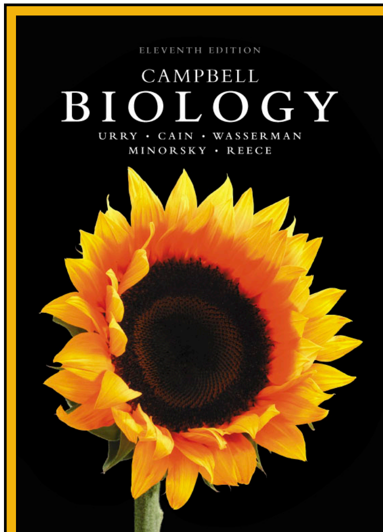

Chapter 13

Meiosis and Sexual Life Cycles

Lecture Presentations by
Nicole Tunbridge and
Kathleen Fitzpatrick

1

Privet shrubs and humans each have a diploid number of 46 chromosomes per cell. Why are the two species so dissimilar?

a) Privet chromosomes undergo only mitosis.
b) Privet chromosomes are shaped differently.
c) Human chromosomes have genes grouped together differently.
d) The two species have appreciably different genes.
e) Privets do not have sex chromosomes.

2

Variations on a Theme

- Offspring resemble their parents more than they do unrelated individuals
- **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
- **Genetics** is the scientific study of heredity and variation

3

Figure 13.1 What Accounts for Family Resemblance?

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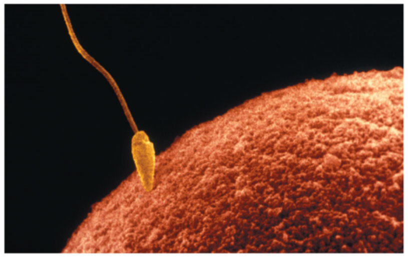
Figure 13.1a What Accounts for Family Resemblance? (Part 1: Fertilization)



A sperm fertilizing an egg

5

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

6

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**

7

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 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

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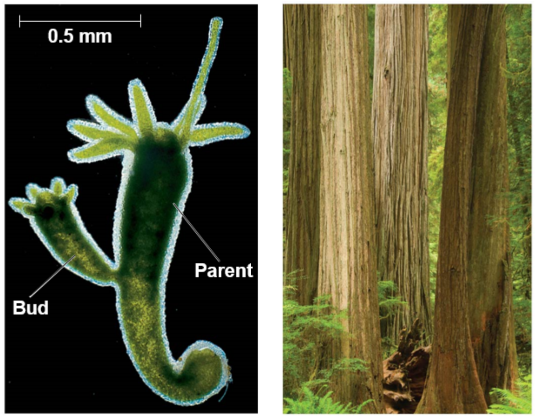
Figure 13.2 Asexual Reproduction in Two Multicellular Organisms



a) Hydra b) Redwoods

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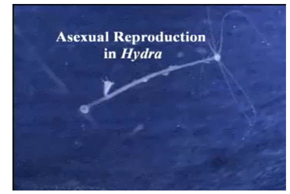
Video: Hydra Budding



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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

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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 are the same length and shape and carry genes controlling the same inherited characters

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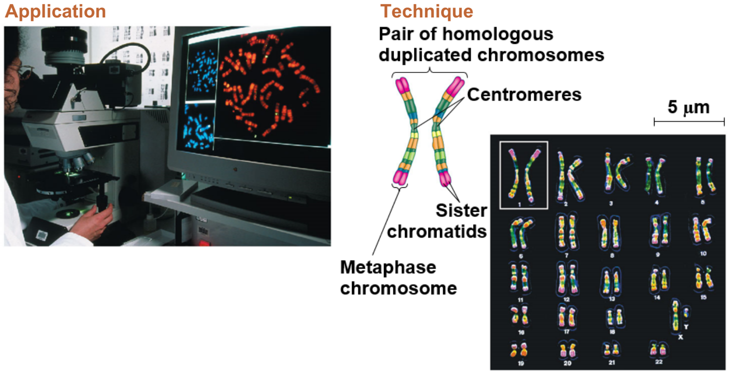
Figure 13.3 Research Method: Preparing a Karyotype



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Sets of Chromosomes in Human Cells, Continued

- 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**

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Sets of Chromosomes in Human Cells, Continued-1

- 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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Sets of Chromosomes in Human Cells, Continued-2

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

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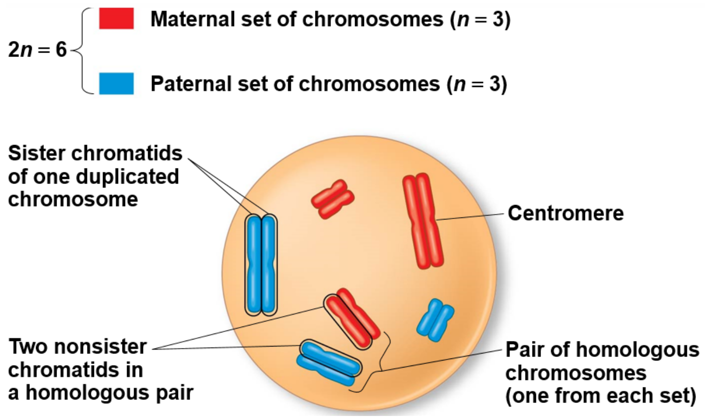
Figure 13.4 Describing Chromosomes



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Sets of Chromosomes in Human Cells, Continued-3

- 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

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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

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Behavior of Chromosome Sets in the Human Life Cycle, Continued

- 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

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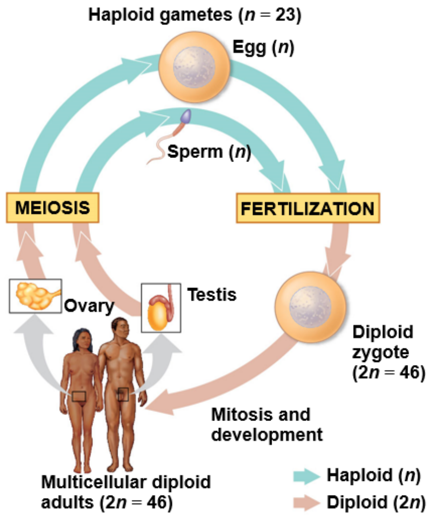
Figure 13.5 The Human Life Cycle



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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

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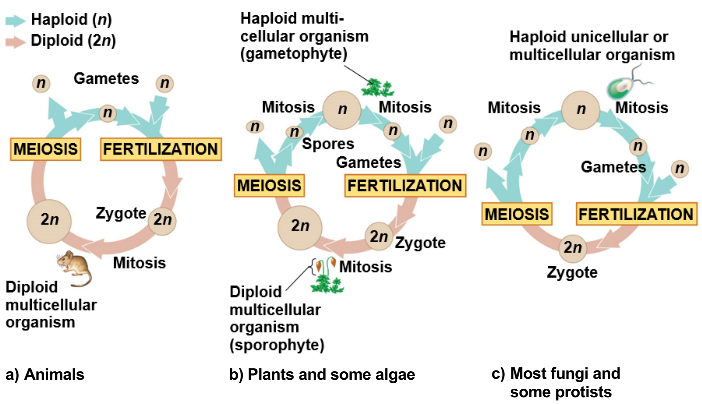
Figure 13.6 Three Types of Sexual Life Cycles



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The Variety of Sexual Life Cycles, Continued

- Gametes are the only haploid cells in 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

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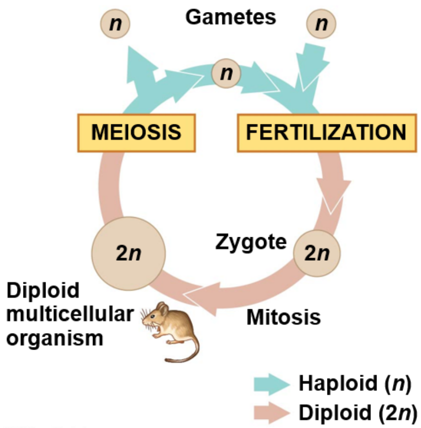
Figure 13.6a Three Types of Sexual Life Cycles (Part 1: Animal)



a) Animals

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The Variety of Sexual Life Cycles, Continued-1

- 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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The Variety of Sexual Life Cycles, Continued-2

- 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

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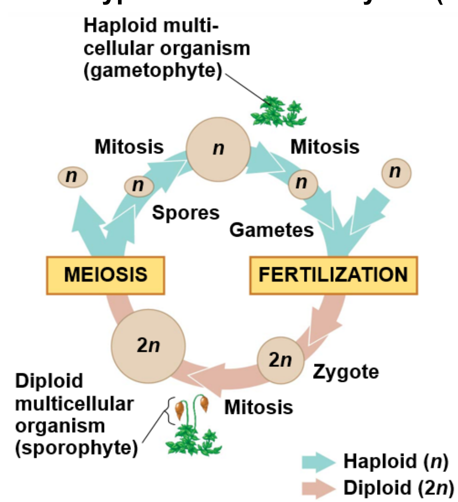
Figure 13.6b Three Types of Sexual Life Cycles (Part 2: Plant)



b) Plants and some algae

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The Variety of Sexual Life Cycles, Continued-3

- 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

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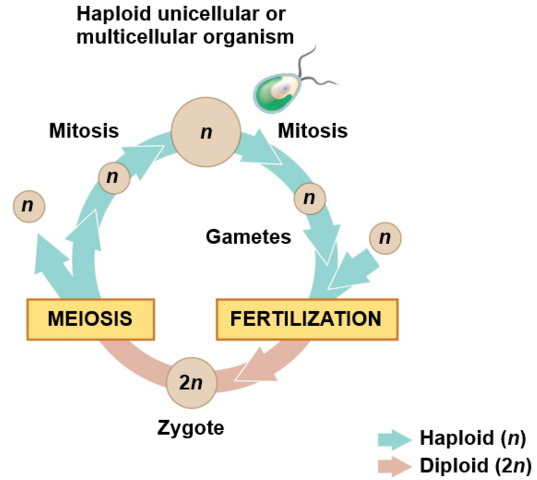
Figure 13.6c Three Types of Sexual Life Cycles (Part 3: Fungi)



c) Most fungi and some protists

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The Variety of Sexual Life Cycles, Continued-4

- 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

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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

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Normal gametes produced from one meiotic event

a) are genetically identical to each other.
b) each have the same chromosome number.
c) are genetically identical to the cells produced from meiosis I.
d) are genetically identical to the parent cell.
e) each have the same mutations.

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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

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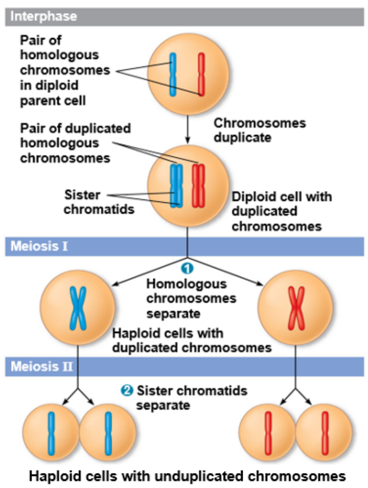
Figure 13.7 Overview of Meiosis: How Meiosis Reduces Chromosome Number



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The Stages of Meiosis, Continued

- Division in meiosis I occurs in four phases:
  - prophase I
  - metaphase I
  - anaphase I
  - telophase I and cytokinesis

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The Stages of Meiosis, Continued-1

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

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The Stages of Meiosis, Continued-2

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

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The Stages of Meiosis, Continued-3

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

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The Stages of Meiosis, Continued-4

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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The Stages of Meiosis, Continued-5

- 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

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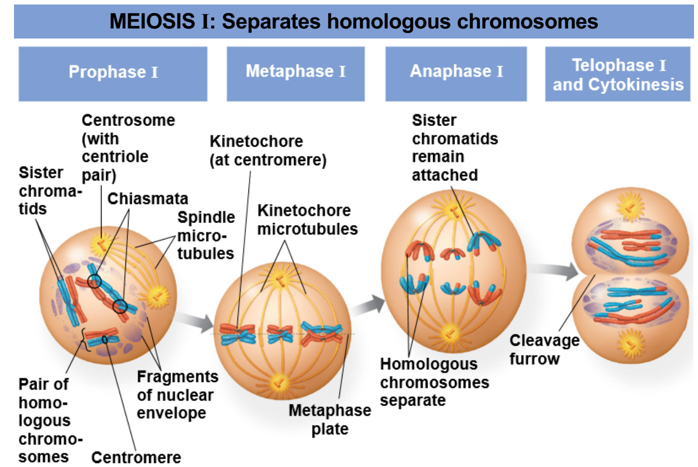
Figure 13.8a Exploring Meiosis in an Animal Cell (Part 1: Meiosis I)



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BioFlix: Meiosis

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Video: Meiosis I in Sperm Formation

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The Stages of Meiosis, Continued-6

- 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

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The Stages of Meiosis, Cointinued-7

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

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The Stages of Meiosis, Continued-8

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

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The Stages of Meiosis, Continued-9

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

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The Stages of Meiosis, Continued-10

Telophase II and Cytokinesis

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

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The Stages of Meiosis, Continued-11

- 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

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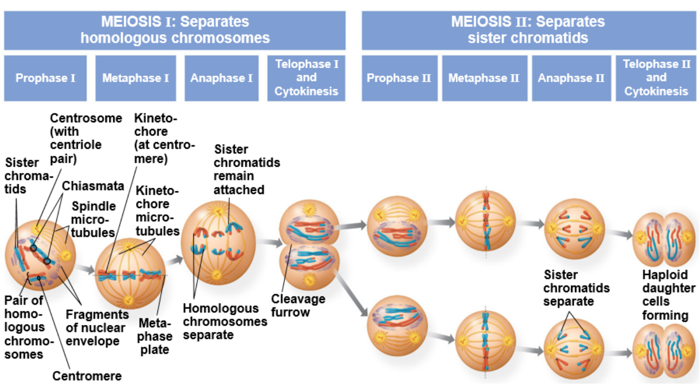
Figure 13.8 Exploring Meiosis in an Animal Cell



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BioFlix Animation: Meiosis

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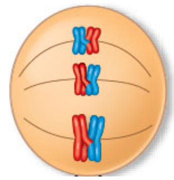
In this cell, what phase is represented?

a) mitotic metaphase
b) meiosis I anaphase
c) meiosis I metaphase
d) meiosis II anaphase
e) meiosis II metaphase



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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 corresponding positions
- 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

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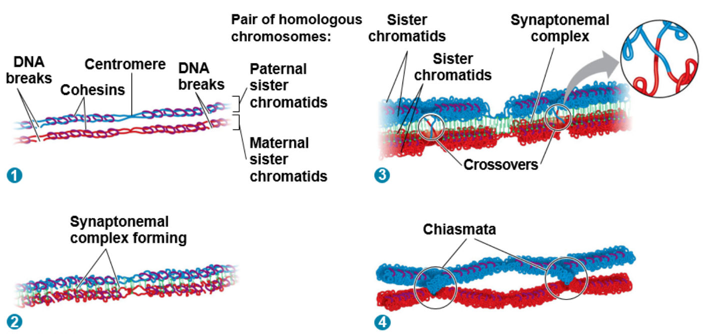
Figure 13.9 Crossing Over and Synapsis in Prophase I: A Closer Look



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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 chromosomes sets from two (diploid) to one (haploid), producing cells that differ genetically from each other and from the parent cell

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A Comparison of Mitosis and Meiosis, Continued

- 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
  - Homologous pairs at the metaphase plate
  - Separation of homologs during anaphase I

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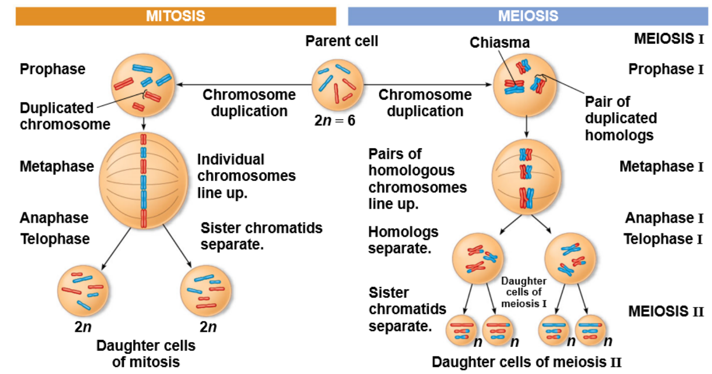
Figure 13.10a A Comparison of Mitosis and Meiosis (Part 1: Mitosis vs. Meiosis Art)



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A Comparison of Mitosis and Meiosis (Part 2: Mitosis vs. Meiosis Table), Continued

SUMMARY

Property	Mitosis (occurs in both diploid and haploid cells)	Meiosis (can only occur in diploid cells)
DNA replication	Occurs during interphase before mitosis begins	Occurs during interphase before meiosis I but not meiosis II
Number of divisions	One, including prophase, prometaphase, metaphase, anaphase, 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 genetically identical to the parent cell, with the same number of chromosomes	Four, each haploid (*n*); genetically different from the parent cell and from each other
Role in animals, fungi, and plants	Enables multicellular animal, fungus, or plant (gametophyte or sporophyte) to arise from a single cell; produces cells for growth, repair, and, in some species, asexual reproduction; produces gametes in the plant gametophyte	Produces gametes (in animals) or spores (in fungi and in plant sporophytes); reduces number of chromosome sets by half and introduces genetic variability among the gametes or spores

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A Comparison of Mitosis and Meiosis, Continued-1

- 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)

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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

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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

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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

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Independent Assortment of Chromosomes, Continued

- 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

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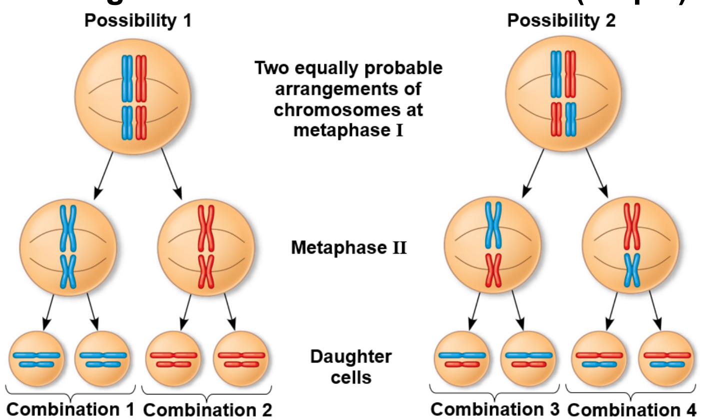
Figure 13.11_3 The Independent Assortment of Homologous Chromosomes in Meiosis (Step 3)



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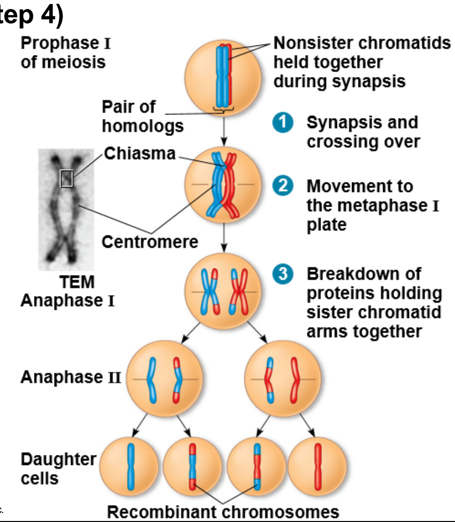
Crossing Over

- 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 occurs per chromosome

66

Figure 13.12_4 The Results of Crossing Over During Meiosis (Step 4)



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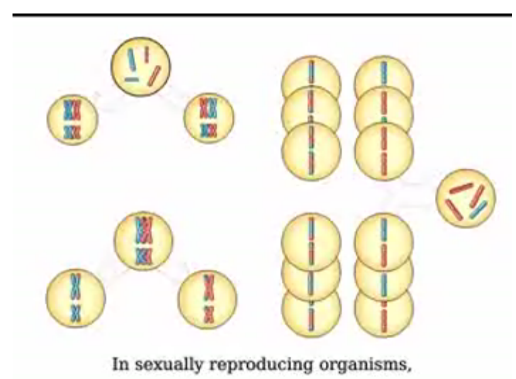
Animation: Genetic Variation



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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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Random Fertilization, Continued

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

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How and at what stage is independent assortment accomplished?

a) pairing of homologs during meiosis I
b) separation of homologs during anaphase II
c) separation of homologs during meiosis II
d) metaphase alignment during meiosis I
e) telophase separation during meiosis I

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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
- Animals that always reproduce asexually are quite rare
- Organisms like the bdelloid rotifer increase their genetic diversity through incorporation of foreign DNA from the environment

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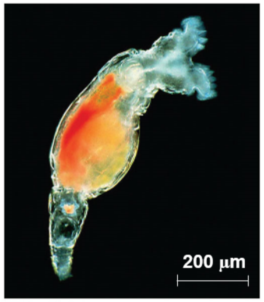
Figure 13.13 A Bdelloid Rotifer, an Animal that Reproduces Only Asexually



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