Answers to Review for Unit Test #3:
Cellular Reproduction: Mitosis, Meiosis, Karyotypes and Non-disjunction Disorders

It may help you to review mitosis, meiosis and non-disjunction by watching the following narrated animations. They are excellent. There is a summary of the important points and a quick quiz at the end:

Mitosis in animal cells (do not worry about kinetochores)
http://www.sumanasinc.com/webcontent/animations/content/mitosis.html

Meiosis in animal cells (do not worry about interkinesis)
http://www.sumanasinc.com/webcontent/animations/content/meiosis.html

Non-disjunction disorders (do not worry about aneuploidy or polyploidy)
http://www.sumanasinc.com/webcontent/animations/content/mistakesmeiosis/mistakesmeiosis.html

1. Know and understand the definitions and meanings of the following terms.

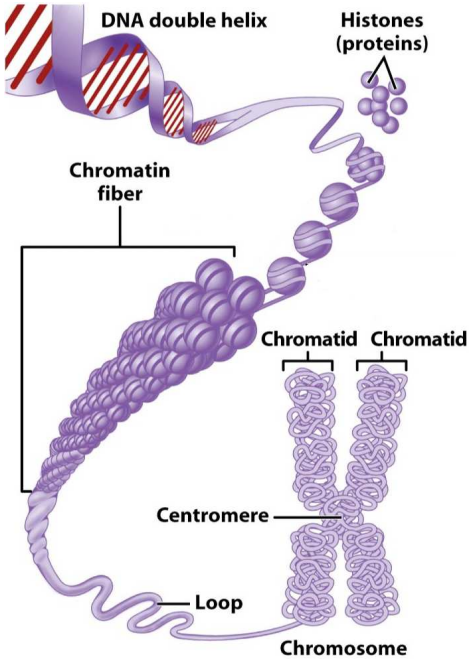
prokaryotic cell	Cell cycle	crossing-over
eukaryotic cell	interphase	chiasmata
chromatin	mitosis	gametes
histones	meiosis	fertilization
DNA replication	cytokinesis	zygote
mutation	cleavage furrow	spermatogenesis
point mutation	cell plate	oogenesis
frameshift mutation	Interphase, Gap 1	ova (ovum)
gene	Interphase, Synthesis	sperm
oncogene (from homework)	Interphase, Gap 2	pollen
unduplicated chromosome	prophase, prophase I and prophase II	karyotype
duplicated chromosome	metaphase, metaphase I and metaphase II	autosome
chromatid	anaphase, anaphase I and anaphase II	sex chromosome
sister chromatids	telophase, telophase I and telophase II	non-disjunction
centromere	homologous chromosomes	syndrome
haploid	synapsis	monosomy
diploid	tetrad	trisomy

2. Clearly explain the difference between the following:

a) chromosomes and chromatin

- Chromatin is the name of the "form" of DNA during interphase, when the cell is between divisions. Chromatin is always found in the nucleus. It is only slightly coiled, with the DNA wrapped around histone proteins. Chromatin allows the DNA to be unwound and unzipped so it can be copied to make mRNA for protein synthesis or for DNA replication during the Synthesis phase of interphase

- Chromosomes are a highly condensed form of DNA which is found only during mitosis or meiosis. The DNA in chromosomes is 'super-coiled' to prevent the DNA from breaking when it is being lined up during metaphase and pulled through the cytoplasm toward the poles during anaphase

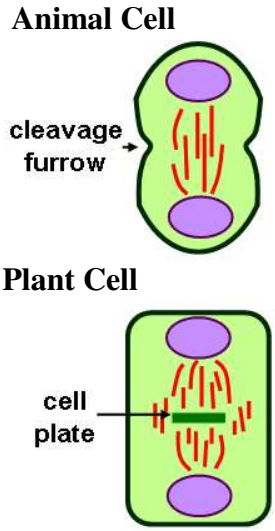


b) the cell cycle and mitosis

- The cell cycle is the entire lifecycle of a cell. It is sub-divided into interphase and division. Division is further divided into mitosis and cytokinesis. Cells spend their entire life going through the cell cycle, but only a very short part of their life is spent in mitosis. Some cells, such as nerve, heart and muscle cells, almost never go through mitosis.
- Mitosis is just one part of the cell cycle; it is just the division of the nuclear material and includes prophase, metaphase, anaphase and telophase.

c) cytokinesis in plant and animal cells

- Cytokinesis refers to the division of the cytoplasm between two daughter cells. It is a part of the cell cycle, but is technically not part of mitosis.
- In an animal cell (which does not have a cell wall), cytokinesis takes place when the cell membrane "pinches in" at the cleavage furrow and the cytoplasm is divided into two cells
- In a plant cell (which does have a cell wall), cytokinesis takes place when a cell plate forms along the cell's equator after the chromosomes have been pulled to opposite poles. The cell plate grows from the middle out (← →), across the centre of the cell, dividing the cytoplasm between both daughter cells.



d) chromatin and chromatid

- Chromatin is the name of the "form" of DNA during interphase, when the cell is between divisions. Chromatin is always found in the nucleus. It is only slightly coiled, with the DNA wrapped around histone proteins. Chromatin allows the DNA to be unwound and unzipped so it can be copied to make mRNA for protein synthesis or for DNA replication during the Synthesis phase of interphase
- A chromatid refers to one half of a duplicated chromosome. Two sister chromatids make up one duplicated chromosome (see diagram on the previous page). Chromatids are made of 'super-coiled' and highly condensed chromatin. DNA is found as chromatids during Gap 2 of interphase, anaphase and metaphase. Once the chromatids have been pulled apart in anaphase, each chromatid is then considered to be an unduplicated chromosome.

e) mitosis and cytokinesis

- Mitosis refers to the division of the nuclear material (the DNA as chromosomes) between the two daughter cells. This happens as a continuous series of four steps: prophase, metaphase, anaphase and telophase
- Cytokinesis refers to the division of the cytoplasm (cytosol and organelles) between the two daughter cells. Cytokinesis takes place as a single step at the very end of telophase, either by the formation of a cleavage furrow in animal cells or a cell plate in plant cells.

f) mitosis and meiosis

- Mitosis is the division of the nuclear material in preparation for asexual reproduction. It occurs in all cells of the body (somatic cells). It involves only one division and produces two daughter cells that are essentially identical to the parent cell and to each other. Mitosis is for maintenance, growth and repair.
- Meiosis is the division of the nuclear material in preparation for sexual reproduction. It occurs only in the germ cells of the gonads (ovaries and testes). Meiosis involves two successive cell divisions so one diploid parent cell produces four unique haploid cells called gametes (eggs and sperm). The four daughter cells are different from the parent cell and different from each other. Meiosis introduces

genetic diversity by crossing over during prophase I and independent (random) assortment of homologous pairs of chromosomes during metaphase I

g) anaphase I and anaphase II

- Anaphase I occurs during meiosis I and involves separating homologous pairs of chromosomes from one another. Each tetrad is pulled apart with one homologous pair being pulled to each pole of the cell. Anaphase I begins with one diploid cell and produces two haploid daughter cells.

- Anaphase II occurs during meiosis II and involves separating sister chromatids from one another. Each homologous pair is pulled apart with one sister chromatid being pulled to each pole of the cell. Anaphase II begins with two haploid cells and produces four haploid daughter cells.

h) autosomes and sex chromosomes

- Autosomes are the chromosomes that are found in all cells of a species and are the same for both males and females. Most cells contain many autosomes of different sizes. An individual has two versions of each autosome, one from each parent. Two versions of each autosome make up a homologous pair.

- The sex chromosomes are the chromosomes that differ between males and females (eg. in humans, the X and Y chromosomes). Most species have only two sex chromosomes which can be very different in size. If the sex chromosomes are different from each other, then they do not make up a homologous pair.

- All monosomies of autosomes are lethal, but monosomy XO (Turner's syndrome) is non-lethal

3. Regarding the cell cycle:

a) What are four reasons that cells divide? Cells divide to:

- keep cells from getting too big. Cells need a large surface area to volume ratio large for adequate diffusion
- reproduce themselves
- replace damaged or dying cells
- enable an organism to grow by making more cells, not larger cells

(the reasons for cell division are often summarized as: growth, maintenance and repair)

b) What are the two main stages of the cell cycle? Clearly explain the difference between these two stages.

- the cell cycle is divided into two main phases: interphase and division
- interphase includes the G1, S and G2 steps that take place in between divisions. In these steps the cell grows, performs its cell functions ('jobs') and duplicates all parts of the cell in preparation for division
- division includes mitosis (the division of the nucleus and all nuclear material) and cytokinesis (the division of the cytoplasm)

a) What two things have to divide during the division stage? What is the name given to each of these types of division?

- both the nuclear material and the cytoplasmic material have to divide
- nuclear division is called mitosis
- cytoplasmic division is called cytokinesis

4. Regarding interphase:

a) What are the three phases of interphase? Briefly describe what happens in each phase.

- interphase is divided into Gap 1, Synthesis and Gap 2
- coming into Gap 1 (G1), the cell is a daughter cell that has just finished cytokinesis, so it is small. The cell grows rapidly, manufactures protein and duplicates all parts of the cytoplasm except the centrosome (remember, the cytoplasm does not include the nucleus)
- during Synthesis (S), the DNA (chromatin) is replicated (unwinds, unzips, matches up with new nucleotides, bonds the sugar-phosphate backbone, then re-winds)
- during Gap 2 (G2), the DNA is "double-checked" and repaired to fix any errors made during DNA replication. The centrioles duplicate and proteins needed for mitosis are produced (for example, to make the spindle fibers)

b) Give two examples of types of cells that spend a long time in interphase.

- brain and nerve cells (such as the nerve cells in the spinal cord), heart cells and muscle cells do not divide very often (hardly ever) so they spend almost their whole life in interphase

c) Give two examples of types of cells that spend a very short amount of time in interphase.

- cells of the skin, blood, stomach lining, intestinal lining and hair follicles all divide very frequently, which means that they spend a short time in interphase before dividing again

5. Regarding mitosis:

a) What are the steps that take place in mitosis? Describe the critical events that take place in each of these steps.

CAREFUL: mitosis only refers to prophase, metaphase, metaphase and telophase (do NOT include interphase or cytokinesis)

Prophase:

- the chromatin condenses to form distinct chromosomes. Each chromosome is formed of two sister chromatids joined at the centromere
- the nucleolus and nuclear membrane dissolve and disappear
- the centrioles migrate to opposite poles of the cell and spindle fibers start to form

Metaphase:

- spindle fibers attach to the centromere
- the spindle fibers tug back and forth on the centromeres until the chromosomes are lined up along the centre (equator) of the cell

Anaphase:

- the centromere splits and the sister chromatids are pulled to opposite poles of the cell
- NOTE: once they have separated from each other, the chromatids are now called chromosomes

Telophase:

- sister chromatids (chromosomes) have reached opposite poles
- the chromosomes start to uncoil back into thin strands of chromatin
- spindle fibers break down and disappear
- the nuclear membrane and nucleolus reform and reappear

b) For diagrams of cells in mitosis, be able to recognize which phase is taking place.
- **Prophase**: look for the nuclear membrane dissolving or completely gone and the beginning of the formation of spindle fibers. The chromosomes may be starting to spread out through the cell but are not yet lined up on the equator
- **Metaphase**: look for the chromosomes lined up along the centre (equator) of the cell
- **Anaphase**: look for "V-shaped" chromosomes as they are pulled to opposite poles
- **Telophase**: look for a single cell with two regions of clustered chromosomes/chromatin. You may see a nuclear membrane reforming. You may also see signs of cytokinesis (a cleavage furrow in animal cells or a cell plate in plant cells) – cytokinesis often overlaps with telophase. As long as the nuclear membrane or cytokinesis are incomplete, the cell is still in telophase

6. What is a **karyotype**? What stage of mitosis is the best for preparing karyotypes?
- a karyotype is a picture of all of the chromosomes in a cell, organized into homologous pairs
- karyotypes are prepared when the cells are in very late prophase or early metaphase when the chromosomes are condensed and most visible

7. What are **genes** and what is their function?
- genes are sections of DNA (chromosomes) which code for one specific thing
- some genes are the 'recipe' for a protein, others are important in regulating cell functions

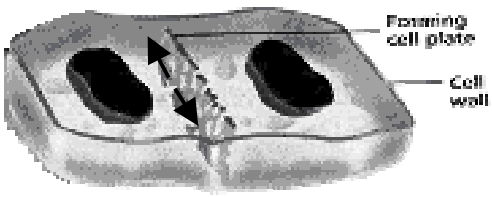
8. What are the roles of the following in the Cell Cycle?

a) **spindle fibers**: attach to the centromeres of the chromosomes and pull the sister chromatids apart, dragging them to opposite poles of the cell

b) **centrioles**: one centriole migrates to each pole of the cell during prophase and the spindle fibers grow out in an aster (star) pattern from each centriole

c) **centromeres**: join the two sister chromatids together after the DNA replicates during interphase. This keeps the two copies of the DNA together until metaphase to help ensure that both daughter cells get one copy of every chromosome

d) **cell plate**: the cell membrane and cell wall grow out from the middle of the equator between the poles of plant daughter cells. The cell plate separates the two daughter cells from one another during cytokinesis



9. Identify the following phases of Meiosis from the description. Include whether it is meiosis I or II.

a) Homologous chromosomes pair up and form tetrads — Prophase I
b) Spindle fibers move homologous chromosomes to opposite poles — Anaphase I
c) Nuclear membrane reforms, cytoplasm divides, 4 daughter cells form — Telophase II (cytokinesis II)
d) A haploid number of chromosomes line up along equator — Metaphase II
e) Crossing-over occurs — Prophase I
f) Chromatids separate — Anaphase II
g) Homologous pairs of chromosomes line up along the equator — Metaphase I
h) Cytoplasm divides, 2 genetically unique daughter cells are formed — Telophase I (cytokinesis I)

10. Regarding meiosis:

a) Which type(s) of cells perform meiosis?
- meiosis takes place in reproductive cells (germ cells) in the gonads

b) What are the two main (overall) purposes of meiosis?

- meiosis is a 'reduction division' so it reduces the number of chromosomes in a diploid cell by one half, producing haploid gametes. When gametes from two individuals join during fertilization, it produces a diploid zygote
- meiosis introduces genetic diversity. The genes in the gametes are mixed in different combinations (by random segregation and crossing over) so the offspring have different traits than the parents. High genetic diversity is important for the survival of the species.

c) Which two processes of meiosis increase the genetic diversity of the offspring? During which stages of meiosis do these processes take place?

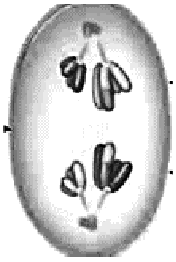
- during Prophase I, the homologous chromosomes in the reproductive cells line up beside one another (synapsis) and non-sister chromatids cross over (at cross-over points called chiasmata). The non-sister chromatids exchange sections of DNA, so all four chromatids have a unique combination of maternal and paternal genes.
- during Metaphase I, the homologous chromosomes randomly move to either side of the equator so the maternal and paternal chromosomes are mixed up between the two daughter cells. Similarly, during Metaphase II, the sister chromatids are oriented randomly on either side of the equator so the maternal and paternal chromosomes are further mixed up between the gametes
- crossing over and random segregation ensure that each gamete is genetically unique, so the offspring have maximal genetic diversity

11. What is the advantage of increased genetic diversity?
    - if all members of a species have very similar genes, if a stress such as a disease, famine or drought hits, then all members of the species will be susceptible to this stress and no members of the species will survive
    - if members of a species have different genes, then some members of the species may be able to survive or adapt to a stress. Not all members of the species will die, so some individuals will live to reproduce and keep the species going
    - genetic diversity is not an advantage to the individual, it is an advantage to the species

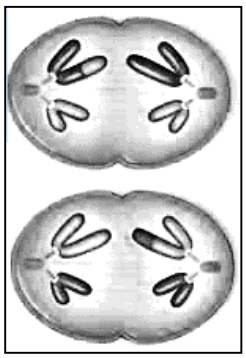
12. What problem can occur during meiosis, and what are the two points at which this problem may arise? What is the effect on the gamete and on the zygote?
    - during meiosis, a **non-disjunction disorder** may occur
    - non-disjunction is caused by an error during anaphase I or II of meiosis
    - during **anaphase I**, if the homologous chromosomes (tetrads) do not separate, both copies of the homologous pair are pulled into the same daughter cell. One daughter cell ends up with an extra copy of a chromosome (causing a trisomy) while the other daughter cell ends up without a copy of this chromosome (causing a monosomy).
    - during **anaphase II**, if the sister chromatids do not separate, both copies of the chromatid are pulled into the same daughter cell. This cell ends up with an extra copy of a chromosome (causing a trisomy) while the other daughter cell ends up without a copy of this chromosome (causing a monosomy).
    - after fertilization, the zygote will have only one copy of a chromosome (a monosomy) or three copies of a chromosome (a trisomy)
    - examples of non-disjunction disorders include trisomy 18 (Edwards syndrome), trisomy 21 (Down syndrome), XO (Turner's syndrome), XXY (Klinefelter syndrome) and XYY ('supermale') syndrome. See notes from class or below for descriptions.
    - all autosomal monosomies are lethal to the fetus, so these fetuses are miscarried
    - **Turner syndrome** is one of the few non-lethal monosomies. A girl gets only one X chromosome. Affected individuals are always girls who are usually shorter than average, have webbed necks, thick legs and arms, are infertile and have normal intelligence. They never mature sexually, but they can be given hormone treatments which will help them to develop some secondary sex characteristics.

There is a summary of steps on the Unit 3 Webpage that may help you to figure out whether the picture is mitosis, meiosis I or meiosis II.

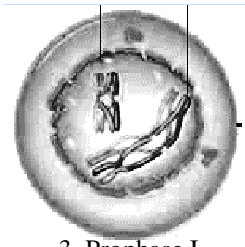
13. **Name the following stages of meiosis. Include whether it is meiosis I or II.**



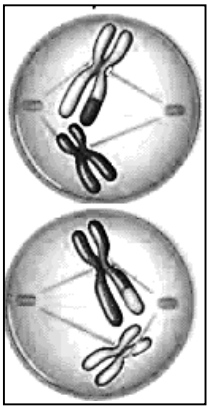
1. Anaphase I (homologous pairs separate)



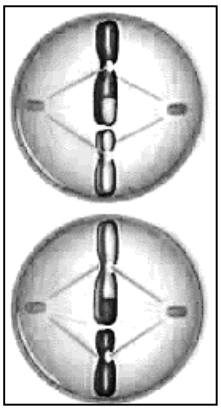
2. Anaphase II (chromatids separate)



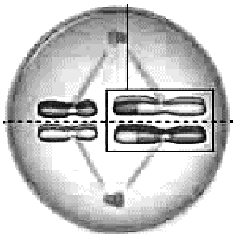
3. Prophase I (crossing over)



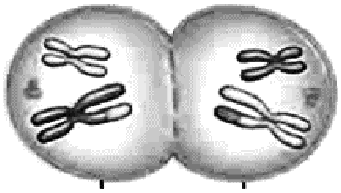
4. Late Prophase II (or Early Metaphase II)



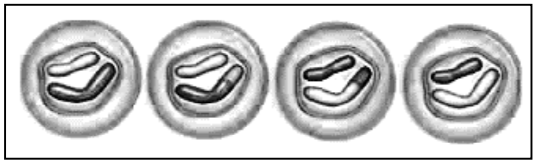
5. Metaphase II



6. Metaphase I (homologous pairs are along the equator & there is only one cell)

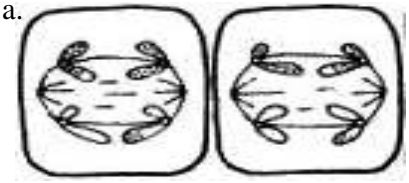
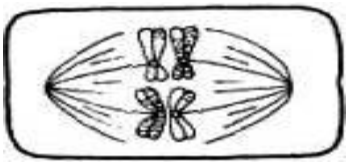
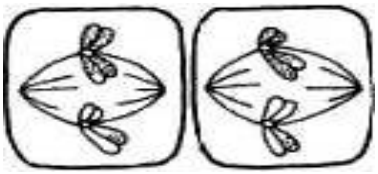
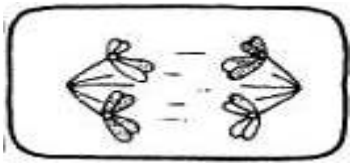
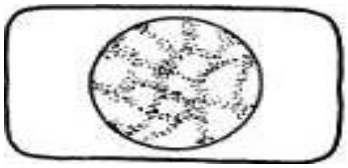
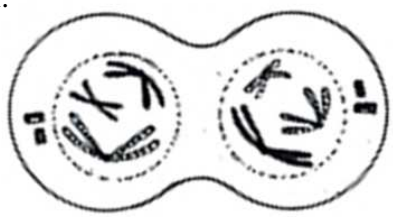
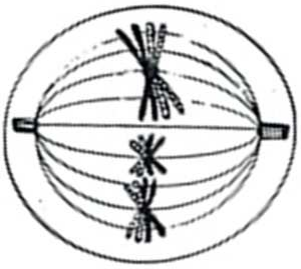
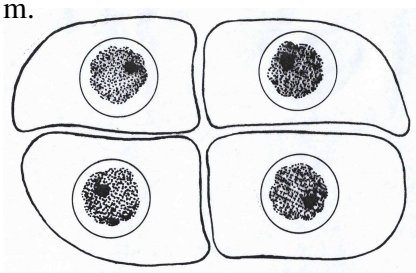
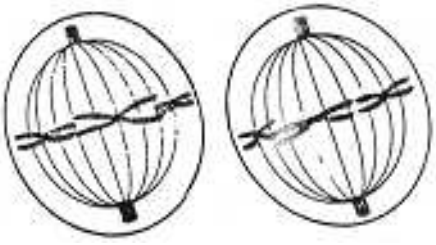
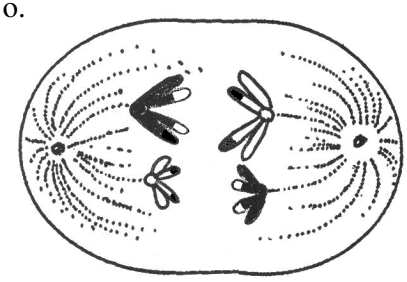


7. Telophase I (two haploid daughter cells are forming)



8. End of Telophase II (four genetically unique gametes have formed)

14. Identify the following stages of mitosis, meiosis I and meiosis II.

a.  Anaphase II of Meiosis II	b.  Prophase I of Meiosis I	c.  Interphase at the end of Telophase II of Meiosis II
d.  Prophase I of Meiosis I (Crossing Over)	e.  Metaphase I of Meiosis I (or very early Anaphase I)	f.  Metaphase II of Meiosis II
g.  Anaphase I of Meiosis I	h.  Interphase of Meiosis I or Mitosis	i.  Telophase I of Meiosis I
j.  Interphase of Mitosis or Meiosis I	k.  Prophase I of Meiosis I (Crossing Over)	l.  Metaphase I of Meiosis I
m.  Interphase at the end of Telophase II of Meiosis II	n.  Metaphase II of Meiosis II	o.  Anaphase I of Meiosis I