

Chapter 13

Meiosis and Sexual Life Cycles

PowerPoint® Lecture Presentations for

Biology

Eighth Edition

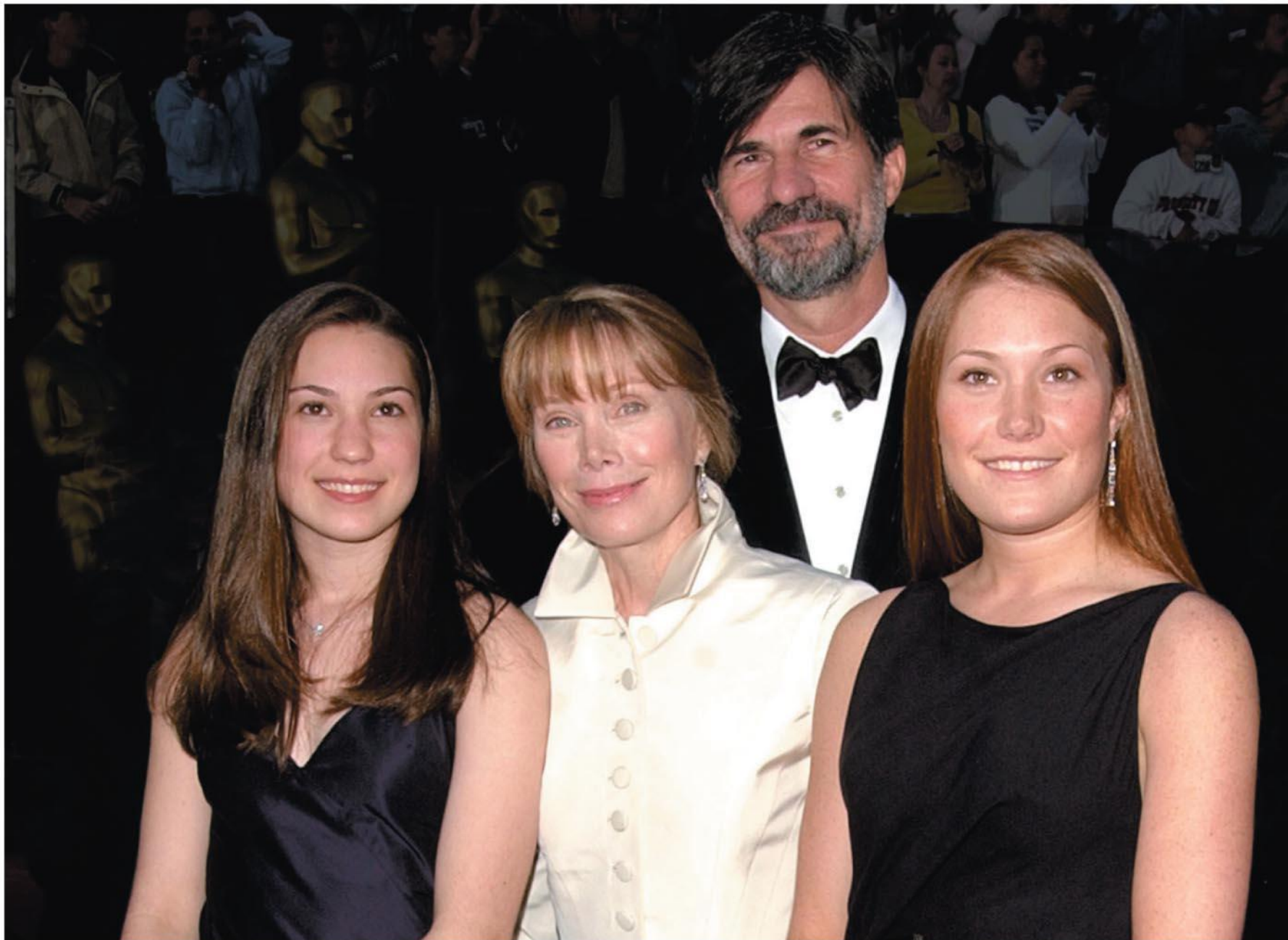
Neil Campbell and Jane Reece

Lectures by Chris Romero, updated by Erin Barley with contributions from Joan Sharp

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

Fig. 13-1



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
- Most DNA is packaged into chromosomes
- One set of chromosomes is inherited from each parent

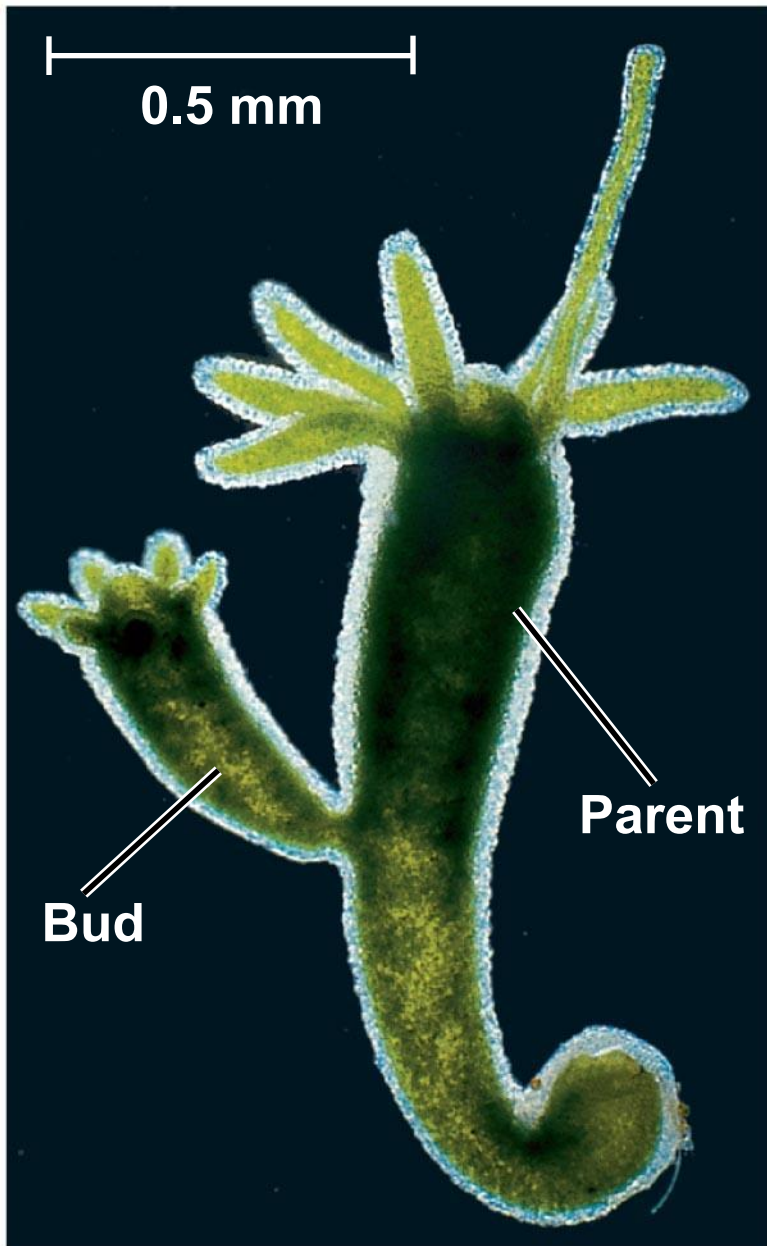
Comparison of Asexual and Sexual Reproduction

- 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

PLAY

Video: Hydra Budding

Fig. 13-2

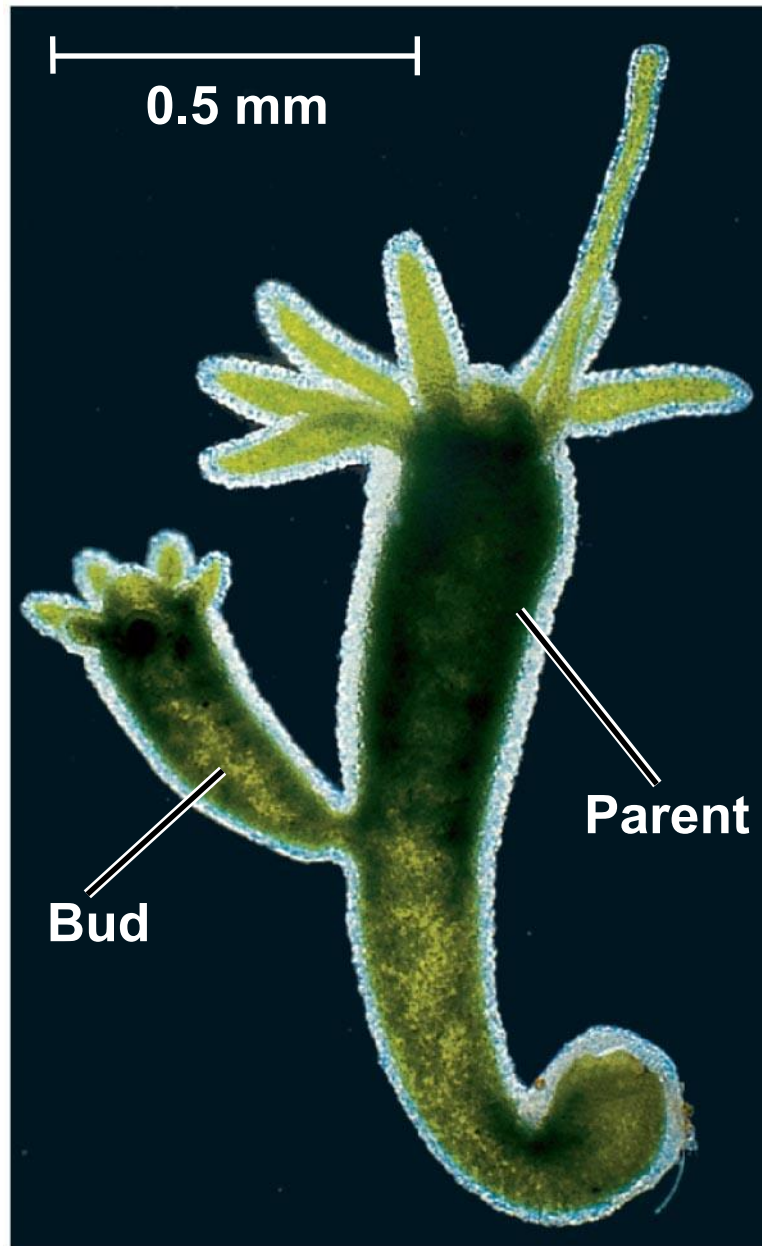


(a) Hydra



(b) Redwoods

Fig. 13-2a



(a) Hydra

Fig. 13-2b



(b) Redwoods

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. 13-3

APPLICATION



TECHNIQU

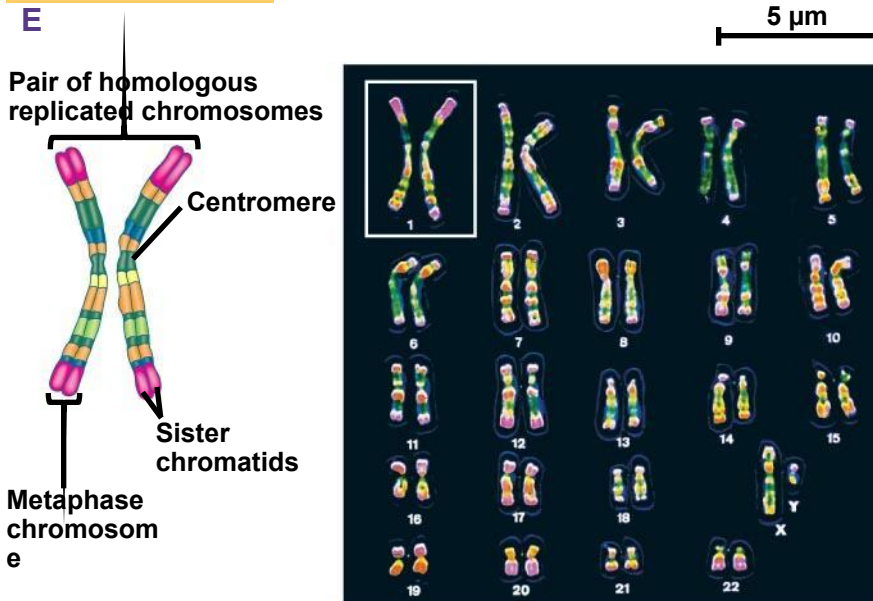


Fig. 13-3a

APPLICATION



TECHNIQUE

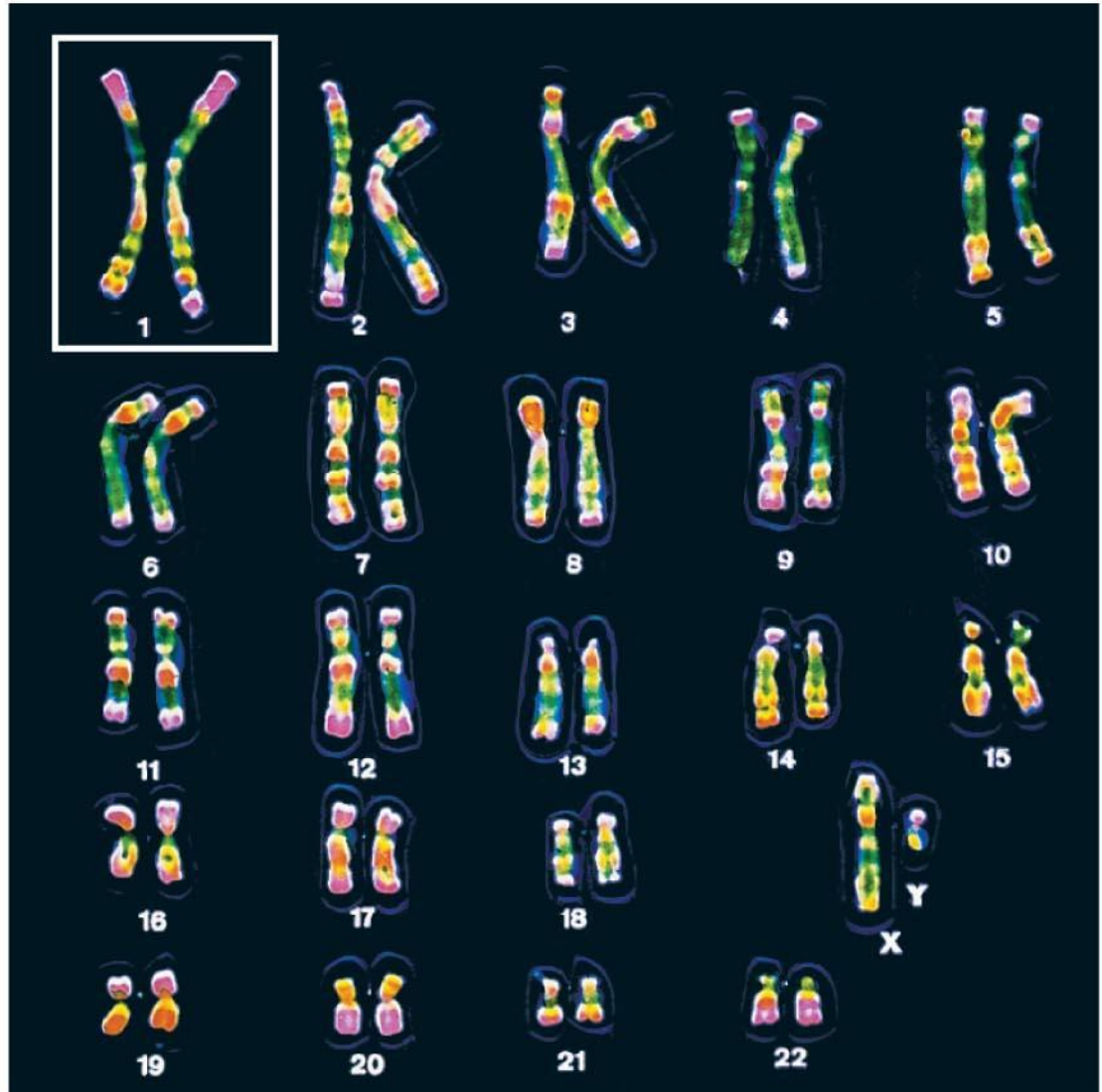
Pair of homologous replicated chromosomes

Centromere

Sister chromatids

Metaphase chromosome

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- 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
 - 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** ($2n$) has two sets of chromosomes
 - For humans, the diploid number is 46 ($2n = 46$)

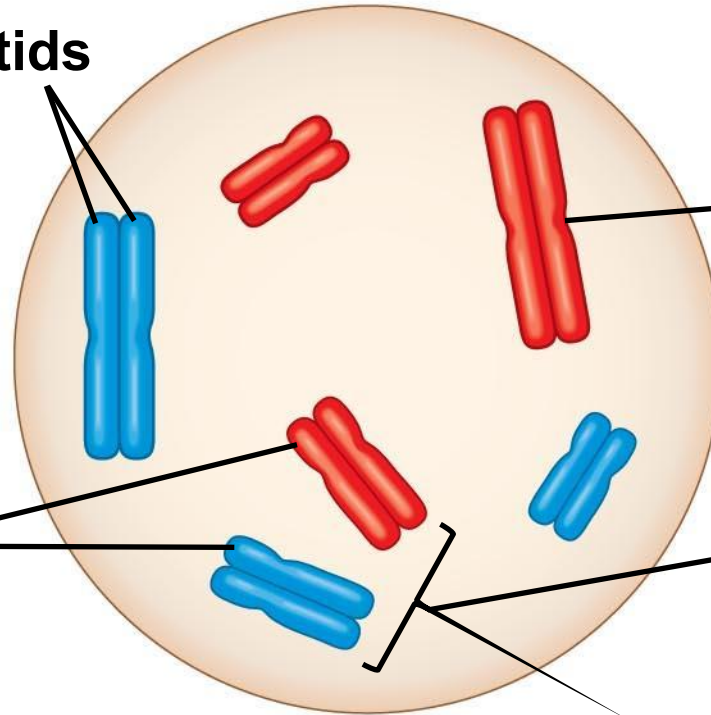
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- In a cell in which DNA synthesis has occurred, each chromosome is replicated
 - Each replicated chromosome consists of two identical sister chromatids

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)

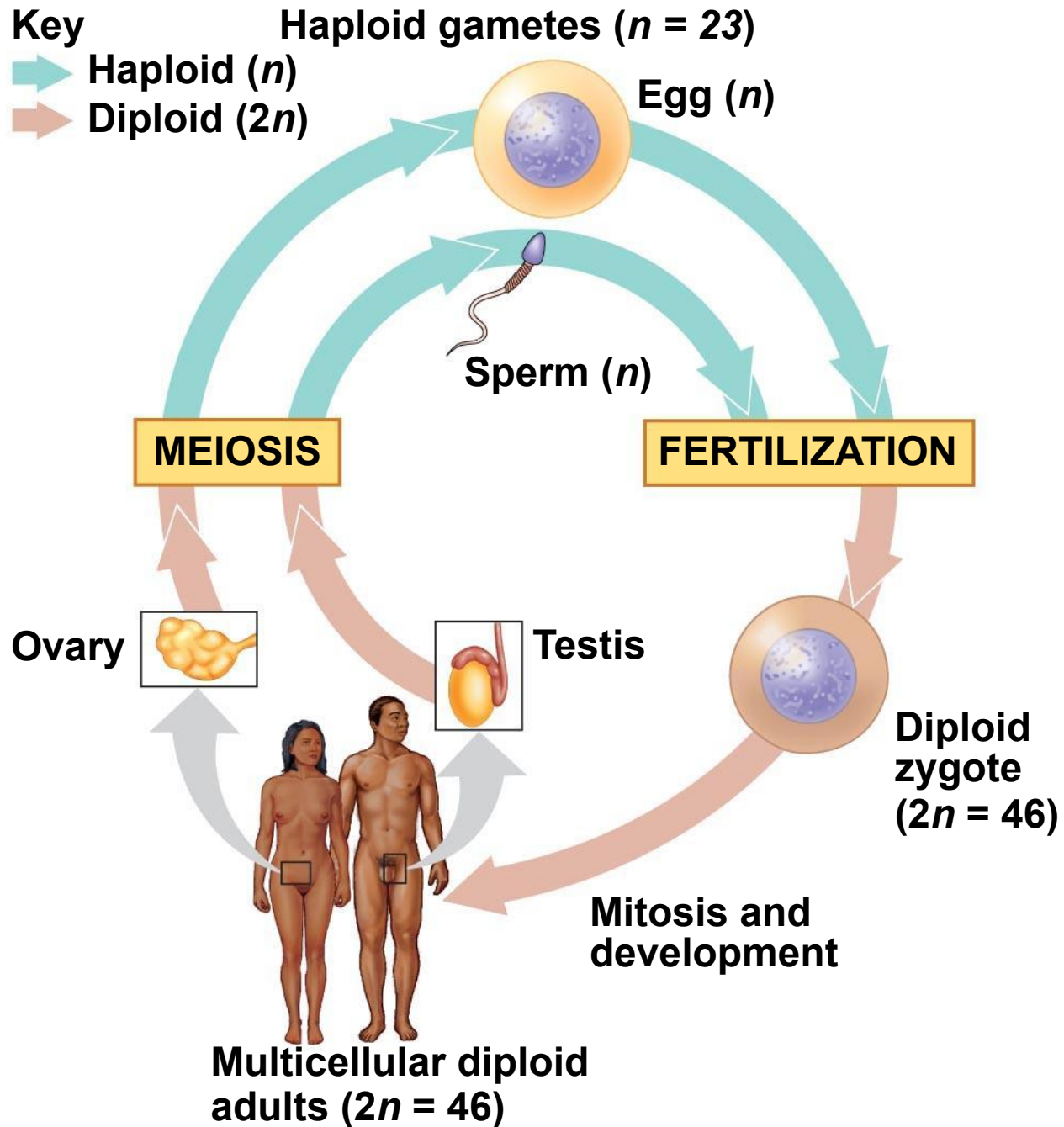
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- A gamete (sperm or egg) contains a single set of chromosomes, and is **haploid** (n)
 - For humans, the haploid number is 23 ($n = 23$)
 - Each set of 23 consists of 22 autosomes and a single sex chromosome
 - In an unfertilized egg (ovum), the sex chromosome is X
 - In a sperm cell, the sex chromosome may be either X or Y

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
 - Fertilization and meiosis alternate in sexual life cycles to maintain chromosome number

Fig. 13-5



The Variety of Sexual Life Cycles

- The alternation of meiosis and fertilization is common to all organisms that reproduce sexually
- The three main types of sexual life cycles differ in the timing of meiosis and fertilization

-
- In animals, meiosis produces gametes, which undergo no further cell division before fertilization
 - Gametes are the only haploid cells in animals
 - Gametes fuse to form a diploid zygote that divides by mitosis to develop into a multicellular organism

Fig. 13-6

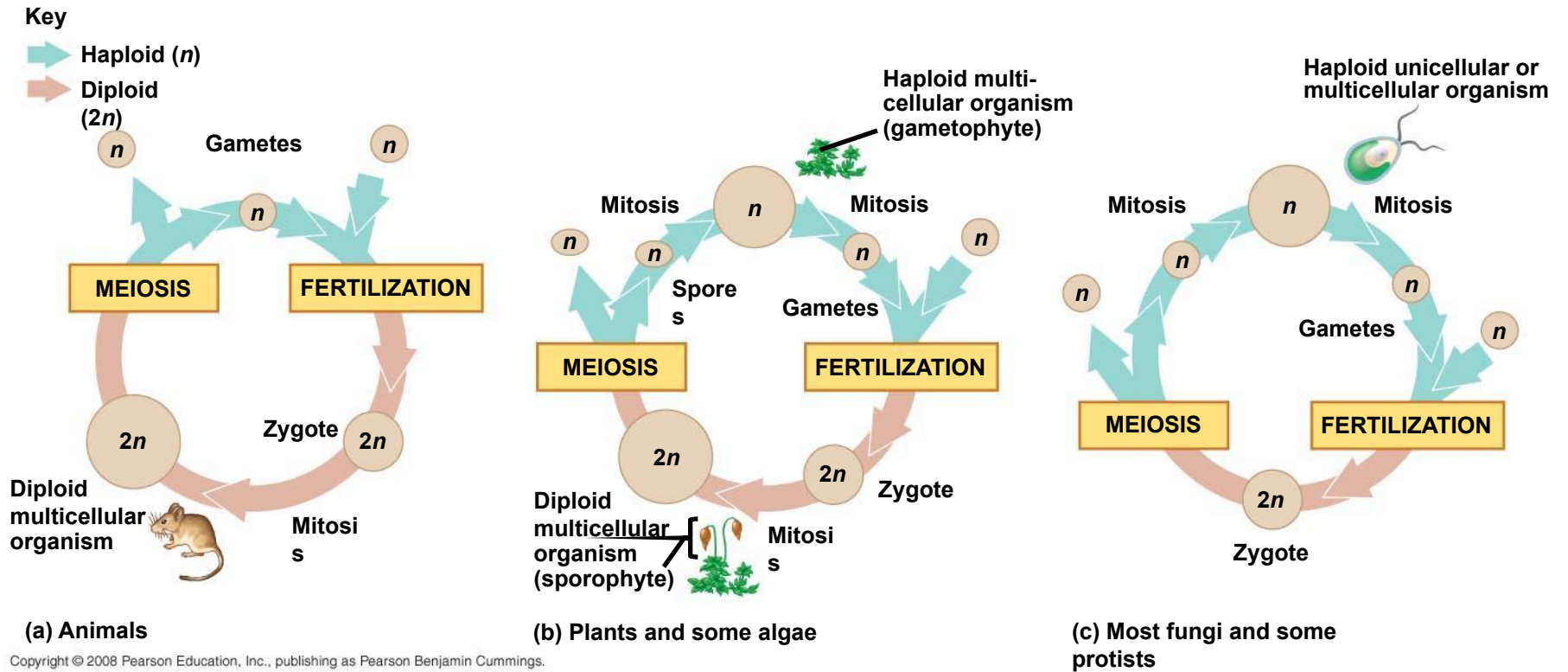
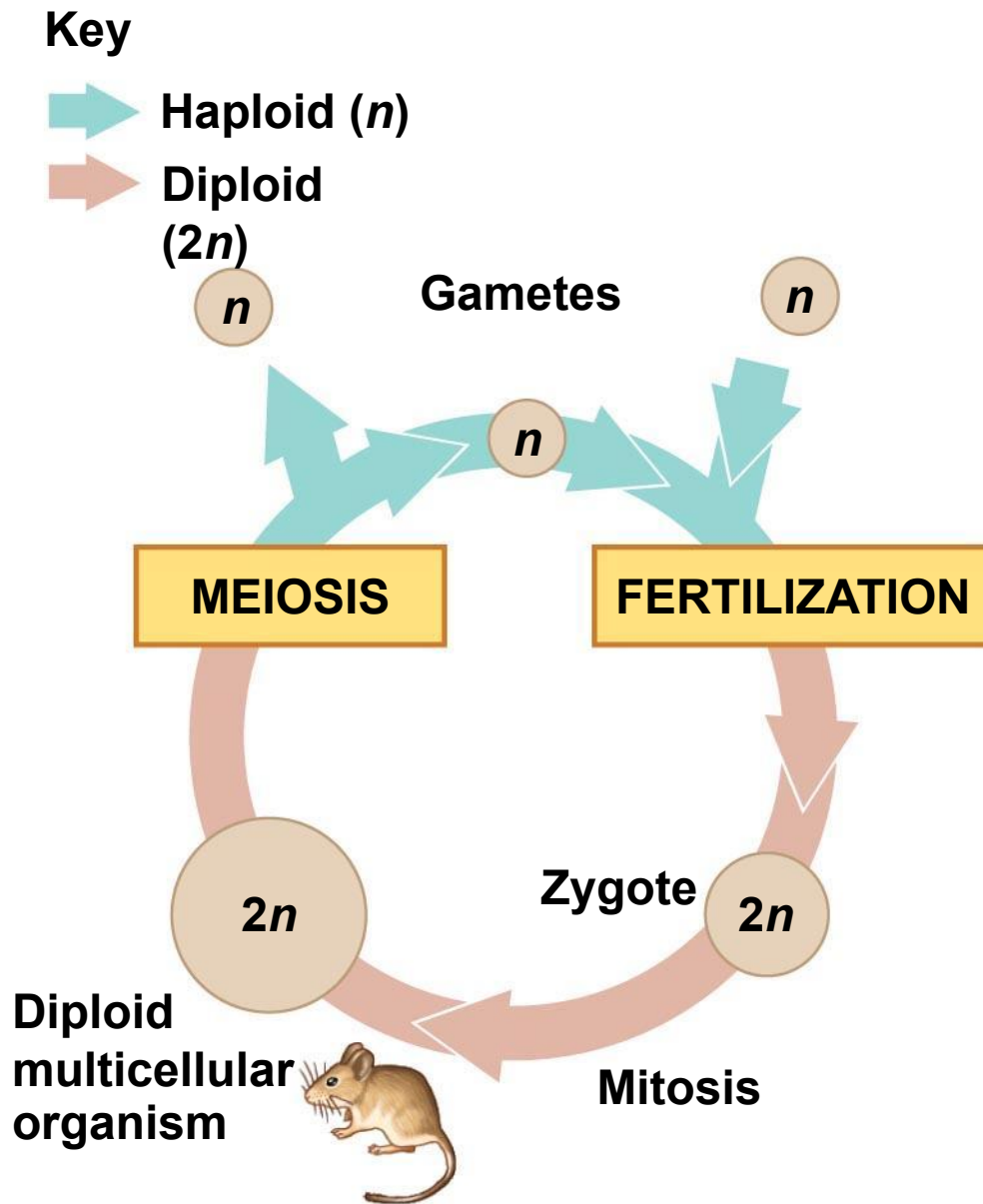


Fig. 13-6a



(a) Animals

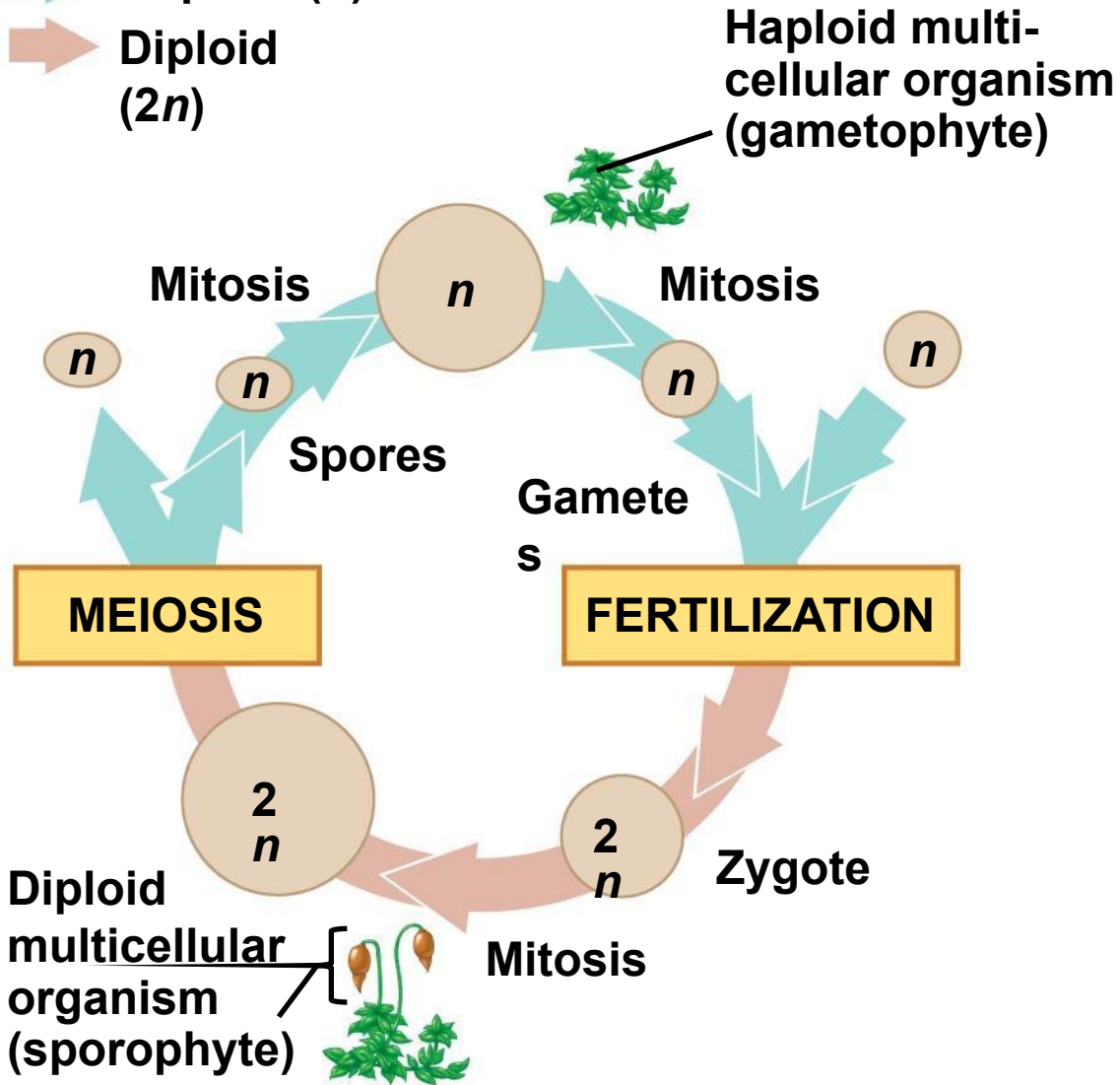
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- Plants and some algae exhibit an **alternation of generations**
 - This life cycle includes both a diploid and haploid multicellular stage
 - The diploid organism, called the **sporophyte**, makes haploid **spores** by meiosis

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- Each spore grows by mitosis into a haploid organism called a **gametophyte**
 - A gametophyte makes haploid gametes by mitosis
 - Fertilization of gametes results in a diploid sporophyte

Key

 Haploid (n)

 Diploid ($2n$)



(b) Plants and some algae

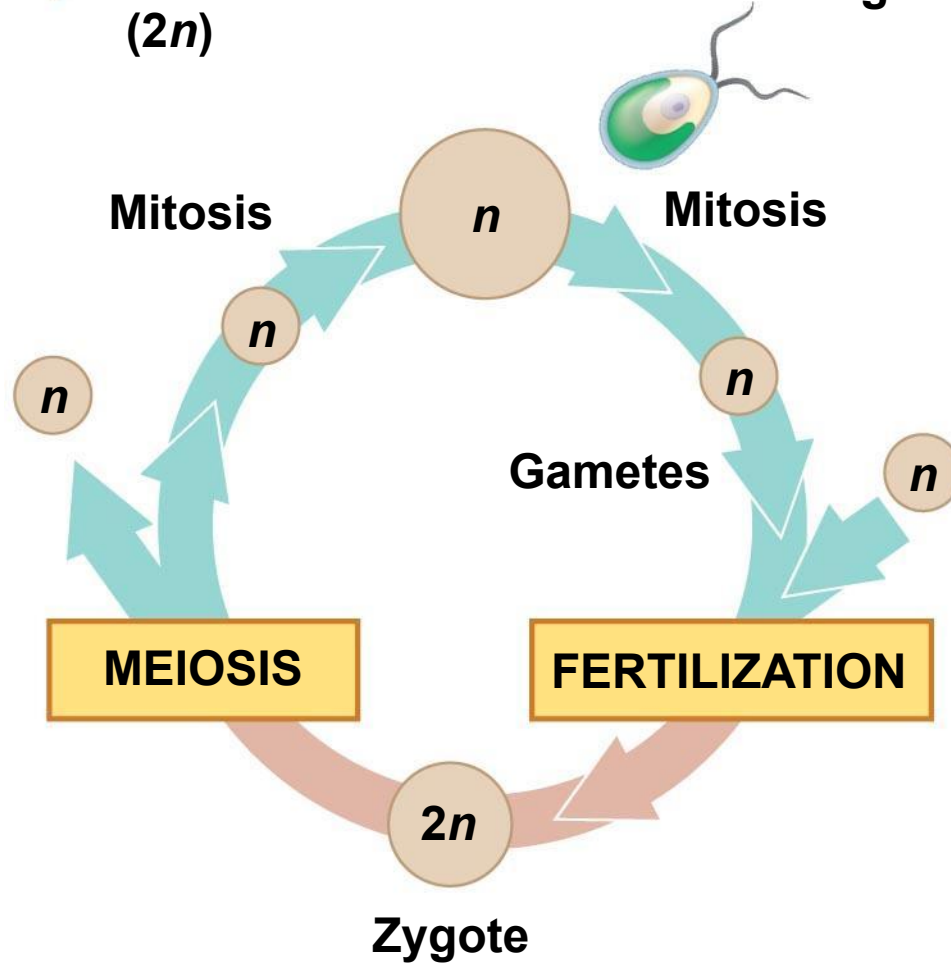
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- In most fungi and some protists, the only diploid stage is the single-celled zygote; there is no multicellular diploid stage
 - The zygote produces haploid cells by meiosis
 - Each haploid cell grows by mitosis into a haploid multicellular organism
 - The haploid adult produces gametes by mitosis

Key

 Haploid (n)

 Diploid ($2n$)

Haploid unicellular or multicellular organism



(c) Most fungi and some protists

-
- Depending on the type of life cycle, either haploid or diploid cells can divide by mitosis
 - However, only diploid cells can undergo meiosis
 - In all three life cycles, the halving and doubling of chromosomes contributes to genetic variation in offspring

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), homologous chromosomes separate
- Meiosis I results in two haploid daughter cells with replicated chromosomes; it is called the reductional division
- In the second cell division (meiosis II), sister chromatids separate
- Meiosis II results in four haploid daughter cells with unreplicated chromosomes; it is called the equational division

Fig. 13-7-1

Interphase

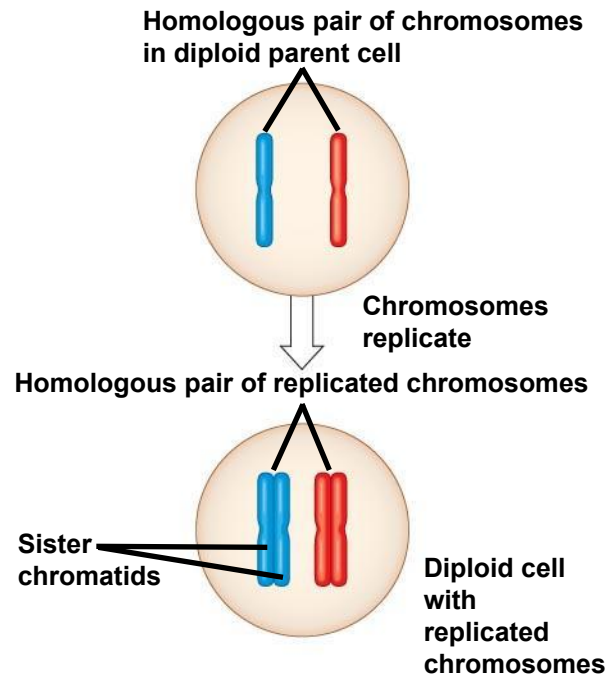


Fig. 13-7-2

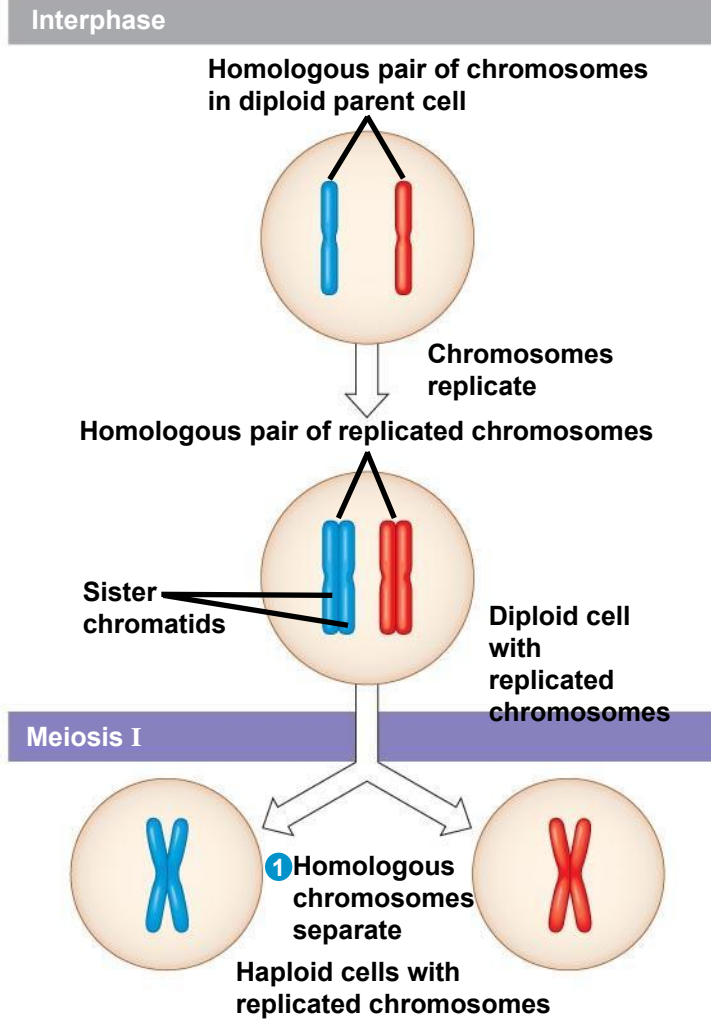
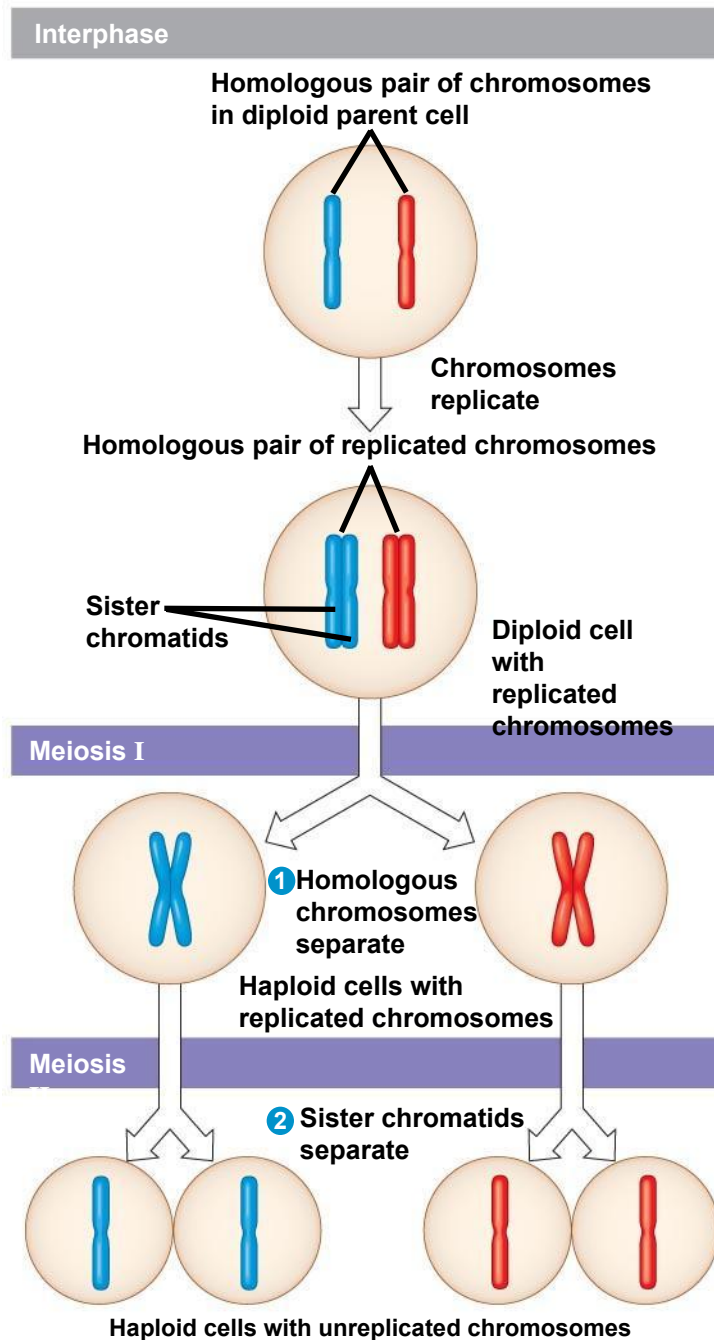


Fig. 13-7-3

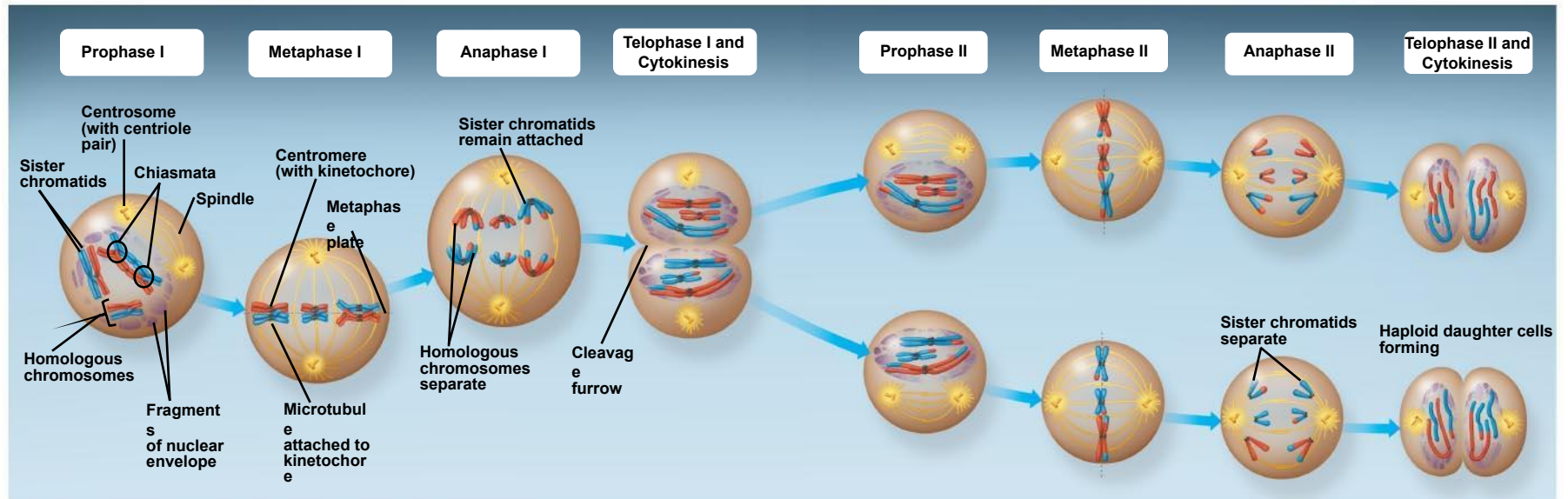


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- Meiosis I is preceded by interphase, in which chromosomes are replicated to form sister chromatids
 - The sister chromatids are genetically identical and joined at the centromere
 - The single centrosome replicates, forming two centrosomes

PLAY

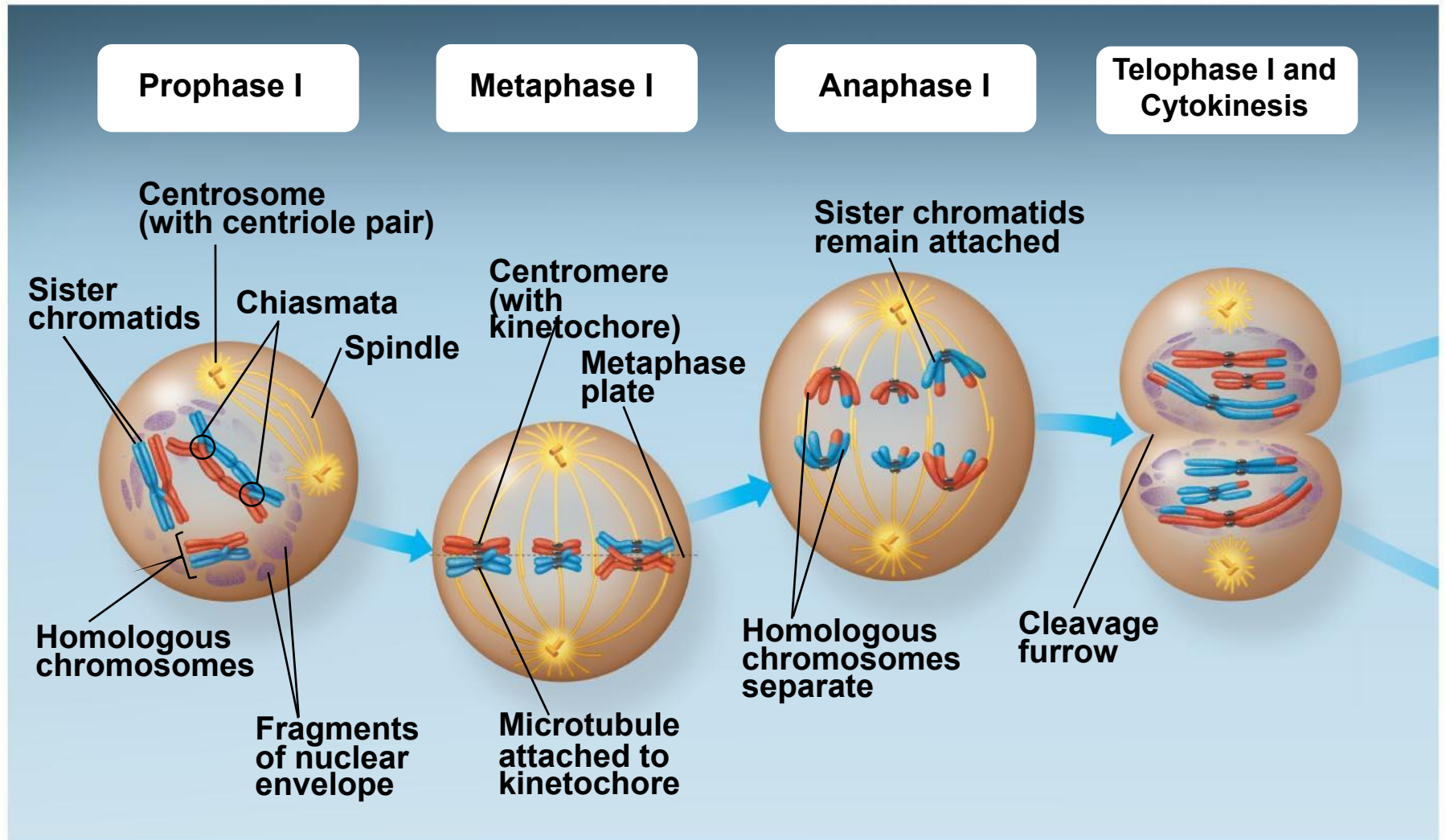
BioFlix: Meiosis

Fig. 13-8



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

Fig. 13-8a



Prophase I

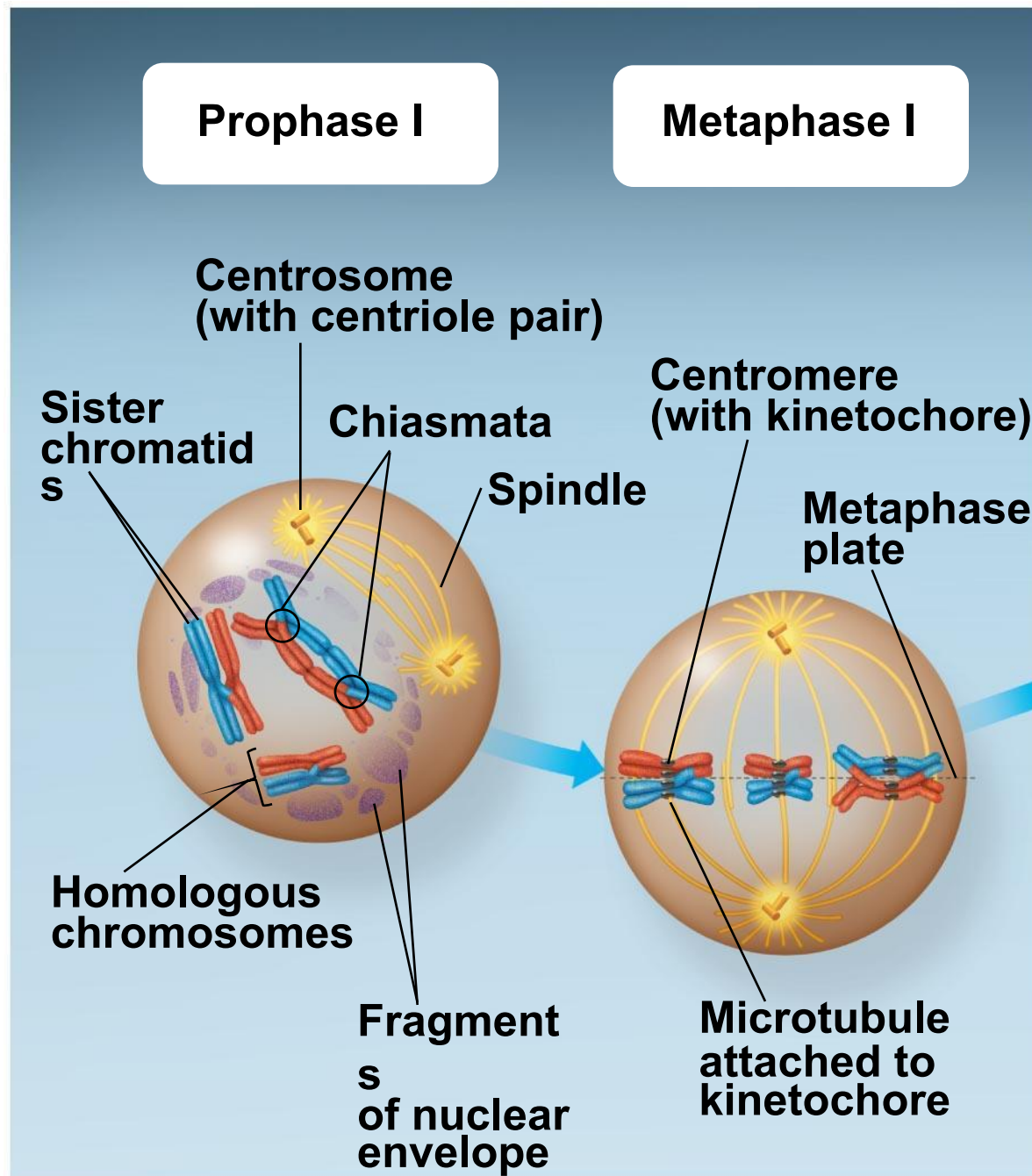
- Prophase I typically occupies more than 90% of the time required for meiosis
- Chromosomes begin to condense
- In **synapsis**, homologous chromosomes loosely pair up, aligned gene by gene

-
- In **crossing over**, nonsister chromatids exchange DNA segments
 - Each pair of chromosomes forms a tetrad, a group of four chromatids
 - Each tetrad usually has one or more **chiasmata**, 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



Anaphase I

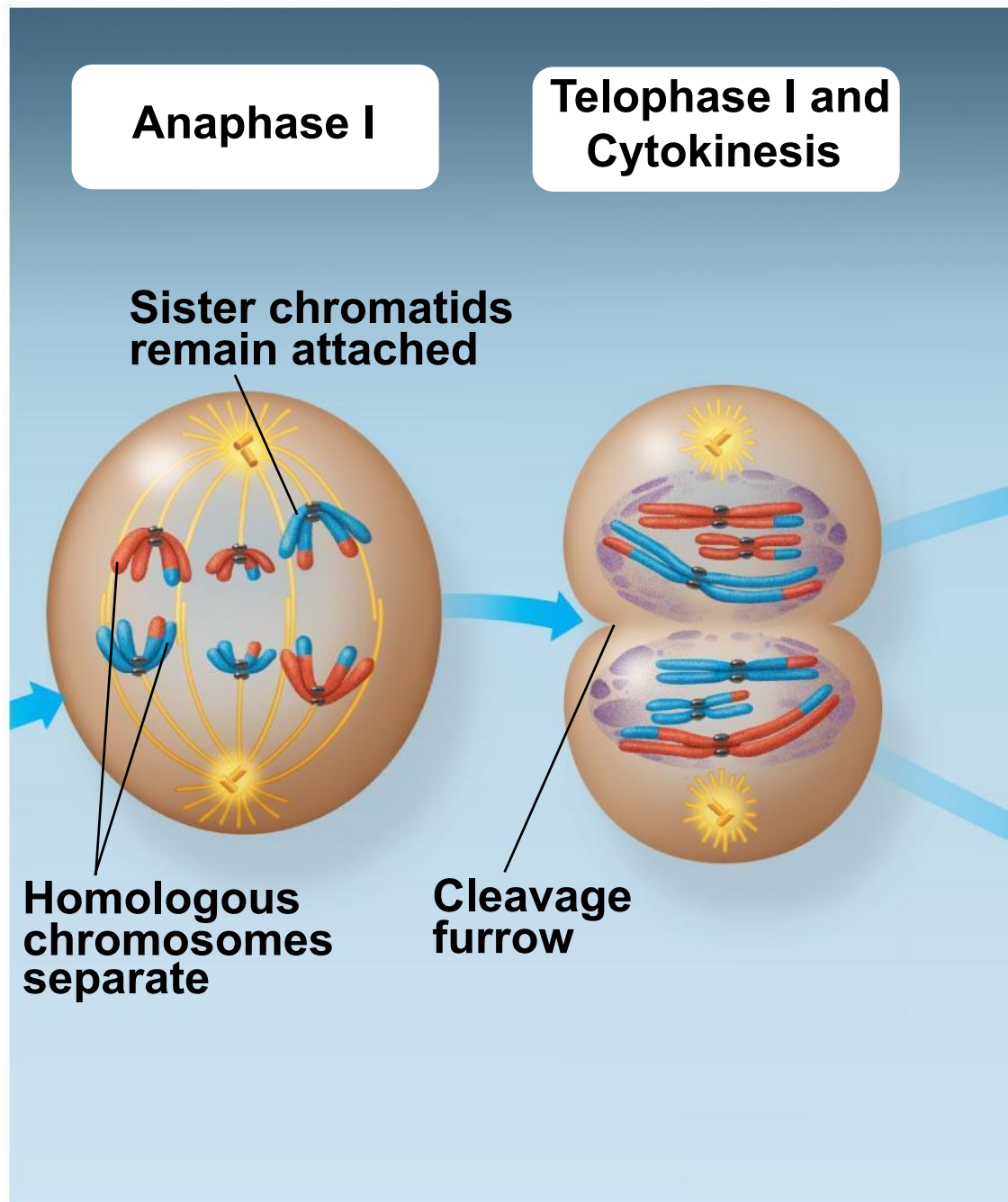
- In anaphase I, pairs of homologous chromosomes separate
- One chromosome moves toward each pole, guided by the spindle apparatus
- Sister chromatids remain attached at the centromere and move as one unit toward the pole

Telophase I and Cytokinesis

- In the beginning of telophase I, each half of the cell has a haploid set of chromosomes; each chromosome still consists of two sister chromatids
- Cytokinesis usually occurs simultaneously, forming two haploid daughter cells

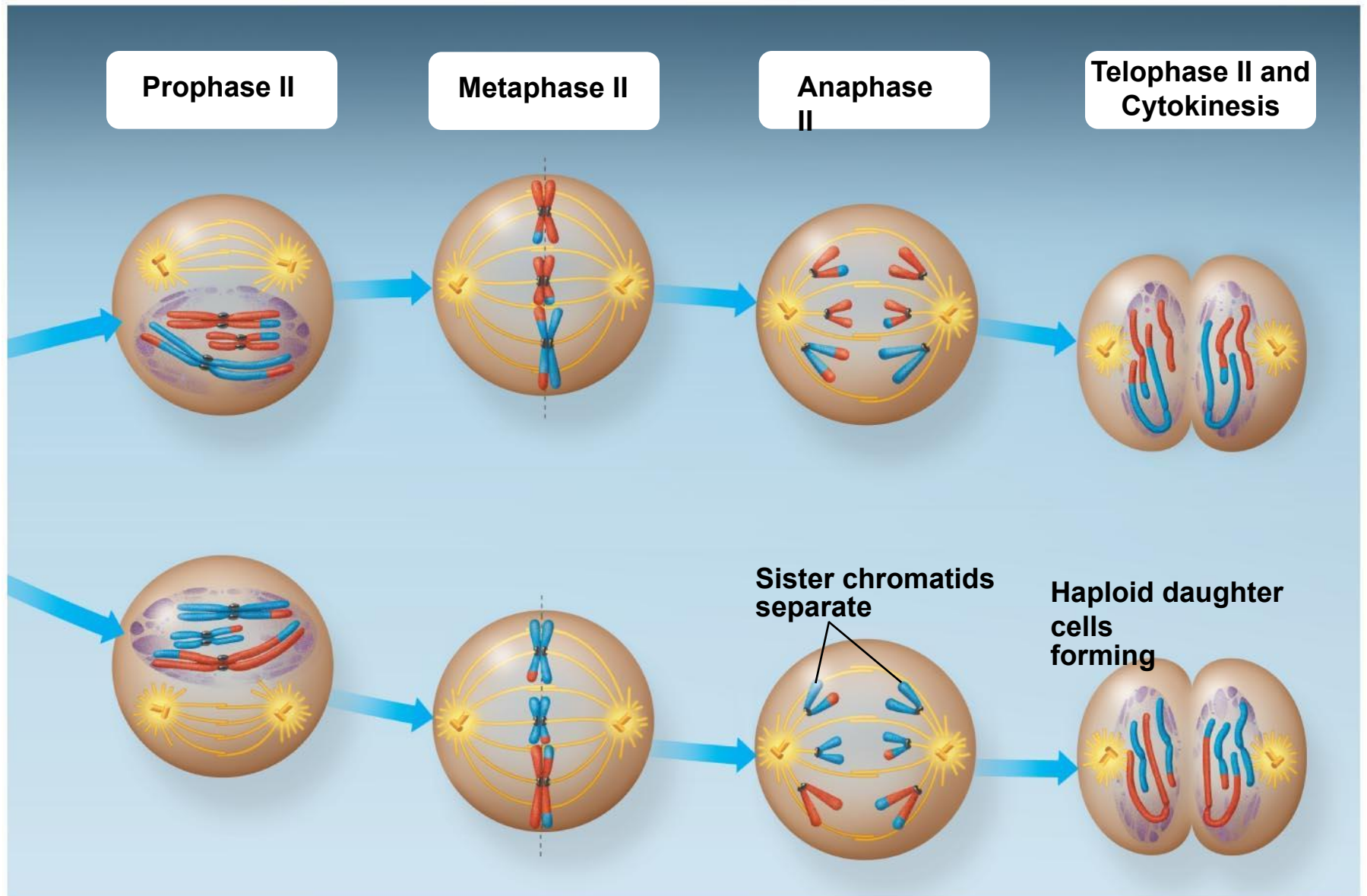
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- In animal cells, a cleavage furrow forms; in plant cells, a cell plate forms
 - No chromosome replication occurs between the end of meiosis I and the beginning of meiosis II because the chromosomes are already replicated

Fig. 13-8c



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

Fig. 13-8d



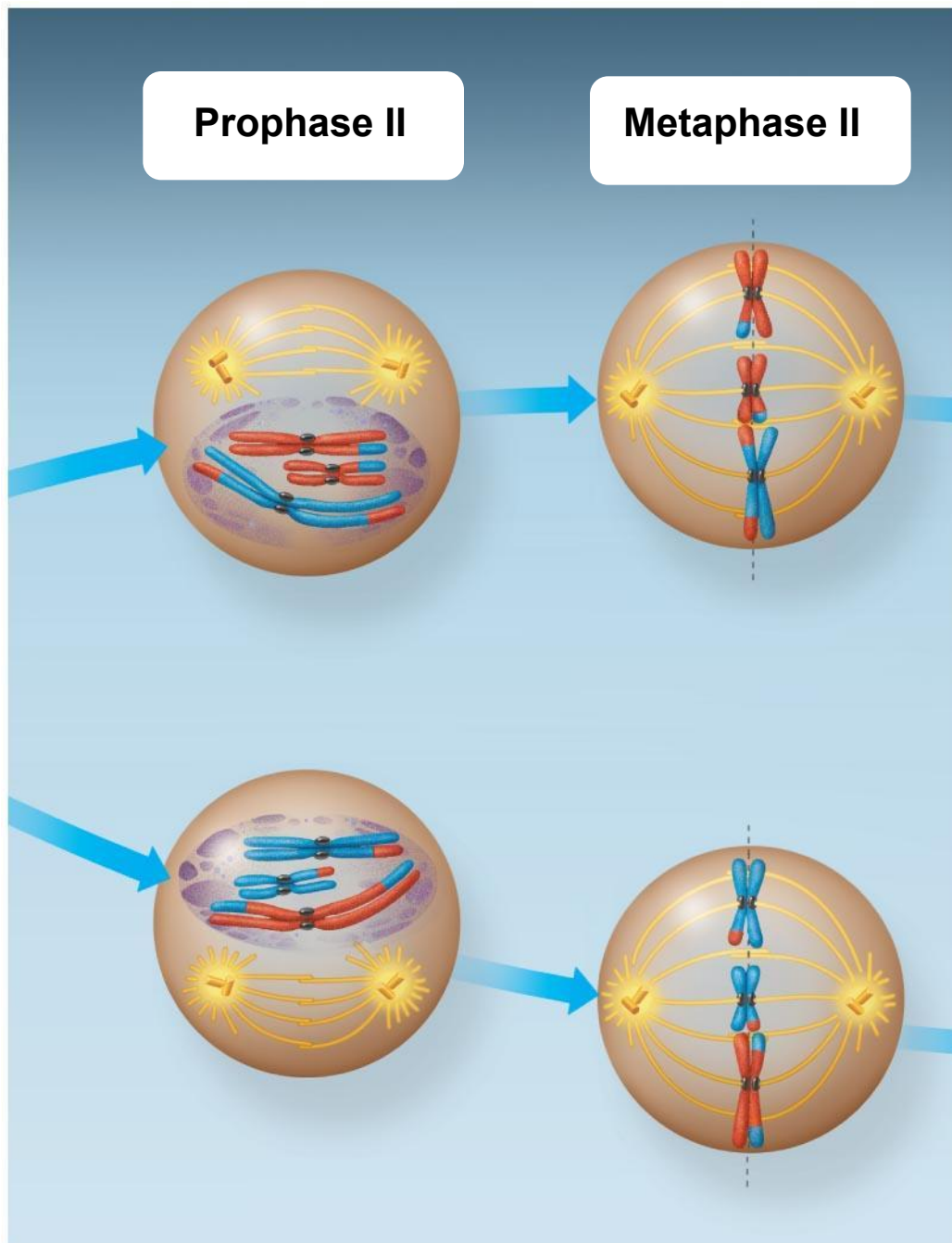
Prophase II

- 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

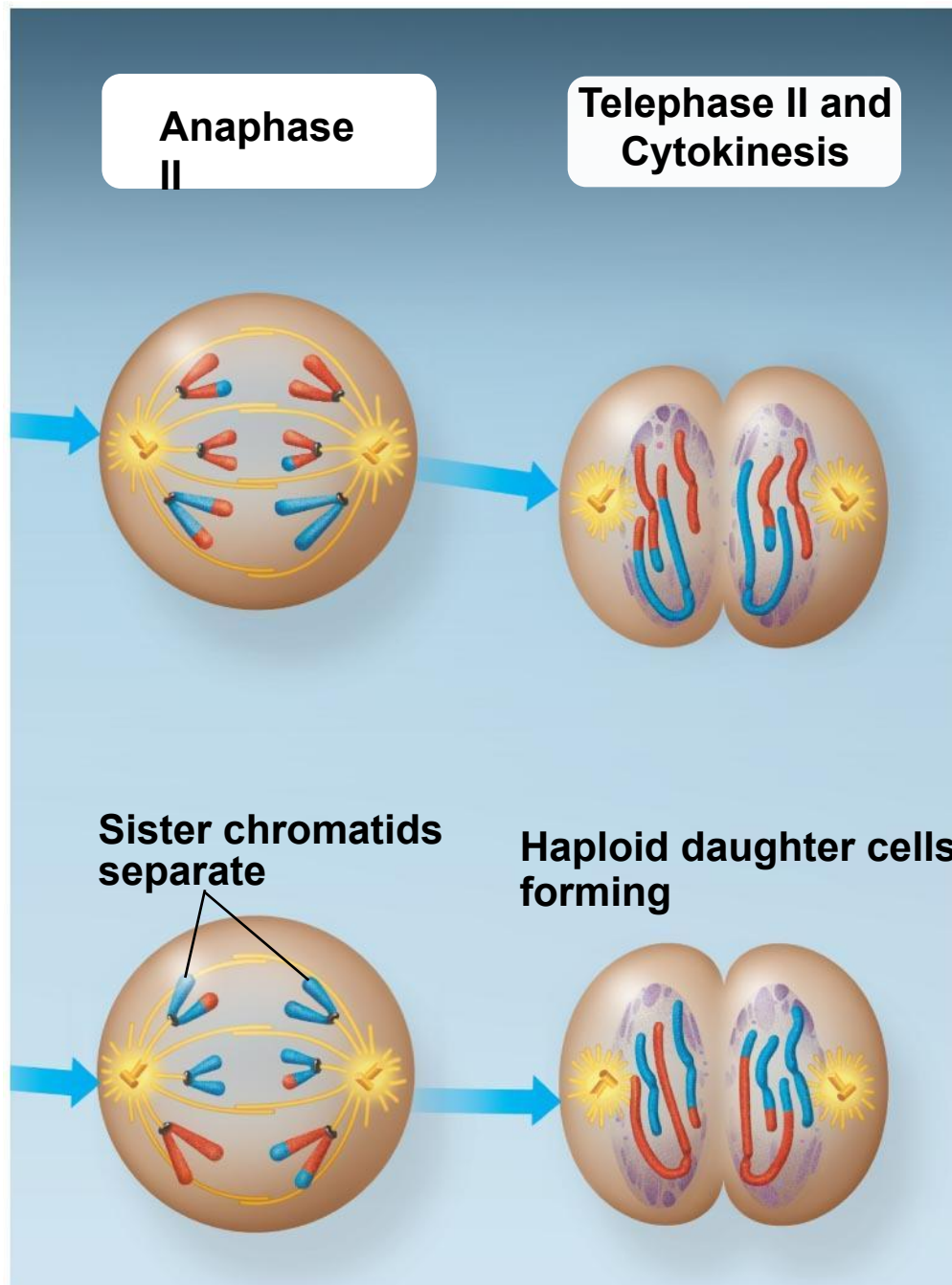
- In anaphase II, the sister chromatids separate
- The sister chromatids of each chromosome now move as two newly individual chromosomes toward opposite poles

Telophase II and Cytokinesis

- In telophase II, the chromosomes arrive at opposite poles
- Nuclei form, and the chromosomes begin decondensing

-
- Cytokinesis separates the cytoplasm
 - At the end of meiosis, there are four daughter cells, each with a haploid set of unreplicated chromosomes
 - Each daughter cell is genetically distinct from the others and from the parent cell

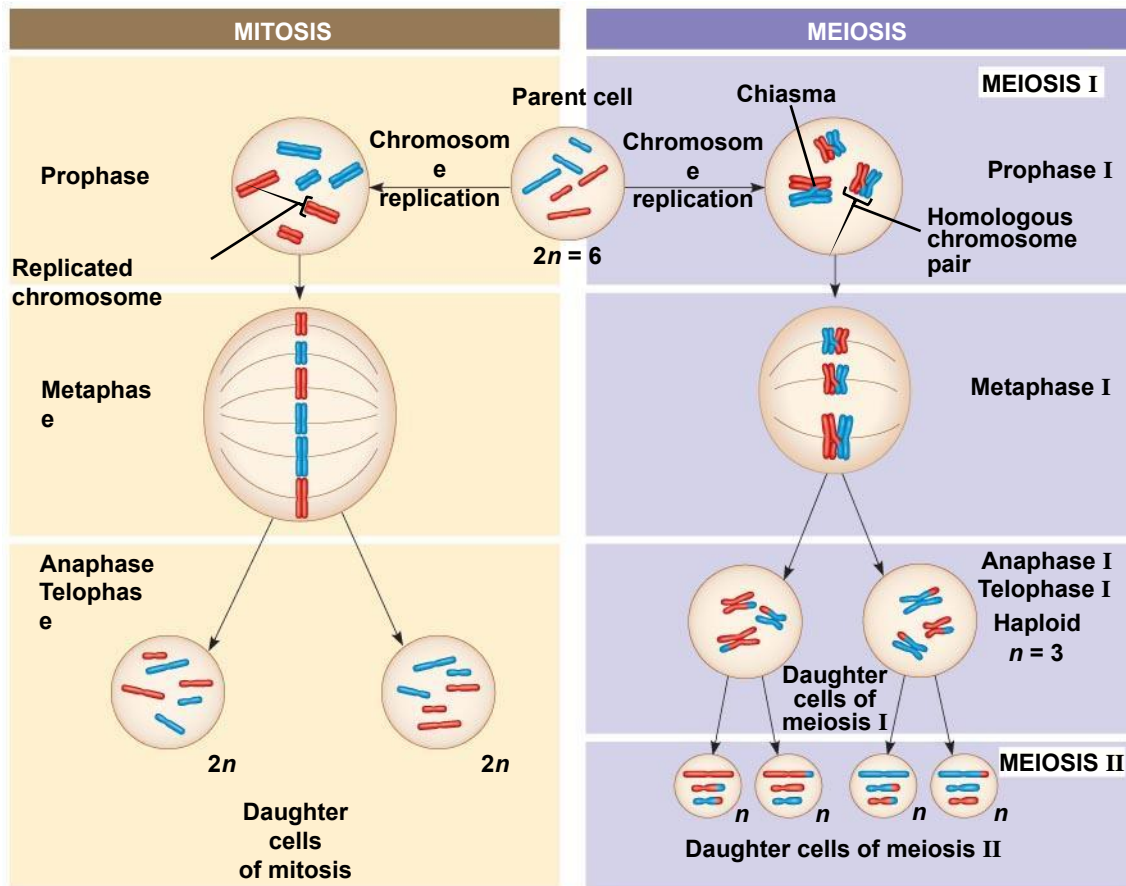
Fig. 13-8f



A Comparison of Mitosis and Meiosis

- Mitosis conserves the number of chromosome sets, producing cells that are genetically identical to the parent cell
- Meiosis reduces the number of chromosome sets from two (diploid) to one (haploid), producing cells that differ genetically from each other and from the parent cell
- The mechanism for separating sister chromatids is virtually identical in meiosis II and mitosis

Fig. 13-9



SUMMARY

Property	Mitosis	Meiosi
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 ($2n$) 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

Fig. 13-9a

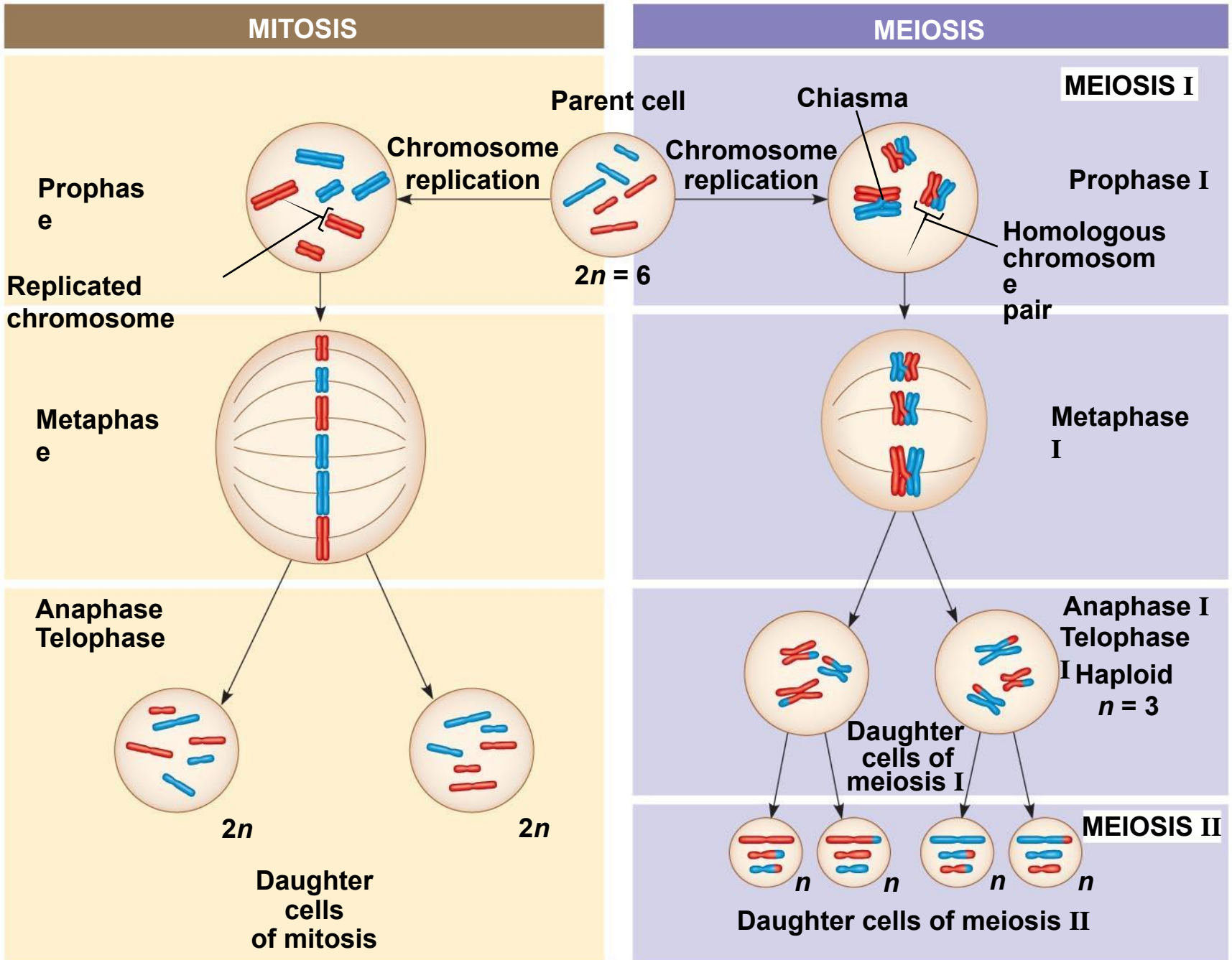


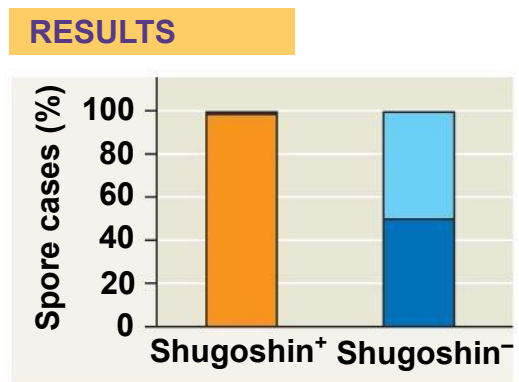
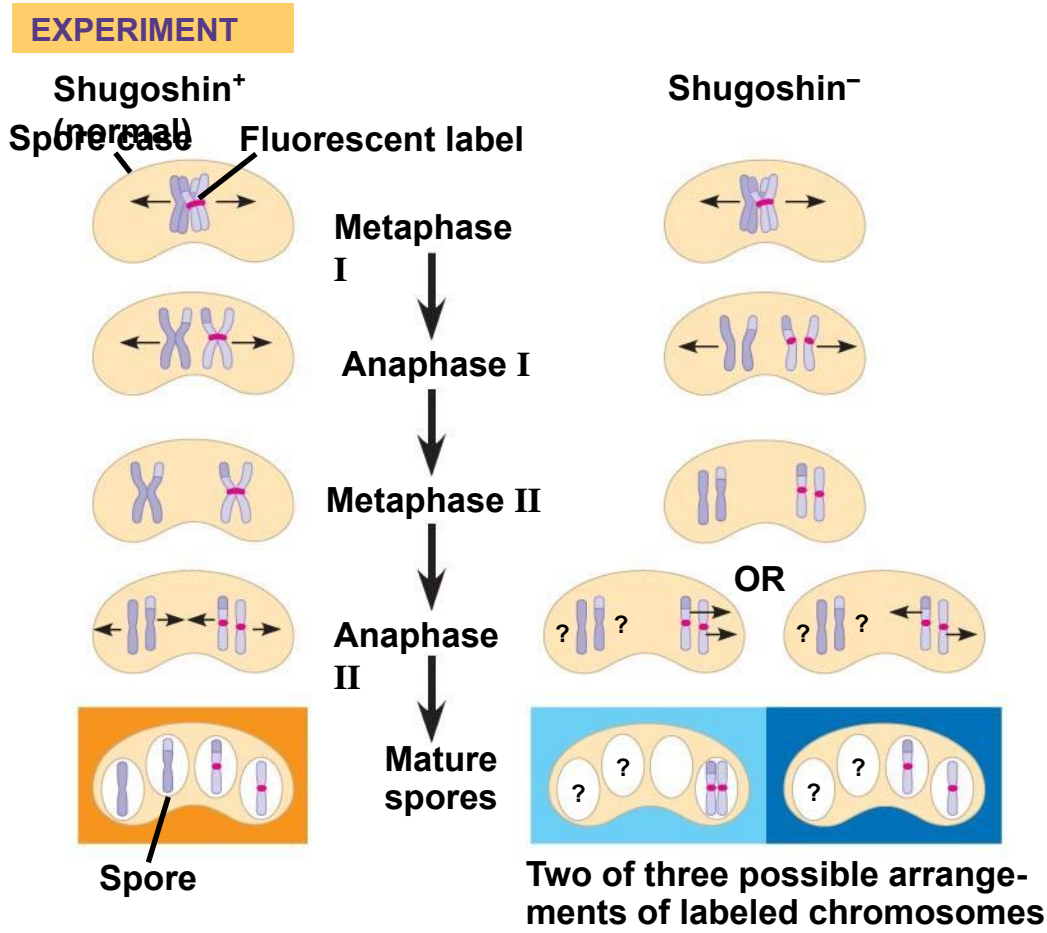
Fig. 13-9b

SUMMARY		
Property	Mitosis	Meiosis
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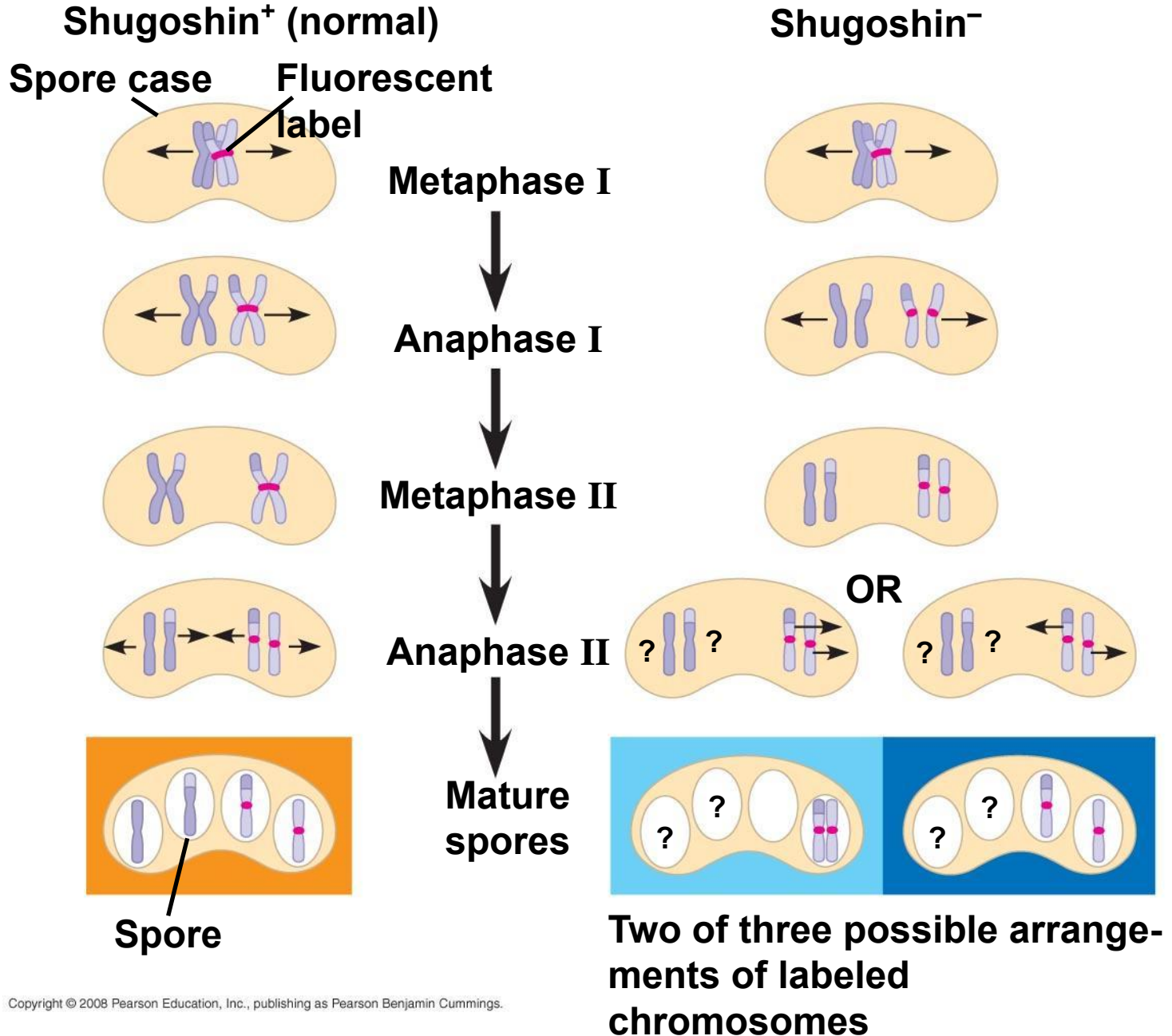
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- Three events are unique to meiosis, and all three occur in meiosis I:
 - Synapsis and crossing over in prophase I: Homologous chromosomes physically connect and exchange genetic information
 - At the metaphase plate, there are paired homologous chromosomes (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 stay together through meiosis I
 - Protein complexes called cohesins are responsible for this cohesion
 - In mitosis, cohesins are cleaved at the end of metaphase
 - In meiosis, cohesins are cleaved along the chromosome arms in anaphase I (separation of homologs) and at the centromeres in anaphase II (separation of sister chromatids)

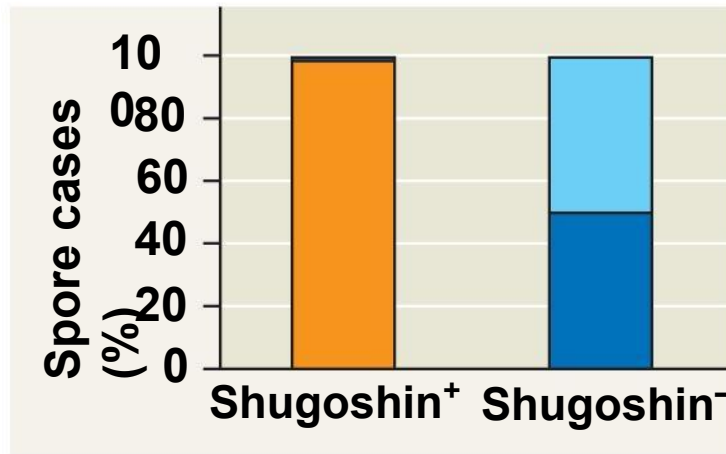
Fig. 13-10



EXPERIMENT



RESULTS



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Concept 13.4: Genetic variation produced in sexual life cycles contributes to evolution

- Mutations (changes in an organism's DNA) are the original source of genetic diversity
- Mutations create different versions of genes called alleles
- Reshuffling of alleles during sexual reproduction produces genetic variation

Origins of Genetic Variation Among Offspring

- The behavior of chromosomes during meiosis and fertilization is responsible for most of the variation that arises in each generation
- Three mechanisms contribute to genetic variation:
 - Independent assortment of chromosomes
 - Crossing over
 - Random fertilization

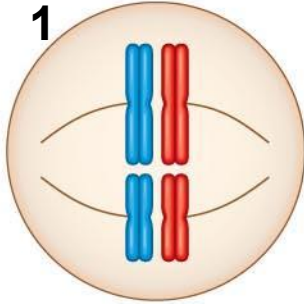
Independent Assortment of Chromosomes

- Homologous pairs of chromosomes orient randomly at metaphase I of meiosis
- In independent assortment, each pair of chromosomes sorts maternal and paternal homologues into daughter cells independently of the other pairs

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- The number of combinations possible when chromosomes assort independently into gametes is 2^n , where n is the haploid number
 - For humans ($n = 23$), there are more than 8 million (2^{23}) possible combinations of chromosomes

Possibility

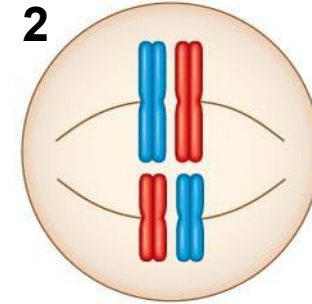
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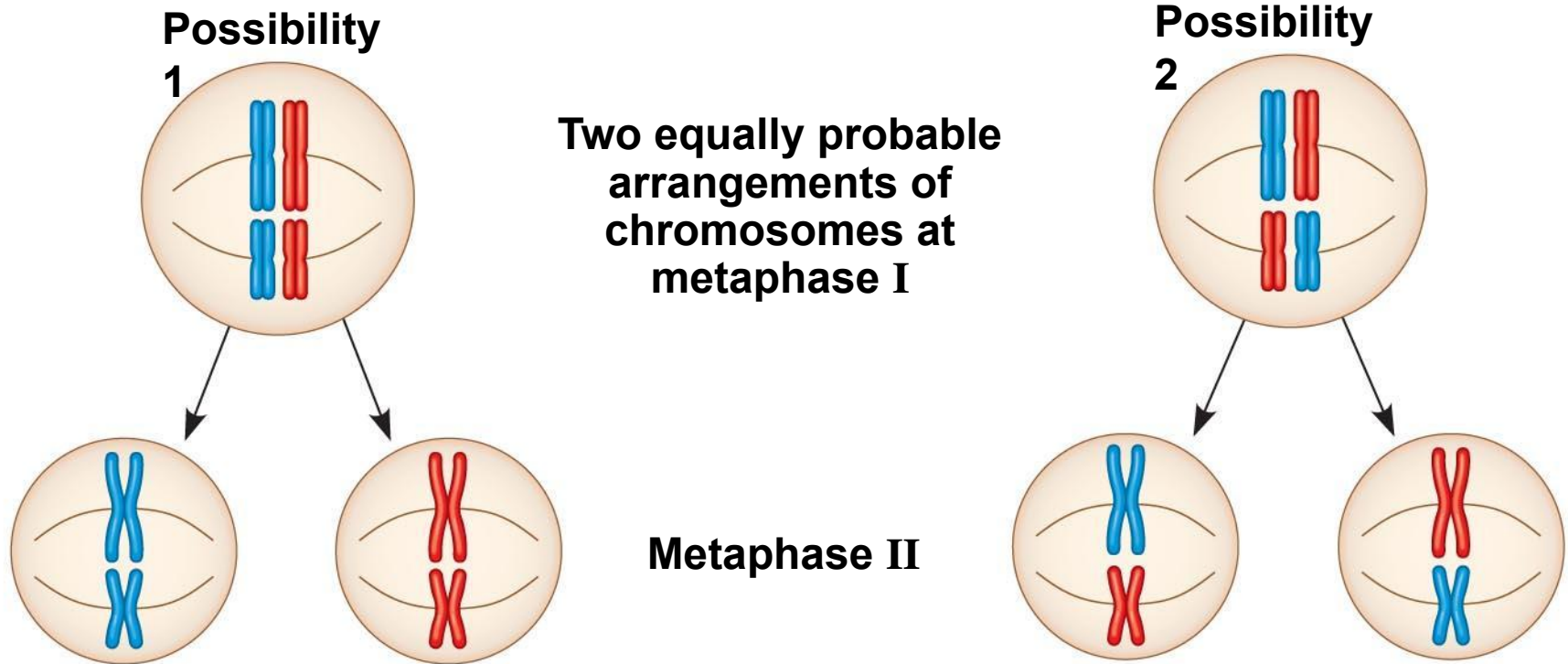


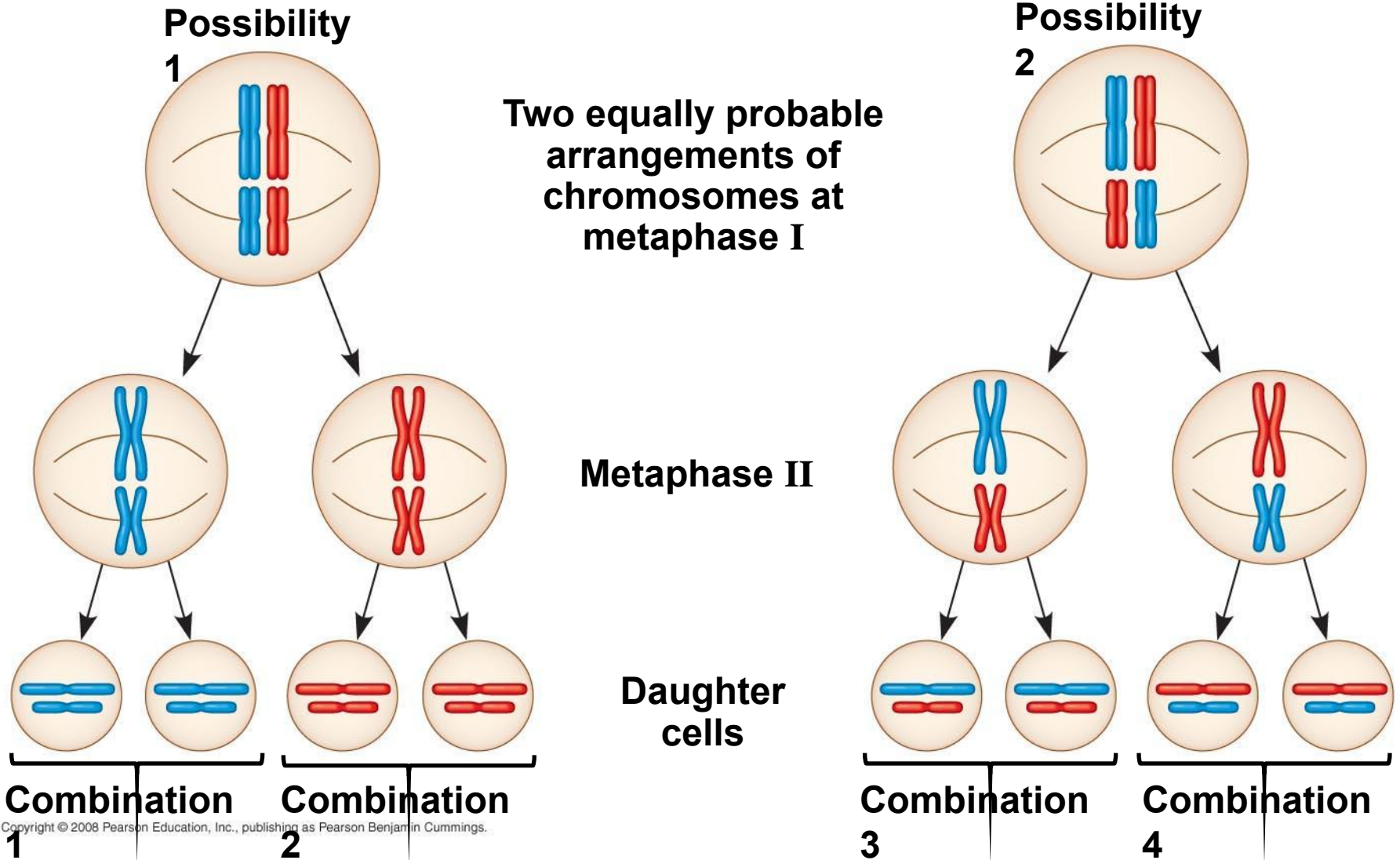
**Two equally probable
arrangements of
chromosomes at
metaphase I**

Possibility

2







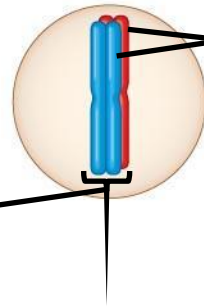
Crossing Over

- Crossing over produces **recombinant chromosomes**, which combine genes inherited from each parent
- Crossing over begins very early in prophase I, as homologous chromosomes pair up gene by gene

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- In crossing over, homologous portions of two nonsister chromatids trade places
 - Crossing over contributes to genetic variation by combining DNA from two parents into a single chromosome

Prophase I of meiosis

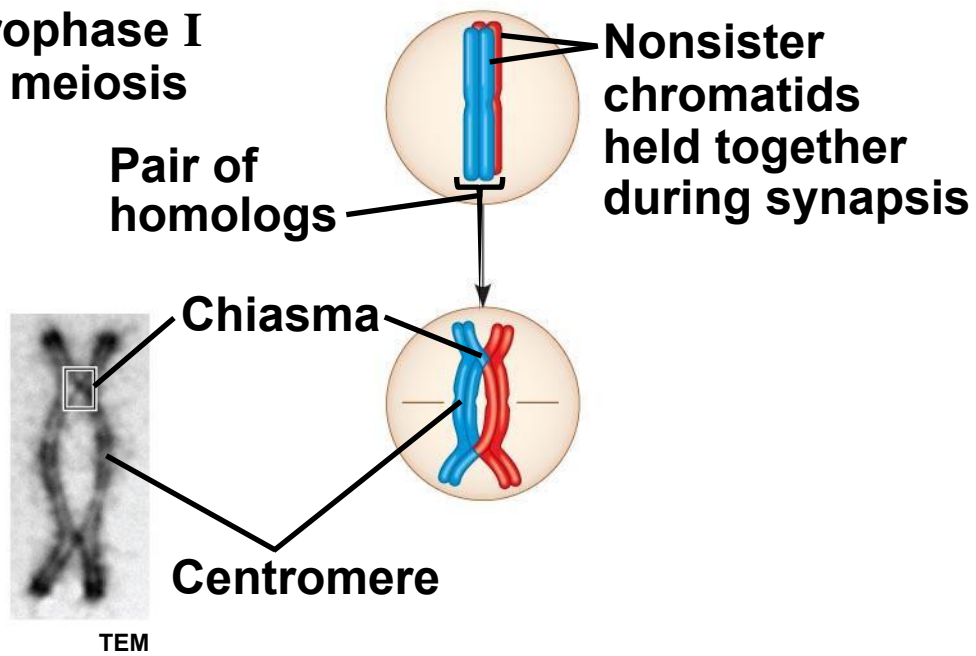
Pair of
homologs



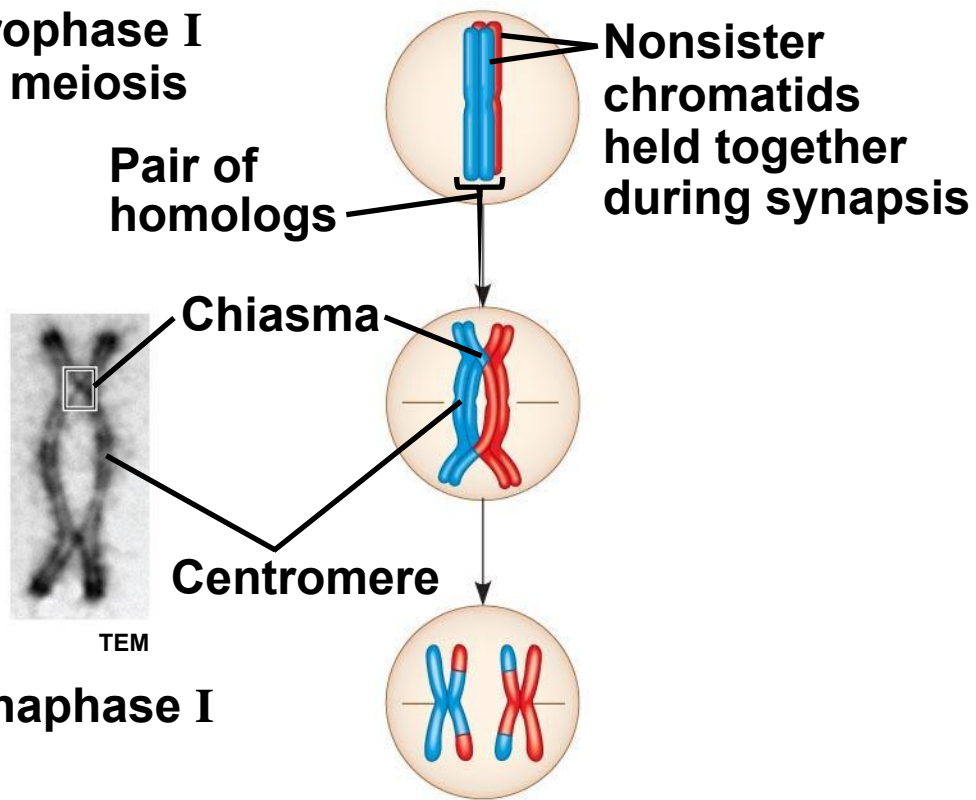
Nonsister
chromatids
held together
during synapsis

Fig. 13-12-2

Prophase I of meiosis



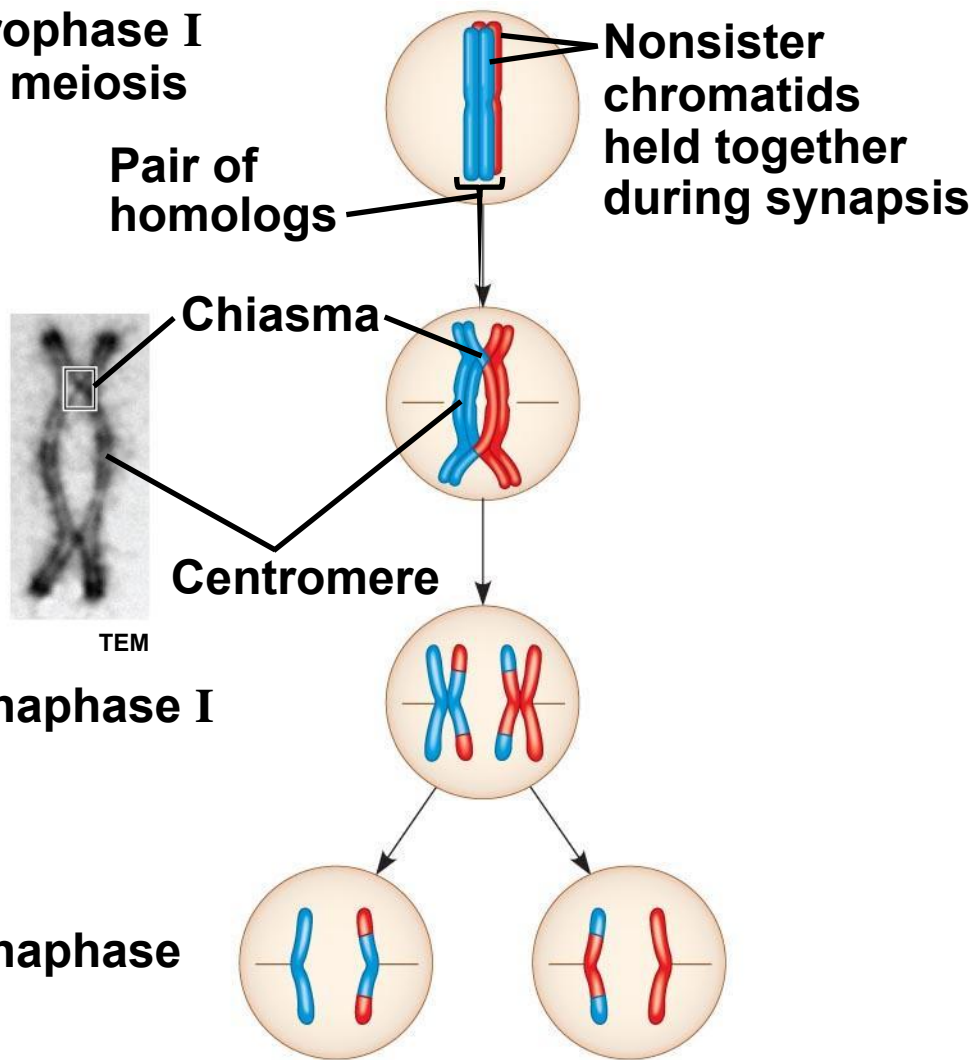
Prophase I of meiosis



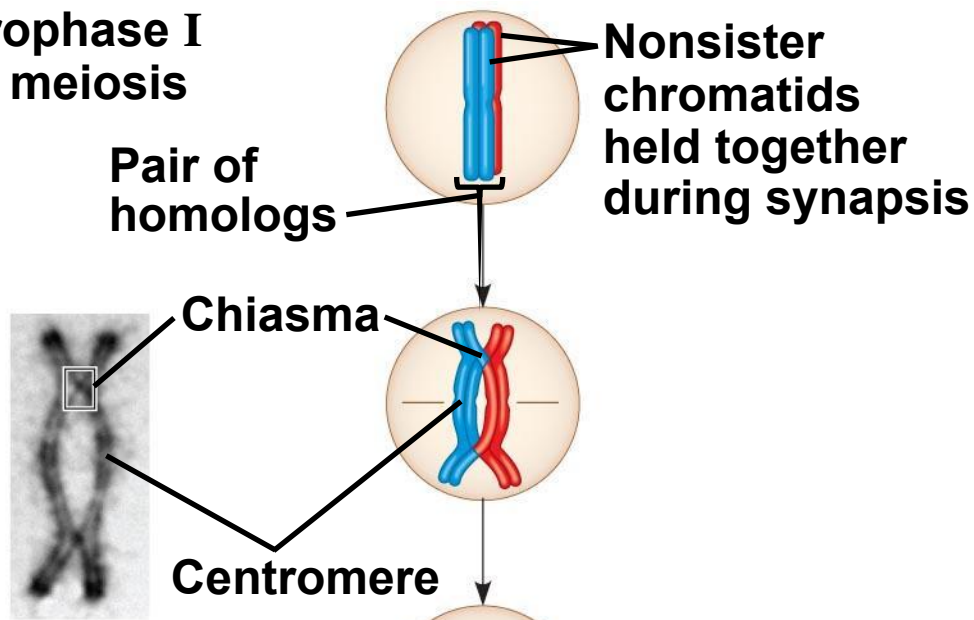
Anaphase I

Fig. 13-12-4

Prophase I of meiosis



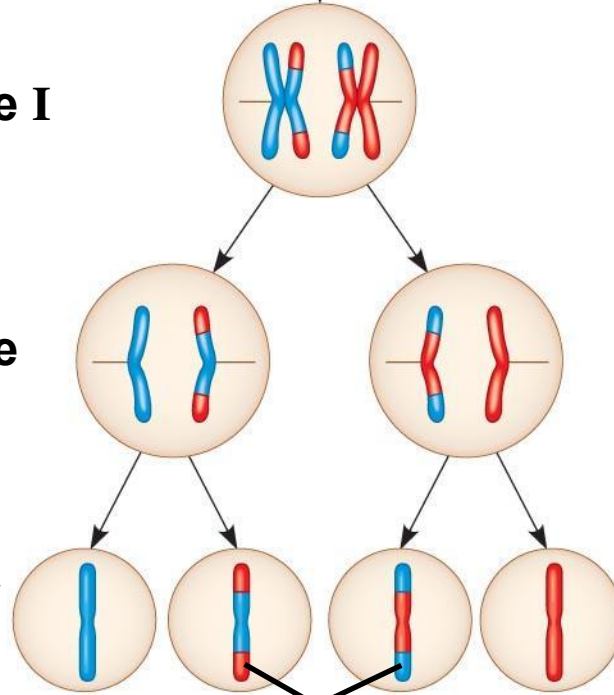
Prophase I of meiosis



Anaphase I

Anaphase II

Daughter cells



Recombinant chromosomes

Random Fertilization

- Random fertilization adds to genetic variation because any sperm can fuse with any ovum (unfertilized egg)
- The fusion of two gametes (each with 8.4 million possible chromosome combinations from independent assortment) produces a zygote with any of about 70 trillion diploid combinations

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- Crossing over adds even more variation
 - Each zygote has a unique genetic identity

PLAY

**Animation: Genetic
Variation**

The Evolutionary Significance of Genetic Variation Within Populations

- Natural selection results in the accumulation of genetic variations favored by the environment
- Sexual reproduction contributes to the genetic variation in a population, which originates from mutations

Prophase I: Each homologous pair undergoes synapsis and crossing over between nonsister chromatids.

Metaphase I: Chromosomes line up as homologous pairs on the metaphase plate.

Anaphase I: Homologs separate from each other; sister chromatids remain joined at the centromere.

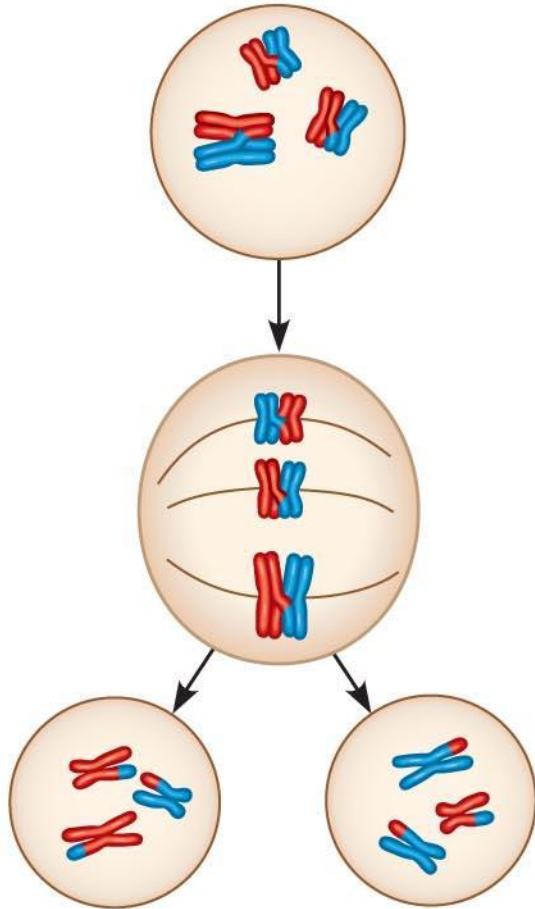


Fig. 13-UN2

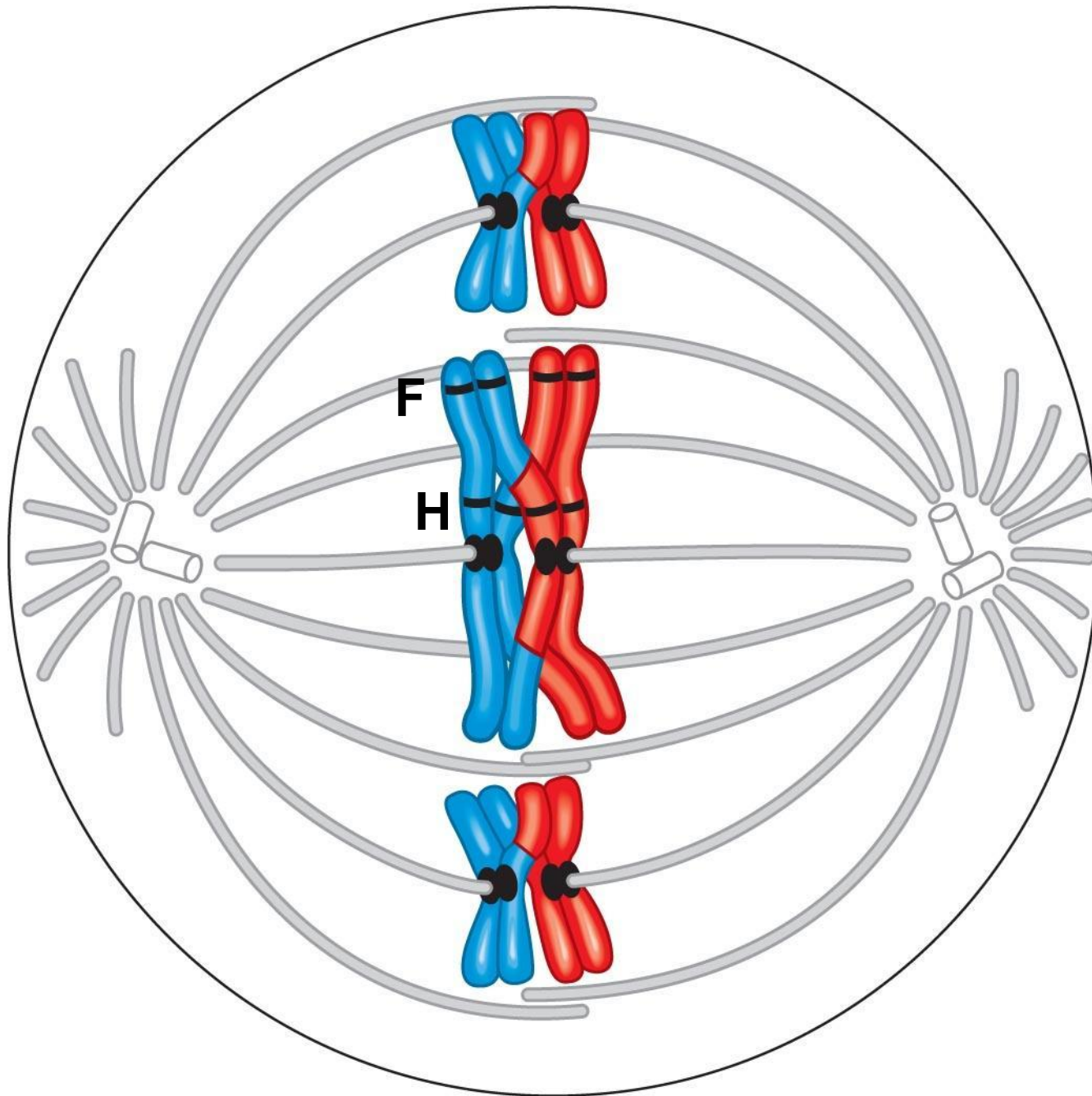


Fig. 13-UN3

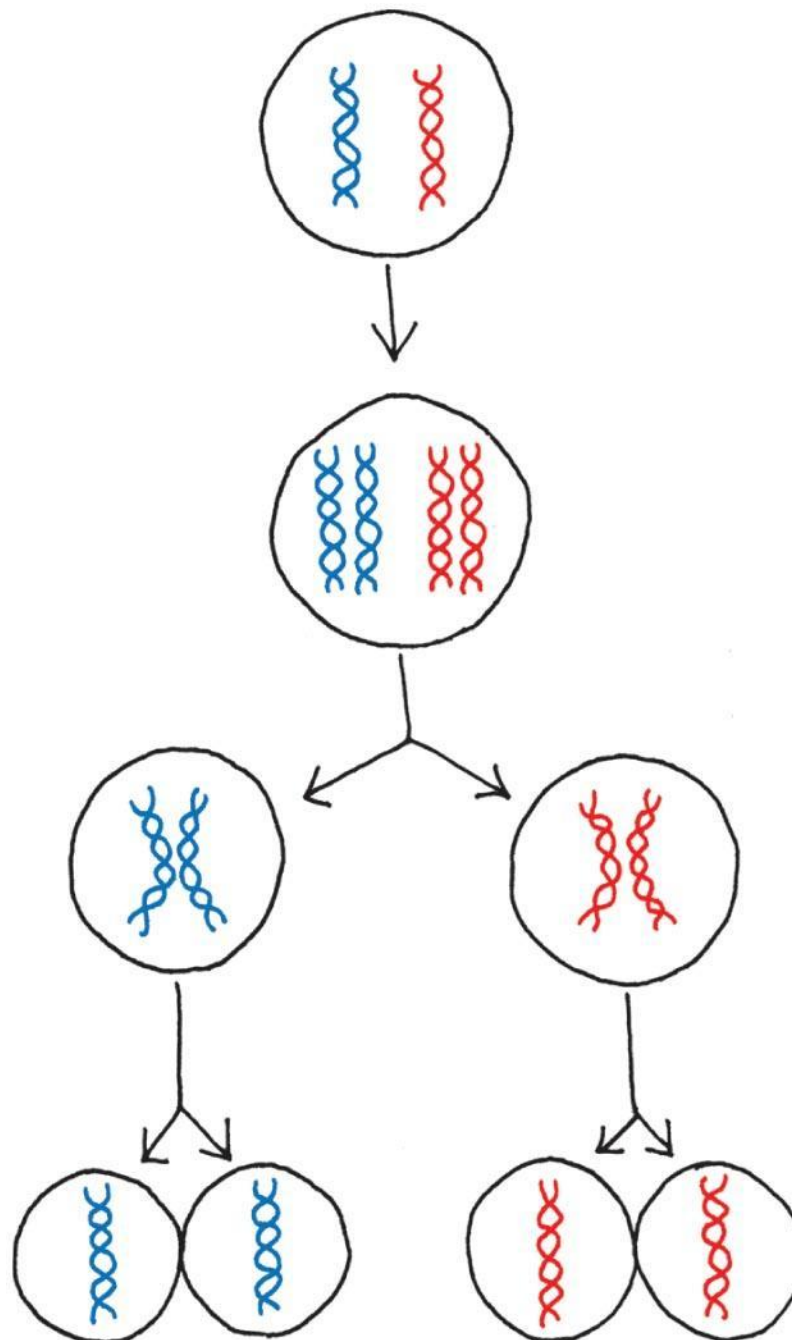
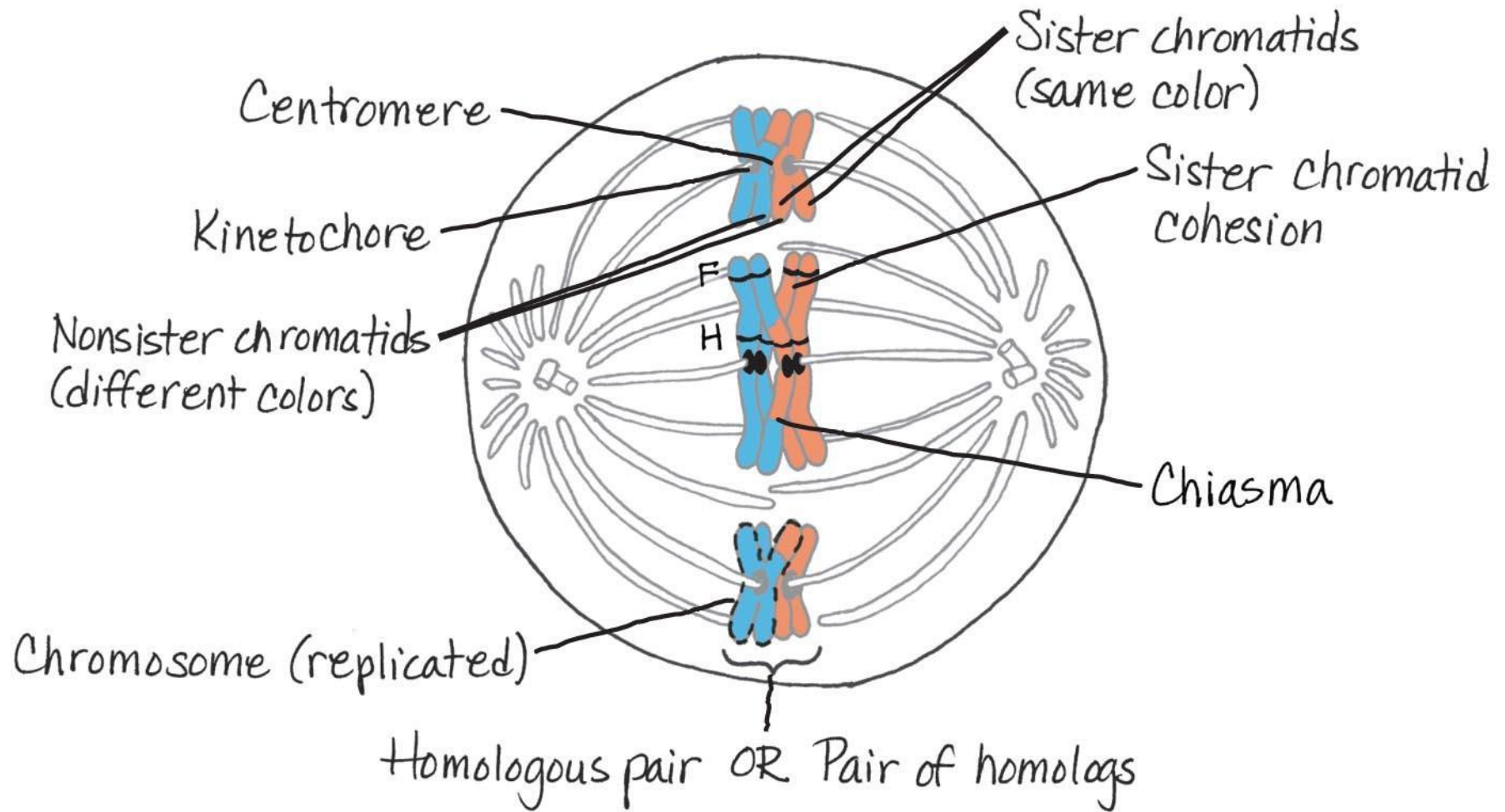


Fig. 13-UN4



The chromosomes of one color make up a haploid set.
All red and blue chromosomes together make up a diploid set.

You should now be able to:

1. Distinguish between the following terms: somatic cell and gamete; autosome and sex chromosomes; haploid and diploid
2. Describe the events that characterize each phase of meiosis
3. Describe three events that occur during meiosis I but not mitosis
4. Name and explain the three events that contribute to genetic variation in sexually reproducing organisms