

Chapter 12: Cell Cycle

1. What are the three key functions of cell division?

Key Function	Example
reproduction	an amoeba dividing into two cells, each constituting an individual organism
growth and development	fertilized egg gives rise to two-celled sand dollar embryo
tissue renewal	dividing cells in bone marrow continuously make new blood cells

2. What is meant by “cell cycle”?

The cell cycle is the life of a cell from the time it is first formed from a dividing parent cell until its own division into two daughter cells. This process is cyclical because every cell forms from a preexisting cell.

3. What is the meaning of “genome”? Compare your genome to that of a prokaryotic cell.

A cell's endowment of DNA, its genetic information, is called its genome. While a prokaryotic genome is often a single DNA molecule, a typical human cell has 46 molecules of DNA.

4. How many chromosomes are in a human somatic cell?

The nuclei of human somatic cells each contain 46 chromosomes, made up of two sets of 23, one set inherited from each parent.

5. Name two types of somatic cells in your body.

Somatic cells include bone cells and liver cells.

6. What is a gamete?

Gametes are reproductive cells.

7. Name the two types of gametes.

Sperm are the gametes in males and eggs are the gametes in females.

8. How many chromosomes are in a human gamete?

A human gamete contains one set of 23 chromosomes.

9. Define chromatin.

Chromatin is the entire complex of DNA and proteins that makes up chromosomes.

10. How many DNA molecules are in each of your somatic cells?

Since each chromosome consists of one DNA molecule, each human somatic cell contains 46 chromosomes.

11. The sketch represents a replicated chromosome that has two sister chromatids.

A chromosome is a packaged gene-carrying structure consisting of chromatin. A chromatid is one copy of a duplicated chromosome. A centromere is a region containing specific DNA sequences where the chromatid is attached most closely to its sister chromatid (represented by the narrow “waist”).

12. Summarize what occurs at the DNA level in each stage of chromosome duplication.

[1] One of the multiple chromosomes in a eukaryotic cell, a long, thin chromatin fiber containing one DNA molecule and associated proteins, is duplicated, involving the replication of DNA, and condensed. [2] Once duplicated, the chromosome consists of two sister chromatids connected along their entire lengths by sister chromatid cohesion. Each chromatid contains a copy of the DNA molecule. [3] Molecular and mechanical processes separate the sister chromatids into two distinct chromosomes and distribute them to two daughter cells.

13. What is mitosis? How is it different from cytokinesis?

Mitosis, the division of the genetic material in the nucleus, is usually followed immediately by cytokinesis, the division of the cytoplasm.

14. What occurs in meiosis? How is the chromosome number of daughter cells different?

Meiosis is the variation of cell division that produces gametes, which yields nonidentical daughter cells that have only one set of chromosomes, half as many chromosomes as the parent cell.

15. Compare mitotic and meiotic processes.

Mitosis is the process by which identical daughter cells are produced, the damaged cells are replaced in a wound, and a zygote develops into a multicellular organism. Meiosis is the process by which eggs are formed and the chromosome number of daughter cells is reduced.

16. A hedgehog has 90 chromosomes in its somatic cells.

The hedgehog inherited 45 chromosomes from each parent. There are 45 chromosomes in each of the hedgehog's gametes. Ninety chromosomes will be in each somatic cell of the hedgehog's offspring.

17. Give a brief explanation of what happens in each subphase of the interphase. ✎

A cell grows (G_1), continues to grow as it copies its chromosomes (S), grows more as it completes preparations for cell division (G_2), and divides (M).

18. What are the components of the mitotic spindle? What is the source of these components?

In animal cells, the mitotic spindle, a structure consisting of fibers made of microtubules and associated proteins, emerges from the centrosome, a subcellular region containing material that functions throughout the cell to organize the cell's microtubules.

19. In animal cells, the assembly of spindle microtubules starts at the centrosome.

The microtubule-organizing center is another name for the centrosome.

21. Describe what happens to the centrosome during interphase and then prophase.

During interphase in animal cells, the single centrosome duplicates, forming two centrosomes, which remain together near the nucleus. The two centrosomes move apart during prophase and prometaphase of mitosis as spindle microtubules grow out from them. By the end of prometaphase, the two centrosomes, one at each pole of the spindle, are at opposite ends of the cell.

22. What is a kinetochore? ✎

Each of the two sister chromatids of a duplicated chromosome has a kinetochore, a structure of proteins associated with specific sections of chromosomal DNA at each centromere.

23. Describe each mitotic phase. ✎

In G_2 of interphase, a nuclear envelope encloses the nucleus, which contains one or more nucleoli. Two centrosomes, each containing two centrioles, are formed by the duplication of a single centrosome. Chromosomes, duplicated during S phase, cannot be individually distinguished because they have not yet condensed.

In prophase, the chromatin fibers condense into discrete chromosomes and the nucleoli disappear. Each duplicated chromosome appears as two identical sister chromatids joined at their centromeres and, in some species, all along their arms by cohesins. The mitotic spindle begins to form. It is composed of the centrosomes and the microtubules that extend from them. The radial arrays of shorter microtubules that extend from the centrosomes are called asters. The centrosomes move away from each other, propelled partly by the lengthening microtubules between them.

In prometaphase, the nuclear envelope fragments, and the microtubules extending from each centrosome can now invade the nuclear area. The chromosomes have become even more condensed. Each of the two chromatids of each chromosome now has a kinetochore, a specialized protein structure at the centromere. Some of the microtubules attach to the kinetochores, becoming “kinetochore microtubules,” which jerk the chromosomes back and forth. Nonkinetochore microtubules interact with those from the opposite pole of the spindle.

In metaphase, the centrosomes reach the opposite poles of the cell while the chromosomes convene at the metaphase plate, a plane that is equidistant between the spindle’s two poles. The chromosomes’ centromeres lie at the metaphase plate. For each chromosome, the kinetochores of the sister chromatids are attached to kinetochore microtubules coming from opposite poles.

Anaphase, the shortest stage of mitosis, begins when the cohesin proteins are cleaved, allowing the two sister chromatids of each pair to part suddenly. Each chromatid thus becomes a full-fledged chromosome. The two liberated daughter chromosomes begin moving toward opposite ends of the cell as their kinetochore microtubules shorten. Because these microtubules are attached at the centromere region, the chromosomes move centromere first. The cell elongates as the nonkinetochore microtubules lengthen. By the end of anaphase, the two ends of the cell have equivalent and complete collections of chromosomes.

In telophase, two daughter nuclei form in the cell. Nuclear envelopes arise from the fragments of the parent cell’s nuclear envelope and other portions of the endomembrane system. Nucleoli reappear and the chromosomes become less condensed. Any remaining spindle microtubules are depolymerized. Mitosis, the division of one nucleus into two genetically identical nuclei, is complete. In animal cells, cytokinesis involves the formation of a cleavage furrow, which pinches the cell in two.

24. Explain the difference between kinetochore and nonkinetochore microtubules and the function of each.

Unlike nonkinetochore microtubules, kinetochore microtubules attach to the kinetochores and jerk the chromosomes back and forth, eventually aligning them along the metaphase plate. In a dividing animal cell, the nonkinetochore microtubules are responsible for elongating the whole cell during anaphase.

26. At which end do kinetochore microtubules shorten during anaphase?

A 1987 experiment to determine whether kinetochore microtubules depolymerize at the kinetochore end or the pole end as chromosomes move toward the poles during mitosis concluded that the microtubule segments on the kinetochore side of the mark shorten, while those on the spindle pole side stay the same length. The experimenters marked a region of the kinetochore microtubules between one spindle pole and the chromosomes, then monitored the changes in microtubule length on either side of the mark. As the chromosomes moved poleward, the microtubule segments on the kinetochore side of the mark shortened, while those on the spindle pole side stayed the same length.

27. Describe cytokinesis in an animal cell. ✍

In animal cells, cytokinesis occurs by a process known as cleavage. The first sign of cleavage is the appearance of a cleavage furrow, a shallow groove in the cell surface near the old metaphase plate. On the cytoplasmic side of the furrow is a contractile ring of actin microfilaments associated with molecules of the protein myosin. The actin microfilaments interact with the myosin molecules, causing the ring to contract. The contraction of the dividing cell’s ring of microfilaments is like the pulling of a drawstring. The cleavage furrow deepens until the parent cell is pinched in two, producing two completely separated cells, each with its own nucleus and share of cytosol, organelles, and other subcellular structures.

28. Describe cytokinesis in a plant cell. ✍

Cytokinesis in plant cells, which have cell walls, does not involve a cleavage furrow. Instead, during telophase, vesicles derived from the Golgi apparatus move along microtubules to the middle of the cell, where they coalesce, producing a cell plate. Cell wall materials carried in the vesicles collect in the cell plate as it grows. The cell plate enlarges until its surrounding membrane fuses with the plasma membrane along the perimeter of the cell. Two daughter cells result, each with its own plasma membrane. Meanwhile, a new cell wall arising from the contents of the cell plate has formed between the daughter cells.

29. How is the cell plate formed? What is the source of the material for the cell plate?

Vesicles from the Golgi apparatus containing cellulose move along microtubules to the center of the cell, where they coalesce, forming the cell plate, as new cell wall materials fuse with the plasma membrane and the old cell wall.

30. Prokaryote reproduction does not involve mitosis, but instead occurs by binary fission. Describe binary fission.

In binary fission, a prokaryotic cell grows to roughly double its size, then divides to form two cells.

31. Besides the fact that prokaryotes lack a membrane-bounded nucleus, contrast prokaryotic and eukaryotic cells.

Prokaryotes reproduce through binary fission, while eukaryotes reproduce through mitosis or meiosis. Prokaryotes typically contain a single bacterial chromosome, while eukaryotes usually contain several chromosomes. In prokaryotes, chromosomes are not condensed; in eukaryotes, chromosomes are condensed into discrete chromosomes with certain genes.

32. What controls the cell cycle?

The sequential events of the cell cycle are directed by a distinct cell cycle control system, a cyclically operating set of molecules in the cell that both triggers and coordinates key events in the cell cycle.

33. What is a cell cycle checkpoint?

A checkpoint in the cell cycle is a control point where stop and go signals can regulate the cycle.

34. Summarize what happens at each checkpoint.

Checkpoint	What happens and how it is controlled
G ₁	“restriction point” in animal cells; continues on to G ₂ if go, will usually complete cycle; exits cell cycle and enters G ₀ , a nondividing state, if no go; regulated by the activity of cyclin-Cdk protein complexes
G ₂	MPF triggers cell’s passage past G ₂ checkpoint into M phase if all chromosomes have been replicated
M	irreversible anaphase stage entered only if all sister chromatids correctly attached to spindle microtubules

35. Describe the G₀ phase.

Most cells of the human body are in the G₀ phase, a nondividing state.

36. What is a protein kinase?

Protein kinases are enzymes that activate or inactivate other proteins by phosphorylating them. Particular protein kinases give the go-ahead signals at the G₁ and G₂ checkpoints.

37. Kinases drive the cell cycle, but they must be activated by the attachment of...

...a cyclin, a protein that derives its name from its cyclically fluctuating concentration in the cell. Because of this requirement, these kinases are called cyclin-dependent kinases (Cdks).

38. Why does the activity of cyclin-dependent kinases (Cdks) rise and fall?

The activity of a Cdk rises and falls with changes in the concentration of its cyclin partner.

39. What does MPF trigger? What are some specific activities that it triggers?

MPF (maturation-promoting factor) triggers the cell’s passage past the G₂ checkpoint into M phase. For example, MPF causes phosphorylation of various proteins of the nuclear lamina, which promotes fragmentation of the nuclear envelope during prometaphase of mitosis.

40. What happens if all the chromosome kinetochores are not attached to spindle fibers?

This condition keeps the cell from passing the M checkpoint. Anaphase, the separation of sister chromatids, does not begin until all the chromosomes are properly attached to the spindle at the metaphase plate.

41. What are growth factors? How does PDGF stimulate fibroblast division?

Growth factors are proteins released by certain cells that stimulate other cells to divide. Fibroblasts have PDGF (platelet-derived growth factor) receptors on their plasma membranes. The binding of PDGF molecules to these receptor tyrosine kinases triggers a signal transduction pathway that allows the cells to pass the G₁ checkpoint and divide.

42. Cancer cells exhibit different behaviors than normal cells. Explain two normal behaviors they no longer show.

Density-dependent inhibition is a phenomenon in which crowded cells stop dividing. The bindings of a cell-surface protein to its counterpart on an adjoining cell sends a growth-inhibiting signal to both cells, preventing them from moving forward in the cell cycle, even in the presence of growth factors. Moreover, in a phenomenon known as anchorage dependence, most cells must be attached to a substratum, such as the extracellular matrix of a tissue, in order to divide. Anchorage is probably signaled to the cell cycle control system via pathways involving plasma membrane proteins and elements of the cytoskeleton linked to them.

43. Cancer cells also show loss of cell cycle controls and may divide without being checked.

HeLa cells are derived from a tumor removed from a woman named Henrietta Lacks in 1951 and are apparently immortal!

44. What is transformation? What is metastasis?

Transformation is the process that converts a normal cell to a cancer cell. Cancer cells may secrete signaling molecules that cause blood vessels to grow toward the tumor. A few tumor cells may separate from the original tumor, enter blood vessels and lymph vessels, and travel to other parts of the body. There, they may proliferate and form a new tumor. This spread of cancer cells to locations distant from their original site is called metastasis.

45. Distinguish between a benign tumor and a malignant tumor.

Most benign tumors do not cause serious problems and can be completely removed by surgery. In contrast to benign tumors, whose abnormal cells remain at the original site if they have too few genetic and cellular changes to survive at another site, malignant tumors include cells whose genetic and cellular changes enable them to spread to new tissues and impair the functions of one or more organs. An individual with a malignant tumor is said to have cancer.

46. List two specific cancer treatments and explain how each treatment works.

The chemotherapeutic drug Taxol freezes the mitotic spindle by preventing microtubule depolymerization, which stops actively dividing cells from proceeding past metaphase. Also, the cells of about 20–25% of breast cancer tumors show abnormally high amounts of a cell-surface receptor tyrosine kinase called HER2, and many show an increase in the number of estrogen receptor (ER) molecules, intracellular receptors that can trigger cell division. In this case, chemotherapy can be prescribed with a molecule that blocks the function of the specific protein (herceptin for HER2 and tamoxifen for ERs).

47. Identify each phase of the cell cycle. ✎

1: prometaphase; 2: prophase; 3: telophase; 4: anaphase; 5: metaphase