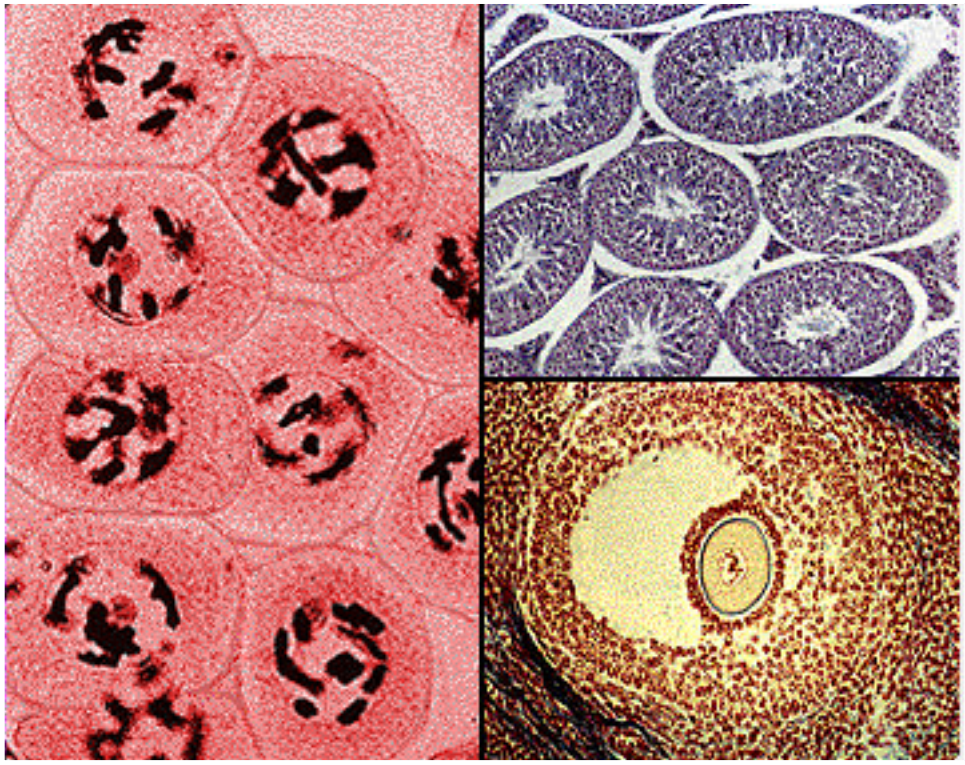
Interactive Biology™ Multimedia Courseware

Meiosis



Meiosis

TEACHING OBJECTIVES

The following subject areas are illustrated throughout the *Interactive Biology Multimedia Courseware* program, *Meiosis.* Ideally, these areas would be augmented with additional course work outside of this program.

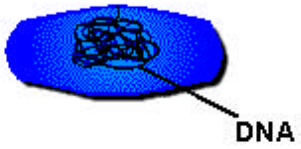
- An examination of the differences between prokaryotic and eukaryotic cells and an introduction to chromosomes.
- An introduction to cell division in prokaryotes and an overview of the cell cycle and mitosis in eukaryotes.
- A comparison of sexual and asexual reproduction.
- An overview of meiosis and an explanation of haploid versus diploid cells.
- A detailed look at beginning of meiosis I, including what occurs during prophase I, the importance of synapsis, and crossing over.
- A detailed look at the completion of meiosis I, including metaphase I, anaphase I, telophase I, and cytokinesis.
- A detailed look at the completion of meiosis; meiosis II.
- An introduction to nondisjunction and aneuploidy.
- A look at gametogenesis, focusing on spermatogenesis and oogenesis in humans.

Study Guide #1

PROKARYOTIC CELLS, EUKARYOTIC CELLS, AND CHROMOSOMES

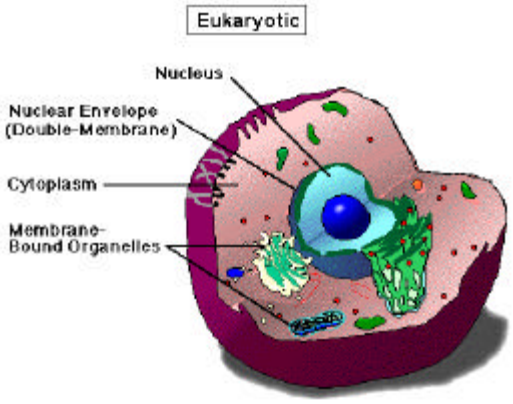
All living things are composed of cells. Some organisms, such as bacteria, are made up of only one cell, while others, such as yourself, are made up of trillions of cells.

Although there are billions of trillions of cells found on the planet earth, there are only two basic types of cells. Cells are either prokaryotic or eukaryotic. Let's first take a look at prokaryotic cells.



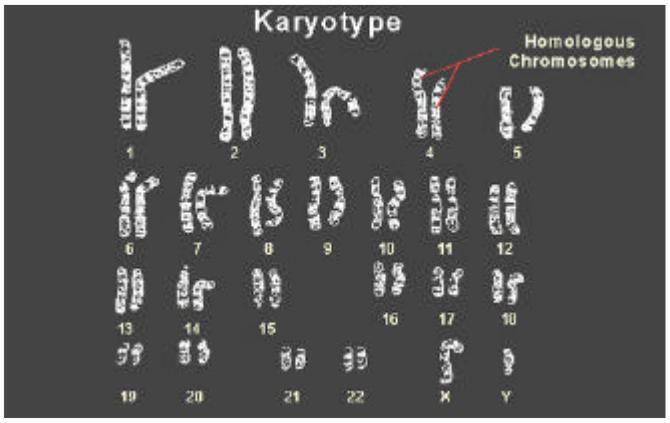
In a prokaryotic cell, genetic material - otherwise known as DNA - is not enclosed in a membrane. Instead, DNA in prokaryotic cells is found in the cytoplasm. Cytoplasm is the thick, watery substance held inside of the cell by a cell membrane or cell wall. Bacteria, which are single-celled organisms, are prokaryotic cells.

In a eukaryotic cell, genetic material is found inside of a membrane bound structure called the nucleus. Prokaryotic cells also contain several other types of membrane-bound organelles, which are found distributed throughout its cytoplasm. Eukaryotic cells are the basic units of multicellular plants, animals, and fungi. Many single-celled organisms, such as amoebas and some algae are eukaryotic organisms. So remember, while all bacteria are prokaryotic, not all single-celled organisms are prokaryotic. There are millions of single-celled eukaryotic organisms found on our planet.



Prokaryotes have one main DNA molecule. In prokaryotes, DNA is compacted along with proteins into a single, circular structure known as a chromosome. On this chromosome, the cell carries all information needed to survive. This information is found in sequences of DNA known as genes. The information carried by genes directs the production of all proteins the cell needs, such as enzymes used in the digestion of food.

Chromosomes in eukaryotes are also made up of DNA. Because these organisms tend to be much larger and more complicated than prokaryotes, their chromosomes have to carry much more information. Instead of having one enormous, circular chromosome, eukaryotes have several compact, linear chromosomes. The number of chromosomes varies in different species of organisms. For example, while human cells have 46 chromosomes, pine trees have 24, dogs have 78, and frogs have 26. Whenever we discuss chromosomes in the remainder of these study guides, assume we are addressing those found in eukaryotic organisms unless we state otherwise.



Chromosomes can be arranged into matching pairs. These matching pairs are made up of two homologous chromosomes, also called homologues. A picture showing all of a cell's chromosomes, each chromosome lined up with its homologue, is known as a karyotype.

There are two types of chromosomes - sex chromosomes and autosomes. In humans there are 46 chromosomes, making a total of 23 pairs. One of these 23 pairs is made up of two sex chromosomes and determines what sex you are. This 23rd pair can either be two X chromosomes (XX), in which case you are a female, or one X and one Y chromosome (XY), in which case you are a male. All of the remaining chromosomes in your cells are

autosomes. In summary then, you have 23 pairs of chromosomes in your cells; one pair of sex chromosomes and twenty-two pairs of autosomes.

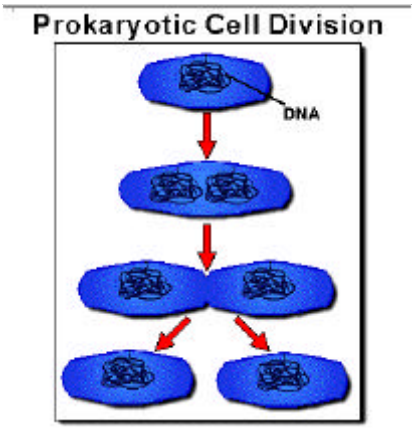
Study Guide #2

PROKARYOTIC AND EUKARYOTIC DIVISION

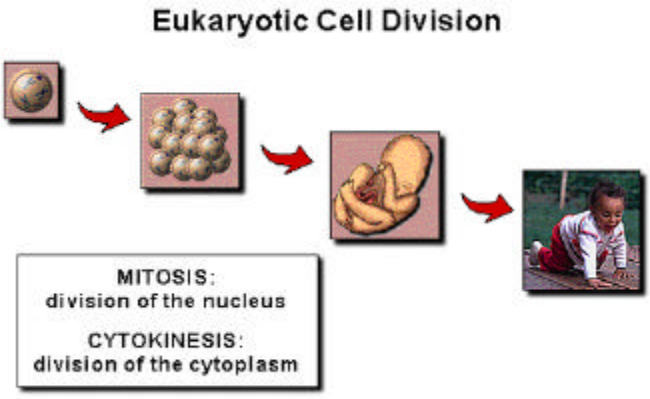
All cells come from preexisting cells. The method of cellular reproduction (cell division) differs between prokaryotes and eukaryotes.

When a prokaryotic cell reproduces, it first makes a copy of its DNA. After this is accomplished, the cell divides in half to form two cells. Each of these cells contains the same DNA as the first cell. Since all prokaryotes are single-celled organisms, their cell division results in the formation of a new organism.

Cell division in eukaryotes is more complicated than in prokaryotes. Eukaryotic cells divide by a process known as mitosis, which divides the chromosomes equally between the two cells. The actual physical splitting of one cell into two cells is known as cytokinesis, and takes place at the end of mitosis.

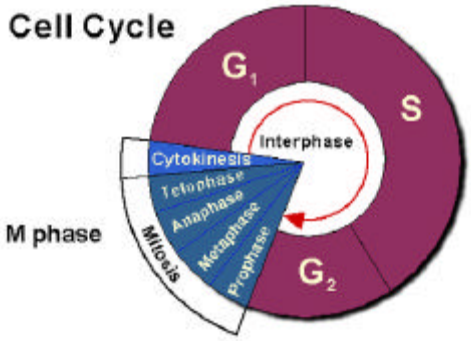


For a multicellular organism, mitosis does not lead to the formation of a new organism. Rather, it leads to growth and development in a single organism. You began as a single cell, and the process of mitosis followed by cytokinesis allowed you to develop into an organism containing trillions of cells. All eukaryotic cells follow a distinctive cell cycle. Let's take a closer look.



The eukaryotic cell cycle involves two main periods. Interphase is one of these periods and the other is mitosis. Interphase is made up of three distinct

phases - the G1, S, and G2 phases. When a cell is not undergoing mitosis or cytokinesis, it is in interphase.



During the G1 phase of interphase, each chromosome in the cell consists of a long, uncoiled strand of DNA. This is a period of general growth for the cell. During the S phase (otherwise known as the synthesis phase), each chromosome in the cell is duplicated. This produces two identical copies of the same chromosome. Each of these copies is called a chromatid, and the two chromatids are joined together by a centromere.

In the final stage of interphase, the G2 phase, the cell continues to grow and metabolize normally. This is a period of preparation for mitosis.

Mitosis, also referred to as the first part of the M phase, consists of four independent stages. These stages, in order, are prophase, metaphase, anaphase, and telophase. Mitosis (the division of chromosomes) is followed by cytokinesis (the division of cytoplasm), producing two cells with equal chromosome content. When we examine meiosis you will notice that its stages are similar to those of mitosis.

Study Guide #3

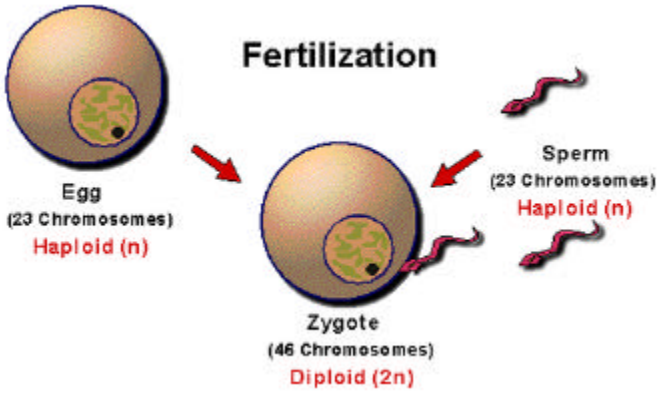
A LOOK AT SEXUAL AND ASEXUAL REPRODUCTION

As mentioned previously, when a single-celled organism divides, it gives rise to an entirely new organism with exactly the same DNA as the original cell. This type of reproduction is known as asexual reproduction since only one parent is involved.

When an organism, such as a bacterium, reproduces asexually, it creates a virtual clone of itself. The new organism will be like the old organism in almost every way; there will normally be only a minute amount of difference between the two. In fact, the only differences will arise from mutations occurring during the copying of the original cell's DNA. One bacterial cell, through asexual reproduction, can produce millions of copies of itself that are nearly indistinguishable from one another.

When multi-cellular organisms reproduce, two parents of the opposite sex are normally required. This type of reproduction is termed sexual reproduction, and requires special cells known as sex cells or gametes. Different gametes are produced by different sexes; males produce sperm and females produce eggs or ova.

In humans, the original cell that eventually gives rise to a full grown adult is formed when a sperm cell unites with an egg cell, or ovum (singular of ova), from a female. This process is known as fertilization and results in the formation of a zygote.



It is obvious from looking around you that human offspring are not virtual clones of one of their parents, but rather have a blend of characteristics from both parents. Why is this?

In all sexually reproducing organisms, offspring receive chromosomes from both parents. In this way, they receive genes for traits only their mothers have as well as genes for traits only their fathers have. Thus they look similar to both parents, but not identical to either.

When an egg and sperm fuse, it would seem that the resulting cell would have twice the number of chromosomes as a normal cell would. This, however, is not the case. The reason behind this is a variation of cell division called meiosis.

Study Guide #4

MEIOSIS OVERVIEW

In humans and most other animals, meiosis occurs in cells residing in the testes of mature males and in the ovaries of mature females. Through meiosis, these cells become sperm in a testis and ova in an ovary.

Meiosis reduces the original number of chromosomes within a cell by one-half. Therefore, each sperm cell and ovum contains only 23 chromosomes rather than 46 - the number found in the body cells, or somatic cells.

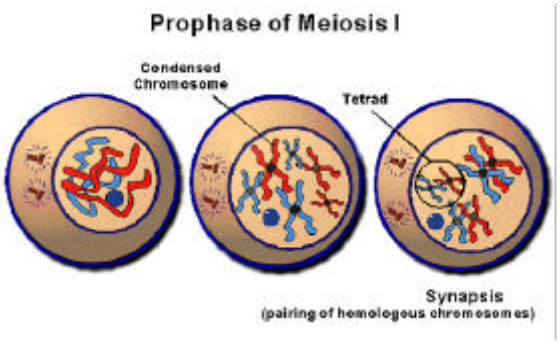
When a zygote is formed upon fertilization, it contains two sets of chromosomes - one from the male parent and one from the female parent. Any organism, including a developing zygote, which contains a full complement of chromosomes, is said to be diploid, or 2n. Any organisms or cell, including sperm and ova, containing only half the normal complement of chromosomes is said to be haploid, or 1n.

Study Guide #5

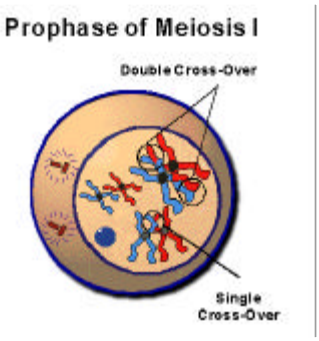
MEIOSIS BEGINS

While at first glance meiosis may appear the same as mitosis, these processes result in the formation of very different cell types. In mitosis, the cell's nucleus divides once to give rise to 2 genetically identical diploid cells. In meiosis, however, there are two nuclear divisions. These two divisions, known as meiosis I and meiosis II, result in the formation of 4 haploid cells that are genetically different than the original cell. Let's take a closer look at the start of meiosis I.

Prophase I marks the start of meiosis I. During prophase I, the chromosomes condense and homologous chromosomes pair up with one another. The process by which these homologous pairs come together is known as synapsis. Synapsis forms a chromosome complex called a tetrad. In summary, synapsis brings homologous chromosomes together, forming tetrads.



The formation of tetrads is unique to meiosis. This alignment of homologous chromosomes allows for a great deal of genetic variability. This genetic variability comes from a process known as crossing over.

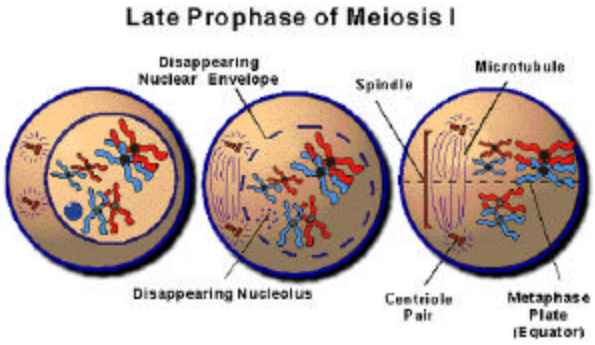


Remember, at this point each chromosome consists of two chromatids. These chromatids are referred to as sister chromatids, and are identical (since one was copied directly from the other). During synapsis, a chromatid from one chromosome may cross over with a chromatid from the other chromosome in the homologous pair. These two chromatids are referred to as non-sister chromatids.

The region in which crossing over occurs between the two non-sister chromatids is called a chiasma. During crossing over, the non-sister chromatids exchange portions of DNA at the chiasma. This results in chromatids containing genetic information from both chromosomes in the homologous pair. For example, you have chromosomes from both your mother and your father. When synapsis takes place in your body, your homologous pairs consist of one maternal chromosome (from your mother) and one paternal chromosome (from your father). After crossing over takes place, you have chromatids that are neither exactly like your mother's nor exactly like your father's, but are rather a hybrid of the two. Meiosis then, during prophase I, rearranges chromosomes and adds genetic variability.

Near the end of prophase I, the nuclear envelope and nucleolus of the cell disappear. Also occurring is the appearance of two structures known as centrioles. These structures, just as in mitosis, move to opposite sides of the cell. Fiber-like microtubules extend from the centrioles to form a spindle.

At this point, the cell is ready to proceed with the last 3 stages of meiosis I: metaphase I, anaphase I, and telophase I.

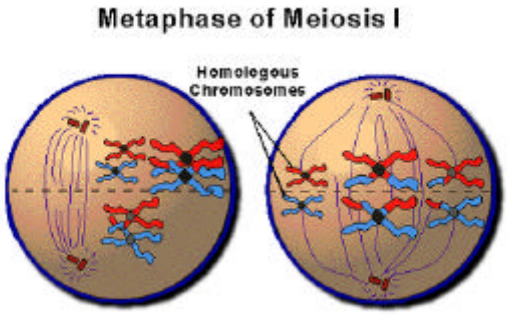


Study Guide #6

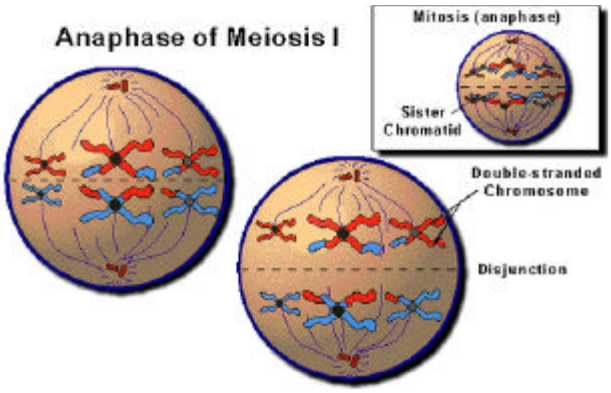
CONCLUSION OF MEIOSIS I

Keep in mind while studying meiosis that, once meiosis begins, these stages are continuous. There is no clear stopping point between prophase, metaphase, anaphase and telophase I. Each stage blends neatly into the next. For that reason, you will sometimes see a process described as the end of one stage or the beginning of the next stage depending upon the textbook you use. That being said, let's continue our look at meiosis I.

By the end of prophase I, the chromosomes had condensed and formed homologous pairs. Also, the centrioles had migrated to opposite sides of the cell and begun to form the spindle (a network of microtubules).



At the start of metaphase I, microtubules attach to the centromere of each chromosome in the tetrad. They attach in a very specific way. Each centromere in the tetrad is attached to a microtubule leading to a different centriole. The importance of this will become clear later. These microtubules then begin to tug and push on the chromosomes, eventually aligning all of them along the equator of the cell, other wise known as the metaphase plate. Once all are properly lined up, the cell proceeds into the next stage of meiosis I.

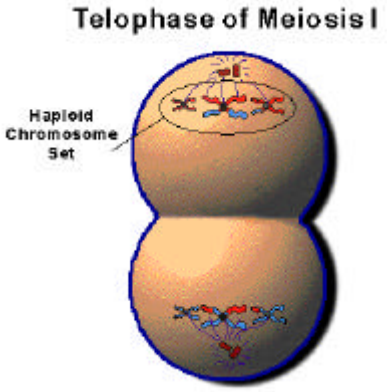


In anaphase I, each spindle begins to pull on the chromosomes it is attached to. The homologous pairs slowly begin to separate, and each chromosome moves toward a spindle. Remember that each chromosome in the tetrad was associated with a different

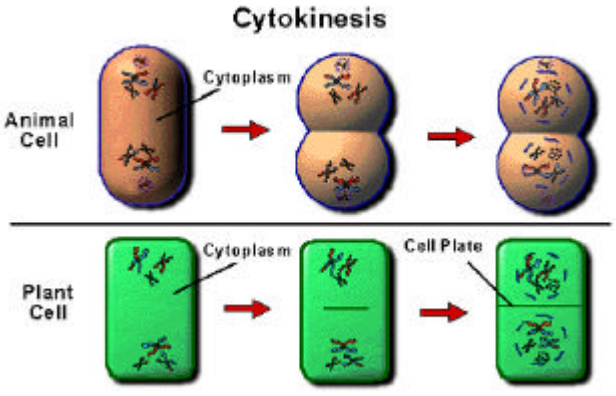
centriole. Therefore, when the chromosomes separate, they move towards opposite sides of the cell. In this way, neither side of the cell attracts two copies of the same chromosome.

This is similar to anaphase in mitosis, but there is one critical difference. You may recall that in mitosis, the centromeres split and each sister chromatid moves to an opposite side of the cell. In anaphase I of meiosis, the sister chromatids remain attached to each other (centromeres do not split). It is the homologous chromosomes that become separated. The separation of homologous chromosomes is called disjunction.

The final stage of meiosis I is telophase I. During telophase I the spindle continues to pull the homologous chromosomes apart until they reach the poles of the cell. Each pole now has a haploid, or 1n set of chromosomes, but each chromosome is composed of two sister chromatids.



Cytokinesis usually occurs simultaneously with telophase I. During cytokinesis, the cytoplasm of the cell divides into two equal portions, each with one set of chromosomes. The entire cell eventually divides in half, forming two daughter cells. The method of cell division differs among plant and animal cells.



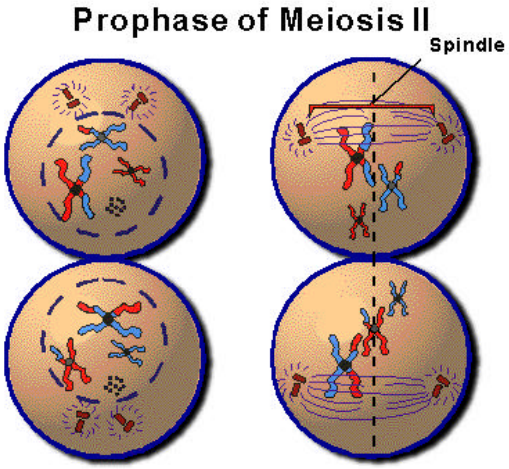
Plant cells form a cell plate in the middle of the cell, dividing the cell into two halves. From the cell plate, two new cell walls are formed, one for each cell. During division in animal cells, however, the cell membrane pinches in at the middle, eventually cleaving the cell evenly into two distinct cells.

Whether occurring in a plant or animal cell, cytokinesis at the end of telophase I mark the beginning of the transition into meiosis II. In some species, nuclear envelopes and nucleoli reform briefly prior to meiosis II. The chromosomes may even uncoil. In many other species, however, these steps do not occur. An abbreviated interphase, called interkinesis, normally occurs at this point regardless of the species in question. This stage is similar to the initial interphase, except there is no replication of the chromosomes. Now, let's look at what happens during meiosis II.

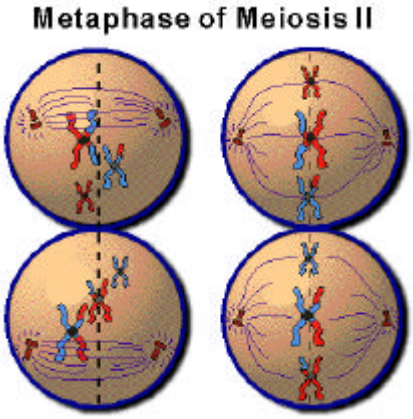
Study Guide #7

MEIOSIS II

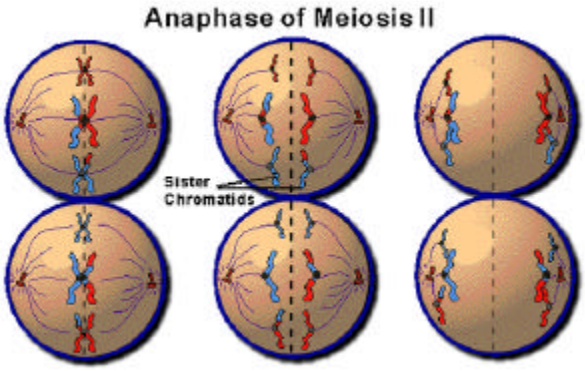
Just as in meiosis I, prophase (in this case, prophase II) marks the beginning of meiosis II. The nuclear envelope and nucleus, if reformed at the end of meiosis I, disappear. If the chromosomes uncoiled, they recondense during prophase II.



Centrioles appear and once more migrate to opposite sides of the cell. From these centrioles, microtubules form the spindle you are familiar with at this point.



As the cell enters metaphase II, the microtubules attach to and position the double-stranded chromosomes at the metaphase plate. Since there are no longer homologous chromosomes, no tetrad formation is possible. Once again, the microtubules attach in a very specific way. In metaphase II, each centromere is attached to 2 microtubules; one leading to each centriole. After the chromosomes are aligned properly, the cell enters anaphase II.

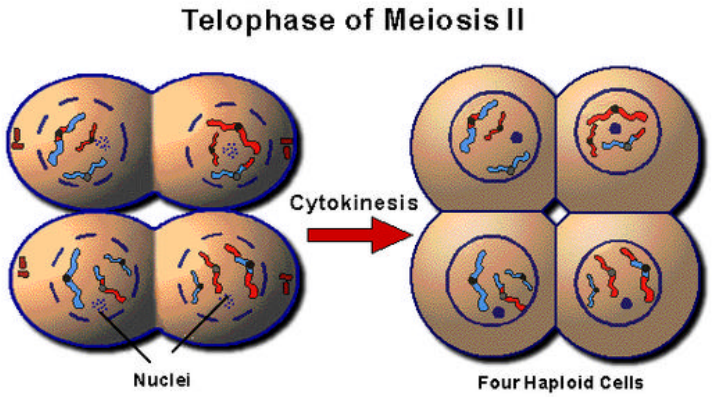


In anaphase II, the centromeres split and the sister chromatids of each double-stranded chromosome are pulled towards opposite poles.

Meiosis II concludes with telophase II and

cytokinesis. At the end of telophase, each side of the cell has received one of the sister chromatids. The spindle fibers and centrioles begin to disappear while nuclei and nucleoli begin to form. The chromosomes begin to uncoil, becoming very difficult to see. While this is happening, the cell undergoes cytokinesis, just as in meiosis I.

We began meiosis with one diploid cell. At the end of meiosis I, 2 haploid cells were formed, each containing a number of pairs of sister chromatids. At the end of meiosis II, that original cell has become 4 haploid cells, each containing one chromatid. Each chromatid is now considered a chromosome. Thus, in humans, one diploid cell containing 46 chromosomes yields 4 haploid cells containing 23 chromosomes through meiosis.

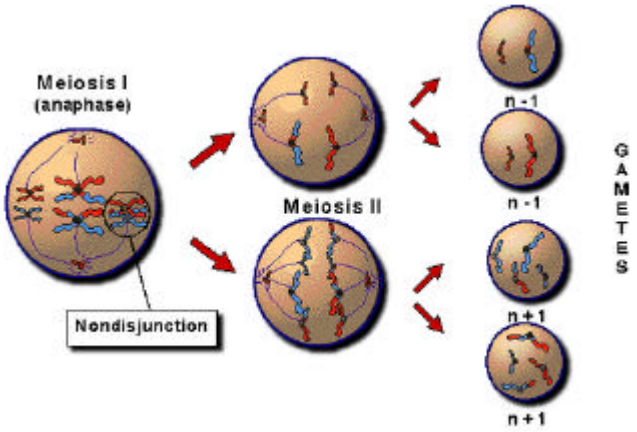


Next, we'll take a look at an error that very often takes place during meiosis.

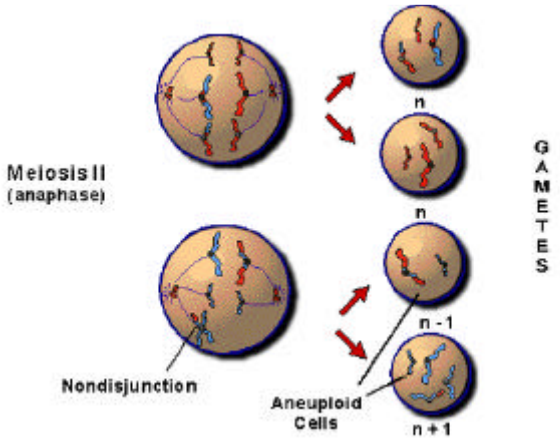
Study Guide #8

NONDISJUNCTION AND ANEUPLOIDY

Occasionally, an error known as nondisjunction will occur during anaphase of either meiosis I or meiosis II. In nondisjunction, chromosomes fail to separate properly. If this occurs during meiosis I, at least one set of homologous chromosomes do not separate. If this occurs during meiosis II, at least one centromere does not separate.



In either case, cells will wind up with an abnormal number of chromosomes. If nondisjunction occurs during anaphase I, two of the four sets of sex cells produced during meiosis will carry and extra chromosome (n+1, where n is equal to the number of chromosomes a cell should carry), and two of the four sets of sex cells will lack a chromosome (n-1). If nondisjunction occurs during anaphase II, two of the four cells will carry the normal number of chromosomes for a haploid cell (n), one cell will carry an extra chromosome (n+1) and the final cell will carry one less chromosome (n-1).



A cell, which carries an abnormal number of chromosomes, is termed aneuploid. If an aneuploid sex cell is involved in fertilization, genetic disorders will occur and fetal development will be disrupted. Most

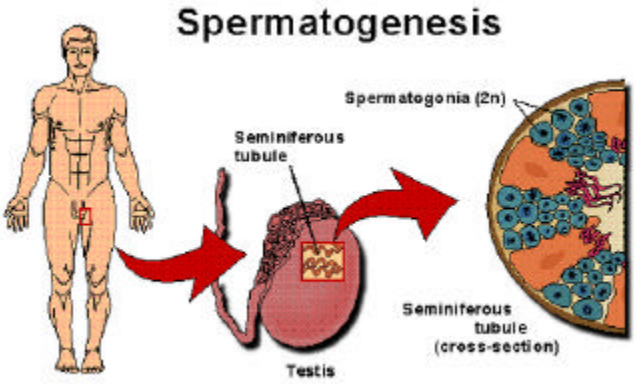
times, aneuploidy results in a non-viable embryo that quickly dies; often within a few hours or days of fertilization.

Sometimes, however, an aneuploid zygote can develop and the fetus can be carried full-term. Humans with the condition known as Down syndrome carry one extra chromosome. Individuals with this disorder carry three copies of chromosome #21 instead of two. Down syndrome is seen in about 1 out of every 700 live births. Other aneuploid conditions are seen in humans, but occur less frequently than Down syndrome.

Study Guide #9

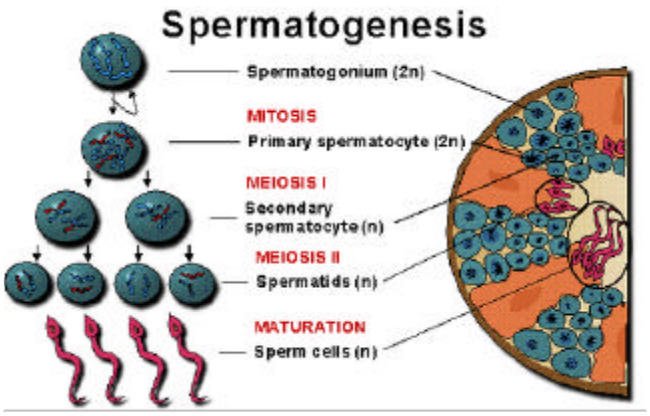
GAMETOGENESIS

The formation of gametes by meiosis is called gametogenesis. In humans and most other animals, gametogenesis takes place in the testes of males and ovaries of females. We will examine this process in humans.

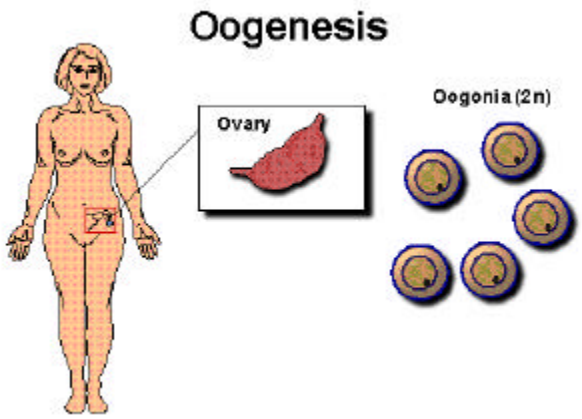


In human males, sperm formation, or spermatogenesis, occurs in the seminiferous tubules of the testes. The original diploid cells from which the haploid sperm eventually arise are called spermatogonia. Throughout childhood, spermatogonia grow and reproduce my mitosis.

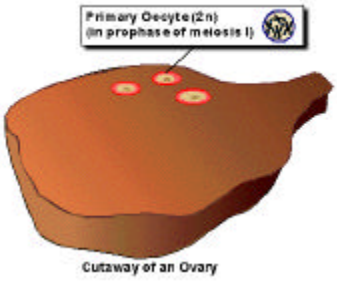
Once a male reaches puberty, some spermatogonia undergo meiosis to form sperm. Prior to undergoing meiosis, a spermatogonium divides by mitosis to form a primary spermatocyte. This primary spermatocyte then undergoes meiosis I to yield two secondary spermatocytes. The secondary spermatocytes undergo meiosis II to form 4 spermatids. Spermatids mature, with the aid of helper cells called Sertoli cells, to form sperm.



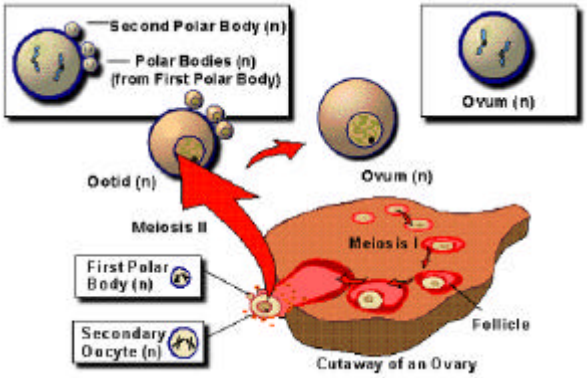
In human females, ova formation, or oogenesis, takes place in the ovaries. The original diploid cells from which ova are derived are called oogonia.



By the time a female is born, all of her oogonia that will potentially become ova have become primary oocytes. These primary oocytes have entered meiosis I, but are held in prophase I until puberty. These primary oocytes can remain locked in prophase I for many decades.



When females reach puberty, meiosis I continues from prophase in a primary oocyte and its follicle. A follicle is a group of cells surrounding the primary oocyte in the ovary. At the end of meiosis I, the primary oocyte divides unequally to form the secondary oocyte and the first polar body. A polar body contains as much genetic material as the secondary oocyte (23 chromosomes), but has very little cytoplasm. Most of the cytoplasm remains in the secondary oocyte. The follicle then ruptures, releasing the secondary oocyte from the ovary and into the fallopian tube.



During meiosis II, the secondary oocyte divides unequally to form a small second polar body and a large ootid. Occasionally, the polar body produced during meiosis I also divides to form two smaller polar bodies. Meiosis I and II, then, results in the formation of 3 small polar bodies and 1 large ootid. The polar bodies eventually degenerate and die, while the ootid develops into a mature ovum.

As described previously, during fertilization a haploid sperm and a haploid ovum unite to form a diploid zygote. The nutritional needs of the developing zygote are very demanding.

Since the nutrients for development are found within the cytoplasm, the greater the amount of cytoplasm the greater the amount of nutrients available to the zygote. The unequal cellular divisions that take place during oogenesis allow the egg to have plenty of cytoplasm (and therefore plenty of cytoplasmic nutrients) for the future zygote.

Meiosis

QUIZ PAC

The following quizzes are meant to test student understanding of specific topic areas covered in the *Interactive Biology Multimedia Courseware* program, *Meiosis*. Many, but not all, of these questions have been addressed directly in the study guides.

QUIZ #1	CELLS & CHROMOSOMES
QUIZ #2	PROKARYOTIC & EUKARYOTIC DIVISION
QUIZ #3	SEXUAL & ASEXUAL REPRODUCTION
QUIZ #4	MEIOSIS OVERVIEW
QUIZ #5	MEIOSIS BEGINS
QUIZ #6	CONCLUSION OF MEIOSIS I
QUIZ #7	MEIOSIS II
QUIZ #8	MISTAKES IN MEIOSIS
QUIZ #9	GAMETOGENESIS

Quiz #1

CELLS AND CHROMOSOMES

1. Most, but not all, living things are composed of cells.

   A. True
   B. False

2. There are two basic cell types, prokaryotic and eukaryotic.

   A. True
   B. False

3. In a prokaryotic cell, DNA is _____.

   A. enclosed in a membrane-bound structure
   B. not enclosed in a membrane-bound structure
   C. Either A or B (depending upon the species in question)
   D. Both A and B.

4. In a eukaryotic cell, DNA is _____.

   A. enclosed in a membrane-bound structure
   B. not enclosed in a membrane-bound structure
   C. Either A or B (depending upon the species in question)
   D. Both A and B.

5. All _____ are _____.

   A. prokaryotes, multicellular
   B. eukaryotes, multicellular
   C. single-celled organisms, prokaryotes
   D. prokaryotes, single-celled organisms

6. A nucleus _____.

   A. is a special structure surrounding DNA
   B. is found in prokaryotes
   C. is found in eukaryotes
   D. All of the above.
   E. A and B only.
   F. A and C only.

7. _____ cells contain cytoplasm.

A. All
B. Prokaryotic
C. Eukaryotic

8. Eukaryotic cells are the basic unit of multicellular _____.

A. animals
B. plants
C. fungi
D. All of the above.” _

9. DNA carries information in the form of _____. This information is used in the production of _____.

A. proteins, chromosomes
B. chromosomes, proteins
C. genes, proteins
D. proteins, genes

10. Eukaryotic cells contain _____.

A. compact circular chromosomes
B. compact linear chromosomes
C. DNA, but no chromosomes
D. chromosomes, but no DNA

11. Prokaryotic cells contain _____.

A. compact circular chromosomes
B. compact linear chromosomes
C. DNA, but not chromosomes
D. chromosomes, but not DNA

12. A pair of matching chromosomes are known as _____.

A. twin chromosomes
B. homozygotic chromosomes
C. heterozygotic chromosomes
D. homologous chromosomes

13. A picture that shows all of a cell's chromosomes, matched up into pairs is called a _____.

A. genetic spread
B. genome
C. karyotype
D. chromosome complement

14. The two types of chromosomes are _____ and _____.

A. sex chromosomes, autosomes
B. plant, animal
C. homozygous, heterozygous
D. paired, unpaired

15. If a person's sex-determining chromosomes consist of two X chromosomes (XX), that person is _____, whereas if they consist of an X and a Y (XY), that person is _____.

A. male, female
B. female, male

Quiz #2

PROKARYOTIC AND EUKARYOTIC DIVISION

1. Cell division in both prokaryotes and eukaryotes ends in the formation of a new organism.

   A. True
   B. False

2. Cell division in eukaryotes is known as mitosis.

   A. True
   B. False

3. When a prokaryotic cell reproduces, _____.

   A. it first makes a copy of its chromosome
   B. the cell pinches in half to form two new cells
   C. each cell forms its own nucleus
   D. All of the above.
   E. A and B only.

4. The division of cytoplasm, or, the physical splitting of the cell is known as _____.

   A. plasmolysis
   B. lysis
   C. cytokinesis
   D. repulsion

5. In multicellular organisms, mitosis leads to _____.

   A. a new multicellular organism
   B. a new unicellular organism
   C. growth and development of the organism
   D. All of the above.

6. The two main periods in the cell cycle are _____.

   A. growth and development
   B. prophase and interphase
   C. mitosis and cytokinesis
   D. interphase and mitosis

7. The G1 phase of interphase _____.

A. ends with cellular division
B. is one of general growth
C. is the phase in which chromosomes are copied

8. During the S phase of interphase, _____.

A. the cell divides
B. the cell's chromosomes are copied
C. the cell's chromosomes divide

9. During the G2 phase of interphase, _____.

A. the cell prepares for mitosis
B. the cell's chromosomes are copied
C. homologous chromosomes come together

10. After chromosomes are copied, each copy is referred to as a _____.

A. homologue
B. centromere
C. chromatid
D. centriole

11. The chromosomes in question #10 are joined together by a _____.

A. homologue
B. centromere
C. chromatid
D. centriole

12. The order of stages in mitosis is _____.

A. prophase, metaphase, anaphase, telophase
B. anaphase, metaphase, telophase, prophase
C. metaphase, telophase, prophase, anaphase

Quiz #3

SEXUAL AND ASEXUAL REPRODUCTION

1. Reproduction in which only one parent is involved is known as asexual reproduction.

   A. True
   B. False

2. Reproduction in which two parents are involved is known as sexual reproduction.

   A. True
   B. False

3. Asexual reproduction results in two organisms that _____.

   A. have very different genetic sequences
   B. are nearly identical
   C. are unrelated to each other
   D. have only half the DNA of the original organism

4. Sex cells are also termed _____.

   A. autosomes
   B. X and Y chromosomes
   C. zygotes
   D. gametes

5. When a sperm cell unites with an ovum (egg), it is called _____ and leads to the formation of _____.

   A. gametogenesis, a zygote
   B. fertilization, ova
   C. fertilization, a zygote
   D. gametogenesis, an aneuploid organism

6. Offspring born through sexual reproduction receive genes from _____.

   A. their mothers only
   B. their fathers only
   C. both parents
   D. either their mothers only or their fathers only

Quiz #4

MEIOSIS OVERVIEW

1. In humans and most other animals, meiosis occurs in the testes of females and in the ovaries of males.

   A. True
   B. False

2. Meiosis reduces the number of chromosomes within a cell by one-half.

   A. True
   B. False

3. Body cells are also called _____.

   A. autosomes
   B. stomata cells
   C. somatic cells

4. Human body cells contain _____ chromosomes.

   A. 23
   B. 30
   C. 36
   D. 46

5. A cell containing the full complement of chromosomes is said to be a _____ cell.

   A. haploid (or 1n)
   B. haploid (or 2n)
   C. diploid (or 1n)
   D. diploid (or 2n)

6. A cell containing one-half of the normal complement of chromosomes is said to be a _____ cell.

   A. haploid (1n)
   B. haploid (2n)
   C. diploid (1n)
   D. diploid (2n)

Quiz #5

MEIOSIS BEGINS

1. In meiosis, two nuclear divisions yield a total of 4 haploid cells.

   A. True
   B. False

2. Which of the following DOES NOT OCCUR during prophase I?

   A. Copies are made of each chromosome.
   B. The chromosomes condense.
   C. Homologous chromosomes pair up.
   D. The nucleus disappears.
   E. The nucleolus disappears.
   F. Centrioles appear.

3. Synapsis forms a chromosome complex known as a _____.

   A. triad
   B. dyad
   C. tetrad
   D. sextant

4. Crossing over _____.

   A. allows chromosomes to move across the cell
   B. increases genetic diversity
   C. decreases genetic diversity
   D. does not occur in human cells

5. If crossing over occurs, it occurs _____.

   A. between two bacteria cells
   B. when homologous chromosomes are paired up
   C. at the chiasma
   D. All of the above.
   E. B and C only.

6. The two chromatids making up a chromosome are _____.

A. called non-competitive chromosomes
B. either X or Y
C. sister chromatids
D. non-sister chromatids

7. Chromatids found on different chromosomes in a homologous pair are _____.

A. called competitive chromosomes
B. either X or Y
C. sister chromatids
D. non-sister chromatids

8. During crossing over, _____ exchange portions of DNA.

A. sister chromatids
B. non-sister chromatids
C. competitive chromatids
D. non-competitive chromatids

9. Crossing over results in a chromosome _____.

A. that carries DNA from one parent only
B. residing on one side of the cell only
C. the produces male offspring
D. that carries DNA from both parents

10. Extending from the centrioles are _____.

A. spindles that form microtubules
B. microtubules that form spindles
C. actin and myosin that form muscle fibers
D. muscle fibers that form actin and myosin

Quiz #6

CONCLUSION OF MEIOSIS I

1. In meiosis I, all stages come to a clear stop before the cell enters the next stage.

   A. True
   B. False

2. At the start of metaphase I, _____.

   A. all chromosomes become attached to the same centriole
   B. chromosomes randomly attach to either centriole
   C. each chromosome in the homologous pair becomes attached to the same centriole
   D. each chromosome in the homologous pair becomes attached to a different centriole

3. At the end of metaphase I, all chromosomes have been aligned at the equator of the cell, known as the _____.

   A. metaphase plate
   B. equatorial rift
   C. cellular equator
   D. chromosomal plate

4. In anaphase I, chromosomes in the homologous pair _____.

   A. move towards the same centriole
   B. have their centromeres split
   C. move towards different centrioles
   D. Both A and B.
   E. Both B and C.

5. Separation of homologous chromosomes is known as _____.

   A. disjunction
   B. non-disjunction
   C. equatorial repulsion
   D. polarization

6. In telophase I, the spindles _____.

A. move towards the center of the cell
B. pull the chromosomes to opposite poles of the cell
C. replicate
D. briefly move to the outside of the cell

7. At the end of telophase I, each pole of the cell is _____.

A. 1n
B. 2n
C. 3n
D. 4n

8. Cytokinesis _____.

A. usually occurs simultaneously with telophase I
B. yields two cells with equal amounts of chromosomes
C. forms two daughter cells
D. All of the above.
E. A and B only.

9. Plant cells form _____ in the middle of the cell from which _____.

A. a cell wall, two cell plates form
B. a cell plate, two cell walls form
C. two cell walls, a cell plate forms
D. two cell plates, a cell wall forms

10. When cytokinesis occurs after telophase I, an abbreviated interphase, known as _____ will normally take place.

A. cytokinesis I
B. cytokinesis II
C. interkinesis
D. plasmolysis

Quiz #7

MEIOSIS II

1. Prophase II marks the beginning of meiosis II.

   A. True
   B. False

2. What event DOES NOT take place in meiosis II?

   A. The nucleus and nucleolus (if reformed at the end of meiosis I) disappear.
   B. The chromosomes (if uncoiling took place at the end of meiosis I) recondense.
   C. The chromosomes (if they did not do so at the end of meiosis I) are copied.
   D. Centrioles reappear.

3. As the cell enters metaphase II, microtubules _____.

   A. detach from the chromosomes
   B. become randomly attached to the chromosomes
   C. attach to the chromosomes in a very specific way

4. _____ are positioned at the equator of the cell in metaphase II.

   A. The double-stranded chromosomes
   B. Homologous pairs of chromosomes
   C. Both A and B.
   D. Neither A nor B.

5. In metaphase II, each centromere is attached to _____.

   A. two different microtubules
   B. microtubules leading to each centriole
   C. Both A and B.
   D. Neither A nor B.

6. hich of the following DOES NOT occur in anaphase II?

   A. The centromeres split.
   B. The homologous pairs separate.
   C. The sister chromatids are pulled towards opposite poles.
   D. All of the above occur in anaphase II.

7. Which of the following DOES NOT occur in telophase II?

A. The spindle fibers and centrioles disappear.
B. The nuclei and nucleoli begin to reform.
C. The chromosomes begin to uncoil.
D. All of the above occur in telophase II.

8. Meiosis begins with _____ and ends in the formation of _____.

A. one haploid cell, four diploid cells
B. one diploid cell, four haploid cells
C. one haploid cell, two diploid cells
D. one diploid cell, two haploid cells

9. Thus in humans, meiosis begins with one cell containing _____ chromosomes and ends with _____ cells containing _____ chromosomes.

A. 23, four, 46
B. 46, four, 23
C. 23, two, 46
D. 46, two, 23

Quiz #8

MISTAKES IN MEIOSIS

1. In nondisjunction, chromosomes fail to separate properly.

   A. True
   B. False

2. If nondisjunction occurs during meiosis I, _____.

   A. all chromosomes in the cell fail to separate
   B. half the chromosomes in the cell fail to separate
   C. at least one homologous pair fails to separate
   D. at least one centromere fails to separate

3. If nondisjunction occurs during meiosis II, _____.

   A. all chromosomes in the cell fail to separate
   B. half the chromosomes in the cell fail to separate
   C. at least on homologous pair fails to separate
   D. at least one centromere fails to separate

In questions #4 and #5, circle all answers that apply.

4. If nondisjunction occurs during anaphase I, _____.

   A. two of the four sex cells will be n+1
   B. two of the four sex cells will be n-1
   C. two of the four sex cells will be normal
   D. one of the four sex cells will be n+1
   E. one of the four sex cells will be n-1

5. If nondisjunction occurs during anaphase II, _____.

   A. two of the four sex cells will be n+1
   B. two of the four sex cells will be n-1
   C. two of the four sex cells will be normal
   D. one of the four sex cells will be n+1
   E. one of the four sex cells will be n-1

6. A cell which carries an abnormal number of chromosomes is termed _____.

A. aneuploid
B. betaploid
C. deficient
D. 2n

7. An embryo with an abnormal number of chromosomes _____.

A. is usually unable to develop normally
B. develops normally in most cases
C. develops if nondisjunction occurred in meiosis I
D. develops if nondisjunction occurred in meiosis II

8. Humans with the condition known as _____ carry one extra chromosome.

A. multiple sclerosis
B. tuberculosis
C. cancer
D. Down syndrome

9. Humans with the condition in question #8 have one extra copy of chromosome _____.

A. #1
B. #13
C. #21
D. #48

Quiz #9

GAMETOGENESIS

1. The production of sperm in males is spermatogenesis.

   A. True
   B. False

2. The production of eggs in females is eggogenesis.

   A. True
   B. False

3. The production of sperm takes place in the _____.

   A. inguinal canal
   B. eustachian tubes
   C. urethra
   D. seminiferous tubules

4. Which of the following is the correct sequence of sperm production?

   A. spermatogonia, primary spermatocyte, secondary spermatocyte, spermatid, sperm
   B. primary spermatocyte, secondary spermatocyte, spermatid, spermatogonia, sperm
   C. spermatid, spermatogonia, secondary spermatocyte, primary spermatocyte, sperm

5. _____ cells aid in the development of sperm.

   A. Epithelial
   B. Sertoli
   C. Mucosal
   D. Phagocytic

6. Which of the following is the correct sequence of egg cell formation?

   A. primary oocyte, secondary oocyte, ovum, ootid, oogonia
   B. oogonia, ovum, secondary oocyte, primary oocyte, ootid
   C. oogonia, primary oocyte, secondary oocyte, ootid, ovum

7. During meiosis I and meiosis II in females, three cells known as _____ are produced. These cells contain chromosomes but relatively little _____.

A. nurse cells, centromeres
B. nurse cells, cytoplasm
C. polar bodies, centromeres
D. polar bodies, cytoplasm

8. Developing egg cells in human females are arrested in _____ until reaching puberty.

A. prophase I
B. anaphase I
C. prophase II
D. anaphase II

9. The group of cells surrounding a primary oocyte is known as its _____.

A. guard cell
B. nurse cell
C. follicle
D. zonapellucida

Meiosis

COMPREHENSIVE EXAM

The following exam is based on the Interactive *Biology Multimedia Courseware* program, Meiosis. Most, but not all of these questions have been addressed directly in the study guides. All of the questions on this exam, however, are based on information put forth in the program.

Please determine if the following statements are true or false.

1. Most, but not all, living things are composed of one or more cells.

   A. True
   B. False

2. Cell division, both in prokaryotes and in eukaryotes, ends in the formation of a new organism.

   A. True
   B. False

3. Cell division in eukaryotes is known as mitosis.

   A. True
   B. False

4. Reproduction in which only one parent is involved is known as asexual reproduction.

   A. True
   B. False

5. In humans and most other animals, meiosis occurs in the testes of females and in the ovaries of males.

   A. True
   B. False

6. Meiosis reduces the number of chromosomes within a cell by one-half.

   A. True
   B. False

7. In meiosis, two nuclear divisions yield a total of 2 haploid cells.

A. True
B. False

8. In meiosis I, all stages come to a clear halt before the cell enters the next stage.

A. True
B. False

9. Prophase II marks the beginning of meiosis II.

A. True
B. False

10. In disjunction, chromosomes fail to separate properly.

A. True
B. False

11. The production of eggs in females is oogenesis.

A. True
B. False

In the following portion of the exam, please choose the letter beside the word, words, or phrase that best completes each sentence.

12. In a prokaryotic cell, DNA is _____.

A. enclosed in a membrane-bound structure
B. not enclosed in a membrane-bound structure
C. Either A or B (depending upon the species in question).
D. Both A and B.

13. In a eukaryotic cell, DNA is _____.

A. enclosed in a membrane-bound structure
B. not enclosed in a membrane-bound structure
C. Either A or B (depending upon the species in question)
D. Both A and B.

14. All _____ are _____.

A. prokaryotes, multicellular
B. eukaryotes, multicellular
C. single-celled organisms, prokaryotes
D. prokaryotes, single-celled organisms

15. _____ cells contain cytoplasm.

A. All
B. Prokaryotic
C. Eukaryotic

16. DNA carries information in the form of _____. This information is used in the production of _____.

A. proteins, chromosomes
B. chromosomes, proteins
C. genes, proteins
D. proteins, genes

17. Eukaryotic cells contain _____.

A. compact circular chromosomes
B. compact linear chromosomes
C. DNA, but no chromosomes
D. chromosomes, but no DNA

18. Prokaryotic cells contain _____.

A. compact circular chromosomes
B. compact linear chromosomes
C. DNA, but no chromosomes
D. chromosomes, but no DNA

19. A pair of matching chromosomes are known as _____.

A. twin chromosomes
B. homozygous chromosomes
C. heterozygous chromosomes
D. homologous chromosomes

20. The two types of chromosomes are _____ and _____.

A. sex chromosomes, autosomes
B. plant, animal
C. homozygous, heterozygous
D. paired, unpaired

21. If a person's sex-determining chromosomes consist of two X chromosomes (XX), that person is _____, whereas if they consist of an X and a Y (XY), that person is _____.

A. male, female
B. female, male

22. When a prokaryotic cell reproduces, _____.

A. it first makes a copy of its chromosome
B. the cell pinches in half to form two new cells
C. each cell forms its own nucleus
D. All of the above
E. A and B only.

23. The two main periods in the cell cycle are _____.

A. growth and development
B. prophase and interphase
C. mitosis and cytokinesis
D. interphase and mitosis

24. The G1 phase of interphase _____.

A. ends in cellular division
B. is one of general growth
C. is the phase in which chromosomes are copied

25. During the S phase of interphase, _____.

A. the cell divides
B. the cell's chromosomes are copied
C. the cell's chromosomes divide

26. During the G2 phase of interphase, _____.

A. the cell prepares for mitosis
B. the cell's chromosomes are copied
C. homologous chromosomes come together

27. After chromosomes are copied, each copy is referred to as a _____.

A. homologue
B. centromere
C. chromatid
D. centriole

28. The chromosomes in question #27 are joined together by a _____.

A. homologue
B. centromere
C. chromatid
D. centriole

29. Asexual reproduction results in two organisms that _____.

A. have completely different genetic sequences
B. are nearly identical to each other
C. are unrelated to each other
D. have only half the DNA of the original organism

30. Offspring born through sexual reproduction receive genes from _____.

A. their mothers only
B. their fathers only
C. both parents
D. either their mothers only or their fathers only

31. Human body cells contain _____ chromosomes.

A. 23
B. 30
C. 36
D. 46

32. A cell containing the full complement of chromosomes is said to be a _____ cell.

A. haploid (or 1n)
B. haploid (or 2n)
C. diploid (or 1n)
D. diploid (or 2n)

33. A cell containing one-half of the normal complement of chromosomes is said to be a _____ cell.

A. haploid (or 1n)
B. haploid (or 2n)
C. diploid (or 1n)
D. diploid (or 2n)

34. Which of the following DOES NOT occur during prophase I?

A. Copies are made of each chromosome.
B. The chromosomes condense.
C. Homologous chromosomes pair up.
D. The nucleus disappears.
E. The nucleolus disappears.
F. The centrioles appear.

35. Synapsis forms a chromosome complex known as a _____.

A. triad
B. dyad
C. tetrad
D. sextant

36. Crossing over _____.

A. allows chromosomes to move across the cell
B. increases genetic diversity
C. decreases genetic diversity
D. does not occur in human cells

37. If crossing over occurs, it occurs _____.

A. between two bacteria cells
B. when homologous chromosomes are paired up
C. at the chiasma
D. All of the above.
E. B and C only.

38. The two chromatids making up a chromosome are _____.

A. called non-competitive chromosomes
B. either X or Y
C. sister chromatids
D. non-sister chromatids

39. Chromatids found on different chromosomes in a homologous pair are _____.

A. called competitive chromosomes
B. either X or Y
C. sister chromatids
D. non-sister chromatids

40. During crossing over, _____ exchange portions of DNA.

A. sister chromatids
B. non-sister chromatids
C. competitive chromatids
D. non-competitive chromatids

41. Crossing over results in a chromosome _____.

A. that carries DNA from one parent only
B. residing on one side of the cell only
C. that produces male offspring
D. that carries DNA from both parents

42. Extending from the centrioles are _____.

A. spindles that form microtubules
B. microtubules that form spindles
C. actin and myosin that form muscle fibers
D. muscle fibers that form actin and myosin

43. At the start of metaphase I, _____.

A. all chromosomes become attached to the same centriole
B. chromosomes randomly attach to either centriole
C. each chromosome in the homologous pair becomes attached to the same centriole
D. each chromosome in the homologous pair becomes attached to a different centriole

44. At the end of metaphase I, all chromosomes have been aligned at the equator of the cell, known as the _____.

A. metaphase plate
B. equatorial rift
C. cellular equator
D. chromosomal plate

45. In anaphase I, chromosomes in the homologous pair _____.

A. move toward the same centriole
B. have their centromeres split
C. move towards different centrioles
D. Both A and B.
E. Both B and C.

46. In telophase I, the spindles _____.

A. move towards the center of the cell
B. pull chromosomes to opposite poles of the cell
C. replicate
D. briefly move to the outside of the cell to jettison excess chromosomes

47. At the end of telophase I, each pole of the cell is _____.

A. 1n
B. 2n
C. 3n
D. 4n

48. Cytokinesis _____.

A. usually occurs simultaneously with telophase I
B. yields two cells with equal amounts of chromosomes
C. forms two daughter cells
D. All of the above.
E. A and B only.

49. Plant cells form _____ in the middle of the cell from which _____.

A. a cell wall, two cell plates form
B. a cell plate, two cell walls form
C. two cell walls, a cell plate forms
D. two cell plates, a cell wall forms

50. When cytokinesis occurs after telophase I, an abbreviated interphase, known as _____ will normally take place.

A. cytokinesis I
B. cytokinesis II
C. interkinesis
D. plasmolysis

51. What event DOES NOT take place in meiosis II?

A. the nucleus and nucleolus (if reformed at the end of meiosis I) disappear.
B. The chromosomes (if uncoiling took place at the end of meiosis I) recondense.
C. The chromosomes (if they did not do so at the end of meiosis I) are copied.
D. The centrioles reappear.

52. As the cell enters metaphase II, microtubules _____.

A. detach from the chromosomes
B. become randomly attached to the chromosomes
C. attach to the chromosomes in a very specific way

53. _____ are positioned at the equator of the cell in metaphase II.

A. The double-stranded chromosomes
B. Homologous pairs of chromosomes
C. Both A and B.
D. Neither A nor B.

54. In metaphase II, each centromere is attached to _____.

A. two different microtubules
B. microtubules leading to each chromosome
C. Both A and B.
D. Neither A nor B.

55. Which of the following DOES NOT occur in anaphase II?

A. The centromeres split.
B. The homologous pairs separate.
C. The sister chromatids are pulled towards opposite poles.
D. All of the above occur in anaphase II.

56. Which of the following DOES NOT occur in telophase II?

A. The spindle fibers and centrioles disappear.
B. The nuclei and nucleoli begin to reform.
C. The chromosomes begin to uncoil.
D. All of the above occur in telophase II.

57. Meiosis begins with _____ and ends in the formation of _____.

A. one haploid cell, four diploid cells
B. one diploid cell, four haploid cells
C. one haploid cell, two diploid cells
D. one diploid cell, two haploid cells

58. Thus in humans, meiosis begins with one cell containing _____ chromosomes and ends with _____ cells containing _____ chromosomes.

A. 23, four, 46
B. 46, four, 23
C. 23, two, 46
D. 46, two, 23

59. If nondisjunction occurs during meiosis I, _____.

A. all chromosomes in the cell fail to separate
B. half the chromosomes in the cell fail to separate
C. at least one homologous pair fails to separate
D. at least one centromere fails to split

60. If nondisjunction occurs during meiosis II, _____.

A. all chromosomes in the cell fail to separate
B. half the chromosomes in the cell fail to separate
C. at least one homologous pair fails to separate
D. at least one centromere fails to split

In questions #61 and #62, circle all answers that apply.

61. If nondisjunction occurs during anaphase I, _____.

A. two of the four sex cells will be n+1
B. two of the four sex cells will be n-1
C. two of the four sex cells will be normal
D. one of the four sex cells will be n+1
E. one of the four sex cells will be n-1

62. If nondisjunction occurs during anaphase II, _____.

A. two of the four sex cells will be n+1
B. two of the four sex cells will be n-1
C. two of the four sex cells will be normal
D. one of the four sex cells will be n+1
E. one of the four sex cells will be n-1

63. An embryo with an abnormal number of chromosomes _____.

A. is usually unable to develop normally
B. develops normally in most cases
C. develops if nondisjunction occurred in meiosis I
D. develops if nondisjunction occurred in meiosis II

64. Humans with the condition known as _____ carry one extra chromosome.

A. multiple sclerosis
B. tuberculosis
C. cancer
D. Down syndrome

65. Humans with the condition in question #64 have one extra copy of chromosome _____.

A. #1
B. #13
C. #21
D. #48

66. The production of sperm takes place in the _____.

A. inguinal canal
B. eustachian tubes
C. urethra
D. seminiferous tubules

67. Which of the following is the correct sequence of sperm production?

A. spermatogonia, primary spermatocyte, secondary spermatocyte, spermatid, sperm
B. primary spermatocyte, secondary spermatocyte, spermatid, spermatogonia, sperm
C. spermatid, spermatogonia, secondary spermatocyte, primary spermatocyte, sperm

68. _____ cells aid in the development of sperm.

A. Epithelial
B. Sertoli
C. Mucosal
D. Phagocytic

69. Which of the following is the correct sequence of egg cell formation?

A. primary oocyte, secondary oocyte, ovum, ootid, oogonia
B. oogonia, ovum, secondary oocyte, primary oocyte, ootid
C. oogonia, primary oocyte, secondary oocyte, ootid, ovum

70. During meiosis I and meiosis II in females, three cells known as _____ are produced. These cells contain chromosomes but relatively little _____.,

A. nurse cells, centromeres
B. nurse cells, cytoplasm
C. polar bodies, centromeres
D. polar bodies, cytoplasm

71. Developing egg cells in human females are arrested in _____ until reaching puberty.

A. prophase I
B. anaphase I
C. prophase II
D. anaphase II

72. The group of cells surrounding a primary oocyte is known as its _____.

A. guard cell
B. nurse cell
C. follicle
D. zona pellucida

In the following portion of the exam, please fill in the word or phrase that best completes each sentence.

73. A picture that shows all of a cell's chromosome, matched up into pairs is called a _____.

74. The division of cytoplasm, or the physical division of a cell is known as _____.

75. Sex cells are also termed _____.

76. Body cells are also termed _____.

77. A cell carrying an abnormal number of chromosomes is said to be _____.

78. The production of sperm is known as _____ and the production of eggs is _____.

Meiosis

ANSWER GUIDE

QUIZ PAC

Quiz #1	Quiz #2	Quiz #3	Quiz #4	Quiz #5	Quiz #6	Quiz #7	Quiz #8	Quiz #9
1. B	1. B	1. A	1. B	1. A	1. B	1. A	1. A	1. A
2. A	2. A	2. A	2. A	2. A	2. D	2. C	2. C	2. B
3. B	3. E	3. B	3. C	3. C	3. A	3. C	3. D	3. D
4. A	4. C	4. D	4. D	4. B	4. E	4. A	4. A,B	4. A
5. D	5. C	5. C	5. D	5. E	5. A	5. C	5. C,D,E	5. B
6. F	6. D	6. C	6. A	6. C	6. B	6. B	6. A	6. C
7. A	7. B			7. D	7. A	7. D	7. A	7. D
8. D	B			8. B	8. D	8. B	8. D	8. A
9. C	9. A			9. D	9. B	9. B	9. C	9. C
10. B	10. C				10. C			
11. A	11. B							
12. D	12. A							
13. C								
14. A								
15. B								

COMPREHENSIVE EXAM

1. A	9. A	18. A	27. C	36. B	45. C	54. C	63. A	72. C
2. B	10. B	19. D	28. B	37. E	46. B	55. B	64. D	73. karyotype
3. A	11. A	20. A	29. B	38. C	47. A	56. D	65. C	74. cytokinesis
4. A	12. B	21. B	30. C	39. D	48. D	57. B	66. D	75. gametes
5. B	13. A	22. E	31. D	40. B	49. B	58. B	67. A	76. somatic cells
6. A	14. D	23. D	32. D	41. D	50. C	59. C	68. B	77. aneuploid
7. B	15. A	24. B	33. A	42. B	51. C	60. D	69. C	78. spermatogenesis,
8. B	16. C	25. B	34. A	43. D	52. C	61. A,B	70. D	oogenesis
	17. B	26. A	35. C	44. A	53. A	62. C,D,E	71. A	

GLOSSARY

anaphase I: the third stage of meiosis I, in which the homologous chromosomes separate and move to opposite ends of the cell.

anaphase II: the third stage of meiosis II, in which the sister chromatids of double-stranded chromosomes separate and move to opposite ends of the cell.

aneuploidy: a genetic condition characterized by the absence of one or more chromosomes or the presence of extra chromosomes.

asexual reproduction: a type of reproduction involving only one parent that produces genetically identical offspring either by budding or by the division of a single cell or the entire organism into two or more parts.

autosome: a chromosome that is not involved in determining the sex of an organism.

cell plate: a cellular structure formed during cytokinesis in a plant cell, which divides the cytoplasm of the cell into two equal portions and gives rise to the cell walls of the two newly formed cells.

centriole: a cellular organelle found in the center of animal cells, made up of nine triplet microtubules in a ring. Centrioles help organize microtubule assembly so that a spindle is formed during cell division.

centromere: the site of attachment for two sister chromatids. Spindle microtubules attach to the centromere during meiosis and mitosis.

chiasma (plural, chiasmata): the x-shaped region representing homologous chromatids that have exchanged genetic material through crossing over during meiosis I.

chromatid: one of two copies of a chromosome in a cell during cell division.

chromosome: a long, thread-like structure consisting of DNA and protein. Chromosomes are found within the nucleus of all eukaryotic cells.

clone: two or more generations of genetically identical organisms.

corpus luteum: progesterone-secreting tissue in the ovary that forms from the follicle after ovulation.

cytokinesis: the division of a cell's cytoplasm into two identical portions to form two separate daughter cells.

daughter cells: two cells formed from the same cell.

deoxyribonucleic acid (DNA): a double-stranded, helical nucleic acid molecule, mainly found in the chromosomes, that contains the hereditary information of organisms.

diploid (2n) cell: a cell containing two sets of chromosomes; one set from each parent.

disjunction: the separation of sister chromatids during anaphase of mitosis and meiosis II, and the separation of homologous chromosomes during anaphase of meiosis I.

eukaryotic cell: a cell in which the genetic material (DNA) is enclosed by a membrane to form a nucleus.

fertilization: the process in which a sperm cell unites with an ovum to form a zygote.

G1 phase: the first growth phase of the cell cycle, which makes up the portion of interphase immediately prior to DNA synthesis.

G2 phase: the second growth phase of the cell cycle, which makes up the portion of interphase immediately following DNA synthesis.

gametes: the sex cells of sexually reproducing organisms, which are capable of fusing to form a zygote.

gametogenesis: the formation of sex cells, or gametes.

haploid (1n) cell: a cell containing only one set of chromosomes.

homologous chromosomes: chromosome pairs of the same length, centromere position and staining pattern that possess genes for the same traits. At fertilization, each parent contributes one homologous chromosome, or homologue, of each pair.

interkinesis: a short interphase that occurs during gamete formation in some species between meiosis I and meiosis II. During interkinesis nuclear membranes and nucleoli reform within the cells.

interphase: the stage in the cell cycle when the nucleus of the cell is not in a state of division. Interphase consists of the G1, S, and G2 phases.

karyotype: a display of an organism's complete set of chromosomes that have been stained and organized into pairs according to length, centromere position, and staining pattern.

M phase: the phase in the cell cycle during which the nucleus of the cell divides.

meiosis: a type of cell division in sexually reproducing organisms in which the nucleus of the diploid parent cell divides twice to form four haploid daughter cells. The haploid cells give rise to gametes.

meiosis I: the first meiotic division during which the parent cell divides into two cells, each with a reduced number of chromosomes.

meiosis II: the second meiotic division during which the chromatids within the two cells formed from meiosis I separate. The cells then divide to form four haploid cells.

metaphase I: the second stage of meiosis I, during which the spindle microtubules attach to the chromosomes of the tetrads that have aligned along the metaphase plate of the cell.

metaphase II: the second stage of meiosis II, during which the spindle microtubules attach to the chromatids of the chromosomes that have aligned along the metaphase plate of the cell.

metaphase plate: a plane at the center of the cell that is at a right angle to the spindle microtubules, which serves as the site of alignment for chromosomes during metaphase.

microtubules: hollow rods of tubulin protein found in the cytoplasm of all eukaryotic cells and in cilia, flagella, and the cytoskeleton.

mitosis: the process of cell division in eukaryotic cells by which the cell nucleus divides and genetic information is distributed equally among two identical daughter cells.

nondisjunction: the failure of both members of a pair of homologous chromosomes or both sister chromatids to separate during anaphase of meiosis I or meiosis II. Nondisjunction can also occur during anaphase of mitosis.

nuclear envelope: the membrane in eukaryotes that encloses the nucleus.

nucleolus: a dark specialized structure within the nucleus.

oogenesis: the process in the ovary that results in the production of female gametes.

oogonia: the original diploid cells within the ovary from which ova are derived. In many female mammals, oogonia are formed prior to birth.

ootid: a female reproductive cell that develops from a secondary oocyte. The ootid matures to form an ovum.

ovary: the female reproductive organ in which ova are generated.

ovum (plural, ova): a female gamete produced in the ovary which may also be called an egg.

polar body: a tiny cell produced during oogenesis when an oocyte undergoes a meiotic division.

primary oocyte: A reproductive cell within the ovary that develops from an oogonium during oogenesis.

primary spermatocyte: a reproductive cell within the seminiferous tubules of the testis that develops from a spermatogonium during spermatogenesis.

prophase I: the first stage of meiosis I, in which the chromosomes condense, and the homologous chromosomes from the father pair up with the homologous chromosomes from the mother to form a tetrad. Near the end of prophase I, the nucleolus and the nuclear envelope of the cell disappear and centriole pairs move to opposite poles of the cell. Fiber-like microtubules extend from the centrioles to form a spindle and the tetrads begin to migrate toward the metaphase plate.

prophase II: the first stage of meiosis II, in which the nucleolus and nuclear envelope, if present, disappear, a spindle forms, and the double-stranded chromosomes begin to migrate toward the middle of the spindle in each daughter cell.

S phase: The synthesis phase of the cell cycle in which the DNA is replicated.

secondary oocyte: a reproductive cell within the ovary that develops from a primary oocyte during oogenesis.

secondary spermatocyte: a reproductive cell within the seminiferous tubules that develops from a primary spermatocyte during spermatogenesis.

seminiferous tubules: a mass of small coiled tubes within the testes, in which sperm are produced.

Sertoli cells: helper cells located in seminiferous tubules that may support and nourish maturing spermatids.

sex chromosomes: the pair of chromosomes that determine sex in most animals. There are two types of sex chromosomes: the X chromosome and the Y chromosome.

sexual reproduction: a type of reproduction in which two gametes, each from either a male or female parent, unite to form a zygote with a unique combination of genes inherited from the parents.

somatic cell: a cell of an organism other than a sex cell.

spermatid: a male reproductive cell that develops from a secondary spermatocyte. Spermatids mature to form spermatozoa.

spermatogonia: the original diploid cells within the seminiferous tubules from which the haploid spermatozoa are formed.

spermatozoa: male gametes.

spindle: the microtubule structure formed during mitosis and meiosis that is responsible for moving the chromatids and chromosomes to opposite poles of the cell.

synapsis: The pairing of replicated homologous chromosomes during prophase of meiosis I.

telophase I: the final stage of meiosis I in which the spindle disappears and nuclei form at opposite poles of the cell. The cell divides via cytokinesis to form two haploid daughter cells.

telophase II: the final stage of meiosis II in which the spindle disappears and nuclei form at opposite poles in each of the two cells formed from meiosis I. Each cell undergoes cytokinesis to give rise to a total of four haploid cells.

testis (plural, testes): the male reproductive organ in which sperm and reproductive hormones are produced.

tetrad: a pair of homologous chromosomes with two chromatids each.

zygote: a fertilized ovum.