said to be dominant if it is expressed only in both homozygous & heterozygous condition.
- Holandric genes are genes located on non- homologous segment of Y chromosome.
- **Cytochimera** means cell having different chromosomes other than vegetative cell.
- Translocation is a type of chromosomal aberration where a part of one chromosome is exchanged between non homologous counterpart.
- The genetic basis of evolution (particular adaptation) was demonstrated in bacteria by **J. Lederberg and E. M. Lederberg**.
- The factors controlling change in gene frequencies are natural selection, mutation, migration, and genetic drift.
- **Gene flow** is described as the transfer of gene between population, which differ genetically from one another but can interbreed.
- **Carmine** is a dye extracted from the cochineal insect (Coccus cacti).
- **Haematoxylin** is a dye extracted from the heartwood of a tropical tree etc. Haematoxylin campechianum both are stain the chromosome and nucleus.

2.9 Linkage

Introduction : "When genes are closely present link together in a group and transmitted as a single unit, the is phenomenon is called linkage".

(1) **Theories of linkage**

(i) **Sutton's hypothesis of linkage (1903) :** The number of groups of genes are equivalent to the number of chromosomes.

(ii) **Morgan's hypothesis of linkage (1910) :** It was given by *T. H. Morgan.* According to him the genes of homologous parents enter in the same gamete and tend to remain together, which is opposite in heterozygous parents. Linked group are located on the same chromosome and distance between linked group of gene limits the grade of linkage.

(iii) **Coupling and repulsion hypothesis :** Proposed by *Bateson* and *Punnet* (1906) that dominant alleles tend to remain together as well with recessive alleles, called gametic coupling. If dominant and recessive alleles are present in different parents they tend to remain separate and called repulsion. When BBLL and bbll are crossed, the F_1 is BbLl and the test cross of it will show progeny in 7 : 1 : 1 : 7 ratio *i.e.* BbLl : Bbll : bbLl : bbll (coupling) when BBll is crossed with bbLL the F_1 is BbLl or the test cross progeny will show 1 : 7 : 7 : 1 ratio *i.e.*, BbLl : Bbll : bbLl : bbll (repulsion). Coupled and repulsed genes are known as linked genes. Linkage has coupling phase and repulsion phase. In coupling phase both the linked genes have their dominant alleles in one chromosome and recessive alleles in other chromosomes. The heterozygotes with such constitution is called *cis* heterozygote. *Cis*-arrangement is a original arrangement. Which form two types of gametes as (**AB**) and (**ab**). In Human X–chromosomes carry 102 genes and Y chromosome carries 10 genes only.

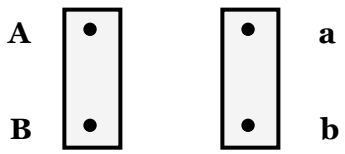


Fig : *CIS* – Arrangement of genes

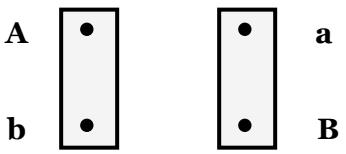


Fig : *TRANS* – Arrangement of genes

In repulsion phase the normal alleles as well as mutant alleles lie in opposite chromosomes of the homologous pair, such heterozygote is called as *trans* heterozygote. It is not original arrangement, caused due to crossing over, which form two types of gametes as (**Ab**) and (**aB**).

(iv) **Chromosomal hypothesis of linkage :** It was given by *Morgan* and *Castle.* According to them linked genes are bound by chromosomal material and are transmitted as a whole.

(2) **Types of linkage :** Depending upon the absence or presence of nonparental or new combination of linked genes, linkage has been found to be complete or incomplete.

(i) **Complete linkage :** Such cases in which linked genes are transmitted together to the offsprings only in their original or parental combination for two or more or several generations exhibit *complete*

linkage. In such cases the linked genes do not separate to form the new or non-parental combinations. This phenomenon is very rare. Some characteristics in males of *Drosophila* are found to exhibit complete linkage.

(ii) **Incomplete linkage :** In majority of cases, the homologous chromosomes undergo breakage and reunion during gametogenesis. During reunion the broken pieces of the chromatids are exchanged, producing some nonparental or new combinations. Therefore, the linkage is rendered incomplete. The phenomenon of interchange of chromosome segments between two homologous chromosomes is called crossing over. Incomplete linkage is very common and has been studied in almost all the organisms.

(3) **Linkage groups :** All the genes which are linked with one another, form a linkage group. Since linked genes are present in the same chromosome, the number of linkage group in an animal or plant is equal to the haploid number of chromosomes present in its cells. This hypothesis was given by *Sutton* and was proved by experiments on *Drosophila* by *T.H. Morgan.*

Examples	Linkage groups
Drosophila	There are four linkage groups corresponding to the four pairs of chromosomes
Zea mays	The ten chromosome pairs of maize correspond with its ten linkage groups
Pisum sativum	The garden pea plant has seven pairs of chromosome and the same number of linkage groups
Man	Man has 23 linkage groups corresponding to 23 pairs of chromosomes

(4) **Strength of linkage :** The strength of linkage between any two pairs of linked genes of a chromosome depend upon the distance between them. Closely located genes show strong linkage, while genes widely located show weak linkages.

(5) **Factor affected to linkage :** Linkage is affected by the following factors.

(i) **Distance :** Closely located genes show strong linkage while genes widely located show weak linkage.

(ii) **Age :** With increasing age the strength of linkage decreases.

(iii) **Temperature :** Increasing temperature decreases the strength of linkage.

(iv) **X-rays :** X-rays treatment reduces the strength of linkage.

(6) **Significance of linkage**

(i) Due to linkage new recombinants are formed.

(ii) It helps in maintaining the valuable traits of a newly developed variety.

(iii) It helps locating genes on chromosome.

(iv) It disallows the breeders to combine all the desirable traits in a single variety.

Important Tips

- Cinderella of genetics is Drosophila melanogaster.
- **H. Lamprecht (1961)** demonstrated that seven genes used by **Mendel** belonged to only four linkage groups (not seven as thought earlier).
- Blue green algae and bacteria contain one linkage group.
- Two dominant nonallelic genes are 50map unit apart then the linkage will be absent.
- Linkage decrease frequency of hybridization.
- In order to remain linked the distance between two genes should not increase beyond 40 map units.
- Linkage was first studied in Lathyrus-odoratus.
- Drosophilla was first animal for which a linkage map was constructed.
- Law of linkage is an exception to **Mendel's law**.

2.10 Crossing over

Introduction : The process by which exchange of chromosomal segment take place is called crossing over. Crossing over may be defined as "*the recombination of linked genes*" brought about as a result of interchange of corresponding parts between the chromatid of a homologous pair of chromosomes, so as to produce new combination of old genes. The term was given by *Morgan* and *Cattle.* Janssen (1909) observed chiasmata during meiosis-I (Prophase). Morgan proposed that chiasmata lead to crossing over by breakage and reunion of homologous chromosomes. Crossing over results in new combination while non-cross over result in parental type, which leads to variations.

(1) **Kinds of crossing over**

(i) **Somatic crossing over :** It is found in somatic cells *e.g., Curt stern* in *Drosophila* and *Potnecorvo* in *Aspergillus nidulans* shown somatic crossing over *i.e.* mitotic crossing over.

(ii) **Germinal crossing over :** It is found in germinal cells during gametogenesis. This is also known as meiotic crossing over.

(iii) **Single cross over :** It takes place at one point only on the non-sister chromatids, only 2 chromatids are involved.

(iv) **Double cross over :** It is the formation of 2 chiasmata in the same chromosome independent of each other. In a double cross over the genes lying outside the crossed regions will retain their original association.

(v) **Multiple cross over :** It is formed when more than 2 chiasmata are formed. It is very rare.

(vi) **Two-stranded crossing over :** It takes place before splitting of homologous chromosomes so all the four resultants are recombinants.

(vii) **Four stranded crossing over :** It takes place after splitting of homologous chromosomes only 2 non-sister chromatids take part in crossing over resulting in 2 parental and 2 recombinant types.

(2) **Crossing over and chiasma :** There are two views extended to explain the relationship between crossing over and chiasma formation. They are summarised here under.

(i) **Chiasma type theory :** According to Janssen, 1909 the act of crossing over is followed by chiasma formation. He suggests that the crossing over takes place at the pachytene stage and the chiasma appear at diplotene.

(ii) **Classical theory :** According to Sharp, 1934, crossing over is the result of chiasma formation. According to this view, the chiasma are organised at pachytene and crossing over takes place at diplotene stage. On the basis of evidence available from molecular biology, that is untenable and hence rejected.

(3) **Mechanism of crossing over :** There are different views put forward to explain the mechanism of crossing over.

(i) **Copy choice hypothesis :** According to *Belling,* 1928 the chromomeres represent the genes joined by interchromomeric regions. The chromomeres duplicate first and then the interchromomeric regions. The synthesis of these regions may occur in such a way that the chromomeres of the chromatid of a homologue get connected of the chromatid of the other homologue at a specific location. As a result, the adjacent chromatids of a pair of homologue are exchanged.

(ii) **Precocity hypothesis :** According to *Darlington,* the pairing of homologues occurs to avoid singleness of a chromosome. The pairing need of a chromosome could be nothing less than the replication of DNA. The crossing over takes place due to torsion on chromosome created by coiling of the two homologues around each other.

In fact, the crossing over is the event which, precisely at molecular level, results in the formation of a hybrid DNA molecule. Such models have been proposed by White house, 1963 as also by Holliday, 1964. These models mainly elaborate the mechanism of breakage and reunion of DNA helicase.

(4) **Cross over value :** The percentage of crossing over varies in different materials. The frequency of crossing over is dependent upon the distance of two genes present on a chromatid.

(5) **Coincidence :** Coincidence or coefficient of coincidence is inverse measure of interface and is expressed as the ratio between the actual number of double cross over and the expected number of such double cross. That is:

$$\text{Coincidenc e} = \frac{\text{Actual number of double cross over}}{\text{Expected number of double cross over}}$$

(6) **Factors controlling frequency of crossing over :** Primarily, frequency of crossing over is dependent upon the distance between the linked genes, but a number of genetic, environmental and physiological factors also affect it. These are:

(i) **Temperature :** High and low temperature increase the frequency of crossing over.

(ii) **X-ray :** Muller has discovered that exposure to X-ray and other radiations increases the frequency of crossing over.

(iii) **Age :** The frequency of crossing over decreases with increasing age in female *Drosophila*.

(iv) **Chemicals :** Certain chemicals which act as mutagens do affect the frequency of crossing over. Gene mutations may affect the frequency of crossing over. Some increase the frequency, whereas some may decrease it.

(v) **Sex :** Crossing over in *Drosophila* males is negligible. Males of mammals also exhibit little crossing over. In silk-moth, crossing over does not occur in females.

(vi) **Chiasmata formation :** Chiasmata formation at one point discourages chiasmata formation and crossing over in the vicinity. This phenomenon is known as interference.

(vii) **Inversions :** Inversions of chromosome segments suppresses crossing over.

(viii) **Distance :** Distance between the linked genes is the major factor which controls the frequency of crossing over. The chances of crossing over between distantly placed genes are much more than between the genes located in close proximity.

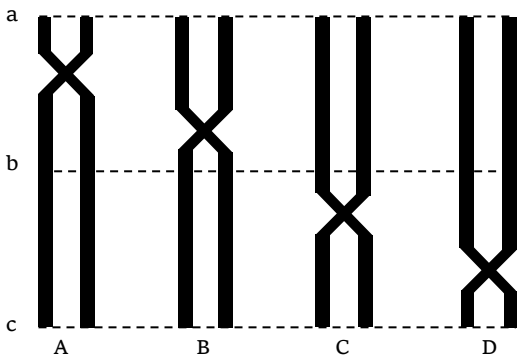


Fig : Diagram showing possibilities of crossing over between genes at different distances

Figure depicts that chance of crossing over between **a** and **c** are double as compared to the chances between **a** and **b** or **b** and **c**.

(ix) **Cytoplasm :** Factor for crossing over is present in cytoplasm and is inherited to the offspring.

(x) **Nutritional effect :** Crossing over frequencies are affected by concentration of metallic ions, such as calcium and magnesium.

(xi) **Genotypic effect :** Crossing over frequencies between the same two loci in different strains of the same species show variation because of numerous gene differences.

(xii) **Chromosome structure effect :** Changes in the order of genes on a chromosome produced by chromosomal aberrations usually act as cross over suppressors.

(xiii) **Centromere effect :** Genes present close to the centromere region show reduced crossing over.

(xiv) **Interference :** If there are two doubles crossovers, then one crossover tries to influence the other by suppressing it. This phenomenon is called as interference. Due to this phenomenon, the frequency of crossing over is always lower than the expected.

(7) **Significance of crossing over :** This phenomenon is of great biological significance, which are as under:

(i) It gives evidence that the genes are linearly arranged on a chromosome. Thus, it throws light on the nature and working of the genes.

(ii) It provides an operational definition to a gene. It is deemed as the smallest heritable segment of a chromosome in the interior of which no crossing over takes place.

(iii) The crossing over is helpful in the chromosomal mapping. The percentage of crossing over is proportional to the distance between two genes.

(iv) It is the main cause of genetic variations. It's occurrence during the act of meiosis produces variations in the heritable characters of the gametes.

(v) This phenomenon has also found it's utility in breeding and evolving new varieties. The linkage of undesirable characters can be broken by temperature treatment, using X-ray or chemicals. Thus, new recombinants can be prepared.

Important Tips

- Separation of a chromosome segment and its union to non-homologous chromosomes is called illegitimate crossing over.
- Two genes situated very close on the chromosome show hardly any crossing over.
- The most acceptable theory to explain crossing over is of Muller.
- Genes of Antibiotic resistance on bacteria are located on plasmid.
- Barr and Bertram (1949) discovered barr body in nerve cell of female cats. Later found in cells of human females
- Study of phenotype to DNA sequence in gene come under **forward genetics**.
- First chromosomal map of a plant was of maize, it was prepared by **Emerson**.
- Plotting of specific genes of the chromosomes is chromosomes map, linkage map, genetic map.
- The most important use in producing transgenic plants and animals is of **Reverse genetics**.
- $tt \times tt \rightarrow Tt$, This type of inheritance is an example of **de-novo mutation**.
- Hugo de Vries worked on evening primrose in preparation of mutation theory.
- **E. coil** is an important material for genetic experiment because it is haploid in nature and also easilly cultured**.**
- The percentage of individuals with a given genotype exhibiting, the phenotype associated genotype is known as penetrance.

2.11 Chromosomal maps

On the basis of the following information, chromosomal maps have been prepared.

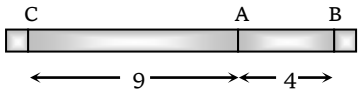
(1) The genes are linearly arranged on a chromosome and therefore, the gene order should be known.

(2) The percentage of crossing over between two genes is directly proportional to their distance. It is infact the index of their distance. The unit of crossing over has been termed as by *Haldane* as *centi Morgan* **(cM)**. One unit of map distance (cM) is therefore, equivalent to 1% crossing over. When chiasma is organised in between two gene loci, only 50% meiotic products shall be crossovers and 50% non-crossovers. Thus, the chiasma frequency is twice the frequency of cross over products *i.e.*, chiasma % = 2 (cross over %) or crossover %= ½ (chiasma %).

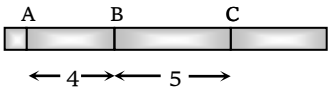
(3) Accordingly, *Sturtevant*, 1911 prepared the first chromosomal map. Infact this map is a line representation of a chromosome where the location of genes has been plotted as points at specific distances. These distances are proportional to their crossing over percentage. Suppose there are three genes on a chromosome say, **A B** and **C** which could be arranged as A, B, C; A, C, B or B, A, C. A three point test cross confirms as to which gene is located in the centre. By determining the crossing over value between A and B, B and C as also between A and C, the linkage maps can be prepared. Broadly speaking, a chromosomal map can be prepared from the following results of crossing over between the genes A, B and C:

(i) 4% crossing over taking place between A and B. (ii) 9% crossing over taking place between A and C.

Hence the genes be located as above and there should be 13% crossing over between B and C and the genes may be arranged as under:



If there is 5% crossing over between **B** and **C**, the genes are arranged in the following manner and there should be 9% crossing over between **A** and **C**.



(4) **Uses of chromosomal map**

(i) Finding exact location of gene on chromosomes.

(ii) Knowing recombination of various genes in a linkage group of chromosomes.

(iii) Predicting result of dihybrid and trihybrid cross.

2.12 NUCLEIC ACIDS

Two types of nucleic acids are found in the cells of all living organisms. These are DNA (Deoxyribonucleic acid) and RNA (Ribonucleic acid). The nucleic acid was first isolated by *Friedrich Miescher* in 1868 from the nuclei of pus cells and was named *nuclein.* The term nuclein was given by *Altman.*

DNA (Deoxyribonucleic Acid)

Introduction : Term was given by *Zacharis,* which is found in the cells of all living organisms except plant viruses,where RNA forms the genetic material and DNA is absent. In bacteriophages and viruses there is a single molecule of DNA, which remains coiled and is enclosed in the protein coat. In bacteria, mitochondria, plastids and other prokaryotes, DNA is circular and lies naked in the cytoplasm but in eukaryotes it is found in nucleus and known as carrier of genetic information and capable of self replication. Isolation and purification of specific DNA segment from a living organism achieved by *Nirenberg H.Harries* is associated with DNA-RNA hybridization technique.

(1) **Chemical composition :** The chemical analysis has shown that DNA is composed of three different types of compound.

(i) **Sugar molecule :** Represented by a pentose sugar the deoxyribose or 2-deoxyribose which derived from ribose due to the deletion of oxygen from the second carbon.

(ii) **Phosphoric acid :** H_3PO_4 that makes DNA acidic in nature.

(iii) **Nitrogeneous base :** These are nitrogen containing ring compound**.** Which classified into two groups:

(a) **Purines :** Two ring compound namely as **Adenine** and **Guanine.**

(b) **Pyramidine :** One ring compound included Cytosine and Thymine in RNA uracil is present instead of Thymine.

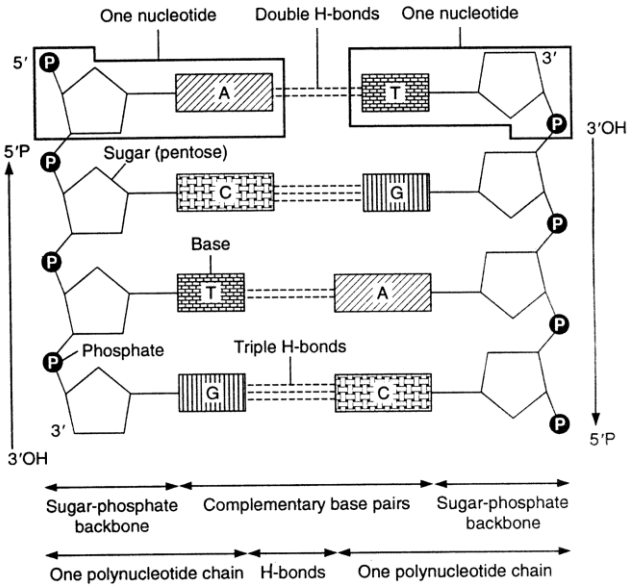


Fig : Diagrammatic representation of Watson's and Crick's modal of DNA

Nucleosides : Nucleosides are formed by a purine or pyrimidine nitrogenous base and pentose sugar. DNA nucleosides are known as deoxyribosenucleosides.

Nucleotides : In a nucleotide, purine or pyrimidine nitrogenous base is joined by deoxyribose pentose sugar (D), which is further linked with phosphate (P) group to form nucleotides.

Composition of nucleoside and nucleotides of DNA and RNA

(D= Deoxyribose sugar, R = Ribose sugar, P = Phosphoric acid)

Base with its symbol	Nucleoside		Nucleotide	
	Formula	**Name**	**Formula**	**Name**
DNA Adenine = A	D – A	Deoxyandenosine	$\begin{matrix} D-A \\ \vert \\ P \end{matrix}$	Deoxyandenosine monophosphate or Adenine deoxyribose nucleotide
Guanine = G	D – G	Deoxyguanine	$\begin{matrix} D-G \\ \vert \\ P \end{matrix}$	Deoxygunine monophosphate or Guanine deoxyribose-nucleotide
Thyamine = T	D – T	Thymidine	$\begin{matrix} D-T \\ \vert \\ P \end{matrix}$	Thymidine monophosphate or Thymidine nucleotide
Cytosine = C	D – C	Deoxycitidine	$\begin{matrix} D-C \\ \vert \\ P \end{matrix}$	Deoxycytidine monophosphate or Cytosine deoxyribose nucleotide
RNA Adenine = A	R – A	Adenoside	$\begin{matrix} R-A \\ \vert \\ P \end{matrix}$	Adenosine monophosphate or Adenine ribose nucleotide
Guanine = G	R – G	Guanosine	$\begin{matrix} R-G \\ \vert \\ P \end{matrix}$	Guanosine monophosphate or Guanine ribose nucleotide
Uracil = U	R – U	Uridine	$\begin{matrix} R-U \\ \vert \\ P \end{matrix}$	Uridine monophosphate or Uracil ribose nucleotide

Cytosine = C	R – C	Cytidine	$\begin{matrix} R-C \\ \vert \\ P \end{matrix}$	Cytidine monophosphate or Cytosine ribose nucleotide

(2) **Watson and Crick's model of DNA :** In 1953 Watson and Crick suggested that in a DNA molecule there are two such polynucleotide chains arranged antiparallal or is opposite directions i.e. one polynucleotide chain runs in $5' \rightarrow 3'$ direction, the other in $3' \rightarrow 5'$ direction. It means the $3'$ end of one chain lies beside the $5'$ end of other in right handed manner.

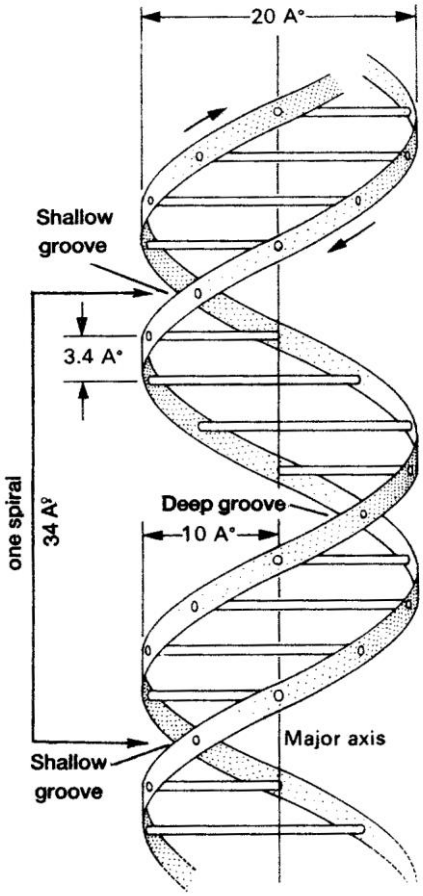


Fig : Helical structure of DNA as suggested by Watson and Crick

(i) **Important features of Watson and Crick double helical model of DNA**

There are important features of DNA double helix.

(a) The double helix comprises of two polynucleotide chains.

(b) The two strands (polynucleotide chains) of double helix are anti-parallel due to phosphodiester bond.

(c) Each polynucleotide chain has a sugar-phosphate 'backbone' with nitrogeneous bases directed inside the helix.

(d) The nitrogenous bases of two antiparallel polynucleotide strands are linked through hydrogen bonds. There are two hydrogen bonds between **A** and **T,** and three between **G** and **C.** The hydrogen bonds are the only attractive forces between the two polynucleotides of double helix. These serve to hold the structure together.

(e) The two polynucleotides in a double helix are complementary. The sequence of nitrogenous bases in one determines the sequence of the nitrogenous bases in the other. Complementary base pairing is of fundamental importance in molecular genetics.

(f) **Erwin Chargaff** (1950) made quantitative analysis of DNA and proposed *"base equivalence rule"* starting that molar concentration of A = T & G ≡ C or $\frac{A+G}{C+T}=1 \& \frac{A+T}{G+C}$ which is constant for a species.

(g) Ten base pairs occur per turn of helix (abbreviated 10bp). The spacing between adjacent base pairs is 10Å. The helix is 20Å in diameter and DNA molecule found 360° in a clockwise.

(3) **Forms of DNA :** Five different morphological forms of DNA double helix have been described. These are A, B, C, D and Z forms. Most of these forms (except B, and Z) occur in rigidly controlled experimental conditions. Watson and crick model represents commonest form, Biotic-form (B-form or B-DNA) of DNA. Some DNA forms are inter convertible also. The differences in these DNA forms are associated with:

(i) The numbers of base pairs, present in each turn of DNA helix.

(ii) The pitch or angle between each base pair.

(iii) The helical diameter of DNA molecule.

(iv) The handedness of double helix. Which is mentioned in table.

Comparison of different types of DNA

Characters	*A*-DNA	*B*-DNA	*C*-DNA	*D*-DNA	*Z*-DNA
Base pair per turn of the helix	11	10	9.33	8	12
Tilt of pairs (γ) base	20.2^0	6.3^0	-7.8^0	-16.7^0	7 Å
Axial rise (h)	2.56 Å	3.37 Å	3.32 Å	3.03 Å	3.7 Å
Helical diameter	23 Å	20 Å	19 Å	-	18 Å
Handedness of the double helix	Right handed	Right handed	Right handed	Right handed	Left handed

(4) **Characteristics of DNA**

(i) **Denaturation or melting :** The phenomenon of separating of two strand of DNA molecule by breaking of hydrogen bond at the temp. 90^0C.

(ii) **Renaturation or annealing :** Separated strands reunite to form double helix molecule of DNA by cooling at the room temp. *i.e.* 25^0C.

These properties help to form hybrid from different DNA or with RNA.

(5) **Evidences of DNA as the genetic material :** The following experiments conducted by the molecular bioloigists provide direct evidences of **DNA** being the genetic material bacterial transformation, bacterial recombination and bacteriophage infection.

(i) **Bacterial transformation or Griffith's Experiments :** *Griffith* (1928) injected into mice with virulent and smooth (S-type, smooth colony with mucilage) form of *Diplococcus pneumoniae*. The mice died due to pneumonia. No death occurred when mice were injected with nonvirulent or rough (R-type, irregular colony without mucilage) form or heat- killed virulent form. However, in a combination of heat killed S-type and live R-type bacteria, death occurred in some mice. Autopsy of dead mice showed that they possessed S-type living bacteria, which could have been produced only by transformation of R-type bacteria. The transforming chemical was found out by *O.T.Avery, C.M. Mc. leod and M. Mc. Carty* (1944). They fractionated heat-killed S-type bacteria into DNA, carbohydrate and protein fractions. DNA was divided into two parts, one with DNAase and the other without it. Each component was added to different cultures of R-type bacteria. Transformation was found only in that culture which was provided with intact DNA of S-type. Therefore, the trait of virulence is present in DNA. Transformation involves transfer of a part of DNA from surrounding medium or dead bacteria (donor) to living bacteria (recipient) to form a recombinant.

(ii) **Evidence from genetic recombination in bacteria or bacterial conjugation :** *Lederberg* and *Tatum* (1946) discovered the genetic recombination in bacteria from two different strains through the process of conjugation. Bacterium *Escherichia coli* can grow in minimal culture medium containing minerals and sugar only. It can synthesize all the necessary vitamins from these raw materials. But its two mutant strains were found to lack the ability to synthesize some of the vitamins necessary for growth. These could not grow in the minimal medium till the particular vitamins were not supplied in the culture medium.

(a) **Mutant strain A :** It (used as male strain) had the genetic composition Met^- , Bio^-, Thr^+, Leu^+, Thi^+. It lacks the ability to manufacture vitamins methionine and biotin and can grow only in a culture medium which contains these vitamins in addition to sugar and minerals.

(b) **Mutant strain B :** It (used as female strain or recipient) has a genetic composition Me^{++}, Bio^+, Thr^-, Leu^-, Thi^-. It lacks the ability to manufacture threonine, leucine and thionine and can grow only when these vitamins are added to the growing medium.

These two strains of *E.coli* are, therefore, unable to grow in the minimal culture medium, when grow separately. But when a mixture of these two strains was allowed to grow in the same medium a number of colonies were formed. This indicates that the portion of donor DNA containing information to manufacture threonine, leucine and thionine had been transferred and incorporated in the recipient's genotype during conjugation.

This experiment of Lederberg and Tatum shown that the conjugation results in the transfer of genetic material DNA from one bacterium to other. During conjugation a cytoplasmic bridge is formed between two conjugating bacteria.

(iii) **Evidence from bacteriophage infection :** *Hershey* and *Chase* (1952) conducted their experiment on $\mathbf{T_2}$ *bacteriophage*, which attacks on *E.coli* bacterium. The phage particles were prepared by using radioisotopes of $^{35}\mathbf{S}$ and $^{32}\mathbf{P}$ in the following steps.

(a) Few bacteriophages were grown in bacteria containing ^{35}S. Which was incorporated into the cystein and methionine amino acids of proteins and thus these amino acids with ^{35} S formed the proteins of phage.

(b) Some other bacteriophages were grown in bacteria having ^{32}P. Which was restricted to DNA of phage particles. These two radioactive phage preparations (one with radioactive proteins and another with radioactive DNA) were allowed to infect the culture of *E.coli.* The protein coats were separated from the bacterial cell walls by shaking and centrifugation.

The heavier infected bacterial cells during centrifugation pelleted to bottom. The supernatant had the lighter phage particles and other components that failed to infect bacteria. It was observed that bacteriophages with radioactive DNA gave rise to radioactive pellets with ^{32} P in DNA. However in the phage particles with radioactive protein (with ^{35} S) the bacterial pellets have almost nil radioactivity indicating that proteins have failed to migrate into bacterial cell. So, it can be safely concluded that during infection by bacteriophage T_2, it was **DNA,** which entered the bacteria. It was followed by an

eclipse period during which phage DNA replicates numerous times within the bacterial cell. Towards the end of eclipse period phage DNA directs the production of protein coats assembly of newly formed phage particles. Lysozyme (an enzyme) brings about the lysis of host cell and release, the newly formed bacteriophages. The above experiment clearly suggests that it is phage DNA and not protein, which contains the genetic information for the production of new bacteriophages. However, in some plant viruses (like TMV), RNA acts as hereditary material (being DNA absent).

(6) **DNA replication :** *Watson* and *Crick* suggested a very simple mechanism of DNA replication or DNA transcription on the basis of its double helical structure. During replication the weak *hydrogen bonds* between the nitrogeneous bases of the nucleotides separate so that the two polynucleotide chains of DNA also separate and uncoil. The chains thus separated are complementary to one another. Because of the specificity of base pairing, each nucleotide of separated chains attracts it complementary nucleotide from the cell cytoplasm. Once the nucleotides are attached by their hydrogen bonds, their sugar radicals unite through their phosphate components, completing the formation of a new polynucleotide chain.

The method of DNA replication is semi-discontinuous and described as *semi-conservative method,* because each daughter DNA molecule is a hybrid conserving one parental polynucleotide chain and the other one newly synthesized strand. DNA replication occur in *S-phage* in cell cycle.

(i) **Mechanism of DNA replication**

The entire process of DNA replication involves following steps in *E.coli.*

(a) **Recognition of the initiation point :** First, DNA helix unwind by the enzyme "Helicase" which use the energy of ATP and replication of DNA begin at a specific point, called initiation point or origin where replication fork begins.

(b) **Unwinding of DNA :** The unwinding proteins bind to the nicked strand of the duplex and separat the two strands at DNA duplex. Topoisomerase (Gyrase is a type of topoisomerase in *E.coli)* helps in unwinding of DNA.

(c) **Single stranded binding protein (SSB) :** Which remain DNA in single stranded position and also known as helix destabilising protein (HDP).

(d) **RNA Priming :** The DNA directed RNA polymerase now synthesizes the primer strands of RNA **(RNA primer).** The priming RNA strands are complementary to the two strands of DNA and are formed of 50 to 100 nucleotides.

(e) **Formation of DNA on RNA primers :** The new strands of DNA are formed in the $5' \rightarrow 3'$ direction from the $3' \rightarrow 5'$ template DNA by the addition of deoxyribonucleotides to the $3'$ end of primer RNA.

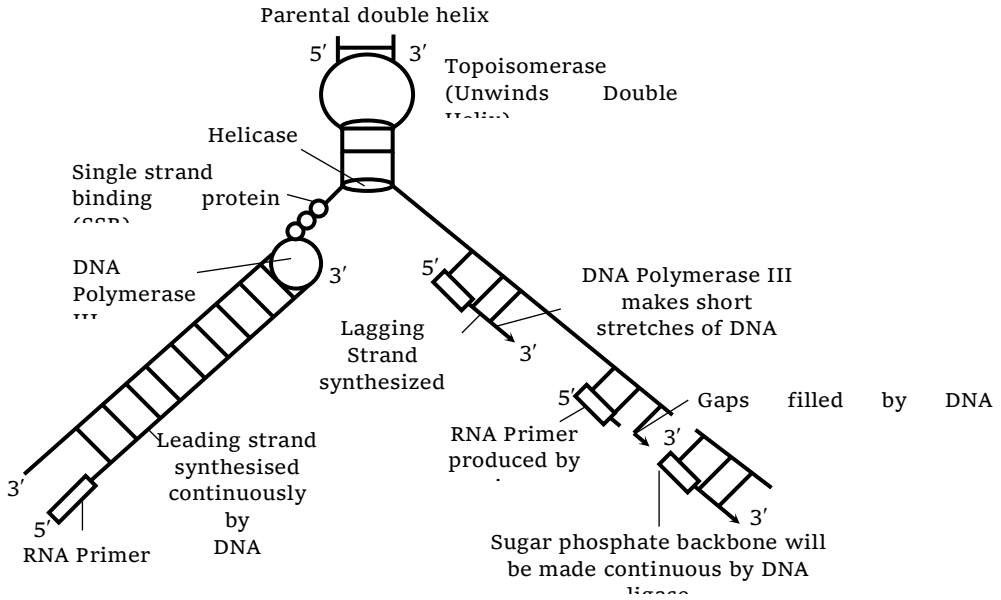


Fig : Showing continuous replication of a daughter DNA strand on leading strand and discontinuous

Addition of nucleotide is done by DNA polymerase III. The leading strand of DNA is synthesized continuously in $5' \rightarrow 3'$ direction as one piece. The lagging strand of DNA is synthesized discontinuously in its opposite direction in short segments. These segments are called *Okazaki fragments*.

(f) **Excision of RNA primers :** Once a small segment of an okazaki fragment has been formed. The RNA primers are removed from the $5'$ by the action of $5' \rightarrow 3'$ exonuclease activity of DNA polymerase I.

(g) **Joining of okazaki fragments :** The gaps left between Okazaki fragments are filled with complimentary deoxyribonucleotide residues by DNA polymerase-I. Finally, the adjacent $5'$ and $3'$ ends are joined by **DNA** ligase.

(ii) **DNA polymerase enzymes :** There are three DNA polymerase enzymes that participate in the process of DNA replication.

(a) **DNA polymerase-I :** This enzyme has been studied in E. coli in detail. It possesses a sulphydryl group, single interchain disulphide and one zinc molecule at the active site. DNA polymerase-I was discovered by *Kornberg* and his colleagues in 1955. It was considered to carry out DNA replication and also participates in the *repair* and *proof reading* of DNA by catalyzing the addition of mononucleotide units (the deoxyribonucleotide residues) to the free $3'$ -hydroxyl end of DNA chain. A pure DNA polymerase-I can add about 1,000 nucleotide residues per minute per molecule and catalyses $5' \rightarrow 3'$ exonuclease activity and removes nucleotide residues of primer RNA at $3'$.

(b) **DNA polymerase-II :** The biological role of polymerase II is not yet known.

(c) **DNA polymerase-III :** This enzyme was discovered by *T. Kornberg* and *M.L. Gefter* (1972). It is the most active enzyme and responsible for DNA *chain elongation.*

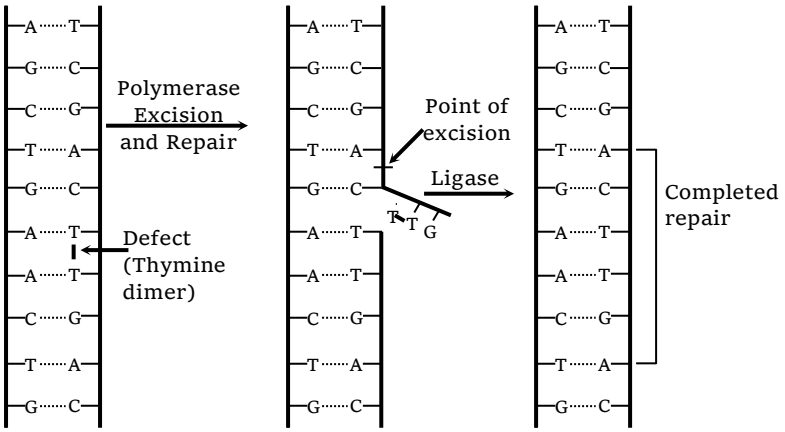


Fig : Repair of ultraviolet-induced thymine dimer which prevents replication

(iii) **DNA repair :** When DNA damaged by mutagen, a system is activate to repair damage DNA. Say for example UV light induced thymidine dimers in DNA and repair mechanism of that DNA called photoreactivation. Many enzyme involved in repair mechanism in which *endonuclease* (Chemical knives) cut the defective part of DNA then gap is filled with DNA polymerase I and finally DNA ligase seals that repaired part.

(iv) **Evidence in support of semiconservative mode of DNA replication (Meselson and Stahl's experiment) :** Meselson and Stahl (1958) cultured (Escherichia coli) bacteria in a culture medium containing $\mathbf{N^{15}}$ were isotopes of nitrogen. After these had replicated for a few generations in that medium both the strands of their DNA contained $\mathbf{N^{15}}$ as constituents of purines and pyrimidines. When these bacteria with $\mathbf{N^{15}}$ were transferred in cultural medium containing $\mathbf{N^{14}}$**,** it was found that DNA separated from fresh generation of bacteria possesses one strand heavier than the other. The heavier strand represents the parental strand and lighter one is the new one synthesized from the culture indicating semiconservative mode of DNA replication. circular form of replication on as characteristic of prokaryotes is *theta* replication discovered by *J. Cairns.*

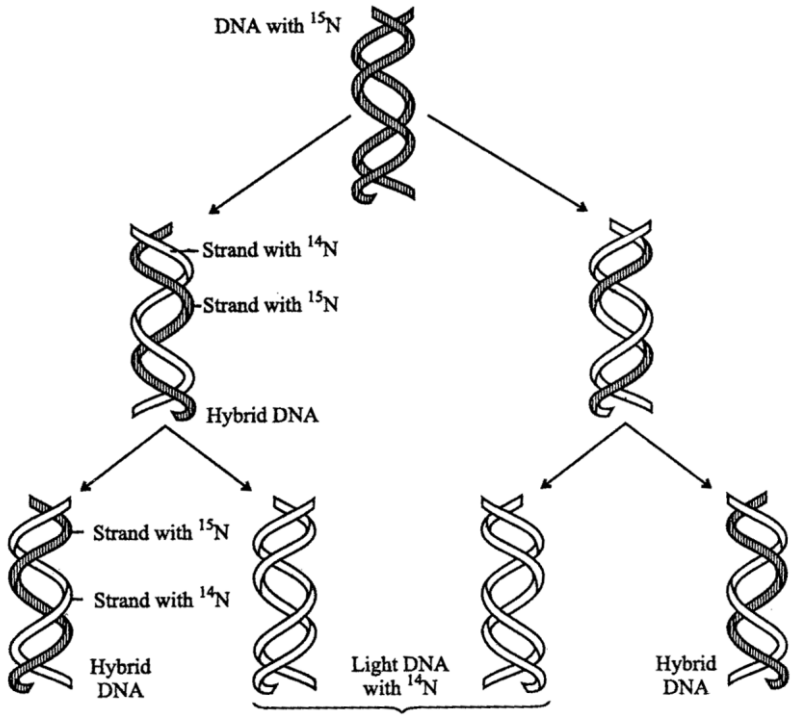


Fig : Second generation daughter molecules after DNA

Important Tips

- The contribution of cytoplasmic DNA to total DNA in a cell is 1-5%.
- **M.H.F. Wilkins** and his associates supported DNA double helical structure using x-ray crystallography technique.
- Fuelgen technique used to identify the location of DNA in a cell as described by Fuelgen.
- F. Sanger determined base sequence in nucleic acid and synthesise of protein invitro.
- Fisher discovered purine and pyamidine bases in DNA
- Phosphoric acid found to be constituent of DNA by Levene (1910).
- **DNA Polymerase–III** performs the function of proof reading in which a wrong segment can be corrected by nicking with endonuclease, synthesis of a new correct segment by DNA polymerase –I and sealing by DNA ligase.
- Repetitive DNA or DNA finger print or satellite DNA consist 16-64 times repeated nitrogen bases in tandem and found only in eukaryotes near the centromere which have unique sequence for every organism.
- **Repetitive DNA or Satelite DNA** It is found in eukaryotes only.
- **Palindromic DNA** are inverted repetitions of bases in double stranded DNA $5' \xrightarrow[ATCGAT]{} 3'$; $3' \xleftarrow[TAGCTA]{} 5'$
- The pattern of protein binding on DNA can be studied by X-ray crystallography.
- Rich et-al discovered a new form of DNA in 1979 having a zig zag sugar-phasphate back bone. This is called Z-DNA. It differs from B-DNA in many characteris like helical sense.
- The phosphodiester bond of a polynucleotide chain can be broken by nuclease. They may remove the terminal nucleotides (Exonuclease) or break the internal bonds (Endonuclease). The restriction enzymes are those endonucleases, which breaks off specific bonds.
- Rodely, sasisekharan independently proposed a new model for DNA called as right – left handed helix or side by side (SBS) model.
- The bond between 'N' atom of nitrogen base and 'C' atom of sugar in DNA is called glycosidic bond, between sugar and phosphate is called phosphodiester bond.
- Nucleotide ATP is always found free in cell.

RNA (Ribonucleic acid)

Introduction : RNA is found in the cytoplasm and nucleolus.Inside the cytoplasm it occurs freely as well as in the ribosomes. RNA can also be detected from mitochondria, chloroplasts and associated with the eukaryotic chromosomes. In some plant viruses RNA acts as hereditary material.

(1) **Structure of RNA :** More commonly RNA is a single stranded structure consisting of an unbranched polynucleotide chain, but it is often folded back on itself forming helices. DNA is a double

stranded structure and its two polynucleotide chains are bounded spirally around a main axis. It is made up by:

(i) **Sugar :** Ribose

(ii) **Phosphate :** In the form of H_3PO_4.

(iii) **Nitrogenous base :** Two types: (a) Purine, (b) Pyramidine

(a) **Purine** is further divided into *Adenine* and *Guanine.*

(b) **Pyramidin** divided into *Cytosine* and *Uracil.*

(2) **Types of RNA :** RNA can be classified into two types.

(i) **Genetic RNA :** Which established by *Conrat.* In most of the plant viruses, some animal viruses and in many bacteriophages DNA is not found and RNA acts as hereditary material. This RNA may be single stranded or double stranded.

(ii) **Nongenetic RNA :** In the all other organisms where DNA is the hereditary material, different types of RNA are nongenetic. The nongenetic RNA is synthesized from DNA template. In general, three types of RNAs have been distinguished:

(a) Messenger RNA or nuclear RNA (mRNA) (b) Ribosomal RNA (rRNA) (c) Transfer RNA (tRNA)

(a) **Messenger RNA or Nuclear RNA :** mRNA is a polymer of ribo-nucleotide as a complementary strand to DNA and carries genetic information in cytoplasm for the synthesis of proteins. For this reason only, it was named messenger RNA (mRNA) by *Jacob* and *Monod* is 5% of total RNA. It acts as a template for protein synthesis and has a short life span.

(b) **Ribosomal RNA :** rRNA constitutes redundant nature upto 80% of total RNA of the cell. It occurs in ribosomes, which are nucleoprotein molecules.

Types of rRNA : Inside the ribosomes of eukaryotic cells rRNA occurs in the form of the particles of three different dimensions. These are designated 28S, 18S, and 5S. The 28S and 5S molecules occur in large subunit (60S subunit) of ribosome, whereas 18S molecules is present in the small subunit (40S subunit) of ribosome. In prokaryotic cells there are only 23S and 16S rRNA are found. Which are synthesized in Nucleolus / SAT region.

(c) **Transfer RNA (tRNA) :** The transfer RNA is a family of about 60 small sized ribonucleic acids which can recognize the codons of mRNA and exhibit high affinity for 21 activated amino acids, combine with them and carry them to the site of protein synthesis. RNA molecules have been variously termed as soluble **RNA** or *supernatant* **RNA** or adapter RNA. It is about 0-15% of RNA of the cell. tRNA molecules are smallest, containing 75 to 80 nucleotides. The **3′** end of the polynucleotide chain ends in **CCA** base sequence. This represents site for the attachment of activated amino acid. The end of the chain terminates with guanine base. The bent in the chain of each tRNA molecule contains a

definite sequence of three nitrogenous bases, which constitute the anticodon. It recognizes the codon on mRNA.

Four different region or special sites can be recognised in the molecule of tRNA.These are :

Amino acid attachement site : It occurs at the 3′ end of tRNA chain and has OH group combines with specific amino acid in the presence of ATP forming amino acyl tRNA.

Site for activating enzymes : Dihydrouridine or DHU loop dictate activation of enzymes.

Anticodon or codon recognition site : This site has three unpaired bases (triplet of base) whose sequence is complementary with a codon in mRNA.

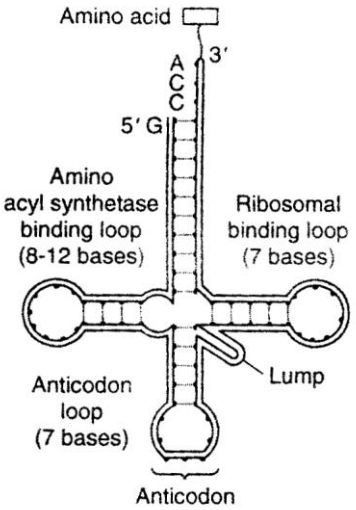


Fig : Clover leaf model of t-RNA structure

Ribosome recognition site ($T_\Psi C$) : This helps in the attachment of tRNA to the ribosome.

Important Tips

- RNA is single stranded but it is double stranded in **reovirus** and **wound tumour plant** and **Rice dwarf Virus.**
- Viroids differ from virus is naked RNA molecule.
- Virus particle can not be observed the stage of infection is eclipse phase.
- 5 Bromouracil is a base analogue.
- Purines in RNA are **uracil** and **Cytosin**.
- CCA base sequence is present in 3′ end of tRNA.
- Anticodons are found in tRNA.
- Non-genetic RNA are of three types. These are tRNA, mRNA and rRNA.
- Ribosomal RNA is synthesised in nucleolus of eukaryotic cells.
- In vitro synthesis of **DNA, RNA** and **Gene** were done by Korenberg, Ochoa and Khorana respectively..
- Overlapping genes reported in $\Phi \times 174$ by **Linney et.al.**(1972) these genes (E.B.K.) also occur in **SV-40.**
- **Ribozyme :** RNA acts as an enzyme having catalytic activity, discovered by **Altman** & **Cock.**

2.13 Genetic code

Introduction : Defined as structure of nitrogen bases(nucleotides) in mRNA molecule which contain the information for the synthesis of protein molecule. It is discovered by frame shift mutation by Crick.

Codon is the sequence of nitrogen bases (nucleotides) in mRNA, which codes for a single amino acid. *Nirenberg* and *Mathaei* (1961) experimentally proved that a single amino acid is determined by a sequence of three nitrogen bases which is known as triplet code. Khorana has got *Nobel prize* on genetic code.

The Genetic Code Dictionary

First Letter	Second Letter U	Second Letter C	Second Letter A	Second Letter G	Third Letter
U	UUU Phenylalanine UUC UUA Leucine UUG	UCU UCC Serine UCA UCG	UAU Tyrosine UAC UAA Ochre (Terminator) UAG Amber (Terminator)	UGU Cystine UGC UGA Opal (Terminator) Tryptophan UGG	U C A G
C	CUU Leucine CUC CUA CUG Isoleucine	CCU Proline CCC CCA CCG Threonine	CAU Histidine CAC Glutamine CAA CAG Asparagine	CGU Arginine CGC CGA CGG Serine	U C A G
A	AUU Methionine AUC AUA AUG Valine	ACU ACC ACA ACG Alanine	AAU Lysine AAC AAA Aspartic AAG Glutamic	AGU Arginine AGC AGA AGG Glycine	U C A G
G	GUU GUC GUA GUG	GCU GCC GCA GCG	GAU GAC GAA GAG	GGU GGC GGA GGG	U C A G

Salient Features

(i) **Triplet :** A single amino acid is specified by a sequence of three nucleotides in mRNA *i.e.* called codon. Due to triplet nature, it consist 64 codon.

(ii) **Universal :** A codon specifies the same amino acid in all organisms from viruses to human beings.

(iii) **Commaless :** There is no pause, so it reads continously.

(iv) **Non-overlapping :** No overlapping between adjacent nucleotide.

(v) **Initiation codon :** The synthesis of polypeptide chain initiated by initiation codon, which located beginning the cistron *i.e.,* AUG or GUG, which codes to *methionine* and *valine* amino acid respectively.

(vi) **Termination codon :** Termination is done by codon. These are **UAA, UGA** or **UAG** which does not code to any amino acid. These are also called nonsense codon.

(vii) **Degeneracy :** A single amino acid may be specified by many codon *i.e.,* called degeneracy. Degeneracy is due to the last base in codon, which is known as *wobble base.* Thus first two codon are more important to determining the amino acid and third one is differ without affecting the coding *i.e.,* known *wobble hypothesis,* which establishes a economy of tRNA molecule and put forwarded by *Crick.* Degeneracy of genetic code was discovered by *Berrfield* and *Nirenberg.*

Important Tips

- **George Gamow (1954)** first propose triplet code and given the term genetic code also proposed diamond code model.
- Different genetic code – in yeast mitochondria, **UGA** represent **tryptophan** while generally it is stop single. In certain ciliates **UAA** and **UAG** represent **Guanine**, Mitochondria DNA has genes for 22 tRNA (instead of 35 in universal code).
- Khorana synthesized gene of **tyrosine** suppressor tRNA gene of E.Coli in 1979, which contained 207 nucleotide pairs functional.
- First artificially gene synthesized **Alanine tRNA** with **77** base pairs by **Hargovind Khorana** non-functional.
- Protein language is composed of **20 alphabets.**

2.14 Central Dogma

Central dogma of molecular biology proposes a unidirectional or one way flow of information from DNA to RNA (transcription) and from RNA to protein (translation). The concept was given by *Watson* and *Crick.*

$$\text{DNA} \xrightarrow{\text{Transcription}} \text{mRNA} \xrightarrow{\text{Translation}} \text{Protein}$$

As mentioned above the first step of central dogma is transcription (synthesis of mRNA from DNA), but in case of reverse transcription DNA is synthesizes from RNA in retrovirus. That concept is given by *Temin* and *Baltimore* in Rous sarcoma virus, also known as *teminism* and enzyme catalyze this reaction is reverse trancriptase or RNA dependent DNA polymerase.

$$\text{DNA} \underset{\text{Reverse Transcription}}{\overset{\text{Transcription}}{\rightleftarrows}} \text{RNA} \longrightarrow \text{Protein}$$

2.15 TRANSCRIPTION

Formation of mRNA from DNA is called as Transcription. It is heterocatalytic function of DNA. Template of DNA called sense strand (Master Strand) is involved. The segment of DNA involved in transcriptions is cistron, which have a promoter region where initiation is start and terminator region where transcription ends. Enzyme involved in transcription is *RNA polymerase-II*. Which consist five polypeptide $\alpha, \beta, \beta', \omega$ (constitute core enzyme) and σ (sigma factor). Sigma (σ) factor recognise promoter site while remaining core enzyme takes part in chain elongation. After transcription, DNA molecule reassociates to form its original structure. In eukaryotes *hn* RNA (heterogenous nuclear RNA) which consist exon (coded region) and introns (non coded region or intervening sequences) formed in nucleus and diffuse in cytoplasm is also known as split gene which goes to transcription changes for removing the introns and later formed mRNA.

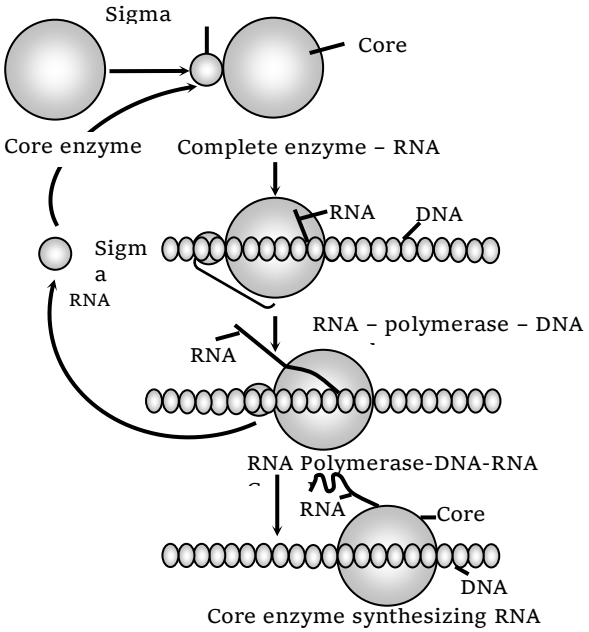


Fig : Role of sigma and core enzyme of RNA polymerase enzyme during transcription

It consist three phenomenon: –

(1) **Initiation :** Initiation start with help of σ (*sigma*) factor of RNA polymerase enzyme. At the cap region which have 7 methyl guanosine residue at the $5'$.

(2) **Elongation :** Elongation is done by *core enzyme*, which moves along the sense strand.

(3) **Termination :** In *prokaryotes* termination is done by *rho* (ρ) factor while in *eukaryotes poly* **A** tail is responsible for termination at the $3'$.

Important Tips

- Central dogma of modern genetics RNA $\rightarrow$DNA$\rightarrow$RNA$\rightarrow$protein.
- Circular flow of information $\rightarrow$DNA$\rightarrow$ RNA$\rightarrow$Protein$\rightarrow$RNA$\rightarrow$ DNA (commoner)
- Eukaryotic mRNA can be modified by the addition (at their $5'$ end) of **methylated argenine.**
- Actinomycin D prevents **transcription.**
- In eukaryotes three types of RNA polymerase are found which synthesizes different RNAs as RNA polymerase I, II & III formed rRNA, mRNA, & tRNA respectively in nucleolus, nucleoplasm.
- The terms cistron, recon and muton were proposed by **S. Benzer.**
- The transcription of genes increased by **Glucocorticoid.**

- When a particular gene codes for a m-RNA strand, it is said to be monocistronic or monogenic. When several genes (Cistrons) transcribe one m-RNA molecule it is called as polycistronic polygenic.
- **Informosomes :** In eukaryotes mRNA is associated with protein forming ribonucleoprotein complex. The name is given by **Spirin** and ratio of **protein** and **mRNA** is **4:1.**

2.16 Translation

Formation of protein from mRNA is called translation is also known as polypeptide synthesis or protein synthesis. It is unidirectional process. The ribosomes of a polyribosome are held together by a strand of mRNA. Each eukaryotic ribosome has two parts, smaller 40S subunit (30S in prokaryotes) and larger 60S subunit (50S in prokaryotes). Larger subunit has a groove for protection and passage of polypeptide, site A (acceptor or aminoacyl site), enzyme peptidyl transferase and a binding site for tRNA. The smaller subunit has a point for *attachment* of mRNA. Along with larger subunit, it forms a P-site or peptidyl transfer (donor site). There are binding sites for initiation factors, elongation factors, translocase, GTPase, etc. The raw materials for protein synthesis are amino acids.mRNA, tRNAs and amino acyl tRNA synthetases.

Amino acids : Twenty types of amino acids and amides constitute the *building blocks* of proteins.

mRNA : It carries the coded information for synthesis of one (unicistronic) or more polypeptides (polycistronic). Its codons are recognised by tRNAs.

tRNAs : They picks up specific amino acid from amino acid pool and carrying over the mRNA strand.

Amino Acyl tRNA Synthetases : The enzymes are specific for particular amino acids and their tRNAs.

(1) **Activation of Amino Acids :** An amino acid combines with its specific *aminoacyl* **tRNA** *synthetase* enzyme (AA-activating enzyme) in the presence of ATP to form aminoacyl adenylate enzyme complex (AA-AMP-E). Pyrophosphate is released. Amino acid present in the complex is *activated amino acid*. It can attach to CCA or 3′ end of its specific tRNA to form aminoacyl or AA-tRNA (*charged* tRNA */ adaptor molecule*)

Amino Acid (AA) + ATP + Aminoacyl tRNA Synthetase (E) $\rightarrow \underset{\text{amino acid adenylate enzyme complex}}{AA - AMP - E} + PPi$

AA-AMP-E + tRNA $\rightarrow$ AA—tRNA + AMP + Enzyme.

(2) **Initiation :** It is accomplished with the help of initiation factors. Prokaryotes have three initiation factors – IF_3, IF_2 and IF_1. Eukaryotes have nine initiation factors – eIF_1, eIF_2, eIF_3, eIF_{4A}, eIF_{4B}, eIF_{4C}, eIF_{4D}, eIF_5, eIF_6,,mRNA attaches itself to smaller subunit of ribosome with its cap coming in contact with 3′ end of 18 S rRNA (16S RNA in prokaryotes). It requires eIF_2 (IF_3 in prokaryotes). The initiation codon **AUG** or **GUG** comes to lie over P-site. It produces 40S – mRNA complex. P-site now attracts met tRNA (depending upon initiation codon). The anticodon of tRNA (UAC or AUG) comes to lie opposite initiation codon. Initiation factor **eIF_3 (*IF_2 in prokaryotes*)** and **GTP** are required. It gives rise to 40S-mRNA - $tRNA^{Met}$. Methionine is *nonformylated* ($tRNA_m^{Met}$) in *eukaryotic* cytoplasm and *formylated* ($tRNA_f^{Met}$) in case of *prokaryotes.* The larger subunit of ribosome now attaches to 40S-mRNA-$tRNA^{Met}$ complex to form 80S mRNA -tRNA complex. Initiation factors **eIF_1** and **eIF_4** (A, B and C) are required in *eukaryotes* and **IF_1** in *prokaryotes.* Mg^{2+} is essential for union of the two subunit of ribosomes. A-site becomes operational. Second codon of mRNA lies over it.

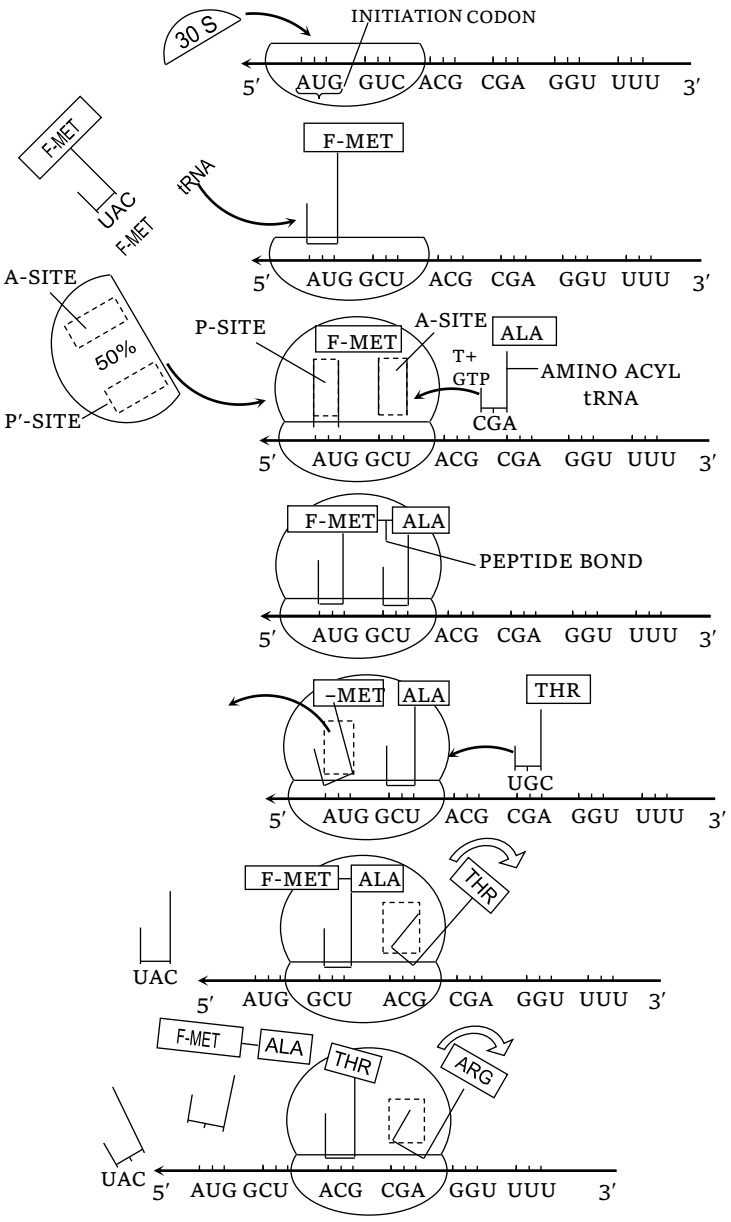


Fig : Diagramatic representation of protein synthesis in prokaryotes

(3) **Elongation/chain formation :** A new AA-tRNA comes to lie over the A site codon by means of **GTP** and elongation factor **(eEF_1** in *eukaryotes,* **EF-Tu** and **EF-Ts** in *prokaryotes*). Peptide bond (–CO.NH–) is established between carboxyl group (–COOH) of amino acid of P-site and amino group ($–NH_2$) of amino acid at A-site with the help of enzyme *peptidyl transferase/synthetase.*

Connection between tRNA and amino acid of P-site and A-site tRNA comes to bear a dipeptydl. Freed tRNA of P-site slips away. By means of *translocase* (**eEF_2** in *eukaryotes* and **EF-G** in *prokaryotes*) and **GTP**, ribosome moves in relation to mRNA so that peptidyl carrying tRNA comes to lie on P-site and a new codon is exposed at A-site.Incorporation of an amino acid in polypeptide chain thus requires one ATP and two GTP molecules. Peptide formation and translocation continue uninterrupted till the whole m-RNA code is translated into polypeptide. In a polyribosome, when a number of ribosomes are helping in translation of same mRNA code, the ribosome nearest the 5′ end of

mRNA carries the smallest polypeptide and the one towards the 3′ end the longest. Of course, ultimately the whole polypeptide is formed by each.

(4) **Termination :** Polypeptide synthesis stops when a nonsense or *termination codon* [UAA, (ochre), UAG (Amber) or UGA (opal)] reaches A-site. It does not attract any AA-tRNA, P-site tRNA seperates from its amino acid in the presence of release factor eRF_1 in *eukaryotes* ($RF_1$for UAG and UAA, RF_2 for UAA and UGA in prokaryotes). The completed polypeptide is released, mRNA and ribosome separate. The two subunits of ribosome also dissociate with the help of dissociation factor.

(5) **Modification :** Formylated methionine present at the beginning of polypeptide in prokaryotes and organelles is either deformylated (enzyme deformylase) or removed from chain (enzyme exopeptidase). Initially the polypeptide is elongated having only primary structure. As soon as the polypeptide comes out the groove of larger ribosome sub-unit, it forms α-helix (secondary structure) which coils further forming a number of linkages (tertiary structure). Two or more polypeptides may get associated to become β-pleated which then coil to produce tertiary and quaternary structure.

Important Tips

- **Garrod** has proposed that genes control production of enzymes.
- **UUU** was first triplet codon discovered.
- **GUG** is **ambiguous codon,** which code more than one amino acid.
- In free ribosomes the protein is released in cytoplasm while in membrane bound polyribosomes, it is released in endoplasmic reticulum.
- Polysome is funtional unit of protein synthesis.
- Gene control both heredity and protein synthesis.
- **Entrance protein** interact with initiation complex and increase the rate of RNA synthesis.
- Monocistronic mRNA has codon to synthesize only one protein molecule.
- One gene one polypeptide theory can be explained by alkaptonuria, phenylketonuria & sickle cell anaemia.
- Puromycin antibiotic inhibits **translation.**
- Gunter Blobel and David Sabatini proposed "Signal hypothesis" in 1971 for secretory type of proteins.

2.17 Genes expression and its regulation

(1) **Gene expression in prokaryotes :** Gene expression refers to the molecular mechainism by which a gene expresses a phenotype by synthesizing a protein or an enzyme. Which determines the character. The gene contains the blue print or the information for the protein or an enzyme.

The category includes mechanism involved in the rapid turn-on and turn-off gene expression in response to environmental changes. Regulatory mechanism of this type are very important in microorganisms, because of the frequent exposure of these organisms to sudden changes in environment.

Gene concept can be studied by operon model. Operon are segment of genetic material which function as regulated unit that can be switched on and switched off, which was given by French scientists. *Jacob* and *Monod* (1961) working at Pasteur institute. They were studying lactose utilisation in mutants of *E.coli.* An operon consists of one to several structural genes (three in lac operon and five in tryptophan operon of *Escherichia coli*, nine in histidine operon of *Salmonella typhimurium*), an operator gene a promoter gene a regulator gene, a repressor and inducer or corepressor. Operons are of two types, inducible and repressible.

(i) **Inducible operon system /lac operon system :** An inducible operon system is that regulated genetic material which remains switched off normally but becomes operational in the presence of an inducer. It occurs in *catabolic pathways*. The components are :–

(a) **Structural genes :** They are genes, which produce mRNAs for forming polypeptides/proteins/enzymes. Lac operon of *Escherichia coli* has three structural *genes*-**Z** (produces enzyme *β-galactosidase* for splitting lactose/galactoside in to glucose and galactose) **Y** (produces enzyme *galactoside permease* required in entry of lactose/galactoside) and **A** (produces enzyme *galactoside acetylase/transacetylase* without any function in *E.coli*). The three structural genes of lac operon produce a single polycistronic mRNA. The three enzymes are, however, produced in different concentration.

(b) **Operator gene :** It gives passage to RNA polymerase when the structural genes are to express themselves. Normally, it is covered by a repressor. Operator gene of lac operon is small, made of 27 base pairs.

(c) **Promoter gene :** It is recognition centre / initiation point for RNA polymerase of the operon.

(d) **Regulator gene (*i* Gene) :** It produces a repressor that binds to operator gene for keeping it nonfunctional (preventing RNA polymerase to pass from promoter to structural genes).

(e) **Repressor :** It is a small protein formed by regulator gene. Which binds to operator gene and blocks passage of RNA polymerase towards structural enzymes. Repressor has two allosteric sites, one for attaching to operator gene and second for binding to inducer. Repressor of lac operon has a molecular weight of 160,000 and 4 subunit of 40,000 each.

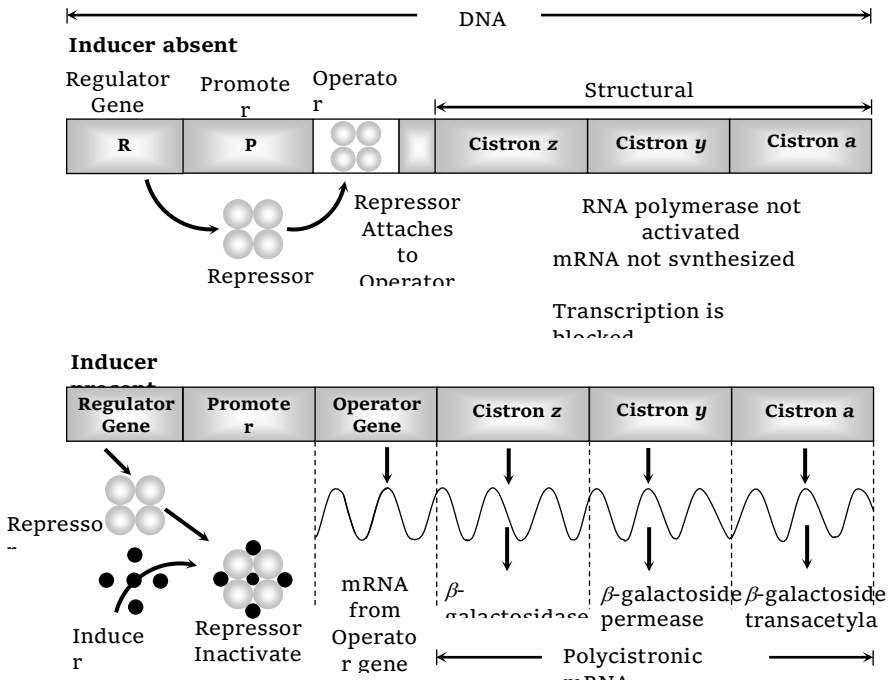


Fig : Diagram representing the function of lac operon in *Escherichia coli*

(f) **Inducer :** It is a chemical which attaches to repressor, changes the shape of operator binding site so that repressor no more remain attached to operator.

Lactose/galctoside is inducer of lac operon. As soon as the operator gene becomes free, RNA polymerase is recognised by promoter gene. cAMP is required, RNA polymerase passes over the operator gene and then reaches the area of structural genes. Here it catalyses transcription of mRNAs.

Induction	Repression
It turns the operon on.	It turns the operon off.
It starts transcription and translation.	It stops transcription and translation.
It is caused by a new metabolite which needs enzymes to get metabolised.	It is caused by an excess of existing metabolite
It operates in a catabolic pathway.	It operates in an anabolic pathway.
Repressor is prevented by the inducer from joining the operator gene.	Aporpressor is enabled by a corepressor to join the operator gene

(ii) **Repressible operon system/tryptophan operon system :** A repressible operon system is that regulated genetic material, which normally remains active/operational and enzymes formed by its structural genes present in the cell till the operon is switched off when concentration of an end product crosses a threshold value. Repressible operon system usually occurs in *anabolic pathways, e.g.*, tryptophan operon, argnine operon. Each has the following parts.

(a) **Structural genes :** They are genes, which take part in synthesis of polypeptides /proteins /enzymes through the formation of specific mRNAs. Tryptophan operon has five structural genes – E, D, C, B and A.

(b) **Operator gene :** It provides passage to RNA polymerase moving from promoter to structural genes. Operator gene of repressible operon is normally kept switched on as aporepressor formad by regulator gene is unable to block the gene.

(c) **Promoter gene :** It is initiation/recognition point for RNA polymerase.

(d) **Regulator gene :** The gene produces an aporepressor.

(e) **Aporepressor :** It is a proteinaceous substance formed through the activity of regulator gene. It is able to block operator gene only when a corepressor is also available.

(f) **Corepressor :** The nonproteinaceous component of repressor, which can be end product (feed back inhibition/repression) of the reaction mediated through enzymes synthesized by structural genes. Corepressor of tryptophan operon is tryptophan. It combines with aporepressor, form repressor which then blocks the operator gene to switch off the operon.

(2) **Gene expression in eukaryotes :** In regulation of gene expression in eukaryotes the chromosomal proteins play important role. The chromosomal proteins are of two types. They are histones and non-histones. The regulation of gene expression involves an interaction between histones

and non-histones. Histones inhibit protein synthesis and non-histones induce RNA synthesis. There are four main steps in the expression of genes. Hence regulation is brought about by the regulation and modification of one or more of these steps. They are

(i) Replication (ii) Transcription (iii) Processing (iv) Translation

(i) **Regulation of replication :** Differential gene expression is achieved by gene amplification.

(ii) **Regulation of transcription :** The regulation of the expression of gene is mainly done at transcription. Hybridization experiments clearly show that production of specialised protein is due to differential gene transcription.

(iii) **Regulation of the processing level :** Some of the RNA synthesized in the nucleus are destroyed without leaving the nucleus. 80% of the nuclear RNA has no equivalent in the cytoplasm and only 20% if the nuclear RNA is identical in the cytoplasm. All the genes in a cell are transcribed into mRNA at all times, but the mRNA produced by some genes is destroyed rapidly. But the mRNA modeled on other genes are stabilized and only these mRNAs are passed into the cytoplasm.

(iv) **Regulation of translation :** The control of mRNA-translation is a fundamental phenomenon. In sea-urchin eggs fertilisation is followed by a tremendous increase in protein synthesis; but in the unfertilised egg, there is no protein synthesis. Still the unfertilised egg has complete machinery (*i.e.*, amino acids, ribosomes, mRNA) for protein synthesis. There are two model for regulation in eukaryotes.

(a) **Frenster's model :** According to 1965, The histones act as repressor's during protein synthesis.

(b) **Britten Davidson model :** This is also called gene battery model or operon-operator model. It was proposed by Britten and Davidson in 1969. They have been proposed four type of genes namely integrator. sensor, producer and receptor.

Important Tips

- **One gene one enzyme theory** was given by **G. W. Beadle** and **E. L. Tatum** they worked on Neurospora crassa (pink bread mould). Which is replaced by **one gene one-polypeptide theory** was given by **Yanofsky** et al. (1965) utilizing bacterium E. coli.
- Structural gene determine the primary structure of protein.
- cAMP- (cyclic adenosine monophosphate)- It exerts a positive control in Lac-operon because in its absnce RNA polymerase is uriable to recognise promoler gene.
- In inducible system when inducer is not present, no m-RNA is transcribed. But, when it is present the m-RNA synthesis occurs.
- In repressible system when co-repressor is present, no m-RNA is transcribed. But, when it is absent the transcription occurs.
- In both the system the proteins synthesis is controlled by regulator gene through operator gene. The end product may also stop it's synthesis by feed back inhibition.
- Two types of genes;

(1) **Constitutive genes :** It constantly express themselves e.g. enzymes of glycolysis, which are also known as **house keeping gene,** which lacks TATA boxes.

(2) **Non constitutive genes :** They express themselves only when needed, known as **luxury genes** Example– Inducible and Repressible genes.

ASSIGNMENT

MENDELISM

Basic Level

1. When the tall plants with red flowers were crossed with dwarf plants having white flowers. Mendel found the ratio of progeny as
(a) 1 : 2 : 1 (b) 3 : 1 (c) 9 : 3 : 3 : 1 (d) 1 : 4 : 6 : 4 : 1

2. In dithybrid cross, out of 16 plants obtained, the number of genotypes shall be
(a) 4 (b) 9 (c) 16 (d) 12

3. When Mendel crossed true breeding white flowered strain of peas with a true breeding red-flowered strain, individuals in the F_2 represented
(a) White-flowered plants (b)Red-flowered plants
(c) Red-flowered and white-flowered plants in the ratio 3 : 1
(d) Red and white-flowered individuals in the ratio 1 : 1

4. Mendelism is related with
(a) Heredity in living beings (b)Meiosis during sexual reproduction
(c) Mutation in living organisms (d)None of the above

5. The term "genotype" was coined by
(a) H.J. Muller (b) T. Boveri (c) W.S. Sutton (d) W.L. Johanssen

6. Mendel is famous for his work on
(a) *Pisum* (b) *Drosophila* (c) *Neurospora* (d) *Oenothera*

7. A complete set of chromosomes inherited as a unit from one parent, is known as
(a) Karyotype (b) Gene pool (c) Genome (d) Genotype

8. Mendel choose the pea plant to study genetics because of many qualities. One of them which he did not consider was
(a) Plant height (b) Plant colour (c) Pod shape (d) Pod colour

9. In 1900 A.D. three biologists independently discovered Mendel's principles. They are
(a) De Vries, Correns and Tschermak (b) Sutton, Morgan and Bridges
(c) Avery, McLeod and McCarthy (d) Bateson, Punnet and Bridges

10. Mendel was lucky, because
(a) He was born in Austria which is a nice country
(b) He used pea plant for his experiment which is rich in protein
(c) The genes for different characters are located on different chromosomes in *Pisum sativum*
(d) The *Pisum sativum* is short-lived plant

11. Which of the following is genotypic ratio of Mendel's monohybrid cross
(a) 1 : 3 (b) 3 : 1 (c) 1 : 2 : 1 (d)1 : 1 : 1 : 1

12. The haploid complement of chromosomes of an organism constitute is
(a) Genome (b) Genotype (c) Phenotype (d) Genetic system

13. The cross used to ascertain whether the plant is homozygous or heterozygous is

(a) Linkage cross (b) Reciprocal cross (c) Test cross (d) Monohybrid cross

14. The dwarfness in plants of F_2 generation is

(a) Recessive (b) Dominant (c) Both the above (d) None of the above

15. An organism's genetic constitution is called its

(a) Genotype (b) Phenotype (c) Holotype (d) None of these

16. Mendel formulated some laws which are known as

(a) Laws of germplasm (b)Laws of origin of species

(c)Laws of recapitulation (d)Laws of inheritance

17. Which of the following is heterozygous for two pairs of alleles

(a) *TTRR* (b) *TrRR* (c) *ttrr* (d) *TtRr*

18. When two individuals are similar in external appearance but differ in their genetic make up they are called as

(a) Phenotype (b) Genotype (c) Homozygous (d) Heterozygous

19. If the cells of an organism heterozygous for two pairs of characters *viz*. *Aa* and *Bb* undergo meiosis, what will be the genotypes of the gametes produced

(a) *Aa* and *Bb* (b) *AB, aB Ab* and *ab* (c) *aB* and *Ab* (d) *Ab* and *ab*

20. When a cross is made between offspring and its parents. It is known as

(a) Monohybrid cross (b) Dihybrid cross (c) Back cross (d) Reciprocal cross

21. How many different kinds of gametes may be produced by an organism with the genotype *RrYy*

(a) One (b) Two (c) Three (d) Four

22. The two organelles responsible for cytoplasmic inheritance among eukaryotes are

or

Extranuclear inheritance is a consequence of presence of genes in

(a) Lysosomes and mitochondria (b)Mitochondria and golgi complex

(c) Chloroplasts and mitochondria (d)Chloroplasts and lysosomes

23. What is the correct sequence of the following events

1. Formation of the chromosome theory of heredity
2. Experiments which proved that DNA is the hereditary material
3. Mendel's laws of inheritance-discovery

Code :

(a) 1, 3 and 2 (b) 1 , 2 and 3 (c) 3, 1 and 2 (d) 2, 1 and 3

24. The genes controlling seven traits in pea studied by Mendel were later found to be located on following number of chromosomes

(a) Seven (b) Four (c) Five (d) Six

25. A cross between a homozygous recessive and a heterozygous plant is called

(a) Monohybrid cross (b) Dihybrid cross

(c) Test cross (d) Back cross

26. In case of incomplete dominance in F_2 generation

(a) Genotypic ratio is 3 : 1 (b)Phenotypic ratio is 3 : 1

(c) Genotypic ratio = phenotypic ratio (d) Nothing can be concluded

27. Mendel enunciated

(a) Two principles of inheritance (b)Three principles of inheritance

(c) Four principles of inheritance (d)Five principles of inheritance

28. The term 'allelomorphic' implies

(a) Any two characters (b) A pair of contrasting characters

(c) Sex linked characters (d)A pair of non-contrasting characters

29. An asexually produced organism inheriting all the characters of its parent is called

(a) Clone (b) Offspring (c) Hybrid (d) Variety

30. Mendel did not recognize the linkage phenomenon in his experiments because

(a) There were many chromosomes to handle

(b) Characters he studied were located on different chromosomes

(c) He did not have powerful microscope

(d) He studied only pure plants

31. The first "geneticist" was

(a) Engler (b) Mendel (c) Schwann (d) Miller

32. The back cross is

(a) A cross between F_1 individual and F_2 individual

(b) A cross between and F_1 individual with another F_1 individual

(c) Cross between F_1 and one of the two parents

(d) Cross between F_2 with one of the parents

33. When a yellow mouse was crossed to another yellow mouse, the F_1 generation produces yellow and brown-black mice in the ratio 2:1 the yellow mice are never homozygous. The reason is

(a) Homozygous yellow cannot survive due to lethal effect of genes

(b) Yellow mice are not very suitable to live

(c) There is no formation of zygotes with homozygous yellow constitution

(d) None of the above

34. If dwarf pea plant was treated with GA_3 it grew as tall as the pure tall pea plant. If this treated plant is crossed with a pure tall plant the phenotypic ratio F_1 is likely to be

(a) All tall (b) All dwarf

(c) 50% tall and 50% dwarf (d) 75% tall and 25% dwarf

35. Which contributed to the success of Mendel

(a) Qualitative analysis of data (b)Observation of distinct inherited traits

(c) His knowledge of biology (d)Consideration of one character at one time

36. In a cross between AABB x aabb, the ratio of F_2 genotypes between AABB, AaBB, Aabb and aabb would be

(a)9:3:3:1 (b) 2:1:1:2 (c) 1:2:2:1 (d) 7:5:3:1

37. If red eyed (dominant) fly is mated with white eyed (recessive) fly, the ratio of red to white eyed in F_2 generation would be

(a) 3:1 (b) 2:2 (c) 2:1 (d) 1:3

38. Mendel's work was rediscovered in

(a) 1756 (b) 1865 (c) 1900 (d) 1910

39. Dihybrid cross is related to

(a) Principle of dominance (b)Principle of independent assortment

(c) Principle of segregation (d)Principle of purity of gametes

40. Cross between AaBB and aaBB will form

(a) 1 AaBB : 1aaBB (b) All AaBB (c) 3AaBB : 1aaBB (d) 1AaBB : 3aaBB

41. Percentage of heterozygous individuals obtained from selfing of Rr individuals is

(a) 100 (b) 75 (c) 50 (d) 25

42. In a experiment on pea plant, pure plants with yellow round seeds crossed with plants producing green wrinkled seeds. What will be phenotypic ratio of F_1 progeny

(a) 9 yellow round: 3 round green: 3 wrinkled yellow: 1green wrinkled

(b) All yellow round

(c) 1 round yellow: 1 round green: 1 wrinkled yellow: 1 wrinkled green

(d) All wrinkled green

43. Development of purple flower character when two white flower of sweet pea are crossed, is an example of

(a) Multiple factor inheritance (b) Multiple allele inheritance

(c) Supplementary genes and gene interaction (d) Complementary genes and gene interaction

44. Mendel proposed which of the following term for heriditary units

(a) Factor (determiner) (b) Genome (c) Genetic particle (d) None

45. A pure dwarf plant was subjected to X-ray treatment, which mutated them to reach the height of a pure tall plant. This new plant was crossed with a hybrid tall. What will be the result of progeny

(a) All tall (b) Tall and dwarf in 1:1 ratio

(c) All dwarf (d) Tall and dwarf in 3:1 ratio

46. 1:1:1:1 ratio will come by

(a) TTRR × ttrr (b) TtRr × ttrr (c) TtRr × Ttrr (d) TtRr × TtRr

47. Mendel Failed to get linkage because

(a) Genes of seven types of traits selected by him were located on four different chromosomes and behaved independently

(b) Genes selected by him were discrete and stable

(c) Genes selected by him were located on seven non homologous chromosomes

(d) He studied crossing over

48. The genetic concept of segregation and independent assortment are most likely to be associated with

(a) Mitosis and meiosis (b) Meiosis and fertilization

(c) Meiosis and reproduction (d)Mitosis and cleavage

49. If the resistant strain is to be developed, what should be the first step

(a) Hybrid (b) Selection of parents

(c) Selection of environment (d) Emasculation

50. For obtaining hybrid ratio which characters of the plant are taken into account

(a) Dominant characters (b) Recessive characters (c) New characters (d) All of these

51. In genetics, the use of chequer board was done by

(a) Mendel (b) Correns (c) Punnet (d) Darwin

52. In Mendelian monohybrid cross, phenotypic ratio F_2 is 3:1, How many types of gametes are formed in F_1 generation

(a) Only one type (b) Two type (c) Four types (d) Eight types

53. Mendel studied on pea plant in

(a) Vienna university (b) University of Austria (c) Monestry of Brun (d) School of Brun

54. Mendel choose pea plants because

(a) They were cheap (b)They were having seven pairs of contrasting characters

(c) They were easily available (d)Of great economic importance

55. The crossing of homozygous tall plant with a dwarf in F_2 would yield plants in the ratio of

(a) All homozygous dwarf (b)All heterozygous tall

(c) One homozygous tall, one homozygous dwarf (d)Two tall and two dwarf

56. The trait which does not blend at all is

(a) Colour (b) Shape (c) Size (d) Sex

57. Which is important from genetical study point of view

(a) *Neurospora* (b) *Drosophila* (c) Mice (d) All of these

58. If a pea plant is represented by Rr. What type of information is obtained

(a) Phenotypic (b) Genotypic

(c) Both (a) and (b) (d) About number of chromosomes

59. How many pairs of contrasting characters in pea pod were chosen by Mendel

(a) 2 (b) 3 (c) 4 (d) 7

60. An exception to Mendel's law is

(a) Law of independent assortment (b) Law of segregation

(c) Law of dominance (d) Law of linkage

61. Self pollination between Tt and Tt plants results into genotype ratio of

(a) 3 : 1 (b) 1: 2: 1 (c) 1 : 3 (d) 4 : 0

62. In Mendel's experiment, the F_1 generation showed only 'tall' plants because

(a) Too much water was given (b) Dwarf plants died because of hot conditions

(c) The 'tall character' was 'dominant' (d) The 'dwarf character' was 'recessive'

63. Who is concerned with law of inheritance

(a) Bateson (b) Mendel (c) Punnet (d) H. Khorana

64. In poultry, new comb colour appears by collaboration of two dominant gene

(a) Walnut (b) Single (c) Pea (d) Rose

65. Complete dominance is absent in

(a) *Pisum sativum* (b) *Mirabilis jalapa* (c) *Lathyrus odoratus* (d) *Oenothera lamarckiane*

66. What type of gametes will form by genotype RrYy

(a) *RY, Ry, rY, ry* (b) *RY, Ry, ry, ry* (c) *RY, Ry, Yy, ry* (d) *Rr, RR, Yy, YY*

67. In Mirabilis a hybrid for red (*RR*) and white (*rr*) flower produces pink (*Rr*) flower. A plant with pink flower is crossed with white flower the expected phenotypic ratio is

(a) Red: Pink: White = 1 : 2 : 1 (b)Pink : White = 1 : 1

(c) Red : Pink = 1 : 1 (d) Red : White = 3 : 1

68. When tall and dwarf plants are crossed, then from which cross 1:1 ratio is obtained

(a) *Tt* and tt (b) *tt* and *tt* (c) *Tt* and *Tt* (d) *TT* and *TT*

69. In a monohybrid cross when F_1 is crossed with homozygous dominant parent then which type of offsprings will obtain

(a)Dominant : recessive 3:1 (b) Only recessive

(c) Dominant : recessive 1:1 (d) No recessive

70. Mendel's law of independent assortment is applicable for

(a) All genes in all organism (b)All genes of pea plant only

(c) All linked genes only (d)All non-linked genes only

71. If hybrid red flowered plants of pea are crossed back to pure red flowered parent. The progeny will show

(a) All red flowered plants (b) White flowered plants

(c) 50% red and 50% white flowered plants (d) 3 red : 1 white flowered plants

72. The emasculation of flower buds is achieved by the removal of

(a) Sepals (b) Anthers (c) Stigma (d) Corolla

73. When a tall and red flowered individual is crossed with a dwarf and white flowered individual, the phenotype in the progeny will be dwarf and white. What will be the genotype of tall and red flowered individual

(a)TTRR (b) TtRR (c) TtRr (d) TTRr

74. A test cross is performed

(a) By selfing of F_2- generation plants (b)By selfing of F_1- generation plants

(c) To determine whether F_1- plant is homozygous or heterozygous

(d) Between a homozygous dominant and homozygous recessive plant

75. Mendel is called the father of
(a) Palaeobotany (b) Genetics (c) Texonomy (d) None of these

76. If a homozygous red-flowered plant is crossed with a homozygous white- flowered plant, the offsprings will be
(a) All red-flowered (b) All white-flowered (c) Half red-flowered (d) Half white-flowered

77. Which of the following is a recessive trait in garden pea
(a) Tall stem (b) Round seeds (c) Wrinkled seeds (d) Coloured seed coat

78. Law of independent assortment was proposed by
(a) Mendel (b) Linnaeus (c) Robert Hook (d) Melvin Kelvin

79. In hybridization, $Tt \times tt$ gives rise to the progeny of ratio
(a) 1 : 1 (b) 1 : 2 (c) 2 : 1 (d) 1 : 2 : 1

80. The dihybrid ratio in F_2 generation is
(a) 1 : 1: 1 : 1 (b) 2 : 1 : 2 (c) 3 : 1 (d) 9 : 3 : 3 : 1

81. Which of the following trait of garden pea studied by Mendal was recessive feature
(a) Round seed shape (b) Axial flower position (c) Green seed colour (d) Green pod colour

82. Two cross between the same pair of genotypes or phenotypes in which the sources of the gametes are reversed in one cross is known as
(a) Reverse cross (b) Test cross (c) Reciprocal cross (d) Dihybrid cross

83. Mendel formulated the laws of heredity considering seven pairs of contrasting characters in the pea plant. If he had studied an eight pair, the law which would have been altered is
(a) Law of segregation (b) Law of dominance
(c) Law of independent assortment (d) Law of unit character

84. Had Mendel decided to study those traits together which are determined by linked genes, he would not have found out
(a) Crossing over (b) Dominance
(c) Principal of segregation (d) Principal of independent assortment

85. Which of the following is true of Mendelism but not to Darwinism
(a) It influenced human thought tremendously (b)It was modified immediately
(c) It gave well-defined principle even in early stage (d)It was based on insufficient data

86. Mendel's second law is
(a) Segregation (b) Dominance
(c) Independent assortment (d) Polygenic inheritance

87. When RR (red) is cross with rr (white), the offspring are pink. This shows that R gene is
(a) Recessive (b) Dominant (c) Incompletely dominant (d)Mutant

88. What is the other name for " incomplete dominance"
(a) Blending inheritance (b)Intermediate inheritance
(c) Mosaic inheritance (d)All the above

89. Self sterility in "*Nicotiana*" was reported dominance by
(a) Morgan (b) East (c) Crick (d) Goldberg

90. In a plant, red fruit (*R*) is dominant over yellow fruit (*r*) and tallness (*T*) is dominant over shortness (*t*). If a plant with *RRTt* genotype is crossed with a plant that is *rrtt*,

(a) 75% will be tall with red fruit (b)All the offspring will be tall with red fruit

(c) 25% will be tall with red fruit (d)50% will be tall with red fruit

91. How many types of genotypes are formed in F_2 progeny obtained from self polination of a dihybrid F_1

(a) 9 (b) 3 (c) 6 (d) 1

92. A gene pair hides the effect of another gene. the phenomenon is called

(a) Epistasis (b) Mutation (c) Dominance (d) Segregation

93. The term test cross refers to a cross between

(a)F_1 hybrid with another F_1 hybrid (b)F_1 hybrid and a double recessive individual

(c) F_1 hybrid and either of the parents (d) F_1 hybrid and F_2 individual

94. Mendel was born in

(a) 17^{th} century (b) 18^{th} century (c) 19^{th} century (d) 8^{th} century

95. When F_1 generation hybrid tall Tt is crossed with dwarf tt parent, it is a case of

(a) Dihybrid cross (b) Test cross (c) Crossing over (d) Reciprocal cross

96. A plant of F_1- generation with genotype " AABLCC " on selfing produces which of the following the phenotypic ratio in F_2- generation

(a) 1 : 1 (b) 3 : 1 (c) 9 : 3 : 3 : 1 (d) 27 : 9 : 3 : 1

97. *Mirabilis jalapa* is an example of

(a) Codominance (b) Supplementary gene

(c) Incomplete dominance (d) Complementary gene

98. A cross between two pairs of alleles called

(a) Crossing over (b) Linkage (c) Monohybrid cross (d) Dihybrid cross

99. F_2 phenotypic ratio of monohybrid cross is

(a) 3 : 1 (b) 1 : 1 (c) 2 : 1 (d) 1: 2: 1

100. When heterozygous tall plants are self pollinated then tall and dwarf plants are obtained this is explain to

(a) Law of purity of gamete (b)Segregation law

(c) Division in spores (d)Independent assortment

101. Which of the following was not considered by Mendel

(a) Test cross (b) Back cross (c) Linkage (d) None of these

102. Cytoplasmic inheritance of kappa particles was reported by T.M. Sonneborn in

(a) *Paramecium aureus* (b)*Paramecium aurelia*

(c) *Entamoeba histolytica* (d)*Ascaris lumbrigonides*

103. A bryophytic plant suddenly started reproducing parthenogenetically. The number of chromosomes of the second generation compared to the parent plant will be

(a) Double (b) One half (c) One fourth (d) Same

104. The branch of botany dealing with heredity and variation is called

(a) Geobotany (b) Sericulture (c) Genetics (d) Evolution

105. Organisms phenotypically similar but genotypically different are said to be

(a) Heterozygous (b) Monozygous (c) Multizygous (d) Homozygous

Advance Level

106. Normal maize has starchy seeds which remain smooth when dry. A mutant form has sugary seed which go wrinckled when dry. When a mutant was crossed with a normal plant, an F_1 was produced which had smooth seeds. What would be the relative ratios of the different seed types, if the F_1 was allowed to self

(a) 1 smooth : 3 sugary (b) 3 smooth : 1 sugary

(c) 1 smooth : 1 sugary (d) All sugary

107. The resemblance of individuals to their progenitors is called

(a) Heredity (b) Genetics (c) Evolution (d) None of these

108. In an organism, pink spot is a sex-linked recessive trait and black hair heterozygous female is mated to a white male which is not spotted, the phenotypic ratio of the offspring would be

(a) 1/4 spotted black; 1/4 pink spotted white; 1/4 unspotted black; 1/4 unspotted white

(b) 1/2 pink spotted black; 1/2 pink spotted white

(c) 3/4 pink spotted black; 1/4 pink spotted white

(d) 3/4 unspotted black; 1/4 pink spotted white

109. When a true breeding pea plant that has yellow seeds is pollinated by a plant that has green seeds, all the F_1 plants have yellow seeds. This means that the allele for yellow is

(a) Heterozygous (b) Dominant (c) Recessive (d) Lethal

110. An organism with two identical alleles for a given trait is

(a) Homozygous (b) Segregating (c) Dominant (d) A hermaphrodite

111. In one cross between red flower and white flower the offsprings have red flower in majority and white flowers are much less. In this cross red colour character is

(a) Dominant (b) Assorted (c) Recessive (d) Hybrid

112. Who out of the following was of the strong opinion that acquired characteristics are inherited

(a) Lamarck (b) Lysenko (c) Mendel (d) Huxley

113. Maternal inheritance is due to the genes present

(a) Lysosome (b) Nucleoplasm (c) Nucleus (d) Mitochondria

114. A tobacco plant which is heterozygous for albinism (a recessive character) is self-pollinated if 1200 seeds are subsequently germinated, how many of the seedlings would have the parental genotype

(a) 300 (b) 600 (c) 900 (d) 1200

115. When both the members of a pair of alleles are identical in a plant, it is called

(a) Heterozygote (b) Hybrid (c) Homozygote (d) Inbreeder

116. Mendel's principle of segregation was based on the separation of alleles in the garden pea during
(a) Pollination (b) Embryonic development (c)Seed formation (d) Gamete formation

117. Alleles of different genes that are on the same chromosome may occasionally be separated by a phenomenon known as
(a) Pleotropy (b) Epistasis (c) Continuous variation (d)Crossing over

118. Alleles which show independent effect are called
(a) Supplementary alleles (b)Codominant alleles
(c)Epistatic alleles (d)Complementary alleles

119. Mendel law is still true because
(a)It takes place in sexually reproducing plants
(b) It takes place in asexually reproducing plants
(c) It takes place in both the above plants
(d) It takes place in apomictic reproducing plants

120. Mendel observed the certain characters did not assort independently. Later researchers found it to be due to
(a)Amitosis (b) Linkage of characters
(c) Dominance of one trait over the other (d) Crossing over

121. For the preparation of genetic maps, the recombination frequencies between genes are additive over short distances but not over long distance due to
(a) Multiple cross overs (b)Lethal mutation
(c) Epistasis (d)Synaptonemal complex

122. In sweet pea plants the presence of dominant *C* and *P* genes is essential for development of purple colour. The ratio of plants producing flowers of different colours in the progeny of the cross *Cc Pp* × *Cc pp* will be
(a) 2 white and 6 purple coloured flowers (b) 2 purple and 6 white coloured flowers
(c) 3 white and 5 purple coloured flowers (d) 3 purple and 5 white coloured flowers

123. Skin colour in man is controlled by
(a) Supplementary genes (b)Epistasis
(c) Complimentary genes (d)Polygenes

124. Failure of one gene to express it in the presence of a non – allelic is known as
(a) Codominance (b) Hypostasis (c) Incomplete dominance (d)Epistasis

125. When a wheat variety of red kernels is crossed with white kerneled wheat the F_2 ratio would be
(a) 9 : 7 (b) 1 : 10 : 4 : 1 (c) 1 : 4 : 6 : 4 : 1 (d) 1 : 2 : 4 : 2 : 4 : 2 : 1

126. Hb^A and Hb^s alleles of normal and sickle cell haemoglobin are
(a) Codominant alleles (b) Multiple alleles
(c) Dominant recessive alleles (d)Cumulative alleles

127. Which one of the following individuals can produce 16 different gametes
(a) Aa Bb cc Dd (b) Aa Bb cc DD Ee Ff (c) Aa Bb Cc dd EE FF (d) Aa Bb Cc DD Ee Ff

128. Sickle cell syndrome is an example of
(a) Pleiotropism (b) Codominance (c) Sublethality (d) All of these

129. Which is the example of supplementary gene
(a) Cucurbitta pepo (b) Skin colour of mice (c) Comb shape of poults (d)Both (b) and (c)

130. Colour of endosperm in maize is an example of
(a) Duplicate genes (b) Inhibitory genes
(c) Polymeric genes (d) Quantitative inheritance

131. The full form of IPGRI is
(a) Indian plant genetic resource institute (b) International plant genetic resource institute
(c) International potato genetic resource Institute (d) International pine genetic resource institute

132. Red and tall dominant character hybrid plant when crossed with recessive white dwarf plant ($RrTt \times rrtt$). What will be the ratio of respective four combinations red tall red dwarf, white tall and white dwarf plants in the next generation
(a) 9 : 3 :3 :1 (b) 15 : 1 : 0 :0 (c) 9 : 3 :4 :0 (d) 4 : 4 : 4 : 4

133. Incomplete dominance is found in
(a) *Pisum sativum* (b) *Antirrhinum majus*
(c) Both *Pisum sativum* and *Antirrhinum majus* (d) None of these

134. By the cross is AaBb, how many percentage ab is found
(a) 100% (b) 25% (c) 7.5% (d) 12.4%

135. A gene pair hides the effect of another gene. The phenomenon is called
(a) Epistasis (b) Mutation (c) Dominance (d) Segregation

136. Which of the following is associated with multiple phenotypes
(a) Epistasis (b) Pleiotropy (c) Polygenic inheritance (d)Mutation

137. In *Lathyrus odoratus* the cross between two purple flowered plants gave a pink flowered progeny. This is due to
(a) Epistasis (b) Co-dominance
(c) Incomplete dominance (d) Complementary gene interaction

138. The monohybrid genotypic ratio 1:2:1 in F_2 generation indicates
(a) Segregation (b) Independent assortment
(c) Dominance (d) Incomplete dominance

139. The F_2 generation of a cross produced identical phenotypic and genotypic ratio. It is not an expected Mendelian result, and can be attributed to
(a) Independent assortment (b)Linkage (c) Incomplete dominance (d)None of these

140. The law of independent assortment can be related to one of the following
(a) Both homologous chromosomes of each pair are received by a single gamete
(b) The genes present on the same chromosomes get randomly redistributed by a single gamete
(c) The non- homologous chromosomes show randomly distribution during anaphase I of meiosis
(d) The exchange of segments between the non- homologous chromosomes

141. An example of the quantitative trait in man is

(a) Hair colour (b) Colour of eye (c) Skin colour (d) Shape of nose

142. Pure red flowered and white flowered plants were crossed. It produced 120 offspring with

(a) 90 white-flowered and 30 red-flowered (b) 90 red-flowered and 30 white-flowered

(c) 60 red-flowered and 60 white-flowered (d) All red flowered

143. Nonallelic genes having similar phenotypic effect, interact to different trait and a ratio of 9:7 in F_2 generation are

(a)Epistatic genes (b) Hypostatic genes

(c) Supplementary genes (d) Complementary genes

144. In *Lathyrus* the purple colour of flowers is controlled by two dominant non allelic genes C and P with are not able to express themselves alone. It is an example of

(a) Supplementary gene (b) Complementary genes (c) Duplicate factors (d) Polygenes

145. In rat grey coat colour (Agouti) shows epistasis and supplementary interaction both. In a cross it produces a ratio of 9:3:4. It is due to

(a) Dominant epistasis (b) Recessive epistasis

(c) Dominant recessive epistasis (d) Hypostatic gene

146. In shorthorn cattle genes for red (r_1) and white (r_2) coat colour occur. Crosses between red (r_1r_2) and white (r_2r_2) produced (r_1r_2) roan. This is an example of

(a) Complementary genes (b)Epistasis

(c) Codominance (d)Incomplete dominance

147. A cross between a plant having genotype AaBb $\times$ aabb do not yield a ratio of 1:1:1:1. What can we safely say

(a) Characters are not obeying segregation (b) Independent assortment is occurring

(c) Independent assortment is not being obeyed (d) Data not sufficient

148. If an individual having the genotype AaBbCc is selfed, how many squares will be required to determine the genotypes of F_2 population by Punnet's checker board method

(a) 8×8 (b) 2×2 (c) 4×4 (d) 1×8

149. If enough crosses are made between flies, male of the genotype 'Aa' and the female flies of the genotype 'aa' to produce about 1000 offspring which one of the following is the most likely distribution of genotypes in the offspring

(a) 249 aa: 751 aa (b) 750 Aa: 250 aa

(c) 243 AA: 517 Aa: 240 aa (d) 481 Aa: 519 aa

150. From a cross PP CC $\times$ pp CC, following genotypic ratio will be obtained in F_1 generation

(a) 1 Pp CC: 3 pp CC (b) 3 PpCC: 1ppCC (c) All Pp CC: No ppCC (d)1 PpCC:1pp CC

151. The percentage of heterozygous individuals obtained in F_2 generation from selfing the plants with genotype Rr would be

(a) 24 (b) 50 (c) 75 (d) 100

152. Frequency of an autosomal recessive lethal gene is 0.4. Frequency of carrier in a population of 200 individuals is

(a) 72 (b) 96 (c) 104 (d) 36

153. Which one of the following is the correct chronological order

(1) Griffith experiment (2) Central dogma of Crick

(3) Mendel's law (4) Chargaff's base equibalance rule

(a) $1 \rightarrow 2 \rightarrow 3 \rightarrow 4$ (b) $3 \rightarrow 1 \rightarrow 4 \rightarrow 2$

(c) $2 \rightarrow 1 \rightarrow 3 \rightarrow 4$ (c) $4 \rightarrow 3 \rightarrow 2 \rightarrow 1$

154. Applicable is

(a) Co-dominance (b) Law of segregation

(c) Law of independent assortment (d) Law of dominance

155. Which of the following scientist rediscovered Mendel's theory

(a) T. H. Morgan (b) W. Bateson (c) E. Strasburger (d) E. Von Tschermak

156. Which of the following is an example of pleiotropic gene

(a) Thalassemea (b) Haemophilia (c) Colour blindness (d) Sickle cell anaemia

157. If Mendel had studied the seven traits using a plant with 12 chromosomes instead of 14, in what way would his interpretation have been different

(a) He could have mapped the chromosome

(b) He would have discovered blending or incomplete dominance

(c) He would not have discovered the law of independent assortment

(d) He would have discovered sex linkage

158. The presence of continuous phenotypic variation in an F_1-generation suggests that a character is inherited by

(a) Epistasis (b) Recombination

(c) Gene linkage (d) Polygenic inheritance

159. The frequency of a allele in the small isolated population may change due to

(a) Gene flow (b) Mutation (c) Genetic drift (d) Natural selection

160. Which of the following is associated with multiple phenotypes

(a) Mutation (b) Polygenic inheritance (c) Epistasis (d) Pleiotropy

161. Which of the following is dominant character according to Mendel

(a) Dwarf plant and yellow fruit (b)Terminal fruit and wrinkled seed

(c) White testa and yellow pericarp (d)Green coloured fruit and rounded seed

162. Genes controlling seven traits in pea studied by Mendel were actually located on

(a) Seven chromosomes (b) Six chromosomes

(c) Four chromosomes (d) Five chromosomes

163. From a cross AABb $\times$ aaBb, the genotypes AaBB: AaBb: Aabb: aabb will be obtained in the following ratio

(a) 1:1:1:1 (b) 1:2:1:0 (c) 0:3:1:0 (d) 1:1:1:0

164. The most important use in producing transgenic plants and animals is of

(a) Reverse genetics (b) Forward genetics (c) Mendelian genetics (d) Mutation

165. Starch branching enzyme SBE-1 is present in

(a) Red flower (b) Round seed (c) Wrinkled seed (d) All the above

166. Pure homozygous recessive allele in 1/16 in a dihybrid cross of F_2 generation what will be the proportion of pure homozygous dominant alleles

(a) 3/16 (b) 9/16 (c) 2/16 (d) 1/16

167. Blue flowered and white flowered plant on crossing gave progeny of blue and white flowered in the ratio of 60 : 40 what ratio of blue and white is expected if the blue flowered are self pollinated

(a) 76 : 24 (b) 40 : 60 (c) 52 : 48 (d) 84 : 16

168. A 1 : 1 phenotypic ratio in a test cross indicates that the

(a) Alleles are codominant

(b) Dominant phenotype of parent was heterozygous

(c) Alleles segregated independently (d) Alleles are dominant

169. From a single ear of corn, a farmer planted 200 kernels which produced 140 tall and 40 dwarf plants. The genotpe of these offspring are most likely

(a) *TT*, *Tt* and *tt* (b) *TT* and *tt* only (c) *TT* and *Tt* only (d) *Tt* and *tt* only

170. In pea plants, red flowers (*R*) are dominant over to white flowers (*r*) and tall plants (*T*) are dominant over to dwarf plants (*t*). The table below shows the gametes and the possible offsprings produced in a dihybrid cross. The numbers 1 to 16 represent the genotypes of each individual cross (*e.g.* 3 = *RrTT*)

	RT	*Rt*	*rT*	*rt*
RT	1	2	3	4
Rt	5	6	7	8
rT	9	10	11	12
rt	13	14	15	16

If plant 7 is crossed with plant 12, then what proportion of the offsprings produced will be homozygous for both the characters

(a) 50% (b) 37.5% (c) 25% (d) 12.5%

171. Variation (change) in the size, shape, colour or structure, of an animal or in its parts are due to

(a) Meristic variations (b) Blastogenic variation (c) Continuous variations (d) Saltations

172. Variations in the life time of an organism due to influence of an environment are due to

(a) Somatogenic variation (b) Blastogenic variations (c) Discontinuous variation (d) Saltations

GENE AND CHROMOSOME

Basic Level

173. Gene controls

(a) Heredity but not protein synthesis (b) Protein synthesis but not heredity

(c) Both heredity and protein synthesis (d) Biochemical action of some enzymes

174. Mc Clintock discovered

(a) Transposons/Jumping gene (b) Retroposons

(c) Plasmids (d) None of the above

175. When a cell with 40 chromosomes undergoes meiosis, each of the four resulting cells has
(a) 20 chromosomes (b) 40 chromosomes (c) 80 chromosomes (d) 10 chromosomes

176. The functional unit of DNA *i.e.* gene is called
(a) Cistron (b) Muton (c) Genome (d) Recon

177. Different types of chromosomes can be recognised by the position of the following separation the two arms
(a) Centromere (b) Genes (c) Spindle (d) Nucleus

178. Nucleosomes are bounded by
(a) RNA (b) Histone H_4 (c) Histone H_3 (d) DNA

179. An inherited factor that determines a biological characteristic of an organism is called
(a) Gene (b) Chromosome (c) Allele (d) Chromatid

180. Who postulated the "Chromosomes Theory of Inheritance"
(a) De Vries (b) Mendel (c) Sutton and Boveri (d) Morgan

181. A gene is made up of
(a) DNA (b) RNA (c) Either DNA or RNA (d)Amino acids

182. One gene one enzyme concept means
(a) One gene controls one enzyme (b)All the enzymes are controlled by genes
(c) All the genes are controlled by enzymes (d) None of these

183. Khorana got the Nobel Prize on
(a) Gene synthesis (b) Genetic code (c) Protein synthesis (d) Enzyme synthesis

184. The complete haploid set of chromosomes in each nucleus of a given species is referred to as the
(a) Allele (b) Genetic code (c) Genome (d) Genotype

185. The eukaryotic chromosomes are made up of
(a) DNA (b) RNA (c) DNA and proteins (d) DNA and lipids

186. The map distance between genes *A* and *B* is 3 units, between *B* and *C* 10 units and between *C* and *A* 7 units. The order of the genes in a linkage map constructed on the above data would perhaps be
(a) *A, B, C* (b) *A, C, B* (c) *B, C, A* (d) *B, A, C*

187. In sweet peas, genes *C* and *P* are necessary for colour in flowers. The flowers are white in the absence of either or both the genes. What will be the percentage of coloured flowers in the offspring of the cross *Cc pp* × *cc Pp*
(a) 100% (b) 75% (c) 25% (d) 50%

188. When a gene exists in more than one form, the different forms are called
(a) Heterozygous (b) Complementary genes (c) Genotypes (d) Alleles

189. What are allosomes
(a) Granular structures on chromosomes (b) Node like structures on chromosomes
(c) Sex chromosomes (d) None of the above

190. When two genetic loci produce identical phenotypes in *cis* as well as in *trans* position, they are considered to be

(a) Pseudo alleles (b) The parts of the same gene

(c) Multiple alleles (d) Different genes

191. In split genes, the coding sequences are called

(a) Cistrons (b) Operons (c) Exons (d) Introns

192. The eukaryotic genome differs from the prokaryotic genome because

(a) Repetitive sequences are present in eukaryotes

(b)Genes in the former case are organized into operons

(c) The DNA is complexed with histones in prokaryotes

(d)The DNA is circular and double stranded in prokaryotes

193. Centromere is also called

(a) Secondary constriction (b)Chromomere (c) Chromocentre (d) Primary constriction

194. Polytene chromosomes were first observed by

(a) Batanetzky -1980 (b) Heitz and Bauer –1935

(c)Balbiani - 1881 (d) Stevens and Wilson – 1905

195. Barr body is associated with

(a) Female autosomes

(b)Female autosome as well as sex chromosomes

(c) Allosomes of male and female (d) Female sex chromosome

196. The genes that keep on changing their location on chromosomes are

(a) Jumping genes (b) Pleiotrophic genes (c) Split genes (d) Duplicate genes

197. The telomeres of eukaryotic chromosomes consist of short sequences of

(a) Adenine rich repeats (b)Guanine rich repeats

(c)Thymine rich repeats (d)Cytosine rich repeats

198. Allele are

(a) Alternate forms of a gene (b)Homologous chromosome

(c) Pair of sex chromosome (d)None of these

199. Noble prize for the concept of jumping genes was awarded to

(a) H. G. Khorana (b) Barbara Mc Clintock (c) Kornberg (d) Watson

200. Genes are made up of

(a) Histones (b) Iipoprotein (c) Hydrocarbons (d) Polynucleotides

201. Histones are

(a) Mucoproteins (b) Glycoproteins (c) Basic proteins (d) Acidic proteins

202. Nucleosome is a coiled beaded fibre which has cylindrical blocks of

(a) H_2a, H_2b, H_3 and H_4 histones (b) H_1a, H_1b, H_3a and H_4b histones

(c) H_2c, H_2b, H_3a and H_2c histones (d) H_4a, H_5b and H_3c histones

203. Alleles of a gene are found on
(a) Same chromosome (b) Homologous chromosomes
(c) Any chromosome (d) Sex chromosomes

204. Gene (Cistron) is a part of DNA with
(a) Functional message (b) Non functional unit
(c) 100 nucleotide sequence (d) m-RNA sequence

205. The terms cistron, recon and muton were proposed by
(a) W. Ingram (b) Bateson (c) J. Lederberg (d) S. Benzer

206. Genetic Map is one that
(a) Shows the distribution of various species in a region
(b) Establishes sites of the genes on a chromosome
(c) Establishes the various stages in gene evolution
(d)Shows the stages during the cell division

207. Extranuclear genes occur in
(a) Plastids and inherited (b) Plasmid and not inherited
(c) Mitochondria and inherited by male (d) Mitochondria and inherited by female

208. How many different types of genetically different gametes will be produced by a heterozygous plant having the genotype *AABbCc*
(a) Two (b) Four (c) Six (d) Nine

209. In multiple allele system a gamete possesses
(a) Two alleles (b) Three alleles (c) One allele (d) Several alleles

210. The polygenic genes show
(a) Similar genotype (b) Different phenotype (c) Different karyotype (d) Different genotype

211. When two odd characters are present in a gene this is known as
(a) Bi-gamous (b) Heterogamous (c) Polymorphic (d) Heteromorphic

212. Satellite DNA is present in
(a) Nucleus (b) Chloroplast (c) Nucleolus (d) Chromosomes

213. The modern concept of gene is
(a) A segment of DNA capable of crossing over (b) A functional unit of DNA
(c) A segment of DNA (d) A segment of chromosome

214. "One gene one enzyme" theory was proposed by
(a) G.W. Beadle and E.L. Tatum (b)O.T. Avery and M. McCarthy
(c) J.H. Tijo and A.Levan (d)C.E. Ford and J.H. Tijo

215. The term "gene" was coined by
(a) Mendel (b) Johannsen (c) Khorana (d) Kornberg

216. Chromosomal number in a somatic cell of a flowering plant is
(a) Only haploid (b) Only diploid (c) Many types (d) None of these

Advance Level

217. An example of pleiotropic gene is

(a) Hb^S (b) HB^A (c) I^A (d) I^B

218. The first plant in which chromosomal basis of sex determination was discovered is

(a) Melandrium (Lychnis) (b) Rumex

(c) Sphaerocarpus (d) Coccinia

219. "Theory of epigenesis" was given by

(a) Aristotle (b) Swamerdom (c) Wolf (d) Dortin

220. Plotting of specific genes on the chromosome is known as

(a) Chromosome map (b) Linkage map (c) Genetic map (d) All the above

221. XY sex chromosome were discovered by

(a) Gregor Johan Mendel (b)M.L.D. White (c) Robert Brown (d) Neittie Stevens

222. If the recombination frequency between genes A and B is 7% and B and C is 4%, it means

(a) A and B are closer to each other (b)B and C are closer to each other

(c) A and C are closer to each other (d)Genes are present in different chromosomes

223. Oncogene is

(a) Structural gene (b) Promoter gene

(c) Inducter gene (d) Cancer gene

224. In which condition, the gene ratio remains constant for any species

(a) Gene flow (b) Mutation

(c) Sexual selection (d) Random mating

225. The genes, which remain confined to differential region of *Y*-chromosome, are

(a) Mutant genes (b) Holandric genes

(c) Autosomal genes (d) Completely sex-linked genes

226. In transgenics, expression of transgene in target tissue is determined by

(a) Promoter (b) Reporter

(c) Enhancer (d) Transgene

227. If gene frequency between genes *a* and *c* is 2% ; *b* and *c* is 13%; *b* and *d* 4%, *a* and *b* 15% ; *c* and *d* 17% and *a* and *d* 19%, what will be the sequence of these genes in a chromosomes

(a) *a,c,b,d* (b) *a,b,c,d* (c) *d,b,a,c* (d) *a,d,b,c*

228. What is incorrect about lampbrush chromosomes

(a) They are diplotene chromosomes (b)They are first described by Ruckert

(c) They are invisible in meiotic prophase (d)They are shorter than polytene chromosomes

229. One map unit correspond to a physical length of chromosome in which

(a) Cross over will occur once in fifty meiosis (b) Non cross over of mitotic divisions

(c) Cross over will occur once after 100 meiosis (d) None of the above

230. What is the name of the Indian scientist from Patna university who studied sex in diploid, triploid and tetraploid plants with and without 'Y' chromosomes

(a) C.B. Gupta (b) R.P. Singh (c) R.P. Roy (d) S.P. Roychaudhry

231. Non constitutive genes express themselves only when needed are also called as
(a) Structural gene (b) Promoter gene
(c) House keeping genes (d) Luxury genes

232. A nutritionally wild type organism, which does not require any additional growth supplement is known as
(a) Auxotroph (b) Prototroph (c) Phenotype (d) Holotype

NUCLEIC ACID (DNA AND RNA)

Basic Level

233. DNA generally acts as template for the synthesis of
(a) Only protein (b) Only DNA (c) Only RNA (d)Both DNA and RNA

234. Higher nucleotides found free in cytoplasm are
(a) Deoxyribonucleoside diphosphate (b)Deoxyribouncleoside triposphate
(c) Ribonucleoside diphosphates and triphosphates (d)All the above

235. Synthesis of DNA takes place by
(a) Transduction (b) Transcription (c) Transformation (d) Replication

236. DNA is concentrated in
(a) Chromatin (b) Ribosome (c) Nucleus (d) Plastid

237. Purines of DNA are represented by
(a) Uracil and thymine (b) Guanine and adenine
(c) Uracil and cytocine (d) Thymine and cytocine

238. DNA is transcribed by some viral RNA using the enzyme
(a) DNA polymerase (b) Reverse transcriptase (c) Endonuclease (d) Ligase

239. Transcription of DNA is aided by
(a) RNA polymerase (b) DNA polymerase (c) Exonuclease (d) Recombinase

240. Transcription means synthesis of
(a) DNA (b) rRNA (c) m-RNA (d) t-RNA

241. Watson and Crick are known for their discovery that DNA
(a) Is a single stranded helix (b) Contains deoxyribose only
(c) Is a double stranded helix (d) Synthesizes rRNA

242. A nucleoside differs from a nucleotide in not having
(a) Phosphate (b) Sugar (c) Nitrogen base (d) Phosphate and sugar

243. Semiconservative model of DNA replication was proposed by which workers in eukaryotes
(a) Taylor, Woods and Hughes (b)Meselson and Stahl
(c) Nirenberg and Khorana (d)Watson and Crick

244. A nucleotide is a molecule consisting of a
(a) Hexose sugar, phosphorus and albumen (b) Phosphorus, iron and calcium
(c) Phosphate, 5-carbon sugar and nitrogen base (d) RNA and glucose

245. New strand of DNA are found in the 5′–3′ direction from the 3′–5′ template DNA by the addition of ------ to the 3′ end of primer RNA

(a) Deoxyribonucleotide (b)Deoxyribonucleoside

(c)Amino terminous (d)Carboxy terminous

246. The two strands of DNA are bound together by

(a) Metallic bonds (b) Peptide bonds (c) Hydrogen bonds (d) Coordinate covalent bonds

247. Chemically DNA differs from RNA in having

(a) Thymine in place of uracil (b)Single strand

(c) Ribose sugar instead of deoxyribose sugar (d) All of the above

248. Anticodon is

(a) Paired triplet of bases on messenger RNA (b) Unpaired triplet of bases on rRNA

(c) Paired triplet of bases on rRNA

(d) An unpaired triplet of bases in an exposed position of tRNA

249. Which of the following bases are attached with double bond

(a) $C = G$ (b) $A - T$ (c) $A \equiv T$ (d) $A = C$

(e) $A = T$

250. DNA replication is

(a) Conservative (b) Non-conservative (c) Semi-conservative (d) Constitutive

251. The *A/U* and *G/U* ratio in RNA is

(a) $\neq 0$ (b) = *T/A* Ratio (c) = *A/T*-Ratio (d) None of these

252. In DNA when AGCT occur, their association is as per the following pairs

(a) AG–CT (b) AC–GT (c) AT–GC (d) All are possible

253. RNA contains the following sugar

(a) Glucose (b) Ribose (c) Hexose (d) Fructose

254. DNA was discovered by

(a) Meischer (b) Robert Koch (c) Flemming (d) Altmann

255. If the DNA strand has the nitrogenous base sequence ATTGCC, the mRNA will have

(a) ATTGCA (b) ATCGCC (c) UGGACC (d) UAACGG

256. A unit composed of a sugar and base linked by β-glycosidic bond is known as a

(a) Nucleotide (b) Nucleoside (c) Glycoside (d) Purine

257. mRNA is a polymer of

(a) Deoxyribonucleosides (b)Ribonucleosides (c) Deoxyribonucleotides (d) Ribonucleotides

258. Restriction endonculease

(a) Cut single strand of DNA (b)Cut double strand of DNA

(c) Join the strand of DNA (d)Cut RNA strand

259. A nucleoside is

(a) Base + sugar (b) Base + phosphate

(c) Sugar + phosphate (d) Base + sugar + phosphate

260. DNA replication is aided by

(a) DNA polymerse only (b) DNA ligase only

(c) Both DNA polymerase and ligase (d) RNA polymerase

261. If the sequence of bases in DNA is ATTCGATG, then the sequence of bases in its transcript will be

(a) GUAGCUUA (b) UAAGCUAC (c) CAUCGAAU (d) AUUCGAUG

262. The enzyme which can cut molecules of DNA into segments is known as

(a) DNA polymerase (b) DNA ligase (c) Restriction enzyme (d) DNA gyrase

263. In DNA base pairing occurs as

(a) Thymine with adenine and cytosine with thymine

(b)Adenine with thymine and cytosine with guanine

(c) Thymine with cytosine and guanine with adenine

(d)Adenine with cytosine and guanine with thymine

264. DNA consists of two complementary nucleotide chains. If the sequence of nucleotide in one of the chains is AGCTTCGA, then the nucleotide sequence in the other chain shall be

(a) TAGCATAT (b) GATCCTAG (c) TCGAAGCT (d) GCTAAGCT

265. During transcription, if the nucleotide sequence of the DNA strand that is being coded is ATACG, then the nucleotide sequence in the mRNA would be

(a) UAUGC (b) UATGC (c) TATGC (d) TCTGG

266. Circular DNA is present in

(a) E.R. and ribosomes (b) Ribosomes and chloroplasts

(c) Ribosomes and mitochondria (d) Mitochondria and chloroplasts

267. Okazaki segments are formed during

(a) Transduction (b) Transcription (c) Replication (d) Translation

268. DNA polymerase helps in

(a) Splitting of two DNA strands (b)Proof reading of DNA

(c) Renaturation of DNA (d)Joining monomers of DNA

269. A compound made of a nitrogen base, a pentose sugar and phosphate it is called

(a) Nucleoside (b) Nucleotide (c) Purine (d) Glycoside

270. Transcription is aided by

(a) DNA polymerase (b) DNA ligase (c) RNA polymerase (d) None of these

271. The one which is capable of self replication is

(a) DNA (b) RNA (c) Enzyme (d)Protein

272. The nitrogenous basses in DNA are

(a) AUGC (b) UTGC (c) ATGC (d) ATUC

273. Octamer which form complex unit with DNA is called

(a) Nucleosome (b) Centrosome (c) Chromosome (d) Endosome

274. Orientation of the two strands of DNA duplex is

(a) 1' → 2'
3' → 5'

(b) 5' → 3'
3' → 5'

(c) 1' → 6'
6' → 1'

(d) 3' → 4'
4' → 3'

275. Short segments of DNA called Okazaki fragments are synthesized during DNA replication. This replication occurs in

(a) 3' → 5' direction

(b) 5' → 3' direction

(c) It is not certain

(d) Only terminal part of strand

276. Eukaryotic genome differs from prokaryotic genome in

(a) DNA is circular and single stranded in prokaryote

(b)Intervening sequences are present in eukaryotic DNA

(c) DNA is complexed with histones in prokaryote

(d) DNA is organised into Operons in eukaryotes

277. Which is recognition site of tRNA

(a) Anticodon (b) Loop I (c) Loop IV (d) 3-OH end

278. The collection of bacteria with cDNA is called

(a) DNA clones (b) DNA library (c) Genomic DNA library (d)None of these

279. Prokaryote genetic system has

(a) DNA and histone (b)DNA and no histone

(c) No DNA and histone (d)No DNA and no histone

280. Purines in RNA are

(a) Adenine and guanine (b)Thiamine and cytosine

(c) Thymine and uracil (d)Uracil and cytosine

281. Which type of RNA is most abundant in cell

(a) m RNA (b) t RNA (c) r RNA (d) Catalytic RNA

282. The model of DNA was proposed by

(a) Watson and Crick (b) Robert hook (c) Schleiden and Schwann (d) None of these

283. DNA and RNA are different molecules as

(a) DNA has cytosine and RNA has guanine

(b) DNA has uracil and RNA has thiamine

(c) DNA is a micromolecule and RNA is a macromolecule

(d) DNA has thymine and RNA has uracil

284. A nucleoside similar from nucleotide in having

(a) Nitrogen base (b) Sugar (c) Phosphate group (d) Bot h (a) and (b)

285. CCA base sequence is present in which part of tRNA

(a) Anticodon loop (b) Variable loop (c) 3′ end (d) 5′ end

286. DNA strand is directly involved in the synthesis of all the following except

(a) tRNA molecule

(b) mRNA molecule

(c) Another DNA strand

(d) Protein synthesis

287. Which of the following enzymes is used to join bits of DNA

(a) Ligase (b) Primase (c) Endonuclease (d) DNA polymerase

288. The direction of DNA replication is

(a) From 5′ end towards 3′ end (b) From 3′ end towards 5′ end

(c) Amino terminus to carboxy terminus (d) Carboxy terminus to amino terminus

289. In DNA, when AG-CT occur, their association is as per which of the following pair

(a) AG-CT (b) AC-GT (c) AT-GC (d) AGC-GCT

290. DNA is mainly found in

(a) Nucleus only (b) Nucleus and cytoplasm

(c)Cytoplasm only (d) Nucleus and cell well

291. The number of hydrogen bonds between adenine and thymine in a DNA molecule are

(a) Two (b) Three (c) Four (d) Eight

292. The similarity between DNA and RNA is that both of them have same

(a) Sugars (b) Purines (c) Pyrimidines (d) None of these

293. Histone proteins are synthesized in

(a) M - Phase (b) S - Phase (c) G_1 - Phase (d) G_2 - Phase

294. Which of the following pyrimidine base in present in *RNA* but not in *DNA*

(a) Thymine (b) Cytosine (c) Guanine (d) Uracil

295. H.J. Muller was awarded Nobel prize in 1946 for his work on

(a) X-ray mutation in animals (Drosophila) (b) Chemistry of nucleic acid

(c) Human cancer (d) Mechanism of protein synthesis

296. Synthesis of mRNA takes place by

(a) Replication (b) Transformation (c) Transduction (d) Transcription

297. DNA replication takes place at

(a) *S*-phase (b) G_1-phase (c) G_2-phase (d) *M*-phase

298. Which base is not found in DNA

(a) Guanine (b) Cytosine (c) Uracil (d) Adenine

299. Cistron is

(a) Functional unit of DNA (b)Functional unit of RNA

(c) Nonfunctional unit of DNA (d)Nonfunctional unit of RNA

300. How many nucleotides are present in one turn DNA helix

(a) 8 (b) 10 (c) 6 (d) 100

301. The carrier of genetic information is

(a) DNA (b) Ribosomal RNA (c) Ribosomes (d) Transfer RNA

302. In which of the following will DNA melt at the lowest temperature

(a) 5’-AATAAAGC-3’ (b) 5’-AATGCTGC-3’ (c) 5’-ATGCTGAT-3’ (d) 5’-GCATAGCT-3’
5’-TTATTTCG-3’ 5’-TTACGACG-3’ 5’-TACGACTA-3’ 5’-CGTATCGA-3’

303. The noble prize for unravelling the helical structure of protein and suggesting three stands in DNA helix was received by

(a) Watson and Crick (b) Wilkins (c) Thomas Morgan (d) Linus Pauling

304. DNA strands are antiparallel because of

(a) H-bonds (b)Phospho-diester bonds

(c)Disulphide (S-S bonds) (d)None of the above

305. Ribozyme is

(a) RNA without sugar (b) RNA without phosphate

(c) RNA having enzymic activity (d) RNA with extraphosphate

306. In DNA if 10% guanine is present, how much thymine is present

(a) 10% (b) 40% (c) 80% (d) 20%

307. The binding site of t RNA with m RNA and amino acids respectively are

(a) m RNA with DHU loop end and amino acid with CCA end

(b) m RNA with CCA end and amino acid with anticodon loop

(c) m RNA with anticodn loop and amino acid with DHU loop

(d) m RNA with anticodon loop and amino acid with CCA end

308. Mark the correct statement

(a) m RNA is polycistronic in eukaryotes and monocistronic in prokaryotes

(b) m RNA is polycistronic in prokaryotes and monocistronic in eukaryotes

(c) m RNA is polycistronic in both eukaryotes and prokaryotes

(d) m RNA is monocistronic in both eukaryotes and prokaryotes

309. Anticodons are found in

(a) m RNA (b) t RNA (c) r RNA (d) All of these

310. The following ratio is generally constant for a given species

(a) G + C / A + T (b) A + C / T + G (c) A + G / C + T (d) T + C / G + A

311. Exon part of m – RNAs has code for

(a) Protein (b) lipid (c) Phospholipid (d) Carbohydrate

312. Which of the following pairs is correctly matched

(a) Central dogma-codon (b)Okazaki fragments-splicing

(c) RNA polymerase-RNA primer (d)Restriction enzymes-genetic engineering

313. Which of the following RNAs picks up specific amino acid (from amino acid pool) in the cytoplasm to ribosome during protein synthesis

(a) tRNA (b) mRNA (c) rRNA (d) All of these

314. A sequence of how many nucleotides in messenger RNA makes a codon for an amino acid

(a) One (b) Two (c) Three (d) Four

315. The coiling of double strands in DNA is

(a) Left handed (b) Right handed (c) Parallel (d) Symmetrical

316. Which of the following is nongenetic, which is utilised for protein synthesis

(a) DNA (b) zDNA (c) mRNA (d) None of these

317. Hargovind Khorana related with

(a) Discovery of transposons (b) Artificial gene synthesis

(c) Genetic code (d) Disease resistant maize

318. During DNA replication the term leading strand is applied to the one which replicate

(a) $5' \rightarrow 3'$ direction continuously (b) $3' \rightarrow 5'$ direction continuously

(c) $5' \rightarrow 3'$ direction discontinuously (d) $3' \rightarrow 5'$ direction discontinuously

319. DNA multiplication is called

(a) Translation (b) Transduction (c) Transcription (d) Replication

320. The substance that acts as connecting link between two generations is

(a) Ribonucleic acid (b) Deoxyribonucleic acid (c)Nucleoplasm (d) Both (a) and (b)

321. If one strand of DNA has the base sequence CAT, GAC, TAG what would be the base sequence in the other strand

(a) GTA, CTG, ATC (b) GAT, GTC, ACT (c) TAC, ACT, GCT (d) CAT, TAG, GAC

322. Eukaryotic RNA polymerase III catalyse the synthesis of

(a) mRNA (b) tRNA (c) 18.5 rRNA (d) Introns

323. The enzyme DNA polymerase was discovered by

(a) Kornberg (b) Okazaki (c) Watson and Crick (d) Jacob and Monad

324. Nucleic acid can be fragmented by the enzyme

(a) Polymerases (b) Nucleases (c) Proteases (d) Ligases

325. What is false about tRNA

(a) It binds with an amino acid at it 5′ end

(b) It has five double stranded regions

(c) It has a codon at one end which recognized the anticodon on messenger RNA

(d) It looks like clover leaf in the three dimensional structure

326. Which RNA is having least age

(a) m RNA (b) t RNA (c) r RNA (d) None of these

327. A type of genetic material present in bacteria is

(a) DNA bound with protein (b)DNA not bound with protein

(c) RNA bound with protein (d)RNA not bound with protein

328. Which of the following is not correct

(a) $\frac{A}{T} = 1$ (b) $A + T = G + C$ (c) $A + G = C + T$ (d) None of these

329. Non-genetic RNA is of

(a) One type (b) Two type (c) Three type (d) Non-functional type

330. Fuelgen reaction is employed to detect the presence of

(a) DNA (b) RNA (c) Protein (d) Fats

331. Clover leaf model of tRNA has

(a) Acceptor arm and C arm (b) Anticodon arm

(c) D arm (d) All the above

332. Franklin and Wilkins showed that DNA

(a) Contains four bases (b) Is a helix

(c) Has equal amount of adenine and thymine (d) Is made up of nucleotides

333. Which one of the following pairs of terms/names mean one and the same thing

(a) Gene pool - Genome (b) Codon – Gene

(c) Cistron - Triplet (d) DNA fingerprinting – DNA profiling

334. Which form of RNA has a structure resembling clover leaf

(a) m RNA (b) t RNA (c) r RNA (d) hn RNA

335. DNA was artificially synthesized in *vitro* by

(a) Ochoa and Nirenberg (b)Ochoa and Kornberg

(c) Kornberg and Nirenberg (d)Nirenberg and Khorana

336. One turn of DNA possesses

(a) One base pair (b) Two base pairs (c) Five base pairs (d) Ten base pairs

337. Match the following and mark the correct option

Column A	Column B
(i) Oncogenes	(1) Causes AIDS
(ii) Single circular DNA	(2) Lac-Operon concept
(iii) Splicing	(3) Component of bacterial chromosome
(iv)Jacob and Monad	(4) Processing of mRNA molecules
	(5) When activated cause cancer

	(i)	(ii)	(iii)	(iv)
(a)	(5)	(4)	(1)	(2)
(b)	(5)	(3)	(4)	(1)
(c)	(5)	(3)	(4)	(2)
(d)	(1)	(3)	(4)	(2)

338. Genes which confer antibiotic resistance on bacteria are located on

(a) Chromosomal DNA (b) Plasmid (c) RNA (d) Polysome

339. Ribosomal RNA is synthesised in

(a) Nucleolus (b) Nucleosome (c) Ribosome (d) Lysosome

Advance Level

340. Eukaryotes differ from prokaryotes in the mechanism of DNA replication due to

(a) Different enzymes (instead of same enzyme) for synthesis of lagging and leading strands

(b) Discontinuous rather than semidiscontinuous replication

(c) Use of DNA primers rather than RNA primers

(d) Unidirectional rather than bidirectional replication

341. Who used heavy nitrogen N^{15} for proving semiconservative way of DNA replication

(a) Masters and Broda (b) Meselson and Stahl

(c) Watson and Crick (d) Jacob and Monad

342. Base of DNA finger prints is

(a) Presence of donar DNA (b) Knowledge of human karyotypes

(c) Restriction fragments length polymorphism (d) Character dissimilarities in human

343. If the DNA codons are ATG ATG ATG and a cytosine base is inserted at the beginning, which of the following will result

(a) A non-sense mutation (b)CA TGA TGA TG (c) CAT GAT GAT G (d) C ATG ATG ATG

344. Heterogenous nuclear RNA

(a) Has lesser number of nucleotides (b) Has at least 50 nucleotides

(c) Has about 100 nucleotides (d) Has about 200 or more nucleotides

345. Double stranded DNA virus with 20,000 base pairs has nucleotides

(a) 20,000 (b) 10,000 (c) 666 (d) 40,000

346. Quantitative analysis of DNA was made by

(a) Watson and Crick (b) Rosalind Franklin (c) Erwin Chargaff (d) Messelson and Stahl

347. The helical structure of DNA is maintained by

(a) Amide bonds (b) H-bond (c) Covalent bonds (d) Phosphodiester bonds

348. The pattern of protein binding on DNA can be studied by

(a) Light microscope (b) X-ray crystallography

(c)Electron microscope (d) Ultracentrifugation

349. If 50 heavy DNA (N^{15}) are replicated 2 time in N^{14} medium, what is obtained

(a) 100 half heavy and half light and 100 light (b) 100 heavy and 100 light

(c) 50 heavy and 150 light (d) None of the above

350. The X-ray crystallography studies of Franklin and Wilkins (1953) showed that

(a) DNA has four types of bases (b)DNA is a helix uniform diameter of 20A

(c) Amount of A is equal to T (d)Same base pairing rule applies to all species

351. What is meant by sense strand

(a) The strand of mRNA involved in protein synthesis

(b) The strand of tRNA which starts protein synthesis

(c) The DNA strand which acts as a template for mRNA transcription

(d) Gradually growing molecule of protein

352. The 5 polypeptide chains of *E. coli* RNA polymerase are

(a) $\beta,\ \beta^1, \beta^2, \sigma, \alpha$ (b) $\beta, \beta^1, \sigma, \alpha, \omega$ (c) $\alpha, \beta, \beta^1, \beta^2, \omega, \sigma$ (d) $\alpha, \beta, \gamma, \omega, \sigma$

353. Life span of mRNA in *E. coli* is

(a) Less than one minute (b)2 minutes

(c) Five minutes (d)More than 10 minutes

354. Which one of the following peak absorption of ultraviolet light by heterocyclic basses (Nitrogen bases)

(a) 1500 *nm* (b) 26 *nm* (c) 75 *nm* (d) 260 *nm*

355. In his experiments on the chemistry of DNA Chargaff estimated the base composition of human sperms and found that adenine constituted 31% and guanine 19%. The quantity of cytosine in the DNA of human somatic cell is likely to be

(a) 31% (b) 19% (c) 38% (d) 68%

356. Bacteria were grown in a medium containing heavy isotope of nitrogen (N^{15}) for many generation and all their DNA contained many heavy nitrogen only. A bacterium of this was transferred to normal medium and allowed to duplicate. After two division of heavy DNA is likely to be that

(a) Only one daughter cell will have heavy DNA

(b) Two daughter cells have normal DNA and other have both normal and heavy DNA

(c) All daughter cells have heavy DNA

(d) Half daughter cells have heavy DNA and other half have normal DNA

357. Ultraviolet light block replication process by forming

(a) Abnormal DNA (b) Thymine dimers (c) Causing mutation (d) All the above

358. Catalytic property of RNA was discovered by

(a) Altmann and Bend (b) Ochoa and Korenberg

(c)Altmann and Cock (d) Fuelgen and Beherence

359. The 3 dimensional structure of tRNA is

(a) Clover leaf shape (b) Heart shape (c) 'L' shapes (d) 'T' shape

360. Taylor demonstrated chromosome replication to be semiconservative in

(a) *Vicia faba* (b) Root cell (c) Pea (d) Mouse liver cell

361. The formation of multivalents at meiosis in diploid organism is due to

(a) Deletion (b) Inversion

(c) Monosomy (d) Reciprocal translocation

362. It is easy to remove DNA histone complex with

(a) $NaCl+Mg(OH)_2$ (b) NaCl only

(c) $Mg(OH)_2$ only (d) Cannot be pulled by chemicals

363. Eukaryotic mRNA are modified by the addition (at their b end) of

(a) Guanosine repeat sequence (b) 7-methyl guanosine cap

(c) Methylated argenine (d) Cytosine cap

364. A radiolabelled cDNA or genomic variance DNA sequence to which it is complementary in sequence is called

(a) Gene cloning (b) Gene family (c) Gene probe (d) Gene therapy

365. After attacking *E. coli* the λ phage first transcribes for nucleases which degrades the host DNA but phage DNA is not affected by the nucleases because it contains

(a) Methylatad adenine (b) Antinucleases (c) Methylated cytosine (d)Uracil

366. For replication viruses use

(a) Its own ribosome, tRNA and other machinery (b) Host ribosome, tRNA and other machinery

(c) Host DNA (d) Host genome

367. The enzyme that breaks H_2 bonds in DNA is

(a) Helicase (b) Topoisomerase (c) Ligase (d) Polymerase

368. The successive nucleotides of RNA are covalently linked through in

(a) Hydrogen bonds (b) Phosphodiester bonds

(c) Glycosidic bonds (d) None of these

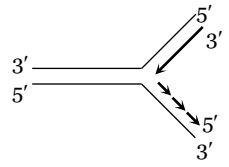
369. Hybrid DNA formed as a result of recombination it is called

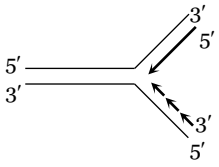
(a) Homoduplex DNA (b) Heteroduplex DNA (c) Z-DNA (d) B-DNA

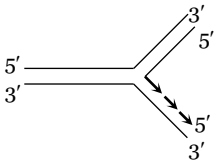
370. Cyclic adenosine monophosphate was discovered by

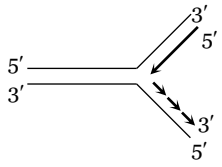
(a) Bekhor *et al.* (b) E.W. Sutherland (c) Beerman (d) Weismann

371. Which one of the following correctly represents the manner of replication of DNA

(a) 

(b) 

(c) 

(d) 

372. Histone occupies the major grooves of DNA at an angle of

(a) 15° (b) 90° (c)45° to the helix axis (d) 30° to the helix axis

PROTEIN SYNTHESIS

Basic Level

373. The synthesis of mRNA by DNA is called

(a) Translation (b) Transcription (c) Transformation (d) Transduction

374. The processes by which mRNA is made by DNA and protein by mRNA are respectively called as

(a)Transcription and translation (b)Translation and transcription

(c) Synthesis of mRNA and protein (d)Replication of mRNA and protein

375. The genes are responsible for growth and differentiation in an organism through regulation of

(a) Translocation (b) Transformation

(c) Transduction and translation (d) Translation and transcription

376. Who discovered "Reverse transcription"

(a) Watson and Crick (b) Beadle and Tatum (c) Temin and Baltimore (d)Khorana

377. 'Central Dogma' was proposed by

(a) Watson and Crick (b) Beadle and Tatum (c) Temin and Batimore (d)Klug

378. Which of the following RNA carries information from DNA in protein synthesis

(a) mRNA (b) rRNA (c) tRNA (d) sRNA

379. What is correct for protein synthesis
(a) Code transfer on mRNA (b)Code transfer on tRNA
(c) Coding is done by DNA strands (d)DNA coding takes place in antiparallel fashion

380. Translation is a process which is
(a) Unidirectional (b) Bidirectional (c) Multidirectional (d) Radial

381. Transcription is a process by which
(a) Amino acids are joined to form polypeptides
(b) An RNA molecule is synthesized on a DNA template
(c) An RNA molecule is synthesized within a ribosome
(d) Two daughter strands of DNA are synthesized

382. The process of RNA formation from DNA is called
(a) Transition (b) Translation (c) Transversion (d) Transcription

383. Protein synthesis takes place on
(a) Mitochondria (b) Ribosomes (c) Chloroplasts (d) Golgi bodies

384. Teminism is the same as
(a) Translation (b) DNA synthesis
(c) Transcription (d) Reverse transcription

385. Teminism phenomenon was discovered by
(a) Temin and Baltimore (b)Temin and Jacob (c) Temin and Levine (d) Stem and Sutton

386. Protein synthesis in an animal cell, which takes place
(a) Only in the cytoplasm (b) In the nucleolus as well as in the cytoplasm
(c) In cytoplasm as well as mitochondria (d) Only on ribose attached to nucleon

387. Which of the following step of translation does not consume a high energy phosphate bond
(a) Translocation (b) Amino acid activation
(c) Peptidyl transferase reaction (d) Amino acyl tRNA binding to A-site

388. In protein synthesis the polymerization of amino acids involves three steps. Which of the following is not involved in protein synthesis
(a)Elongation (b) Transcription (c) Termination (d) Initiation

389. Which of the following type of RNA molecule is essential for protein synthesis
(a) m-RNA (b) t-RNA (c) r-RNA (d) All of these

390. The name of Temin and Baltimore is associated with
(a) Photorespiration (b) RNA synthesis (c) Reverse transcription (d)All of these

391. Which one of the following triplet codes, is correctly matched with its specificity for an amino acid in protein synthesis or as 'start' or 'stop' codon
(a) UAC-Tyrosine (b) UCG- Start (c) UUU - Stop (d) UGU - Leucine

392. Which amino acid has no asymmetrical carbon atom
(a) Glycine (b) Threonine (c) Histidine (d) Proline

393. A peptide chain assumes secondary structure through the formation of
(a) Interchain ionic bond (b)Interchain hydrogen bond
(c) Peptide bond (d) Interchain disulphide linkage

394. Which of the following will be translated into a protein

(a) UAA AUG CCC TCC ATT ATG (b)AUG CCC UCU AUA GUA GTC.

(c) UAA CCC UCU AUA GUA GUC (d)AUG CCC UCU AUG GUC UAG

395. Translation is the process in which

(a) DNA is formed on DNA template (b) RNA is formed on DNA template.

(c) DNA is formed on RNA template (d) Protein is formed from RNA message

396. Genes express their character by forming

(a) Enzymes (b) Carbohydrates (c) Fats (d) Vitamins

397. What are informosomes

(a) They are special types of tRNA

(b)They are more stable forms of eukaryotic mRNA

(c) They are eukaryotic rRNA (d)Both (b) and (c)

398. Synthesis of any protein in a cell determines

(a) Types of ribosomes (b) Mitochondria

(c) Sequence of nucleotides in DNA (d) Suger and phosphate of DNA

399. Which of the following is a sulphur containing amino acid

(a) Alanine (b) Glycine (c) Methionine (d) Valine

400. Consider the following

1. Structural gene 2. Messenger RNA 3. Ribosomes
4. Transcription 5. Translation

Which of the following is the correct sequence for protein synthesis

(a) 1, 4, 3, 2, 5 (b) 1, 4, 5, 2, 3 (c) 1, 4, 2, 3, 5 (d) 3, 5, 4, 2, 1

401. DNA strand is involved in the synthesis of following

(a) mRNA (b) tRNA

(c) Other DNA strand (d) All of these

Advance Level

402. Which type of RNA molecules copy the nucleotide sequence from DNA dictate the sequence of amino acids in the growing polypeptide chain

(a) mRNA (b) rRNA (c) tRNA (d) HnRNA

403. After transcription takes place, the DNA molecule

(a) Distintegrates (b) Move of cytoplasm

(c) Replicates itself (d) Reassociates to form its original structure

404. Who proposed the 'signal hypothesis' meant for the biosynthesis of secretory type of proteins

(a) Baltimore (b) Camillo Golgi

(c) Blobel and Sabatini (d) Sheeler and Bianchi

405. Who first suggested the idea of circular flow of genetic information

(a) Barry Commoner (b) Nirenberg (c) Matthaei (d) Phil lader

GENE REGULATION AND GENETIC CODE

Basic Level

406. Assumption that *genetic code* is a *triplet* was suggested by

(a) Gamow (b) Beadle and Tatum

(c) S. Brenner (d) Nirenberg and Mathaei

407. Wild type *E.coli* cells are growing in normal medium with glucose. They are transferred to a medium containing only lactose as the sugar. Which one of the following changes take place

(a) The lac-Operon is repressed (b)All Operons are induced

(c) *E. coli* cells stop dividing (d)The lac-Operon is induced

408. Genetic code of nucleic acid depends upon

(a) Number of nucleic acid (b)Position of nucleic acid

(c) Sequence of nucleic acid (d)All the above

409. When more than one codon code for the same amino acid, this is called as

(a) Universal nature of genetic code (b)Redundancy of genetic code

(c) Punctuation in genetic code (d)Continuous nature of genetic code

410. The lac-Operon is an example of

(a) Arabinose Operon (b) Inducible Operon (c) Repressible Operon (d) Overlapping genes

411. The arrangement of three bases in the genetic code signifies a specific

(a) Protein (b) Amino acid (c) Plasmid (d) Nucleic acid

412. The genetic code is called a degenerate code because

(a) More than one codon has the same meaning (b) 1 codon has many meaning

(c) 1 codon has one meaning (d) There are 64 codons

413. A triplet codon means

(a) A sequence of three nitrogen bases on mRNA (b) A sequence of three nitrogen bases in tRNA

(c) A sequence of three bases in rRNA (d) The presence of only three bases in mRNA

414. The Operon model of gene regulation and organization in prokaryotes was proposed by

(a) Jacob and Monod (b) Beadle and Tatum

(c) Meselson and Stahl (d) Wilkins and Franklin

415. Triplet for inhibiting process of translation is

(a) *UAU* (b) *UAA* (c) *UAC* (d) *UGG*

416. In mRNA, AUG is the initiation codon and UAA, UAG and UGA are termination codons, therefore polypeptide cannot be synthesized beyond any of these triplets to the end of mRNA. Then which one of the following mRNA can be translated completely

(a) AUG UUC UCC UGG UAA UAU (b) AUG UUC UCC UGA UGG UAU

(c) AUC ACG UAU UUC UGA CUC (d) AUG UAU UUC UGC CUC UAG

417. Genetic code consists of

(a) 4 codons, each with two nucleotides (b) 16 codons, each with four nucleotides

(c) 64 codons, each with two nucleotides (d) 64 codons, each with three nucleotides

418. Genes (also called factors, alleles, merkmets) are the unit of information. These are stable and discrete and therefore, do not get blended as thought earlier when the hereditary material was supposed to be a fluid (blood). Who concluded that these discrete stable units are responsible for expression of traits

(a) Mendel (b) Morgan (c) Kolreuter (d) Gelton

419. The genetic code necessary for building up its own amino acids during the multiplication of virus, is carried by

(a) The virus nucleic acid (b)The virus protein

(c) The host protein (d)The host nucleic acid

420. Nirenberg and Mathaei synthesized RNA using only

(a) Guanine (b) Uracil (c) Cytosine (d) None of these

421. Genetic code was cracked (deciphered) by

(a) Watson and crick (b) Beadle and Tatum

(c) Gamow (d) Nirenberg, Mathaei and Khorana

422. Codon of mRNA and anticodon of tRNA is made of

(a) A set of three out of U,A,C and G (b) Three and one nitrogen bases respectively

(c) A set of two nitrogen bases (d)A set of three and two respectively

423. Wobble hypothesis was given by

(a) R. W. Holley (b) H. G. Khorana (c) M. Nirenberg (d) F. H. C. Crick

424. Who explained the Operon model for the first time

(a) Francois Jacob (b) Jacques Monod

(c) Francois Jacob and Jacques Monod (d) None of these

425. Which of the following statements about genetic code is correct

(a) It is triple, universal, ambiguous and degenerate

(b)It is triplet, universal, non-ambiguous and degenerate

(c) It is triplet, universal, non-ambiguous and non-degenerate

(d) It is triplet, universal, non-ambiguous and non-generate

426. Who proposed the Operon model of gene regulation

(a) Khorana (b) Monod (c) Jacob (d) Jacob and Monod

427. What does 'lac' refer to in what we call the lac Operon

(a) The number 1,00,000 (b) Lactose

(c) Lactase (d) Lac insect

428. An inactive repressor produced by regulator gene that does not block the operator site in the tryptophan operon is called

(a) Aporepressor (b) Intron (c) Exon (d) Clone

429. In trp Operon the co-repressor is

(a) Tryptophan (b) Lactose (c) β - galactoside (d) Glucose

430. A sequence of three bases code along the DNA molecule is called

(a) Genetic code (b) Gene pool (c) Genetic drift (d) Genome

431. The sequence of genes in lac – Operon in *E. coli* are

(a) Promotor gene → operator gene → structural gene

(b) Structural gene → promotor gene → operator gene

(c) Operator gene → promotor gene → structural gene

(d) Structural gene → operator gene → promotor gene

432. Which is not true for Operon model

(a) Regulator gene (b) Promotor gene (c) Repressor gene (d) Operator gene

433. Jacob and Monad studied lactose metabolism in *E. coli* and proposed Operon concept, which is applicable for

(a) Prokaryotes (b) Eukaryotes (c) Protozoanes (d) All of these

434. In *E. coli*, during lactose metabolism repressor binds to

(a) Regulator gene (b) Promoter gene (c) Operator gene (d) Structural gene

435. Which one of the following is not a component of lac Operon model

(a) Primer gene (b) Structural gene (c) Regulator gene (d) Promoter gene

436. The enzyme responsible for transcription is

(a) DNA polymerase I (b) RNA polymerase (c) Reverse transeriptase (d)DNA polymerase III

437. Functional unit of gene is

(a) Muton (b) Recon (c) Cistron (d) Codon

438. Which of the following is a non-sense codon

(a) DNA (b) GCG (c) UUU (d) UAG

439. In Operon concept regulator gene functions as

(a) Repressor (b) Regulator (c) Inhibitor (d) Initiator

440. Functioning of structural genes is controlled by

(a) Operator (b) Promoter (c) Ligase (d) Regulatory gene

441. Degeneration of a genetic code is attributed to the

(a) Third member of a codon (b)First member of a codon

(c) Second member of a codon (d)Entire codon

442. The codons causing chain termination are

(a) TAG, TAA, TGA (b) GAT, AAT, AGT (c) AGT, TAG, UGA (d) UAG, UGA, UAA

443. Who first discovered genetic code

(a) Khorana (b) Nirenberg and Mathaei

(c)Kornberg (d) Phil Lader and Barnett

444. Genes that are involved in turning on or off the transcription of a set of structural genes are called

(a) Polymorphic genes (b) Operator genes

(c) Redundant genes (d) Regulatory genes

445. An environmental agent that triggers transcription from an Operon is a

(a) Derepressor (b) Inducer (c) Regulator (d) Controlling element

Advance Level

446. Out of 64 codons, 61 codons code for 20 types of amino acid. It is called
(a) Wobbling of codon (b)Overlapping of gene
(c) Universility of codons (d)Degeneracy of genetic code

447. In yeast mitochondria UGA codes for
(a) Termination codon (b) Initiation codon (c) Tryptophan (d) Tyrosine

448. The complex CAP-cAMP which increases the affinity of RNA polymerase for lac Operon promoter so that the lac- genes are transcribed, is formed in
(a) Cytoplasm (b) Low glucose concentration
(c) High glucose concentration (d) High glycerate concentration

449. Regulator gene controls chemical synthesis (Operon concept) by
(a) Inhibiting transcription (b)Inhibiting enzymes
(c) Inhibiting passage of mRNA (d)Inhibiting substrate enzyme reaction

450. According to Operon theory, an operator gene combines with
(a) Inducer gene to switch on structural gene transcription
(b) Regulator gene to switch on structural gene transcription
(c) Regulator protein to switch off structural gene transcription
(d) Regulator protein to switch on structural gene transcription

LINKAGE AND CROSSING OVER

Basic Level

451. The scientists who have given the theory of linkage are
(a) Morgan and Castle (b) Beadle and Tatum (c) Watson and Crick (d) Bateson and Punnet

452. When two genes are situated very close to each other in a chromosome
(a) The percentage of crossing over between them is very high
(b) Hardly any cross over are detected
(c) No crossing over can take place between them
(d)Only double cross overs can takes place between them

453. Crossing-over occurs in the
(a) Leptotene stage (b) Pachytene stage (c) Anaphase stage (d) Diakinesis stage

454. Crossing over completed in
(a) Diakinesis (b) Pachytene (c) Diplotene (d) Zygotene

455. Which of the theory is concerned with crossing over
(a) Copy choice theory (b) Precocity theory (c) Both (a) and (b) (d) None

456. Role of cyclic AMP in lac Operon is
(a) Positive control (b) Magnetic control (c) Negative control (d) Both (b) and (c)

457. Linked gene are separated by
(a) Crossing over (b) Mutation (c) (a) and (b) both (d) None of these

458. Lack of independent assortment of two genes *A* and *B* in fruit fly *Drosophila* is due to
(a) Linkage (b) Crossing over (c) Repulsion (d) Recombination

459. Crossing over occurs in
(a) Four strand stage (b) Three strand stage (c) Two strand stage (d) Single strand stage

460. If gene exchange rate is 30% of the two linked genes, then the distance between these two gene is
(a) 30 unit (b) 15 unit (c) 60 unit (d) 45 unit

461. Exchange of chromosome segments between maternal and paternal chromatids during synapsis in meiosis is called
(a) Linkage (b) Crossing over (c) Dominance (d) Mutation

462. Linkage decrease the frequency of
(a) Recessive allele (b) Dominant allele (c) Hybridization (d) Mitochondria and chloroplasts

463. Crossing over that results in genetic recombination in higher organisms occurs between
(a) Two daughter nuclei (b) Two different bivalents
(c) Sister chromatids of a bivalent (d) Non-sister chromatids of a bivalent

464. Linkage was first studied by
(a) Darwin (b) Morgan (c) Bateson and Punnett (d) Mendel

465. Linkage was first observed in
(a) Field pea (b) Sweet pea (c) Pea (d) Grass pea

466. Crossing over during meiosis occurs at which of the following stage
(a) Daikinesis (b) Leptotene (c) Zygotene (d) Pachytene

467. Two dominant nonallelic genes are exactly 50 map unit apart. It means that linkage is
(a) 'CIS' type (b) 'TRANS' type (c) Complete (d) Absent

468. To show the linkage for the first time…….plant was worked on
(a) *Pisum sativum* (b) *Zea mays* (c) *Oenothera lamarkiana* (d)*Lathyrus odoratus*

469. Genetic recombination is due to
(a) Fertilization and meiosis (b) Mitosis and meiosis
(c) Fertilization and mitosis (d) None of these

470. Crossing over in diploid organism is responsible for
(a) Dominance of genes (b) Linkage between genes
(c) Segregation of alleles (d) Recombination of linked allele

471. Coupling and repulsion are the two faces of
(a) Crossing over (b) Linkage (c) Chiasmata (d) Mutation

472. Which one of the following pair is correctly matched
(a) Van Helmont Discovered mutations
(b) Louis Pasteur Wrote "The origin of Species"
(c) T.H. Morgan Studied sex-linked inheritance
(d) H.Khorana Studied DNA replication

Advance Level

473. *Drosophila melanogaster* has

(a) 2 pairs of autosomes and 1 pair of sex chromosomes

(b) 3 pairs of autosomes and 1 pairs of sex chromosomes

(c) 1 pair of autosomes and 3 pairs of sex chromosomes

(d) 2 pairs of autosomes and 2 pairs of sex chromosomes

474. The four daughter cells derived from a single meiosis differ from each other due to

(a) Difference in chromosome number (b) Crossing over only

(c) Independent assortment of chromosomes

(d) Crossing over as well as independent assortment of chromosomes

475. What will be the number of linkage groups in maize if it has 10 pairs of chromosomes

(a) 5 (b) 10 (c) 0 (d) 20

476. Sexual reproduction leads to

(a) Genetic recombination (b)Polyploidy (c) Aneuploidy (d) Euploidy

477. Complete linkage is reported in

(a) Neurospora (male) (b) Neurospora (female) (c) Drosophila (male) (d) Drosophila (female)

478. The degree of intensity with which two genes are linked together is known as

(a) Linked genes (b) Linkage value

(c) Mulational genes (d) Linked value

479. The evidence that crossing over occurs at four stranded stage and not at two stranded stage of chromosomes, comes from

(a) 2 : 2 : 2 : 2 arrangement of ascospores in *Neurospora*

(b) 4 : 4 arrangement of ascospores in *Neurospora*

(c) Studies of meiosis in maize

(d) Studies on linkage maps of chromosomes in *Drosophila*

480. The word 'crossing over' is given by

(a) Bateson (b) Darlington (c) Morgan (d) Muller

ANSWER

ASSIGNMENT (BASIC & ADVANCE LEVEL)

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
c	b	c	a	d	a	c	b	a	c	c	a	c	a	a	d	d	a	b	c
21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
d	c	c	b	c	c	b	b	a	b	b	c	a	a	d	c	a	c	b	a
41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60
c	b	d	a	d	b	a	b	b	d	c	b	c	b	c	d	d	b	a	d
61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80
b	c	b	a	b	a	b	a	d	d	a	b	c	c	b	a	c	a	a	d
81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100
c	c	c	d	c	c	c	a	b	d	a	a	b	c	b	b	c	d	a	b
101	102	103	104	105	106	107	108	109	110	111	112	113	114	115	116	117	118	119	120
c	b	d	c	a	b	a	a	b	a	a	a	d	b	c	d	d	b	a	b
121	122	123	124	125	126	127	128	129	130	131	132	133	134	135	136	137	138	139	140
a	d	d	b	c	a	b	d	d	a	b	d	b	b	a	b	d	a	c	c
141	142	143	144	145	146	147	148	149	150	151	152	153	154	155	156	157	158	159	160
c	d	d	b	b	c	c	a	d	c	b	b	b	a	d	d	c	d	c	d
161	162	163	164	165	166	167	168	169	170	171	172	173	174	175	176	177	178	179	180
d	c	b	a	b	d	a	b	a	c	d	a	c	a	a	a	a	d	a	c
181	182	183	184	185	186	187	188	189	190	191	192	193	194	195	196	197	198	199	200
c	a	a	c	c	d	c	d	c	a	c	d	d	c	d	a	b	a	b	d
201	202	203	204	205	206	207	208	209	210	211	212	213	214	215	216	217	218	219	220
c	a	b	a	d	b	d	b	c	b	b	d	b	a	b	b	a	a	c	d
221	222	223	224	225	226	227	228	229	230	231	232	233	234	235	236	237	238	239	240
d	b	d	d	b	a	a	d	a	c	d	b	d	c	d	a	b	b	a	c
241	242	243	244	245	246	247	248	249	250	251	252	253	254	255	256	257	258	259	260
c	a	b	c	a	c	a	d	e	c	a	c	b	a	d	b	d	b	a	c
261	262	263	264	265	266	267	268	269	270	271	272	273	274	275	276	277	278	279	280
b	c	b	c	a	d	c	d	b	c	a	c	a	b	b	b	a	a	b	a
281	282	283	284	285	286	287	288	289	290	291	292	293	294	295	296	297	298	299	300
c	a	d	d	c	d	a	a	c	a	a	b	b	d	a	d	a	c	a	b

301	302	303	304	305	306	307	308	309	310	311	312	313	314	315	316	317	318	319	320
a	a	d	b	c	b	d	b	b	a	a	d	a	c	b	c	b	a	d	b
321	322	323	324	325	326	327	328	329	330	331	332	333	334	335	336	337	338	339	340
a	b	a	b	a	a	b	b	c	a	d	b	d	b	b	d	c	b	a	b
341	342	343	344	345	346	347	348	349	350	351	352	353	354	355	356	357	358	359	360
b	b	c	b	d	c	b	b	a	b	c	b	b	d	b	b	b	c	c	a
361	362	363	364	365	366	367	368	369	370	371	372	373	374	375	376	377	378	379	380
d	a	c	c	c	b	a	b	b	b	d	c	b	a	d	c	a	a	a	a
381	382	383	384	385	386	387	388	389	390	391	392	393	394	395	396	397	398	399	400
b	d	b	d	a	b	a	b	d	c	a	a	b	d	d	a	b	c	c	c
401	402	403	404	405	406	407	408	409	410	411	412	413	414	415	416	417	418	419	420
d	a	d	c	a	a	d	c	b	b	b	a	a	a	b	d	d	a	a	b
421	422	423	424	425	426	427	428	429	430	431	432	433	434	435	436	437	438	439	440
d	a	d	c	b	d	b	a	a	a	a	c	a	c	a	b	c	d	a	a
441	442	443	444	445	446	447	448	449	450	451	452	453	454	455	456	457	458	459	460
a	d	b	b	b	d	c	b	a	c	a	b	b	a	c	a	a	a	a	a
461	462	463	464	465	466	467	468	469	470	471	472	473	474	475	476	477	478	479	480
b	c	d	c	b	d	b	d	a	d	b	c	b	d	b	a	c	b	a	c