

Lecture Outline: Sexual Life Cycles, Ploidy, and Meiosis

I. Introduction to Meiosis and Sexual Life Cycles

A. Context and Placement

1. Focuses on **DNA**, continuing from previous units
2. Chapter 13 in the textbook, positioned before previously covered material
3. Uses examples of the hydra and the redwood

B. Organism Comparison (Hydra vs. Redwood)

1. Shared Trait: Both are **eukaryotes**
2. Key Difference: Reproduction Type
 - a. Hydra: **Asexual**
 - b. Redwood: **Sexual**

II. Modes of Reproduction

A. Asexual Reproduction

1. Characteristics
 - a. Involves **only one parent**
 - b. Produces offspring that are **genetically identical** to the single parent and to each other
2. Arguments For and Against
 - a. Advantage: Beneficial if the parent already has **very high fitness** and is perfectly adapted to its living conditions ("if it ain't broke, don't fix it")
 - b. Disadvantage: Offspring lack genetic diversity, making

them **vulnerable if the environment changes** suddenly

B. Sexual Reproduction

1. Characteristics

- a. Involves **two organisms or individuals** (parents)
- b. Never produces offspring that are genetically identical to the parent
- c. Has the effect of **amplifying genetic variation**

- 2. Advantage: Allows species to **adjust and adapt to changing environments** by producing varied offspring, increasing the chance that some will be well-adapted

III. Chromosomes and Ploidy

A. Karyotype

- 1. Definition: A **photographic image of all the chromosomes** in a specific individual or species
- 2. Preparation: A photomicrograph is taken of a cell, and chromosomes are **arranged by size in homologous pairs** (largest to smallest)
- 3. Optimal Viewing: Karyotypes are typically prepared from cells captured during **metaphase** of the cell cycle, when chromosomes are most compact and distinct
- 4. Human Karyotype: Shows 23 pairs of chromosomes, totaling **46 chromosomes** (because humans have 23 kinds of chromosomes, with two of each kind)

B. Chromosome Structure and Origin

- 1. Replicated Chromosome: Each chromosome appears as an "X" shape, composed of **two identical sister chromatids** connected at a **centromere** (formed after DNA replication in S-phase)
- 2. **Homologous Chromosomes (Homologues)**: Two

chromosomes of the same type (e.g., both "number one" chromosomes), with one originating from the **mother** and the other from the **father**

3. Genetic Identity: Homologous chromosomes are **not genetically identical** to each other because they come from different parents
4. Behavior: Homologues generally act independently in a cell, but they **find each other and come together only during meiosis**

C. Ploidy Definitions

1. Clarification: Ploidy is **not the total number of chromosomes** in a cell, nor is it the number of types of chromosomes
2. "**n**": Represents the number of **different kinds or types of chromosomes** a species has (e.g., $n=23$ for humans)
3. Ploidy: Refers to **how many of each type of chromosome are present in a cell**
 - a. **Haploid (n)**: A cell that has **only one of each type** of chromosome; therefore, it contains " n " total chromosomes
 - b. **Diploid (2n)**: A cell that has **two of every chromosome type** (a homologous pair for each type); therefore, it contains " $2n$ " total chromosomes

IV. Sexual Life Cycles and Alternation of Generations

A. Fundamental Processes in All Sexual Species

1. All sexual species (and only sexual species) undergo a generation-to-generation **alternation between two key biological processes: fertilization and meiosis**
2. Every sexual life cycle inherently features both a **haploid (n) stage** and a **diploid (2n) stage**

B. Fertilization

1. Definition: The **union or fusion of two different cells** (specifically sex cells) into one new cell
2. It is the **hallmark that defines a sexual species**
3. Sex Cells (Gametes): The two cells involved in fertilization are called **gametes** (unisexual term); in humans, these are **sperm** (male gamete) and **eggs or ova** (female gamete)
4. Zygote: The single cell that results from the successful fusion of two gametes; it is considered the official starting point of a new individual
5. Effect on Ploidy: Fertilization results in a **doubling of the ploidy** because two haploid gametes (each 'n' chromosomes) combine to form a diploid zygote (2n chromosomes)
6. Evolutionary Challenge: If fertilization were the only process, ploidy would continually double each generation, leading to an unsustainable amount of DNA and causing the species to die off rapidly

C. Meiosis

1. Definition: A counteracting process that **cuts the ploidy in half**
2. Purpose: To "undo" the doubling of ploidy accomplished by fertilization, ensuring that the ploidy remains constant across generations (alternating between diploid and haploid)
3. Meiosis is a process that **evolved with, and is exclusive to, sexual species**

D. Variations in Sexual Life Cycles Among Major Eukaryotic Groups

1. **Animals** (e.g., Humans)
 - a. Multicellular Stage: The adult individual is a **multicellular diploid (2n) organism**

- b. Gametes: Produced by meiosis, these are **unicellular haploid (n)** cells (sperm or eggs)
- c. Haploid Stage: There is **no multicellular haploid stage**; the haploid stage exists only as unicellular gametes
- d. Development: The diploid zygote develops into a multicellular animal through repeated **mitotic cell divisions**

2. Most Fungi

- a. Multicellular Stage: An adult fungus typically lives as a **multicellular haploid (n) organism** (its body cells are haploid)
- b. Gamete Formation: Since fungal body cells are already haploid, they produce gametes by **mitosis** (meiosis would not make sense as it halves ploidy)
- c. Diploid Stage: Fertilization produces a **diploid (2n) zygote**; unlike animals, this unicellular zygote **immediately undergoes meiosis** to produce haploid cells
- d. Development: These haploid cells then undergo **mitosis** multiple times to grow into new haploid multicellular fungi
- e. The **diploid stage is unicellular only**, while the haploid stage is multicellular

3. Plants (Alternation of Generations)

- a. Distinguishing Feature: Plants exhibit **multicellularity in both their haploid and diploid stages** within the same species
- b. **Sporophyte**: The **diploid (2n)**, spore-bearing plant, which is typically the familiar visible plant form
- c. **Gametophyte**: The **haploid (n)**, gamete-producing plant, which for many plants lives inside the sporophyte but is a

distinct multicellular individual

- d. "Alternation of Generations" is the specific term for this unique life cycle where multicellularity occurs in both ploidy stages

V. Meiosis: Detailed Process and Comparison to Mitosis

A. Cell Types in the Human Body Relevant to Division

1. Somatic Cells

- a. Definition: Cells that make up the "body" (soma means body); they constitute almost the entire organism (e.g., skin cells)
- b. Ploidy: They are **diploid (2n)**
- c. Division: If they reproduce themselves, they undergo **only mitosis** (and cytokinesis) to produce two genetically identical diploid copies

2. Germline Cells

- a. Definition: A tiny minority of cells found exclusively in the **gonads** (ovaries in females, testes in males)
- b. Ploidy: They are also **diploid (2n)** to begin with
- c. Division: They undergo **both mitosis** (first, to maintain their small population over time) **and meiosis**
- d. Products: Germline cells that undergo meiosis produce **haploid gametes** (which are distinct from the germline cells themselves)

B. Major Differences Between Mitosis and Meiosis

1. Ploidy Change

- a. Mitosis: **Maintains ploidy**; the daughter cells have the same ploidy as the parent cell (e.g., diploid parent produces diploid daughters)

- b. Meiosis: **Reduces or halves the ploidy** (e.g., diploid parent produces haploid daughters); this critical ploidy reduction occurs specifically in **Meiosis I**

2. Number of Nuclear Divisions

- a. Mitosis: Involves a **single division event**, typically resulting in two daughter cells from one original cell
- b. Meiosis: Features **two distinct rounds of nuclear division** (Meiosis I and Meiosis II), ultimately resulting in four daughter cells from one original cell

C. Meiosis I (The Reductional Division)

1. Prophase I: Key Events

- a. **Synapsis**: The two **homologous chromosomes** find **each other** and come together closely, forming a complex called a **tetrad** (or bivalent)
- b. **Crossing Over**: A crucial process where **non-sister chromatids** (one chromatid from each homologous chromosome in the pair) physically **cross over and exchange segments of DNA** at points called **chiasmata**
- c. Genetic Outcome of Crossing Over: This exchange creates **brand new, recombinant chromosomes** that have never existed before, featuring novel combinations of genetic material; this is a primary source of genetic variation

2. Metaphase I: The **homologous pairs (tetrads)** **line up** at the metaphase plate; for humans, 23 pairs (N pairs) line up

3. Anaphase I: The **homologous chromosomes separate** from each other and move to opposite poles of the cell

- 1. Each separating chromosome still consists of **two sister chromatids** (it remains a replicated chromosome)

2. This separation is the specific event where the **ploidy is reduced** (e.g., a cell originally $2n$ now has two sets of n chromosomes, one set in each forming daughter cell)
4. **Independent Assortment**: Refers to the **random orientation of each homologous pair** as it lines up at the metaphase plate during Meiosis I
 1. The way one tetrad lines up (e.g., which parent's chromosome faces which pole) is **independent** of how other tetrads line up
 2. This random alignment leads to a wide variety of combinations of maternal and paternal chromosomes being distributed into the resulting daughter cells, further contributing to genetic variation
 3. The number of different gametes possible solely due to independent assortment is calculated as 2^n (where n is the number of chromosome types)

D. Meiosis II (The Equational Division)

1. Similarity to Mitosis: Meiosis II is mechanistically very similar to **mitosis**, as its purpose is to separate the remaining sister chromatids
2. Sub-steps: Includes Prophase II, Metaphase II, Anaphase II, and Telophase II
3. Metaphase II: **Individual replicated chromosomes line up** at the metaphase plate (similar to metaphase in mitosis)
4. Anaphase II: The **sister chromatids separate** from each other and move to opposite poles
 1. It is important to note that after Meiosis I, due to crossing over, the "sister" chromatids may **no longer be genetically identical** to each other

- E. Overall Result of Meiosis: From one original diploid cell that enters meiosis, the entire process (Meiosis I and Meiosis II combined) produces **four genetically distinct haploid cells** (which develop into gametes)

VI. Sources of Genetic Variation Amplified by Sexual Reproduction

- A. **Mutation**: The **original and fundamental source of all genetic variation**; it creates new versions of DNA sequences ("different cards in the deck") that sexual reproduction can then reshuffle
- B. Mechanisms within Sexual Reproduction that Drastically Amplify Variation

1. **Crossing Over** (Occurs in **Prophase I of Meiosis**)

- Generates an **effectively infinite number of possibilities** for new gene combinations
- This is due to the presence of multiple chromosomes, millions of potential crossover points along DNA strands, and the ability for multiple crossover events to occur within a single homologous pair

2. **Independent Assortment** (Occurs in **Metaphase I of Meiosis**)

- Refers to the random and independent alignment of homologous chromosome pairs during Meiosis I
- For humans (with $n=23$ types of chromosomes), independent assortment alone can produce over **8 million (2^{23}) different kinds of gametes** (sperm or eggs)
- While a large number, this is still a tiny fraction of the variation generated by crossing over

3. **Random Fertilization**

- Involves the **random union of a randomly chosen sperm** (from the male) and a **randomly chosen egg**

(from the female) during fertilization

- b. Because both parents produce gametes with immense genetic variation (due to crossing over and independent assortment), the combination of these two randomly selected gametes results in a truly astronomical number of possible zygotic combinations
- c. This process explains why every human individual (except for identical twins, who originate from a single zygote splitting) is genetically unique