

Chapter Two: Chromosomes and Cellular Reproduction

COMPREHENSION QUESTIONS

Section 2.1

- *1. Give some genetic differences between prokaryotic and eukaryotic cells.

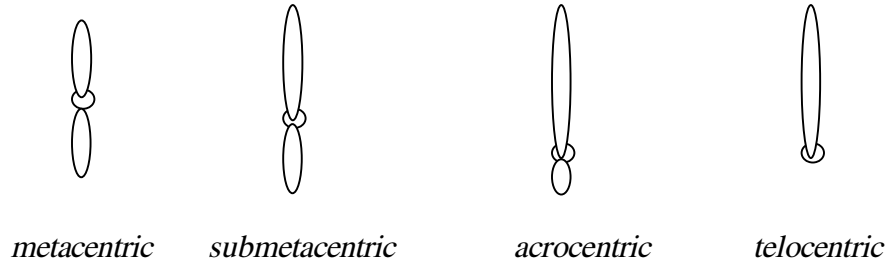
<i>Prokaryotic cell</i>	<i>Eukaryotic cell</i>
<i>No nucleus</i>	<i>Nucleus present</i>
<i>No paired chromosomes (haploid)</i>	<i>Paired chromosomes common (diploid)</i>
<i>Typically single circular chromosome containing a single origin of replication</i>	<i>Typically multiple linear chromosomes containing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

2. Why are the viruses that infect mammalian cells useful for studying the genetics of mammals?
It is thought that viruses must have evolved after their host cells because a host is required for viral reproduction. Viral genomes are closely related to their host genomes. The close relationship between a mammalian virus and its mammalian 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 structure to the mammalian 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.
- (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.*
4. Outline the process by which prokaryotic cells reproduce.
- (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.
- (1) *Centromere: serves as the point of attachment for the spindle fibers (microtubules).*
 - (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 label four different types of chromosomes based on the position of the centromere.



7. List the stages of interphase and the major events that take place in each stage.
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. List the stages of mitosis and the major events that take place in each stage.
- (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.*
9. Briefly describe how the chromosomes move toward the spindle poles during anaphase.

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Due to the actions of the microtubule subunits attached to the kinetochores of the chromosome and motor proteins such as kinesin, 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.

- *10. What are the genetically important results of the cell cycle?
In the mitotic cell cycle, the genetic material is precisely copied so that the two resulting cells contain the same genetic information. In other words, the cells have genomes identical to each other and to the mother cell.
11. Why are the two cells produced by the cell cycle genetically identical?
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 copy of the two identical sister chromatids. Thus, the newly formed cells will contain identical daughter chromosomes.
12. What are checkpoints? List some of the important checkpoints in the cell cycle. What two general classes of compounds regulate progression through the cell cycle?
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 G₁/S checkpoint, which occurs during G₁ prior to the S phase; the G₂/M checkpoint, which occurs in G₂ prior to mitosis; and the spindle-assembly checkpoint, which occurs during mitosis.
Two types of proteins are responsible for movement through the cell cycle: cyclin proteins and cyclin-dependent kinases.

Section 2.3

13. What are the stages of meiosis and what major events take place in each stage?
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?
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?
 (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 chromosomes to the daughter cells, which takes place in anaphase I of meiosis.*
- *16. List similarities and differences between mitosis and meiosis. Which differences do you think are most important and why?

<i>Mitosis</i>	<i>Meiosis</i>
<i>A single cell division produces two genetically identical progeny cells.</i>	<i>Two cell divisions usually result in four progeny cells that are not genetically identical.</i>
<i>Chromosome number of progeny cells and the original cell remain</i>	<i>Daughter cells are haploid and have half the chromosomal complement of the original diploid</i>

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<i>the same.</i>	<i>cell as a result of the separation of homologous pairs during anaphase I.</i>
<i>Daughter cells and the original cell are genetically identical. No separation of homologous chromosomes or crossing over takes place.</i>	<i>Crossing over in prophase I and separation of homologous pairs during anaphase I produce daughter cells that are genetically different from each other and from the original cell.</i>
<i>Homologous chromosomes do not synapse.</i>	<i>Synapsis of homologous chromosomes takes place during prophase I.</i>
<i>In metaphase, individual chromosomes line up on the metaphase plate.</i>	<i>In metaphase I, homologous pairs of chromosomes line up on the metaphase plate. Individual chromosomes line up in metaphase II.</i>
<i>In anaphase, sister chromatids separate.</i>	<i>In anaphase I, homologous chromosomes separate. Separation of sister chromatids takes place in anaphase II.</i>

The most important difference is that mitosis produces cells genetically identical to each other and to the original cell, resulting in the orderly passage of information from one cell to its progeny. In contrast, by producing progeny that do not contain pairs of homologous chromosomes, meiosis results in the reduction of chromosome number from the original cell. Meiosis also allows for genetic variation through crossing over and the random assortment of homologous chromosomes.

17. Briefly explain why sister chromatids remain together in anaphase I but separate in anaphase of mitosis and anaphase II of meiosis.
- During the S phase, the cohesin protein complex forms and holds together the sister chromatids throughout the early stages of mitosis or meiosis I. In mitosis at the end of metaphase, the cohesin molecules that connect the sister chromatids at the centromeres are cleaved by the protein separase, which allows the sister chromatids to separate. Prior to this point, separase is kept inactive by a protein called securin. Securin is broken down at the end of metaphase, allowing separase to become active.*
- In meiosis, a similar process occurs. The cohesin complexes 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 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.*
- Also during metaphase I, proteins called monopolins function to allow only the two kinetochores of sister chromatids to orient toward the same spindle pole and attach to microtubules of the same pole. The end result is that the attached sister chromatids move toward the same pole during meiosis.*
18. Outline the process of spermatogenesis in animals. Outline the process of oogenesis in animals.

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 process by which male gametes are produced in plants. Outline the process of female gamete formation in plants.

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.

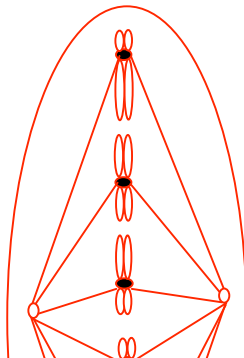
In flowering plants, the microsporocytes found in the stamen of the flower undergo meiosis to produce four haploid microspores. Each microspore divides by mitosis to produce the pollen grain, or the microgametophyte. Within the pollen grain are two haploid nuclei. One of the haploid nuclei divides by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

Section 2.2

20. 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.



21. A biologist examines a series of cells and counts 160 cells in interphase, 20 cells in prophase, 6 cells in prometaphase, 2 cells in metaphase, 7 cells in anaphase, and 5 cells in telophase. If the complete cell cycle requires 24 hours, what is the average duration of M phase in these cells? Of metaphase?

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.

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

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 hours, or 14.4 minutes.

Section 2.3

- *22. A cell in G₁ 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?

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.

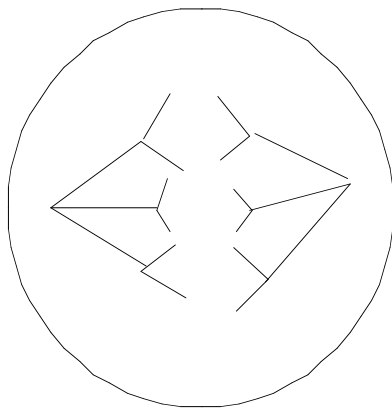
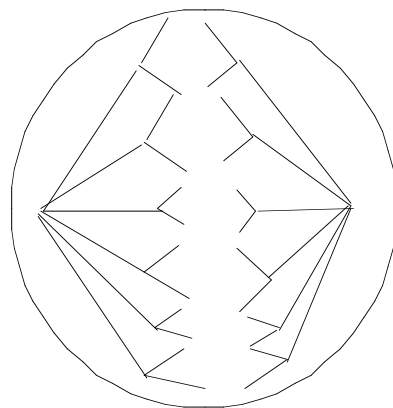
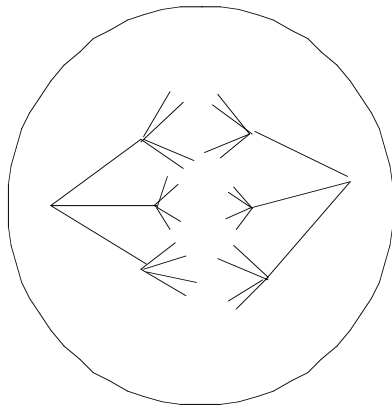
- a. *G₂ of interphase*
G₂ of interphase occurs after S phase, when the DNA molecules are replicated. Each chromosome now consists of two DNA molecules. So a cell in G₂ will contain 12 chromosomes and 24 DNA molecules.
 - b. *Metaphase I of meiosis*
Neither homologous chromosomes nor sister chromatids 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*
This cell will contain 12 chromosomes and 24 DNA molecules.
 - d. *Anaphase I of meiosis*
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*
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*
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*
After cytokinesis following mitosis the daughter cells will enter G₁. Each cell will contain 12 chromosomes and 12 DNA molecules.
 - h. *After cytokinesis following meiosis II*
After cytokinesis following meiosis II, the haploid daughter cells will contain six chromosomes and six DNA molecules.
23. How are the events that take place in spermatogenesis and oogenesis similar? How are they different?

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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.

- *24. All of the following cells, shown in various stages of mitosis and meiosis, come from the same rare species of plant. What is the diploid number of chromosomes in this plant? Give the names of each stage of mitosis or meiosis shown.



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.

- a. *This cell is undergoing anaphase of meiosis I, as indicated by the separation of the homologous pairs of chromosomes.*
- b. *In the diagram, the cell 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.*
- c. *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.*

25. 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. Match the amounts of DNA on the left with the corresponding stages of the cell cycle on the right. You may use more than one stage for each amount of DNA.

Stage of mitosis	Amount of DNA per cell
a. G_1	
b. Prophase I	<u>d</u> 3.7 pg
c. G_2	<u>a, f</u> 7.3 pg
d. Following telophase II and cytokinesis	<u>b, c, e</u> 14.6 pg
e. Anaphase I	
f. Metaphase II	

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.

- a. *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. *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 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 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. *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.*

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- f. *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).*

*26. Fill in the following table.

Event	Mitosis	Meiosis I	Meiosis II
Does crossing over occur?	No	Yes	No
What separates in anaphase?	Sister chromatids	Homologous pairs of chromosomes	Sister chromatids
What lines up on the metaphase plate?	Individual chromosomes	Homologous pairs of chromosomes	Individual chromosomes
Does cell division usually take place?	Yes	Yes	Yes
Do homologs pair?	No	Yes	No
Is genetic variation produced?	No	Yes	No

*27. What would be the consequences of each of the following events to the outcome of mitosis or meiosis?

- a. Mitotic cohesin fails to form early in mitosis.
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.
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 shugoshin 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.
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.

28. 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?

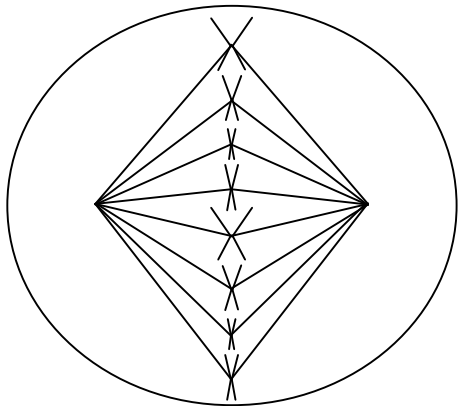
A cell in prophase II of meiosis will contain the haploid number of chromosomes. For this organism, 12 chromosomes represent the haploid chromosome number of a cell, or one complete set of chromosomes.

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.

29. A cell has eight chromosomes in G₁ 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.

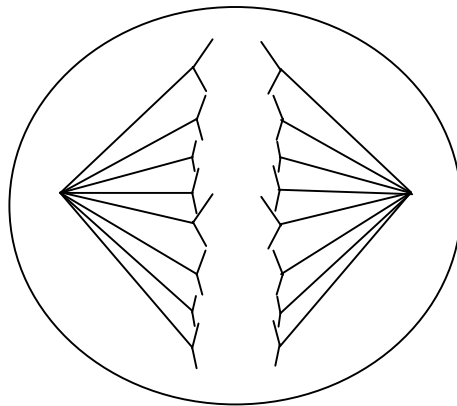
a. Metaphase of mitosis



8 chromosomes

16 DNA molecules

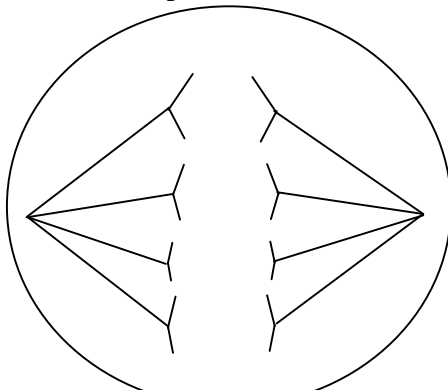
b. Anaphase of mitosis



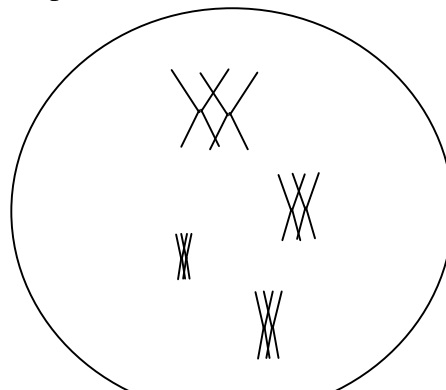
16 Chromosomes

16 DNA molecules

c. Anaphase II of meiosis



d. Diplotene of meiosis I



8 chromosomes
8 DNA molecules

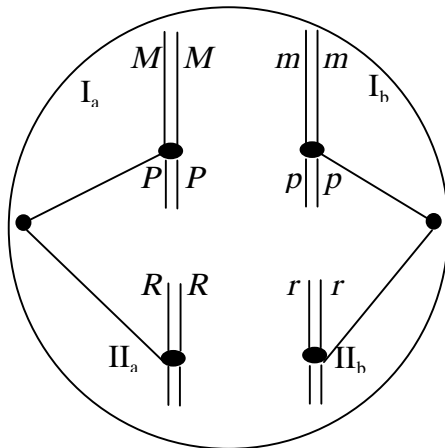
8 Chromosomes
16 DNA molecules

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

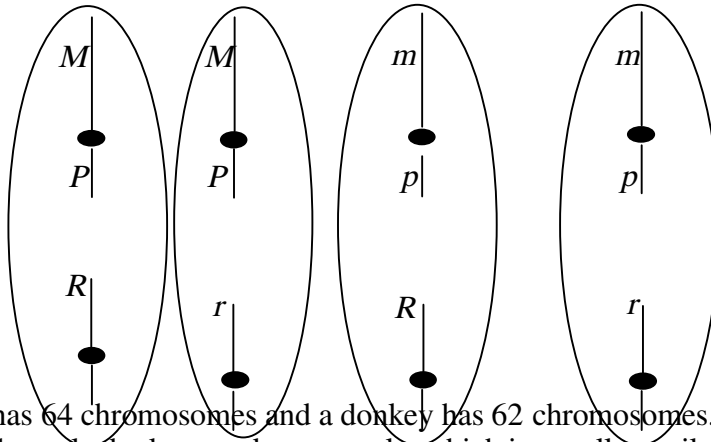
*The progeny of an organism whose cells contain more homologous pairs of chromosomes should be expected to exhibit more variation. The number of different combinations of chromosomes that are possible in the gametes is 2^n , where n is equal to the number of homologous pairs of chromosomes. For the fruit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

- *31. 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, labeling genes *M*, *m*, *P*, *p*, *R*, and *r*, as they might appear in metaphase I of meiosis. Assume that there is no crossing over.

Metaphase I



- b. Considering the random separation of chromosomes in anaphase I, draw the chromosomes (with labeled genes) present in all possible types of gametes that might result from this cell going through meiosis. Assume that there is no crossing over.



32. 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?

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.

33. 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?

<u>Cell type</u>	<u>Number of chromosomes</u>	<u>Number of DNA molecules</u>
a. Spermatogonium	64	64
<i>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.</i>		
b. First polar body	32	64
<i>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.</i>		
c. Primary oocyte	64	128
<i>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.</i>		
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.

- *34. 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.
- Is the genetic information found in the first polar body identical with that found in the secondary oocyte? Explain your answer.
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.
 - Is the genetic information found in the second polar body identical with that in the ovum? Explain your reasoning.
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

35. Eighty to ninety percent of the most common chromosome abnormalities in humans arise because the chromosomes fail to divide properly in *female* oogenesis. Can you think of a reason why failure of chromosome division might be more common in female gametogenesis than male gametogenesis?
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.

36. On average, what proportion of the genome in the following pairs of humans would be exactly the same if no crossing over occurred? (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
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
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 who have the same two biological parents)
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 $\frac{1}{4} + \frac{1}{4}$).
 - d. Half siblings (offspring that have only one biological parent in common)
Half siblings share only one-fourth of their genomes with each other because they have only one parent in common.
 - e. Uncle and niece
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 ($\frac{1}{2} \times \frac{1}{2}$).
 - f. Grandparent and grandchild
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.
- *37. 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?
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.