Chapter 13

Meiosis and Sexual Life Cycles

PowerPoint® Lecture Presentations for

Biology

Eighth Edition
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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

- 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.

[Video: Hydra Budding]
(a) Hydra

(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
APPLICATION

TECHNIQUE

Pair of homologous replicated chromosomes

Centromere

Sister chromatids

Metaphase chromosome

5 µm
• 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 \((2n = 46)\).
In a cell in which DNA synthesis has occurred, each chromosome is replicated.

Each replicated chromosome consists of two identical sister chromatids.
Key

- **Maternal set of chromosomes** \((n = 3)\)
- **Paternal set of chromosomes** \((n = 3)\)

\[ 2n = 6 \]

- Two sister chromatids of one replicated chromosome
- 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 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
Key

- Haploid (n)
- Diploid (2n)

**Haploid gametes (n = 23)**

- Egg (n)
- Sperm (n)

**MEIOSIS**

- Ovary
- Testis

**FERTILIZATION**

- Diploid zygote (2n = 46)

**Mitosis and development**

- Multicellular diploid adults (2n = 46)
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.
Key
- Haploid (n)
- Diploid (2n)

(a) Animals
- Haploid unicellular or multicellular organism
- Diploid multicellular organism
- Zygote
- Mitosis
- Gametes
- MEIOSIS
- FERTILIZATION

(b) Plants and some algae
- Haploid multicellular organism (gametophyte)
- Spores
- Gametes
- Meiosis
- Fertilization
- Mitosis
- Zygote

(c) Most fungi and some protists
- Haploid unicellular or multicellular organism
- Gametes
- Mitosis
- Zygote
- Meiosis
- Fertilization
- Mitosis
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

Key
- Haploid (n)
- Diploid (2n)

Haploid unicellular or multicellular organism

Mitosis

Gametes

MEIOSIS

FERTILIZATION

Zygote

(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
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
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.

Division in meiosis I occurs in four phases:

- Prophase I
- Metaphase I
- Anaphase I
- Telophase I and cytokinesis
Metaphase I

Anaphase I

Telophase I and Cytokinesis

Prophase I

Centrosome (with centriole pair)

Sister chromatids

Chiasmata

Spindle

Centromere (with kinetochore)

Metaphase plate

Microtubule attached to kinetochore

Homologous chromosomes

Fragments of nuclear envelope

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 **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

Prophase I

- Centrosome (with centriole pair)
- Sister chromatids
- Chiasmata
- Homologous chromosomes
- Fragments of nuclear envelope

Metaphase I

- Centromere (with kinetochore)
- Spindle
- Metaphase plate
- 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 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.
• 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
Anaphase I

- Sister chromatids remain attached

Homologous chromosomes separate

Telophase I and Cytokinesis

- 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.
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.

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Fig. 13-8e

Prophase II

Metaphase II
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

Anaphase II

Sister chromatids separate

Telephase II and Cytokinesis

Haploid daughter cells forming
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.

- The mechanism for separating sister chromatids is virtually identical in meiosis II and mitosis.
**SUMMARY**

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

Shugoshin⁺ (normal)  Shugoshin⁻

Spore case          Spore case

Fluorescent label

Metaphase I

Anaphase I

Metaphase II

Anaphase II

Mature spores

Two of three possible arrangements of labeled chromosomes

RESULTS

Spore cases (%)

0  20  40  60  80  100

Shugoshin⁺  Shugoshin⁻
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.
• 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.
Two equally probable arrangements of chromosomes at metaphase I

Possibility 1

Possibility 2

Metaphase II

Daughter cells

Combination 1

Combination 2

Combination 3

Combination 4
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.
- 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

Chiasma

Centromere

Anaphase I

Anaphase II

Daughter cells

Recombinant chromosomes

TEM
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.
- 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
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

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