7 The Cell Cycle and Cell Division

Chapter Outline

A cell, like any other living thing, does not live forever. The continuity of life in a single-celled organism requires that it produce copies. Multicellular organisms start life as a single "parent" cell and then produce many, many "offspring" cells during growth and development.

To understand cell replication, you must learn how DNA is duplicated in a parent cell and then evenly shared between two offspring cells. After the duplication and segregation of DNA are complete, the parent cell physically splits into two offspring cells, each enclosed by its own membrane via a process called *cytokinesis*.

Binary fission and mitosis are the two primary mechanisms by which cells produce copies of themselves. Prokaryotes are unicellular organisms that typically contain only one chromosome, and they achieve cell duplication via binary fission. The DNA in the chromosome is copied end-to-end, with one copy ending up on one side of the cell and the other copy on the other. As this separation occurs, the cell membranes grow toward the middle of the parent cell to effectively pinch it in half, with each half receiving one complete copy of the chromosome. In contrast, eukaryotic cells undergo mitosis. Because they have multiple chromosomes, the copying of these individual molecules of DNA must be synchronized and coordinated. After copying is complete, the two full sets of chromosomes must be moved to opposite ends of the parent cell before it separates into two offspring cells.

The phases of the cycle of eukaryotic cell duplication make up the cell cycle. The cell (e.g., a liver cell involved in metabolism) grows and carries out its normal function during the G1 phase of the cell cycle. At some point, a growth regulator protein called cyclin activates the cellular machinery that replicates DNA. This is known as the S phase of the cycle, as in DNA synthesis. The next phase of the cycle, during which the components needed for mitosis are made, is called the G2 phase. At the end of the G2 phase, the stage is set for mitosis. Mitosis proceeds, and the cell cycle moves from interphase to prophase, during which distinct duplicated chromosomes are microscopically visible. Next, the duplicated chromosomes line up across the middle of the cell during metaphase, and they are pulled to opposite poles during anaphase. Finally, during telophase, each set of chromosomes becomes surrounded by nuclear membranes, and during cytokinesis, the membranes enclose each new cell.

Eukaryotes that reproduce sexually gain the evolutionary benefits of mixing together the genes of two different parents, resulting in offspring that are not identical to either parent. In this scenario, the parents' reproductive systems have cells that undergo two nuclear divisions, producing haploid cells called gametes via the process of meiosis. Gametes are cells with only one copy of the otherwise paired chromosomes that are typical of diploid cells. The gametes become fused into a single diploid cell, called a zygote, as a result of mating. As in previous chapters, you have seen many new terms. Two of these—*haploid* and *diploid*—are very important to understanding the nature of life cycles of living organisms.

You should now realize that cell reproduction is highly regulated; otherwise, living organisms would use up all of their resources and perish. When regulation breaks down, uncontrolled growth and cancer can result.

Chapter 7 concludes with a description of cell death, which takes place either by extensive damage to the cell, killing it outright, or by the initiation of genetic programming that results in hydrolytic destruction. This "genetically regulated cell death" is called apoptosis. It can protect an individual from a spreading infection and facilitate the recycling of cellular materials.

In the AP Biology Curriculum Framework, Chapter 7 develops **Big Idea 2**, invoking regulatory mechanisms of living organisms, but it is more directed at understanding **Big Idea 3**, information transfer.

Big Idea 2 states that utilization of free energy and use of molecular building blocks are characteristic of life processes. Chapter 7 discusses the signals that initiate cell duplication and cell death. Specific parts of the AP Biology curriculum that are covered in Chapter 7 include:

- **2.C.1:** Organisms use feedback mechanisms to maintain their internal environments and respond to external environmental changes.

Big Idea 3 states that living systems store, retrieve, transmit, and respond to information essential to life processes. Chapter 7 lays the groundwork for examining cellular reproduction. Specifically, Chapter 7 includes:

- **3.A.2:** In eukaryotes, heritable information is passed to the next generation via processes that include the cell cycle and mitosis or meiosis plus fertilization.
- **3.C.1:** Changes in genotype can result in changes in phenotype.
- **3.C.2:** Biological systems have multiple processes that increase genetic variation.

Chapter Review

Concept 7.1 *examines how different life cycles use various modes of cell reproduction. The reproduction of cells is the basis for the continuity of life. Cells reproduce through both sexual and asexual means. Diploid cells carry two sets of homologous chromosomes, one from each parent. Mitosis replicates all of these chromosomes identically to create a new cell via asexual reproduction. In sexual reproduction, meiosis halves the diploid number of chromosomes, creating haploid gametes. When two gametes unite to create a new generation, a single-celled diploid zygote results and proceeds to mitosis.*

1. Identify the three major reasons for the reproduction of cells.

   a. _____

   b. _____

   c. _____

2. The clonal production of identical cells is called _____

3. Discuss the possible consequences of the inexact duplication of DNA.

   _____

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4. Describe the differences between haploid and diploid cells, and identify the processes by which these two types of cells are produced.

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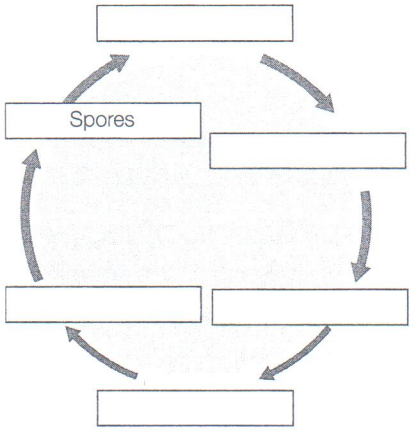
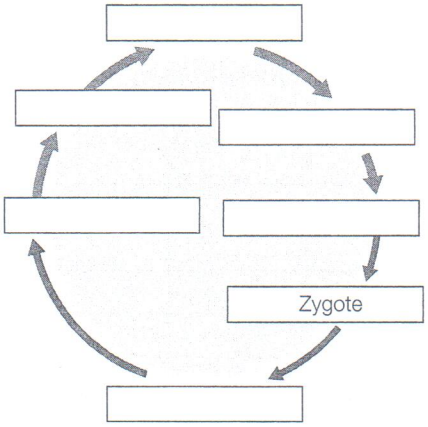
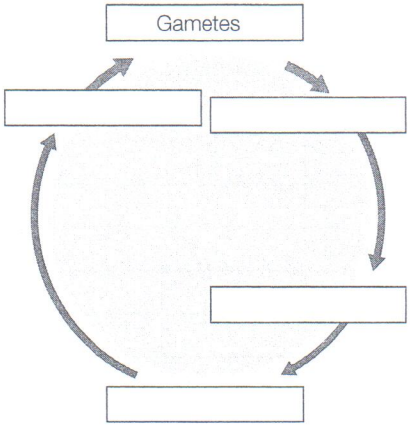
5. Discuss the formation of the diploid cell known as the zygote.

6. Briefly describe what happens to a zygote after it is formed, assuming success in its first week.

7. Complete the life-cycle diagrams shown by writing meiosis, fertilization, zygote, spore, gamete, mature organism, haploid, alternation of generations, and diploid in the correct boxes. Write mold, plant, or animal on the line below the appropriate diagram.







8. Describe the relative advantage of asexual reproduction over sexual reproduction during prolonged periods of favorable environmental conditions and abundant resources.

9. Discuss the relative advantage of sexual reproduction over asexual reproduction during prolonged periods of varying environmental conditions with fluctuations in resource availability.

Concept 7.2 *explores how both binary fission and mitosis produce genetically identical cells. Asexual reproduction by either method produces such cells. In single-celled organisms, such as the amoeba, this is how new amoeba arise. For multicellular organisms, such as birds and insects, mitosis is the mechanism of growth and development or repair and replacement of dead, dying, or worn-out tissues.*

10. Briefly describe each of the four key events that are common to both binary fission and mitosis.

a. _____

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b. _____

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c. _____

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d. _____

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11. Describe two ways that binary fission differs from mitosis.

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12. Compare cytokinesis in plant and animal cells.

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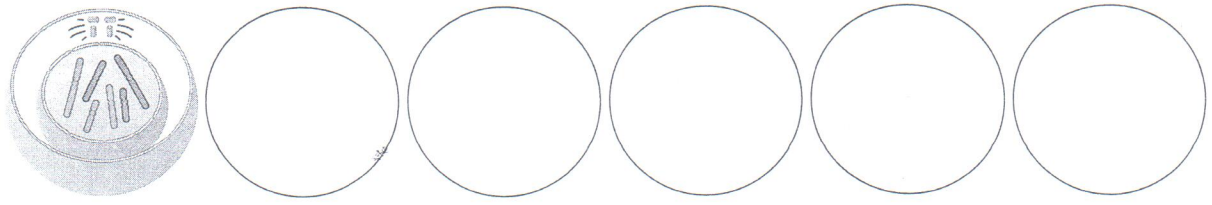
13. The diploid ($2n = 6$) cell shown below is in interphase, prior to DNA replication. In the circles below, draw the five steps of mitosis that this cell would undergo during replication.



14. The interphase of the cell cycle is divided into three distinct phases: G1, S, and G2. Briefly describe what happens during each part of interphase.

a. G1: _____

_____

b. S: _____

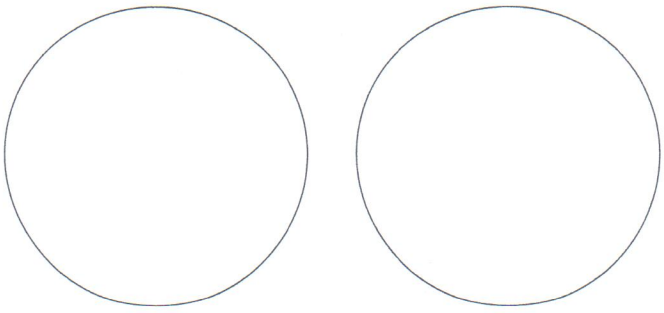
_____

c. G2: _____

_____

15. Draw a chromosome that has two chromatids, and label the centromere and sister chromatids.

16. In the circles at the right, draw the nuclear contents of a cell with $2n = 8$ at the beginning and end of the S phase of interphase.



Beginning of S phase End of S phase

17. Assume that a mutation in a cell results in nonfunctional proteins needed for the kinetochore to function properly. Describe what would happen to that cell during attempted duplication.

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Concept 7.3 *explains how cell reproduction is under precise control. Cell reproduction requires access to nutrients and space and is closely regulated by signaling mechanisms. A single-celled species with unregulated reproduction would likely soon exceed the carrying capacity of its environment and would starve to death. In a multicellular organism, cell reproduction is closely regulated to maintain the forms and functions of different parts of the body. Cancer is largely a disease of deregulated mitosis, and rapidly growing tumors deprive other body parts access to nutrients and waste removal.*

18. Identify and describe the key restriction point of the cell cycle. Identify the phase where this regulation takes place.

19. Explain the biochemical actions of protein kinases in controlling the cell cycle.

20. The cyclin-CDK complexes regulate the cell cycle by many of the mechanisms described in previous chapters. Briefly explain how each mechanism below plays a role in the regulation of the G1 (restriction point) checkpoint of interphase.

a. Allosteric regulation:

b. Gene expression:

c. Protein synthesis:

d. Signal transduction:

e. Cell division:

Concept 7.4 *describes how meiosis halves the nuclear chromosome content and generates diversity among offspring. Meiosis forms haploid gametes that unite to initiate the next generation. Meiosis also results in offspring that are inexact copies of any one parent, providing fodder for natural selection as the environment or ecosystem changes. Without meiosis, each new generation would be a clone of the previous generation and would be at a disadvantage to react to changes in the environment. Crossing over and independent assortment rearrange existing genetic variation between gametes, while other meiotic errors can create new variation, often leading to cancer and other diseases.*

21. Meiosis serves several important purposes for sexual reproduction. Describe what would happen if each of the following did *not* occur prior to sexual reproduction.

a. Chromosome number reduced: _____

_____

_____

b. A complete set of chromosomes made: _____

_____

_____

c. Genetic diversity generated: _____

_____

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22. Complete the chart below, comparing mitosis and meiosis.

	Mitosis	**Meiosis**
Number of daughter cells		
Chromosome number of parent cell	____n	____n
Chromosome number of daughter cell	____n	____n
Number of nuclear divisions		
Pairing of homologous chromosomes? (Yes/No)		
Daughter nuclei are genetically identical? (Yes/No)		

23. Identify and describe two processes that cause daughter nuclei formed during meiosis to be genetically different.

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_____

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24. Calculate the quantity of each of the following for an organism with a diploid number of $2n = 12$.

a. Chromatids at prophase of mitosis: _____

b. Chromosomes at metaphase of mitosis: _____

c. Centromeres at prophase of meiosis I: _____

d. Chromosomes in a gamete: _____

e. Chromosomes in a skin cell: _____

f. Daughter nuclei after mitosis: _____

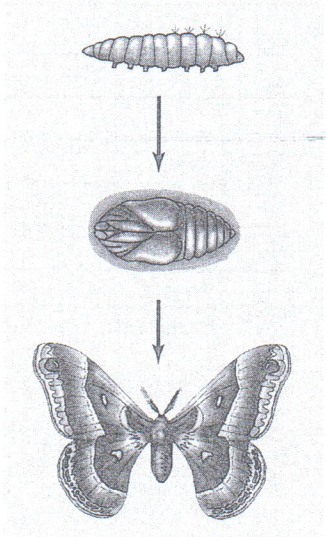
g. Chromosomes after meiosis I: _____

Concept 7.5 *explains why programmed cell death is a necessary process in living organisms. Cells die in two primary ways. Necrosis occurs when cells die of starvation, are cut open (wounded), or are poisoned. This frequently causes inflammation, which is the redness and swelling we associate with an injury. More often, cell death is due to apoptosis, a genetically programmed series of events.*

25. Explain the difference between apoptosis and necrosis. Give an example of each.

26. Why is apoptosis important to the normal, healthy development of an organism? Give an example of when and where it occurs in humans.

27. Explain how a caterpillar forms a cocoon and then develops into a moth, as shown in the figure at the right.



28. Two types of proteins implicated in the regulation of the cell cycle are oncogene proteins and tumor suppressors. Briefly describe the role that each plays in cancer.

a. Oncogene proteins: _____

_____

b. Tumor suppressors: _____

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Science Practices & Inquiry

In the AP Biology Curriculum Framework, there are seven **Science Practices**. In this chapter, we focus on **Science Practice 6:** The student can work with scientific explanations and theories; and **Science Practice 7:** The student is able to connect and relate knowledge across various scales, concepts, and representations in and across domains.

Question 29 focuses on **Science Practice 6,** asking you to construct an explanation, using visual representations or narrative, as to how DNA in chromosomes is transmitted to the next generation via mitosis or meiosis followed by fertilization.

29. In an elegant set of experiments, Rao and Johnson (published in *Nature*, 1970) determined some of the important elements of cell cycle regulation. Rao and Johnson fused together mammalian cells at different times of the cell cycle (G1, S, and G2). After fusion, the nuclei were monitored and the time required for mitosis to occur was measured. Below are three of their experiments with the results. For each, write a two- or three-sentence conclusion about what the experiment shows.

a. Fusion of S-phase cells with G2-phase cells

Result: Chromosome replication continued in the S nucleus, while the G2 nucleus was unable to synthesize DNA.

Conclusion: _____

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b. Fusion of S-phase cells with G1-phase cells

Result: The G1 nuclei rapidly moved into S phase.

Conclusion: _____

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c. Fusion of G1-phase cells with G2-phase cells

Result: The entry of the G2 nucleus into mitosis was delayed.

Conclusion: _____

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