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Chapter 2: Reproduction and Chromosome Transmission

Student Learning Objectives

Upon completion of this chapter the student should be able to:

1. Know the general features of chromosomes.
2. Understand the process of binary fission in bacteria.
3. Know the stages of mitosis and recognize diagrams associated with this process.
4. Understand the process of cytokinesis and how it differs in animals and plants.
5. Know the stages of meiosis and the cellular processes involved with each stage.
6. Know the end result of mitosis and meiosis in terms of number of cells and their chromosome content.
7. Understand the process of gamete formation in both plants and animals.

Key Terms

- Alleles
- Anaphase
- Asexual reproduction
- Binary fission
- Bivalents
- Cell cycle
- Cell plate
- Centrioles
- Centromere
- Centrosomes
- Chiasma (pl. Chiasmata)
- Chromatids / Sister chromatids
- Chromatin
- Chromosomes
- Cleavage furrow
- Condense
- Crossing over
- Cytogenetics
- Cytogeneticist
- Cytokinesis
- Decondensed
- Diakinesis
- Diploid
- Diplotene
- Dyad
- Egg cell / Ovum
- Embryo sac
- Eukaryotes
- G_1 phase
- G_2 phase
- Gamete
- Gametogenesis
- Gametophyte
- Haploid
- Heterogamous
- Heterozygous
- Homologs
- Homozygous
- Interphase
- Isogamous
- Karyotype
- Kinetochore
- Leptotene
- Locus (pl. Loci)
- M phase
- Meiosis
- Metaphase
- Metaphase plate
- Microtubule-organizing centers (MTOCs)
- Mitosis
- Mitotic spindle apparatus / Mitotic spindle
- Monad
- Nucleoid
- Nucleus

- Oogenesis
- Organelles
- Pachytene
- Pollen grain
- Prometaphase
- Prophase
- Prokaryotes
- Reproduction
- Restriction point
- S phase
- Sexual reproduction
- Somatic cell
- Sperm cells
- Spermatogenesis
- Spindle pole
- Sporophyte
- Synapsis
- Synaptonemal complex
- Telophase
- Tetrad
- Zygotene

Chapter Outline

2.1 General Features of Chromosomes

1. The cellular structures that contain the genetic material are the chromosomes. The structure of prokaryotic and eukaryotic chromosomes differs slightly, although both are comprised of long chains of DNA.
2. Prokaryotic cells, such as the bacteria, typically have a single, circular chromosome located within an area of the cell called the nucleoid (Figure 2.1a).
    a. prokaryotic cells also possess a cell wall
3. Eukaryotic cells (fungi, protists, plants, and animals) contain internal compartments, called organelles, that have specialized functions (Figure 2.1b).
    a. nucleus of eukaryotic cells contains the majority of the chromosomes and DNA
    b. other organelles, such as the mitochondria and chloroplast, contain small amounts of DNA

Eukaryotic Chromosomes Are Examined Cytologically to Yield a Karyotype

1. The field of cytogenetics involves the microscopic examination of chromosomes.
2. In actively dividing cells, the chromosomes are condensed allowing an easier examination of their structure and number.
3. To prepare an organism's chromosomes for viewing (Figure 2.2):
    a. somatic cells are obtained from the blood.
    b. the cells are exposed to drugs that stimulate cell division.
    c. the cells are placed in a hypotonic solution that makes them swell, but not burst.
    d. the cells are exposed to a fixative to prevent movement.
    e. a dye is applied to the cells that binds to the chromosomes.
    f. the cells are then placed on a microscope slide and viewed.
4. At this point the chromosomes may be photographed, and a karyotype prepared to aide in the analysis of the organism's chromosomes.

Eukaryotic Chromosomes Are Inherited in Sets

1. The majority of eukaryotic species are diploid, thus all somatic cells have two sets of chromosomes.

   a. Pairs of the same chromosomes are called homologs (Figure 2.3).
   b. Homologous chromosomes are very similar in sequence and have the same genes, but may contain different alleles of these genes.
   c. If the alleles are the same, then they are called homozygous. If the alleles are different, they are called heterozygous.
   d. Sex chromosomes are not homologous.
2. Genes on homologous chromosomes have the same locations, or loci.

2.2 Cell Division

1. Asexual reproduction involves the division of a preexisting cell to form two new cells.
   a. process is common in bacteria and some eukaryotic species (yeast, amoeba)
2. Cell division is necessary for the formation of multicellular organisms from fertilized eggs.

Bacteria Reproduce Asexually by Binary Fission

1. Prokaryotic organisms typically live as single cells.
2. Some bacteria, such as *E. coli*, can divide every 20-30 minutes.
   a. Prior to cell division the bacteria duplicates its chromosome.
   b. Division, called binary fission, occurs by forming a septum down the center of the cell (Figure 2.4).
   c. The end result is two daughter cells that are genetically identical.
   d. FtsZ, a protein that is evolutionarily related to microtubules, helps to identify the site of wall formation between the two new daughter cells.

Eukaryotic Cells Progress Through a Cell Cycle to Produce Genetically Identical Daughter Cells

1. Eukaryotic cells undergo a cell cycle (Figure 2.5) that consists of several distinct phases.
   a. G_1 and G_2 (gap phases), S and M (mitosis).
   b. G_1, S, and G_2 phases are collectively called interphase.
   c. Some cells remain in G_0 phase (just prior to S phase) for extended periods of time, thus arresting cell division.
2. Preparation for cell division begins in the G_1 phase. Molecular changes accumulate in the cell, allowing it to pass through a restriction point and into S phase.
3. In S phase the chromosomes are replicated, forming the sister chromatids. Sister chromatids are linked together and are considered a single chromosome.
   a. at this point the cell has twice as many chromatids as chromosomes (46 pairs of sister chromatids in humans)
4. In M phase (mitosis) the cell distributes the replicated chromosomes so that each of the new daughter cells has an exact complement of chromosomes that were found in the original cell.

2.3 Mitosis and Cytokinesis

The Mitotic Spindle Apparatus Organizes and Sorts Eukaryotic Chromosomes

1. The mitotic spindle apparatus is involved in the organization and sorting of chromosomes (Figure 2.7)
2. The spindle is formed from microtubule-organizing centers (MTOCs). In animal cells, there are two MTOCs called centrosomes. Each is located at a spindle pole.
3. There are three types of spindle fibers, all formed from microtubules.
   a. Aster microtubules emanate away from the chromosomes and are important in the positioning of the spindle fibers in the cell.
   b. Polar microtubules project toward the chromosomes and are involved in the separation of the two poles.
   c. Kinetochore microtubules attach to the kinetochore, a group of proteins that associate with the centromere of each chromosome. Kinetochores also help to hold sister chromatids together.

The Transmission of Chromosomes During the Division of Eukaryotic Cells Involves a Process Known as Mitosis

1. Mitosis proceeds through five phases: prophase, prometaphase, metaphase, anaphase, telophase (Figure 2.8).
2. During prophase the nuclear membrane dissociates and the chromosomes condense. The mitotic spindle also begins to form.
3. The interaction of the spindle fibers with the chromosomes occurs during prometaphase.
   a. Once a kinetochore microtubule comes in contact with the kinetochore, it is captured and no longer moves.
   b. Kinetochore microtubules connect to the kinetochore from both poles of the cell, and gently tug the chromosomes back and forth during prometaphase.
4. Metaphase occurs when the chromosomes align along a central plane called the metaphase plate.
5. The sorting of the chromosomes occurs during anaphase, when the connection between the sister chromatids breaks. At this point each of the chromatids is linked to only one of the poles.
   a. Each chromatid is now considered to be an independent chromosome.
   b. The chromosomes now begin to migrate to their respective poles of the cell.
6. When the chromosomes reach opposite sides of the cell, they begin to decondense. This marks the start of telophase. The nuclear membrane then reforms around the chromosomes.
7. Following telophase, the cell proceeds into cytokinesis, or cytoplasmic division (Figure 2.9).
   a. In animal cells this involves the use of a cleavage furrow.
   b. In plant cells this involves the use of a cell plate constructed from material carried by Golgi-derived vesicles.
8. The end result of mitosis and cytokinesis is two daughter cells that are genetically identical.
   a. Small variations are possible due to mutation in DNA sequence during replication.

2.4 Meiosis

1. Diploid eukaryotic cells may divide by meiosis to produce cells that are haploid. These cells contain a single set of chromosomes.

Meiosis Produces Cells That Are Haploid

1. Meiosis is similar to mitosis in many aspects, except that it involves two consecutive cell divisions within an intervening interphase.
2. The following events occur during prophase I (Figure 2.10).
    a. The first stage is called leptotene. During this time the chromosomes start to condense, forming threadlike structures.
    b. During the second stage, called zygotene, the homologous chromosomes recognize each other by a process known as synapsis. The chromosomes align along their entire lengths. At this point the pairs of homologous chromosomes are called bivalents (or tetrads). There are four sister chromatids in a bivalent.
    c. As the bivalent structure forms the synaptonemal complex forms between the homologous chromosomes. The synaptonemal complex consists of lateral and central elements that interact. The synaptonemal complex is not found in all species.
    d. Just prior to the third stage, pachytene, the process of crossing over occurs between non-sister chromatids in the bivalent. The site of crossing over is called the chiasma.
    e. In the fourth stage, called diplotene, the synaptonemal complex dissociates. The individual chromatids are usually visible at this point.
    f. By the last stage, diakinesis, the synaptonemal complex has completely disappeared.
3. The events of prometaphase I resemble those of mitosis, in which the spindle apparatus is complete and the chromatids are attached via kinetochore microtubules (Figure 2.11).
4. During metaphase I the chromosomes align along a central line in the cell in the same manner as mitosis, except for the following:
    a. the bivalent chromosomes are aligned in a double row, rather than the single row of mitosis.
    b. the kinetochore microtubules link one of the homologous chromosomes to one of the poles, while a second set of kinetochore microtubules link the other homologous chromosome to the other pole (Figure 2.12).
5. At metaphase I, each bivalent pair may align in one of two configurations. The number of different, random alignments for a species is equal to 2^n, where n equals the chromosome number.
6. During anaphase I the homologous chromosomes separate from each other and begin to migrate to opposite poles. The sister chromatids remain connected during meiosis I.
7. At telophase I the chromosomes reach the opposite poles of the cell and begin to decondense. The nuclear membrane then reforms around the chromosomes.
8. Following telophase I, cytokinesis occurs. The cell then proceeds directly to meiosis II.

9. The sequence of events for meiosis II is identical to that of mitosis, except that two cells are now dividing and each cell contains half the number of chromosomes. Cytokinesis follows meiosis II.
10. For a single diploid cell entering meiosis, the end result is four haploid daughter cells. These daughter cells vary in their genetic composition (Table 2.1).

2.5 Sexual Reproduction

1. The purpose of sexual reproduction is to produce gametes, a process known as gametogenesis. These gametes then combine by the process of fertilization to produce a new individual.
2. Isogamous organisms, such as some species of fungi and algae, produce gametes that are morphologically similar. Heterogamous organisms produce gametes that are not morphologically the same.
   a. Sperm cells are produced by the male, are typically small, and must travel a significant distance to reach the egg.
   b. Egg cells are produced by the female, are typically large, and usually nonmotile.

In Animals, Spermatogenesis Produces Four Haploid Sperm Cells and Oogenesis Produces a Single Haploid Egg Cell

1. In male animals, the formation of the sperm, called spermatogenesis, occurs in the testes (Figure 2.13a).
2. In the testes a spermatogonial cell divides by mitosis to produce two identical cells. One of these is a spermatocyte and enters into meiosis, while the other remains a spermatogonial cell.
3. The four haploid cells produced by meiosis mature into sperm cells. Each sperm cell contains a haploid nucleus, an acrosome that contains digestive enzymes, and a long flagellum.
4. Oogenesis is the formation of the egg cells (Figure 2.13b). It begins with oogonia located in the ovary of the female. The oogonia begin meiosis, but are arrested at prophase I.
   a. After the female reaches a reproductive age, the primary oocytes are periodically activated.
   b. Unlike spermatogenesis in males, oogenesis only produces a single egg cell. During meiosis the division of the cytoplasm is asymmetric and produces polar bodies. The larger cell is called the secondary oocyte, and represents the cell that is released during ovulation.
   c. If the secondary oocyte is fertilized, it completes meiosis II. In the second cytokinesis there is again an unequal division of the cytoplasm, producing another polar body.

Plant Species Alternate Between Haploid (Gametophyte) and Diploid (Sporophyte) Generations

1. Plants alternate between haploid and diploid generations. The haploid generation is called the gametophyte and the diploid generation is called the sporophyte.
2. The process of meiosis produces haploid cells called spores, which then divide by

mitosis to produce the gametophyte.

   a. For most higher plants, the dominant stage is the sporophyte stage.

3. Gametogenesis in higher plants occurs in the anthers (male) and ovaries (female) (Figure 2.14).
   a. In the anther diploid cells called microsporocytes undergo meiosis to produce four haploid microspores. These cells then go through mitosis to produce a pollen grain, or male gametophyte. The pollen grain consists of two cells, the tube cell and the generative cell. The generative cell undergoes mitosis to produce two haploid sperm.
   b. In the ovaries a cell called the megasporocyte goes through meiosis to produce four haploid megaspores. Only one of these megaspores survives, the others degenerate. The remaining undergoes three consecutive cell divisions, with asymmetrical cytokinesis, to produce a seven cell structure called the embryo sac. This is the female gametophyte.
4. Fertilization in plants involves the following:
   a. A pollen grain lands on the stigma, stimulating the tube cell to form a pollen tube to the ovary of the plant.
   b. The generative cell in the pollen grain finishes meiosis, producing two sperm cells. These migrate through the pollen tube to the ovary.

List of Key Investigators

None cited in this chapter.

CONCEPTS OF GENETICS, 2/e

ANSWERS TO PROBLEM SETS
Chapters 1-26

CHAPTER 1
Note: the answers to the Comprehension questions are at the end of the chapter.

Concept check questions (in figure legends)
FIGURE 1.1 Understanding our genes may help to diagnose inherited diseases. It may also lead to the development of drugs to combat diseases. Other answers are possible.
FIGURE 1.2 Many ethical issues are associated with human cloning. Is it the wrong thing to do? Does it conflict an individual's religious views? And so on.
FIGURE 1.3 By sorting the mosquitos, sterile males can be released into the environment to limit mosquito reproduction, because females mate only once.
FIGURE 1.4 DNA is a macromolecule.
FIGURE 1.5 DNA and proteins are found in chromosomes. RNA may also be associated with chromosomes.
FIGURE 1.6 The information to make a polypeptide is stored in DNA.
FIGURE 1.7 The dark-colored butterfly has a more active pigment-producing enzyme.
FIGURE 1.8 Genetic variation is the reason these frogs look different.
FIGURE 1.9 These are examples of variation in chromosome number.
FIGURE 1.10 If this girl had been given a standard diet, she would have developed the harmful symptoms of PKU, which include mental impairment and foul-smelling urine.
FIGURE 1.11 A corn gamete would contain 10 chromosomes. (The leaf cells are diploid.)
FIGURE 1.12 The horse populations have become adapted to their environment, which has changed over the course of many years.
FIGURE 1.13 There are several possible examples of other model organisms, including rats and frogs.

End-of-chapter Questions:
Conceptual Questions
C1. A chromosome is a very long polymer of DNA. A gene is a specific sequence of DNA within that polymer; the sequence of bases creates a gene and distinguishes it from other genes. Genes are located in chromosomes, which are found within living cells.
C2. At the molecular level, a gene (a sequence of DNA) is first transcribed into RNA. The genetic code within the RNA is used to synthesize a protein with a particular amino acid sequence. This second process is called translation.
C3. A. Molecular level. This is a description of a how an allele affects protein function.
B. Cellular level. This is a description of how protein function affects cell structure.
C. Population level. This is a description of how the two alleles affect members of a population.
D. Organism level. This is a description of how the alleles affect the traits of an individual.
C4. Genetic variation involves the occurrence of genetic differences within members of the same species or different species. Within any population, variation may occur in the genetic material.

Variation may occur in particular genes so that some individuals carry one allele and other individuals carry a different allele. Examples include differences in coat color among mammals or flower color in plants. At the molecular level, this type of genetic variation is caused by changes in the DNA sequences of genes. There also may be variation in chromosome structure and number.

C5. An extra chromosome (specifically an extra copy of chromosome 21) causes Down syndrome.

C6. You could pick almost any trait. For example, flower color in petunias would be an interesting choice. Some petunias are red and others are purple. There must be different alleles in a flower color gene that affect this trait in petunias. In addition, the amount of sunlight, fertilizer, and water also affects the intensity of flower color.

C7. The term *diploid* means that a cell has two copies of each type of chromosome. In humans, nearly all of the cells are diploid except for gametes (i.e., sperm and egg cells). Gametes usually have only one set of chromosomes.

C8. A DNA sequence is a sequence of nucleotides. Each nucleotide may have one of four different bases (i.e., A, T, G, or C). When we speak of a DNA sequence, we focus on the sequence of bases.

C9. The genetic code is the way in which the sequence of bases in RNA is read to produce a sequence of amino acids within a protein.

C10. A. A gene is a segment of DNA. For most genes, the expression of the gene results in the production of a functional protein. The functioning of proteins within living cells affects the traits of an organism.

B. A gene is a segment of DNA that usually encodes the information for the production of a specific polypeptide. Genes are found within chromosomes. Many genes are found within a single chromosome.

C. An allele is an alternative version of a particular gene. For example, suppose a plant has a flower color gene. One allele could produce a white flower, while a different allele could produce an orange flower. The white allele and orange allele are alleles of the flower color gene.

D. A DNA sequence is a sequence of nucleotides. The information within a DNA sequence (which is transcribed into an RNA sequence) specifies the amino acid sequence within a polypeptide.

C11. The statement in part A is not correct. Individuals do not evolve. Populations evolve because certain individuals are more likely to survive and reproduce and pass their genes to succeeding generations.

C12. A. How genes and traits are transmitted from parents to offspring.

B. How the genetic material functions at the molecular and cellular levels.

C. Why genetic variation exists in populations, and how it changes over the course of many generations.

Application and Experimental Questions

E1. There are many possible answers. Some common areas to discuss might involve the impact of genetics in the production of new medicines, the diagnosis of diseases, the production of new kinds of food, and the use of DNA fingerprinting to solve crimes.

E2. A genetic cross involves breeding two different individuals.

E3. This would be used to a great extent by molecular geneticists. The sequence of DNA is a molecular characteristic of DNA. In addition, as we will learn throughout this textbook, the sequence of DNA is interesting to transmission and population geneticists as well.

E4. You would see 47 chromosomes instead of 46. There would be three copies of chromosome 21 instead of two copies.

E5. A. Transmission geneticists. Dog breeders are interested in how genetic crosses affect the traits of dogs.
B. Molecular geneticists. This is a good model organism to study genetics at the molecular level.
C. Both transmission geneticists and molecular geneticists. Fruit flies are easy to cross and study the transmission of genes and traits from parents to offspring. Molecular geneticists have also studied many genes in fruit flies to see how they function at the molecular level.
D. Population geneticists. Most wild animals and plants would be the subject of population geneticists. In the wild, you cannot make controlled crosses. But you can study genetic variation within populations and try to understand its relationship to the environment.
E. Transmission geneticists. Agricultural breeders are interested in how genetic crosses affect the outcome of traits.

E6. You need to follow the scientific method. You can take a look at an experiment in another chapter to see how the scientific method is followed.

CHAPTER 2

Note: the answers to Comprehension questions are at the end of the chapter.

Concept check questions (in figure legends)

FIGURE 2.1 Compartmentalization means that cells have membrane-bound compartments.

FIGURE 2.2 The chromosomes would not be spread out very well, and would probably be overlapping. It would be difficult to see individual chromosomes.

FIGURE 2.3 Homologs are similar in size, banding pattern, and carry the same types of genes. However, the alleles of a given gene may be different.

FIGURE 2.4 FtsZ assembles into a ring at the future site of the septum and recruits other proteins to this site that produce a cell wall between the two daughter cells.

FIGURE 2.5 The G_1 phase is a phase of the cell cycle when a cell may make the decision to divide. By comparison, the G_0 phase is a phase in which a cell is either not progressing through the cell cycle or has made a decision to never divide again.

FIGURE 2.6 Homologs are genetically similar; one is inherited from the mother and the other from the father. By comparison, chromatids are the product of DNA replication. The chromatids within a pair of sister chromatids are genetically identical.

FIGURE 2.7 One end of a kinetochore microtubule is attached to a kinetochore on a chromosome. The other end is within the centrosome.

FIGURE 2.8 Anaphase.

FIGURE 2.9 Ingression occurs because myosin motor proteins shorten the contractile ring, which is formed from actin proteins.

FIGURE 2.10 The end result of crossing over is that homologous chromosomes have exchanged pieces.

FIGURE 2.11 The cells at the end of meiosis are haploid whereas the mother cell is diploid.

FIGURE 2.12 In mitosis, each pair of sister chromatids is attached to both poles, whereas in metaphase of meiosis I, each pair of sister chromatids is attached to just one pole.

FIGURE 2.13 Polar bodies are small cells produced during oogenesis that degenerate.

FIGURE 2.14 All of the nuclei in the embryo sac are haploid. The central cell has two haploid nuclei and all of the other cells, including the egg, have just one.

End-of-chapter Questions:
Conceptual Questions

C1. They are genetically identical, barring rare mutations, because they receive identical copies of the genetic material from the mother cell.

C2. The term homolog refers to the members of a chromosome pair. Homologs are usually the same size and carry the same types and order of genes. They may differ in that the genes they carry may be different alleles.

C3. Sister chromatids are identical copies derived from the replication of a chromosome. They remain attached to each other at the centromere. They are genetically identical, barring rare mutations and crossing over with homologous chromosomes.

C4. Metaphase is the organization phase and anaphase is the separation phase.

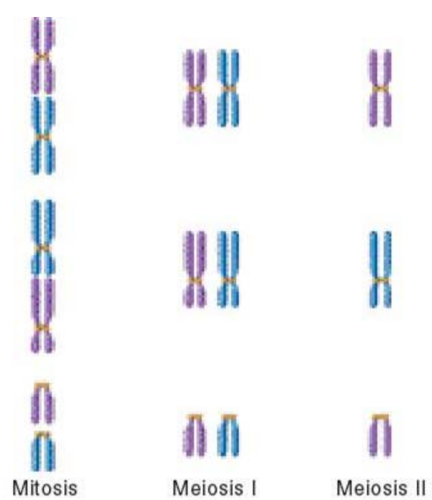
C5. In G_1, there should be six linear chromosomes. In G_2, there should be 12 chromatids that are attached to each other in pairs of sister chromatids.

C6. In metaphase I of meiosis, each pair of chromatids is attached to only one pole via the kinetochore microtubules. In metaphase of mitosis, there are two attachments (i.e., to both poles). If the attachment was lost, a chromosome would not migrate to a pole and may not become enclosed in a nuclear membrane after telophase. If left out in the cytosol, it would eventually be degraded.

C7. A. During mitosis and meiosis II
B. During meiosis I
C. During mitosis, meiosis I, and meiosis II
D. During mitosis and meiosis II

C8. The reduction occurs because there is a single DNA replication event but two cell divisions. Because of the nature of separation during anaphase I, each cell receives one copy of each type of chromosome.

C9.



C10. It means that the maternally derived and paternally derived chromosomes are randomly aligned along the metaphase plate during metaphase I.

C11. Mitosis—two diploid cells containing 10 chromosomes each (two complete sets). Meiosis—four haploid cells containing 5 chromosomes each (one complete set)

C12. There are three pairs of chromosomes. The number of different, random alignments equals 2^n, where n equals the number of chromosomes per set. So the possible number of arrangements equals 2^3, which is 8.

C13. $(1/2)^n = (1/2)^4 = 1/16$ or 6.25%

C14. The probability would be much lower because pieces of maternal chromosomes would be mixed with the paternal chromosomes. Therefore, a gamete is unlikely to carry a chromosome that was completely paternally derived.

C15. Bacteria do not need to sort their chromosomes because they only have one type of chromosome. Though not discussed in the text, the attachment of the two copies of the chromosomes to the cell membrane prior to cell division also helps to ensure that each daughter cell receives one copy.

C16. During interphase, the chromosomes are greatly extended. In this conformation, they might get tangled up with each other and not sort properly during meiosis and mitosis. The condensation process probably occurs so that the chromosomes easily align along the equatorial plate during metaphase without getting tangled up.

C17. To produce identical quadruplets, fertilization begins with one sperm and one egg cell. This fertilized egg then could divide twice by mitosis to produce four genetically identical cells. These four cells could then separate from each other to begin the lives of four distinct individuals. Another possibility is that mitosis could produce two cells that separate from each other. These two cells could then divide by mitosis to produce two pairs of cells, which also could separate to produce four individual cells.

C18. During prophase II, your drawing should show four replicated chromosomes (i.e., four structures that look like Xs). Each chromosome is one homolog. During prophase of mitosis, there should be eight replicated chromosomes (i.e., eight Xs). During prophase of mitosis, there are pairs of homologs. The main difference is that prophase II has a single copy of each of the four chromosomes, whereas prophase of mitosis has four pairs of homologs. At the end of meiosis I, each daughter cell has received only one copy of a homologous pair, not both. This is due to the alignment of homologs during metaphase I and their separation during anaphase I.

C19. The products of meiosis have only one copy of each type of chromosome. For example, one human gamete may contain the paternally derived copy of chromosome 11, whereas a different gamete may contain the maternally derived copy of chromosome 11. These two homologs may carry different alleles of the same genes and therefore are not identical. In contrast, mitosis produces genetically identical daughter cells that have both copies of all the pairs of homologous chromosomes.

C20. DNA replication does not take place during interphase II. The chromosomes at the end of telophase I have already replicated (i.e., they are found in pairs of sister chromatids). During meiosis II, the sister chromatids separate from each other, yielding individual chromosomes.

C21.

Prophase/Prometaphase	Telophase
Nuclear membrane dissociates.	Nuclear membrane re-forms.
Mitotic spindle forms.	Mitotic spindle disassembles.
Chromosomes condense.	Chromosomes decondense.
Chromosomes attach to spindle.	Chromosomes detach from the spindle.

C22. A. 20
B. 10
C. 30
D. 20

C23. The hybrid offspring would have 44 chromosomes (i.e., 25 + 19). The reason for infertility is because each chromosome does not have a homologous partner. Therefore, the chromosomes cannot properly pair during metaphase I, and the gametes do not receive one copy of each homolog. Gametes will be missing certain chromosomes, which makes them infertile.

C24. Male gametes are usually small and mobile. Animal and some plant male gametes often contain flagella, which make them motile. The mobility of the male gamete makes it likely that it will come in contact with the female gamete. Female gametes are usually much larger and contain nutrients to help the growth of the embryo after fertilization occurs.

C25. To produce sperm, a spermatogonial cell first goes through mitosis to produce two cells. One of these remains a spermatogonial cell and the other progresses through meiosis. In this way, the testes continue to maintain a population of spermatogonial cells.

C26. During oogenesis in humans, the cells are arrested in prophase I of meiosis for many years until selected primary oocytes progress through the rest of meiosis I and begin meiosis II. If fertilization occurs, meiosis II is completed.

C27. There is a 1/2 chance that the mother will transmit her abnormal chromosome and a 1/2 chance that the father will. We use the product rule to calculate the chances of both outcomes happening. So the answer is $1/2 \times 1/2 = 1/4$, or 25%. The probability that such a child will pass both chromosomes to an offspring is also 25% because that child had a 1/2 chance of passing either chromosome.

Application and Experimental Questions

E1. A. G_2 phase (it could not complete prophase)
B. Metaphase (it could not enter anaphase)
C. Telophase (it could not divide into two daughter cells)
D. G_2 phase (it could not enter prophase)

E2. During interphase, the chromosomes are longer, thinner, and much harder to see. In metaphase, they are highly condensed, which makes them thicker and shorter.

E3. You could karyotype other members of the family and see if affected members always carry the abnormal chromosome.

Questions for Student Discussion/Collaboration

1. It's not possible to give a direct answer, but the point is for students to be able to draw chromosomes in different configurations and understand the various phases. The chromosomes may or may not be:
    1. In homologous pairs
    2. Connected as sister chromatids
    3. Associated in bivalents
    4. Lined up in metaphase
    5. Moving toward the poles.
2. A major advantage of sexual reproduction is that it fosters genetic diversity within future populations. A major disadvantage is that individuals of opposite sex must find a mate.

CHAPTER 3

Note: the answers to Comprehension questions are at the end of the chapter.

Concept check questions (in figure legends)

FIGURE 3.2 The male gamete is found within pollen.