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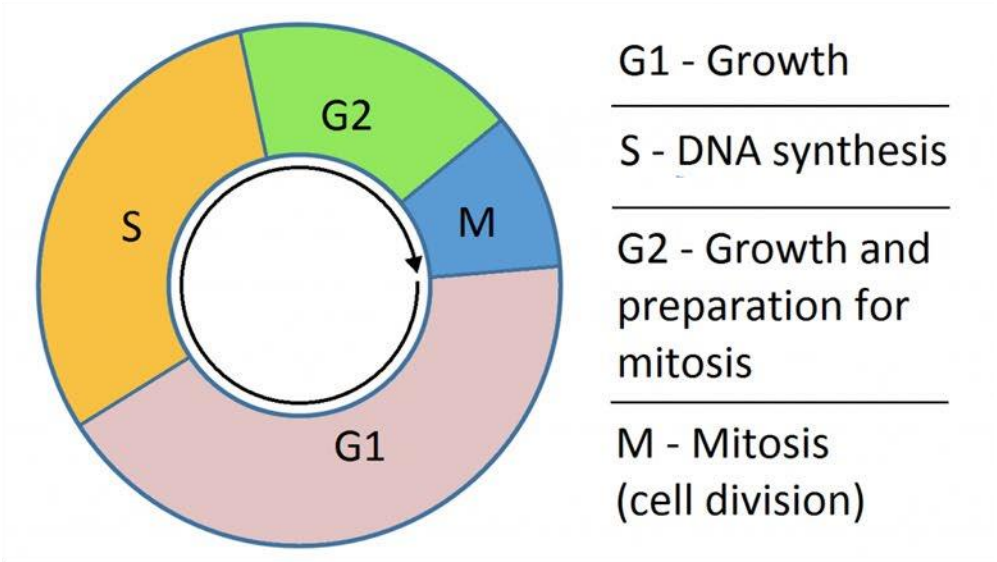
SUBJECT NAME	CELL BIOLOGY
COURSE	M.Sc. LIFE SCIENCE
COURSE DURATION	2 Years
SUBTOPIC NAME	Chromosomes and genome organization
CONTENT TYPE	PDF
SEARCH KEYWORDS	chromosomes, Chromatin, Nucleosome, histones, supercoiling

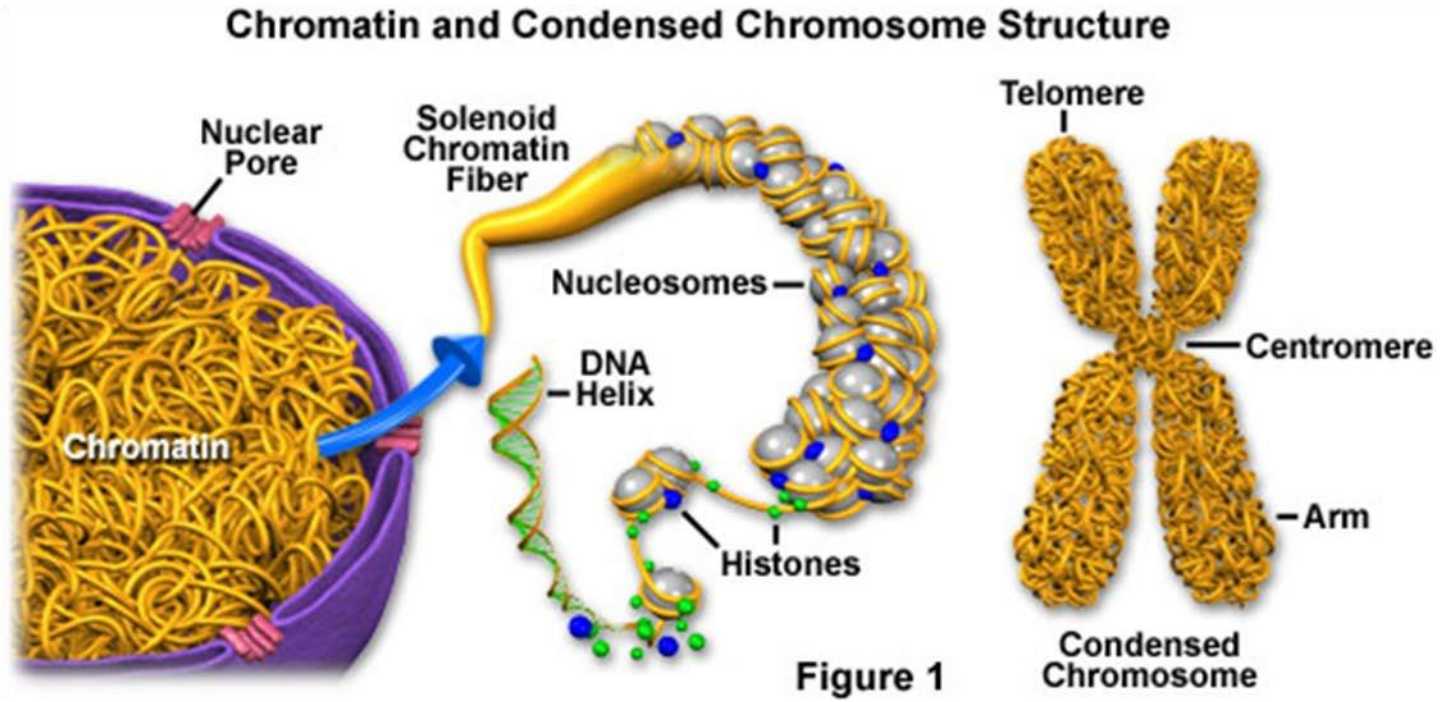
Chromosome and Genome Organization

Genomic Materials

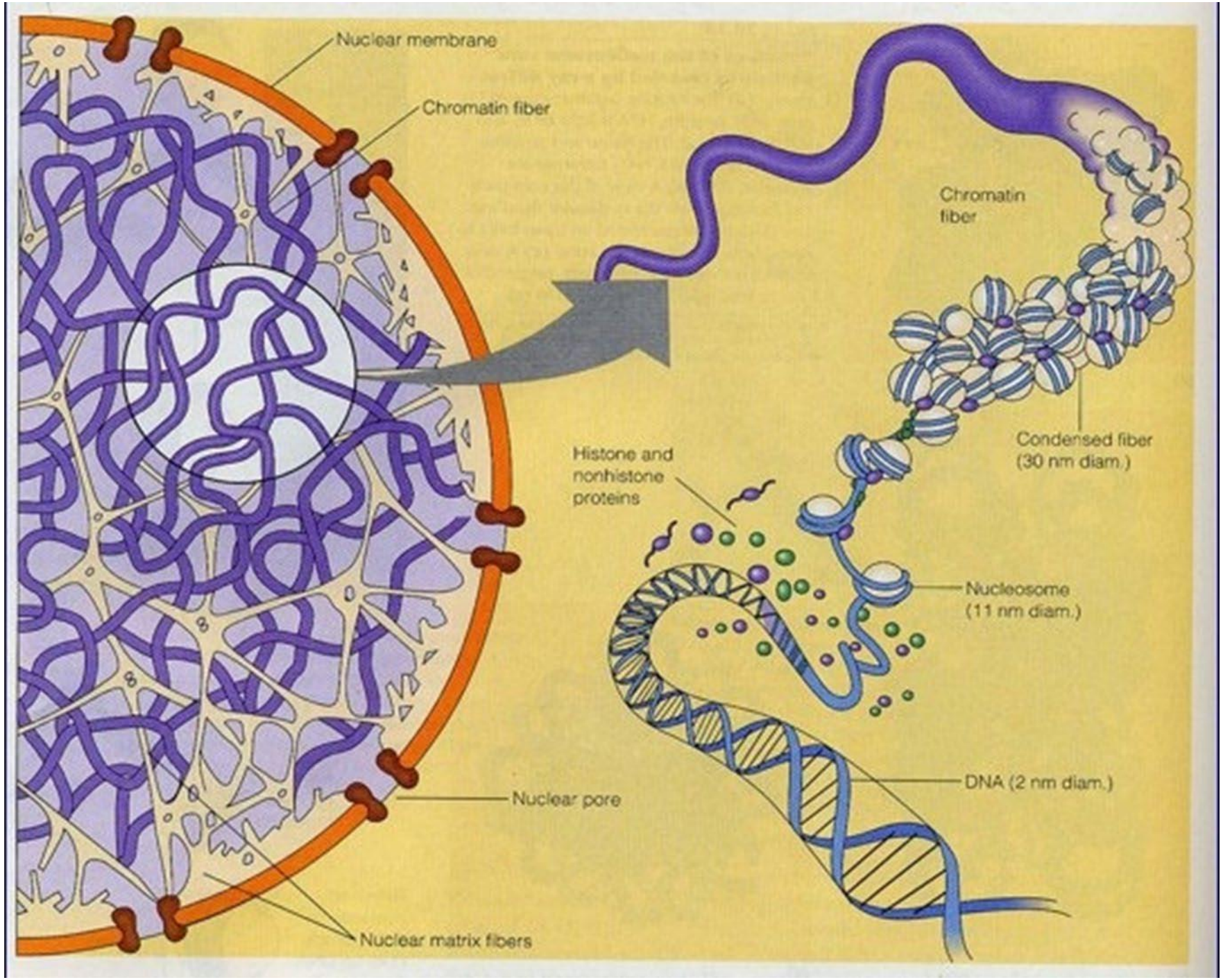
Interphase Nucleus:
In interphase, the chromatin is not yet condensed. Cell performs normal functions.



Mitotic Metaphase Nucleus: chromatin is condensed and organized in the form of chromosomes.



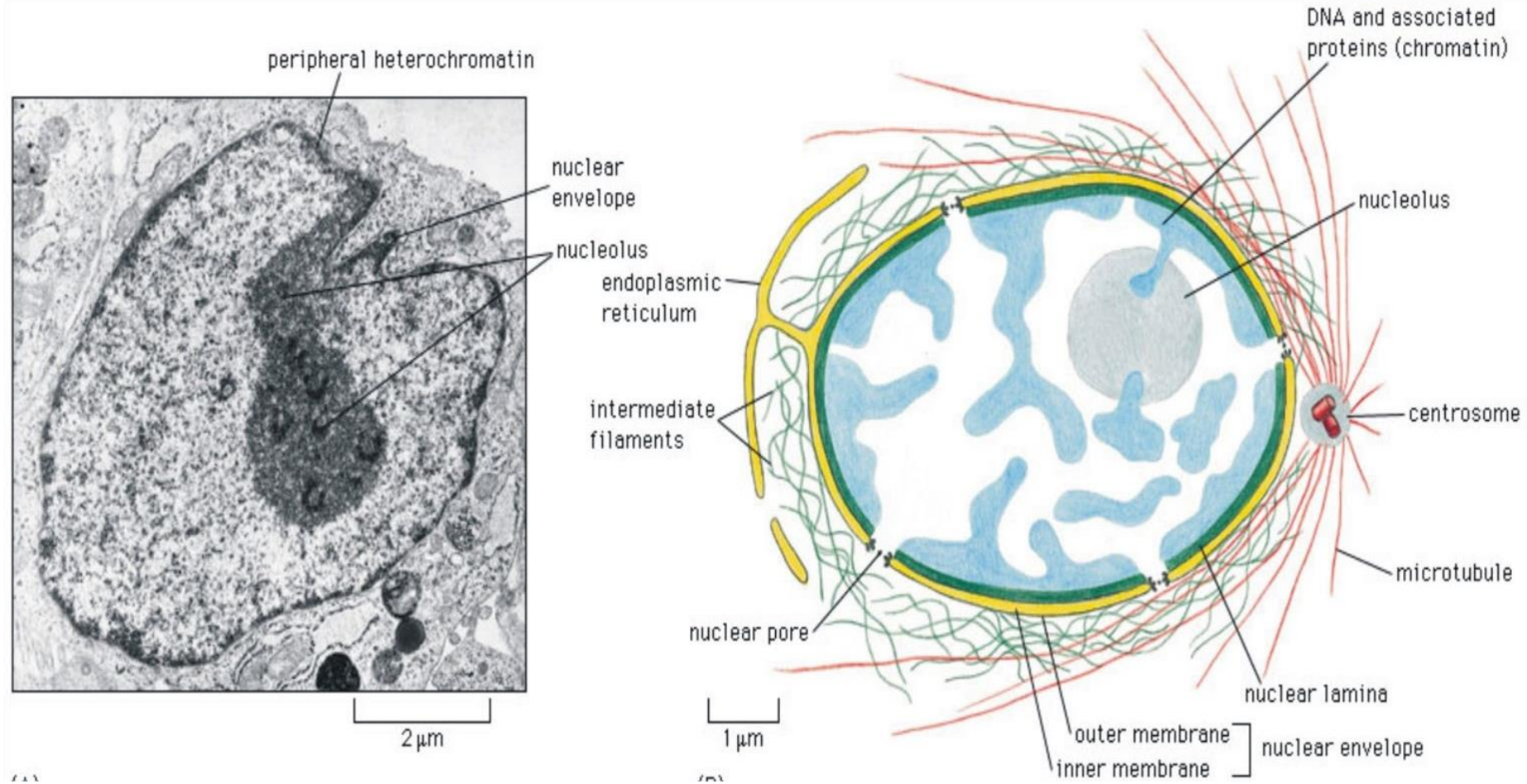
Model for Organization of Chromatin in the Interphase Cell Nucleus



Eukaryotic genetic material: A Eukaryotic cell has genetic material in the form of genomic DNA enclosed within the nucleus. Genes or the hereditary units are located on the chromosomes which exist as chromatin network in the non dividing cell/interphase.

Interphase Nucleus

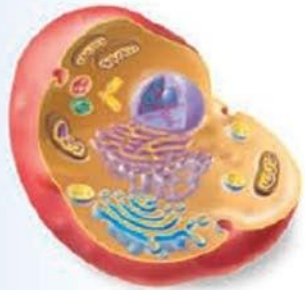
- In interphase, the **chromatin** is not yet condensed.
- Cell performs normal functions.

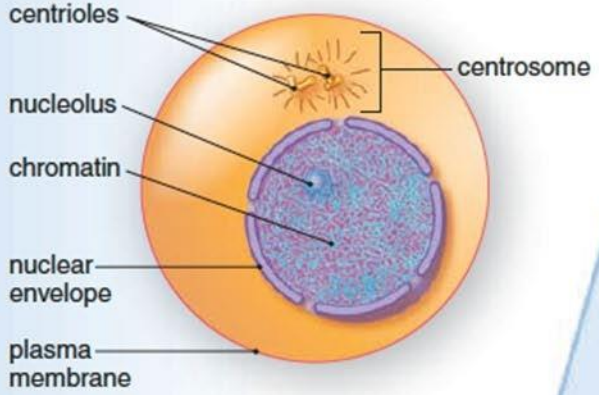


Cell cycle G_1, S, G_2

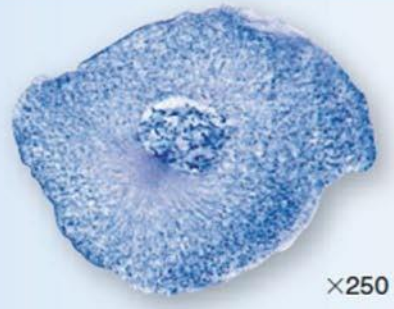
Cell cycle M: Phases of mitosis

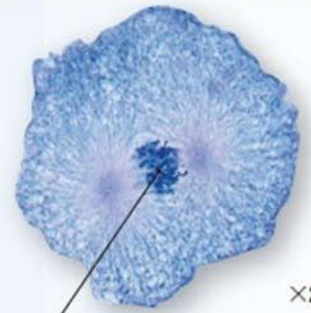
Interphase

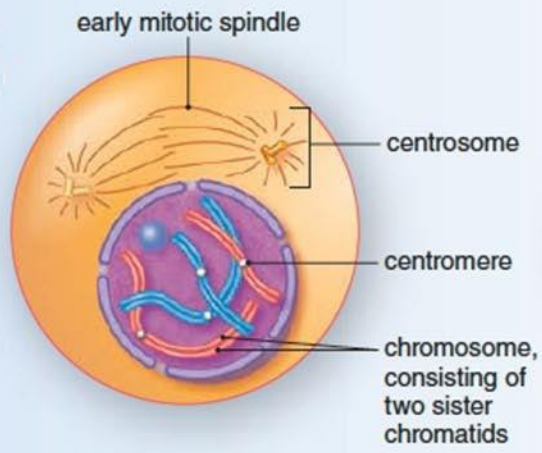


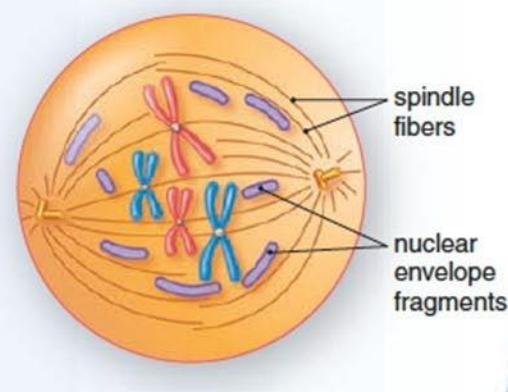


Prophase









Interphase
During interphase, the eukaryotic cell duplicates the contents of the cytoplasm, and DNA replicates in the nucleus. The duplicated chromosomes are not yet visible. A pair of centrosomes is outside the nucleus.

Prophase

During prophase, the chromosomes are condensing. Each consists of two sister chromatids held together at a centromere. Outside the nucleus, the spindle begins to assemble between the separating centrosomes.

Prophase continues with the disappearance of the nucleolus and the breakdown of the nuclear envelope. Spindle fibers from each pole attach to the chromosomes at specialized protein complexes on either side of each centromere. During attachment, a chromosome first moves toward one pole and then toward the other pole.

Chromosome

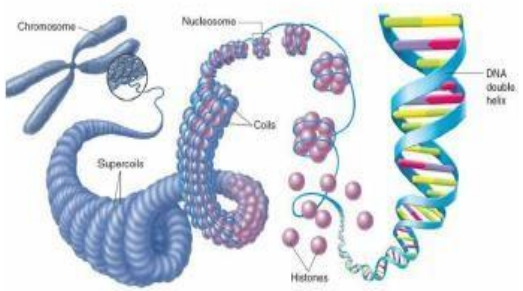
- Chromosomes were first discovered in 1842 by the Swiss botanist Karl Wilhelm von Nageli.
- The name "chromosomes," meaning "colored bodies," was coined by W. Waldeyer in 1888.
- Chromosomes are long string-like structures.
- They are coiled to fit into the nucleus.
- Chromosomes are made of DNA.
- They are the genetic information of the organism.

Size: 05 – 30 µM length 0.2 – 3µM diameter

- Genes, the unit of inheritance are located on the chromosomes of the gametes.
- Passed from parents to progeny.
- Chromosome term was introduced by Waldeyer in 1888.
- Number of chromosomes is fixed in each cell but varies from species to species.
- In human beings, the total number is 46 or 23 pairs named as ‘diploid’ (2n).
- While in gametes (male or female) the number is 23 i.e. ‘haploid’ (n).
- 22 pair chromosomes are autosomes while 1 pair is sex chromosome.
- Length: 4-6 µ

Chemical Constituents

- DNA
- RNA
- Histones (basic in nature)
- Non-histone proteins (acidic in nature)



Chromosomes:

- complexes of DNA and proteins – chromatin
- Viral – linear, circular; DNA or RNA
- Bacteria – single, circular
- Eukaryotes – multiple, linear

Genome

- The genetic material that an organism possesses
- Nuclear genome
- Mitochondrial & chloroplasts genome

Chromosomes

- Tightly packaged DNA
- Found only during cell division
- DNA is not being used for macromolecule synthesis

Chromatin

- Unwound DNA
- Found throughout Interphase
- DNA *is* being used for macromolecule synthesis

Chromosome:

German biologist Walter Flemming in the early 1880s revealed that during cell division the nuclear material organize themselves into visible thread like structures which were named as chromosomes **which stains deep with basic dyes**. The term chromosome was coined by W. Waldeyer in 1888. Chrome is coloured and soma is body, hence they mean "*colored bodies*" and can be defined as higher order organized arrangement of DNA and proteins. It contains many genes or the hereditary units, regulatory elements and other nucleotide sequences. Chromosomes also contain DNA-bound proteins, which serve in packaging the DNA and control its functions. Chromosomes vary both in number and structure among organisms (Table 1) and the number of chromosomes is characteristic of every species. Benden and Bovery in 1887 reported that the number of chromosomes in each species is constant. **W.S. Sutton and T. Boveri in 1902 suggested - chromosomes are physical structures which act as messengers of heredity**.

Chromosomes are tightly coiled DNA around basic histone proteins, which help in the tight packing of DNA. During interphase, the DNA is not tightly coiled into chromosomes, but exists as chromatin. In eukaryotes to fit the entire length of DNA in the nucleus it undergoes condensation and the degree to which DNA is condensed is expressed as its **packing ratio** which is the length of DNA divided by the length into which it is packaged into chromatin along with proteins.

Chromosome number:

There are normally two copies of each chromosome present in every somatic cell. The number of unique chromosomes (N) in such a cell is known as its haploid number, and the total number of chromosomes (2N) is its diploid number.

The suffix 'ploid' refers to chromosome 'sets'. The haploid set of the chromosome is also known as the genome.

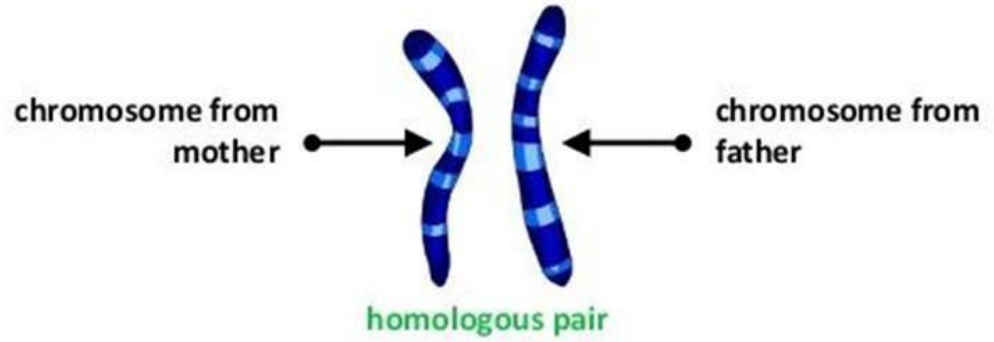
Structurally, eukaryotes possess large linear chromosomes unlike prokaryotes which have circular chromosomes. In Eukaryotes other than the nucleus chromosomes are present in mitochondria and chloroplast too. The number of chromosomes in each somatic cell is same for all members of a given species. The organism with lowest number of chromosome is the nematode, *Ascaris megalocephalusunivalens* which has only two chromosomes in the somatic cells (2n=2).

Table 1: Number of chromosomes in different organisms

Organism	No. of chromosomes
Arabidopsis thaliana (diploid)	10
Maize (diploid)	20
Wheat (hexaploid)	42
Common fruit fly (diploid)	8
Earthworm (diploid)	36
Mouse (diploid)	40
Human (diploid)	46
Elephants (diploid)	56
Donkey (diploid)	62
Dog (diploid)	78
Gold Fish (diploid)	100-104
Tobacco(tetraloid)	48

Types of Chromosomes

•**Homologous chromosomes**pertain to two chromosomes which are same, at least in terms of the gene sequences and loci.

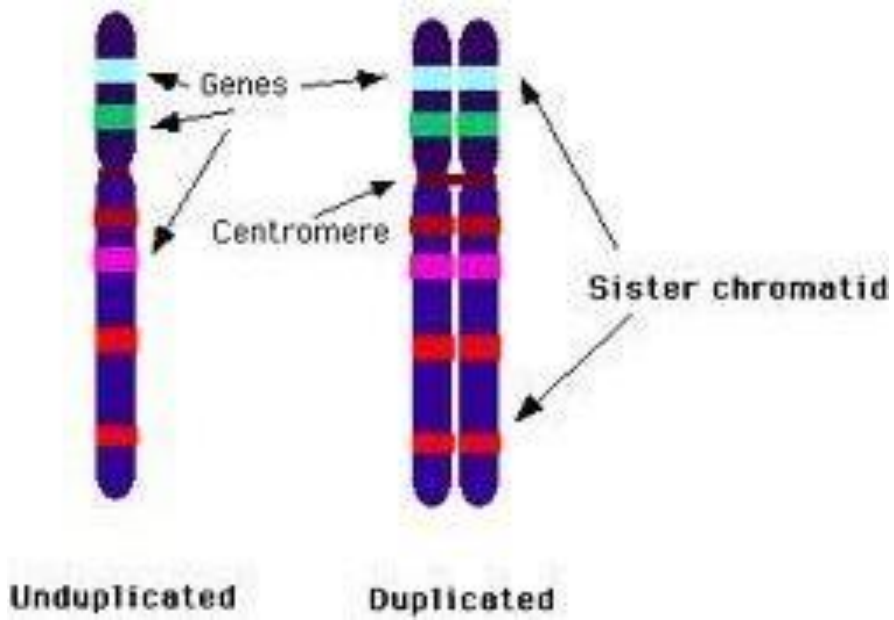


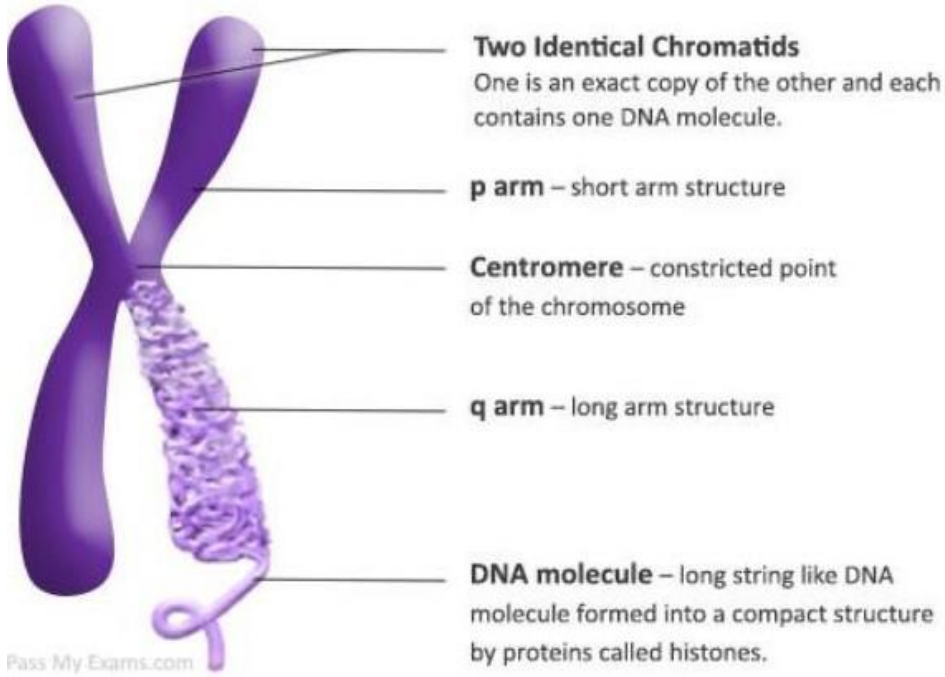
•**Heterologous** (non-homologous) **chromosomes** pertain to any two **chromosomes** that are different, such as in terms of gene sequence and loci.

Size: The size of chromosome is normally measured at mitotic metaphase and may be as short as 0.25µm in fungi and birds to as long as 30 µm in some plants such as Trillium. However, most mitotic chromosome falls in the range of 3µm in Drosophila to 5µm in man and 8-12µm in maize. The monocots contain large sized chromosomes as compared to dicots. Organisms with less number of chromosomes contain comparatively large sized chromosomes. The chromosomes in set vary in size.

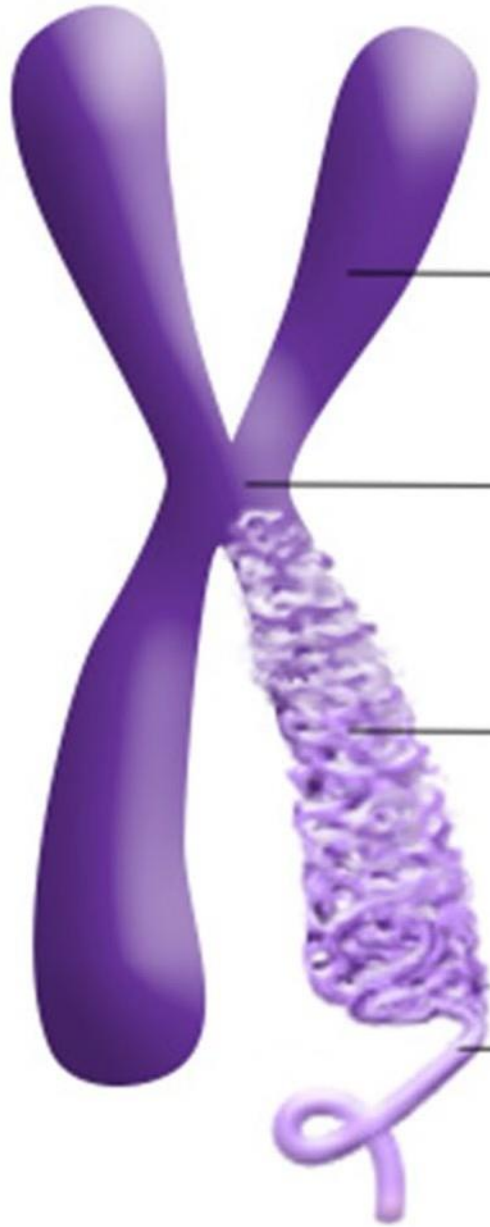
- Longest and thinnest chromosome seen during interphase.
- In prophase, decreases in length with an increase in thickness.
- Smallest chromosome seen during anaphase.

Shape: The shape of the chromosome changes from phase to phase in the continuous process of cell growth and cell division. During the resting/interphase stage of the cell, the chromosomes occur in the form of thin, coiled, elastic and contractile, thread like stainable structures, the chromatin threads. In the metaphase and the anaphase, the chromosome becomes thick and filamentous. Each chromosome contains a clear zone, known as **centromere or kinetochore**, along their length. The centromere divides the chromosome into two parts and each part is called chromosome arm.





Chromosome



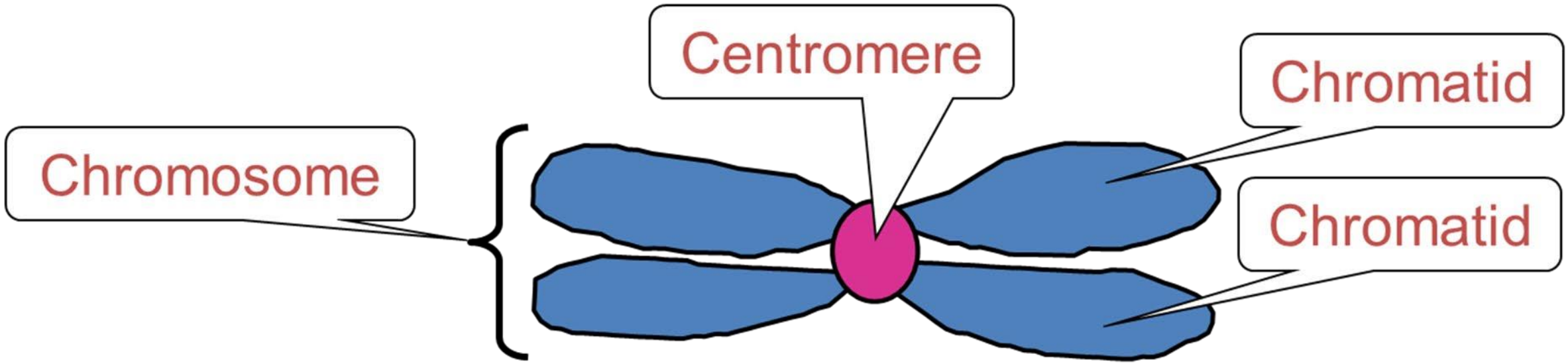
p arm – short arm structure

Centromere – constricted point of the chromosome

q arm – long arm structure

DNA molecule – long string like DNA molecule formed into a compact structure by proteins called histones.

- A chromatid is a chromatid as long as it is held in association with a sister chromatid at the centromere



- When two sister chromatids separate (after metaphase) they go from being a single chromosome to being two different chromosomes

The position of centromere varies from chromosome to chromosome providing it a different shape. They could be **telocentric** (centromere on the proximal end of the chromosome), **acrocentric** (centromere at one end giving it a very short and another long arm), **submetacentric** (J or L shaped chromosome with the centromere near the centre), **metacentric** (v shaped with centromere at the centre).

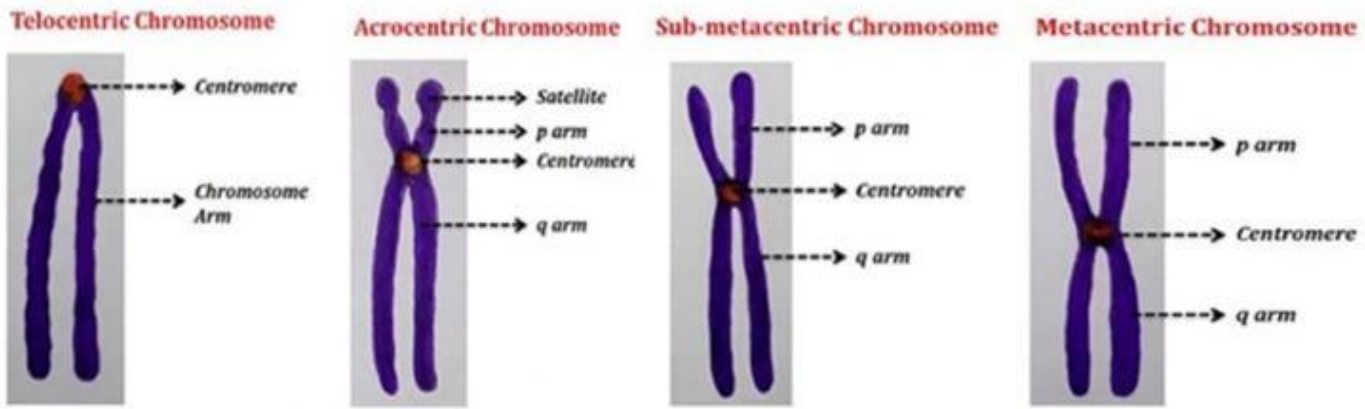
CLASSIFICATION OF CHROMOSOMES

- **According to position of the centromere:**

1. Metacentric
2. Submetacentric
3. Telocentric
4. Acrocentric:

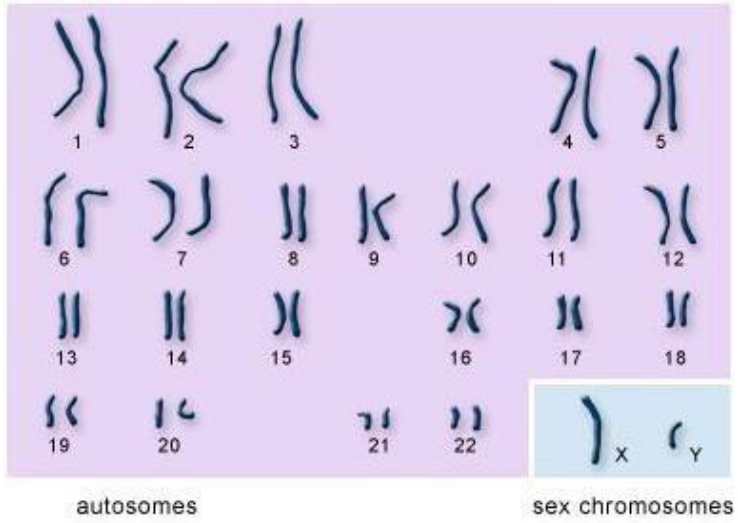
   Satellite chromosomes

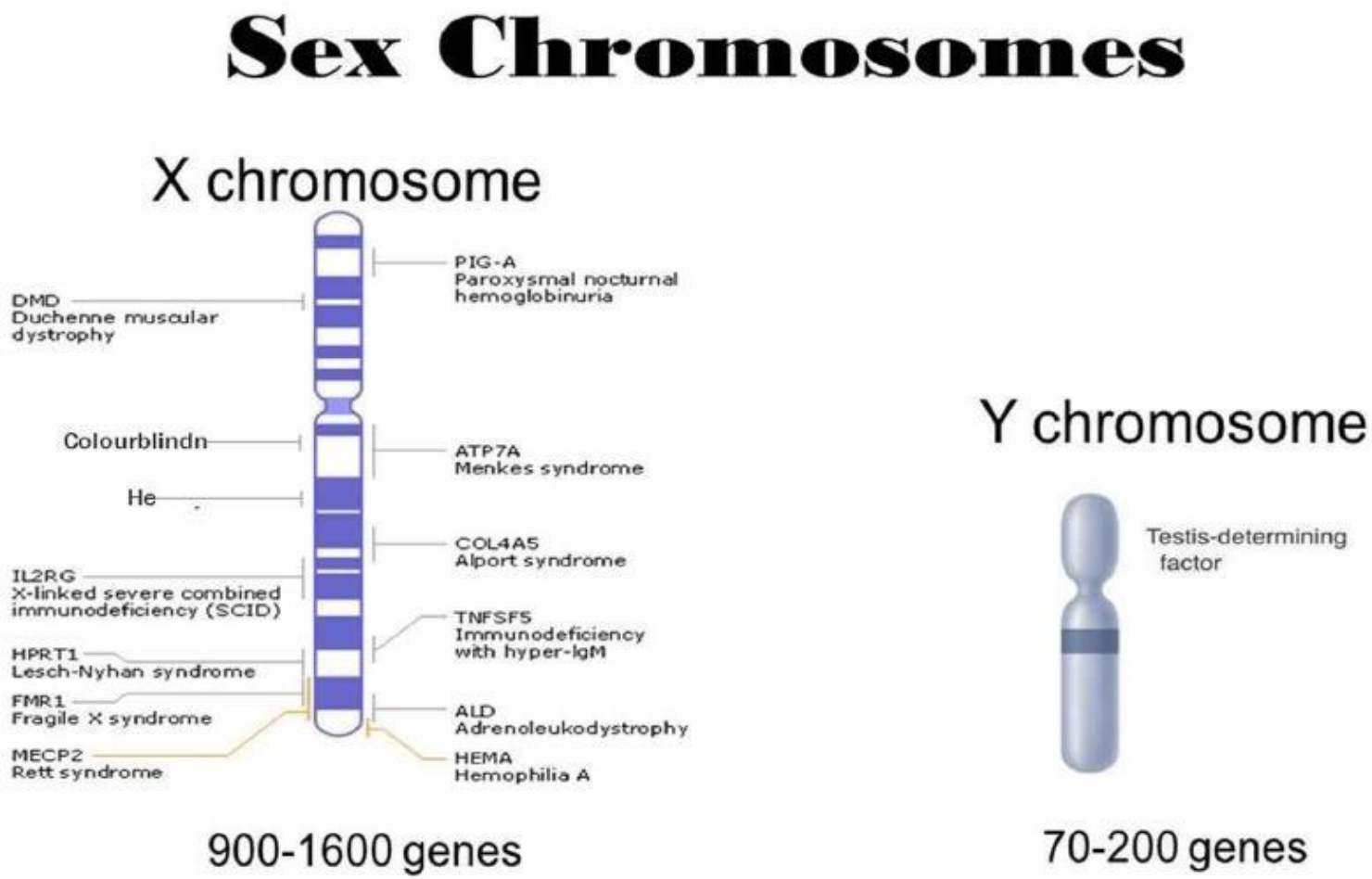
   (SAT chromosomes)



Autosomes and sex chromosomes:

In a diploid cell, there are two of each kind of chromosome (termed homologus chromosomes) except the sex chromosomes. In humans one of the sex has two of the same kind of sex chromosomes and the other has one of each kind. In humans there are 23 pairs of homologous chromosomes (2n=46). The human female has 44 non sex chromosomes, termed autosomes and one pair of homomorphic sex chromosomes given the designation XX. The human male has 44 autosomes and one pair of heteromorphic sex chromosomes, one X and one Y chromosome.





Centromere- It is a localized region of the chromosome with which spindle fibers attached is known as centromere or primary constriction or kinetochore

Chromatid- One of the two distinct longitudinal subunits of a chromosome is called as chromatid. Chromatids are of two types sister chromatids and non-sister chromatids.

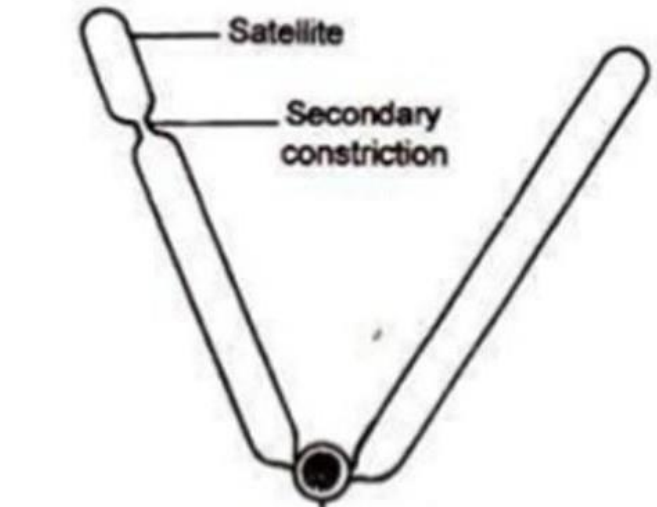
Secondary constriction- Some chromosome exhibits secondary constriction in addition to primary constriction. The chromosomal region between telomere is called as **satellite** or **trapant.** *The chromosome having satellite is called as satellite chromosome.*

Telomere- The two ends of chromosome are called as telomeres. Telomere are highly stable and they do not fuse or unite with telomere of other chromosome.

Chromomere- The chromosomes of some of the species shows small bead like structures called as chromomeres. The structure of chromomeres in chromosome is constant.

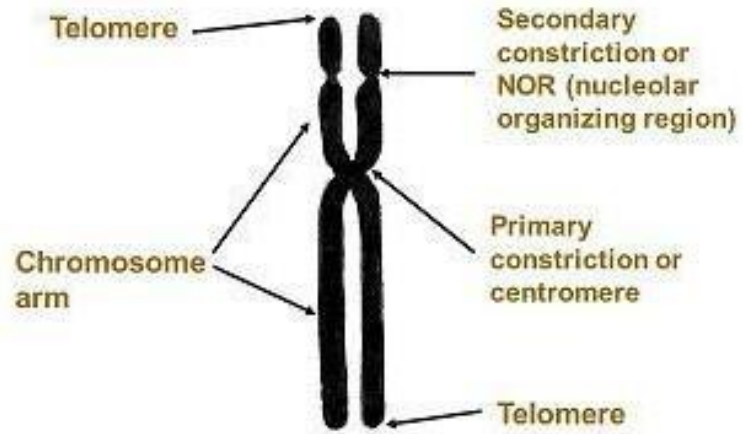
Secondary Constriction

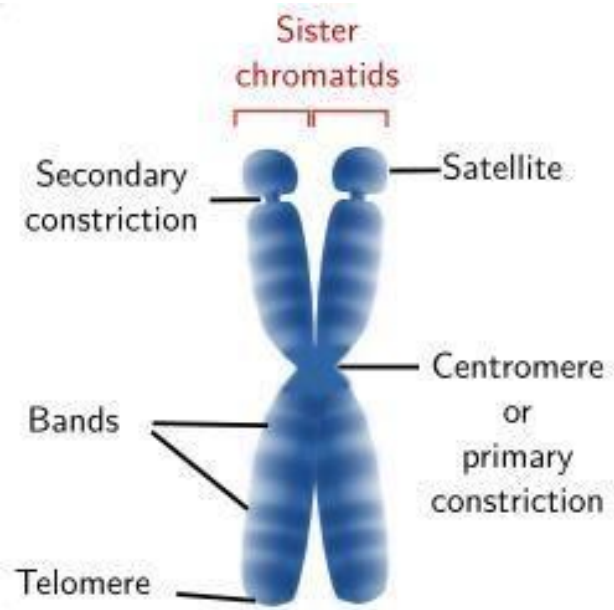
- ✓ In some chromosomes a second constriction, in addition to that due
  centromere (primary constriction) is also present. It is known
  "Secondary constriction).
- ✓ It is present in short arm near one end, or in
  are located in the long arm nearer to
- ✓ The region between the secon
  telomere is known as
  secondary co
  Chro



Centromere located in primary constriction.

- the chromosomes number **13, 14, 15, 21 and 22** are examples of SAT chromosomes





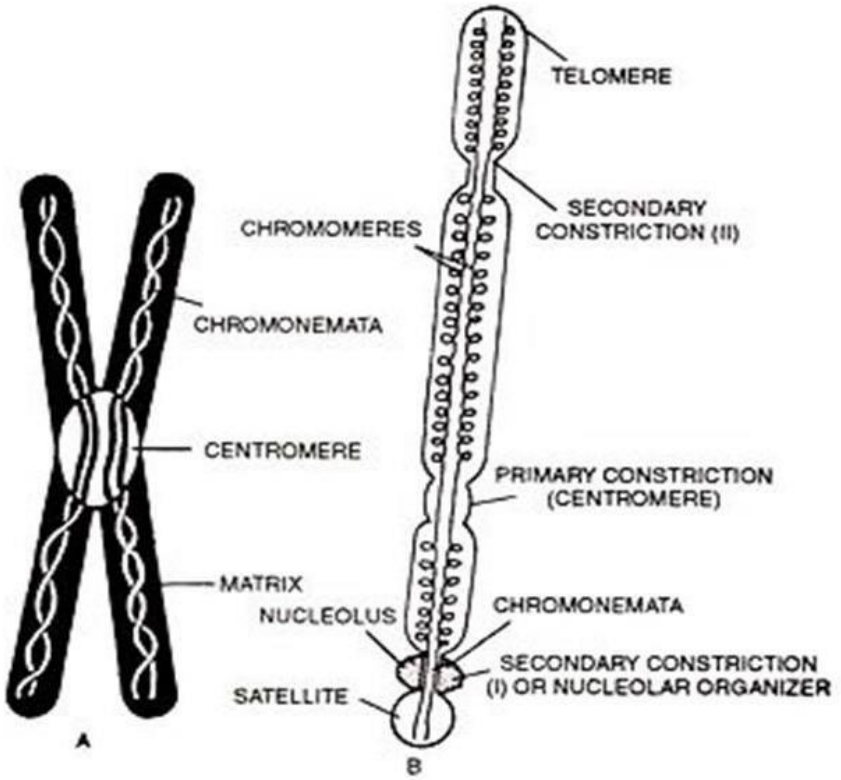
CHROMOMERE

•A chromomere, also known as an idiomere, is one of the serially aligned beads orgranules of a eukaryotic chromosome, resulting from local coiling of a continuous DNA thread

CHROMONEMATA

•The spirally coiled central filament of a chromatid carrying all the inherited instructions, along which the chromomeres are aligned.

•The set of instructions is called as **‘genome’**.

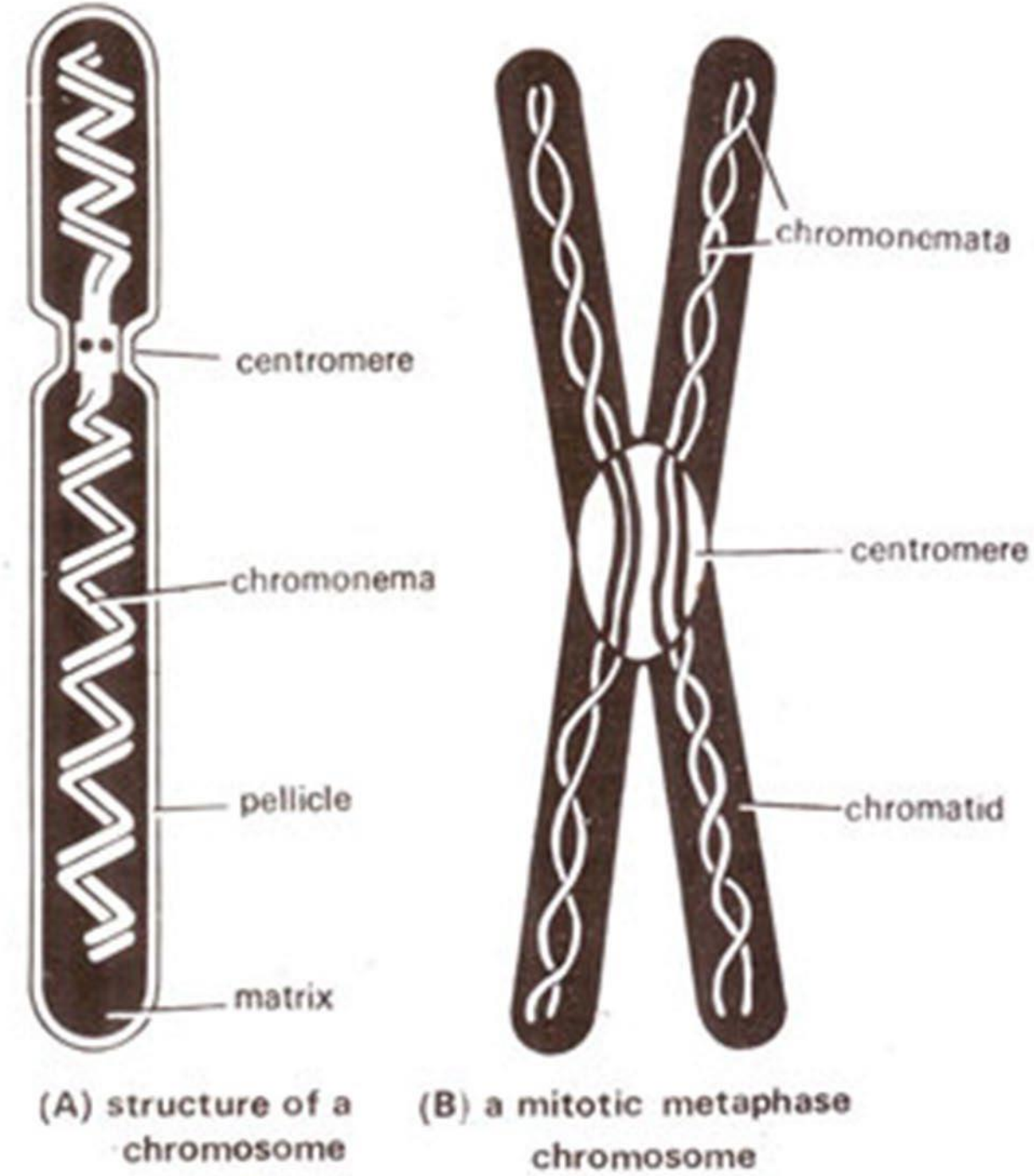


FUNCTIONS OF CHROMOSOME

•It provides genetic information for cellular functions of organisms.

•It protects genetic material(DNA)from damage during cell division.

•They ensure a precise distribution of DNA to daughter nuclei during cell division.

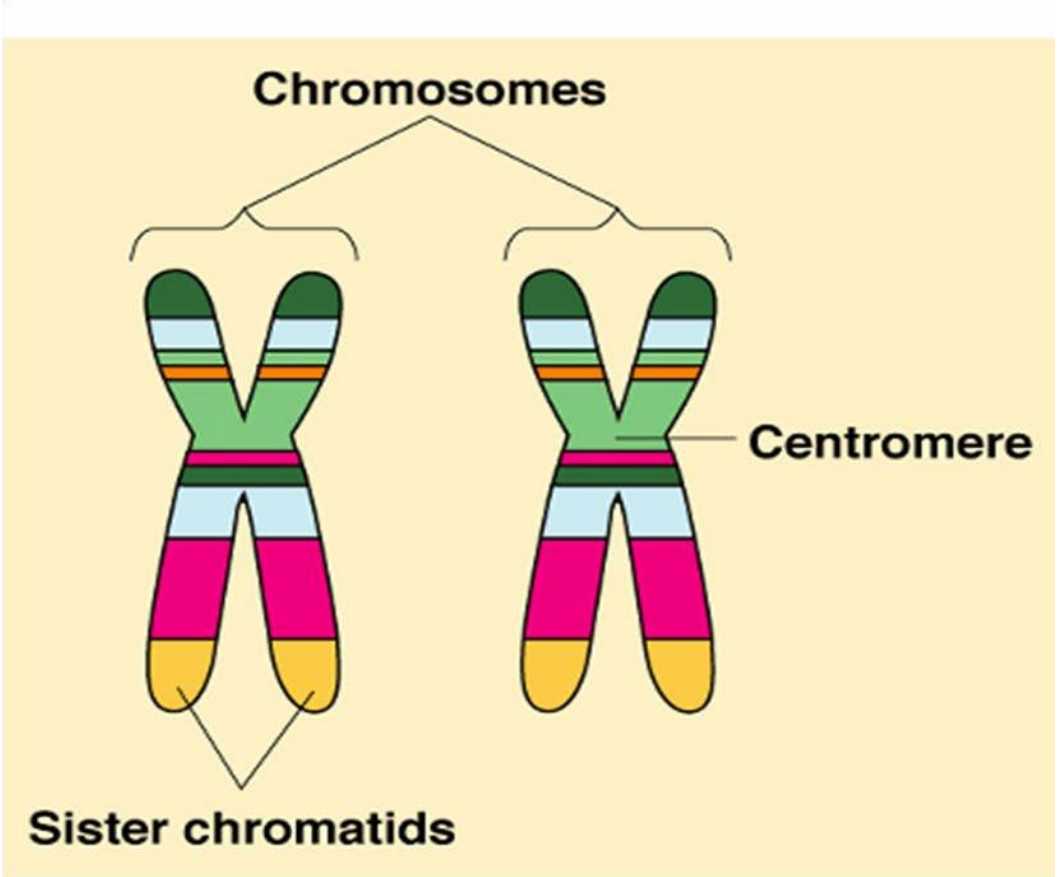


(A) structure of a chromosome

(B) a mitotic metaphase chromosome

Chromatid:
one copy of a duplicated chromosome

Chromonema / Chromonemata:
central thread of a chromatid



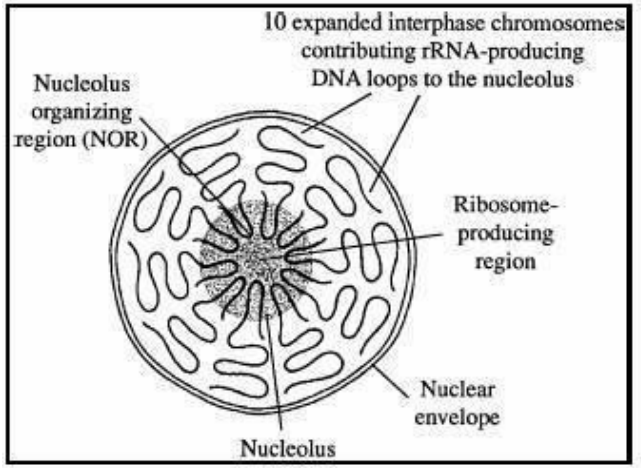
Inc.

NUCLEOLUS ORGANISER REGION

•**Nucleolus organizer regions**(NORs) are chromosomal regions crucial for the formation of the nucleolus.

•In humans, the NORs are located on the short arms of the acrocentric chromosomes 13, 14, 15, 21 and 22.

•Theseregionscode for 5.8S, 18S, and 28S ribosomal RNA.



CHROMOSOME NUMBER

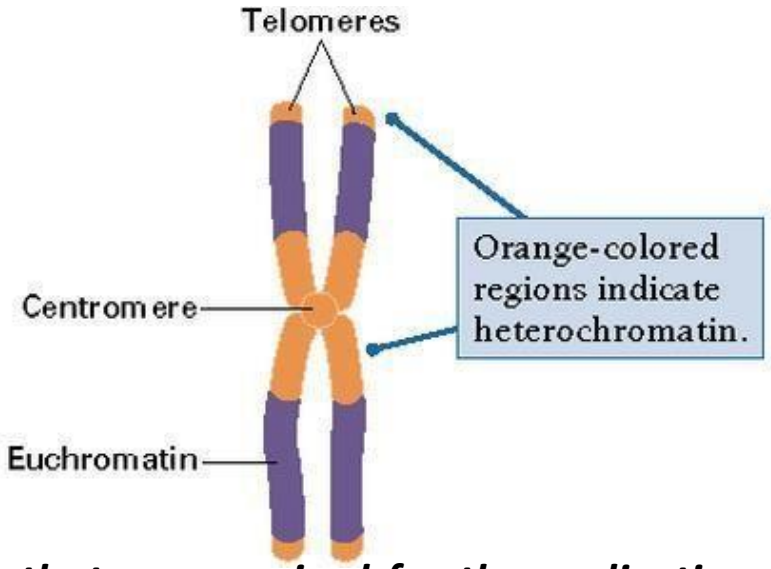
Two types:

1)Somatic chromosome number (2n):any chromosome that is not a sex chromosome; appear in pairs in body cells but as single chromosomes in spermatozoa.

2)Gametic chromosome number (n):any of the chromosomes contained in a haploid cell, specifically a spermatozoon or an ovum, as contrasted with those in a diploid, or somatic cell.

TELOMERE

- At two ends of chromosome
- Highly stable
- Made up of loops of chromatin fibers
- Maintenance of structural integrity



Telomeres:
Telomeres are the ***region of DNA at the end of the linear eukaryotic chromosome that are required for the replication and stability of the chromosome***.

McClintock recognized their special features when she noticed, that if two chromosomes were broken in a cell, the ends were sticky and end of one could attach to the other and vice versa. However she never observed the attachment of the broken end to the end of an unbroken chromosome suggesting that the end of chromosomes have unique features.

Telomere sequences remain conserved throughout vertebrates and they **form caps that protect the chromosomes from nucleases** and other destabilizing influences; and they prevent the ends of chromosomes from fusing with one another.
The telomeric DNA contains direct tandemly repeated sequences of the form $(T/A)_xG_y$ where x is between 1 and 4 and y is greater than 1.
Human telomeres contain the sequence TTAGGG repeated from about 500 to 5000 times.

Only about 1.5% of the genome codes for proteins, while the rest consists of non-coding genes, regulatory sequences, introns, and noncoding DNA.

-osome

A thread-like structure of nucleic acids and proteins found in the nucleus of most living cells, carrying genetic information in the forms of genes.

-atid

Each of the two thread-like strands into which a chromosome divides longitudinally during cell division. Each contains a double-helix of DNA.

-atin

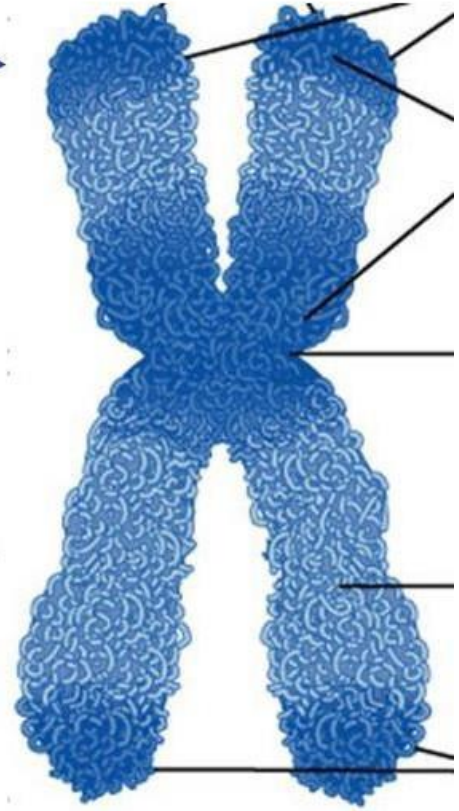
The material of which the chromosomes of organisms other than bacteria (i.e. eukaryotes) are composed, consisting of proteins, RNA and DNA

Chromatin

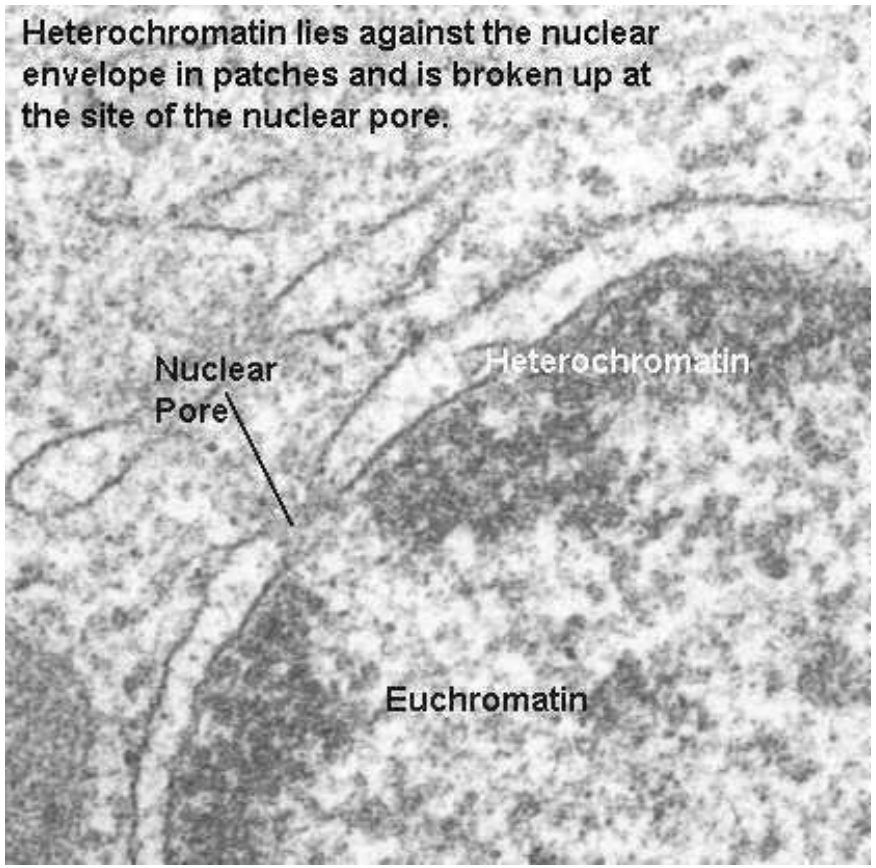
•Coiled strands of DNA bound to basic proteins (histones).
•2 types:

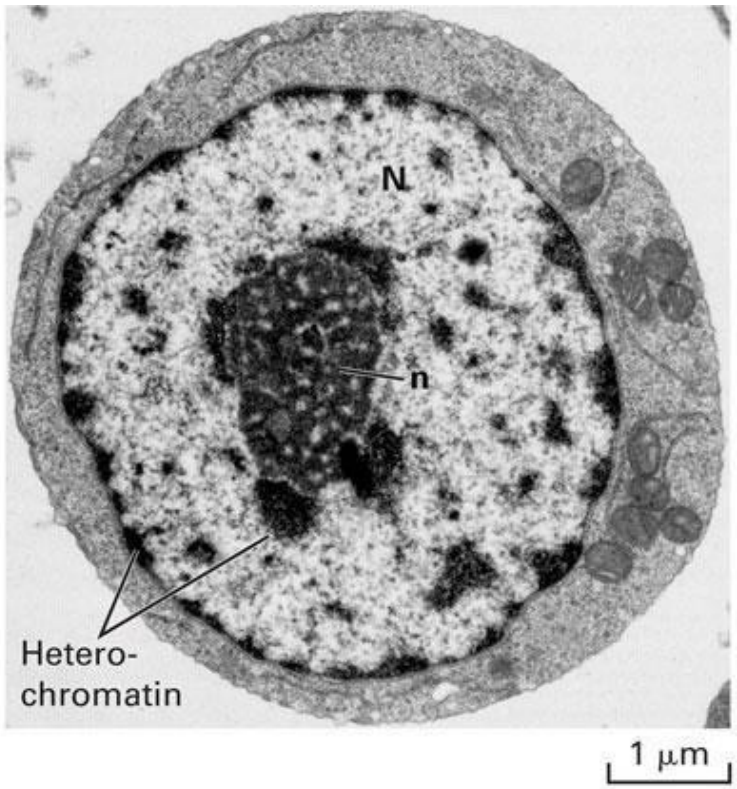
(1) Euchromatin
(2) Heterochromatin
•Basic structural unit: Nucleosome

- Heterochromatin:
  - More condensed
  - Silenced genes (methylated)
  - Gene poor (high AT content)
  - Stains darker
- Euchromatin:
  - Less condensed
  - Gene expressing
  - Gene rich (higher GC content)
  - Stains lighter



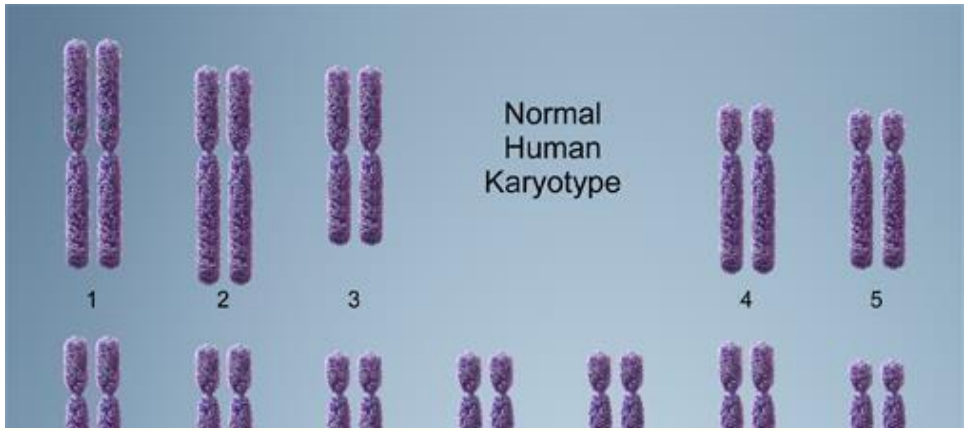
HETERO & EUCHROMATIN





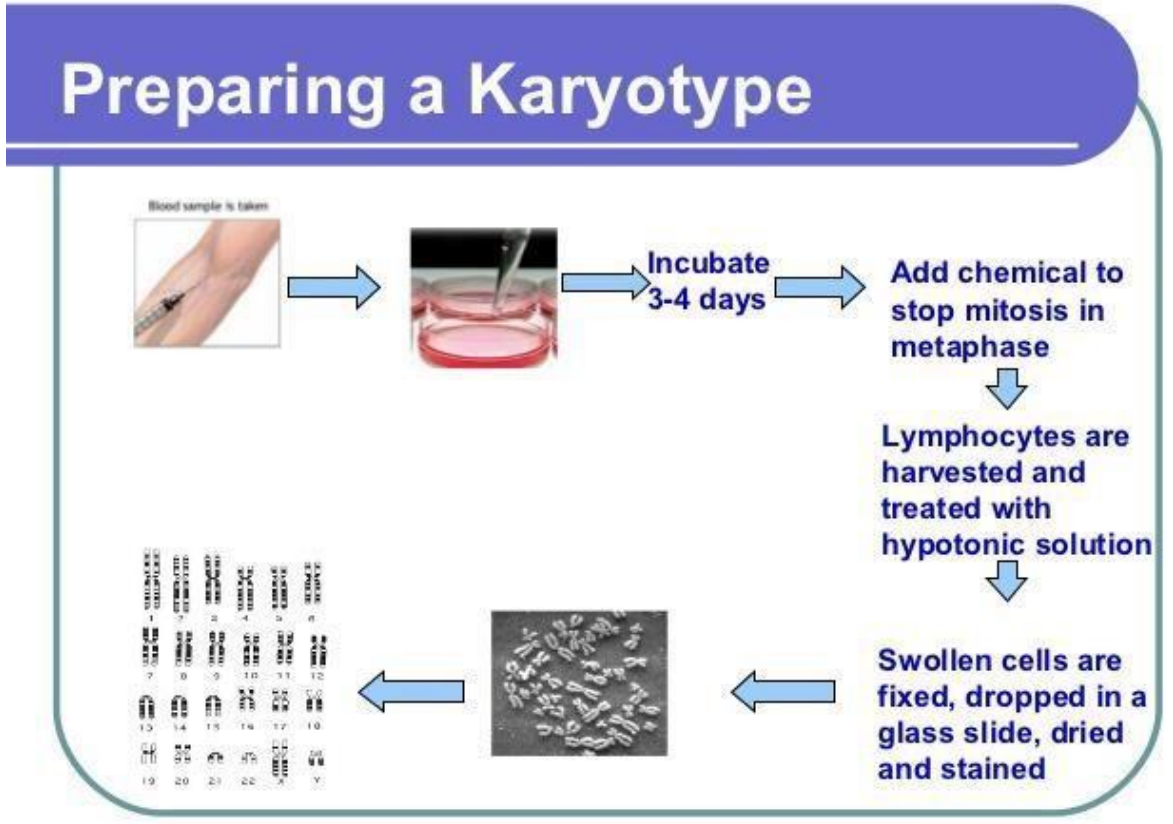
KARYOTYPE

•Generalmorphologyofsomaticchromosomecomplementofanin dividual.



Karyotyping

Karyotypingis the process of pairing and ordering all the chromosomes of an organism, thus providing a genome-wide snapshot of an individual's chromosomes.
Karyotypes describe thechromosome count of an organismand what these chromosomes look like under a lightmicroscope.
Attention is paid to their length, the position of thecentromeres, banding pattern, any differences between thesex chromosomes, and any other physical characteristics.
Karyotypesare prepared using standardized staining procedures that reveal characteristic structural features for each chromosome.



EUCHROMATIN:

The **lightly-stained regions in chromosome when stained with basic dyes** are called euchromatin and contain single-copy of **genetically-active DNA**. The extent of chromatin condensation varies during the life cycle of the cell and plays an important role in regulating gene expression.

In the interphase of cell cycle the chromatin are decondensed and known as euchromatin leading to gene transcription and DNA replication.

HETEROCHROMATIN:

The word heterochromatin was coined by Emil Heitz based on cytological observations. They are **highly condensed and ordered areas** in nucleosomal arrays. About **10% of interphase chromatin** is called heterochromatin and is in a ***very highly condensed state that resembles the chromatin of cells undergoing mitosis*** .

They **contain a high density of repetitive DNA found at centromeres and telomeres** form heterochromatin.

Heterochromatin are of two types, the ***constitutive and facultative heterochromatin***. The regions that remain condensed throughout the cell cycle are called **constitutive heterochromatin** whereas the regions where heterochromatin condensation state can change are known as **facultative**.

Constitutive heterochromatin is found in the region that flanks the telomeres and centromere of each chromosome and in the distal arm of the Y chromosome in mammals. Constitutive heterochromatin possesses very few genes and they also lead to transcriptional inactivation of nearby genes. This phenomenon of gene silencing is known as “position effect”. Constitutive heterochromatin also inhibits genetic recombination between homologous repetitive sequences circumventing DNA duplications and deletion.

Whereas facultative heterochromatin is chromatin that has been specifically inactivated during certain phases of an organism’s life or in certain types of differentiated cells.

Chromosomes are stained with A-T (G bands) and G-C (R bands) base pair specific dyes. When they are stained, the mitotic chromosomes have a banded structure that unambiguously identifies each chromosome of a karyotype. Each band contains millions of DNA nucleotide pairs which do not correspond to any functional structure.

G-banding is obtained with Giemsa stain yielding a series of lightly and darkly stained bands. The dark regions tend to be heterochromatic and AT rich. The light regions tend to be euchromatic and GC rich.

R-banding is the reverse of G-banding where the dark regions are euchromatic and the bright regions are heterochromatic.