UNIT 3

Genetics

Chapter 13

Meiosis and Sexual Life Cycles

Key Concepts

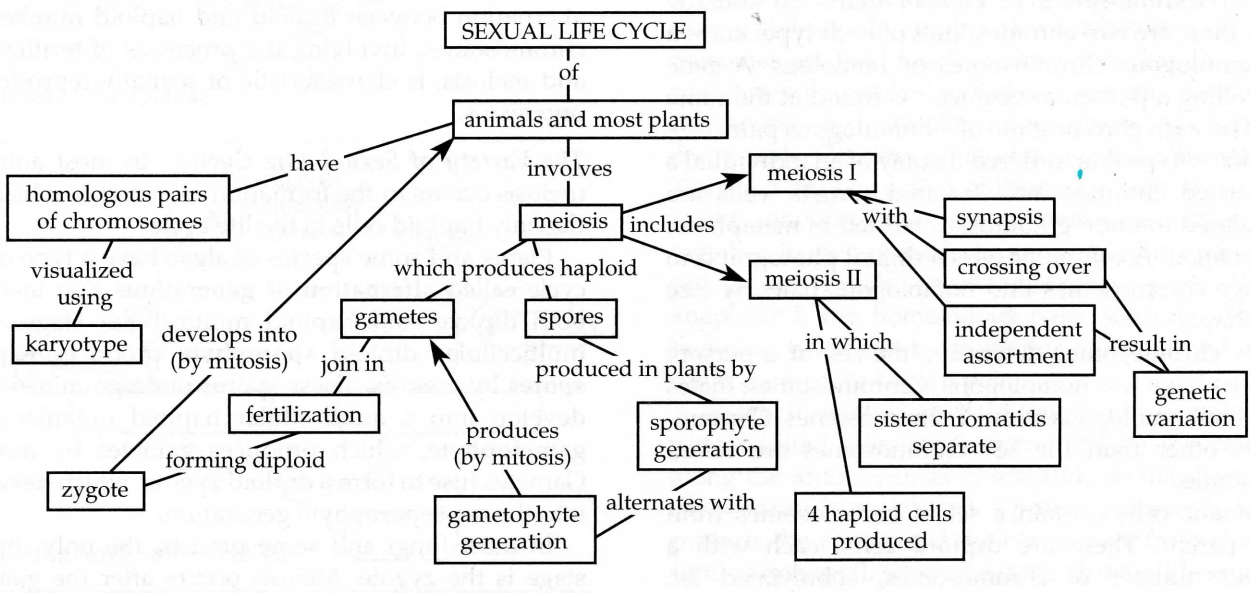
13.1 Offspring acquire genes from parents by inheriting chromosomes

13.2 Fertilization and meiosis alternate in sexual life cycles

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

13.4 Genetic variation produced in sexual cycles contributes to evolution

Framework



Chapter Review

Genetics is the scientific study of the transmission of traits from parents to offspring **(heredity)** and the **variation** between and within generations.

13.1 Offspring acquire genes from parents by inheriting chromosomes

Inheritance of Genes The inheritance of traits from parents to offspring involves the transmission of discrete units of information coded in segments of DNA known as **genes.** Most genes contain instructions for synthesizing enzymes and other proteins that then guide the development of inherited traits.

Precise copies of an organism's genes are packaged into **gametes** (sperm and eggs). Upon fertilization, genes from both parents are passed on to offspring. The DNA of a eukaryotic cell is packaged along with various proteins into a species-specific number of chromosomes. The entire complement of DNA is called the genome. A gene's **locus** is its location on a chromosome.

Comparison of Asexual and Sexual Reproduction In **asexual reproduction,** a single parent passes copies of all its genes to its offspring. A **clone** is a group of genetically identical offspring. In **sexual reproduction,** an individual receives a unique combination of genes inherited from two parents.

13.2 Fertilization and meiosis alternate in sexual life cycles

An organism's **life cycle** is the sequence of stages from conception to production of its own offspring.

Sets of Chromosomes in Human Cells In **somatic cells,** there are two chromosomes of each type, known as **homologous chromosomes** or homologs. A gene controlling a particular character is found at the same locus on each chromosome of a homologous pair.

A **karyotype** is an ordered display of an individual's condensed chromosomes. Isolated somatic cells are stimulated to undergo mitosis, arrested in metaphase, and stained. A computer uses a digital photograph to arrange chromosomes into homologous pairs by size and shape.

Sex chromosomes determine the sex of a person: Females have two homologous X chromosomes; males have nonhomologous X and Y chromosomes. Chromosomes other than the sex chromosomes are called **autosomes.**

Somatic cells contain a set of chromosomes from each parent. These are **diploid cells,** each with a diploid number of chromosomes, abbreviated $2n$. Gametes, egg and sperm, are **haploid cells** and contain a single set of chromosomes. The haploid number (n) of chromosomes for humans is 23.

INTERACTIVE QUESTION 13.1

a. If $2n = 14$, how many chromosomes will be present in the somatic cells of an animal? __________
How many chromosomes will be found in gametes? __________

b. If $n = 14$, how many chromosomes will be found in diploid somatic cells?__________
How many sets of homologous chromosomes will be found in gametes? __________

c. If $2n = 28$, how many chromatids will be found in a cell in which DNA synthesis has occurred prior to cell division? __________ What is the difference between sister and nonsister chromatids?

Behavior of Chromosome Sets in the Human Life Cycle **Fertilization,** or fusion of sperm and ovum (egg), produces a **zygote** containing both paternal and maternal sets of chromosomes. The diploid zygote then divides by mitosis to produce the somatic cells of the body, all of which contain the diploid number ($2n$) of chromosomes.

Meiosis is a special type of cell division that halves the chromosome number and provides a haploid set of chromosomes to each gamete. Gametes are produced by meiosis from specialized *germ cells* in the gonads. An alternation between diploid and haploid numbers of chromosomes, involving the processes of fertilization and meiosis, is characteristic of sexually reproducing organisms.

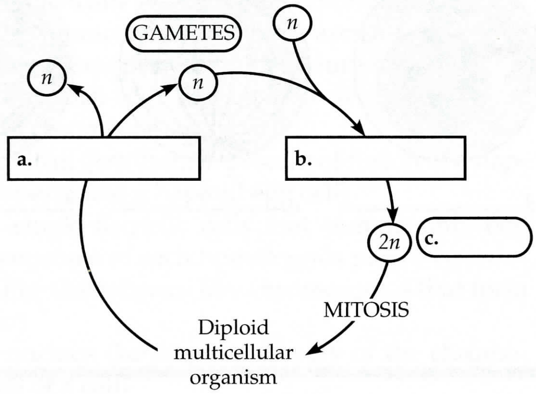
The Variety of Sexual Life Cycles In most animals, meiosis occurs in the formation of gametes, which are the only haploid cells in the life cycle.

Plants and some species of algae have a type of life cycle called **alternation of generations** that includes both diploid and haploid multicellular stages. The multicellular diploid **sporophyte** produces haploid **spores** by meiosis. These spores undergo mitosis and develop into a multicellular haploid organism, the **gametophyte,** which produces gametes by mitosis. Gametes fuse to form a diploid zygote, which develops into the next sporophyte generation.

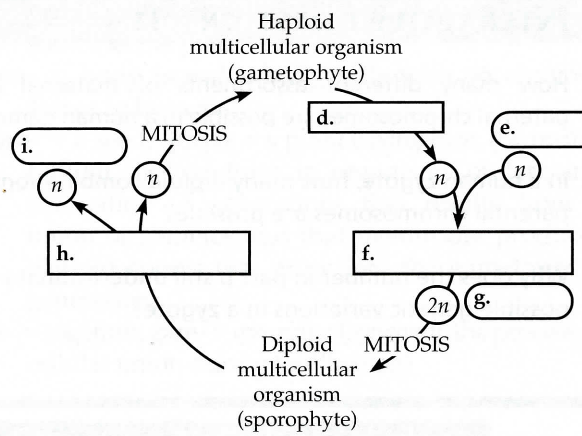
In most fungi and some protists, the only diploid stage is the zygote. Meiosis occurs after the gametes fuse, producing haploid cells that divide by mitosis to create a unicellular or multicellular haploid organism. Gametes are produced by mitosis in these organisms.

INTERACTIVE QUESTION 13.2

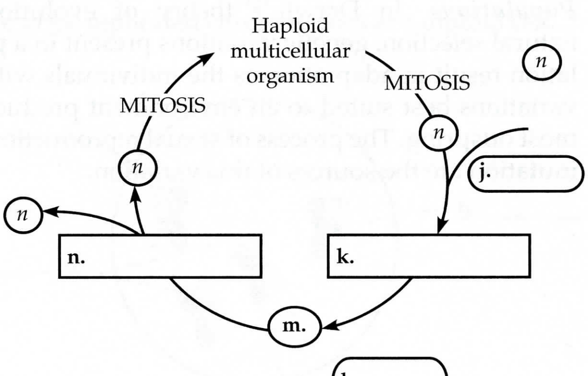
Complete these three diagrams of sexual life cycles by filling in the type of cell division, the type of cells, and the ploidy (*n* or 2*n*).



Animals



Plants and Some Algae



Most Fungi and Some Protists

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

In meiosis, chromosome replication is followed by two consecutive cell divisions: **meiosis I** and **meiosis II,** producing four haploid daughter cells, each with one set of chromosomes.

The Stages of Meiosis In **interphase,** each chromosome replicates, producing two genetically identical sister chromatids that remain attached at the centromere and along their length (called *sister chromatid cohesion*). During prophase I, homologous chromosomes synapse. Crossing over may occur between nonsister chromatids, forming chiasmata.

In metaphase I, homologous pairs line up on the metaphase plate with their kinetochores attached to spindle fibers from opposite poles. Each pair separates in anaphase I, with one homolog moving toward each pole. In telophase I, a haploid set of chromosomes, each composed of two sister chromatids, reaches each pole. Cytokinesis usually occurs during telophase I. There is no replication of genetic material prior to the second division of meiosis.

Meiosis II looks like a regular mitotic division, in which chromosomes line up individually on the metaphase plate, and sister chromatids separate and move apart in anaphase II. These sister chromatids, however, are not genetically identical due to crossing over in prophase I. At the end of telophase II, there are four haploid daughter cells.

A Comparison of Mitosis and Meiosis Mitosis produces daughter cells that are genetically identical to the parent cell. Meiosis produces haploid cells that differ genetically from their parent cell and from each other.

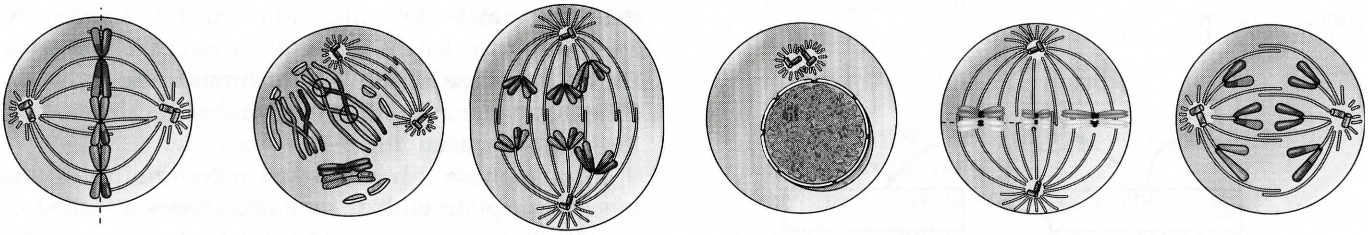
The three unique events that produce this result occur during meiosis I: In prophase I, when homologous chromosomes are held together along their lengths by the *synaptonemal complex* (**synapsis**), genetic material is rearranged by **crossing over** between nonsister chromatids. Crossovers are visible later in this stage as X-shaped regions called **chiasmata** where sister chromatid cohesion holds the original sister chromatids together. In metaphase I, chromosomes line up in pairs, not as individuals, on the metaphase plate. During anaphase I, the homologous pairs separate and one homolog (with sister chromatids still attached at the centromere) goes to each pole.

Sister chromatids are held together by protein complexes called *cohesins*. Enzymes cleave the cohesins along the arms of sister chromatids so that homologs can separate in anaphase I. A protein named shugoshin protects the cohesins at the centromere from cleavage until anaphase II, when the sister chromatids separate.

Meiosis I is called a *reductional division* because it reduces the chromosome sets from two (diploid) to one (haploid). The sister chromatids of each homolog do not separate until meiosis II, sometimes called the *equational division.*

INTERACTIVE QUESTION 13.3

The following diagrams represent some of the stages of meiosis (not in the right order). Label these stages.



a.__________ b.__________ c.__________ d.__________ e.__________ f.__________

Now place these stages in the proper sequence.

_____ _____ _____ _____ _____ _____

13.4 Genetic variation produced in sexual life cycles contributes to evolution

Origins of Genetic Variation Among Offspring Mutations that result in different alleles are the original source of genetic variation. The three mechanisms that generate genetic variation in sexual reproduction are independent assortment of chromosomes, crossing over, and random fertilization.

Each homologous pair lines up independently at the metaphase plate—the orientation of the maternal and paternal chromosomes is random. The number of possible combinations of maternal and paternal chromosomes in gametes is 2^n, where n is the haploid number.

In prophase I, homologous segments of nonsister chromatids are exchanged by crossing over, forming **recombinant chromosomes** with new genetic combinations of maternal and paternal genes on the same chromosome. These no-longer-equivalent sister chromatids assort independently during meiosis II.

The random nature of fertilization adds to the genetic variability established in meiosis.

INTERACTIVE QUESTION 13.4

a. How many different assortments of maternal and paternal chromosomes are possible in a human gamete?

b. In a human zygote, how many diploid combinations of parental chromosomes are possible?

c. Why does the number in part b still underestimate the possible genetic variations in a zygote?

Evolutionary Significance of Genetic Variation within Populations In Darwin's theory of evolution by natural selection, genetic variations present in a population result in adaptation as the individuals with the variations best suited to an environment produce the most offspring. The process of sexual reproduction and mutation are the sources of this variation.

Word Roots

a- = not or without (*asexual:* type of reproduction not involving fertilization)

-apsis = juncture (*synapsis:* the pairing of replicated homologous chromosomes during prophase I of meiosis)

auto- = self (*autosome:* the chromosomes that do not determine gender)

chiasm- = marked crosswise (*chiasma:* the X-shaped microscopically visible region representing homologous chromosomes that have exchanged genetic material through crossing over during meiosis)

di- = two (*diploid:* cells that contain two homologous sets of chromosomes)

fertil- = fruitful (*fertilization:* process of fusion of a haploid sperm and a haploid egg cell)

haplo- = single (*haploid:* cells that contain only one chromosome of each homologous pair)

homo- = like (*homologous:* like chromosomes that form a pair)

karyo- = nucleus (*karyotype:* a display of the chromosomes of a cell)

meio- = less (*meiosis:* a variation of cell division that yields daughter cells with half as many chromosomes as the parent cell)

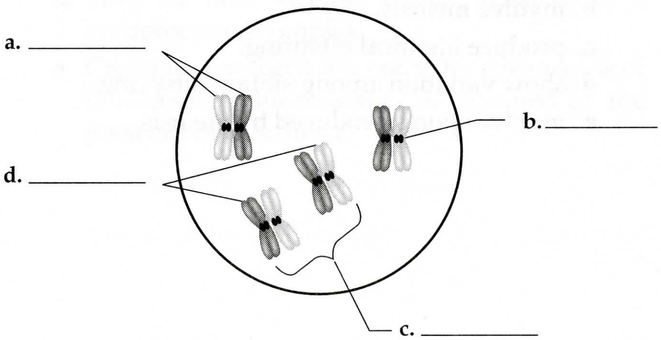
soma- = body (*somatic:* body cells with 46 chromosomes in humans)

sporo- = a seed; **-phyte** = a plant (*sporophyte:* the multicellular diploid form in organisms undergoing alternation of generations that results from a union of gametes and that meiotically produces haploid spores that grow into the gametophyte generation)

syn- = together; **gam-** = marriage (*syngamy:* the process of cellular union during fertilization)

Structure Your Knowledge

1. Label the following diagram to review the terms that describe replicated chromosomes in a diploid cell.



2. Describe the key events of these stages of meiosis.

a. Interphase
b. Prophase I
c. Metaphase I
d. Anaphase I
e. Metaphase II
f. Anaphase II

3. Create a concept map to help you organize your understanding of the similarities and differences between mitosis and meiosis. *Compare your map with those of some classmates to see different ways of organizing the material.*

Test Your Knowledge

MULTIPLE CHOICE: *Choose the one best answer.*

1. What is a karyotype?
   a. a genotype of an individual
   b. a pictorial display of an individual's chromosomes
   c. a blood type determination of an individual
   d. a unique combination of chromosomes found in a gamete
   e. a species-specific diploid number of chromosomes

2. A synaptonemal complex would be found during
   a. prophase of mitosis.
   b. fertilization or syngamy of gametes.
   c. metaphase II of meiosis.
   d. prophase of meiosis I.
   e. anaphase I of meiosis.

3. What are autosomes?
   a. sex chromosomes
   b. chromosomes that occur singly
   c. chromosomal abnormalities that result in genetic defects
   d. chromosomes found in mitochondria and chloroplasts
   e. none of the above

Word Roots

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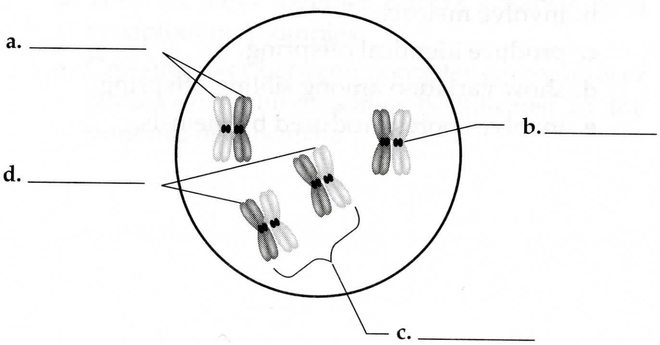

2. Describe the key events of these stages of meiosis.

a. Interphase	
b. Prophase I	
c. Metaphase I	
d. Anaphase I	
e. Metaphase II	
f. Anaphase II	

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e. none of the above

4. Which of the following statements is *not* true?
   a. The restoration of the diploid chromosome number after halving in meiosis is due to fertilization.
   b. Sister chromatid cohesion at areas where crossing over has occurred holds homologous chromosomes together until anaphase I.
   c. Recombinant chromosomes are produced when both maternal and paternal chromosomes independently assort into the same gamete.
   d. In mitosis, separation of sister chromatids in anaphase results in two identical cells.
   e. Separation of sister chromatids in anaphase II does not usually result in two identical cells.

5. During the first meiotic division (meiosis I),
   a. homologous chromosomes separate.
   b. the chromosome number is reduced in half.
   c. crossing over between nonsister chromatids occurs.
   d. paternal and maternal chromosomes assort randomly.
   e. all of the above occur.

6. A cell with a diploid number of 6 could produce gametes with how many different combinations of maternal and paternal chromosomes?
   a. 6 c. 12 e. 128
   b. 8 d. 64

7. The DNA content of a diploid cell is measured in the G_1 phase. After meiosis I, the DNA content of one of the two cells produced would be
   a. equal to that of the G_1 cell.
   b. twice that of the G_1 cell.
   c. one-half that of the G_1 cell.
   d. one-fourth that of the G_1 cell.
   e. impossible to estimate due to independent assortment of homologous chromosomes.

8. In most fungi and some protists,
   a. the zygote is the only haploid stage.
   b. gametes are formed by meiosis.
   c. the multicellular organism is haploid.
   d. the gametophyte generation produces gametes by mitosis.
   e. reproduction is exclusively asexual.

9. In the alternation of generations found in plants,
   a. the sporophyte generation produces spores by mitosis.
   b. the gametophyte generation produces gametes by mitosis.
   c. the zygote will develop into a sporophyte generation by meiosis.
   d. spores develop into the haploid sporophyte generation.
   e. the gametophyte generation produces spores by meiosis.

10. Which of the following is least likely to be a source of genetic variation in sexually reproducing organisms?
    a. crossing over
    b. replication of DNA during S phase before meiosis I
    c. independent assortment of chromosomes
    d. random fertilization of gametes
    e. mutation

11. Meiosis II is similar to mitosis because
    a. sister chromatids separate.
    b. homologous chromosomes separate.
    c. DNA replication precedes the division.
    d. they both take the same amount of time.
    e. haploid cells are almost always produced.

12. Pairs of homologous chromosomes
    a. have identical DNA sequences in their genes.
    b. have genes for the same characters at the same loci.
    c. are found in gametes.
    d. separate in meiosis II.
    e. have all of the above characteristics.

13. Asexual reproduction of a diploid organism would
    a. be impossible.
    b. involve meiosis.
    c. produce identical offspring.
    d. show variation among sibling offspring.
    e. involve spores produced by meiosis.

14. In a sexually reproducing species with a diploid number of 8, how many different diploid combinations of chromosomes would be possible in the *offspring*?

a. 8
b. 16
c. 64
d. 256
e. 512

15. The calculation of offspring in question 14 includes only variation resulting from

a. crossing over.
b. random fertilization.
c. independent assortment of chromosomes.
d. a, b, and c.
e. only b and c.

16. How many *chromatids* are present in metaphase II in a cell undergoing meiosis from an organism in which $2n = 24$?

a. 12
b. 24
c. 36
d. 48
e. 96

17. Which of the following would *not* be considered a haploid cell?

a. daughter cell after meiosis II
b. gamete
c. daughter cell after mitosis in gametophyte generation of a plant
d. cell in prophase I
e. cell in prophase II

18. Which of the following is *not* true of homologous chromosomes?

a. They behave independently in mitosis.
b. They synapse during the S phase of meiosis.
c. They travel together to the metaphase plate in meiosis I.
d. They are held together during synapsis by a synaptonemal complex.
e. Crossing over between nonsister chromatids of homologous chromosomes is indicated by the presence of chiasmata.

19. Which of the following describes why or how recombinant chromosomes add to genetic variability?

a. They are formed as a result of random fertilization when two sets of chromosomes combine in a zygote.
b. They are the result of mutations that change alleles.
c. They randomly orient during metaphase II and the nonequivalent sister chromatids separate in anaphase II.
d. Genetic material from two parents is combined on the same chromosome.
e. Both c and d are true.

20. A cell in G_2 before meiosis compared with one of the four cells produced by that meiotic division has

a. twice as much DNA and twice as many chromosomes.
b. four times as much DNA and twice as many chromosomes.
c. four times as much DNA and four times as many chromosomes.
d. half as much DNA but the same number of chromosomes.
e. half as much DNA and half as many chromosomes.