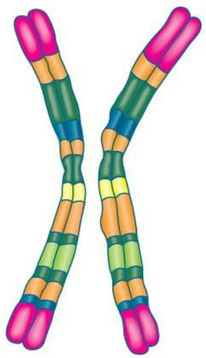
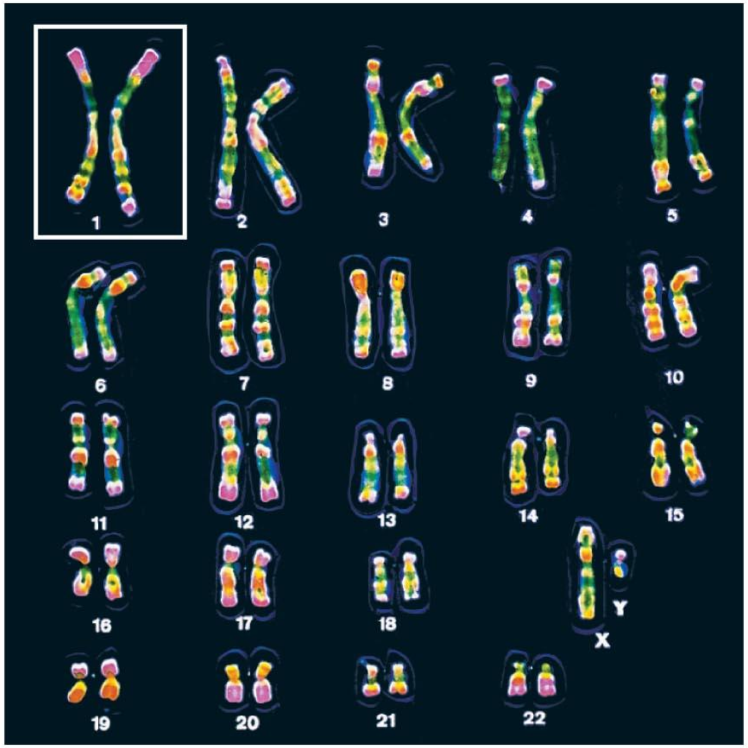
# Chapter 13
# Meiosis and Sexual Life Cycles





# Overview: Variations on a Theme

- Living organisms are distinguished by their ability to reproduce their own kind

- **Genetics** is the scientific study of heredity and variation
- **Heredity** is the transmission of traits from one generation to the next

- **Variation** is demonstrated by the differences in appearance that offspring show from parents and siblings

# Concept 13.1: Offspring acquire genes from parents by inheriting chromosomes

- In a literal sense, children do not inherit particular physical traits from their parents.

- It is **genes** that are actually inherited

# Inheritance of Genes

- Genes are the units of heredity, and are made up of segments of DNA

- Genes are passed to the next generation through reproductive cells called gametes (sperm and eggs)

- Each gene has a specific location called a locus on a certain chromosome

- One set of chromosomes is inherited from each parent

# Comparison of Asexual and Sexual Reproduction

- In **asexual reproduction**, one parent produces genetically identical offspring by mitosis

- A **clone** is a group of genetically identical individuals from the same parent

- In **sexual reproduction**, two parents give rise to offspring that have **unique combinations of genes** inherited from the two parents

# Concept 13.2: Fertilization and meiosis alternate in sexual life cycles

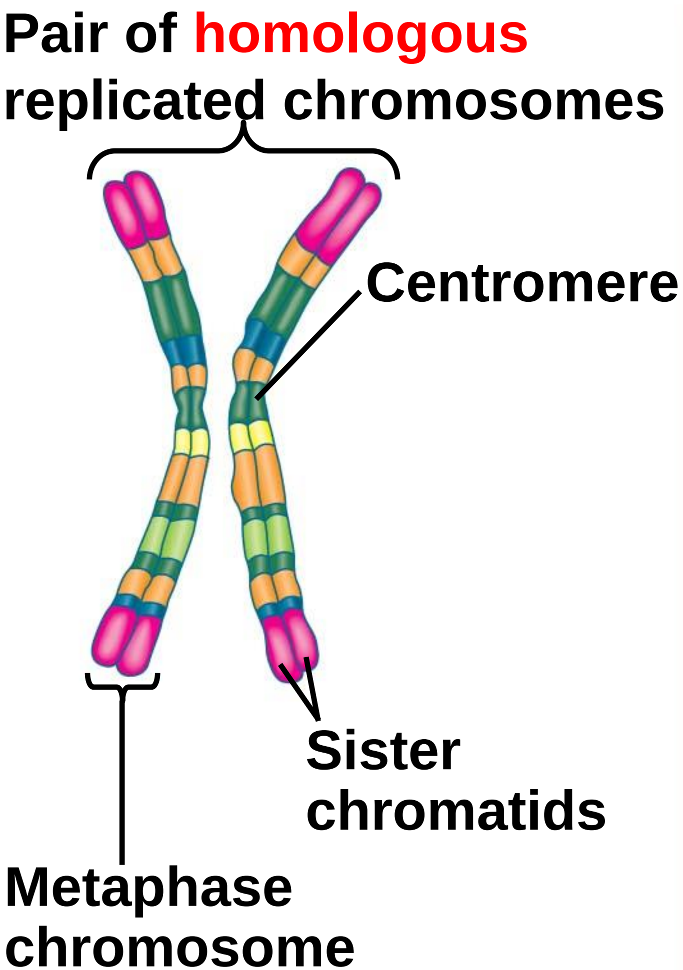
- A **life cycle** is the generation-to-generation sequence of stages in the reproductive history of an organism

# Sets of Chromosomes in Human Cells

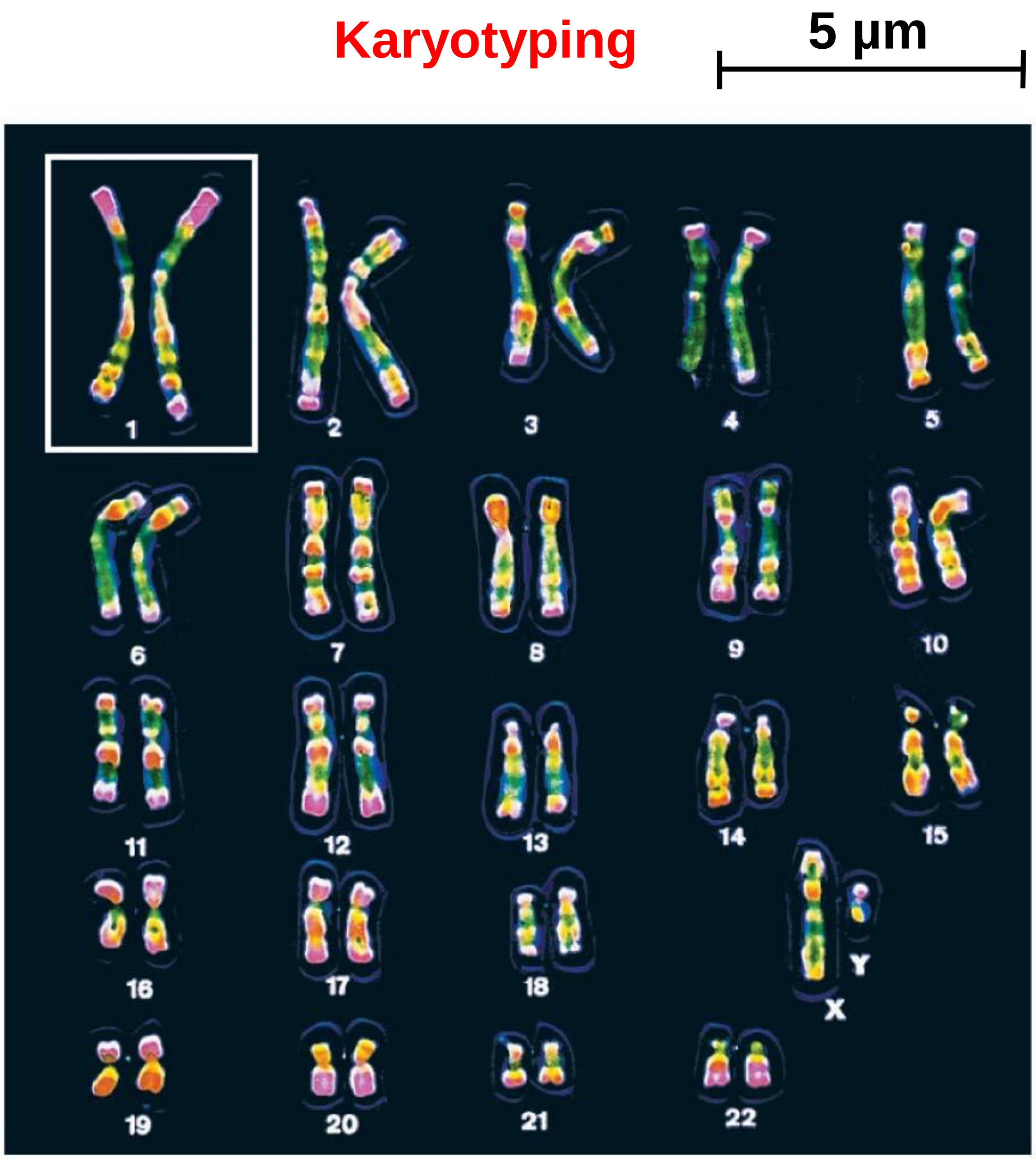
- **Human somatic cells (any cell other than a gamete) have 23 pairs of chromosomes**
- **A karyotype is an ordered display of the pairs of chromosomes from a cell**
- **The two chromosomes in each pair are called homologous chromosomes, or homologs**
- **Chromosomes in a homologous pair are the same length and carry genes controlling the same inherited characters**

Fig. 13-3b

# TECHNIQUE




Karyotyping



- **The sex chromosomes are called X and Y**

- **Human females have a homologous pair of X chromosomes (XX)**

- **Human males have one X and one Y chromosome (XY)**

- **The 22 pairs of chromosomes that do not determine sex are called autosomes**

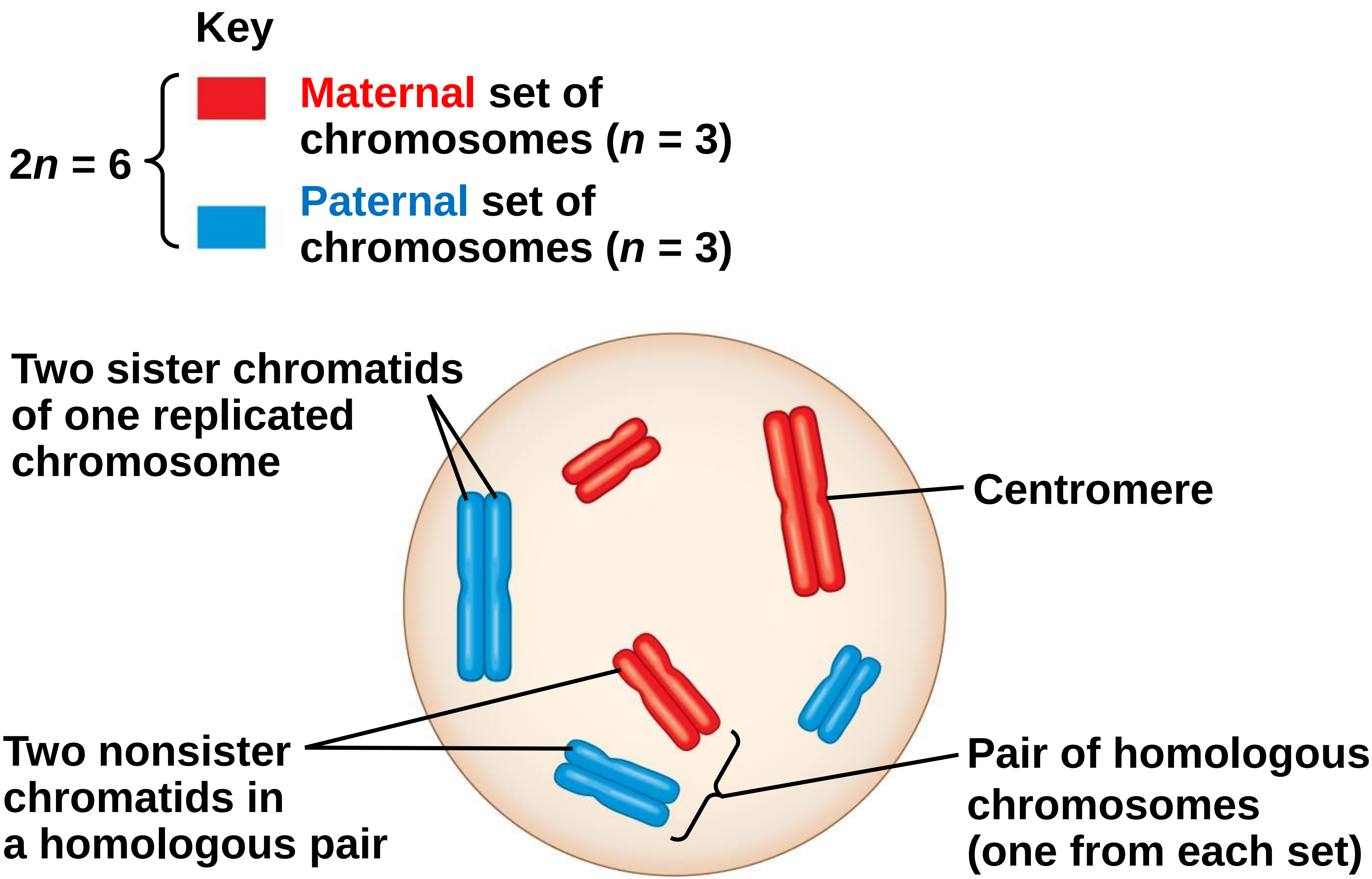
- **Each pair of homologous chromosomes includes one chromosome from each parent**

- **The 46 chromosomes in a human somatic cell are two sets of 23: one from the mother and one from the father**

- **A diploid cell (2*n*) has two sets of chromosomes**

- **For humans, diploid number is 46 (2*n* = 46)**

Fig. 13-4


Key
2n = 6
Maternal set of chromosomes (n = 3)
Paternal set of chromosomes (n = 3)
Two sister chromatids of one replicated chromosome
Centromere
Two nonsister chromatids in a homologous pair
Pair of homologous chromosomes (one from each set)

- **A gamete (sperm or egg) contains a single set of chromosomes, and is haploid (*n*)**
- **For humans, the haploid number is 23 (*n* = 23)**
- **Each set of 23 chromosomes consists of 22 autosomes and a single sex chromosome**
- **Other example: Drosophila melanogaster: 2n-8, 1n=4**
- **Dogs: 2n=78, 1n=39**

# Behavior of Chromosome Sets in the Human Life Cycle

- **Fertilization** ***is the union of gametes (the sperm and the egg)***

- **The fertilized egg is called a zygote and has one set of chromosomes from each parent**

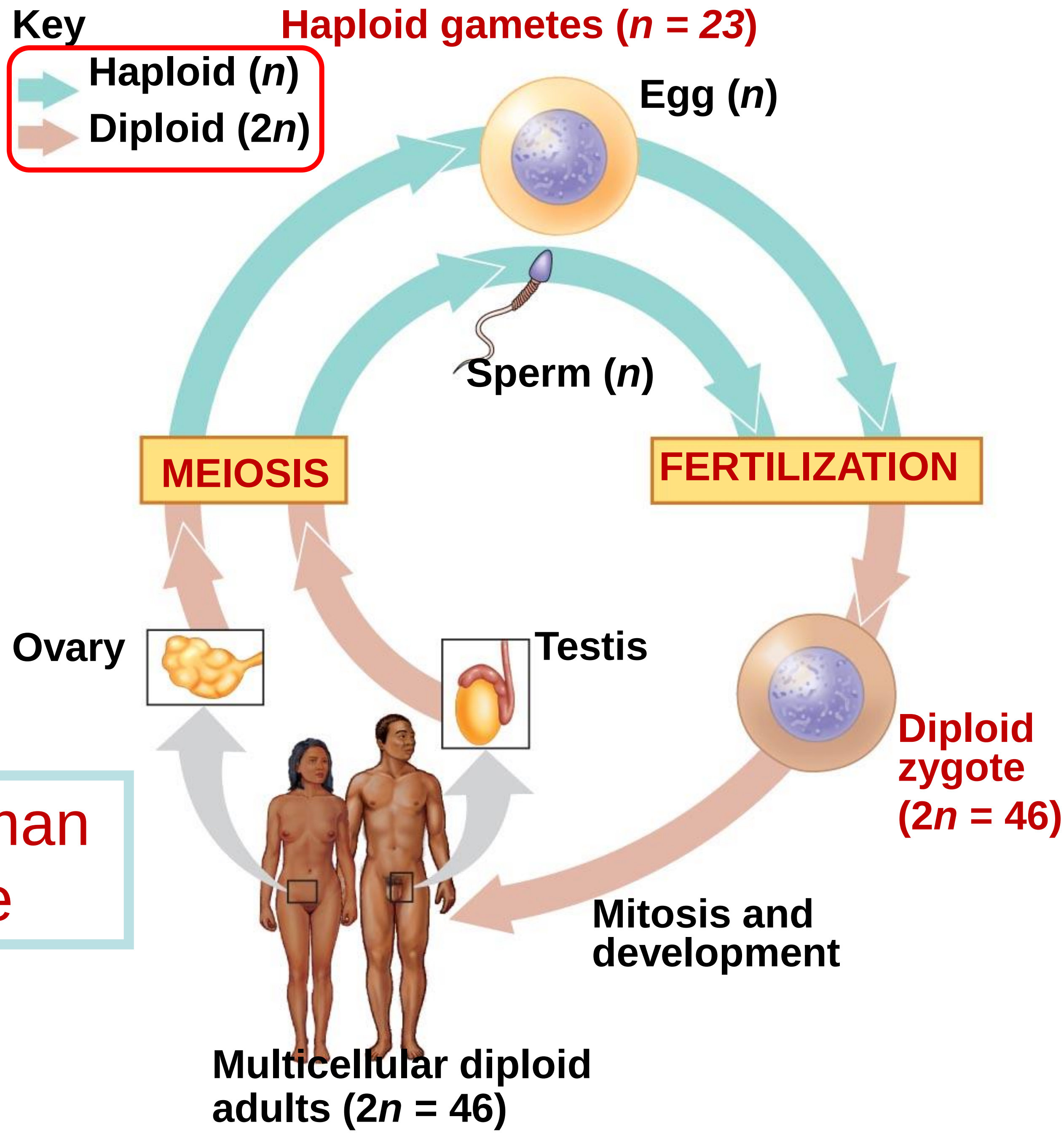
- **The zygote produces somatic cells by mitosis and develops into an adult**

- At **sexual maturity**, the **ovaries and testes produce haploid gametes**

- **Gametes** are the only types of human cells produced by **meiosis**, rather than mitosis

- Meiosis results in one set of chromosomes in each gamete

Fig. 13-5




The human life cycle

## Concept 13.3: Meiosis reduces the number of chromosome sets from diploid to haploid

- Like mitosis, meiosis is preceded by the replication of chromosomes
- Meiosis takes place in two sets of cell divisions, called meiosis I and meiosis II
- The two cell divisions result in four daughter cells, rather than the two daughter cells in mitosis
- Each daughter cell has only half as many chromosomes as the parent cell

# The Stages of Meiosis

- In the first cell division (meiosis I), <u>homologous chromosomes separate</u>
- Meiosis I results in <u>two haploid daughter cells with replicated chromosomes</u>; it is called the <u>reductional division</u>

- In the second cell division (meiosis II), <u>sister chromatids separate</u>
- Meiosis II results in four haploid daughter cells with <u>unreplicated chromosomes</u>; it is called the <u>equational division</u>

Fig. 13-7-1

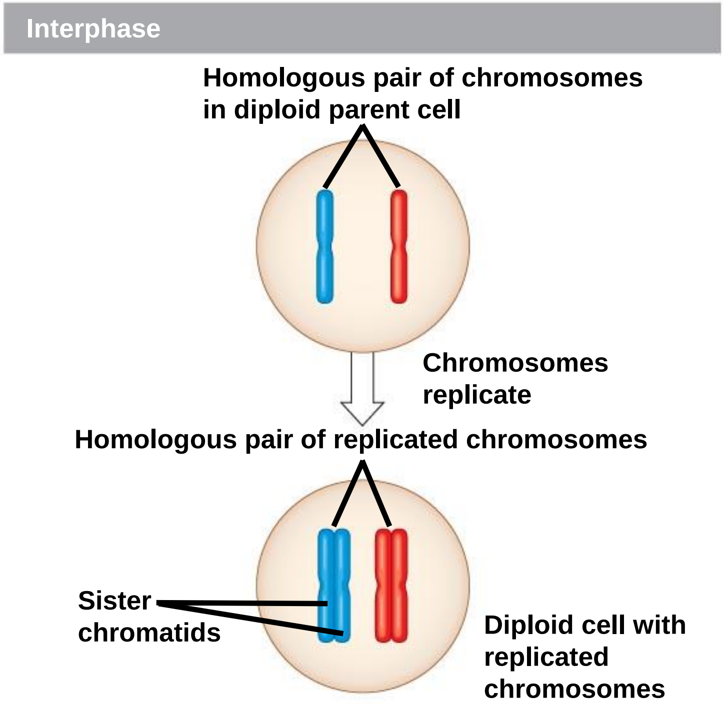

Interphase
Homologous pair of chromosomes
in diploid parent cell
Chromosomes
replicate
Homologous pair of replicated chromosomes
Sister
chromatids
Diploid cell with
replicated
chromosomes

Fig. 13-7-2

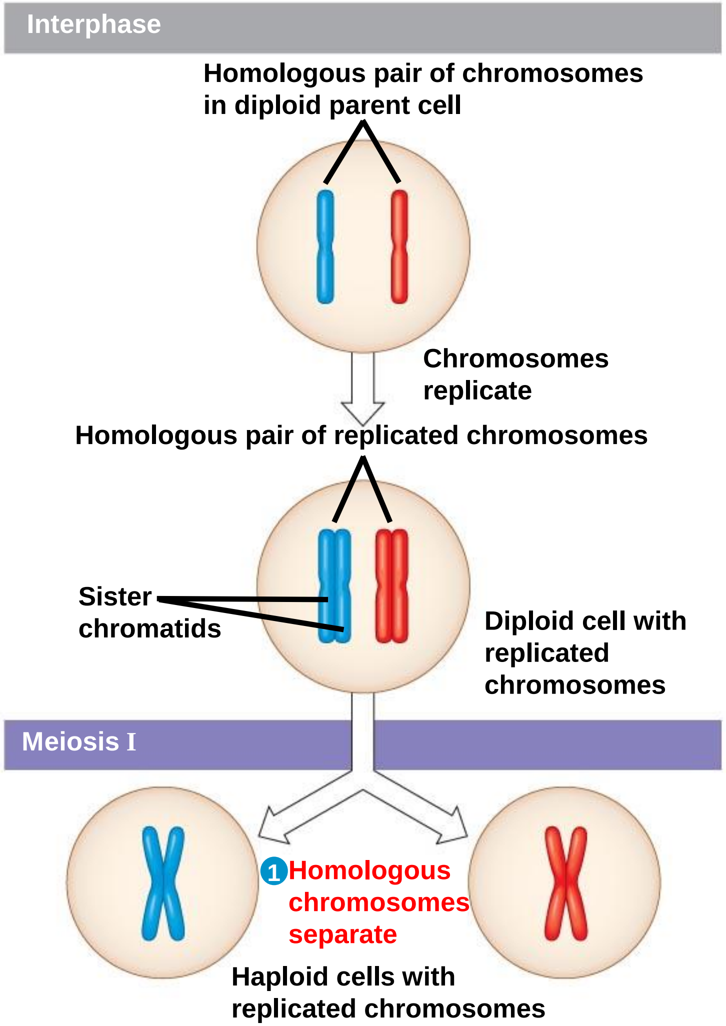

Interphase
Homologous pair of chromosomes
in diploid parent cell
Chromosomes
replicate
Homologous pair of replicated chromosomes
Sister
chromatids
Diploid cell with
replicated
chromosomes
Meiosis I
1 Homologous
chromosomes
separate
Haploid cells with
replicated chromosomes

Fig. 13-7-3

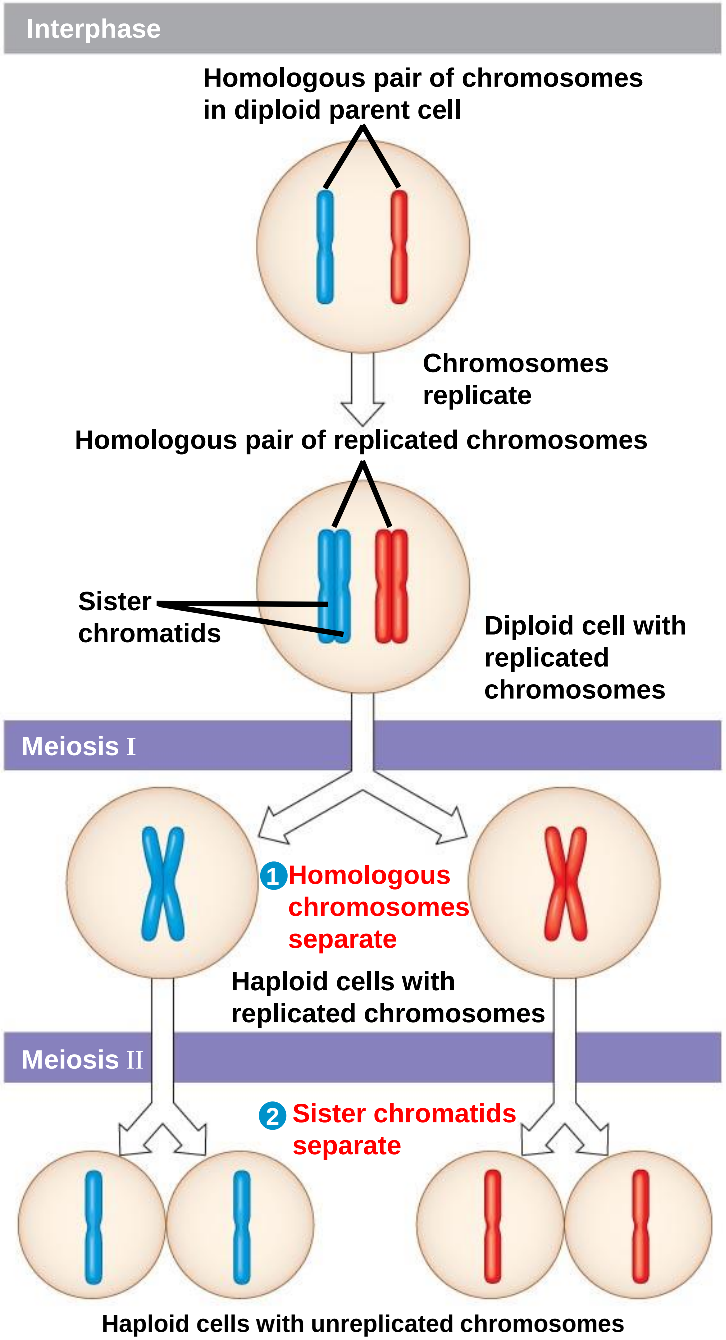
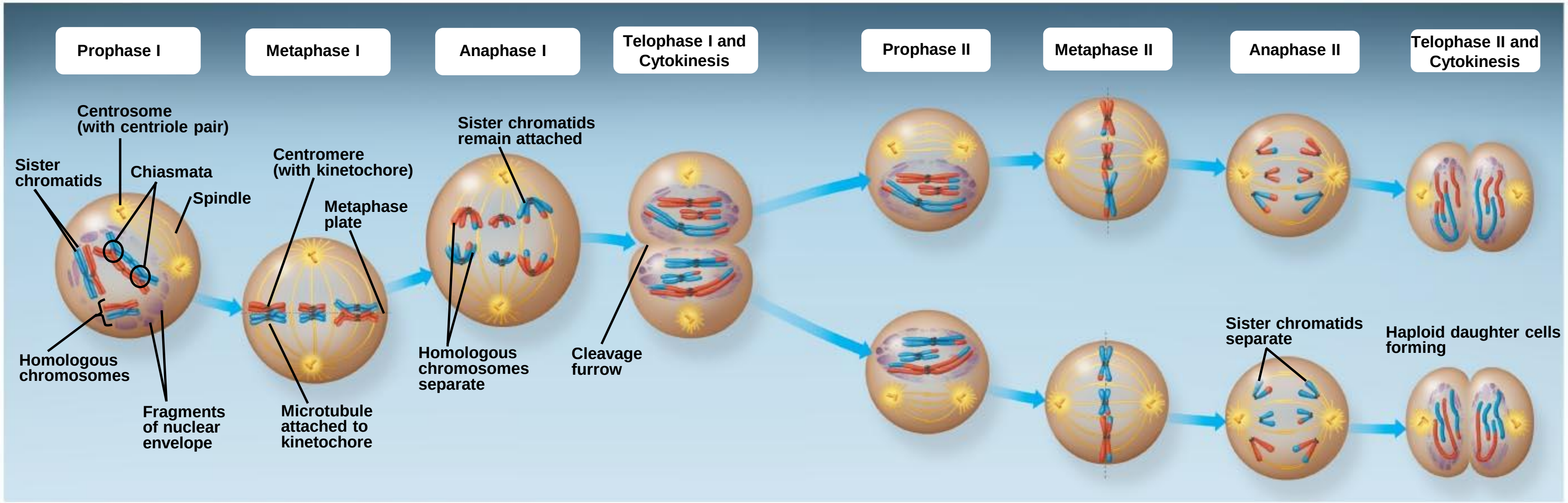

Interphase
Homologous pair of chromosomes in diploid parent cell
Chromosomes replicate
Homologous pair of replicated chromosomes
Sister chromatids
Diploid cell with replicated chromosomes
Meiosis I
1 Homologous chromosomes separate
Haploid cells with replicated chromosomes
Meiosis II
2 Sister chromatids separate
Haploid cells with unreplicated chromosomes

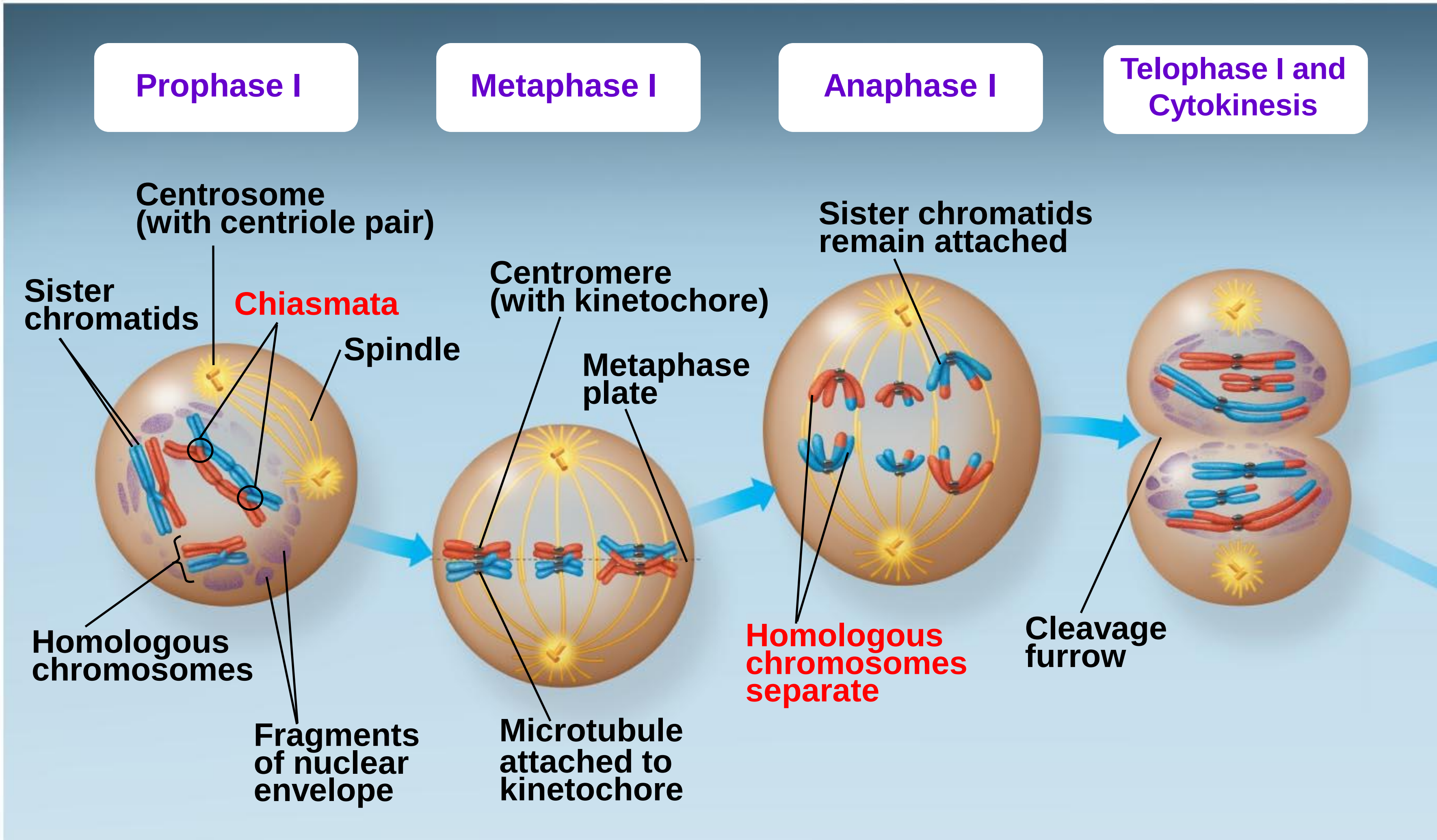
Fig. 13-8



Prophase I
Metaphase I
Anaphase I
Telophase I and Cytokinesis
Prophase II
Metaphase II
Anaphase II
Telophase II and Cytokinesis
Centrosome (with centriole pair)
Sister chromatids
Chiasmata
Spindle
Homologous chromosomes
Fragments of nuclear envelope
Centromere (with kinetochore)
Metaphase plate
Microtubule attached to kinetochore
Sister chromatids remain attached
Homologous chromosomes separate
Cleavage furrow
Sister chromatids separate
Haploid daughter cells forming

- Division in **meiosis I** occurs in four phases:
  - Prophase I
  - Metaphase I
  - Anaphase I
  - Telophase I and cytokinesis

Fig. 13-8a


Prophase I
Metaphase I
Anaphase I
Telophase I and Cytokinesis
Centrosome (with centriole pair)
Sister chromatids
Chiasmata
Spindle
Homologous chromosomes
Fragments of nuclear envelope
Centromere (with kinetochore)
Metaphase plate
Microtubule attached to kinetochore
Sister chromatids remain attached
Homologous chromosomes separate
Cleavage furrow

# Prophase I

- **Prophase I typically occupies more than 90% of the time required for meiosis**

- **Chromosomes begin to condense**

- **In <u>synapsis</u>, homologous chromosomes loosely pair up, aligned gene by gene**

- **In <u>crossing over</u>, nonsister chromatids <u>exchange</u> DNA segments**

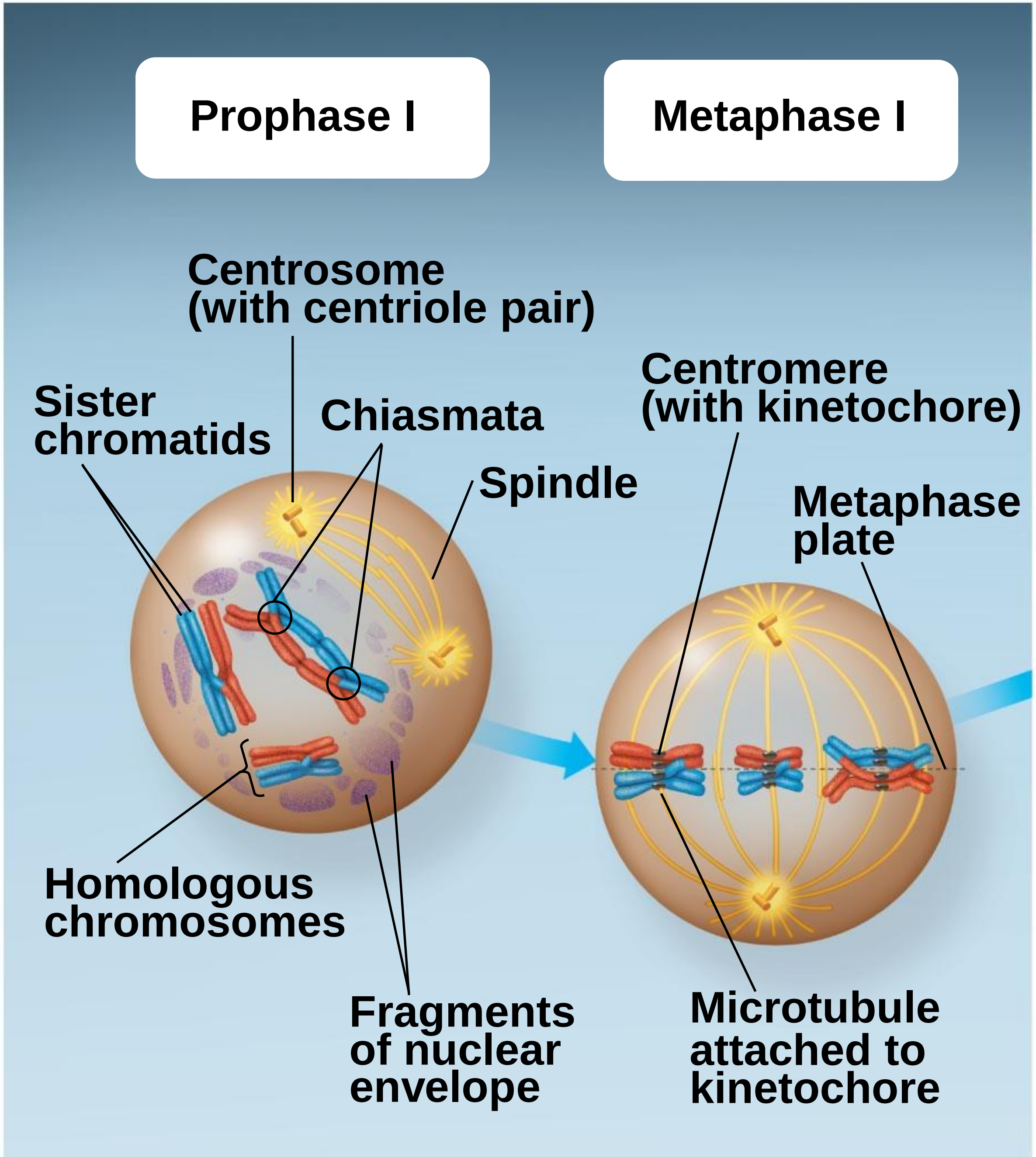
- **Each pair of chromosomes forms a <u>tetrad</u>, a group of four chromatids**

- **Each tetrad usually has one or more <u>chiasmata</u>, *X-shaped regions where crossing over occurred***

# Metaphase I

- In metaphase I, **tetrads line up at the metaphase plate**, with one chromosome facing each pole
- **Microtubules from one pole are attached to the kinetochore** of one chromosome of each tetrad
- Microtubules from the other pole are attached to the kinetochore of the other chromosome

Fig. 13-8b


Prophase I
Metaphase I
Centrosome
(with centriole pair)
Sister
chromatids
Chiasmata
Spindle
Centromere
(with kinetochore)
Metaphase
plate
Homologous
chromosomes
Fragments
of nuclear
envelope
Microtubule
attached to
kinetochore

# Anaphase I

- In anaphase I, **pairs of homologous chromosomes separate**
- **One chromosome** moves toward each pole, guided by the spindle apparatus
- **Sister chromatids remain attached** at the centromere and **move as one unit** toward the pole

# Telophase I and Cytokinesis

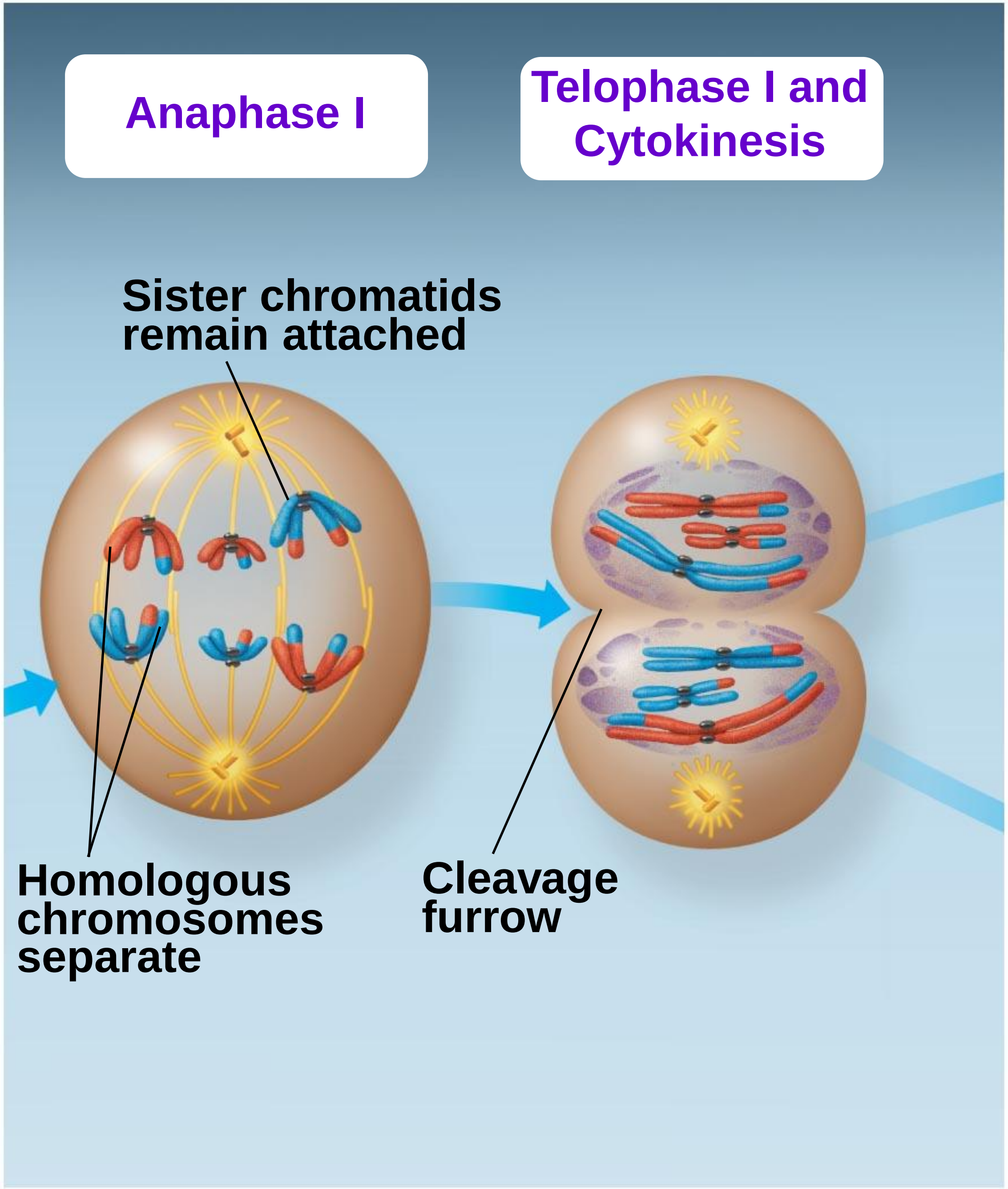
- **In the beginning of <u>telophase I</u>, each half of the cell has a haploid set of chromosomes; <u>each chromosome still consists of two sister chromatids</u>**

- **<u>Cytokinesis</u> usually occurs simultaneously, forming <u>two haploid daughter cells</u>**

- **In animal cells, a <u>cleavage furrow</u> forms; in plant cells, a <u>cell plate</u> forms**

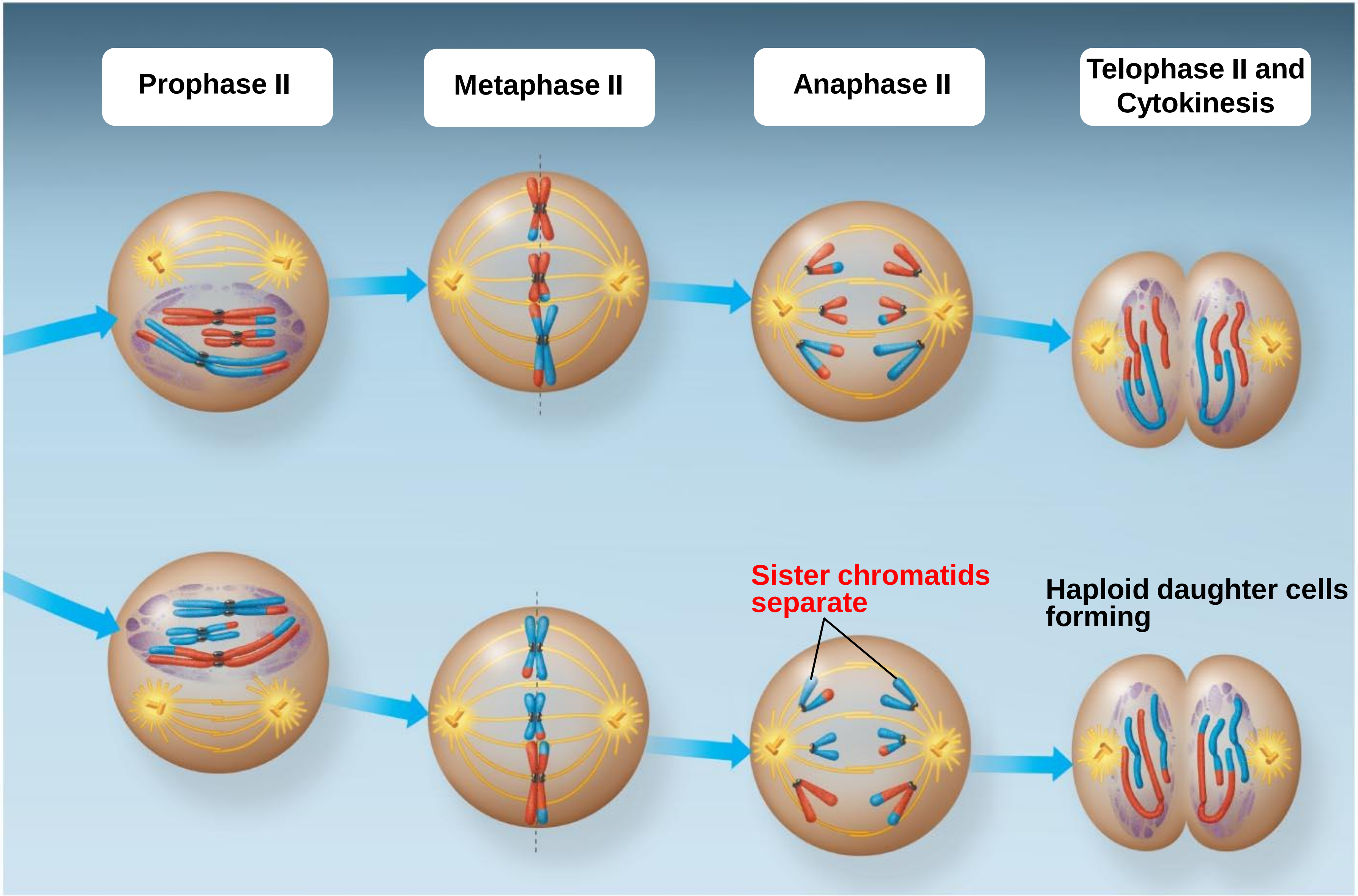
- ***<u>No chromosome replication</u> occurs between the end of meiosis I and the beginning of meiosis II***

Fig. 13-8c


Anaphase I
Telophase I and Cytokinesis
Sister chromatids remain attached
Homologous chromosomes separate
Cleavage furrow

- **Division in meiosis II also occurs in four phases:**
  - **Prophase II**
  - **Metaphase II**
  - **Anaphase II**
  - **Telophase II and cytokinesis**
- **Meiosis II is <u>very similar to mitosis</u>**

Fig. 13-8d


Prophase II
Metaphase II
Anaphase II
Telophase II and Cytokinesis
Sister chromatids separate
Haploid daughter cells forming

# Prophase II

- **In prophase II, a spindle apparatus forms**
- **In late prophase II, chromosomes (each still composed of two chromatids) move toward the metaphase plate**

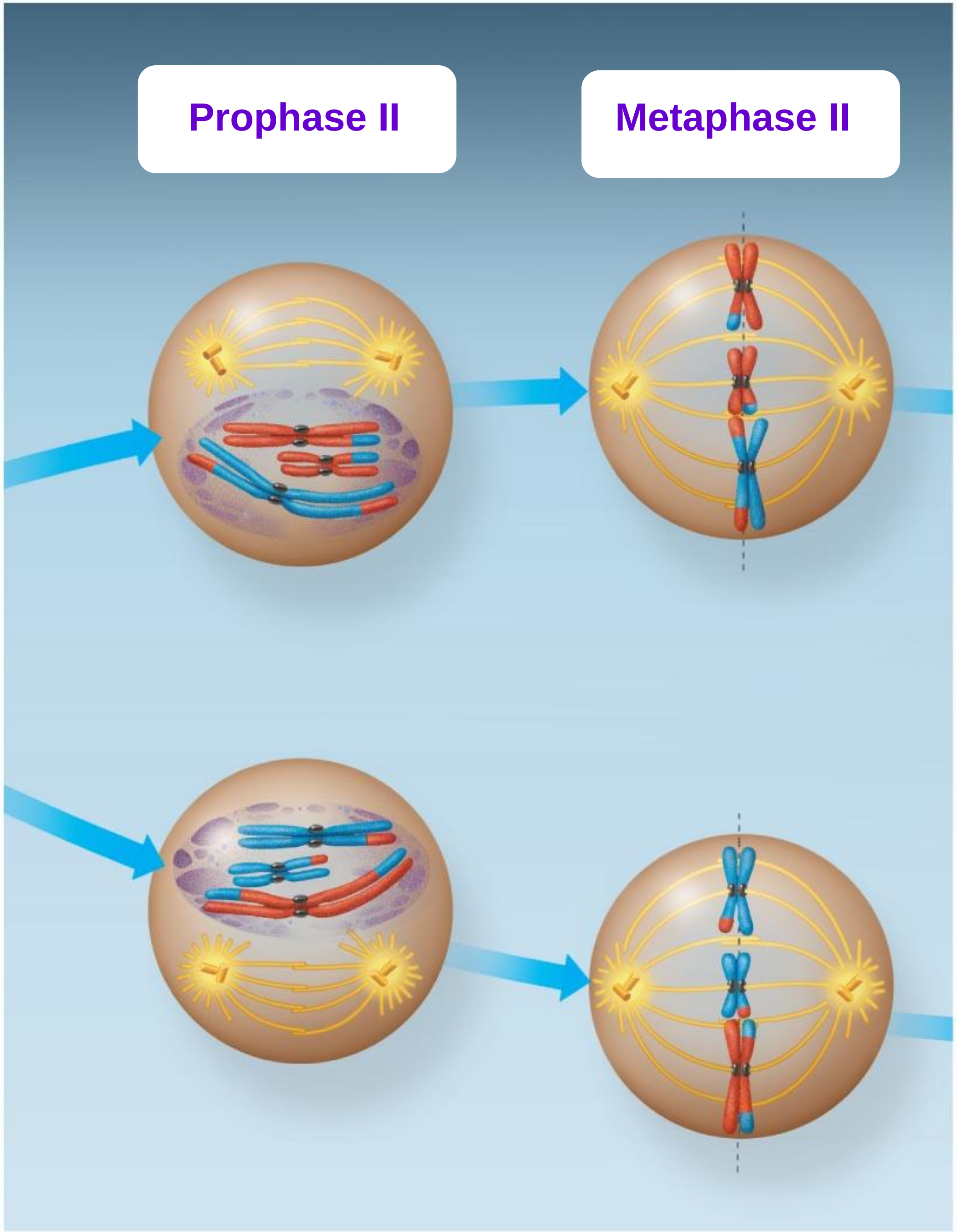
# Metaphase II

- In metaphase II, the sister chromatids are arranged at the metaphase plate

- Because of crossing over in meiosis I, the two sister chromatids of each chromosome are **no longer genetically identical**

- The kinetochores of sister chromatids attach to microtubules extending from opposite poles

Fig. 13-8e



# Anaphase II

- In anaphase II, **the sister chromatids separate**
- The sister chromatids of each chromosome now **move** as two newly individual chromosomes **toward opposite poles**

# Telophase II and Cytokinesis

- **In telophase II, the chromosomes arrive at opposite poles**

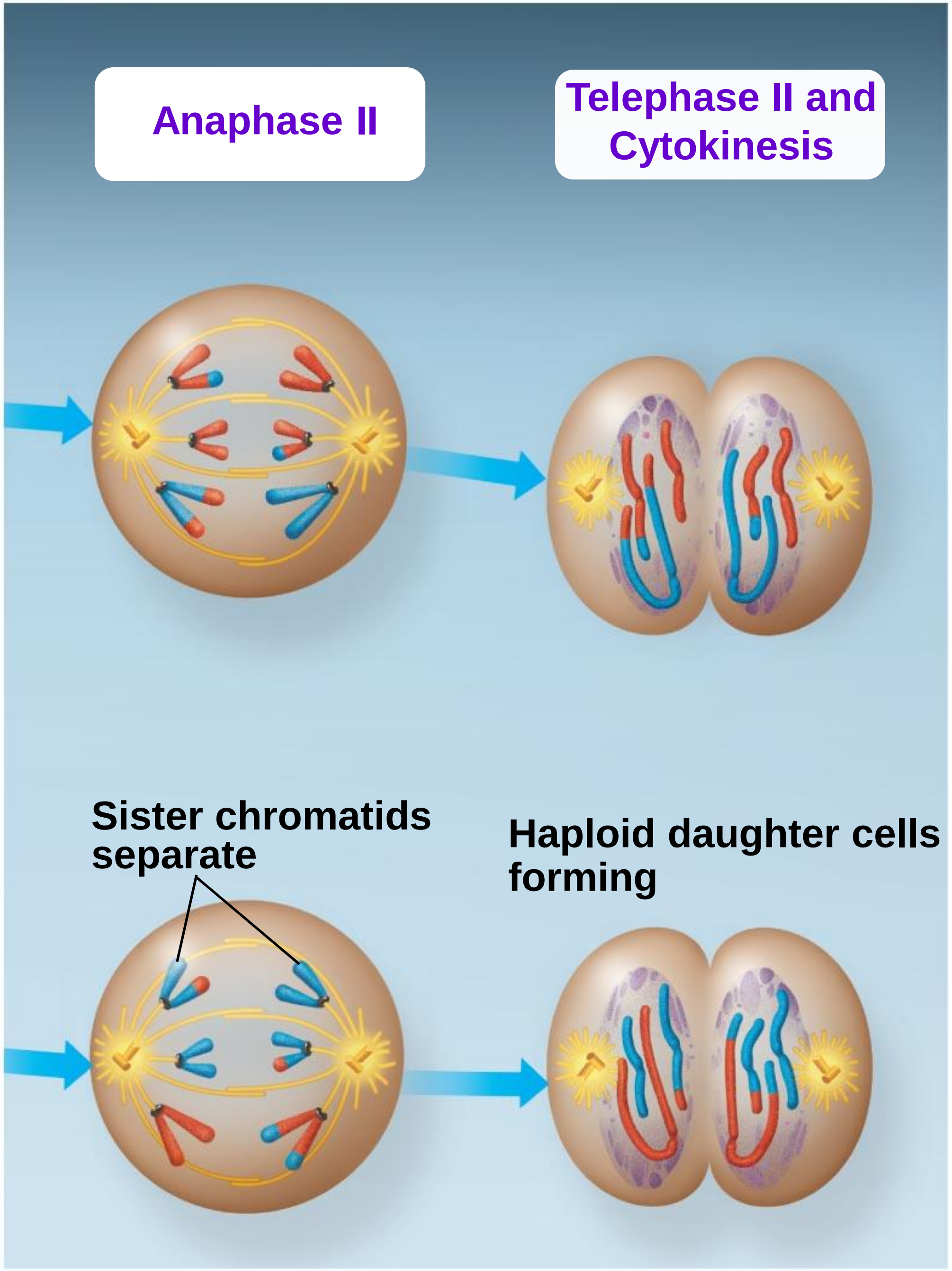
- **Nuclei form, and the chromosomes begin decondensing**

- Cytokinesis <u>separates</u> the cytoplasm

- At the end of meiosis, there are four daughter cells, each with a <u>haploid set </u>of chromosomes

- Each daughter cell is genetically <u>distinct</u> from the others and from the parent cell

Fig. 13-8f

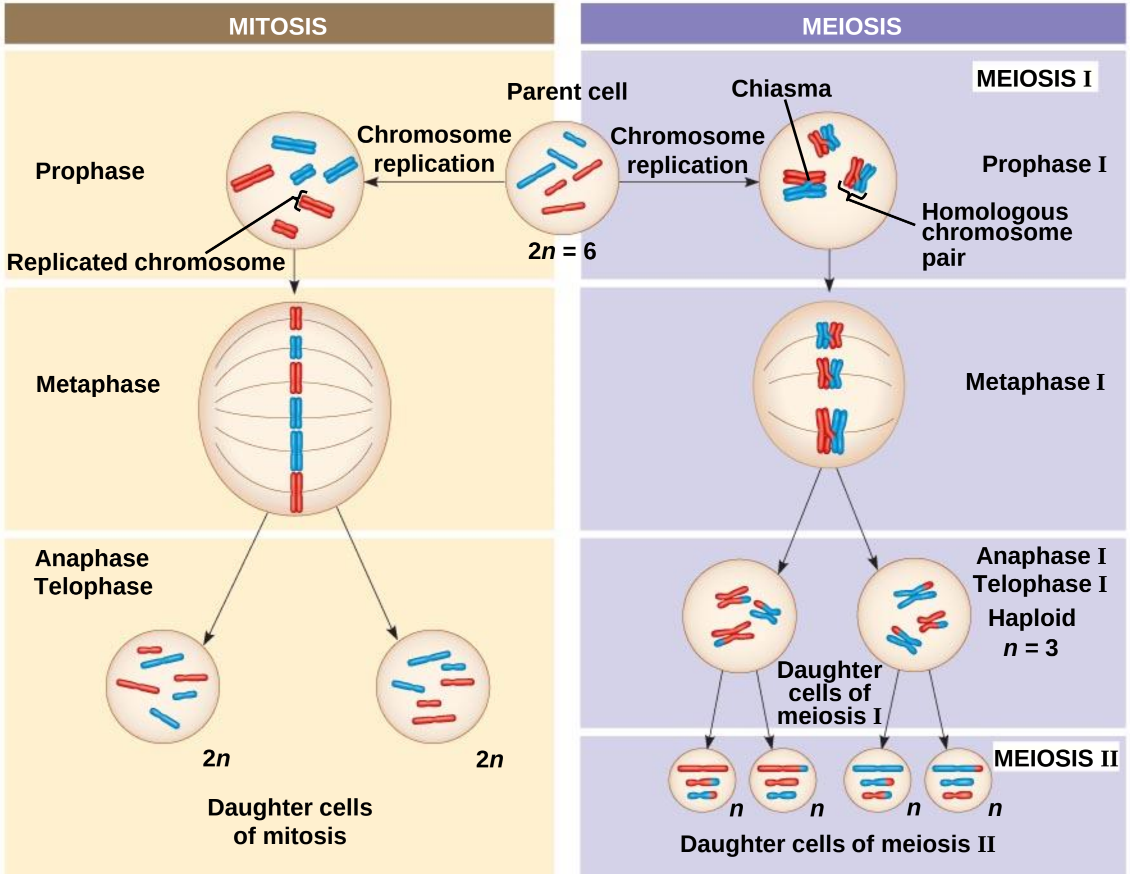

Anaphase II
Telephase II and Cytokinesis
Sister chromatids separate
Haploid daughter cells forming

# A Comparison of Mitosis and Meiosis

- Mitosis <u>**conserves**</u> the number of chromosome sets, producing cells that are genetically identical to the parent cell

- Meiosis <u>**reduces**</u> the number of chromosomes sets from two (diploid) to one (haploid), producing cells that differ genetically from each other and from the parent cell

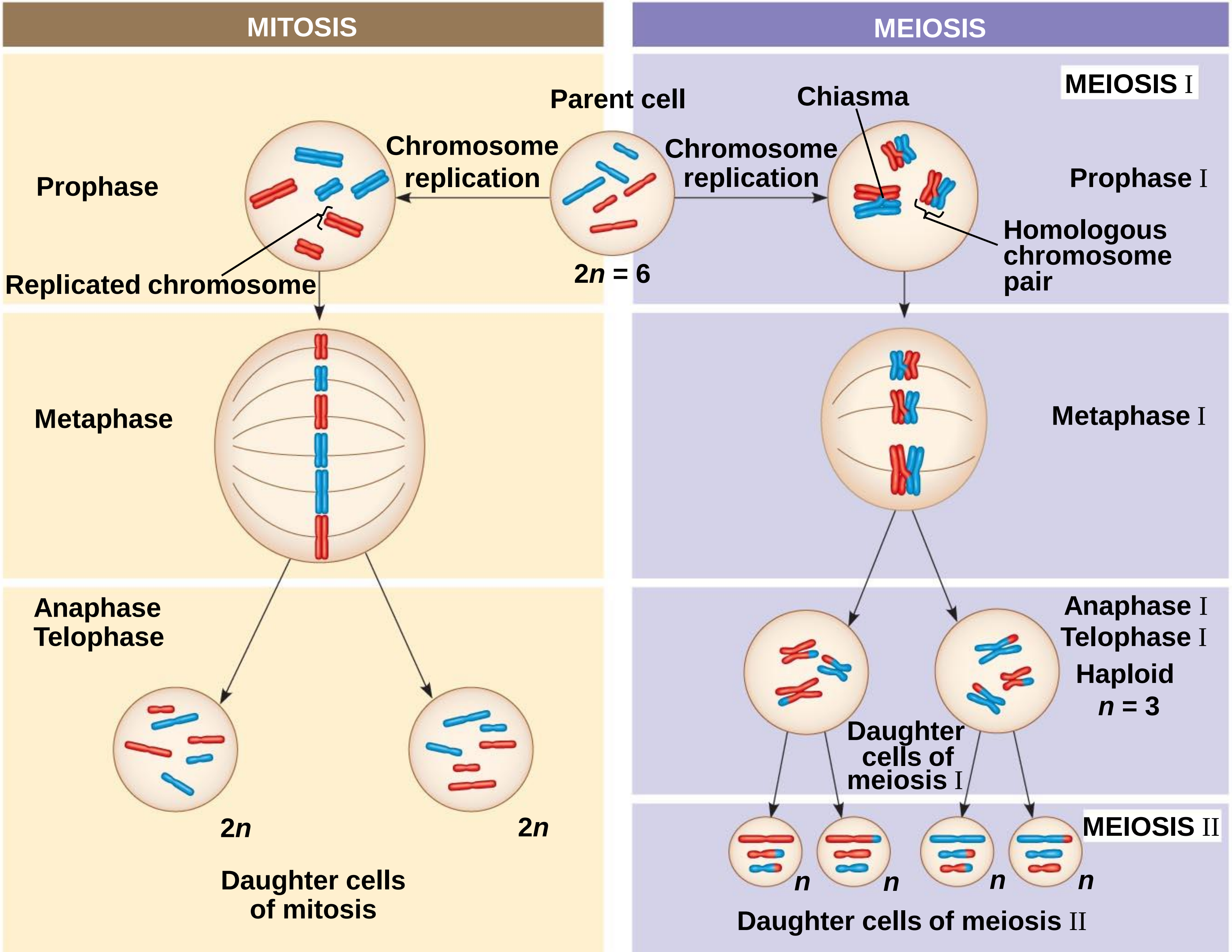
Fig. 13-9




**SUMMARY**

| Property | Mitosis | Meiosis |
|---|---|---|
| DNA replication | Occurs during interphase before mitosis begins | Occurs during interphase before meiosis I begins |
| Number of divisions | One, including prophase, metaphase, anahase, and telophase | Two, each including prophase, metaphase, anaphase, and telophase |
| Synapsis of homologous chromosomes | Does not occur | Occurs during prophase I along with crossing over between nonsister chromatids; resulting chiasmata hold pairs together due to sister chromatid cohesion |
| Number of daughter cells and genetic composition | Two, each diploid (2*n*) and genetically identical to the parent cell | Four, each haploid (*n*), containing half as many chromosomes as the parent cell; genetically different from the parent cell and from each other |
| Role in the animal body | Enables multicellular adult to arise from zygote; produces cells for growth, repair, and, in some species, asexual reproduction | Produces gametes; reduces number of chromosomes by half and introduces genetic variability amoung the gametes |

Fig. 13-9a



MITOSIS
MEIOSIS
MEIOSIS I
Parent cell
Chiasma
Chromosome replication
Chromosome replication
Prophase
Prophase I
Homologous chromosome pair
Replicated chromosome
2n = 6
Metaphase
Metaphase I
Anaphase
Telophase
Anaphase I
Telophase I
Haploid
n = 3
Daughter cells of meiosis I
2n
2n
MEIOSIS II
n
n
n
n
Daughter cells of mitosis
Daughter cells of meiosis II

Fig. 13-9b

| SUMMARY | | |
|---|---|---|
| **Property** | **Mitosis** | **Meiosis** |
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| Number of daughter cells and genetic composition | Two, each diploid ($2n$) and genetically identical to the parent cell | Four, each haploid ($n$), containing half as many chromosomes as the parent cell; genetically different from the parent cell and from each other |
| Role in the animal body | Enables multicellular adult to arise from zygote; produces cells for growth, repair, and, in some species, asexual reproduction | Produces gametes; reduces number of chromosomes by half and introduces genetic variability among the gametes |

- **Three events are unique to meiosis, and <u>all three occur in meiosis I</u>:**
  - **Synapsis and crossing over in prophase I: Homologous chromosomes physically connect and *exchange genetic information***
  - **At the <u>metaphase plate</u>, there are paired homologous chromosomes (tetrads), instead of individual replicated chromosomes**

– **At anaphase I, it is homologous chromosomes, instead of sister chromatids, that separate**

*** Sister chromatid cohesion allows sister chromatids of a single chromosome to <u>stay together through meiosis I</u>**

**** Protein complexes <u>called cohesins</u> are responsible for this <u>cohesion</u>**