Chapter Two: Chromosomes and Cellular Reproduction

COMPREHENSION QUESTIONS

Section 2.1

1. What are some genetic differences between prokaryotic and eukaryotic cells?

Solution:

Prokaryotic cell	Eukaryotic cell
No nucleus No paired chromosomes (haploid) Typically single circular chromosome containing a single origin of replication Single chromosome is replicated with each copy moving to opposite sides of the cell No histone proteins bound to DNA	Nucleus present Paired chromosomes common (diploid) Typically multiple linear chromosomes containing centromeres, telomeres, and multiple origins of replication Chromosomes are replicated and segregate during mitosis or meiosis to the proper location Histone proteins are bound to DNA

2. Why are viruses often used in the study of genetics?

Solution:
The close relationship between a virus and its cell host, along with the simpler structure of the viral particle, makes it useful in studying the genetics of mammals. The viral genome will have a similar genetic structure to its cell host, but because it has fewer genes, it will be easier to decipher the interactions and regulation of the viral genes.

Section 2.2

3. List three fundamental events that must take place in cell reproduction.

Solution:
(1) A cell's genetic information must be copied.
(2) The copies of the genetic information must be separated from one another.
(3) The cell must divide into two daughter cells.

4. Outline the process by which prokaryotic cells reproduce.

Solution:
(1) Replication of the circular chromosome takes place.
(2) The two replicated chromosomal copies attach to the plasma membrane.

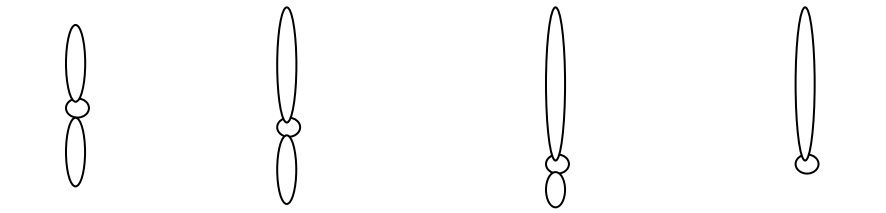
(3) The plasma membrane grows, which results in the separation of the two chromosomes.
(4) A new cell wall is formed between the two chromosomes, producing two cells, each with its own chromosome.

5. Name three essential structural elements of a functional eukaryotic chromosome and describe their functions.

Solution:
(1) Centromere: serves as the point of attachment for the kinetochore to which spindle fibers (microtubules) attach
(2) Telomeres, or the natural ends of the linear eukaryotic chromosome: serve to stabilize the ends of the chromosome; may have a role in limiting cell division
(3) Origins of replication: serve as the starting place for DNA synthesis

6. Sketch and identify four different types of chromosomes based on the position of the centromere.

Solution:



7. List the stages of interphase and the major events that take place in each stage.

Solution:
Three predominant stages are found in interphase of cells active in the cell cycle.
(1) G_1 (Gap 1): In this phase, the cell grows and synthesizes proteins necessary for cell division. During G_1, the G_1/S checkpoint takes place. Once the cell has passed this checkpoint, it is committed to divide.
(2) S phase: During S phase, DNA replication takes place.
(3) G_2 (Gap 2): In G_2, additional biochemical reactions take place that prepare the cell for mitosis. A major checkpoint in G_2 is the G_2/M checkpoint. Once the cell has passed this checkpoint, it enters into mitosis.

A fourth stage is frequently found in cells prior to the G_1/S checkpoint. Cells may exit the active cell cycle and enter into a nondividing stage called G_0.

8. What are checkpoints? List some of the important checkpoints in the cell cycle.

Solution:
Checkpoints function to ensure that all the cellular components, such as important proteins and chromosomes, are present and functioning before the cell moves to the next stage of the cell cycle. If components are missing or not functioning, the checkpoint will prevent the cell from moving to the next stage. The checkpoints prevent defective cells from replicating and malfunctioning.

These checkpoints occur throughout the various stages of the cell cycle. Important checkpoints include the G_1/S checkpoint, which occurs during G_1 prior to the S phase; the G_2/M checkpoint, which occurs in G_2 prior to mitosis; and the spindle-assembly checkpoint, which occurs during mitosis.

9. List the stages of mitosis and the major events that take place in each stage.

Solution:
(1) Prophase: The chromosomes condense and become visible, the centrosomes move apart, and microtubule fibers form from the centrosomes.
(2) Prometaphase: The nucleoli disappear and the nuclear envelope begins to disintegrate, allowing for the cytoplasm and nucleoplasm to join. The sister chromatids of each chromosome are attached to microtubules from the opposite centrosomes.
(3) Metaphase: The spindle microtubules are clearly visible and the chromosomes arrange themselves on the equatorial plane of the cell.
(4) Anaphase: The sister chromatids separate at the centromeres after the breakdown of cohesin protein, and the newly formed daughter chromosomes move to the opposite poles of the cell.
(5) Telophase: The nuclear envelope reforms around each set of daughter chromosomes. Nucleoli reappear. Spindle microtubules disintegrate.

10. Briefly describe how the chromosomes move toward the spindle poles during anaphase.

Solution:
Due to the actions of the microtubule subunits attached to the kinetochores of the chromosome and motor proteins (e.g., the protein kinesin is a motor protein), the chromosomes are pulled toward the spindle poles during anaphase. The spindle fibers are composed of tubulin protein subunits. As the tubulin subunits are removed from the "–" end of the microtubule, the chromosome is pulled (or "reeled in") toward the spindle pole as the microtubule is shortened. While at the "+" end, the kinetochore is removing tubulin subunits of the microtubule attached to the kinetochore with the net effect being the movement of the chromosome closer to the spindle pole. Molecular motor proteins, such as kinesin, are responsible for removing the subunits at the "+" and "–" ends of the microtubules and thus generate the force needed to move the chromosomes.

11. What are the genetically important results of the cell cycle and mitosis?

Solution:

In the mitotic cell cycle, the genetic material is precisely copied and mitosis ensures that the identical copies of the genetic material are separated accurately into the new daughter cells, resulting in two cells containing the same genetic information. In other words, the cells have genomes identical to each other and to the mother cell.

12. Why are the two cells produced by the cell cycle genetically identical?

Solution:
The two cells are genetically identical because during S phase an exact copy of each DNA molecule was created. These exact copies give rise to the two identical sister chromatids. Mitosis ensures that each new cell receives one of the two identical sister chromatids. Thus, the newly formed cells will contain identical daughter chromosomes.

Section 2.3

13. What are the stages of meiosis and what major events take place in each stage?

Solution:
Meiosis I: Separation of homologous chromosomes

Prophase I: The chromosomes condense and homologous pairs of chromosomes undergo synapsis. While the chromosomes are synapsed, crossing over occurs. The nuclear membrane disintegrates and the meiotic spindle begins to form.

Metaphase I: The homologous pairs of chromosomes line up on the equatorial plane of the metaphase plate.

Anaphase I: Homologous chromosomes separate and move to opposite poles of the cell. Each chromosome possesses two sister chromatids.

Telophase I: The separated homologous chromosomes reach the spindle poles and are at opposite ends of the cell.

Meiosis I is followed by cytokinesis, resulting in the division of the cytoplasm and the production of two haploid cells. These cells may skip directly into meiosis II or enter interkinesis, where the nuclear envelope reforms and the spindle fibers break down.

Meiosis II: Separation of sister chromatids

Prophase II: Chromosomes condense, the nuclear envelope breaks down, and the spindle fibers form.

Metaphase II: Chromosomes line up at the equatorial plane of the metaphase plate.

Anaphase II: The centromeres split, which results in the separation of sister chromatids.

Telophase II: The daughter chromosomes arrive at the poles of the spindle. The nuclear envelope reforms, and the spindle fibers break down. Following meiosis II, cytokinesis takes place.

14. What are the major results of meiosis?

Solution:
Meiosis involves two cell divisions, thus producing four new cells (in many species). The chromosome number of a haploid cell produced by meiosis I (haploid) is half the chromosome number of the original diploid cell. Finally, the cells produced by meiosis are genetically different from the original cell and genetically different from each other.

15. What two processes unique to meiosis are responsible for genetic variation? At what point in meiosis do these processes take place?

Solution:
(1) Crossing over, which begins during the zygotene stage of prophase I and is completed near the end of prophase I.
(2) The random distribution of separated members of the homologous chromosomes (the maternal and paternal chromosomes) to daughter cells, which takes place in anaphase I of meiosis. The arrangement for separation is determined by the random alignment of homologs in metaphase I.

16. How does anaphase I of meiosis differ from anaphase of mitosis?

Solution:
In anaphase I of meiosis, homologous chromosomes separate whereas in anaphase of mitosis the sister chromatids separate.

17. Briefly explain why sister chromatids remain together in anaphase I but separate in anaphase II of meiosis.

Solution:
In meiosis, a similar process to mitosis occurs. Meiosis-specific cohesin complexes (different from cohesion proteins in mitosis) form at the centromeres of the sister chromatids during the S phase. At the beginning of meiosis, cohesin molecules are also found along the entire length of the chromosome arms assisting in the formation of the synaptonemal complex and holding together the two homologs. During anaphase I of meiosis, the cohesin molecules along the arms are cleaved by activated separase allowing the homologs to separate. However, the cohesin complexes at the centromeres of the sister chromatids are protected from the action of separase by the protein shugoshin and are unaffected. The result is that sister chromatids remained attached during anaphase I. At the end of metaphase II, the

protection of the cohesin molecules at the centromeres is lost, and the separase proteins can now cleave the cohesin complex, which allows the sister chromatids to separate.

18. Outline the processes of spermatogenesis and oogenesis in animals.

Solution:
In animals, spermatogenesis occurs in the testes. Primordial diploid germ cells divide mitotically to produce diploid spermatogonia that can either divide repeatedly by mitosis or enter meiosis. A spermatogonium that has entered prophase I of meiosis is called a primary spermatocyte and is diploid. Upon completion of meiosis I, two haploid cells, called secondary spermatocytes, are produced. Upon completing meiosis II, the secondary spermatocytes produce a total of four haploid spermatids.

Female animals produce eggs through the process of oogenesis. Similar to what takes place in spermatogenesis, primordial diploid cells divide mitotically to produce diploid oogonia that can divide repeatedly by mitosis, or enter meiosis. An oogonium that has entered prophase I is called a primary oocyte and is diploid. Upon completion of meiosis I, the cell divides, but unequally. One of the newly produced haploid cells receives most of the cytoplasm and is called the secondary oocyte. The other haploid cell receives only a small portion of the cytoplasm and is called the first polar body. Ultimately, the secondary oocyte will complete meiosis II and produce two haploid cells. One cell, the ovum, will receive most of the cytoplasm from the secondary oocyte. The smaller haploid cell is called the second polar body. Typically, the polar bodies disintegrate, and only the ovum is capable of being fertilized.

19. Outline the processes of male gamete formation and female gamete formation in plants.

Solution:
Plants alternate between a multicellular haploid stage called the gametophyte and a multicellular diploid stage called the sporophyte. Meiosis in the diploid sporophyte stage of plants produces haploid spores that develop into the gametophyte. The gametophyte produces gametes by mitosis.

In flowering plants, the microsporocytes found in the stamen of the flower undergo meiosis to produce four haploid microspores. Each microspore divides by mitosis to produce the pollen grain, or the microgametophyte. Within the pollen grain are two haploid nuclei. One of the haploid nuclei divides by mitosis to produce two sperm cells. The other haploid nucleus directs the formation of the pollen tube.

Female gamete production in flowering plants takes place within the megagametophyte. Megasporocytes found within the ovary of a flower divide by meiosis to produce four megaspores. Three of the megaspores disintegrate, while the remaining megaspore divides mitotically to produce eight nuclei that form the embryo sac (or female gametophyte). Of the eight nuclei, one will become the egg.

APPLICATION QUESTIONS AND PROBLEMS

Introduction

*20. Answer the following questions about the blind men's riddle, presented in the introduction to this chapter.

a. What do the two socks of a pair represent in the cell cycle?

Solution:
The two chromatids of a chromosome

b. In the riddle, each blind man buys his own pairs of socks, but the clerk places all the pairs in one bag. Thus, there are two pairs of socks of each color in the bag (two black pairs, two blue pairs, two gray pairs, etc.). What do the two pairs (four socks in all) of each color represent?

Solution:
The two chromosomes of a homologous pair

c. What is the thread that connects the two socks of a pair?

Solution:
Cohesin

d. What is the molecular knife that cuts the thread holding the two socks in a pair together?

Solution:
The enzyme separase

e. What in the riddle performs the same function as spindle microtubles?

Solution:
The hands of the two blind men

f. What would happen if one man failed to grasp his sock of a particular pair? How does that outcome relate to events in the cell cycle?

Solution:
If one man failed to grasp his sock, it would be difficult for the knife to cut the string holding them together. The two socks of a pair would not be separated and both would end up in one man's bag. Similarly, if each chromatid is not attached to spindle fibers and pulled in opposite directions, the two chromatids will not separate and both would migrate to the same cell. This cell would have two copies of one chromosome.

Section 2.1

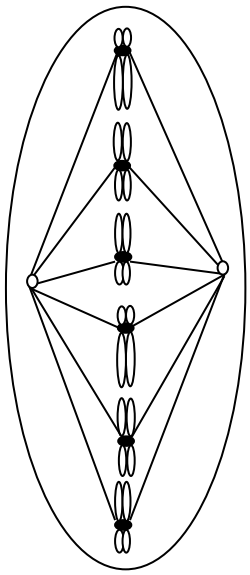
21. A cell has a circular chromosome and no nuclear membrane. Its DNA is complexed with some histone proteins. Does this cell belong to a eubacterium, an archaean, or a eukaryote? Explain your reasoning.

    Solution:
    This cell is most likely an archaea. The cell is not eukaryotic because it lacks a nuclear membrane and has a single circular chromosome. The cell is not a eubacterium because it has histone proteins, which are present in archaea and eukaryotes but lacking in eubacteria.

Section 2.2

22. A certain species has three pairs of chromosomes: an acrocentric pair, a metacentric pair, and a submetacentric pair. Draw a cell of this species as it would appear in metaphase of mitosis.

    Solution:



23. Examine **Figure 2.6a**. What type of chromosome (metacentric, submetacentric, acrocentric, or telocentric) is chromosome 1? What about chromosome 4?

    Solution:
    The centromere in chromosome 1 is centrally located, so it is metacentric. The centromere of chromosome 4 is located between the center and the end of the chromosome, so it is submetacentric.

*24. A biologist examines a series of cells and counts 160 cells in interphase, 20 cells in prophase, six cells in prometaphase, two cells in metaphase, seven cells in anaphase, and five cells in telophase. If the complete cell cycle requires 24 hours, what is the average duration of the M phase in these cells? Of metaphase?

Solution:
To determine the average duration of M phase in these cells, the proportion of cells in interphase, or in each stage of M phase, should be calculated by dividing the number of cells in each stage by the total number of cells counted. To calculate the time required for a given phase, multiply 24 hours by the proportion of cells at that stage. This will give the average duration of each stage in hours.

Stage	Number of cells counted	Proportion of cells at each stage	Average duration (hours)
Interphase	160	0.80	19.2
Prophase	20	0.10	2.4
Prometaphase	6	0.03	0.72
Metaphase	2	0.01	0.24
Anaphase	7	0.035	0.84
Telophase	5	0.025	0.6
Totals	200	1.0	24

The average duration of M phase can be determined by adding up the hours spent in each stage of mitosis. In these cells, M phase lasts 4.8 hours. The table shows that metaphase requires 0.24 hour, or 14.4 minutes.

25. In what stage of mitosis is the cell illustrated in the **chapter-opening figure** (p. 17)?

Solution:
In the chapter-opening figure, the sister chromatids within the cell have already separated and have moved apart. Likely the cell is either in late anaphase or in telophase.

Section 2.3

26. A certain species has three pairs of chromosomes: one acrocentric pair and two metacentric pairs. Draw a cell of this species as it would appear in the following stages of meiosis:
a. Metaphase I

Solution:

b. Anaphase I

Solution:

c. Metaphase II

Solution:

d. Anaphase II

Solution:

a.Metaphase I b. Anaphase I c. Anaphase d. Anaphase II

27. Construct a table similar to that in **Figure 2.12** for the different stages of meiosis, giving the number of chromosomes per cell and the number of DNA molecules per cell for a cell that begins with four chromosomes (two homologous pairs) in G_1. Include the following stages in your table: G_1, S, G_2, prophase I, metaphase I, anaphase I, telophase I (after cytokinesis), prophase II, metaphase II, anaphase II, and telophase II (after cytokinesis).

Solution:

	G_1	S	G_2	MI	A1	T1	PII	MII	AII	TII
Number of Chromosomes per cell	4	4	4	4	4	2	2	2	4	2
Number of DNA Molecules per cell	4	4 to 8	8	8	8	4	4	4	4	2

*28. A cell in G_1 of interphase has 12 chromosomes. How many chromosomes and DNA molecules will be found per cell when this original cell progresses to the following stages?

Solution:
The number of chromosomes and DNA molecules depends on the stage of the cell cycle. Each chromosome contains only one centromere, but after the completion of S phase, and prior to anaphase of mitosis or anaphase II of meiosis, each chromosome will consist of two DNA molecules.

a. G_2 of interphase

Solution:
G_2 of interphase occurs after S phase, when the DNA molecules are replicated. Each chromosome now consists of two DNA molecules. So a cell in G_2 will contain 12 chromosomes and 24 DNA molecules.

b. Metaphase I of meiosis

Solution:
Neither homologous chromosomes nor sister chromatids have separated by metaphase I of meiosis. Therefore, the chromosome number is 12, and the number of DNA molecules is 24.

c. Prophase of mitosis

Solution:
This cell will contain 12 chromosomes and 24 DNA molecules.

d. Anaphase I of meiosis

Solution:
During anaphase I of meiosis, homologous chromosomes separate and begin moving to opposite ends of the cell. However, sister chromatids will not separate until anaphase II of meiosis. The number of chromosomes is still 12, and the number of DNA molecules is 24.

e. Anaphase II of meiosis

Solution:
Homologous chromosomes were separated and migrated to different daughter cells at the completion of meiosis I. However, in anaphase II of meiosis, sister chromatids separate, resulting in a temporary doubling of the chromosome number in the now haploid daughter cell. The number of chromosomes and the number of DNA molecules present will both be 12.

f. Prophase II of meiosis

Solution:
The daughter cells in prophase II of meiosis are haploid. The haploid cells will contain six chromosomes and 12 DNA molecules.

g. After cytokinesis following mitosis

Solution:
After cytokinesis following mitosis the daughter cells will enter G_1. Each cell will contain 12 chromosomes and 12 DNA molecules.

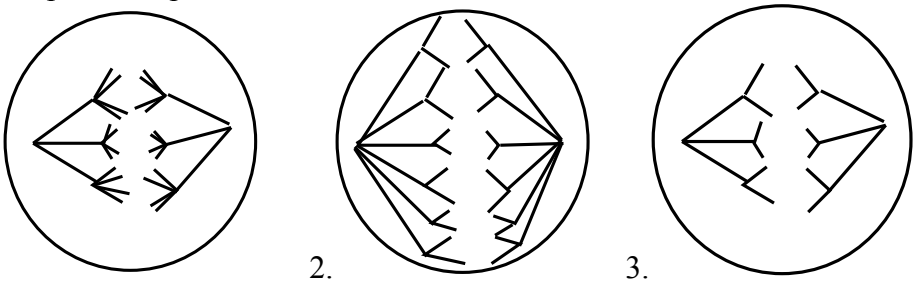
h. After cytokinesis following meiosis II

Solution:
After cytokinesis following meiosis II, the haploid daughter cells will contain six chromosomes and six DNA molecules.

29. How are the events that take place in spermatogenesis and oogenesis similar? How are they different?

Solution:
Both spermatogenesis and oogenesis begin similarly in that the diploid primordial cells (spermatogonia and oogonia) can undergo multiple rounds of mitosis to produce more primordial cells, or both types of cells can enter into meiotic division. In spermatogenesis, cytokinesis is equal, resulting in haploid cells of similar sizes. Upon completion of meiosis II, four haploid spermatids have been produced for each spermatogonium that began meiosis. In oogenesis, cytokinesis is unequal. At the completion of meiosis I in oogenesis, a secondary oocyte is produced, which is much larger and contains more cytoplasm than the other haploid cell produced, called the first polar body. At the completion of meiosis II, the secondary oocyte divides, producing the ovum and the second polar body. Again, the division of the cytoplasm in cytokinesis is unequal, with the ovum receiving most of the cytoplasmic material. Usually, the polar bodies disintegrate, leaving the ovum as the only product of meiosis.

*30. All of the following cells, shown in various stages of mitosis and meiosis, come from the same rare species of plant.



1. 2. 3.

a. What is the diploid number of chromosomes in this plant?

Solution:
To determine the diploid chromosome number in this plant, the number of centromeres present within a cell that contains homologous pairs of chromosomes must be determined. Remember, each chromosome possesses a single centromere. The location and presence of a centromere are determined by the attachment of the spindle fibers to the chromosome, which occurs at the centromere in the above diagram. Only the cell in stage (a) clearly has homologous pairs of chromosomes. So the diploid chromosome number for cells of this species of plant is six.

b. Give the names of each stage of mitosis or meiosis shown.

Solution:
Cell 1 is undergoing anaphase of meiosis I, as indicated by the separation of the homologous pairs of chromosomes. Cell 2 in the diagram contains six chromosomes, the diploid chromosome number for this species. Also in this cell, sister chromatids have separated, resulting in a doubling of the chromosome number within the cell from six to 12. Based on the number of chromosomes, the separation of sister chromatids in this cell must be occurring during anaphase of mitosis. In cell 3 again, sister chromatids are being separated, but the number of chromosomes present in the cell is only six. This indicates that no homologs are present within the cell, so in this cell the separation of sister chromatids is occurring in anaphase II of meiosis.

c. Give the number of chromosomes and number of DNA molecules per cell present at each stage.

Solution:
Cell 1, which is in anaphase I of meiosis contains six chromosomes and 12 DNA molecules (or sister chromatids). Cell 2 has 12 chromosomes and 12 DNA molecules in anaphase of mitosis. Cell 3, which is in anaphase II of meiosis has six chromosomes and six DNA molecules.

*31. The amount of DNA per cell of a particular species is measured in cells found at various stages of meiosis, and the following amounts are obtained:

Amount of DNA per cell in pictograms (pg)

___3.7 pg ___ 7.3 pg ___14.6 pg

Match the amounts of DNA above with the corresponding stages of meosis (*a* through *f*). You may use more than one stage for each amount of DNA.

Stage of meiosis

a. G_1

Solution:
7.3 pg
G_1 occurs prior to S phase and the doubling of the amount of DNA and prior to the completion of the meiosis II and cytokinesis, which will result in a haploid cell containing one-half the amount of DNA that was contained in the cell in G_1.

b. Prophase I

Solution:
14.6 pg
During prophase I of meiosis, the amount of DNA in the cell is two times the amount in G_1. The homologous chromosomes are still located within a single cell, and there are two sister chromatids per chromosome.

c. G_2

Solution:
14.6 pg
G_2 takes place directly after the completion of S phase, so the amount of DNA is two times the amount prior to the S phase.

d. Following telophase II and cytokinesis

Solution:
3.7 pg
Following cytokinesis associated with meiosis II, each daughter cell will contain only one-half the amount of DNA of a mother cell found in G_1 of interphase. By the completion of cytokinesis associated with meiosis II, both homologous pairs of chromosomes and sister chromatids have been separated into different daughter cells. Therefore, each daughter cell will contain only one-half the amount of DNA of the original cell in G_1.

e. Anaphase I

Solution:
14.6 pg
During anaphase I of meiosis, the amount of DNA in the cell is two times the amount in G_1. The homologous chromosomes are still located within a single cell, and there are two sister chromatids per chromosome.

f. Metaphase II

Solution:
7.3 pg
Metaphase II takes place after the cytokinesis associated with meiosis I and results in the daughter cells receiving only one-half the DNA found in their mother cell. In metaphase II of meiosis, the amount of DNA in each cell is the same as G_1 because each chromosome still consists of two DNA molecules (two sister chromatids per chromosome).

The amount of DNA in the cell will be doubled after the completion of S phase in the cell cycle and prior to cytokinesis in either mitosis or meiosis I. At the completion of cytokinesis following meiosis II, the amount of DNA will be halved.

*32. How would each of the following events affect the outcome of mitosis or meiosis?
a. Mitotic cohesin fails to form early in mitosis.

Solution:
Cohesin is necessary to hold the sister chromatids together until anaphase of mitosis. If cohesin fails to form early in mitosis, the sister chromatids could separate prior to

anaphase. The result would be improper segregation of chromosomes to daughter cells.

b. Shugoshin is absent during meiosis.

Solution:
Shugoshin protects cohesin proteins from degradation at the centromere during meiosis I. Cohesin at the arms of the homologous chromosomes is not protected by shugoshin and is broken in anaphase I, allowing for the two homologs to separate. If shugosin is absent during meiosis, then the cohesin at the centromere may be broken, allowing for the separation of sister chromatids along with the homologs during anaphase I, leading to improper segregation of chromosomes to daughter cells.

c. Shugoshin does not break down after anaphase I of meiosis.

Solution:
If shugoshin is not broken down, then the cohesins at the centromere will remain protected from degradation. The intact cohesins will prevent the sister chromatids from separating during anaphase II of meiosis, resulting in an improper separation of sister chromatids and daughter cells with too many or too few chromosomes.

d. Separase is defective.

Solution:
Homologous chromosomes and sister chromatids would not separate in meiosis and mitosis, resulting in some cells that have too few chromosomes and some cells that have too many chromosomes.

*33. A cell in prophase II of meiosis contains 12 chromosomes. How many chromosomes would be present in a cell from the same organism if it were in prophase of mitosis? Prophase I of meiosis?

Solution:
A cell in prophase II of meiosis will contain the haploid number of chromosomes. For this organism, 12 chromosomes represent the haploid chromosome number of a cell, or one complete set of chromosomes.

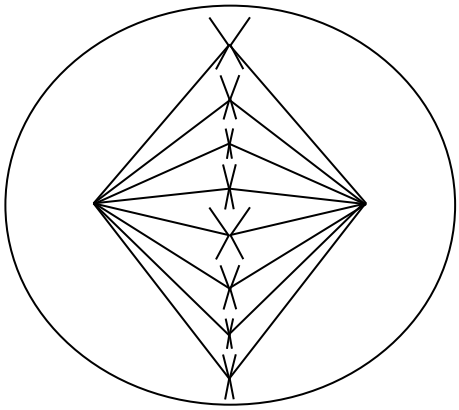
A cell from the same organism that is undergoing prophase of mitosis would contain a diploid number of chromosomes, or two complete sets of chromosomes, which means that homologous pairs of chromosomes are present. So a cell in this stage should contain 24 chromosomes.

Homologous pairs of chromosomes have not been separated by prophase I of meiosis. During this stage, a cell of this organism will contain 24 chromosomes.

34. A cell has eight chromosomes in G_1 of interphase. Draw a picture of this cell with its chromosomes at the following stages. Indicate how many DNA molecules are present at each stage.

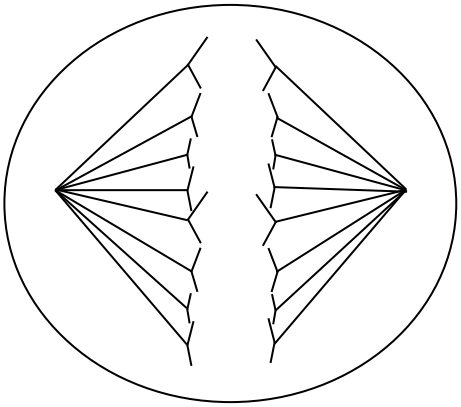
Solution:

a. Metaphase of mitosis



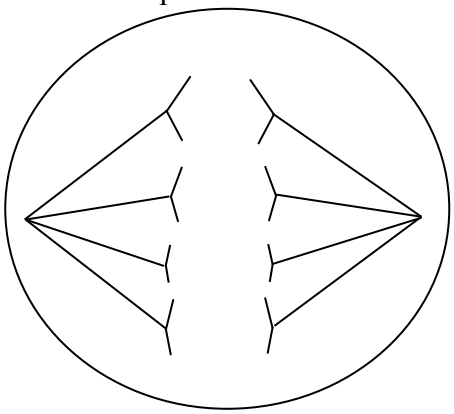
8 chromosomes
16 DNA molecules

b. Anaphase of mitosis



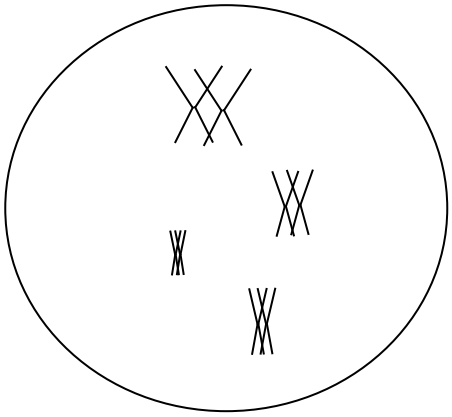
16 Chromosomes
16 DNA molecules

c. Anaphase II of meiosis



8 chromosomes
8 DNA molecules

d. Diplotene of meiosis I



8 Chromosomes
16 DNA molecules

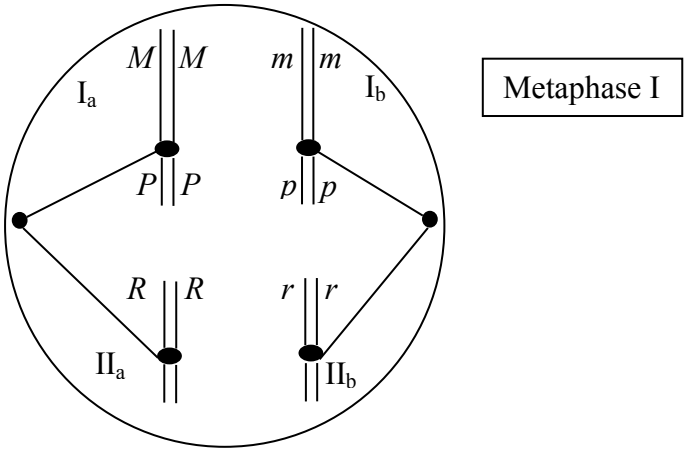
*35. The fruit fly *Drosophila melanogaster* has four pairs of chromosomes, whereas the house fly *Musca domestica* has six pairs of chromosomes. In which species would you expect to see more genetic variation among the progeny of a cross? Explain your answer.

Solution:
The progeny of an organism whose cells contain more homologous pairs of chromosomes should be expected to exhibit more variation. The number of different combinations of chromosomes that are possible in the gametes is 2^n, where n is equal to the number of homologous pairs of chromosomes. For the fruit fly with four pairs of chromosomes, the number of possible combinations is $2^4 = 16$. For *Musca domestica* with six pairs of chromosomes, the number of possible combinations is $2^6 = 64$.

*36. A cell has two pairs of submetacentric chromosomes, which we will call chromosomes I_a, I_b, II_a, and II_b (chromosomes I_a and I_b are homologs, and chromosomes II_a and II_b are homologs). Allele *M* is located on the long arm of chromosome I_a, and allele *m* is located at the same position on chromosome I_b. Allele *P* is located on the short arm of chromosome I_a, and allele *p* is located at the same position on chromosome I_b. Allele *R* is located on chromosome II_a and allele *r* is located at the same position on chromosome II_b.

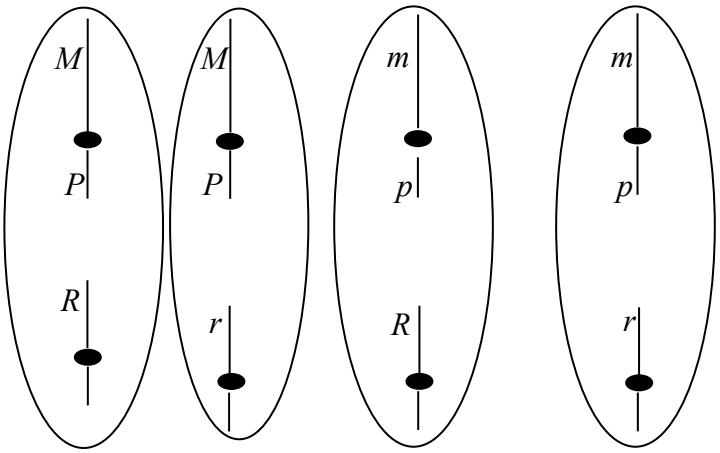
a. Draw these chromosomes, identifying genes *M, m, P, p, R,* and *r,* as they might appear in metaphase I of meiosis. Assume that there is no crossing over.

Solution:



b. Taking into consideration the random separation of chromosomes in anaphase I, draw the chromosomes (with genes identified) present in all possible types of gametes that might result from this cell's undergoing meiosis. Assume that there is no crossing over.

Solution:



37. A horse has 64 chromosomes and a donkey has 62 chromosomes. A cross between a female horse and a male donkey produces a mule, which is usually sterile. How many chromosomes does a mule have? Can you think of any reasons for the fact that most mules are sterile?

Solution:
The haploid egg produced by the female horse contains 32 chromosomes. The haploid sperm produced by the male donkey contains 31 chromosomes. The union of the horse and donkey gametes will produce a zygote containing 63 chromosomes. From the zygote, the adult mule will develop and will contain cells with a chromosome number of 63. Because an odd number of chromosomes in the mule's cells are present, at least one chromosome will not have a homolog. During the production of gametes by meiosis when pairing and separation of homologous chromosomes occurs, the odd chromosome will be unable to pair up. Furthermore, the mule's chromosomes, which are contributed by the horse and donkey, are from two different species. Not all of the mule's chromosomes may be able to find a suitable homolog during meiosis I and thus may not synapse properly during prophase I of meiosis. If improper synapsis or no synapsis occurs during prophase I, this will result in faulty segregation of chromosomes to the daughter cells produced at the conclusion of meiosis I. This leads to gametes that have abnormal numbers of chromosomes. When these abnormal gametes unite, the resulting zygote has an abnormal number of chromosomes and will be nonviable.

*38. Normal somatic cells of horses have 64 chromosomes ($2n = 64$). How many chromosomes and DNA molecules will be present in the following types of horse cells?

Solution:

	Cell type	**Number of chromosomes**	**Number of DNA molecules**
a.	Spermatogonium	64	64

Assuming the spermatogonium is in G_1 prior to the production of sister chromatids in S phase, the chromosome number will be the diploid number of chromosomes.

b. First polar body 32 64
The first polar body is the product of meiosis I, so it will be haploid; but the sister chromatids have not separated, so each chromosome will consist of two sister chromatids.

c. Primary oocyte 64 128
The primary oocyte has stopped in prophase I of meiosis. So the homologs have not yet separated, and each chromosome consists of two sister chromatids.

d. Secondary spermatocyte 32 64
The secondary spermatocyte is a product of meiosis I and has yet to enter meiosis II. So the secondary spermatocyte will be haploid because the homologous pairs were separated in meiosis I; but each chromosome is still composed of two sister chromatids.

39. Indicate whether each of the following cells is haploid or diploid.

Solution:

Cell Type	**Haploid or Diploid?**
Microspore	haploid
Primary spermatocyte	diploid
Microsporocyte	diploid
First polar body	haploid
Oogonium	diploid
Spermatid	haploid
Megaspore	haploid
Ovum	haploid
Secondary oocyte	haploid
Spermatogonium	diploid

*40. A primary oocyte divides to give rise to a secondary oocyte and a first polar body. The secondary oocyte then divides to give rise to an ovum and a second polar body.

a. Is the genetic information found in the first polar body identical with that found in the secondary oocyte? Explain your answer.

Solution:
No, the information is not identical with that found in the secondary oocyte. The first polar body and the secondary oocyte are the result of meiosis I. In meiosis I, homologous chromosomes segregate and thus both the first polar body and secondary oocyte will contain only one member of each original chromosome pair, and these will have different alleles of some of the genes. Also the recombination that took place in prophase I will have generated new and different arrangements of genetic material for each member of the pair.

b. Is the genetic information found in the second polar body identical with that in the ovum? Explain your answer.

Solution:
No, the information is not identical. The second polar body and the ovum will contain the same members of the homologous pairs of chromosomes that were separated during meiosis I and produced by the separation of sister chromatids during anaphase II. However, the sister chromatids are no longer identical. The sister chromatids have undergone recombination during prophase I and thus contain genetic information that is not identical to the other sister chromatids.

CHALLENGE QUESTIONS

Section 2.3

41. From 80% to 90% of the most common human chromosome abnormalities arise because the chromosomes fail to divide properly in oogenesis. Can you think of a reason why failure of chromosome division might be more common in female gametogenesis than male gametogenesis?

Solution:
Male gametogenesis, or spermatogenesis in human males, occurs regularly. Once the spermatogonium begins meiosis, the process quickly goes to completion, resulting in the formation of four spermatids that can mature into sperm cells. Female gametogenesis, or oogenesis in human females, is more complicated. Each oogonium enters meiosis I but stops at prophase I, generating a primary oocyte. This primary oocyte remains frozen in prophase I until ovulation begins and continues through meiosis I. Only if the egg is fertilized will meiosis II be completed. Because the primary oocyte is present at birth, the completion of meiosis I by a primary oocyte may not occur for many years (35 to 40 years or more). The length of time could lead to degradation or damaging of the meiotic machinery (such as the meiotic spindle fibers or cohesin complex). The damaged meiotic machinery could result in an improper separation of homologous pairs or of sister chromatids during the meiotic process. The spermatogenesis process does not have this time delay, which may protect the process from age-induced damage to the meiotic machinery.

42. On average, what proportion of the genome in the following pairs of humans would be exactly the same if no crossing over took place? (For the purposes of this question only, we will ignore the special case of the X and Y sex chromosomes and assume that all genes are located on nonsex chromosomes.)
a. Father and child

Solution:
The father will donate one-half of his chromosomes to his child. Therefore, the father and child will have one-half of their genomes that are similar.

b. Mother and child

Solution:
The mother will donate one-half of her chromosomes to her child. Therefore, the mother and child will have one-half of their genomes that are similar.

c. Two full siblings (offspring that have the same two biological parents)

Solution:
The parents can contribute only one-half of their genome to each offspring. So it is likely that the siblings share one-fourth of their genes from one parent. Because each sibling would share one-fourth of their genes from each parent, their total relatedness is one-half (or ¼ + ¼).

d. Half siblings (offspring that have only one biological parent in common)

Solution:
Half siblings share only one-fourth of their genomes with each other because they have only one parent in common.

e. Uncle and niece

Solution:
An uncle would share one-half of his genomes with his sibling, who would share one-half of his or her genome with his or her child. So, an uncle and niece would share one-fourth of their genomes (½ × ½).

f. Grandparent and grandchild

Solution:
The grandparent and grandchild would share one-fourth of their genomes because the grandchild would share one-half of her genome with her parent and the parent would share one-half of her genome with the child's grandparent.

*43. Female bees are diploid, and male bees are haploid. The haploid males produce sperm and can successfully mate with diploid females. Fertilized eggs develop into females and unfertilized eggs develop into males. How do you think the process of sperm production in male bees differs from sperm production in other animals?

Solution:
Most male animals produce sperm by meiosis. In haploid male bees, meiosis will not occur since meiosis can only occur in diploid cells. Male bees can still produce sperm, but only through mitosis. Haploid cells that divide mitotically produce more haploid cells.

Chapter 2

Think-Pair-Share questions for the chapter opening story:

- In the blind men's riddle, two blind men must sort out 10 pairs of socks so that each man gets exactly five pairs of different colored socks. In the analogy, is it important that the men are blind? In a cell, what does the blindness represent?

  Possible Answers: The analogy depends on the men being blind. If they could see they could distinguish the socks by color and easily sort the socks so that each man got two socks of each color. While theoretically it might be possible for cells to evolve some mechanism by which they distinguish each pair of chromosomes and by this discrimination ensure that one chromosome of each pair ends up in a resulting cell, cells have not evolved such a mechanism. Through the process of mitosis, each chromosome replicates and the two replicated copies (analogous to the two socks of a pair) get pulled in opposite directions and end up in separate cells. The cells don't have a mechanism to see the different types of chromosomes and ensure at the end that each daughter cell gets exactly one copy of each pair—this is what the blindness represents.

End-of-chapter Think-Pair-Share questions:

Section 2.2

1. A chromosome consists of two sister chromatids. Does the genetic information on the two sister chromatids come from only one parent or from both parents? Explain your reasoning.

Possible Answers: This questions is designed to help address the difference between sister chromatids and homologous chromosomes, a common point of confusion for many students. For the most part, the genetic information on the two sister chromosomes comes from the same parent, because the sister chromatids are produced by replication and are exact copies of the genetic information originally present on a single chromosome, which comes from one parent. However, crossing over can produce information from two different parents on the same chromosome. One chromosome of a homologous pair comes from one parent and the other homolog comes from the other parent. When

crossing over takes place, information is exchanged between nonsister chromatids—chromatids from different but homologous chromosomes. So, after crossing over, the information on one chromatid may contain information from the other homolog (which comes from the other parent).

2. Are homologous pairs of chromosome present in mitosis? Explain your reasoning.

Possible Answers: This question addresses a common misconception among students who often assume that homologous pairs of chromosomes exist in meiosis but not in mitosis. Homologous pairs of chromosomes are present in mitosis. However, they don't pair up in mitosis like they do in meiosis, and sister chromatids of each chromosome separate independently.

3. A cell has eight chromosomes in metaphase II of meiosis. How many chromosomes and DNA molecules will be present per cell in this same organism at the following stages?

a. Prophase of mitosis

b. Metaphase I of meiosis

c. Anaphase of mitosis

c. Anaphase II of meiosis

d. Anaphase I of meiosis

e. After cytokinesis that follows mitosis

f. After cytokinesis that follows meiosis II.

Possible Answers: This question requires that students think through the different steps of mitosis and meiosis and fully understand what is happening in each stage.

	Number of Chromosomes	**Number of DNA Molecules**
a. Prophase of mitosis	16	32
b. Metaphase I of meiosis	16	32
c. Anaphase of mitosis	32	32

c. Anaphase II of meiosis	16	16
d. Anaphase I of meiosis	16	32
e. After cytokinesis that follows mitosis	16	16
f. After cytokinesis that follows meiosis II	8	8

Section 2.3

4. What is the difference between sister chromatids and homologous chromosomes?

Possible Answers: Students often are confused and have misconceptions about the difference between sister chromatids and homologous chromosomes. Sister chromatids are identical copies (unless crossing over takes place) of the same original chromosome. Homologous chromosomes are different chromosomes, containing information for the same traits (homologous information) but not the same genetic information. One homolog comes from one parent; the other homolog comes from the other parent.

5. List as many similarities and differences in mitosis and meiosis as you can. Which differences do you think are most important and why?

Possible Answers:

Similarities

- Both involve chromosome and cell division.
- Both are preceded by DNA replication.
- Both use spindle fibers to separate chromosomes.
- Both have a stage where sister chromatids separate.

Differences

- Meiosis normally involves two cell divisions; mitosis usually has only a single cell division.
- Chromosome reduction occurs in meiosis but not in mitosis.
- Resulting daughter cells are genetically different in meiosis but not in mitosis.
- Crossing over occurs in meiosis but does not normally take place in mitosis.
- Random assortment of chromosomes occurs in anaphase I of meiosis but does not occur

in anaphase of mitosis.

- In metaphase I of meiosis, pairs of homologous chromosomes line up; in metaphase of mitosis (and metaphase II of meiosis) individual chromosomes line up.
- In anaphase I of meiosis, homologous chromosomes separate; in anaphase of mitosis (and anaphase II of meiosis) sister chromatids separate.

6. Describe how and where each of the following terms applies to mitosis and/or meiosis: (1) replication; (2) pairing; and (3) separation.

Possible Answers:

Replication, pairing, and separation are key events that take place in mitosis and meiosis.

Replication: In mitosis and meiosis, DNA replication takes place during S phase preceding nuclear division.

Pairing: Homologous chromosomes pair up in meiosis, but no pairing of homologous chromosomes takes place in mitosis. However, the sister chromatids of each chromosome are paired in both mitosis and meiosis.

Separation: In mitosis, sister chromatids separate in anaphase. In meiosis, homologous chromosomes separate in anaphase I and sister chromatids separate in anaphase II.

7. Do you know of any genetic diseases or disorders that result from errors in mitosis or meiosis? How do errors in mitosis or meiosis bring about these diseases?

Possible Answers: There are many chromosome abnormalities that result from errors in mitosis and/or meiosis, including Down syndrome (resulting from an extra copy of chromosome 21) and Turner syndrome (resulting from a single X chromosome). Many cancers have abnormal chromosomes that result from errors in mitosis (see Chapter 23). Errors in mitosis and/or meiosis often result in abnormal separation of chromosomes, so that cells end up with too many or too few chromosomes.