CELLULAR BASIS OF INHERITANCE: MITOSIS AND MEIOSIS

- Study aims and objectives

  - To observe the morphology of chromosomes
  - To understand the processes of mitosis and meiosis
  - To analyze the relationship between meiosis and Mendel's rule

Chromosome

- It is a thread-like entity composed entirely of nucleic acid, that carries genetic information.

Chromosomes

- In more complex organisms such as plants and animals (eukaryotes), each ***somatic cell*** contains one set of chromosomes inherited from the maternal parent and a **comparable** set of chromosomes called the ***homologous chromosome*** or ***homologue*** from the paternal parent.

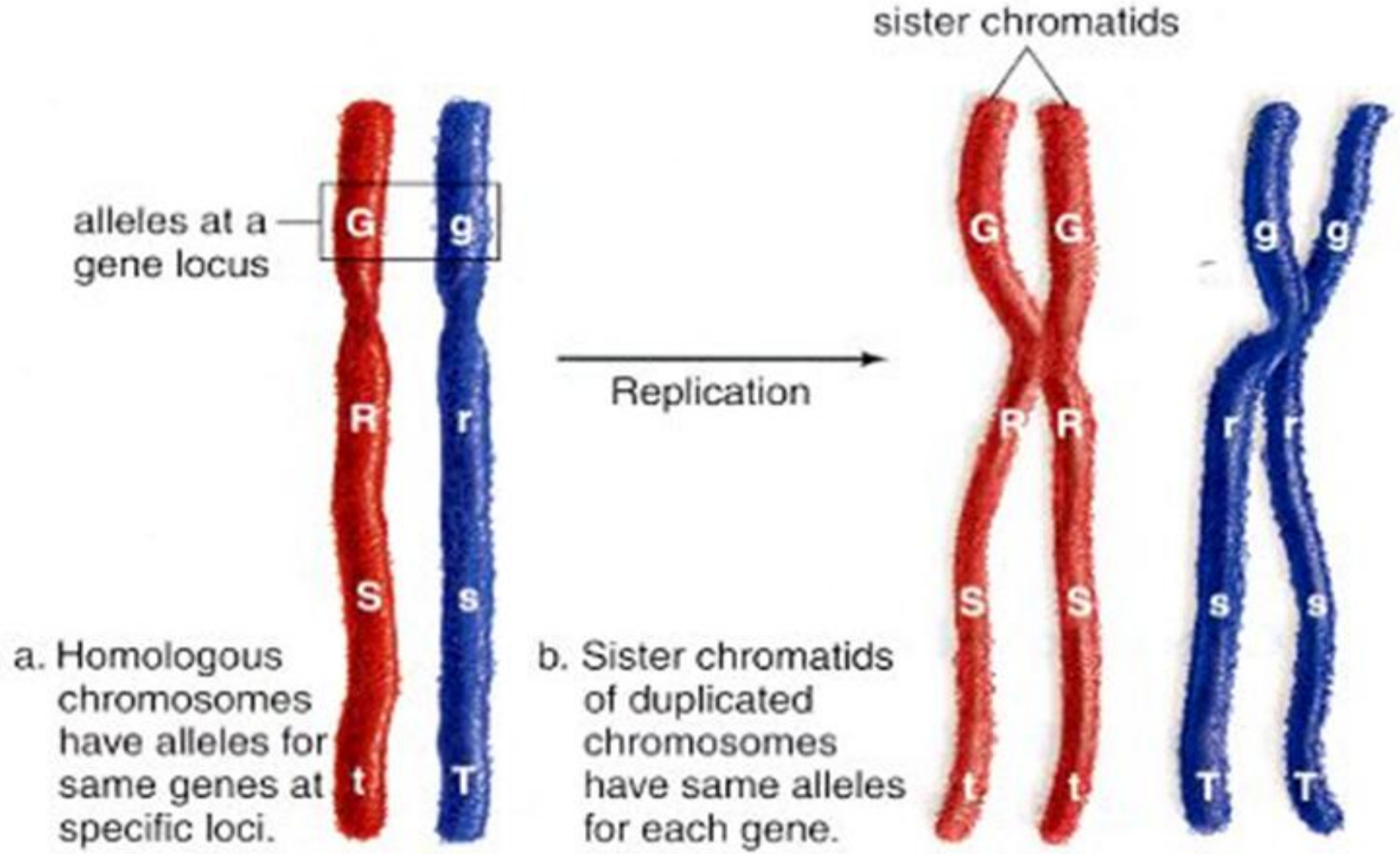


FIGURE 11.4 Classical view of homologous chromosomes.

a. The letters represent alleles; that is, alternate forms of a gene. Each allelic pair, such as *Gg* or *Tt*, is located on homologous chromosomes at a particular gene locus. **b.** Sister chromatids carry the same alleles in the same order.

Chromosomes

- The number of chromosomes in this dual set is called the **diploid** (2n) number.

- **Sex cells**, or **gametes**, with half the number of chromosome sets found in somatic cells, are referred to as **haploid** cells (n).

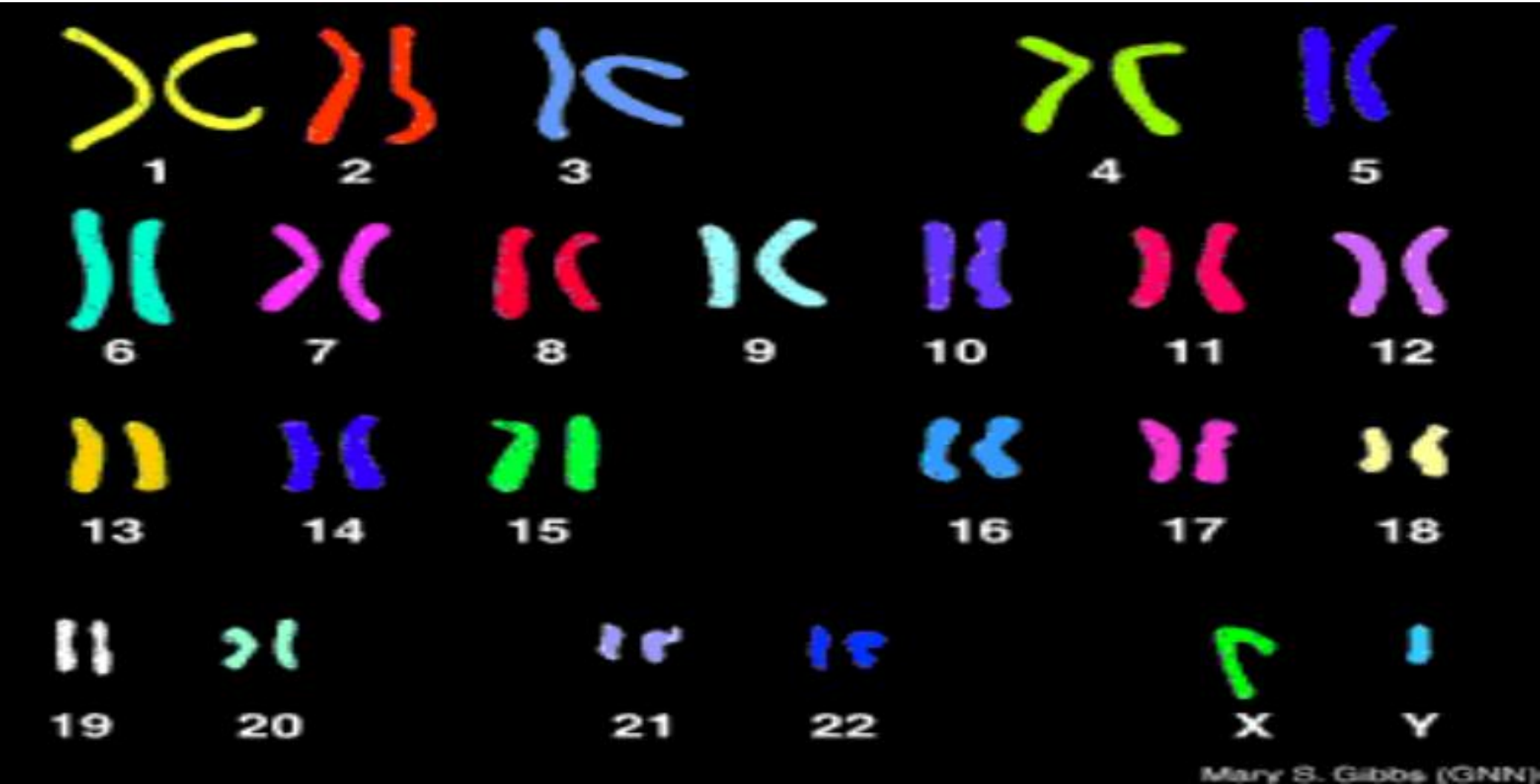
Chromosomes

- The number of chromosomes in each somatic cell is the same for all members of a given species.

- Example: human somatic cells contain 46 chromosomes, the garden pea 14, the cattle 60, etc.

Human Chromosomes

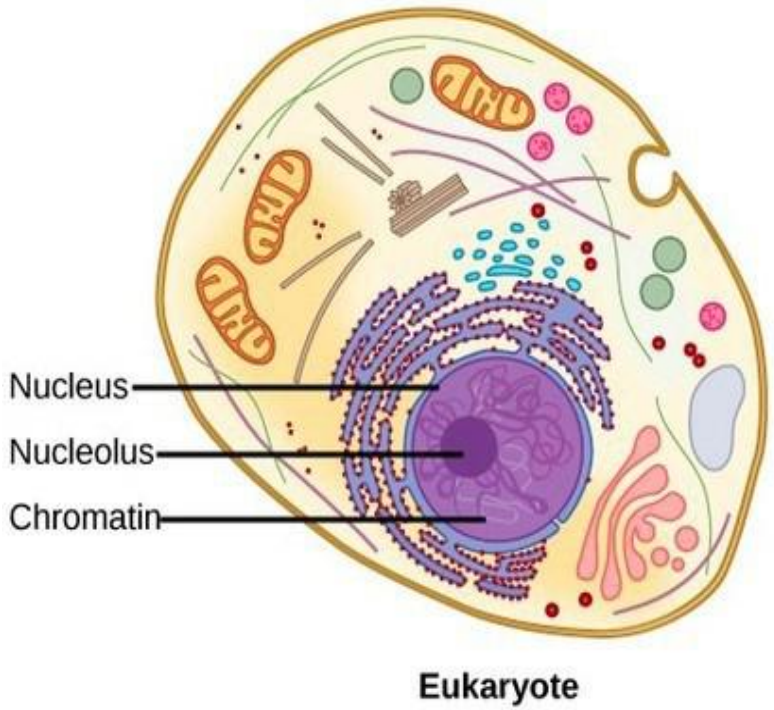
- 22 pairs of autosomes, one pair of sex chromosomes



Chromosome Morphology

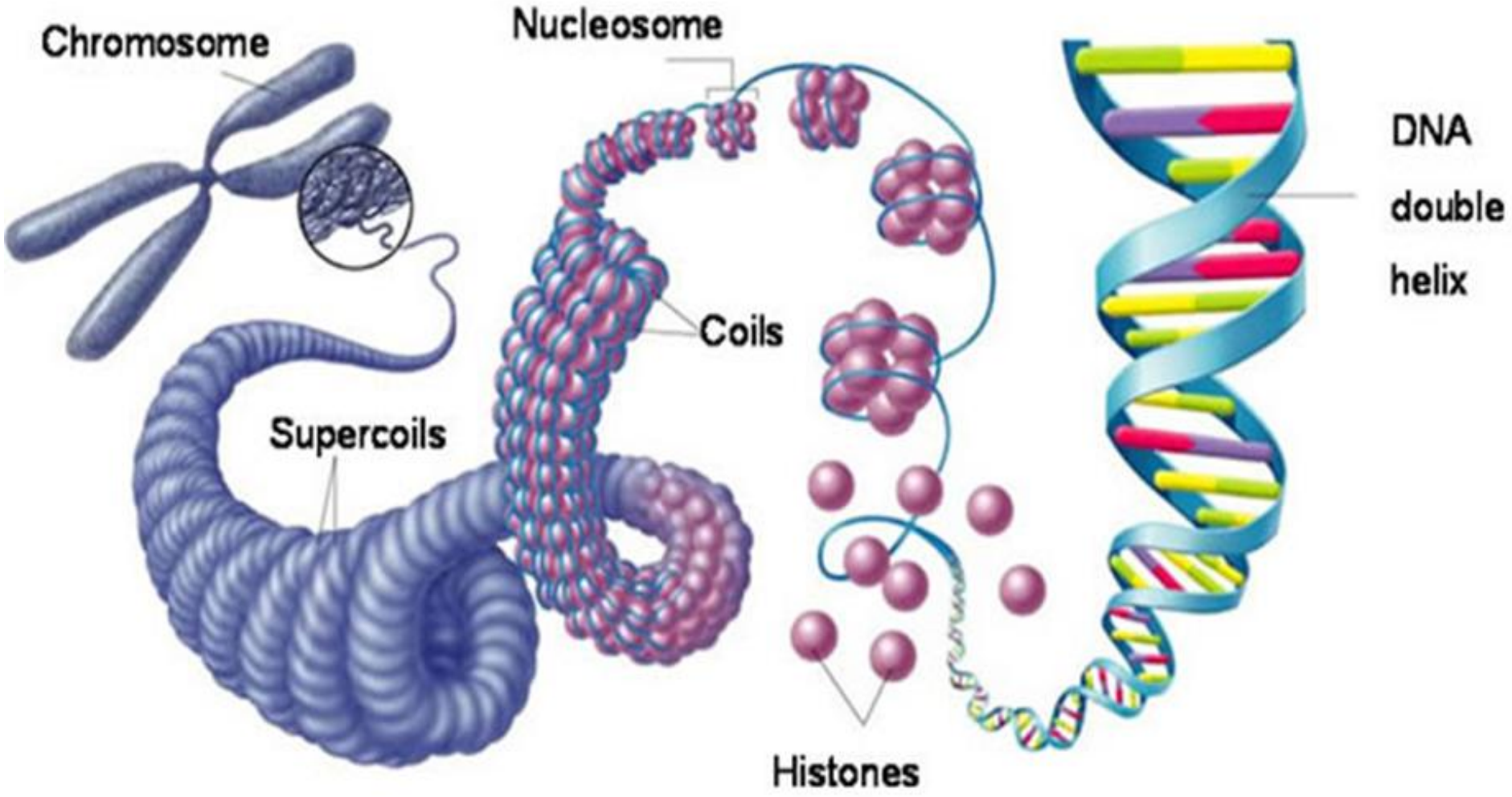
- Chromosomes are composed of DNA (nucleic acid) associated with a variety of proteins.

- This complex of DNA and protein (nucleoprotein) material of chromosome is called **chromatin**



Chromosome Morphology

- One group of the proteins called **histones** help to organize the long strands of DNA into structures known as **nucleosomes**.


Chromosome
Nucleosome
DNA
double
helix
Coils
Supercoils
Histones

Chromosome Characterization

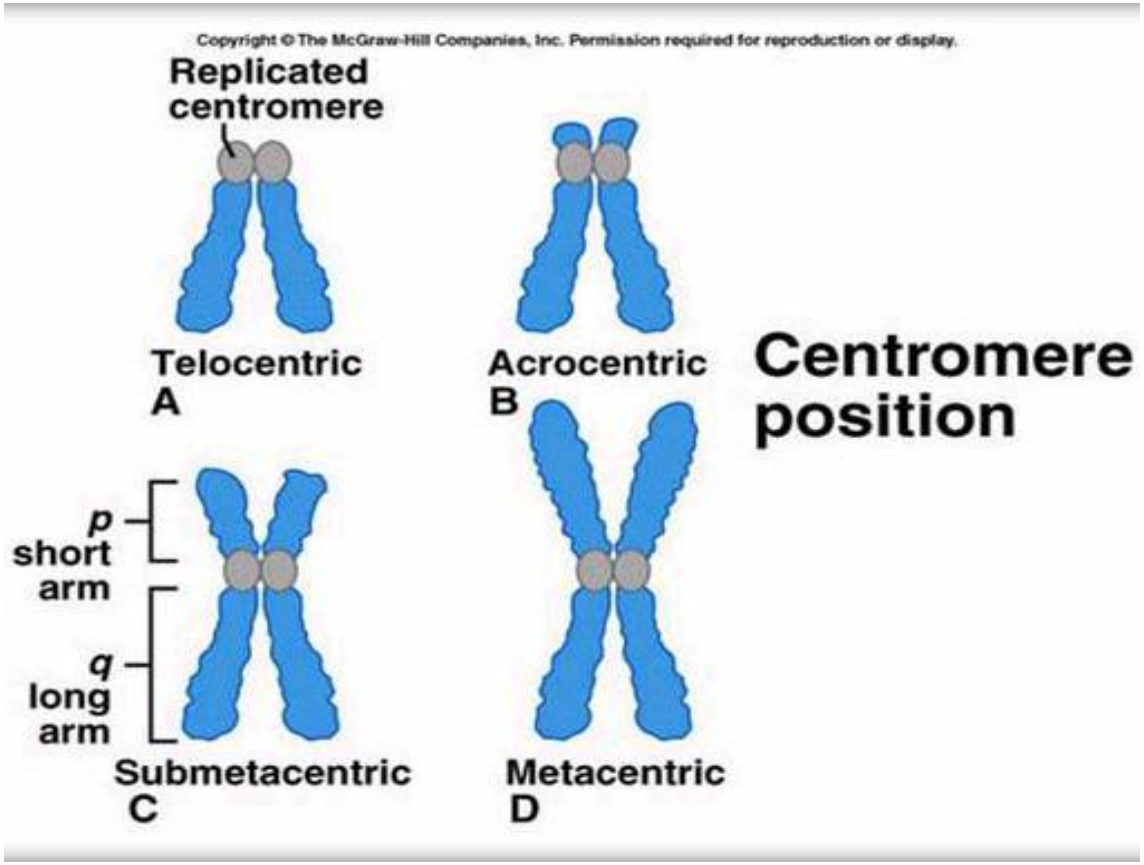
- Chromosomes can generally be distinguished by several criteria, including:

  * the relative lengths of the chromosomes,

  * the position of the ***centromere*** (*a condensed or constricted structure that divides the chromosome into two arms of varying length*).

Depending on the location of the centromere, different arm ratios are produced, and we can have the following descriptions:

- **Metacentric**
- **Submetacentric**
- **Acrocentric**
- **Telocentric**
- **Subtelocentric**



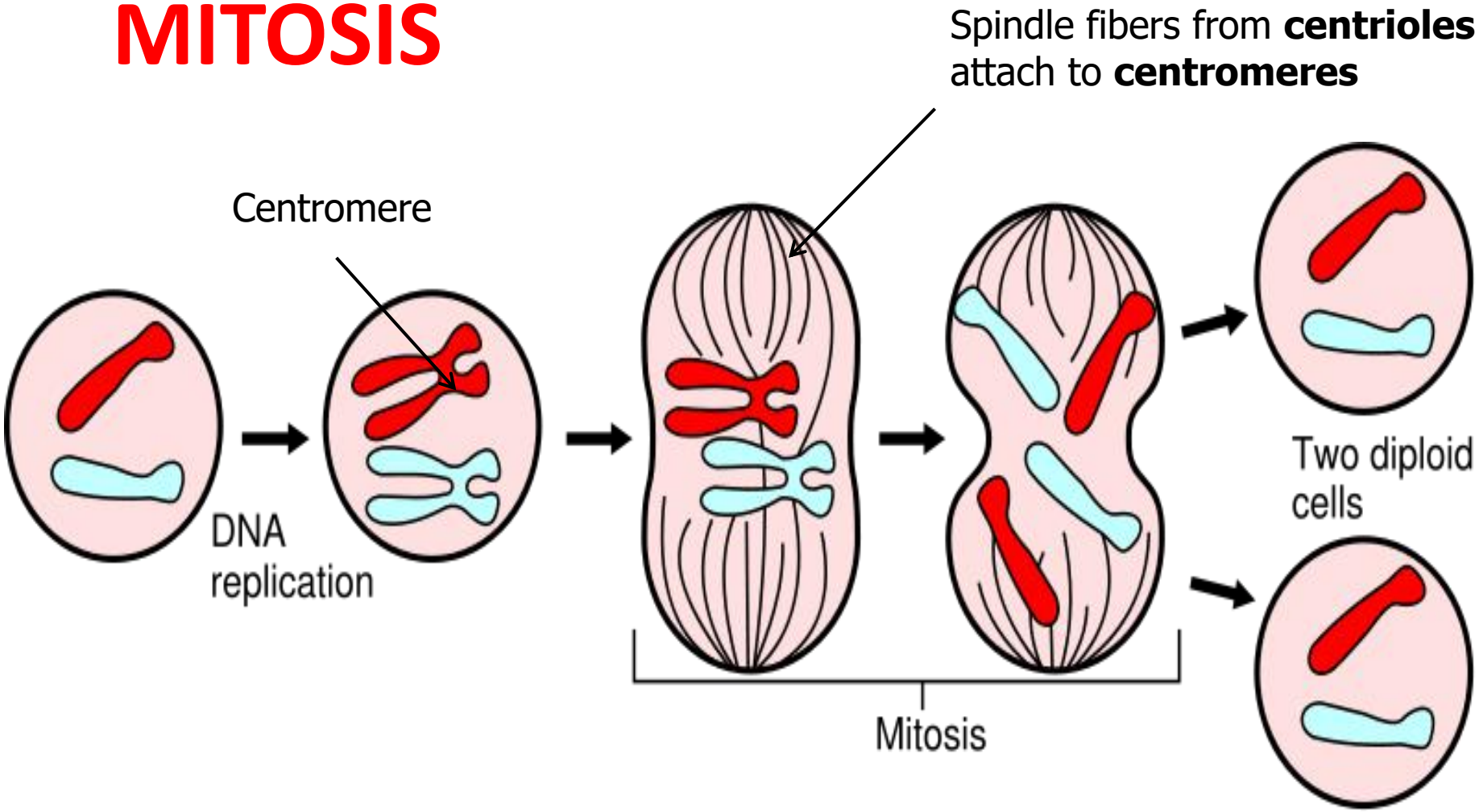
- The shorter arm is called the **p arm** whilst the longer arm is called the **q arm**

- It must be noted that, all chromosomes exclusive of the sex chromosomes are called **autosomes**.

Mitosis

- It is a **non-reductional nuclear division** by which one cell results in two daughter cells, each with a set of chromosomes identical to that of the parental cell.
- Why is mitosis important?

MITOSIS



Chromosomes are copied
Two copies are called **chromatids**
Held in place until separation by **centromere**

End Results of Mitosis

- Construct an exact copy of each chromosome.

- Distribute an identical set of chromosomes to each of the two progeny or daughter cells.

The Process of Mitosis

- It is designated as the ***M phase***
- It is a smooth process with no clear-cut discontinuities.
- Yet, certain landmark events serve to identify FOUR stages.

Prophase **Metaphase**

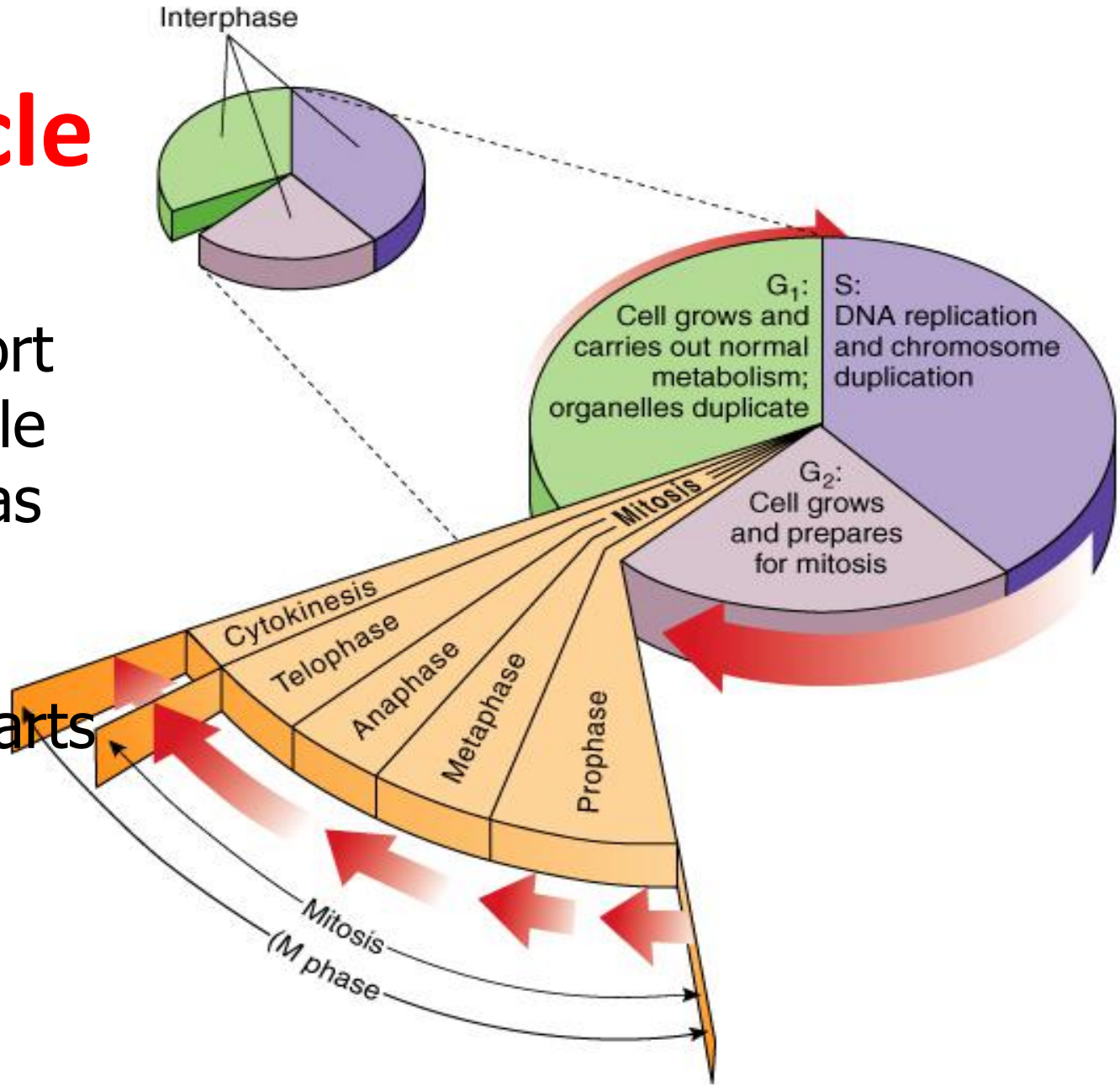
Anaphase **Telophase**

The Cell Cycle

Mitosis is just a short part of the Cell Cycle
The rest is known as **Interphase**

Interphase has 3 parts

- G_1 (Gap 1)
- S (Synthesis)
- G_2 (Gap 2)



Interphase

- Interphase is divided into three phases, **G_1, S** and **G_2**
- During all three phases, cell lives and grows; produces proteins and organelles
- Chromosomes replicated (copied) only during S phase
- What is the importance of interphase?

Interphase

- In G_2, cell is preparing for mitosis
- Cell continues to grow through all three phases
- *M phase* is for mitosis
- A cell spends most of its life in Interphase

- During S phase, the DNA molecules of each chromosomes are replicated producing an identical pair of DNA molecules called **chromatids or "sister" chromatids.**

- Each replicated chromosome then enters mitosis with two identical DNA molecules.

- During G_1, cells are preparing themselves for DNA synthesis.
- In the G_2 phase, the chromosomes begin the process of **condensation**, i.e., coiling into more and more tightly compacted bodies.
- Once a cell enters G_1 of the cell cycle, it is committed to completing the cycle.

- ***Interphase is that portion of the cell cycle in which the condensed chromosomes are not visible under the light microscope. It includes the G_1, S, and G_2 phases.***

- Mitosis is the shortest phase of the cycle.
- It takes about 1 hour of an 18–24 hour total cell cycle time in an ideal animal cell.
- The amount of time spent in the other phases can vary.
    - A typical G_1 phase can lasts between 6-12h,
    - *S phase* 6-8h
    - G_2 phase between 3-4h.

Formation of the Mitotic Apparatus: Prophase

- It is initiated by **centrioles** which are reproducing organelles in the cytoplasm of animal cells.
- They initiate and organize the mitotic apparatus consisting of *asters* and *spindle fibers.*
- It must be noted that, plant cells do not contain centrioles.

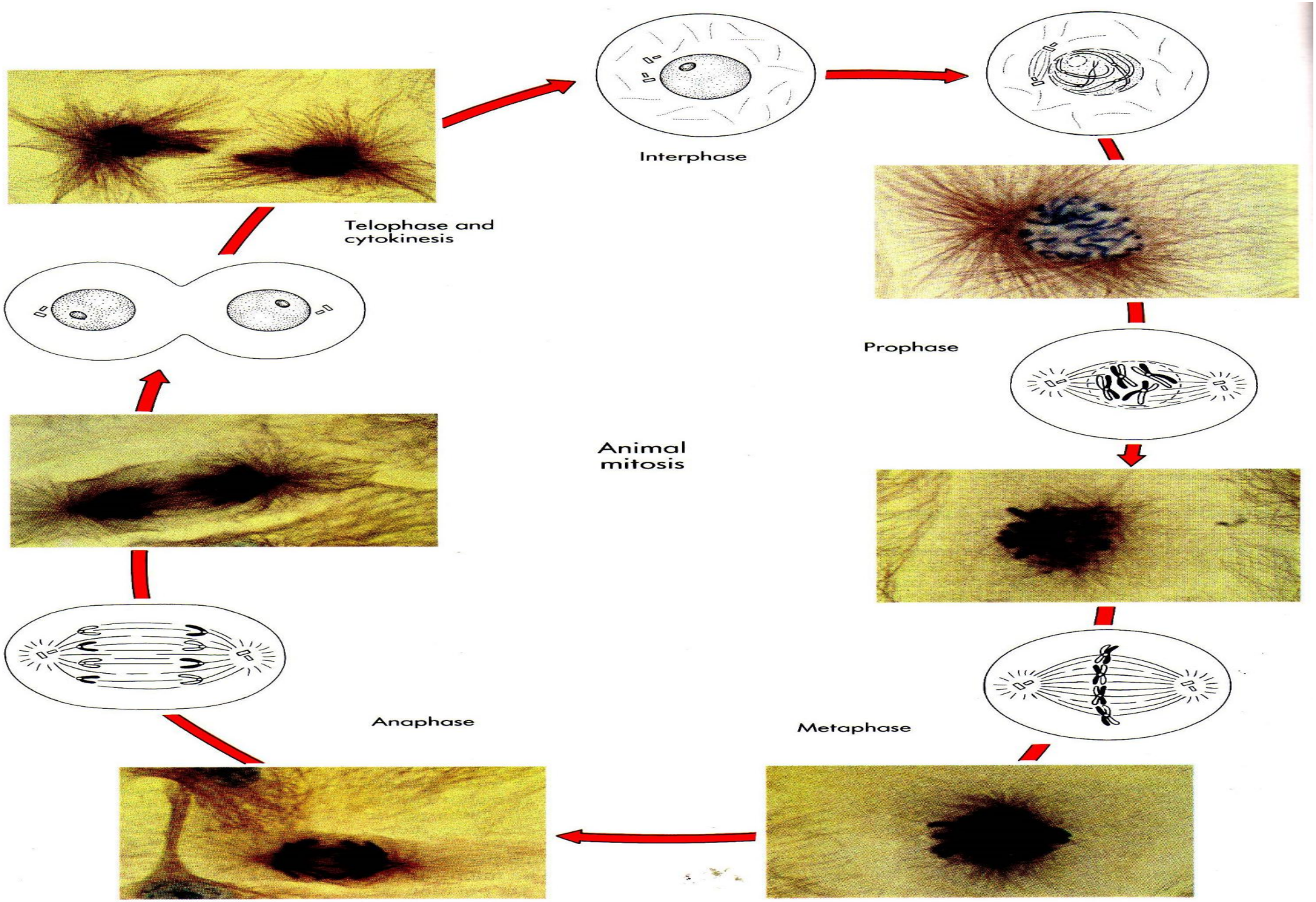


FIGURE 10-9
Animal mitosis. In this remarkable series of photographs, the chromosomes of a kangaroo have been staine

Early Prophase

- Progeny centrioles move apart
- Thin and uncoiled replicated sister chromatids become coiled, shortened and discrete (condensed)
- Visible under the light microscope as thin threads

Late Prophase

- By late prophase, the two chromatids of each chromosome are held together at a constricted region called the **centromere** where spindle fiber attachment is located

- The nuclear membrane and nucleolus disappear

- Late prophase is the best time to study and count chromosomes because they are highly condensed and not confined within a nuclear membrane.

- Mitosis can be arrested at this stage by exposing cells to a chemical called ***colchicine***. It interferes with the assembly of spindle fibers, hence, cannot proceed to the metaphase.

Prophase is the stage of mitosis characterized by the condensation of the chromosomes. During this stage, the nuclear envelope breaks down, and a network of microtubules called the spindle apparatus forms between opposite poles of the cell.

Division of the Centromere: Metaphase

- It begins when pairs of sister chromatids align in the center or at the spindle equator of the cell.
- Each chromosome is drawn to that position by the microtubules extending from it to the two poles of the spindle.
- The chromatids are held together by centromeres until the beginning of anaphase.

Separation of the Chromatids: Anaphase

- Sister chromatids separate at the centromere.

- Chromosomes move to opposite poles by contraction of the spindle fibers.

Separation of the Chromatids: Anaphase

- The shape of the moving chromosome is determined by the position of the centromere.
- Metacentric chromosomes appear **V-shaped.**
- Submetacentric chromosomes appear as **J-shaped.**
- Telocentric appear **rod-shaped.**

Anaphase is the stage of mitosis characterized by the physical separation of sister chromatids. The poles of the cell are pushed apart by microtubular sliding, and the sister chromatids are drawn to opposite poles by the shortening of the microtubules attached to them.

Reformation of Nuclei: Telophase

- Nuclear membranes reform around each daughter nucleus and the nucleolus reappears.
- Spindle fibers disappear.
- The cytoplasmic part of the cell then divides.

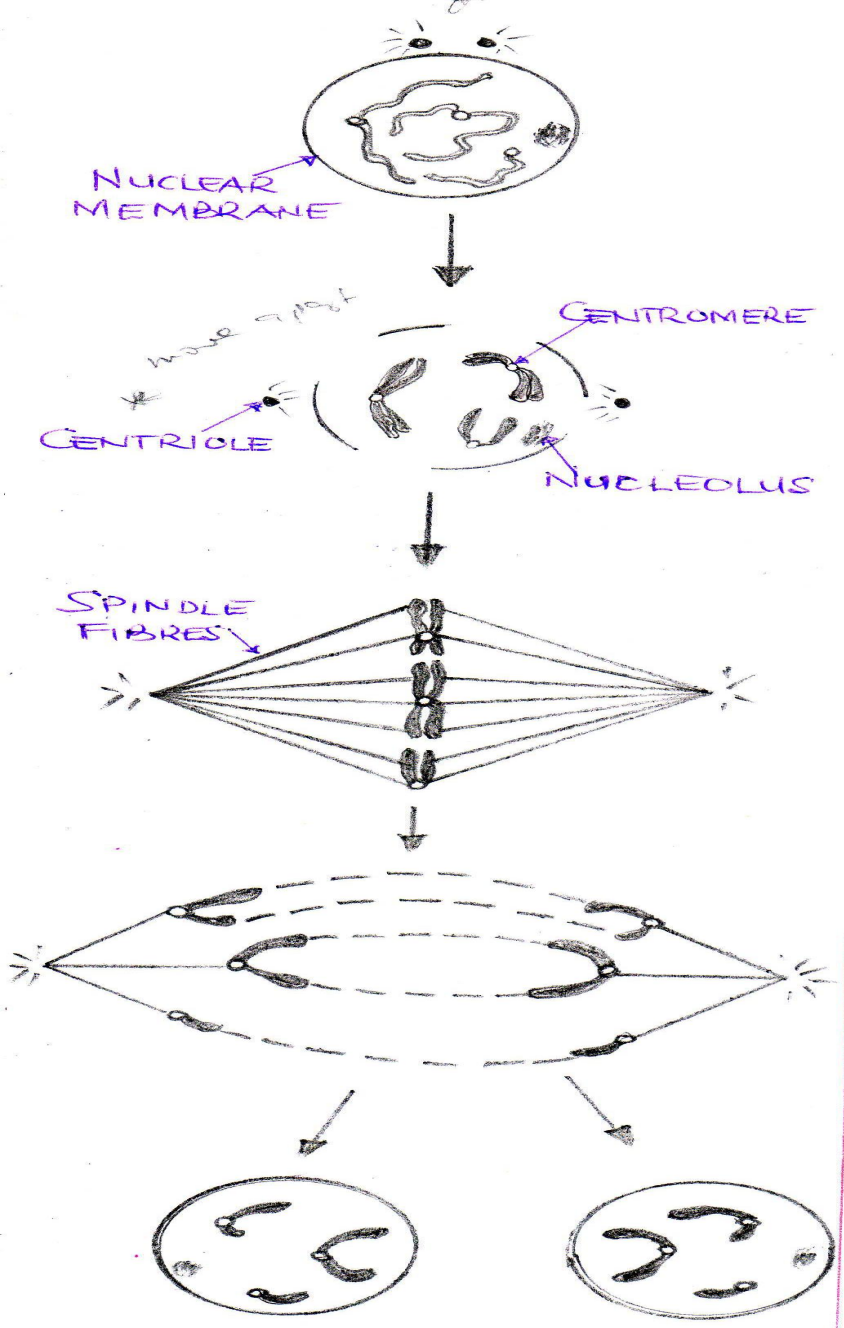
Reformation of Nuclei: Telophase

- In animal cells, **cytokinesis** (cell division) is accomplished by the formation of a cleavage that deepens and eventually pinches the cell into two.

- The chromosomes relax into their extended phase.

- ***Cytokinesis is the physical division of the cytoplasm of a eukaryotic cell into two daughter cells.***

- Cytokinesis in plants with their rigid cell walls begins with the formation of a partition or cell plate between the daughter cells.



EARLY PROPHASE

Replicated chromosomes appear as two chromatids held together at the centromere. The centriole divides.

LATE PROPHASE

The chromatids become short and thick. The centrioles move to opposite poles. The nucleolus and nuclear membrane disappear.

METAPHASE

The paired chromatids align at the spindle equator. Spindle fibers attach to kinetochores within the centromeres.

ANAPHASE

Centromeres divide and chromosomes move to opposite poles by contraction of the spindle fibers. The shape of the moving chromosome is determined by the position of the centromere.

TELOPHASE

Nuclear membranes reform. Spindle fibers disappear. Each mitotic product has identical chromosome complements. The chromosome relax into their extended phase

REVIEW QUESTIONS

- ***In chronological order, what are the stages of mitosis? Indicate a key characteristic of each stage.***

- ***What is a karyotype? How are chromosomes differentiated from one another?***

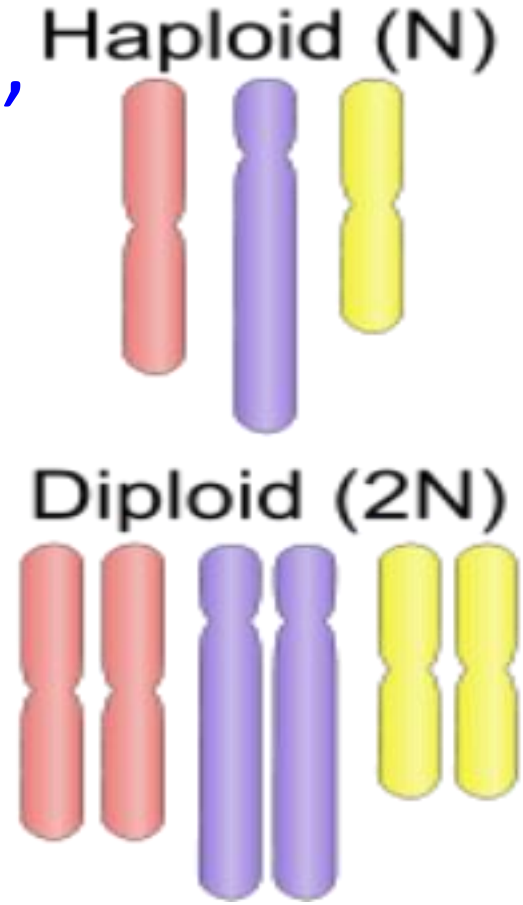
Sexual Reproduction and Meiosis

Sexual reproduction involves the production of **gametes** and the union of a male and a female gamete **(syngamy or fertilization)** to produce a **zygote**.

- In humans, male gametes are **sperms,** and the females are **eggs**, or **ova** (**ovum**)

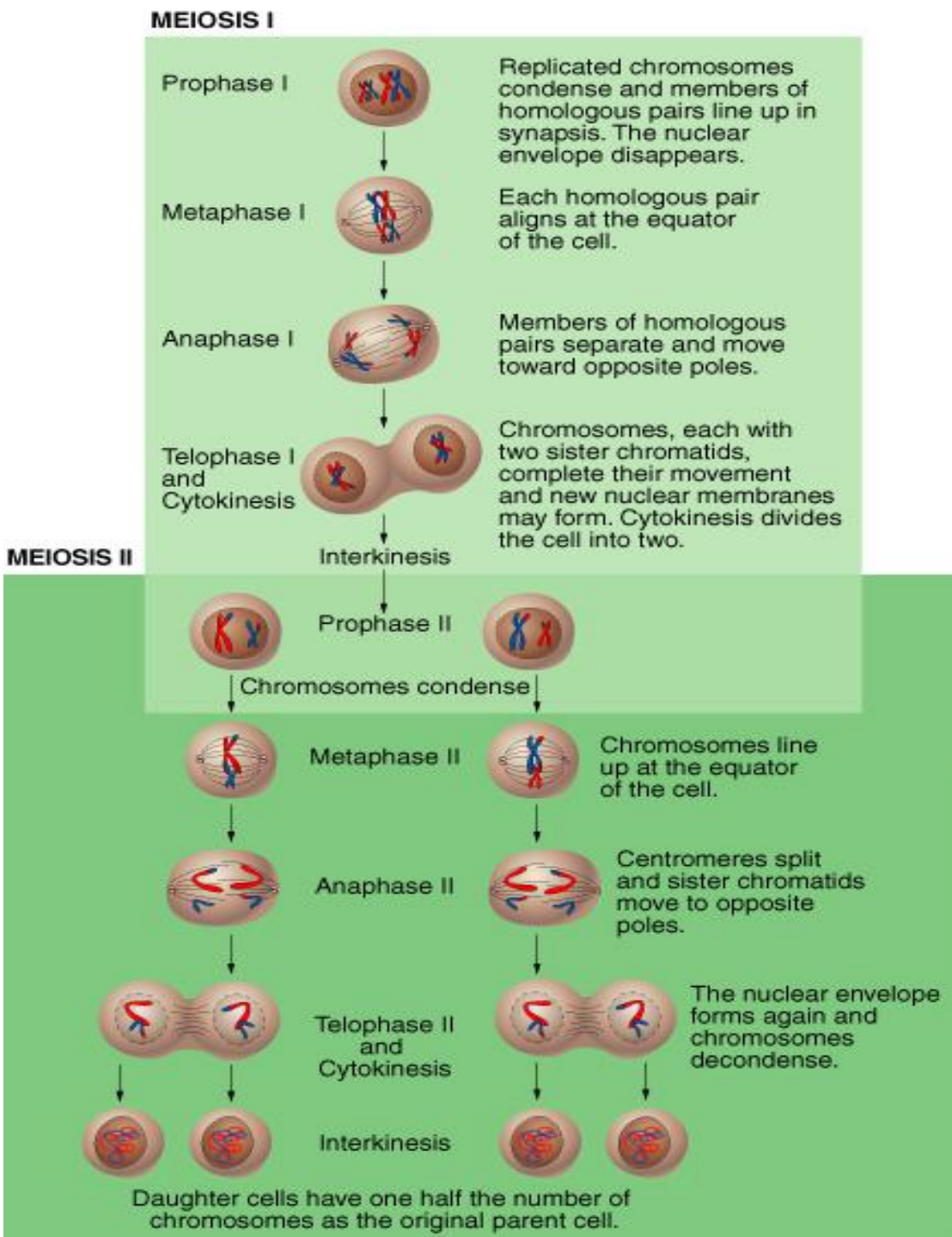
Meiosis

- Meiosis consists of two specialized, consecutive cell divisions in which the chromosome number of the resulting cells is reduced from a **diploid** (2n) to a **haploid** (n) number.



- Specifically, meiosis involves a single DNA replication and two divisions of the cytoplasm.

- The first meiotic division (meiosis I) is a **reductional division** that produces two diploid cells from a single diploid cell.
- The second meiotic division (meiosis II) is an equational division. It is identical to normal mitotic division, in that it is sister chromatids of the diploid cells that are separated.



Characteristics of Meiosis I

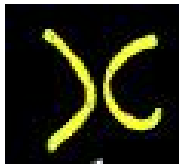
- Replicated chromosomes thicken and condense.
- Metaphase I differs from mitotic metaphase in that, homologous chromosomes come to lie side by side in a pairing process called **synapsis**.
- Each pair of the synapsed chromosomes is called a **bivalent** (two chromosomes) or a **tetrad** (four chromatids).

- The cell at this stage contains one set of maternally derived and one set of paternally derived chromosomes.

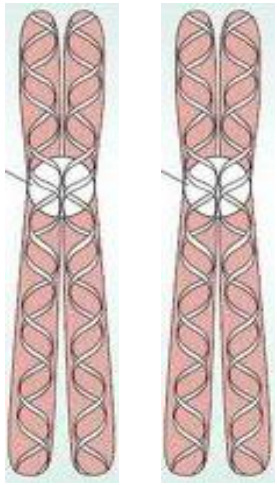
- During synapsis, chromatids may cross over and exchange genetic material in a process called **crossing over** and **recombination**.

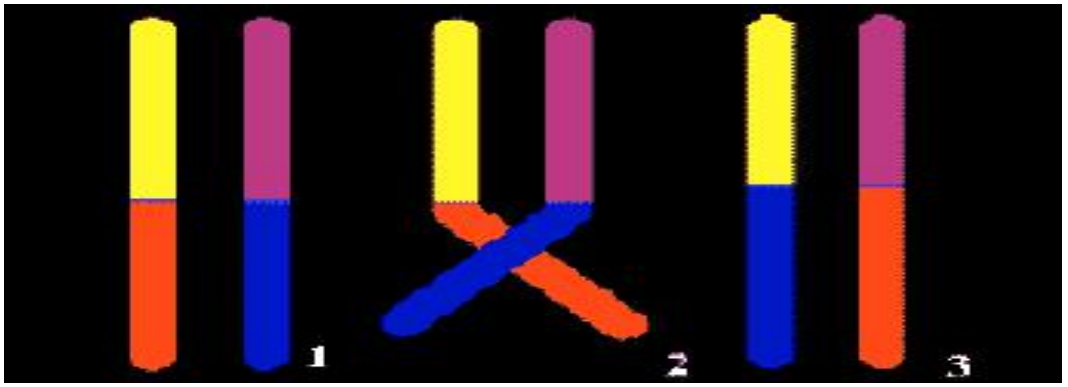
Genetic Variation

- Recombination
  - Crossing over – the exchange of genetic materials between non-sister chromatids during Prophase I of Meiosis I



Think a and b

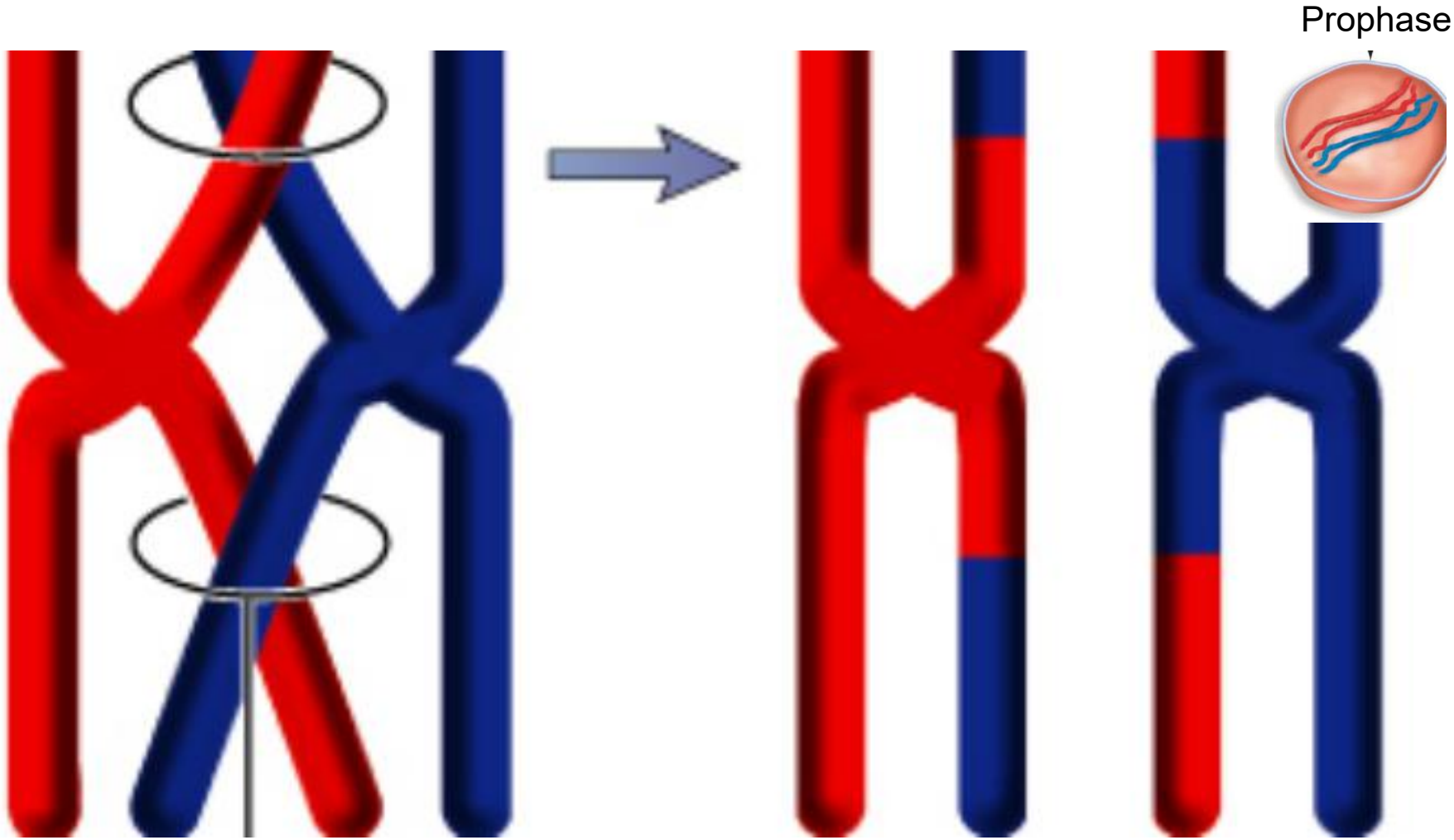




Remember crossing over occurs during prophase I

- Independent assortment during metaphase I of meiosis I

Crossing over between chromatids of homologous pairs of chromosomes



Tetrads form by synapsis of homologous chromosomes. Crossing over occurs.

PROPHASE I

The events of Prophase I are complex and can be sub-divided into five stages.

(i) **Leptonema** (**Leptotene** or thin-thread stage)

(ii) **Zygonema** (**Zygotene** or joined-thread stage)

(iii) **Pachynema** (**Pachytene** or thick-thread stage)

(iv) **Diplonema** (**Diplotene** or double-thread stage)

(v) **Diakinesis** (double movement stage)

Homework

- Read more on the sub-divisions.
- Understand the synaptonemal complex and chiasma (chiasmata, plural)

Metaphase I

- The bivalents orient at random on the equatorial plane or towards the metaphase plate by the help of the spindle fiber

- ***The pairing of homologous chromosomes make metaphase I of meiosis distinct from mitotic metaphase, where no such pairing exists***

Anaphase I

- The centromeres do not separate but continue to hold sister chromatids together.

- Each member of the pair of homologous chromosomes (consisting of two sister chromatids) move to opposite poles.

An important distinction with mitotic anaphase is that, in meiotic anaphase I, the centromeres do not divide.

Telophase I

- Occurs when the nuclear membrane reforms and the chromosomes have reached their polar destination.

- Cytokinesis follows and results in a division of the diploid mother cell into two haploid daughter cells.

- Note: Genetic aberrations can occur if mistakes are made during the separation of homologous chromosomes at anaphase I.

- If homologues fail to disjoin, and migrate to the same pole (nondisjunction), the resulting gametes will contain two of those chromosomes, instead of just one.

Meiosis II

- The period between the first and second meiotic divisions is called ***interkinesis***.
- It is usually either brief or lacking altogether
- It is different from the interphase preceding mitosis, because ***there is no synthesis of new DNA.***

Prophase II

- Chromosomes recondense.
- Spindle fibers reforms.
- This phase is very brief

Metaphase II

- The chromosomes are attached to spindle fibers by their centromeres.

- Chromosomes align on a metaphase plate or equatorial plane.

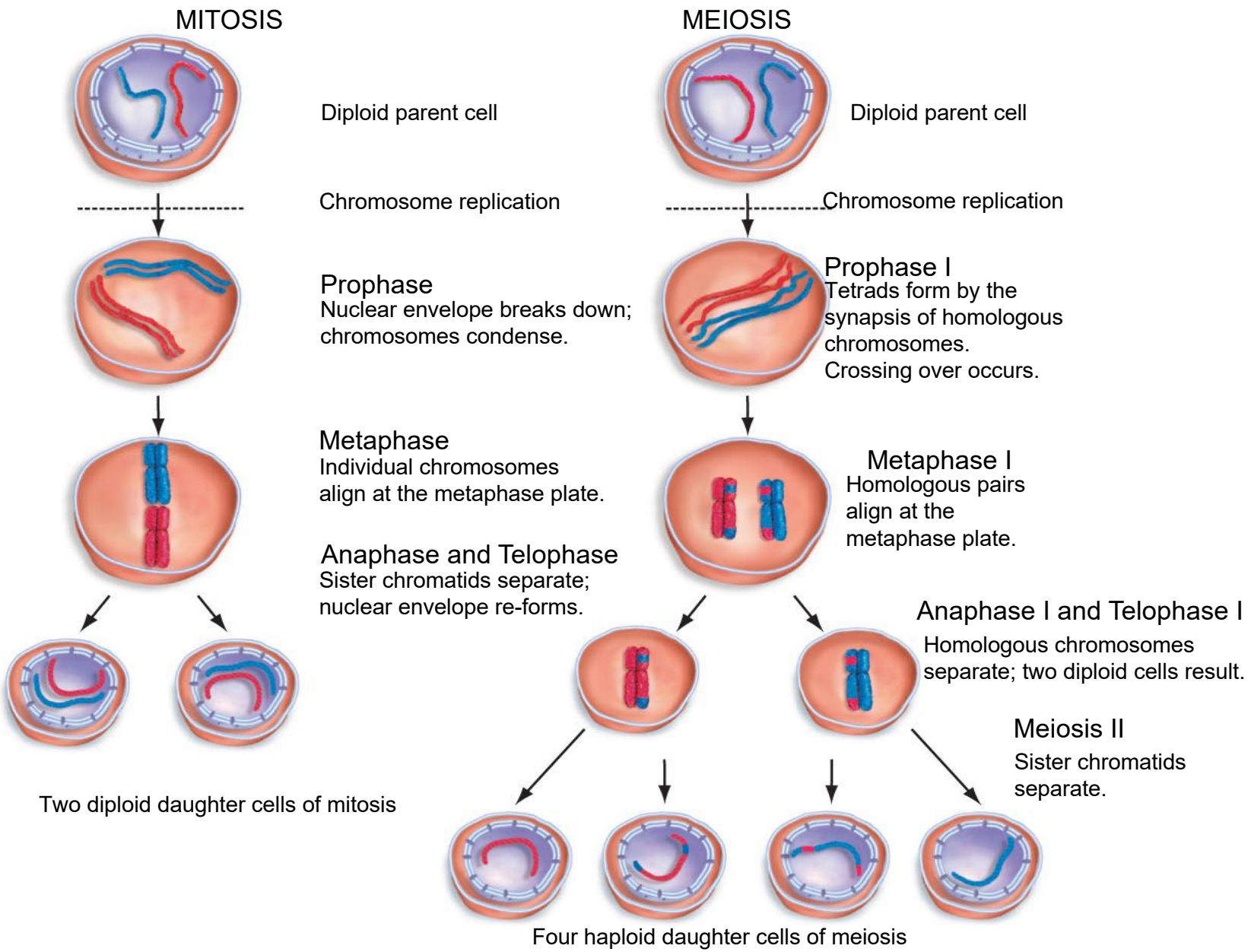
Anaphase II

- Each centromere divides.
- Sister chromatids separate and move to opposite poles.

Telophase II

- During this phase, nuclear membrane reappears.
- Each cell divides by cytokinesis into two progeny cells.
- Thus, a diploid mother cell becomes four haploid progeny cells as a consequence of meiosis I and II.

Comparison of Mitosis with Meiosis



Significance of Meiosis

(i) It makes possible *the conservation of the number of chromosomes* from generation to generation in sexually reproducing organisms.

Note that sexual reproduction involves fertilization - which is the fusion of two gametes or sex cells.

(ii) Crossing over between non- sister chromatids contribute to *the recombination of paternal and maternal hereditary traits in gametes.*

Note: Owing to this exchange, the number of different kinds of gametes is virtually infinite.

Review Questions

1. How does meiosis differ from mitosis? Consider differences in mechanisms as well as end results.
2. What events occur at the level of the DNA during synaptonemal crossing-over?
3. Are human somatic cells generally haploid or diploid? Are gamete-producing cells haploid or diploid?

Homework:

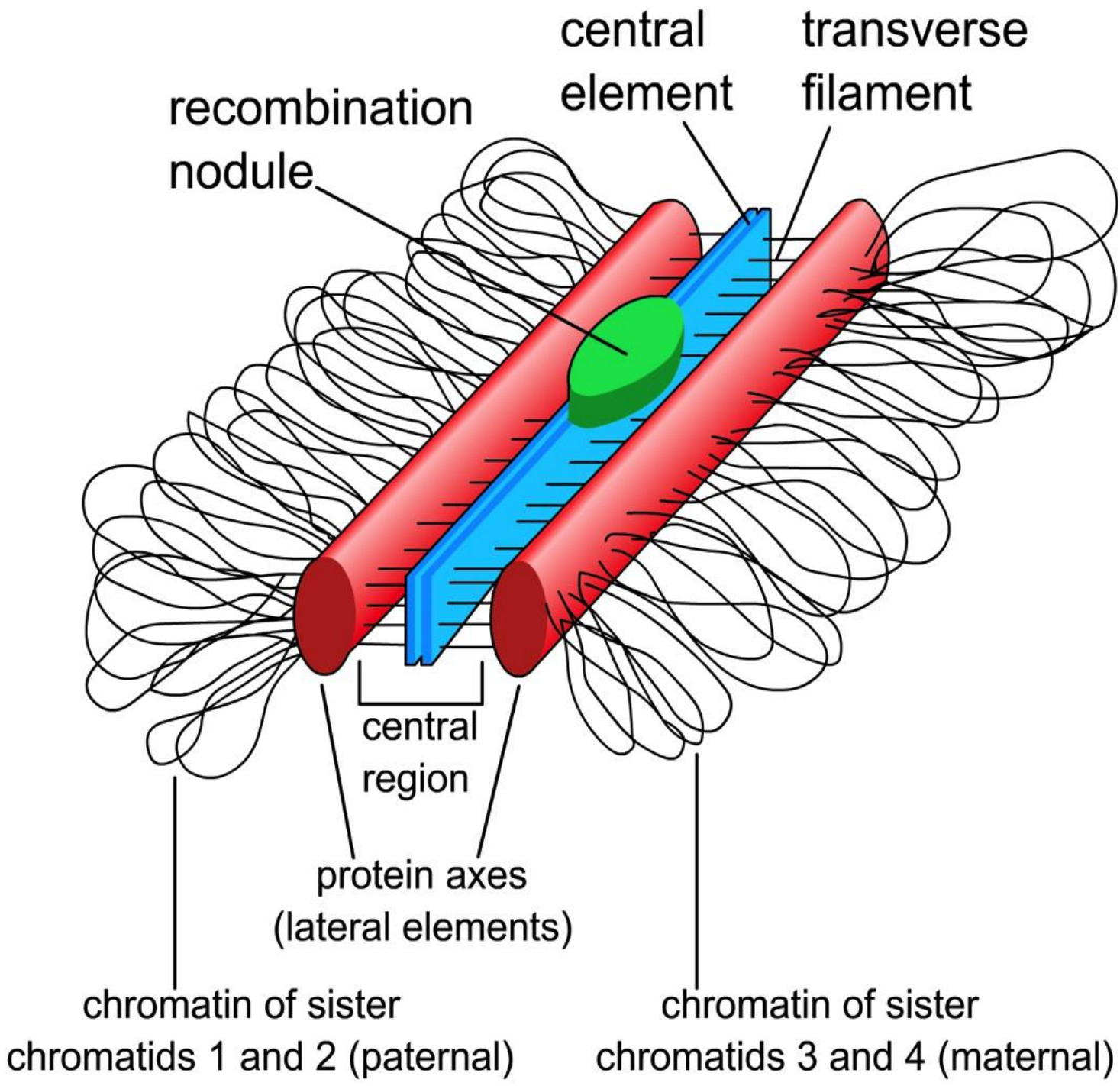
- Read and make notes on **animal gametogenesis** (as represented in mammals). Lay emphasis on **oogenesis** and **spermatogenesis**.

Vocabulary

- Locus
- Allele
- Genotype
- Phenotype
- Heterozygous
- Homozygous
- Dominant
- Recessive
- Law of segregation
- P
- F1
- F2
- Monohybrid
- Dihybrid

The Synaptonemal Complex

Functions to allow interacting chromatids to complete their crossing over activities.



Chiasma (plural: Chiasmata)

The point where two homologous non-sister chromatids exchange genetic materials during crossing over