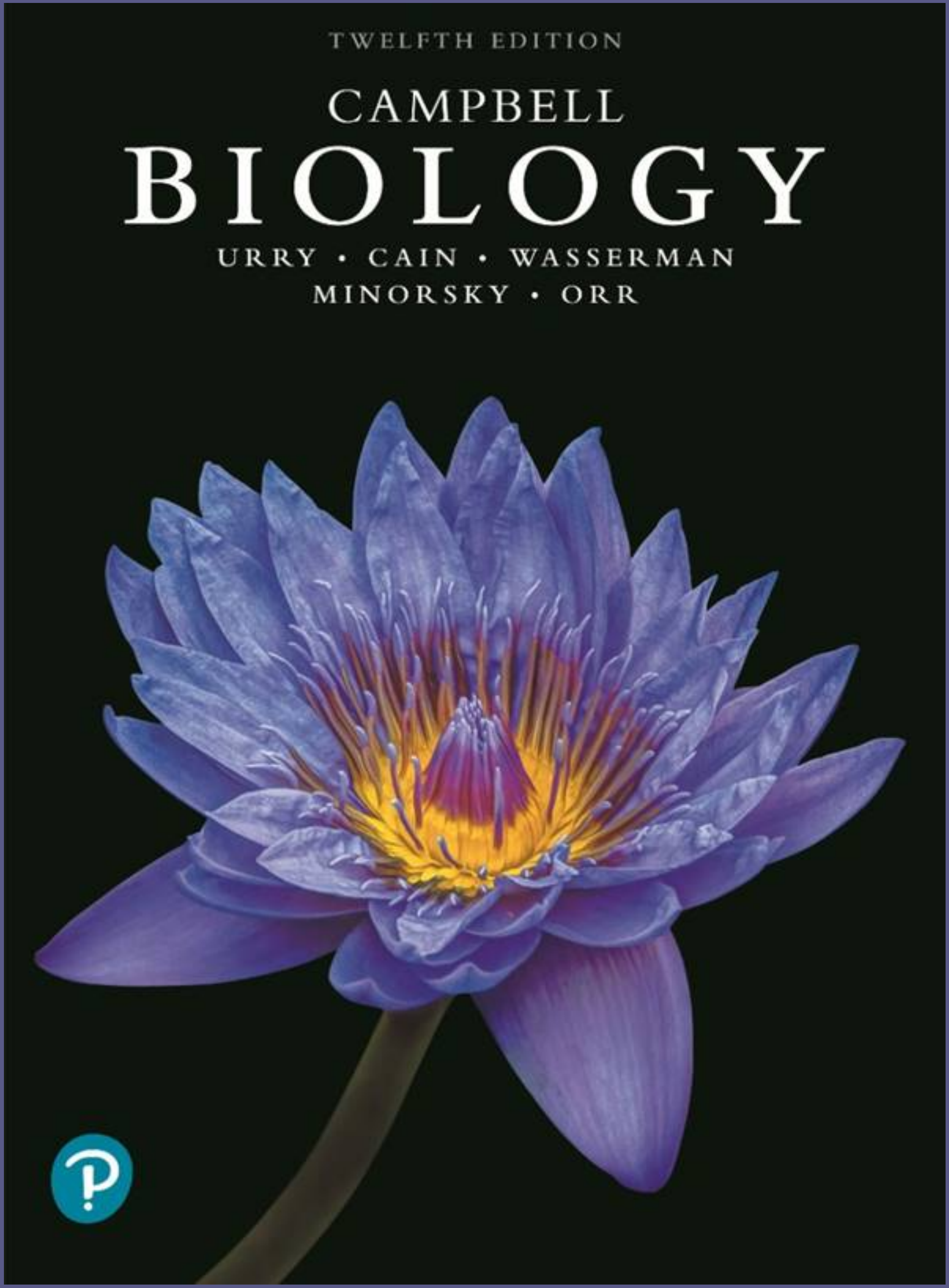


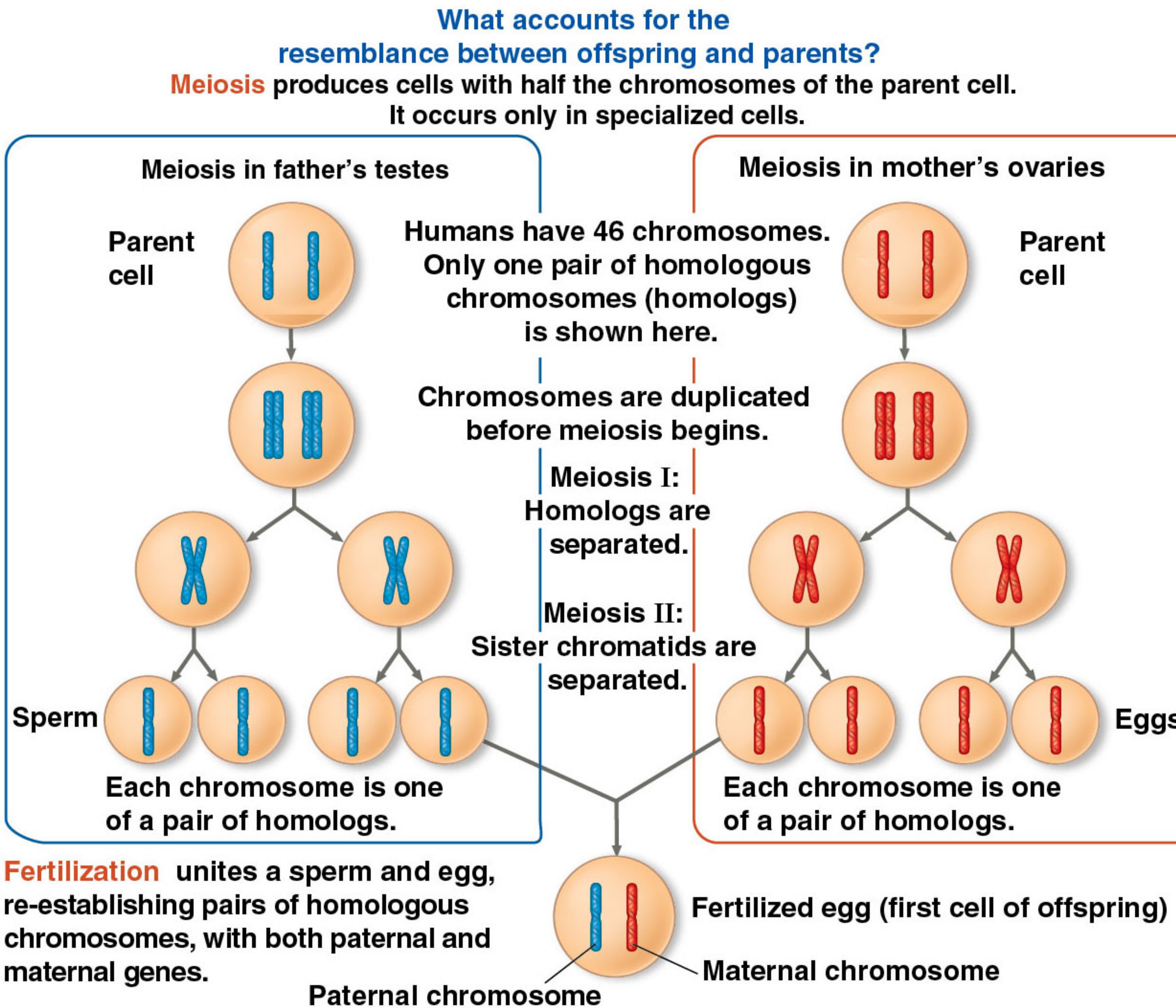
Chapter 13

Meiosis and Sexual Life Cycles

Lecture Presentations by
Nicole Tunbridge and
Kathleen Fitzpatrick

Figure 13.1

Figure 13.1


What accounts for the
resemblance between offspring and parents?
Meiosis produces cells with half the chromosomes of the parent cell.
It occurs only in specialized cells.
Meiosis in father's testes
Meiosis in mother's ovaries
Parent cell
Parent cell
Humans have 46 chromosomes.
Only one pair of homologous
chromosomes (homologs)
is shown here.
Chromosomes are duplicated
before meiosis begins.
Meiosis I:
Homologs are
separated.
Meiosis II:
Sister chromatids are
separated.
Sperm
Eggs
Each chromosome is one
of a pair of homologs.
Each chromosome is one
of a pair of homologs.
Fertilization unites a sperm and egg,
re-establishing pairs of homologous
chromosomes, with both paternal and
maternal genes.
Fertilized egg (first cell of offspring)
Maternal chromosome
Paternal chromosome

CONCEPT 13.1: Offspring acquire genes from parents by inheriting chromosomes

- The transmission of traits from one generation to the next is called inheritance, or **heredity**
- Sons and daughters are not identical copies of either parent or of their siblings
- Along with inherited similarity, there is **variation**
- The study of heredity and inherited variation is called **genetics**

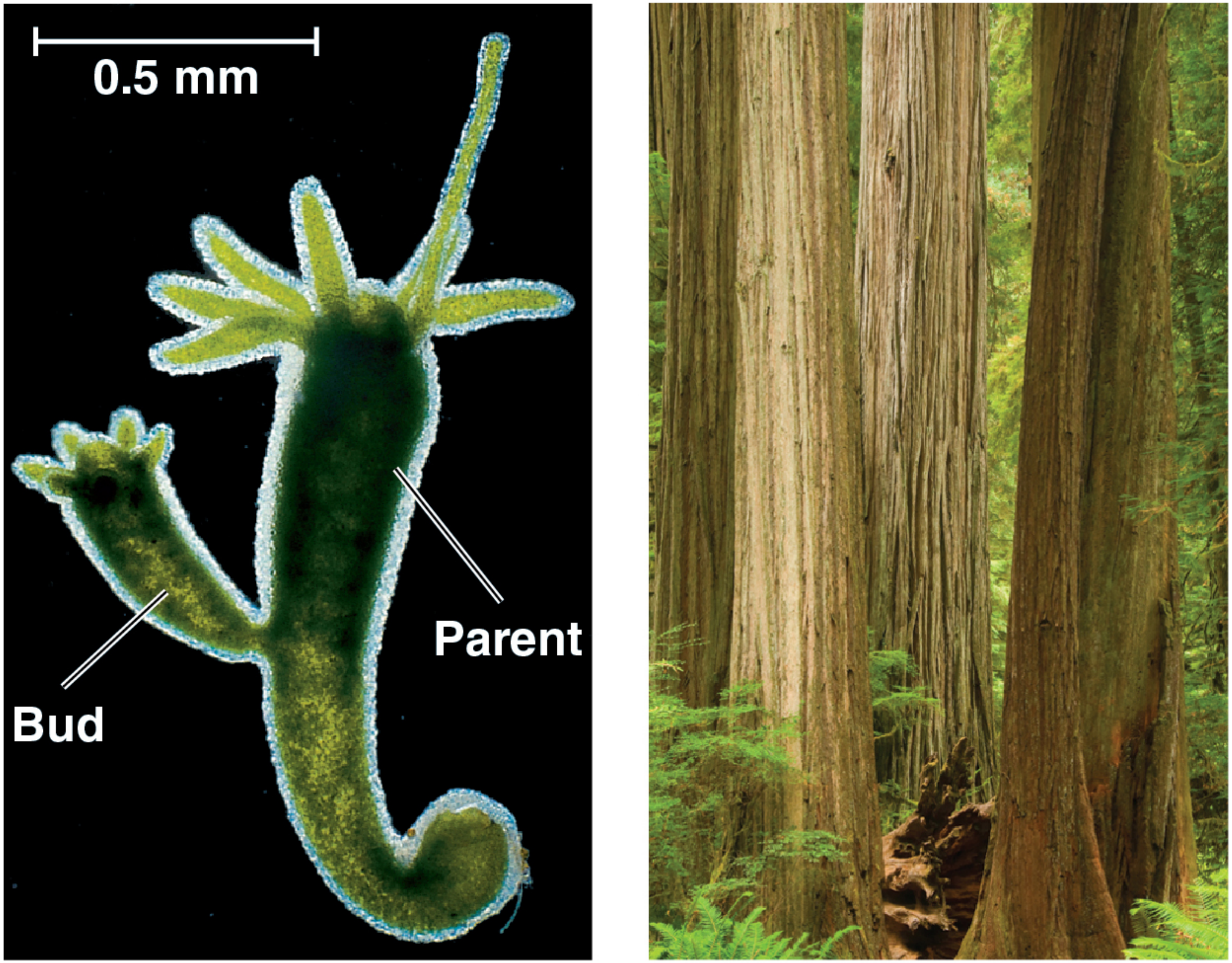
Inheritance of Genes

- **Genes** are the units of heredity and are made up of segments of DNA
- Genes are passed to the next generation via reproductive cells called **gametes** (sperm and eggs)
- Most DNA is packaged into chromosomes
- Humans have 46 chromosomes in the nuclei of their **somatic cells**—all cells of the body except gametes and their precursors
- A gene's specific position along a chromosome is called its **locus**

Comparison of Asexual and Sexual Reproduction

- In **asexual reproduction**, a single individual passes all of its genes to its offspring without the fusion of gametes
- A **clone** is an individual or 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

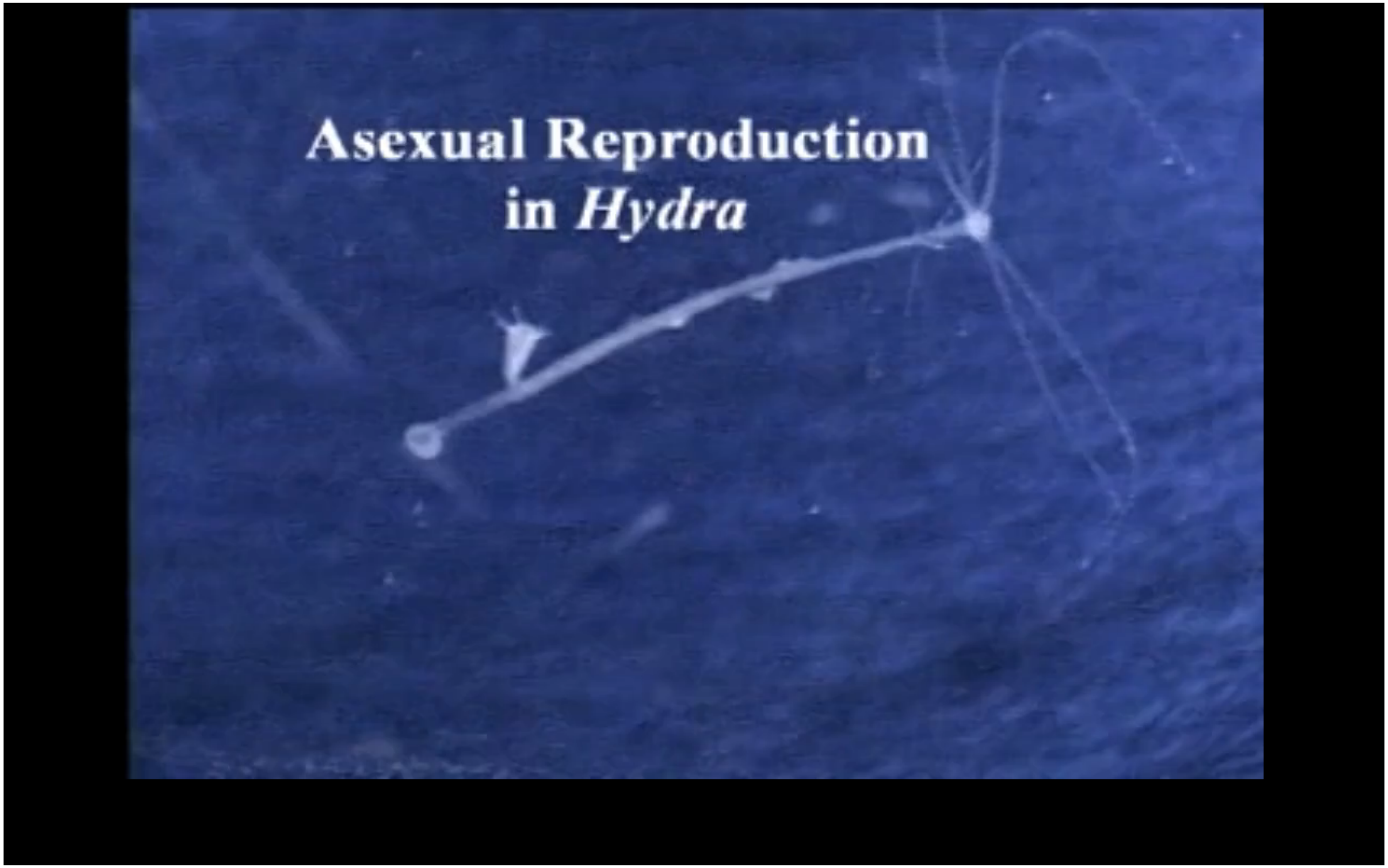
Figure 13.2



(a) Hydra

(b) Redwoods

Video: Hydra Budding



CONCEPT 13.2: Fertilization and meiosis alternate in sexual life cycles

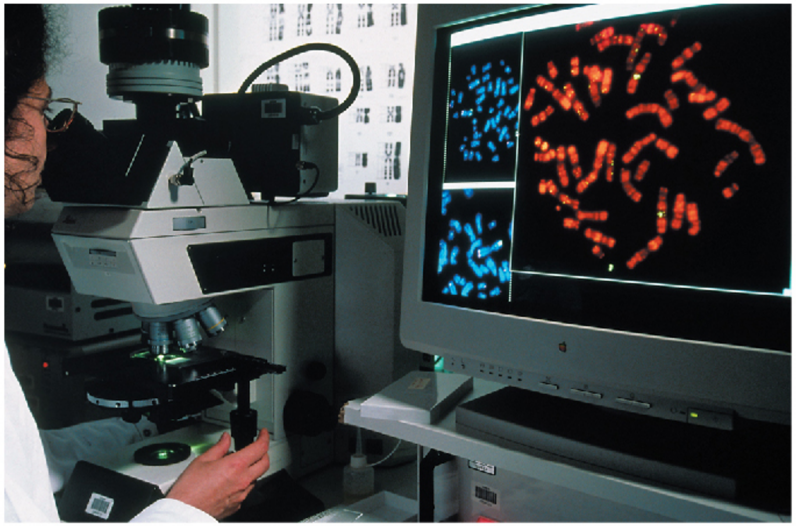
- A **life cycle** is the generation-to-generation sequence of stages in the reproductive history of an organism
- The behavior of chromosomes is related to the human lifecycle and other types of sexual life cycles

Sets of Chromosomes in Human Cells

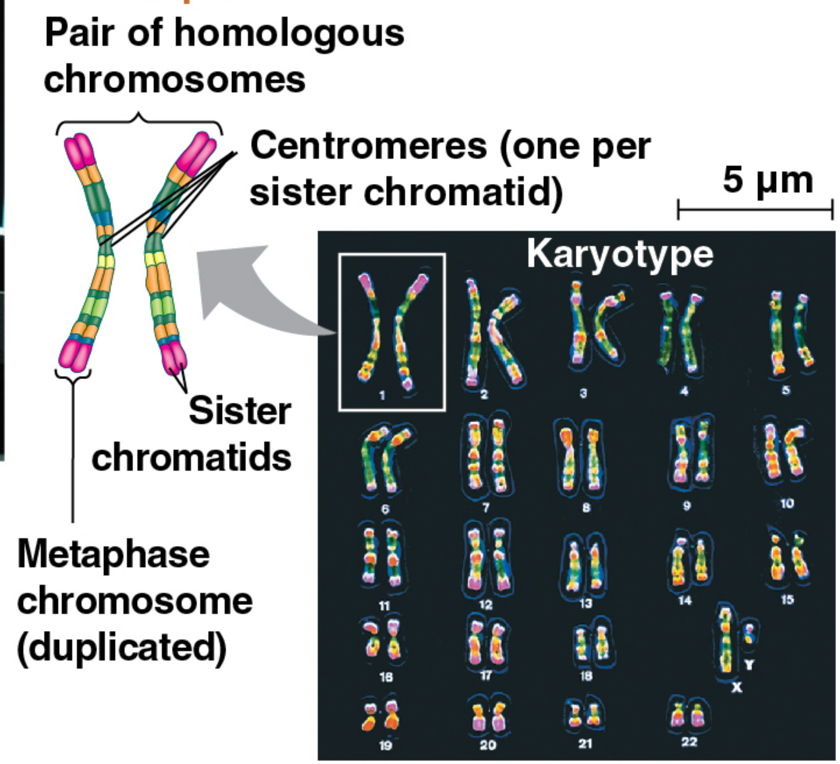
- Human somatic cells have 23 pairs of chromosomes
- A **karyotype** is an ordered display of the pairs of chromosomes from a cell
- The two chromosomes in each pair are called **homologous chromosomes**, or **homologs**
- Chromosomes in a homologous pair have the same length, centromere position, and staining pattern
- They also carry genes controlling the same inherited characters

Figure 13.3

Application



Technique



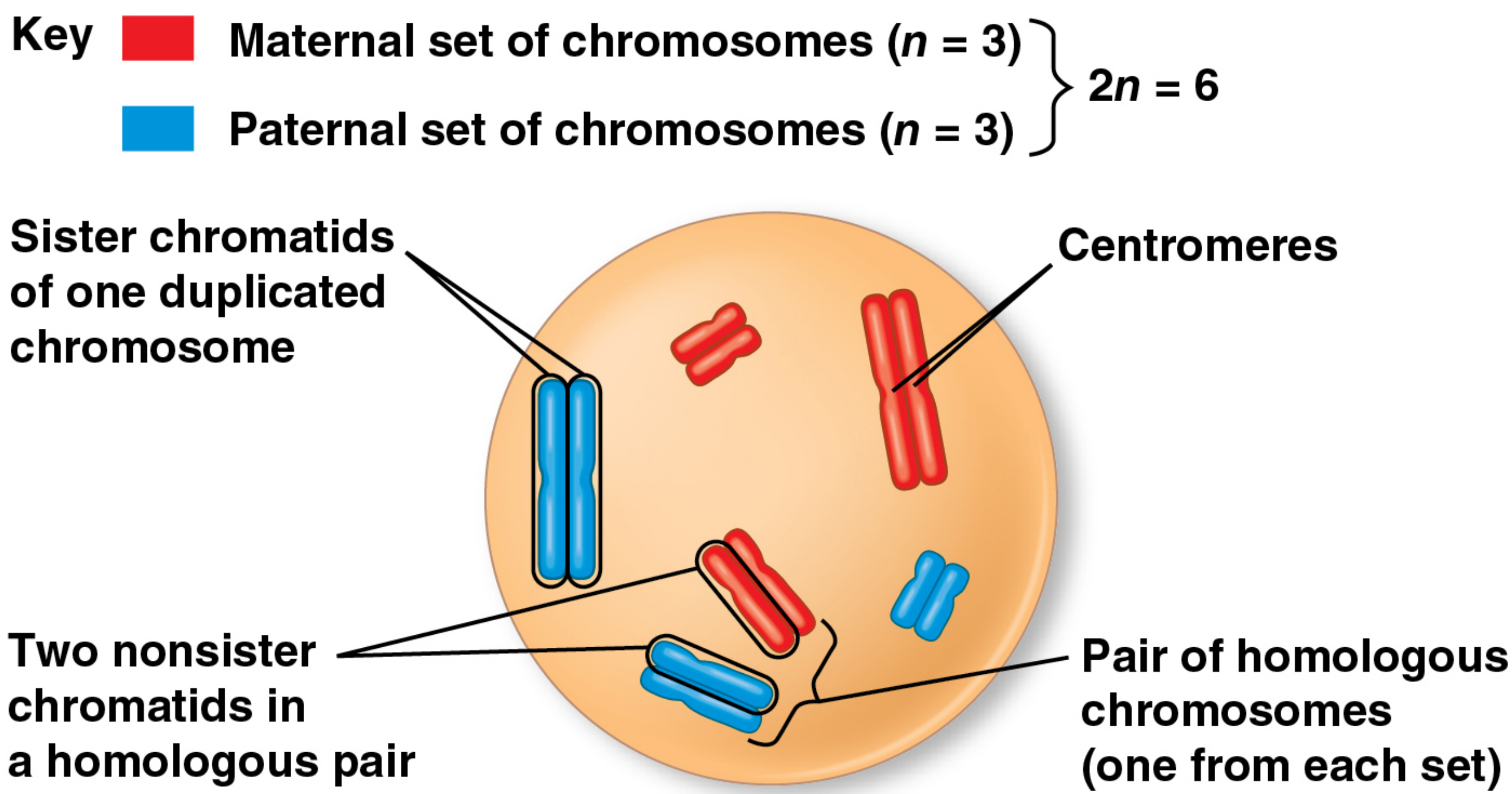
- The **sex chromosomes**, which determine the sex of the individual, are called X and Y
- Human females have a homologous pair of X chromosomes (XX)
- Human males have one X and one Y chromosome
- The remaining 22 pairs of chromosomes are called **autosomes**

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

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

- A gamete (sperm or egg) contains a single set of chromosomes and is thus a **haploid cell** (*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

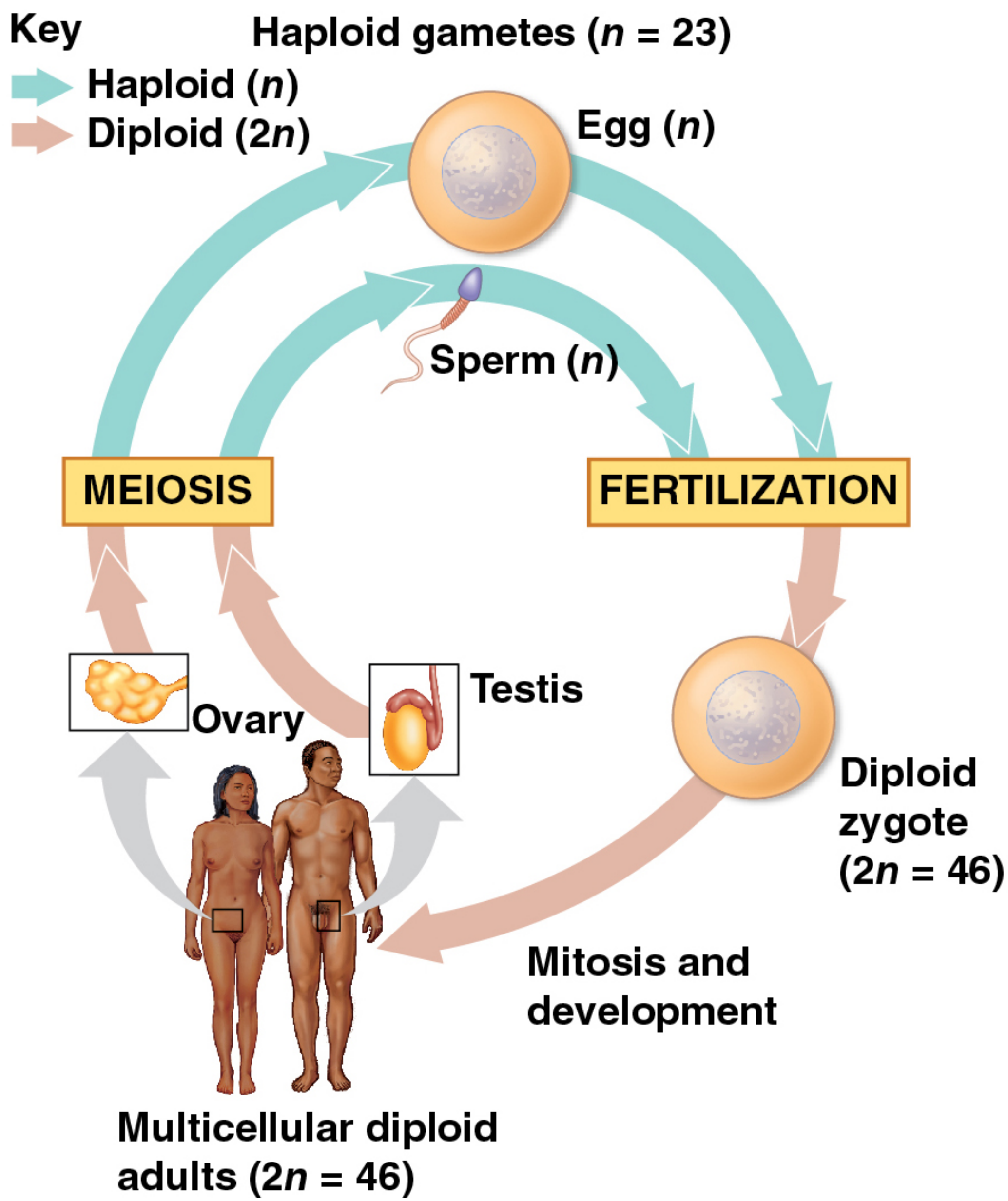
Figure 13.4


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

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

Figure 13.5



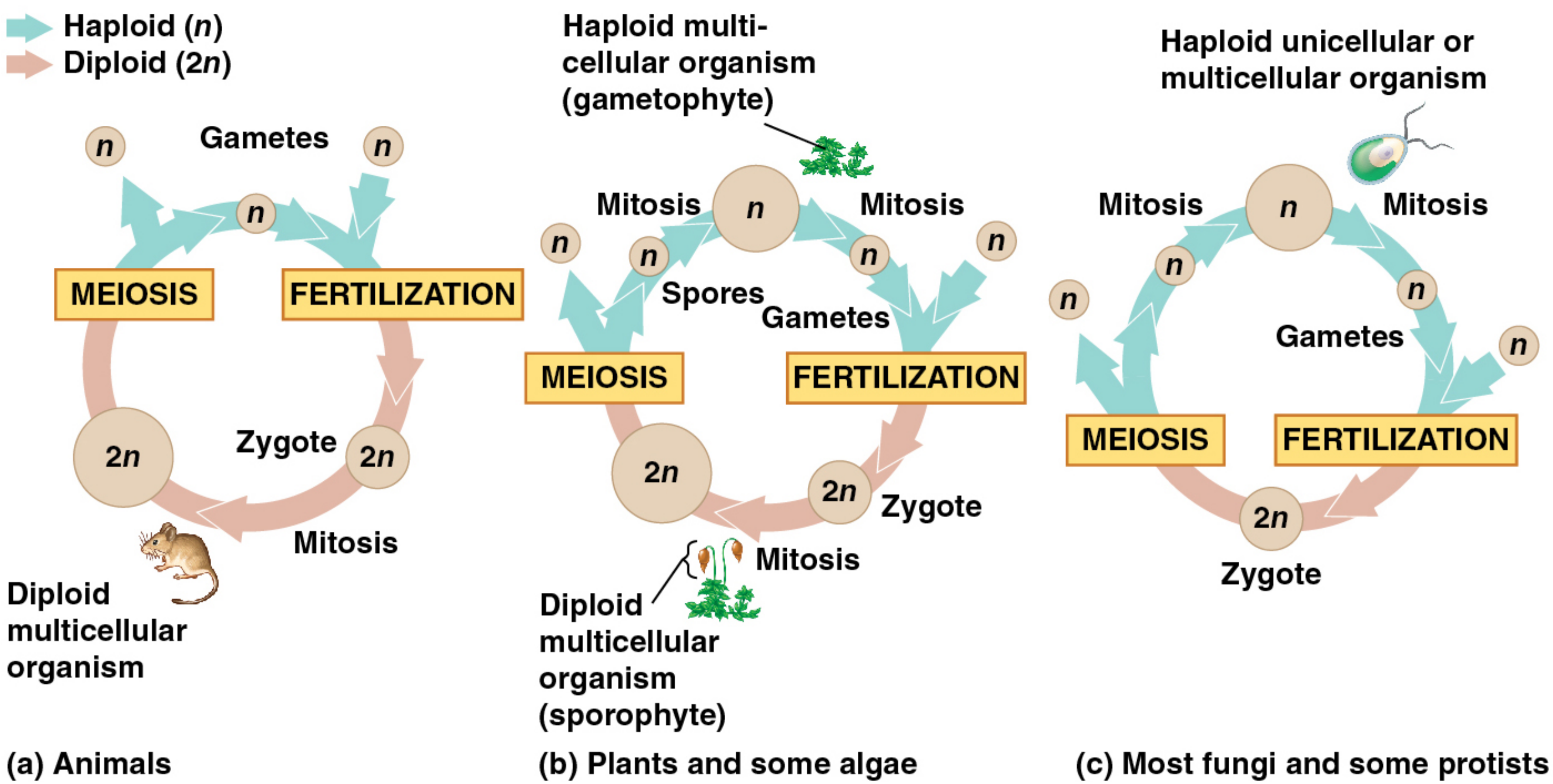
Key
Haploid (n)
Diploid (2n)
Haploid gametes (n = 23)
Egg (n)
Sperm (n)
MEIOSIS
FERTILIZATION
Ovary
Testis
Diploid zygote (2n = 46)
Mitosis and development
Multicellular diploid adults (2n = 46)

- The ovaries and testes produce haploid gametes
- Gametes are the only type of human cells produced by **meiosis**, rather than by mitosis
- Meiosis results in one set of chromosomes in each gamete
- Fertilization and meiosis alternate in sexual life cycles to maintain chromosome number

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

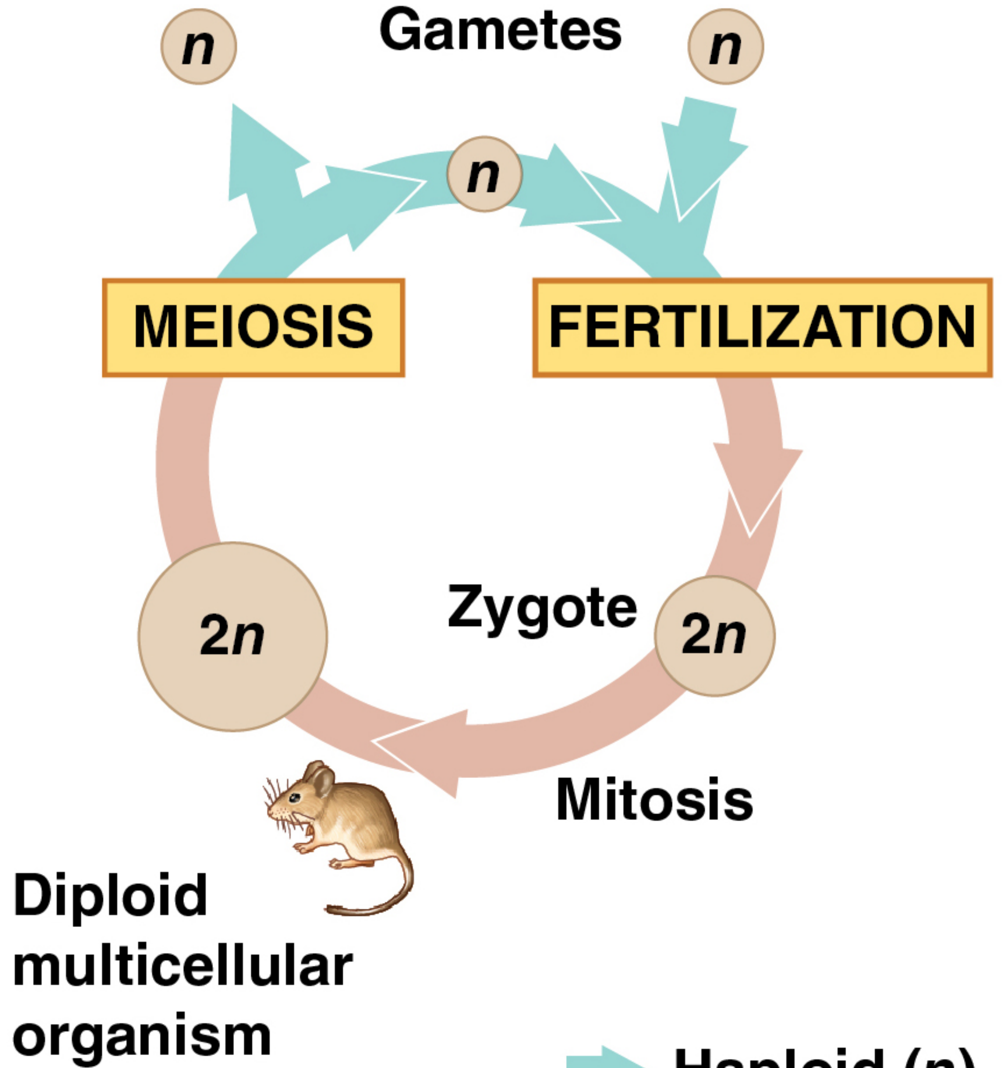
Figure 13.6



Haploid (n)
Diploid (2n)
n
Gametes
n
n
MEIOSIS
FERTILIZATION
2n
Zygote
2n
Mitosis
Diploid multicellular organism
(a) Animals
Haploid multi-cellular organism (gametophyte)
Mitosis
n
Mitosis
n
n
n
n
Spores
Gametes
MEIOSIS
FERTILIZATION
2n
2n
Zygote
Mitosis
Diploid multicellular organism (sporophyte)
(b) Plants and some algae
Haploid unicellular or multicellular organism
Mitosis
n
Mitosis
n
n
n
Gametes
n
MEIOSIS
FERTILIZATION
2n
Zygote
(c) Most fungi and some protists

- Gametes are the only haploid cells in most animals
- They are produced by meiosis and undergo no further cell division before fertilization
- Gametes fuse to form a diploid zygote that divides by mitosis to develop into a multicellular organism

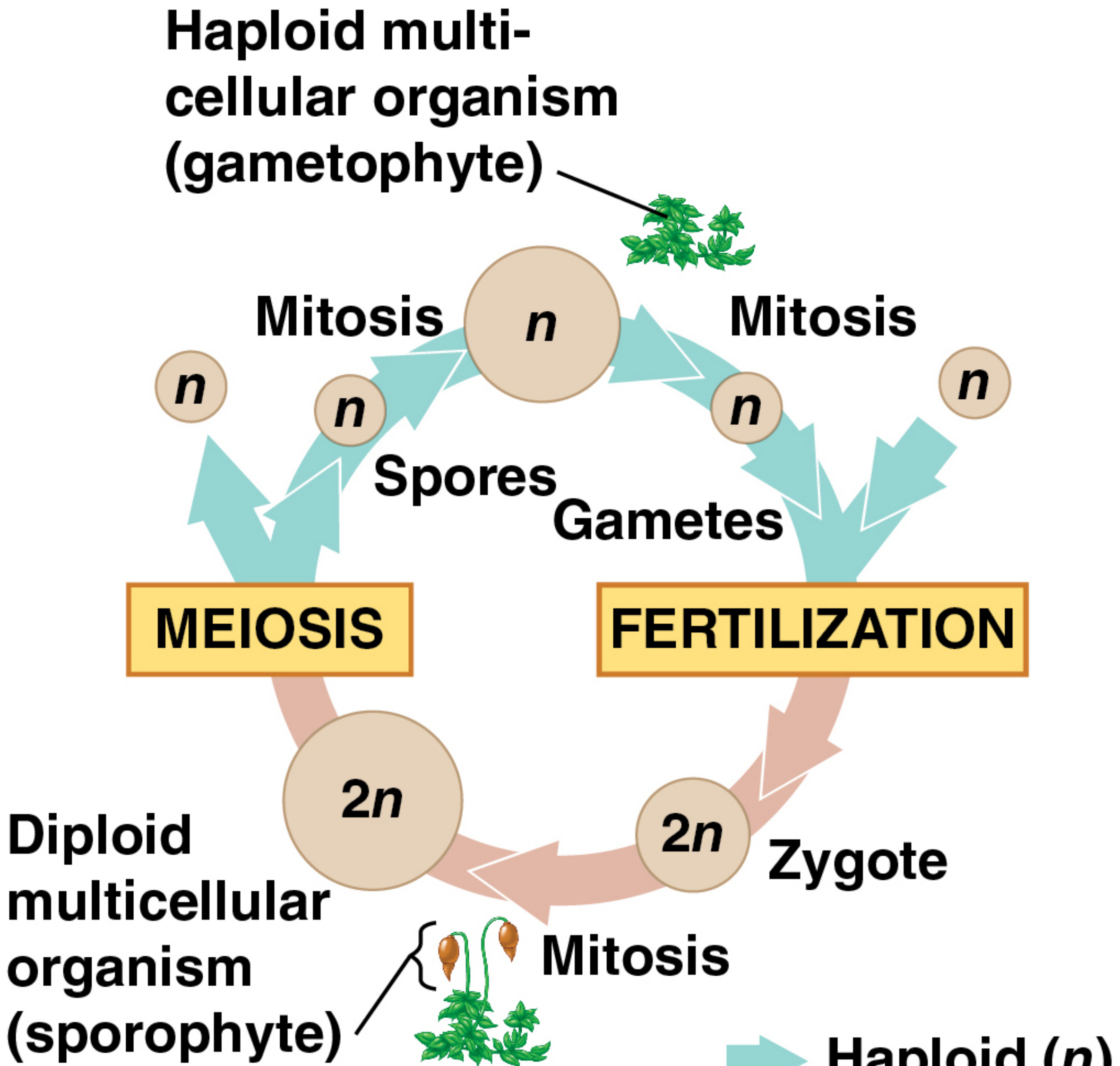
Figure 13.6a



(a) Animals

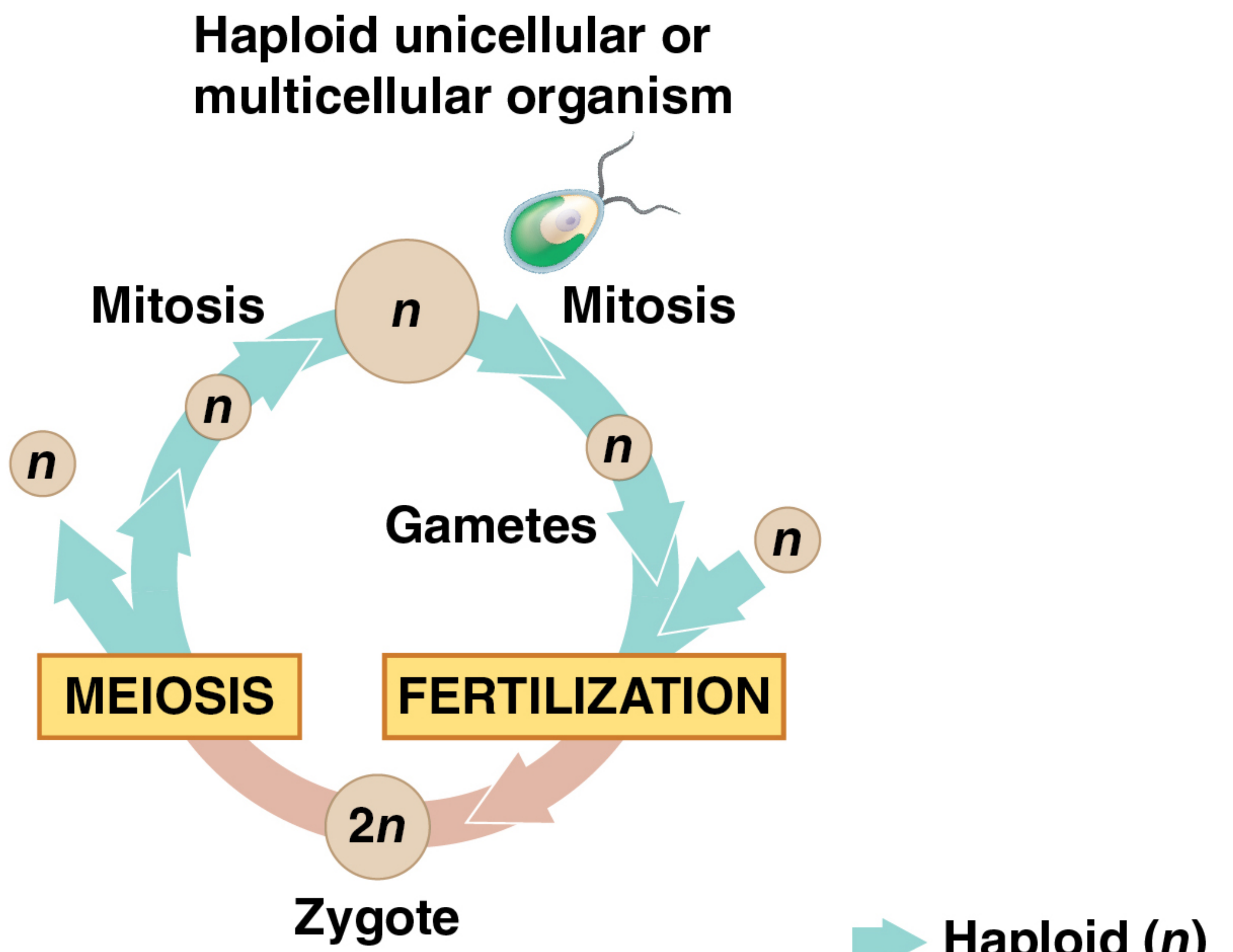
- Plants and some algae exhibit an **alternation of generations**
- This life cycle includes both a diploid and haploid multicellular stage
- The diploid organism, called the sporophyte, makes haploid spores by meiosis

- 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



(b) Plants and some algae

- 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



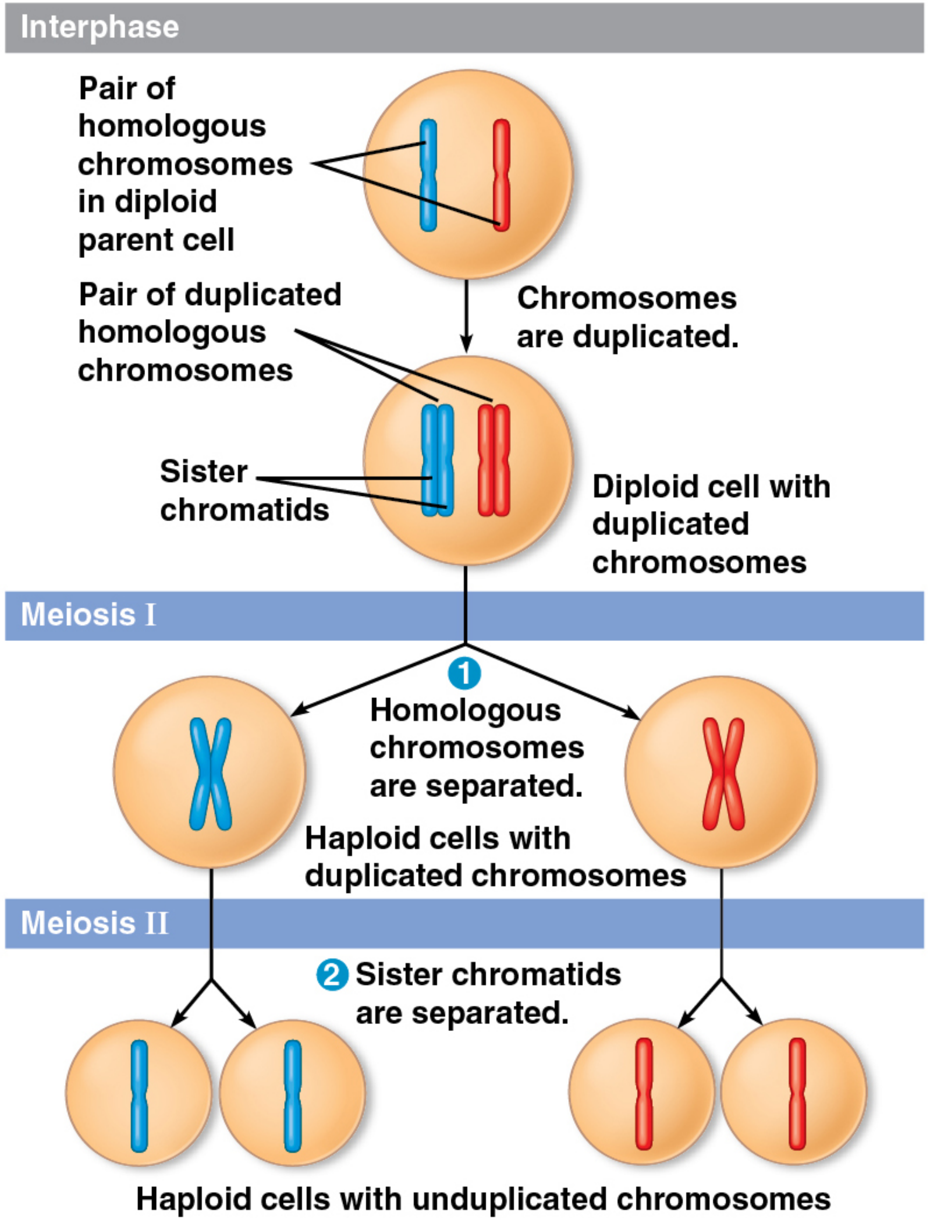
(c) Most fungi and some protists

- 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 contribute 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 consecutive 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

Figure 13.7


Interphase
Pair of homologous chromosomes in diploid parent cell
Chromosomes are duplicated.
Pair of duplicated homologous chromosomes
Sister chromatids
Diploid cell with duplicated chromosomes
Meiosis I
1 Homologous chromosomes are separated.
Haploid cells with duplicated chromosomes
Meiosis II
2 Sister chromatids are separated.
Haploid cells with unduplicated chromosomes

The Stages of Meiosis

- Chromosomes duplicate before meiosis
- The resulting sister chromatids are closely associated along their lengths
- This is called sister chromatid cohesion
- The chromatids are sorted into four haploid daughter cells

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

Prophase I

- In early prophase I, each chromosome pairs with its homolog and **crossing over** occurs
- X-shaped regions called **chiasmata** are sites of crossovers

Metaphase I

- In metaphase I, pairs of homologs 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 pair
- Microtubules from the other pole are attached to the kinetochore of the other chromosome

Anaphase I

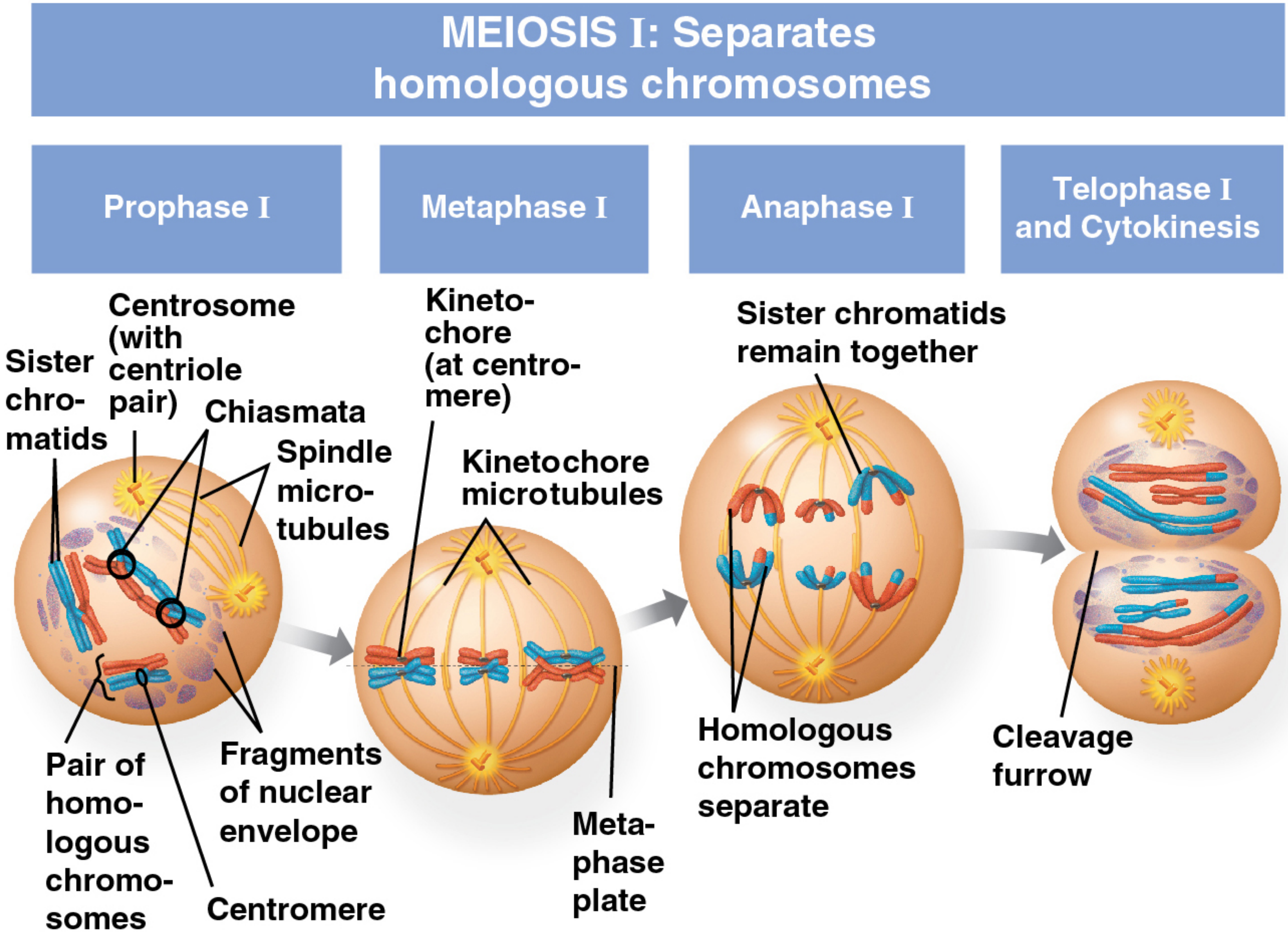
- In anaphase I, pairs of homologous chromosomes separate
- One chromosome of each pair moves toward opposite poles, guided by the spindle apparatus
- Sister chromatids remain attached at the centromere and move as one unit toward the pole

Telophase I and Cytokinesis

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

- 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

Figure 13.8a


MEIOSIS I: Separates homologous chromosomes
Prophase I
Metaphase I
Anaphase I
Telophase I and Cytokinesis
Centrosome (with centriole pair)
Sister chro- matids
Chiasmata
Spindle micro- tubules
Kineto- chore (at centro- mere)
Kinetochore microtubules
Sister chromatids remain together
Pair of homo- logous chromo- somes
Fragments of nuclear envelope
Centromere
Meta- phase plate
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 very similar to mitosis

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

Anaphase II

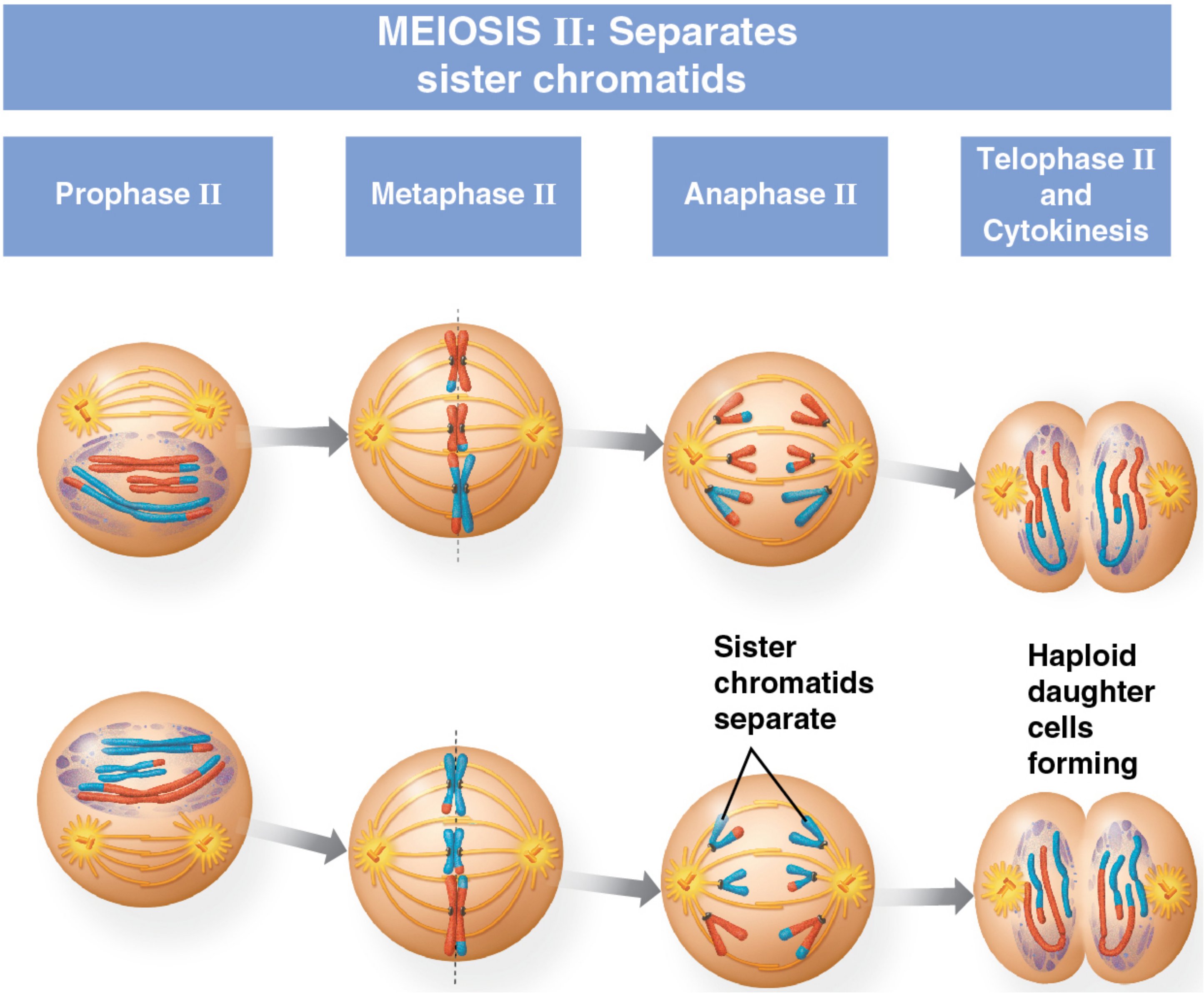
- In anaphase II, the sister chromatids separate
- The sister chromatids of each chromosome now move as two newly individual chromosomes toward opposite poles

Telophase II and Cytokinesis

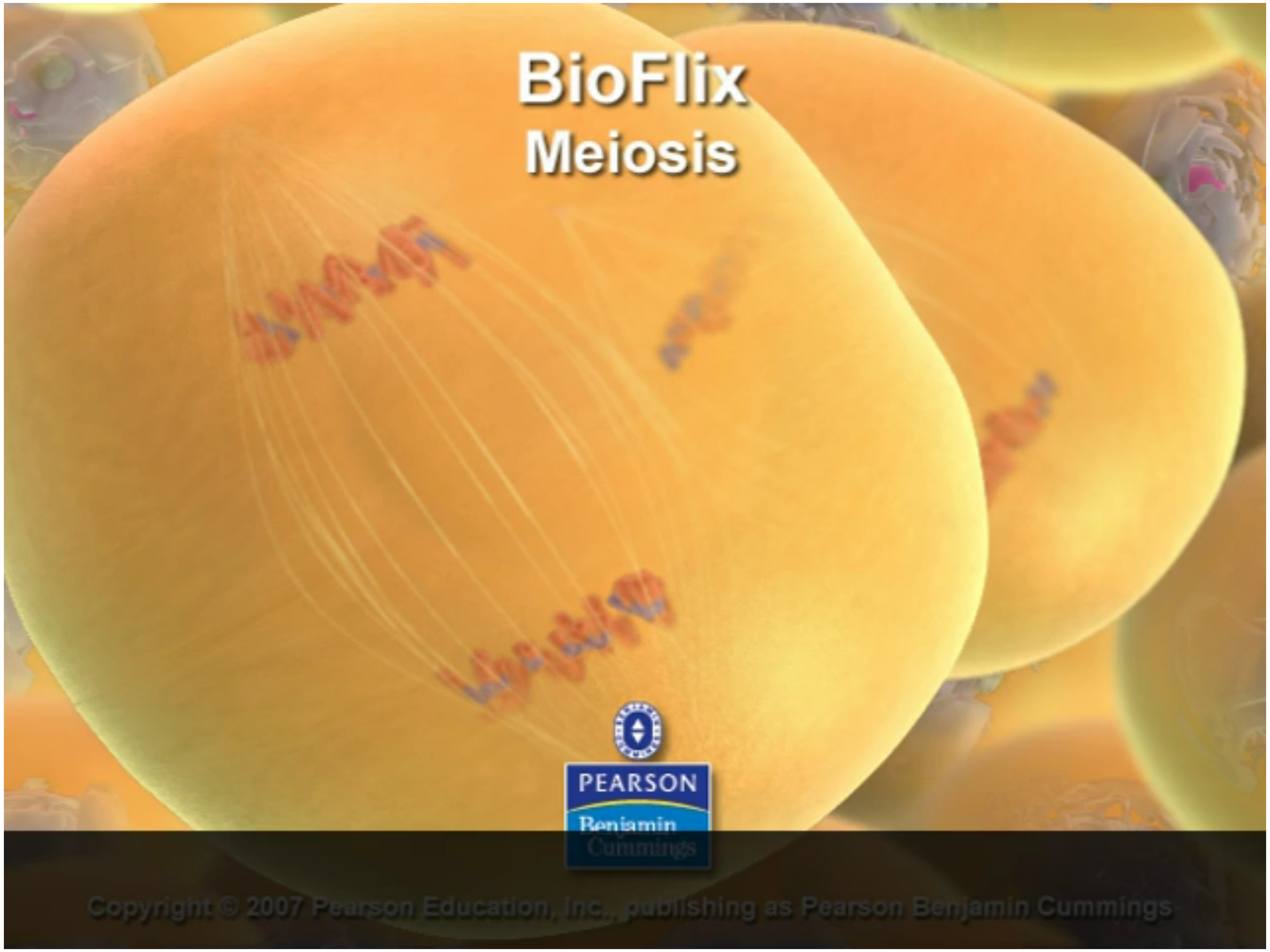
- In telophase II, the chromosomes arrive at opposite poles
- Nuclei form, and the chromosomes begin decondensing

- 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

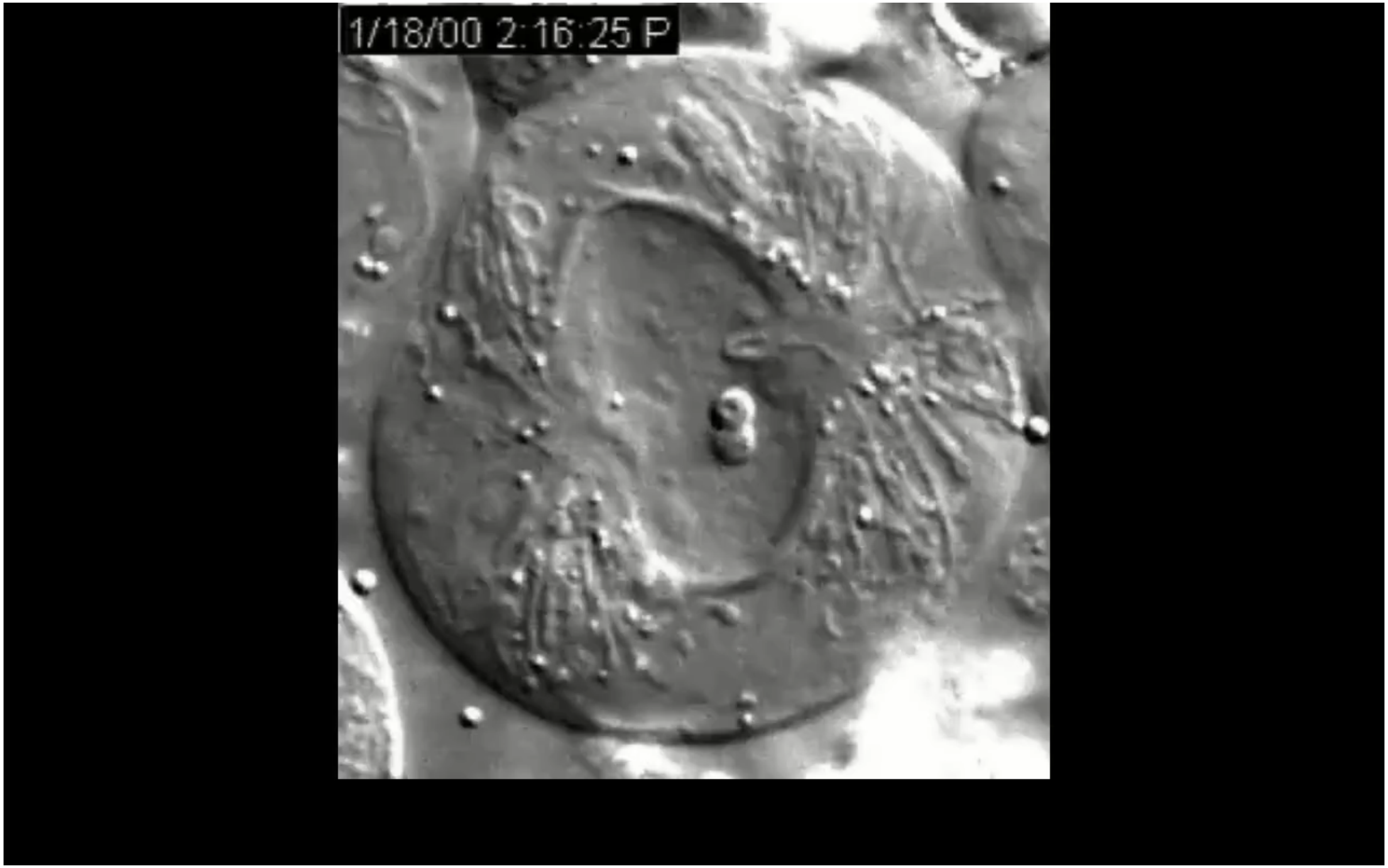
Figure 13.8b


MEIOSIS II: Separates sister chromatids
Prophase II
Metaphase II
Anaphase II
Telophase II and Cytokinesis
Sister chromatids separate
Haploid daughter cells forming

BioFlix® Animation: Meiosis



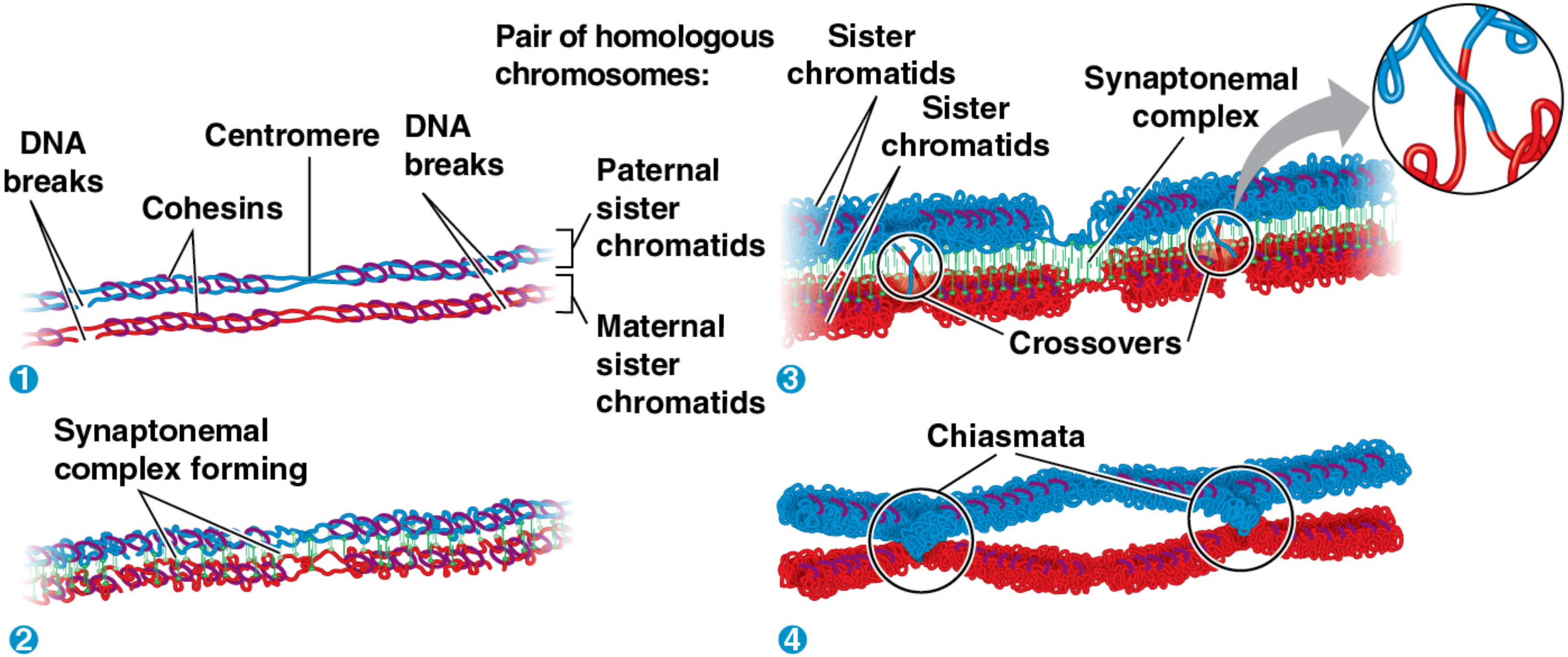
Video: Meiosis I in Sperm Formation



Crossing Over and Synapsis During Prophase I

- After interphase, the sister chromatids are held together by proteins called cohesins
- The nonsister chromatids are broken at precisely matching points
- A zipper-like structure called the **synaptonemal complex** holds the homologs together tightly
- During **synapsis**, DNA breaks are repaired, joining DNA from one nonsister chromatid to the corresponding segment of another

Figure 13.9



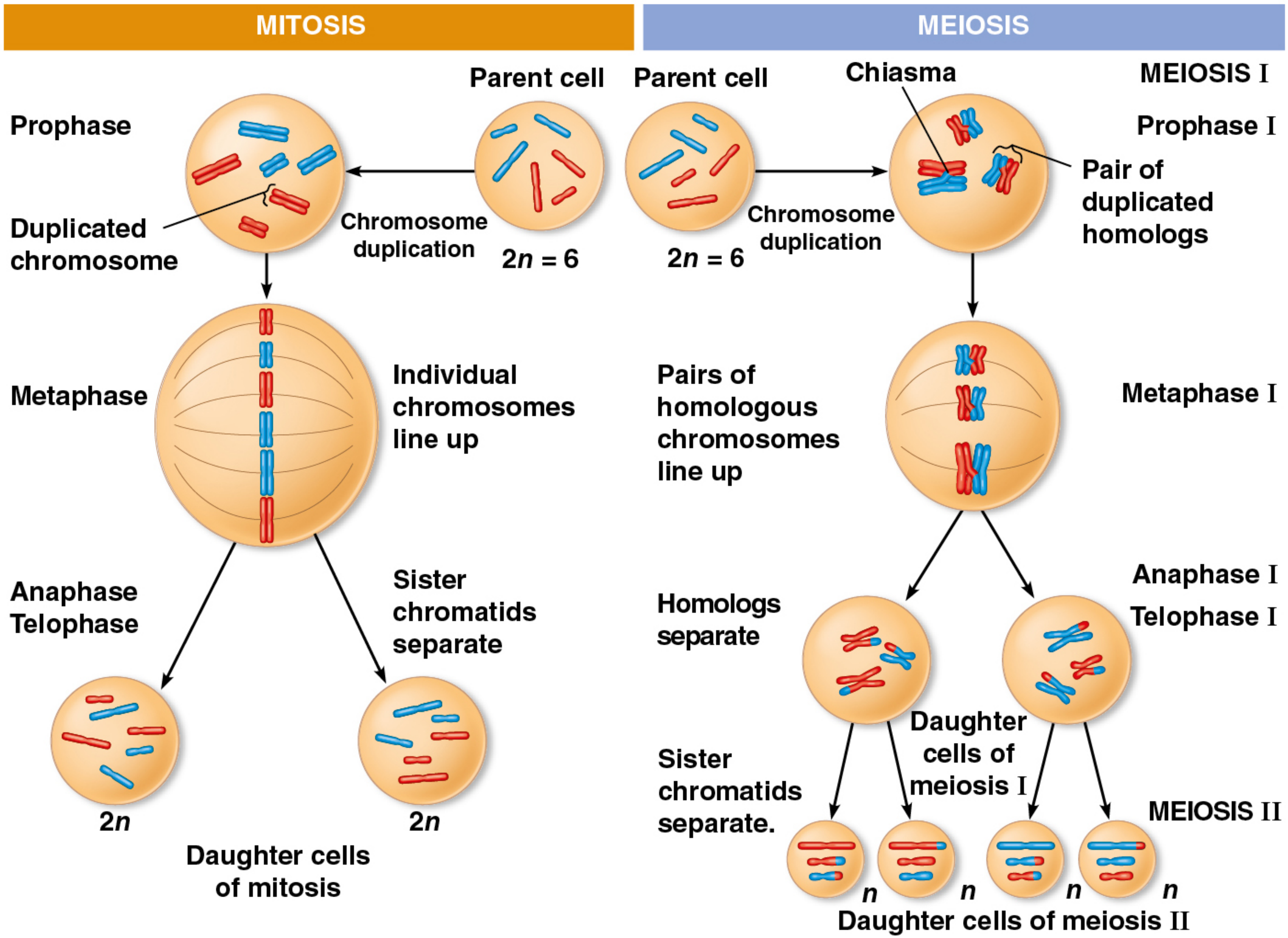
Pair of homologous chromosomes:
DNA breaks
Centromere
DNA breaks
Cohesins
Paternal sister chromatids
Maternal sister chromatids
1
Synaptonemal complex forming
2
Sister chromatids
Sister chromatids
Synaptonemal complex
Crossovers
3
Chiasmata
4

A Comparison of Mitosis and Meiosis

- Mitosis conserves the number of chromosome sets, producing two cells that are genetically identical to the parent cell
- Meiosis reduces the number of chromosomes sets from two (diploid) to one (haploid), producing four cells that differ genetically from each other and from the parent cell

- Three events are unique to meiosis, and all three occur in meiosis I
  - 1. **Synapsis and crossing over** in prophase I: Homologous chromosomes physically connect and exchange genetic information
  - 2. **Alignment of homologous pairs at the metaphase plate**
  - 3. **Separation of homologs** during anaphase I

Figure 13.10



MITOSIS
MEIOSIS
Parent cell
Parent cell
Chiasma
MEIOSIS I
Prophase
Prophase I
Pair of duplicated homologs
Duplicated chromosome
Chromosome duplication
2n = 6
2n = 6
Chromosome duplication
Metaphase
Individual chromosomes line up
Pairs of homologous chromosomes line up
Metaphase I
Anaphase Telophase
Sister chromatids separate
Homologs separate
Anaphase I
Telophase I
Daughter cells of meiosis I
Sister chromatids separate.
MEIOSIS II
2n
2n
Daughter cells of mitosis
n
n
n
n
Daughter cells of meiosis II

- Sister chromatid cohesion allows sister chromatids to stay together through meiosis I
- 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)

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

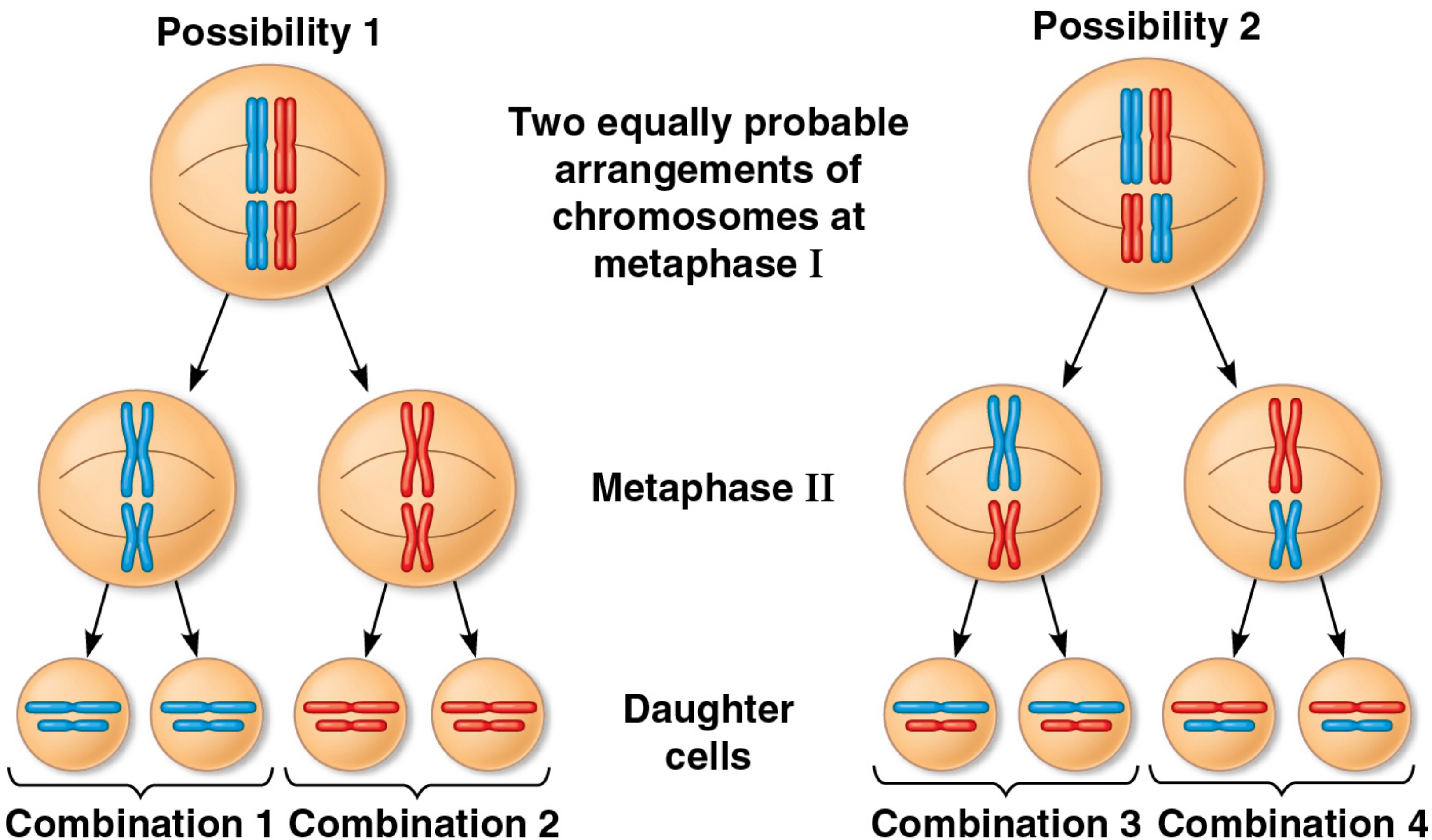
- The behavior of chromosomes during meiosis and fertilization is responsible for most of the variation that arises in each generation
- Three mechanisms contribute to genetic variation:
  - Independent assortment of chromosomes
  - Crossing over
  - Random fertilization

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 homologs into daughter cells independently of the other pairs

- 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

Figure 13.11

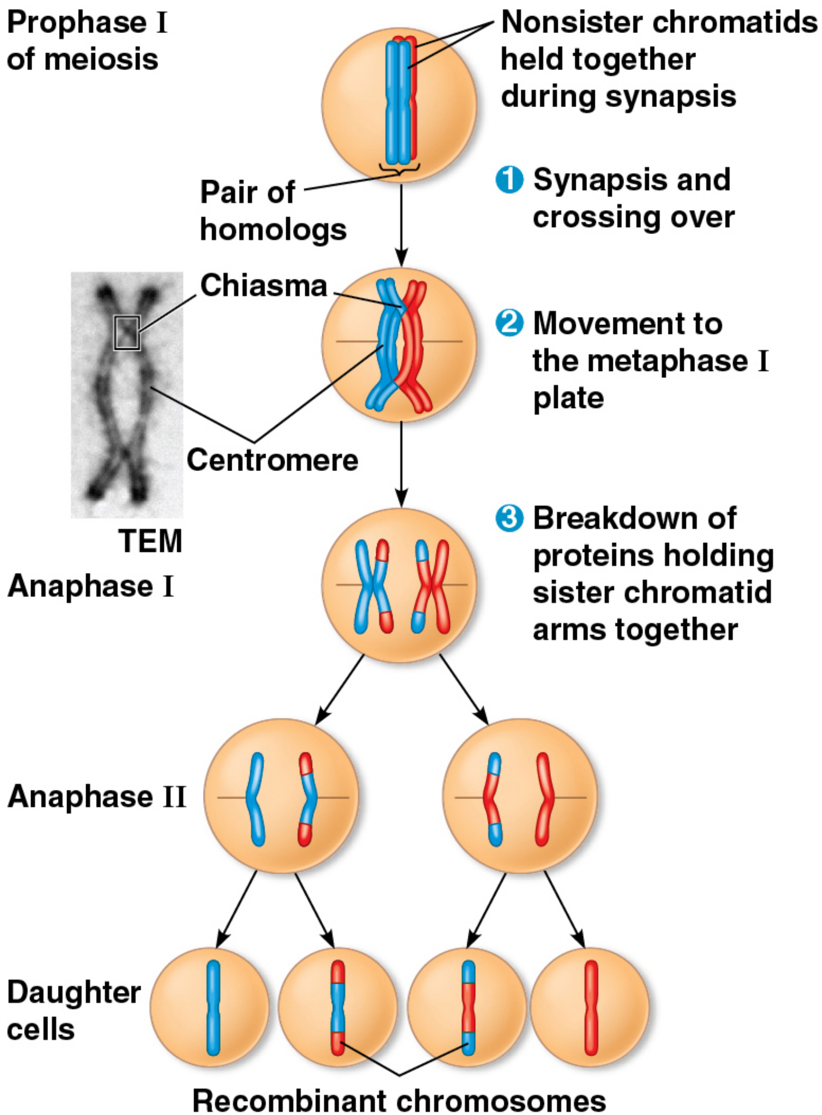


Possibility 1
Possibility 2
Two equally probable arrangements of chromosomes at metaphase I
Metaphase II
Daughter cells
Combination 1
Combination 2
Combination 3
Combination 4

Crossing Over

- Crossing over produces **recombinant chromosomes**, which combine DNA inherited from each parent
- Crossing over contributes to genetic variation by combining DNA from two parents into a single chromosome
- In humans, an average of one to three crossover events occur per chromosome

Figure 13.12



Prophase I of meiosis
Nonsister chromatids held together during synapsis
Pair of homologs
1 Synapsis and crossing over
Chiasma
Centromere
TEM
2 Movement to the metaphase I plate
Anaphase I
3 Breakdown of proteins holding sister chromatid arms together
Anaphase II
Daughter cells
Recombinant chromosomes

Animation: Genetic Variation from Independent Assortment of Chromosomes

[redacted]

Animation: Genetic Variation from Crossing Over

[redacted]

Random Fertilization

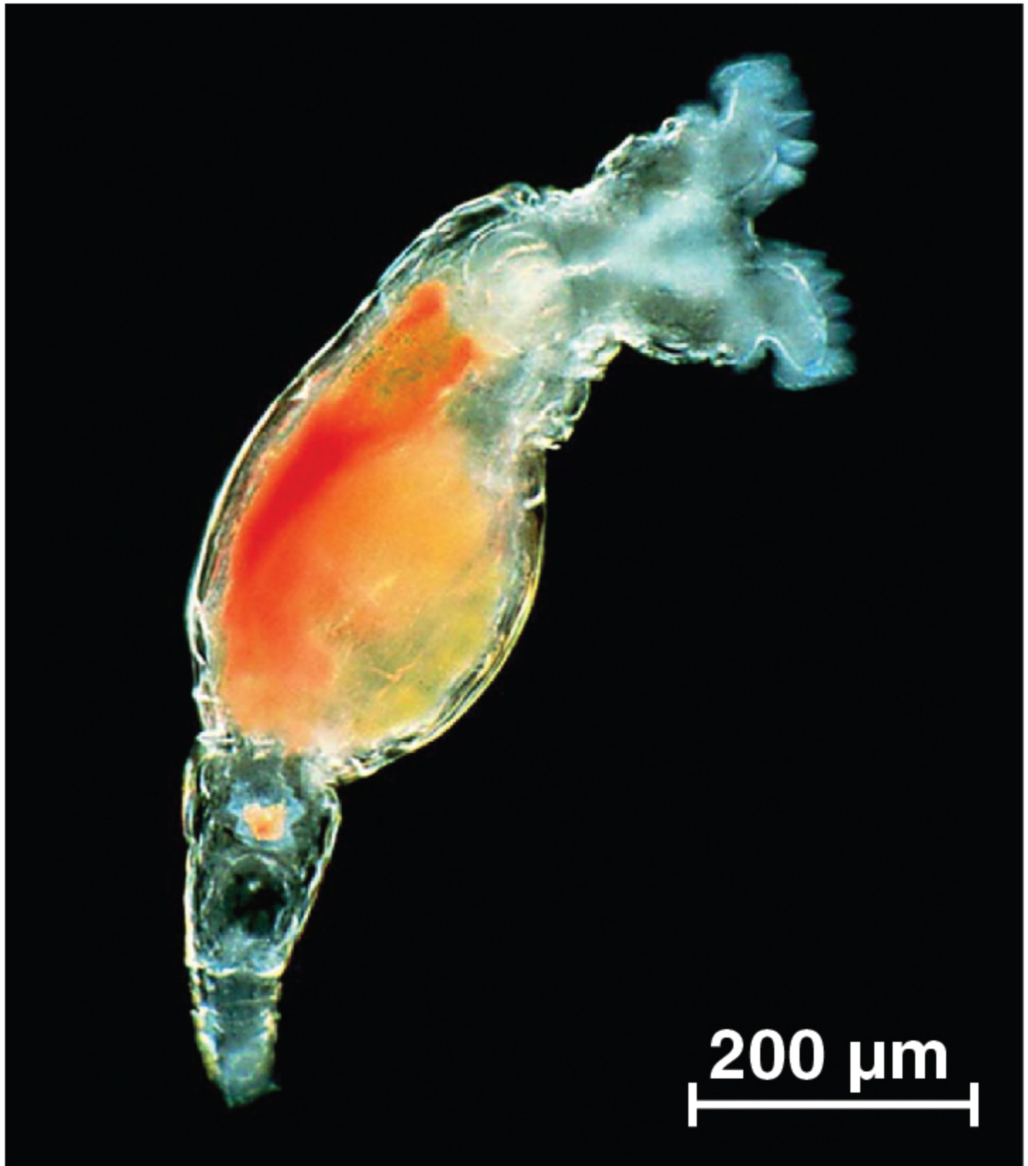
- Random fertilization adds to genetic variation because any sperm can fuse with any ovum (unfertilized egg)
- The fusion of two gametes (each with 8.4 million possible chromosome combinations from independent assortment) produces a zygote with any of about 70 trillion diploid combinations

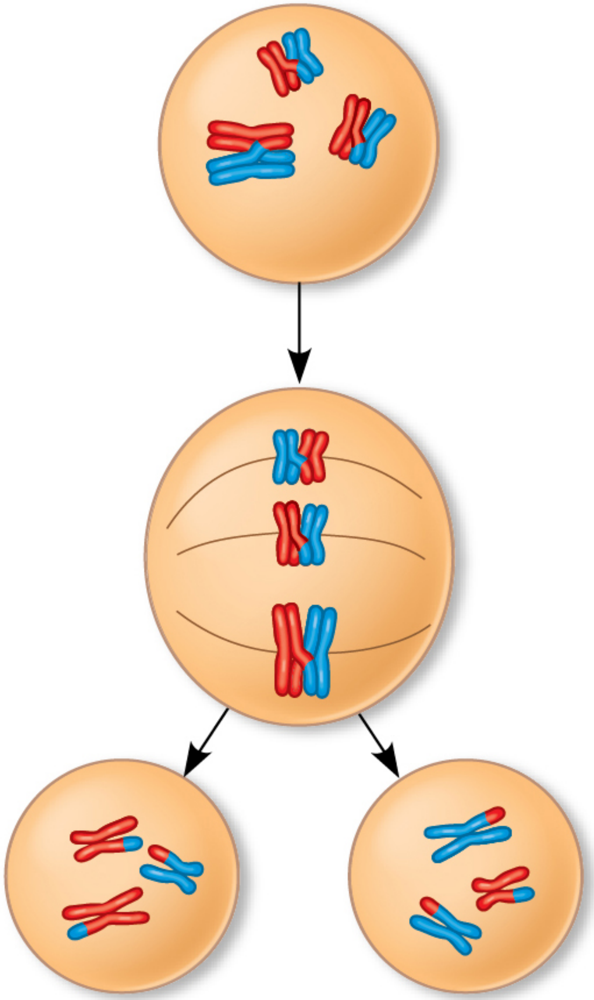
- Crossing over adds even more variation
- Each zygote has a unique genetic identity

The Evolutionary Significance of Genetic Variation Within Populations

- Natural selection results in the accumulation of genetic variations favored by the environment
- Mutations are the original source of different alleles
- These are mixed and matched during meiosis
- Sexual reproduction is almost universal among animals
- Asexually reproducing organisms like the bdelloid rotifer increase genetic diversity by incorporating foreign DNA from the environment

Figure 13.13





Prophase I: Each pair of homologous chromosomes undergoes synapsis and crossing over between nonsister chromatids with the subsequent appearance of chiasmata.

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.

Figure 13-eco-02

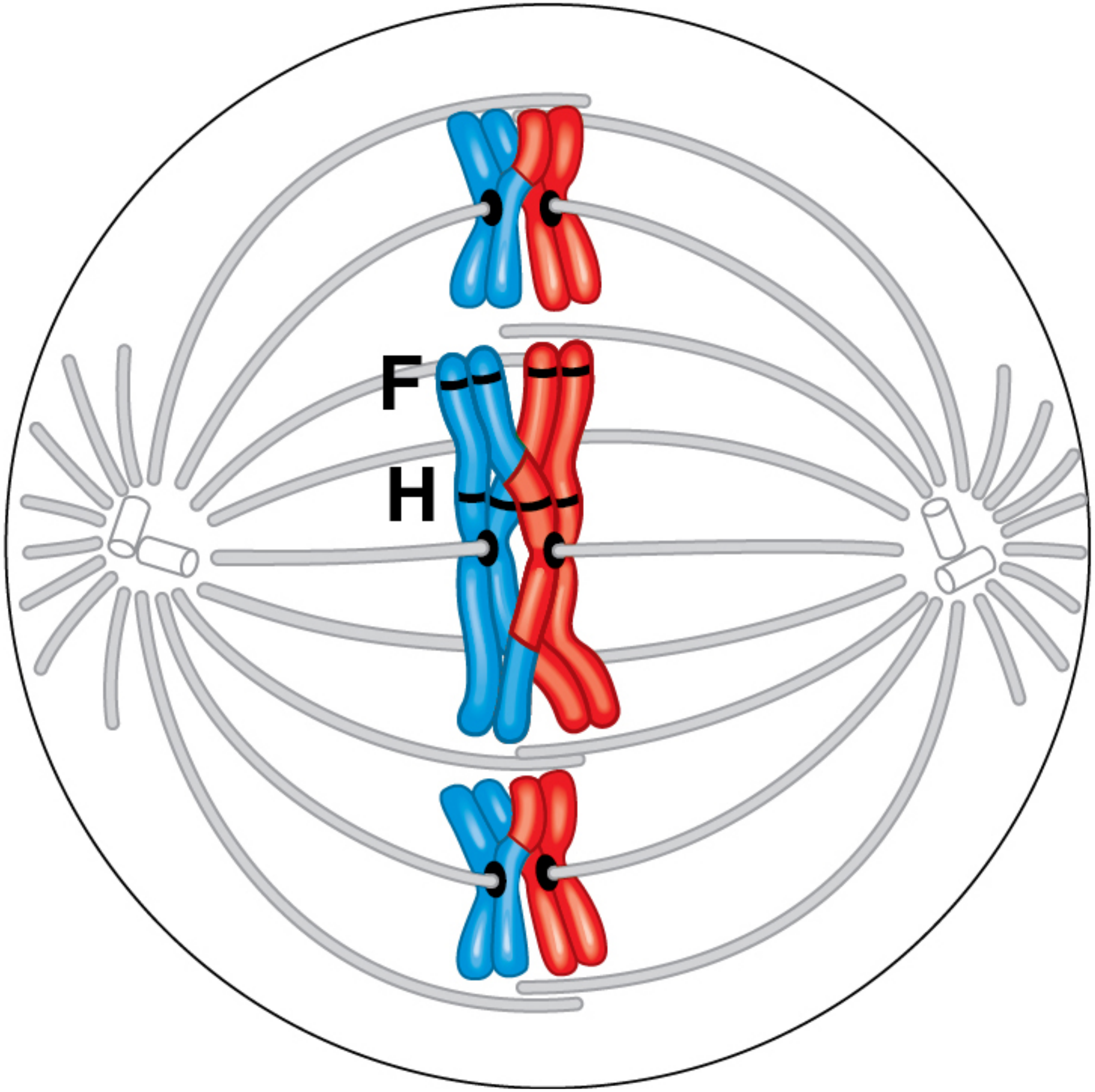


Figure 13-eco-03