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.*

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.g.* 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.

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).

(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.

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

(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.

(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.

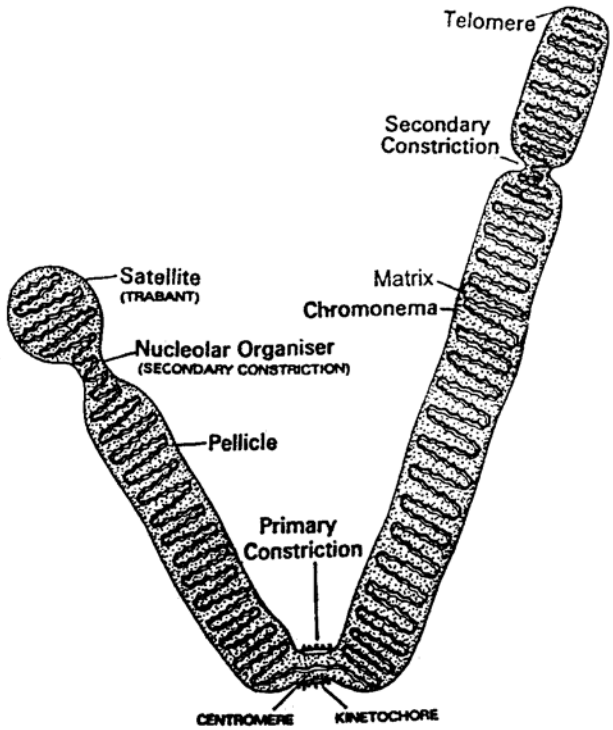

Fig : Structure of chromosome

(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*).

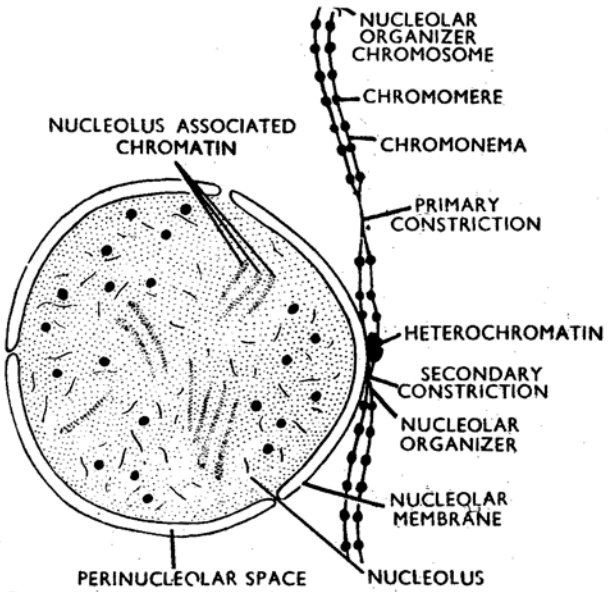

Fig : Nucleolus organizer or secondary constriction and its association with necleolus

(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.

(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.

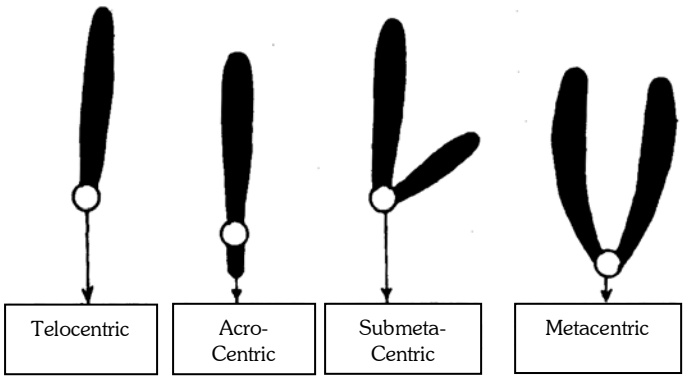

Fig : Types of chromosomes

(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.

(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.

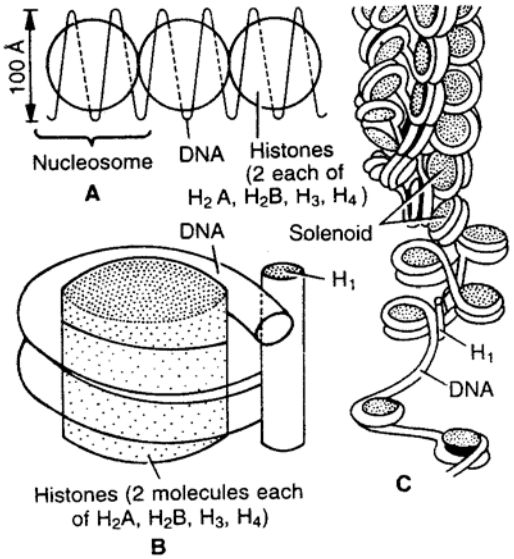

Fig : A-C Nucleosome : A Units of nucleosome, B Nucleosome model C Solenoid model

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 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.

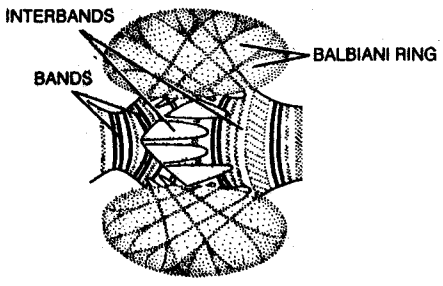

Fig : Polytene chromosome showing balbiani ring

(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* 5900*μm*. 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.

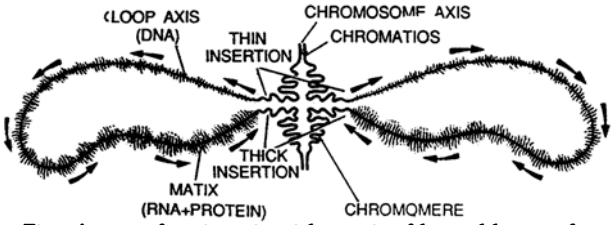

Fig : A part of main axis with a pair of lateral loops of a lampbrush chromosome showing synthesis of RNA

(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.

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

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.*

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**

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.

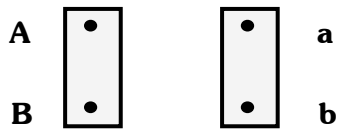

Fig : *CIS* – Arrangement of genes

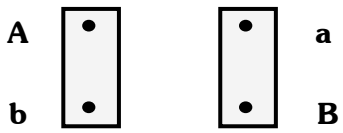

Fig : *TRANS* – Arrangement of genes

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.