CHAPTER 10 MEIOSIS AND SEXUAL REPRODUCTION

Chapter Outline

10.1 Halving the Chromosome Number

A. Sexual Reproduction
   1. **Meiosis** is nuclear division reducing the chromosome number from the diploid (2n) to the haploid (n) number.
   2. The **haploid (n) number** is half of the diploid number of chromosomes.
   3. Sexual reproduction requires gamete formation and then fusion of gametes to form a **zygote.**
   4. A **zygote** always has the full or diploid (2n) number of chromosomes
   5. If gametes contained same number of chromosomes as body cells, doubling would soon fill cells.
   6. The Belgian cytologist Pierre-Joseph van Beneden found the *Ascaris* egg and sperm contain two chromosomes while body cells contained four.

B. Homologous Pairs of Chromosomes
   1. In diploid body cells, chromosomes occur as pairs.
      a. Each set of chromosomes is a **homologous** pair; each member is a **homologous chromosome** or **homologue.**
      b. Homologues look alike, have the same length and centromere position, and have a similar banding pattern when stained.
      c. A location on one homologue contains gene for the same trait which occurs at this locus on the other homologue, although the genes may code for different variations of that trait.
   2. Chromosomes duplicate just before nuclear division.
      a. Duplication produces two identical parts called sister chromatids; they are held together at centromere.
      b. Non-sister chromatids do not share the same centromere.
   3. One member of each homologous pair is inherited from the male parent, the other member is from the female parent.
   4. One member of each homologous pair will be placed in each sperm or egg.

C. Overview of Meiosis
   1. **Meiosis** involves two nuclear divisions and produces four haploid daughter cells.
   2. Each daughter cell has half the number of chromosomes found in the diploid parent nucleus.
   3. **Meiosis I** is the nuclear division at the first meiotic division.
      a. Prior to meiosis I, DNA replication occurs and each chromosome has two sister chromatids.
      b. During meiosis I, homologous chromosomes come together and line up in **synapsis.**
      c. During synapsis, the two sets of paired chromosomes lay alongside each other as **bivalents** or a **tetrad.**
   4. Meiosis II
      a. No replication of DNA is needed between meiosis I and II because chromosomes are already doubled.
      b. During meiosis II, centromeres divide; daughter chromosomes derived as sister chromatids separate.
      c. Chromosomes in the four daughter cells have only one chromatid.
      d. Counting the number of centromeres verifies that parent cells were diploid, each daughter cell is haploid.
      e. In the animal life cycle, daughter cells become gametes that fuse during fertilization.
      f. Fertilization restores the diploid number in body cells.

10.2 Genetic Recombination

A. Genetic Recombination
   1. Due to genetic recombination, offspring have a different combination of genes than their parents.
   2. Without recombination, asexual organisms must rely on mutations to generate variation among offspring; this is sufficient because they have great numbers of offspring.
   3. Meiosis brings about genetic recombination in two ways: crossing-over and independent assortment.

B. Crossing-Over of Nonsister Chromatids
   1. Crossing-over results in exchange of genetic material between non-sister chromatids of a bivalent and this introduces variation.
   2. At synapsis, homologous chromosomes are held in position by a nucleoprotein lattice (the **synaptonemal complex**).
   3. As the lattice of the synaptonemal complex breaks down at beginning of anaphase I, homologues are temporarily held together by **chiasmata,** regions where the non-sister chromatids are attached due to crossing-over.
   4. The homologues separate and are distributed to separate cells.
   5. Due to crossing-over, daughter chromosomes derived from sister chromatids are no longer identical.

C. Independent Assortment of Homologous Chromosomes
   1. Independent assortment in a cell with only three pairs of chromosomes is 2^3 or eight combinations of maternal and paternal chromosomes.
   2. In humans with 23 pairs of chromosomes, the combinations possible are 2^{23} or 8,388,608, and this does not consider the variation from crossing-over.

D. Fertilization
   1. Meiosis increases variation.
   2. When gametes fuse at fertilization, chromosomes donated by parents combine.
   3. The chromosomally different zygotes from same parents have $(2^{23})^2$ or 70,368,744,000,000 combinations possible without crossing-over.
   4. If crossing-over occurs once, then $(4^{23})^2$ or 4,951,760,200,000,000,000,000,000,000 genetically different zygotes are possible for one couple.

E. Significance of Genetic Recombination
   1. A successful parent in a particular environment can reproduce asexually and produce offspring adapted to that environment.
   2. If the environment changes, differences among offspring provide the sexual parents with much improved chances of survival.

10.3 The Phases of Meiosis

A. Number of Phases
   1. Both meiosis I and meiosis II have four phases: prophase, metaphase (preceded by prometaphase), anaphase, and telophase.

B. **Prophase I**
   1. Nuclear division is about to occur: nucleolus disappears; nuclear envelope fragments; centrosomes migrate away from each other; and spindle fibers assemble.
   2. Homologous chromosomes undergo synapsis forming bivalents; crossing over may occur at this time in which case sister chromatids are no longer identical.
   3. Chromatin condenses and chromosomes become microscopically visible.

C. **Metaphase I**
   1. During **prometaphase I,** bivalents held together by chiasmata have moved toward the metaphase plate at the equator of the spindle.
   2. In **metaphase I,** there is a fully formed spindle and alignment of the bivalents at the metaphase plate.
   3. Kinetochores are regions just outside centromeres; they attach to spindle fibers called **kinetochore spindle fibers.**
   4. Bivalents independently align themselves at the metaphase plate of the spindle.
   5. Maternal and paternal homologues of each bivalent may be oriented toward either pole.

D. **Anaphase I**
   1. The homologues of each bivalent separate and move toward opposite poles.
   2. Each chromosome still has two chromatids.

E. **Telophase I**
   1. In animals, this stage occurs at the end of meiosis I.
   2. When it occurs, the nuclear envelope reforms and nucleoli reappear.
   3. This phase may or may not be accompanied by cytokinesis.

F. **Interkinesis**
   1. This period between meiosis I and meiosis II is similar to the interphase between mitotic divisions.
   2. However, no DNA replication occurs (the chromosomes are already duplicated).

G. **Meiosis II**
   1. During metaphase II, the haploid number of chromosomes align at the metaphase plate.
   2. During **anaphase II**, chromosomes separate at the centromeres the two daughter chromosomes move toward the poles.
   3. Due to crossing-over, each gamete can contain chromosomes with different types of genes.
   4. At the end of **telophase II** and cytokinesis, there are four haploid cells.
   5. In animals, the haploid cells mature and develop into gametes.
   6. In plants, the daughter cells become spores and divide to produce a haploid adult generation.
   7. In some fungi and algae, a zygote results from gamete fusion and immediately undergoes meiosis; therefore, the adult is always haploid.

10.4 Comparison of Meiosis to Mitosis

A. Overall Comparison
   1. Meiosis requires two nuclear divisions; mitosis requires only one nuclear division.
   2. Meiosis produces four daughter nuclei and four daughter cells; mitosis produces only two.
   3. The daughter cells produced by meiosis are haploid; the daughter cells produced by mitosis are diploid.
   4. The daughter cells produced by meiosis are not genetically identical; the daughter cells produced by mitosis are genetically identical to each other and to the parental cell.

B. Occurrence
   1. In humans, meiosis occurs only in reproductive organs to produce gametes.
   2. Mitosis occurs in all tissues for growth and repair.

C. Comparison of Meiosis I to Mitosis
   1. DNA is replicated only once before both mitosis and meiosis; in mitosis there is only one nuclear division; in meiosis there are two nuclear divisions.
   2. During prophase I of meiosis, homologous chromosomes pair and undergo crossing-over; this does not occur during mitosis.
   3. During metaphase I of meiosis, bivalents align at the metaphase plate; in mitosis individual chromosomes align.
   4. During anaphase I in meiosis, homologous chromosomes with centromeres intact separate and move to opposite poles; in mitosis at this stage, sister chromatids separate and move to poles.

D. Comparison of Meiosis II to Mitosis
   1. Events of meiosis II are the same stages as in mitosis.
   2. However, the nuclei contain the haploid number of chromosomes in meiosis.
   3. Mitosis produces two daughter cells; meiosis produces four daughter cells.

10.5 The Human Life Cycle

A. Life Cycle has Both Meiosis and Mitosis.
   1. **Life cycle** refers to all reproductive events between one generation and next.
   2. In animals, the adult is always diploid [Instructors note: some bees, etc. have haploid male adults].
   3. In plants, there are two adult stages: one is diploid and one is haploid.
   4. Mosses are haploid most of their cycle; oak trees are diploid most of their cycle.
   5. In fungi and some algae, the organism you see is haploid and produces haploid gametes; only the zygote is diploid.
   6. In human males, meiosis is part of **spermatogenesis,** the production of sperm, and occurs in the testes.
   7. In human females, meiosis is part of **oogenesis,** the production of egg cells, and occurs in the ovaries.
   8. After birth, mitotic cell division is involved in growth and tissue regeneration of somatic tissue.

B. Spermatogenesis and Oogenesis in Humans
   1. Spermatogenesis
      a. In the testes of males, **primary spermatocytes** with 46 chromosomes divide meiotically to form two **secondary spermatocytes,** each with 23 duplicated chromosomes.

b. Secondary spermatocytes divide to produce four **spermatids**, also with 23 daughter chromosomes.
c. Spermatids then differentiate into **sperm.**
d. Meiotic cell division in males always results in four cells that become sperm.

2. Oogenesis
   a. In the ovaries of human females, **primary oocytes** with 46 chromosomes divide meiotically to form two cells, each with 23 duplicated chromosomes.
   b. One of the cells, a **secondary oocyte**, receives most cytoplasm; the other cell, a **polar body**, disintegrates or divides again.
   c. A secondary oocyte begins meiosis II and then stops at metaphase II.
   d. At ovulation, the secondary oocyte leaves the ovary and enters an oviduct where it may meet a sperm.
   e. If a sperm enters secondary oocyte, the oocyte is activated to continue meiosis II to completion; the result is a mature egg and another polar body, each with 23 daughter chromosomes.
   f. Meiosis produces one egg and three polar bodies; polar bodies serve to discard unnecessary chromosomes and retain most of the cytoplasm in the egg.
   g. The cytoplasm serves as a source of nutrients for the developing embryo.