CHROMOSOME STRUCTURE AND PACKAGING OF DNA

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WHAT IS CHROMOSOME?

It is a combination of two words, i.e., "**Chroma**"-means '**colour**' and "**Somes**"-means '**body**'.

So, the coloured thread like bodies present in the nucleoplasm of the living cells, which helps in the inheritance (transmission) of characters in form of Genes from generation to generation are known as **CHROMOSOMES.**

HISTORY

- **W. Hofmeister (1848):**
  First discovered chromosomes in the dividing pollen mother cells of Tradescantia.
- **Strasburger (1875):**
  First observed chromosome during cell division.
- **W. Flemming (1879):**
  Described the splitting of dark stained rod-like structures during cell division which he called as chromatin.
- **Beneden and Boveri (1887):**
  First discovered that the number of chromosome in a given species remains constant.
- **W. Waldyer (1888):**
  Coined the term chromosome.
- **Sutton and Boveri (1902):**
  Proposed the chromosome theory of inheritance.
- **Boveri (1932):**
  He described chromosomes as bearer of hereditary traits.
- **Kornberg (1974):**
  Proposed the concept of chromosome ultra-structure in the form of nucleosome.

CHROMOSOME NUMBER:

- Each species contain a fixed number of chromosomes. However, change in chromosome number can be seen in a species and is called as **Polyploidy** (euploidy and aneuploidy).
  - Normally gamete or gametophyte cells contain one set of chromosomes called genome and the cells are called **Haploid(n)**.
  - The somatic cells of animals and sporophytes have two haploid sets or genomes and are said to be **Diploid cells(2n).**
  - The number of chromosomes varies from species to species.
    Minimum: Mucor hiemalis (bread mould), n=2
    Maximum: Aulocantha sp (protozoa), 2n = 1600
  - Normally all individual of a species have the same chromosome number.

CHROMOSOME SIZE:

- The size of chromosome is normally measured at mitotic metaphase when they are very thick, quite short and well-spread.
- Chromosome of various plants and animals varies from 0.5µ to 32µ in length and 0.2 µ to 3.0 µ in diameter.

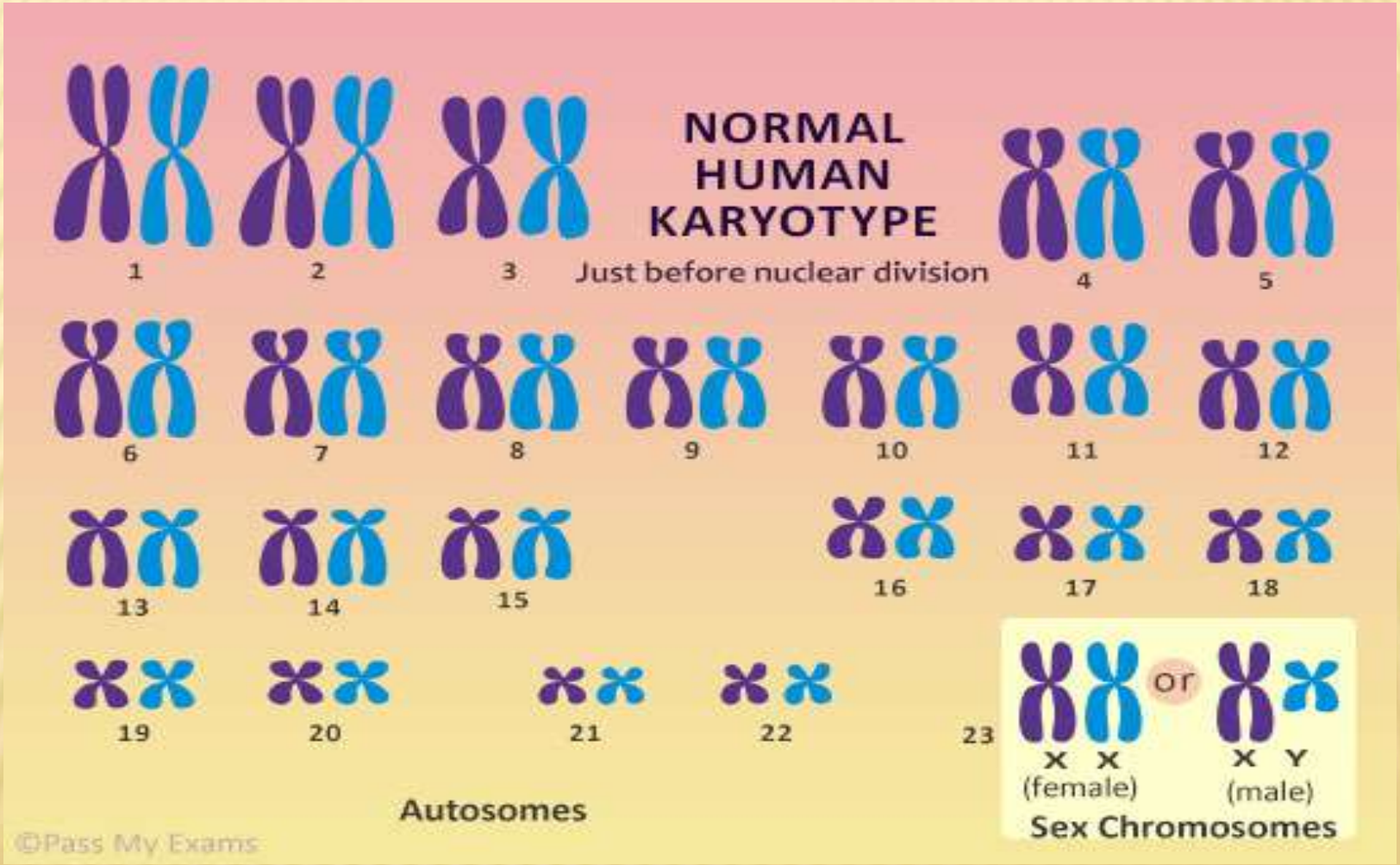
  - Generally, plant chromosomes are longer than animal ones. The longest metaphase chromosomes of plant are found in Trillium i.e. 30 µm.
  - In angiosperm, chromosomes of monocots are bigger than those of dicots and other plants. While, Orthoptera (Grasshopper) and Amphibia among animals have larger chromosomes.
  - The size of chromosome may vary in the different tissues within a single organism. For example, in plant Medeola, the root tip chromosomes are 50% bigger than the shoot tip chromosomes.
  - In fungi and birds it may be as short as 0.25 µm

TYPES OF CHROMOSOMES

- **Autosomes:** These are present in all cells of all organisms
  - Autosomes that are of same size (& structure) are called **homologues.**
  - In humans there are 22 pairs of autosomes

- **Allosomes or Sex Chromosomes :** Chromosomes that are connected with the determination of sex, are called **sex chromosomes**.
  - Existence of allosomes is not always universal.
  - Allosomes are **non homologous**
  - There are two types of sex chromosomes; X and Y.
  - X chromosome is found in both males and females although one sex has only one while the other sex have two X-chromosomes..
  - Y-chromosome contains mostly heterochromatin and only few genes are located in it. On the other hand, X-chromosome is made of euchromatin and many genes are located on it.

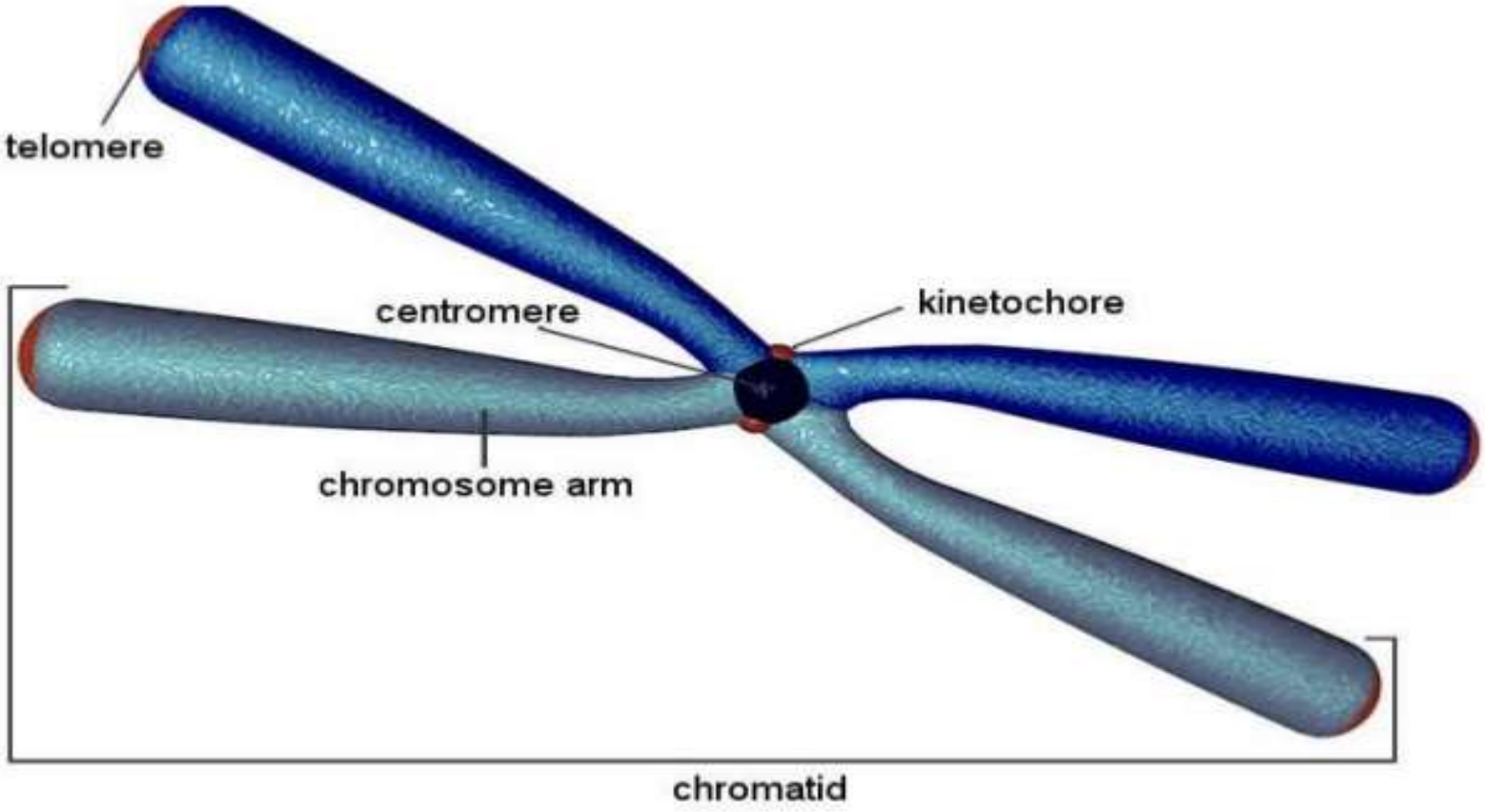
HUMAN KARYOTYPE:



MORPHOLOGY OF CHROMOSOMES

- The shape and size of chromosomes change along with cell cycle.
  - **During Interphase**: the chromosomes remain in form of chromatin reticulum.
  - **During cell division**: the chromatin reticulum condenses, so that by the end of prophase distinct thread like structures appear called **chromonemata** (sing, chromonema).
  - **Metaphase and anaphase:** the chromonemeta become fully condensed and take the shapes of chromatids in eukaryotic nuclear chromosomes.
- This cyclic change in shape and size of chromosomes during cell cycle is called **chromosomal cycle**.

STRUCTURE OF CHROMOSOME



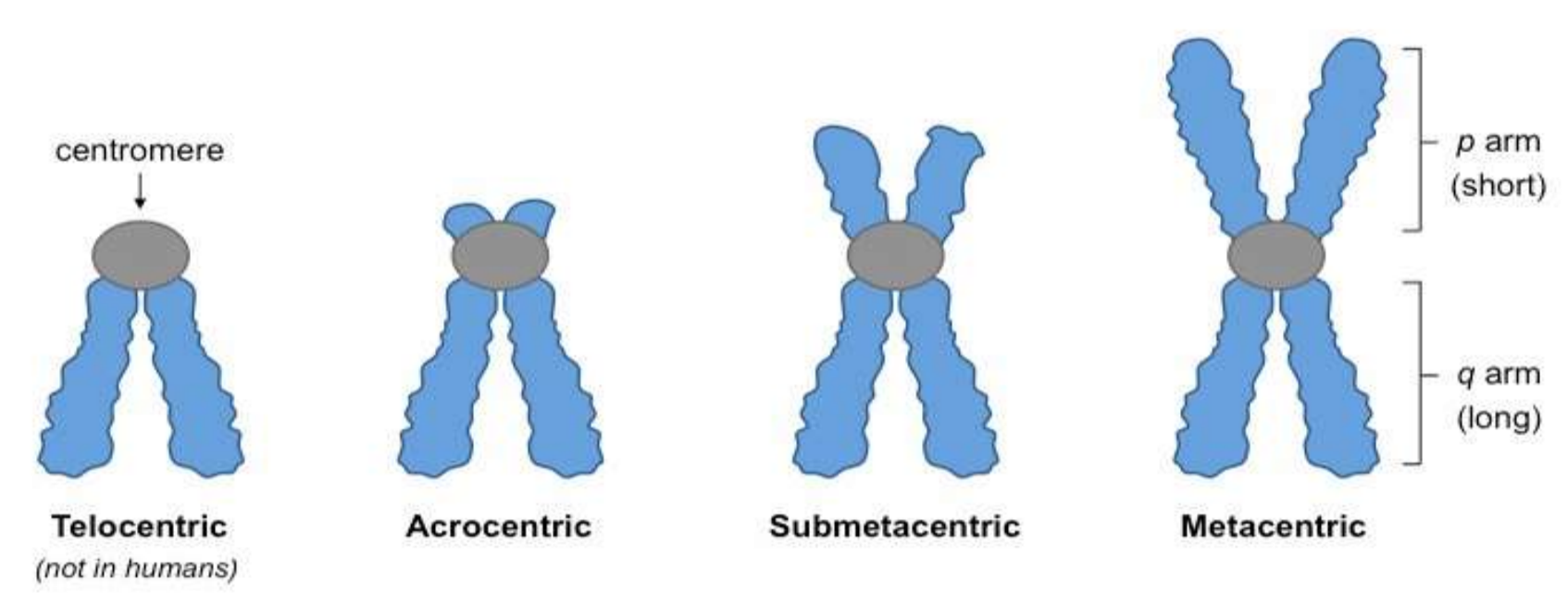
PARTS OF CHROMOSOME:

- **Centromere (Primary constriction):** The region where two sister chromatids are held together is called the centromere.
  - This region generally appears as a constricted or narrowed zone in the centromere, hence it is also known as primary constriction.

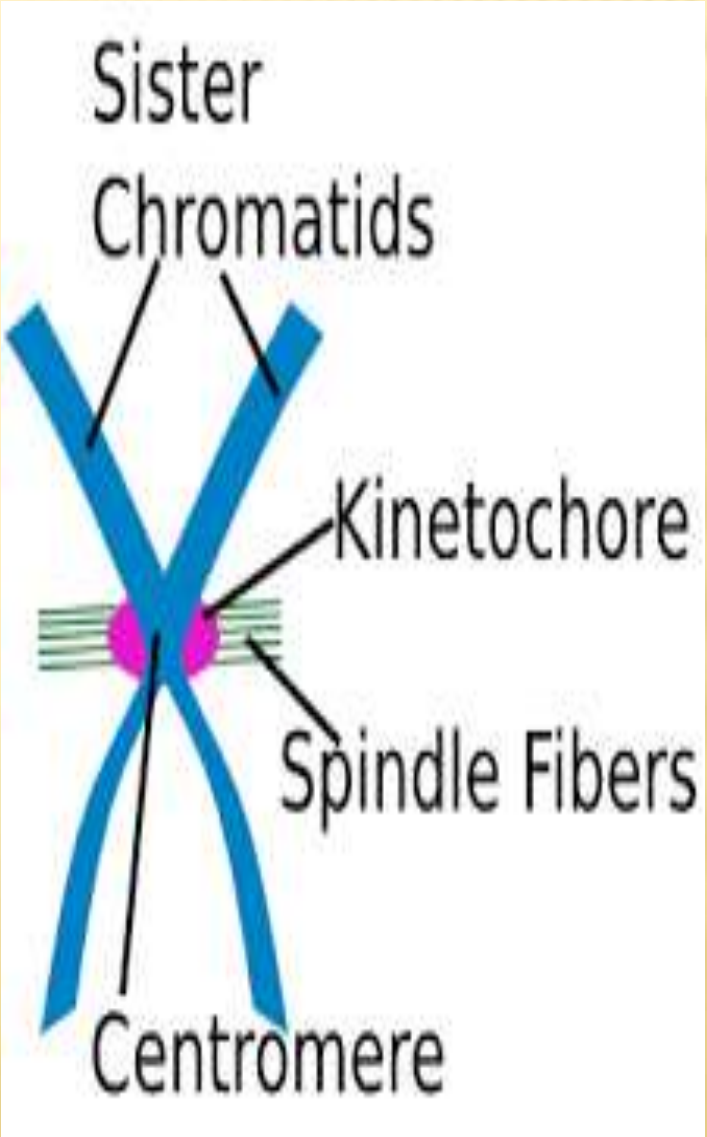
- Based on the **no. of centromere**, chromosomes are called
  - **Acentric** (without cetromere)
  - **monocentric** (one centromere);
  - **dicentric** (e.g. in wheat, maize etc.)
  - **polycentric** (e.g. Luzula. Ascaris etc.).

BASED ON THE POSITION OF CENTROMERE, CHROMOSOMES ARE CALLED:

i. Telocentric (centromere terminal),
ii. Acrocentric (centromere subterminal and capped by telomere),
iii. Sub-metacentric (centromere is submedian),
iv. Metacentric (centromere median).



- **kinetochore:**
  - a complex of proteins associated with the centromere of a chromosome during cell division, to which the microtubules of the spindle attach.
  - The structure of kinetochore is complex and is seen during late prophase.

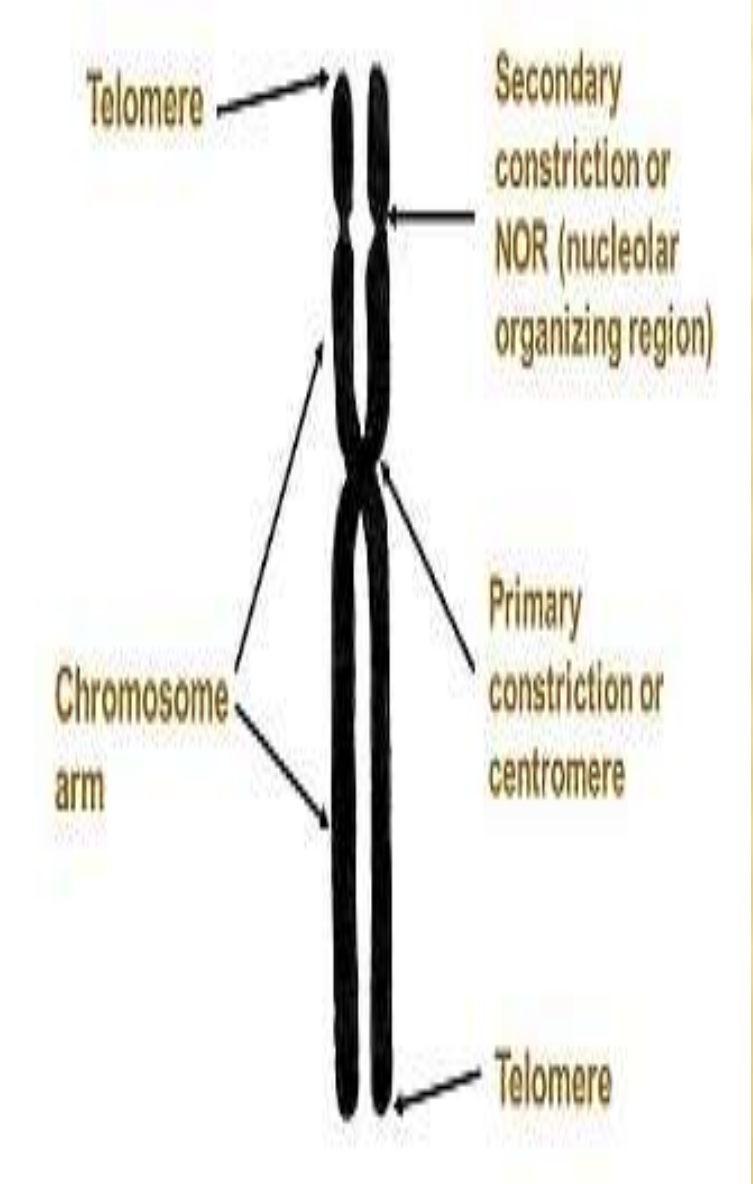


- **Secondary Constrictions:**

  - Besides centromere a chromosome may have one or more secondary constrictions.

  - Secondary constrictions are of two types **NOR** and **Joint**. They are always constant in their positions and often used as markers.

  - The NOR (nucleolar organizer region) are specialized to produce nucleolus and rRNA. The joints sometimes develop due to breaking and fusion of chromosome segments.



❑Satellite region:

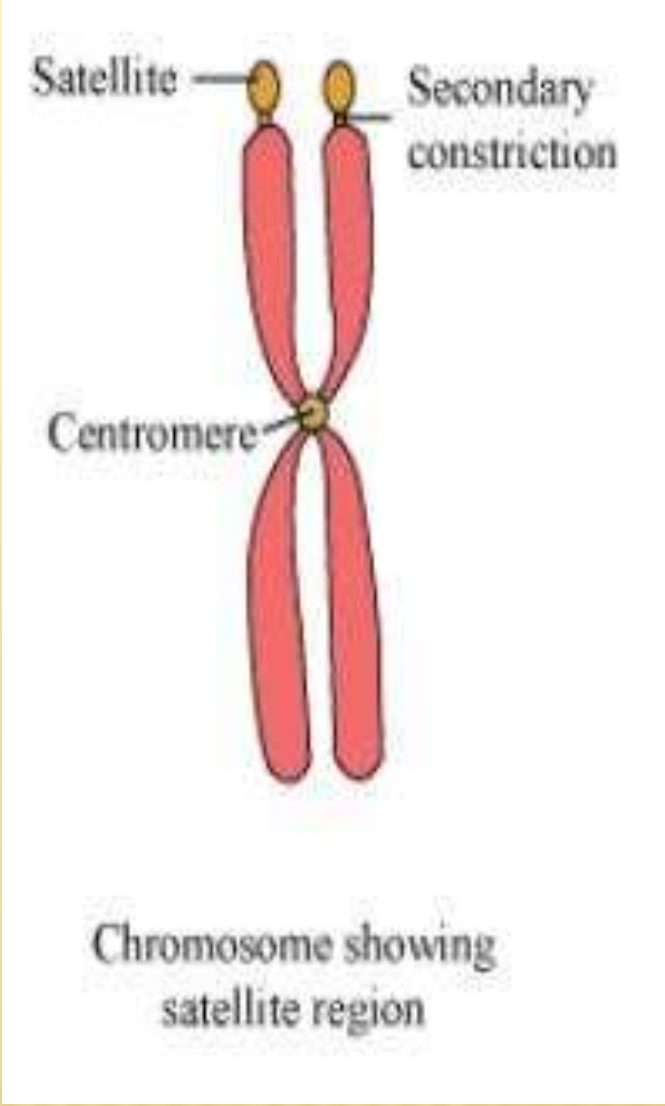
➢The part of chromosome beyond secondary constriction is called **satellite or trabant** which remains attached to the main part of chromosomes by a thread of chromatin.

➢ The chromosome having satellite is called **sat chromosome**.

❑Telomeres:

➢The terminal ends of chromosomes are called **telomeres**. A telomere is a short repeated DNA sequence (GC rich) complexed with proteins.

➢They are synthesized separately and later add to the chromosomal tips.



Chromosome showing satellite region

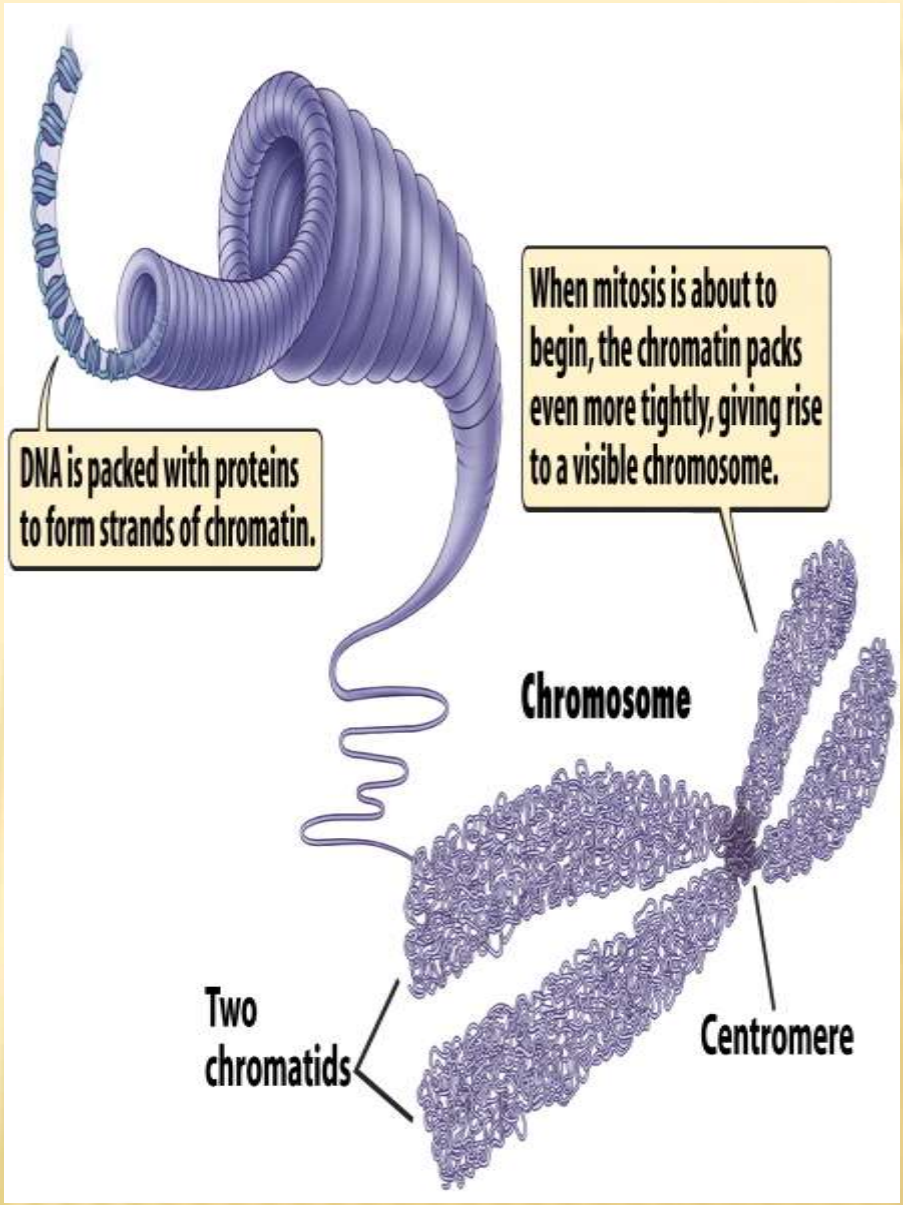
Chromomeres:

- A chromomere, also known as an **idiomere**, is one of the serially aligned beads or granules of a eukaryotic chromosome, resulting from local coiling of a continuous DNA thread.

- In areas of chromatin with the absence of transcription, condensing of DNA and protein complexes will result in the formation of **chromomeres**.

Chromatids:

- A **chromatid** is an identical copy of a chromosome produced each time the chromosome replicates.
- Chromatids that are joined together via centromeres are known as **sister chromatids.**
- Chromatids are formed from **Chromatin fibers.**
- Chromatin is DNA that is wrapped around proteins (Histone) and further coiled to form chromatin fibers.
- Chromatin allows DNA to be compacted to fit within the cell nucleus. Chromatin fibers condense to form chromosomes.



www.csus.edu/indiv/l/loom/lect%2013.htm

FUNCTIONS OF CHROMOSOMES:

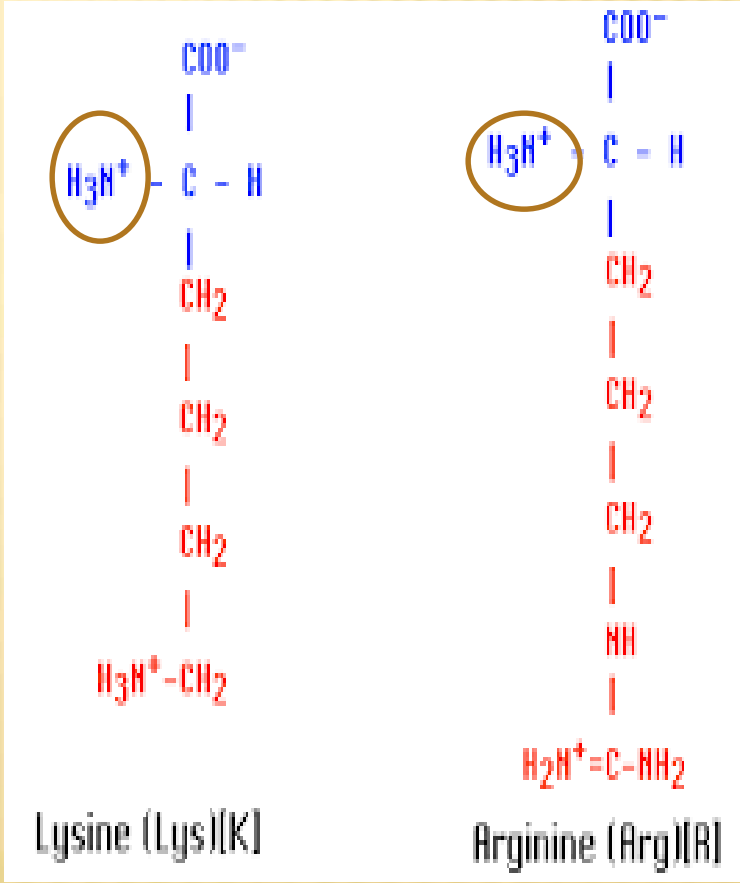
1. They contain hereditary information in the form of genes and act as hereditary vehicle.
2. They control division, growth, metabolism and differentiation of cell.
3. The ploidy of chromosomes determines the expression of gametophyte or sporophyte generation.
4. Sex chromosomes determine sex of the individuals.
5. Crossing over and aberrations of chromosomes introduce variations in population.
6. They transmit hereditary information from generation to generation.

NEED TO PACKAGE DNA?

- The haploid human genome contains approximately 3 billion base pairs of DNA packaged into 23 chromosomes.
- That makes a total of 6 billion base pairs of DNA per cell. Because each base pair is around 0.34 nanometers long (a nanometer is one-billionth of a meter), each diploid cell therefore contains about 2 meters of DNA
- Moreover, it is estimated that the human body contains about 50 trillion cells—which works out to 100 trillion meters of DNA per human.
- Now, consider the fact that the Sun is 150 billion meters from Earth. This means that each of us has enough DNA to go from here to the Sun and back more than 300 times, or around Earth's equator 2.5 million times! How is this possible?

PACKAGING OF CHROMOSOME

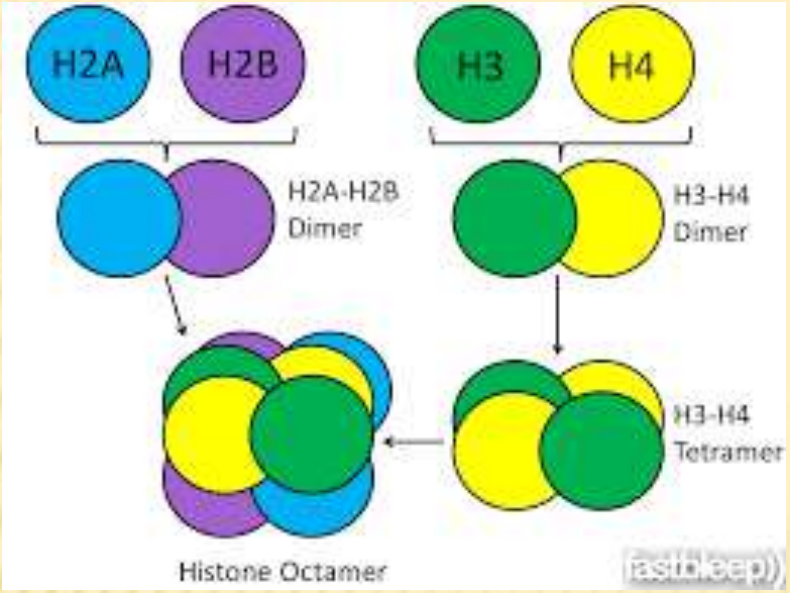
- The chromosomes are composed of DNA and associated proteins.
- The DNA and associated proteins are together called as the **chromatin**.
- The protein components of chromosome are grouped into two categories.
  - **Histone proteins**
  - **Non histone proteins**
- Histones are the basic proteins (positively charged) rich in lysine and arginine amino acids.
- Lysine and arginine are basic amino acids since their side chain (R group) contains additional amino group (NH3) which can accept protons to form NH3+

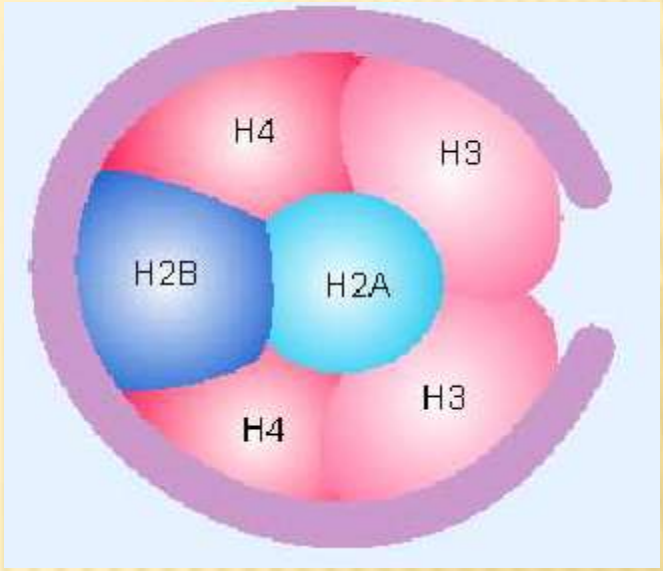


Histone Proteins:

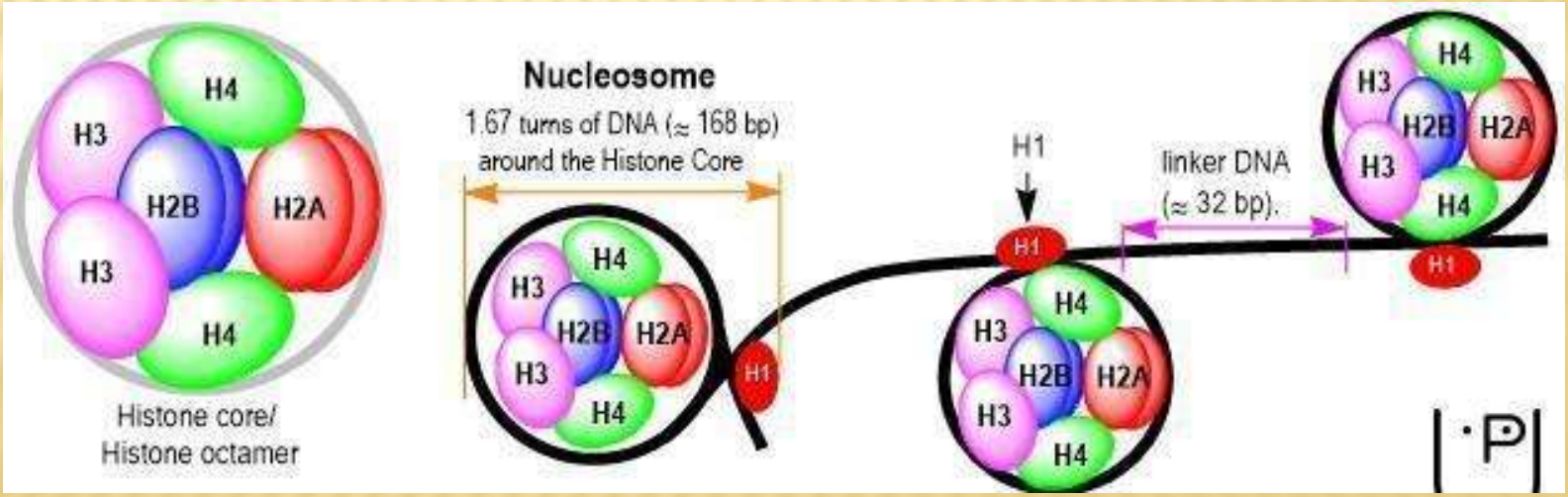
- **histones** are highly alkaline proteins found in eukaryotic cell nuclei that package and order the DNA into structural units called nucleosome. They are the chief protein components of chromatin, acting as spools around which DNA winds, and playing a role in gene regulation.
- The histones are classified on the bases of Structural differences, molecular weight and lysine/arginine ratio.
- All amino acid of the histone protein are in direct contact with the DNA (**negatively charged** due to presence of phosphate group) or other histones.

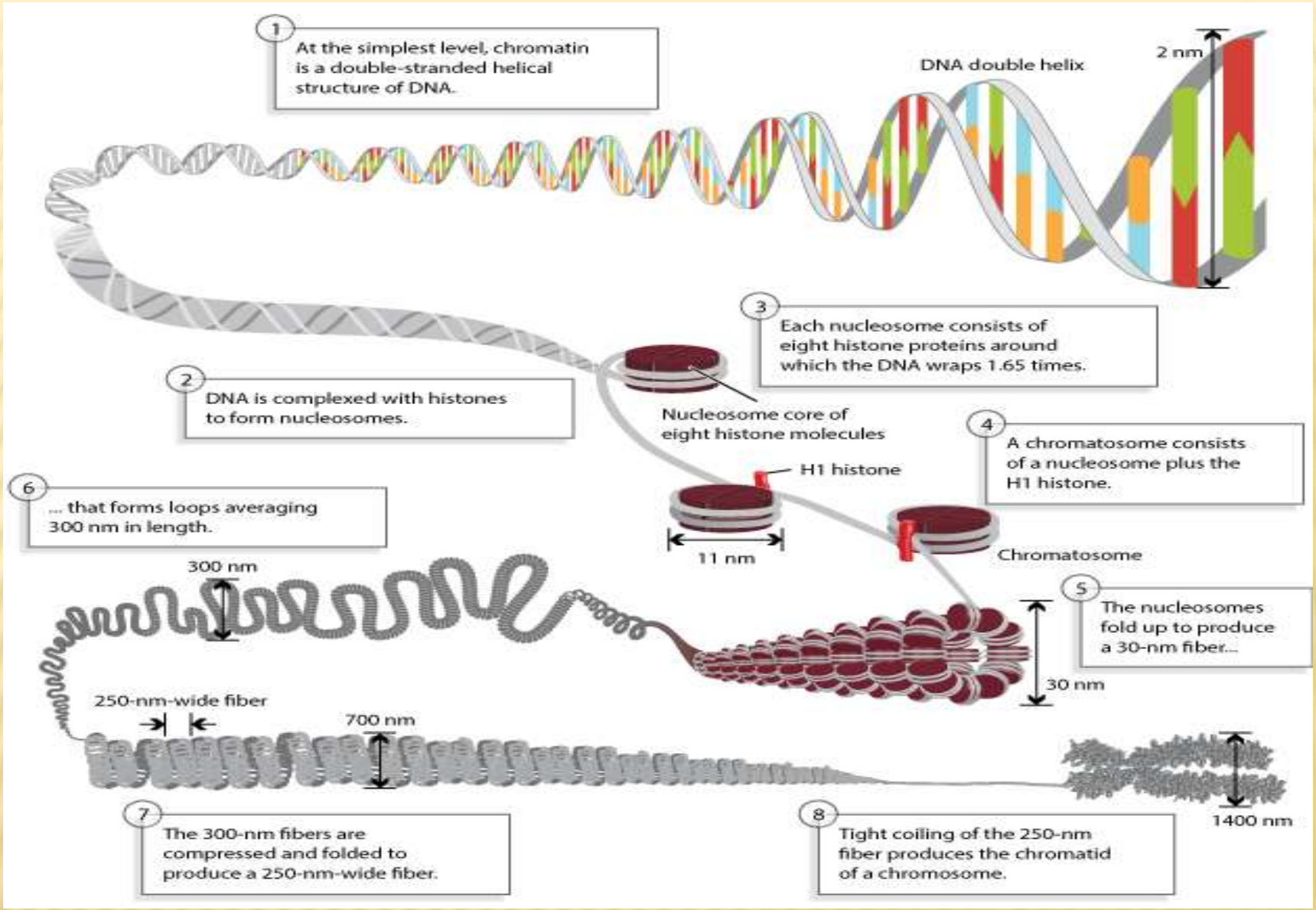
- The five classes of histones are **H1, H2A, H2B, H3** and **H4.**
  - Histones H2A, H2B, H3 and H4 are known as the **core histones**, while histones H1/H5 are known as the **linker histones**.
  - H1, H2A & H2B, are rich in lysine whereas H3 & H4 are arginine rich.
  - H1 is highly unconserved and mutable while, core histones are highly conserved molecules.
  - Histones octamer has a structural core of an H3.H4 tetramer associated with two H2A.H2B dimmers.





Histone Octamer of core histones





https://www.nature.com/scitable/topicpage/dna-packaging-nucleosomes-and-chromatin-310

NUCLEOSOME MODEL OF CHROMOSOME:

- Nucleosome represents the **"beads"** as proposed in the **'beads on string'** organisation of chromtin.
- ***1974: Roger Kornberg discovers nucleosome who won Nobel Prize in 2006*.**
- **Nucleosome:**
  - Nucleosome are the fundamental repeating units of chromatin.
  - The nucleosome consists of a core particle of eight histone proteins and DNA that wraps around the core.
  - Chromatosome, which are nucleosomes bound to an H1 histone, are separated by linker DNA.
  - Each histone core is encircled by 1.8 turns of DNA.
  - This 1.8 turn of DNA represents about 146bp.
  - Each nucleosome is about 10nm in diameter.
  - The H1 histone stays outside the histone octamer.
  - Adjacent nucleosome are connected by a short stretch of DNA called linker DNA.

- Linker DNA is about 10-80bp in length.
- The H1 histone binds near the site where DNA enters and exits the nucleosome.
- The interaction of histones and DNA in nucleosome is stabilized by several types of **non-covalent bonds.**
- Among these bonds, **ionic bonds** formed between the negatively charged phosphate groups in the DNA with the positively charged amino groups of histones were very important.
- Nucleosmes fold to form a 30-nm chromatin fiber, which appears as a series of loops that pack to create a 250 nm wide fiber.
- Helical coiling of the 250 nm fiber produces a chromatid.


Thank you for listening..
Any questions?