Chapter 13: Meiosis and Sexual Life Cycles

- modes of reproduction
- diploid/haploid and meiosis
- meiosis I and meiosis II phases
- key differences between mitosis and meiosis
- variation in position of meiosis in life cycles
- why sex?
Why is mitosis alone insufficient for the life cycle of sexually reproducing eukaryotes?
Different modes of reproduction require different types of cell division

- **asexual reproduction** creates offspring that are genetically identical to each other and to the parent cell (clones)
  - only mitotic cell division is required
  - the parent may split, bud, or fragment (cellular budding has unequal partitioning during cytokinesis)
  - asexual reproduction is typically rapid and efficient compared to sexual reproduction
sexual reproduction

- sexual reproduction occurs when specialized sex cells called **gametes** fuse to form a single cell called a **zygote**
  - gametes that fuse usually come from are produced by different individuals
  - in plants and animals the gametes are called the **egg** (ovum) and the **sperm**
  - the offspring are not genetically identical to their parents
sexual reproduction

- genetic recombination
  - may produce some offspring that are better adapted to the environment than either parent
  - may produce some offspring that are more poorly adapted than either parent
sexual reproduction

- must have a way to half the number of chromosomes at some point

- otherwise, the number of chromosomes would double with each generation

- halving the chromosome number is accomplished through meiosis
• Why is mitosis alone insufficient for the life cycle of sexually reproducing eukaryotes?
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- why sex?
• Define:
  – gamete
  – zygote
  – meiosis
  – homologous chromosomes
  – diploid
  – haploid
Diploid cells give rise to haploid cells during meiosis

- the somatic (body) cells of most animals and many plants are diploid cells
  - each chromosome in a diploid cell has a partner chromosome
  - the partners are called homologous chromosomes
    - one member of each pair came from the father (paternal homolog), and one from the mother (maternal homolog)
    - thus, for humans, the 46 chromosomes are in 23 pairs
Diploid cells give rise to haploid cells during meiosis

- Each member in a pair of homologous chromosomes contains very similar, but not identical, genetic information (more on this in the next unit, genetics).

- Sex chromosomes aren’t strictly homologous (an X chromosome has different genes than a Y chromosome), but they act as if they are homologous during meiosis.
Diploid cells give rise to haploid cells during meiosis

- a set of chromosomes \((n)\) has one member for each homologous pair

- a **diploid** cell has two complete sets \((2n)\)

- a **haploid** cell has one set \((n)\)

- sometimes, cells have extra sets \((3n\ or\ more;\ \text{polyploid}\ \text{cells} – \text{common in plants, rare and usually fatal in animals})\)
Diploid cells give rise to haploid cells during meiosis

- Meiosis reduces chromosome number, producing up to 4 haploid cells from one diploid cell

- Meiosis has two successive cell divisions after only one DNA replication

- The two cell divisions are called meiosis I and meiosis II
  - Homologous chromosomes separate during meiosis I
  - Sister chromatids separate during meiosis II
• Define:
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  – zygote
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  – homologous chromosomes
  – diploid
  – haploid
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With a partner, do the “chromosome dance” for meiosis. Make sure that you distinguish between:

- tetrads
- chromosomes
- chromatids

Note at each stage the number of sister chromatids per chromosome.
Meiosis I and Meiosis II

**INTERPHASE**

**MEIOSIS I: Separates homologous chromosomes**

- **PROPHASE I**
  - Centromeres (with kinetochores)
  - Homologous chromosomes (red and blue) pair and exchange segments; $2n = 6$ in this example
  - Chromosomes duplicate
- **METAPHASE I**
  - Nuclear envelope
  - Tetrads
- **ANAPHASE I**
  - Sister chromatids remain attached
- **TELOPHASE I AND CYTOKINESIS**
  - Cleavage furrow
  - Sister chromatids separate
  - Haploid daughter cells forming

**MEIOSIS II: Separates sister chromatids**

- **PROPHASE II**
  - Homologous chromosomes separate
- **METAPHASE II**
  - Metaphase plate
- **ANAPHASE II**
  - Two haploid cells form; chromosomes are still double
- **TELOPHASE II AND CYTOKINESIS**
  - During another round of cell division, the sister chromatids finally separate; four haploid daughter cells result, containing single chromosomes
# Meiosis I

<table>
<thead>
<tr>
<th>INTERPHASE</th>
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- **Centrosomes (with centriole pairs)**
- **Sister chromatids**
- **Chiasmata**
- **Spindle**
- **Chromatid**
- **Chromatids (red and blue) pair and exchange segments; \(2n = 6\) in this example**
- **Homologous chromosomes separate**
- **Pairs of homologous chromosomes split up**
- **Two haploid cells form; chromosomes are still double**
# Meiosis II

<table>
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<td><strong>TELOPHASE I AND CYTOKINESIS</strong></td>
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During another round of cell division, the sister chromatids finally separate; four haploid daughter cells result, containing single chromosomes.
• With a partner, do the “chromosome dance” for meiosis. Make sure that you distinguish between:
  – tetrads
  – chromosomes
  – chromatids

Note at each stage the number of sister chromatids per chromosome.
• Summarize the key events of prophase I.
Meiosis I

**INTERPHASE**

**MEIOSIS I:** Separates homologous chromosomes

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<td>METAPHASE I</td>
<td>Sister chromatids, Chiasmata, Centromere (with kinetochore)</td>
</tr>
<tr>
<td>ANAPHASE I</td>
<td>Spindle, Microtubule attached to kinetochore, Homologous chromosomes separate</td>
</tr>
<tr>
<td>TELOPHASE I AND CYTOKINESIS</td>
<td>Sister chromatids remain attached, Tetrads line up, Pairs of homologous chromosomes split up, Two haploid cells form; chromosomes are still double</td>
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Chromatin, Nuclear envelope, Tetrad.
Meiosis I: Prophase I

- homologous chromosomes pair
  - synapsis
  - tetrad
  - synaptonemal complex
Meiosis I: Prophase I

- crossing over for genetic recombination
Meiosis I: Prophase I

- as in mitosis

- *sister chromatids* are held together at centromeres and have kinetochores

- BUT their kinetochores are *side-by-side* and attach to spindle fibers from the same pole
Meiosis I: Prophase I

- by the end of prophase I:
  - the spindle has formed
  - the nuclear membrane has vesicularized
  - nucleoli have disintegrated
  - homologous chromosomes are attached by their kinetochores to spindle fibers from opposite poles
  - homologous chromosomes are held together only at **chiasmata**, the sites where crossing-over occurred
• Summarize the key events of prophase I.
• In which phase do sister chromatids segregate?

• In which phase do homologous chromosomes segregate?
Meiosis I: **Metaphase I**

- tetrads line up along the midplane of the cell
Meiosis I: Anaphase I

- homologous chromosomes separate and are moved toward opposite poles

- each pole gets one set of homologous chromosomes

- the initial “maternal” or “paternal” chromosome sets are mixed and distributed randomly (crossing-over largely blurs such identity anyway)
Random Orientation on Metaphase Plate
Independent Assortment and Genetic Variability

Paternal gamete  
Maternal gamete  
Diploid offspring

Homologous pairs  
Potential gametes
**Meiosis I: Telophase I**

- generally:
  - the spindle fibers disintegrate
  - the chromosomes partially decondense
  - nuclear membranes may form around the genetic material
  - cytokinesis occurs
Meiosis: Interkinesis

- period between meiosis I and meiosis II
- varies in length and distinctiveness
- no S phase (no DNA replication)
- typically brief
Meiosis II

**TELOPHASE I AND CYTOKINESIS**

**PROPHASE II**

**METAPHASE II**

**ANAPHASE II**

**TELOPHASE II AND CYTOKINESIS**

- Two haploid cells form; chromosomes are still double.
- During another round of cell division, the sister chromatids finally separate; four haploid daughter cells result, containing single chromosomes.
Meiosis II: Prophase II

- similar to prophase of mitosis
- BUT usually very short
  - chromatin did not completely decondensate after meiosis I
Meiosis II: Metaphase II

- similar to metaphase of mitosis
  - chromosomes line up along the midplane of the cell
  - sister chromatids are connected by their kinetochores to spindle fibers from opposite poles
Meiosis II: Anaphase II

- like in mitotic anaphase, sister chromatids segregate toward opposite poles
Meiosis II: Telophase II

- much like mitotic telophase:
  - the spindle is disintegrated
  - the chromosomes decondense
  - nuclear membranes reform around the genetic material to form nuclei
  - nucleoli reappear, and interphase cellular functions resume
- cytokinesis usually begins during telophase II and ends shortly thereafter
• In which phase do sister chromatids segregate?

• In which phase do homologous chromosomes segregate?
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• Compare and contrast meiosis and mitosis.
SUMMARY: Meiosis vs. Mitosis

mitosis
- one DNA replication (back in S phase of interphase)
- one division
- results in two genetically identical daughter cells
- homologous chromosomes
  - do not pair
  - do not cross-over
  - do not segregate

meiosis
- one DNA replication (back in S phase of interphase)
- two divisions (reductive division)
- results in up to four genetically distinct daughter cells
- homologous chromosomes
  - pair (synapsis)
  - cross over (homologous recombination)
  - segregate
• Compare and contrast meiosis and mitosis.
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• Draw:

- zygotic meiosis
- gametic meiosis
- sporic meiosis (alternation of generations)

For each, note the organisms that use it.
The products of meiosis can vary between sexes and between species

- in many eukaryotes:
  - zygote undergoes meiosis
  - most of the life cycle is spent as haploid cells
  - gametes are produced by mitosis and fuse to make the zygote
The products of meiosis can vary between sexes and between species

- in most animals:
  - somatic (body) cells are typically diploid
  - special germ line cells undergo meiosis to form haploid gametes (gametogenesis)
    - male gametogenesis (spermatogenesis) typically produces 4 viable haploid sperm for each germ cell that undergoes meiosis
    - female gametogenesis (oogenesis) typically produces 1 haploid egg cell (ovum) for each germ cell that undergoes meiosis
    - the rest of the genetic material goes to polar bodies, cells that get little of the original cytoplasm and eventually die
  - a sperm and an egg fuse to make a diploid zygote, which gives rise to the multicellular animal

![Diagram of meiosis and fertilization](image-url)
The products of meiosis can vary between sexes and between species

- plants and some algae have distinct **alternation of generations**
  - spores produced after meiosis
    - divide (mitotically) into a multicellular haploid gametophyte
    - gametes are eventually produced mitotically
  - zygote gives rise (through mitotic divisions) to a multicellular diploid sporophyte
    - produces specialized cells that undergo meiosis to produce spores
• Draw:
  – zygotic meiosis
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  – sporic meiosis (alternation of generations)

For each, note the organisms that use it.
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• Describe Miller’s Ratchet, DNA repair, and the Red Queen hypotheses for sex.
Why sex? The origin and maintenance of sex is an evolutionary puzzle

- Sexual reproduction dilutes the genes from the “best adapted” individuals, and thus must offer a significant advantage or asexual reproduction will win out.

- Even when sex clearly benefits a population or species, it must directly benefit individuals or it will lose out via evolution.
Why sex? The origin and maintenance of sex is an evolutionary puzzle

- There may be no single hypothesis that explains “Why sex?” for all sexually reproducing organisms.

- Leading hypotheses for why sex occurs include Miller’s Ratchet, DNA repair, and the Red Queen.
Why sex? The origin and maintenance of sex is an evolutionary puzzle

- **Miller’s Ratchet** – asexual populations tend to accumulate harmful mutations
  - by chance over time
  - no good way to get rid of them
  - like turning a ratchet, you can’t go back
Why sex? The origin and maintenance of sex is an evolutionary puzzle

- **DNA Repair** – many species reproduce sexually only during times of stress
  - some types of DNA repair can only take place with a diploid cell
  - that type of repair is most likely needed in times of stress
  - this allows these species to overcome Miller’s Ratchet
Why sex?  The origin and maintenance of sex is an evolutionary puzzle

- Red Queen – sex allows for populations to “store” genetic diversity so that it is available for each generation
  - this only provides an advantage if the environment provides ever-changing physical and/or biological constraints
  - an ‘evolutionary arms race’ between parasites and their hosts may be a key factor in producing such ‘treadmill evolution’
• Describe Miller’s Ratchet, DNA repair, and the Red Queen hypotheses for sex.