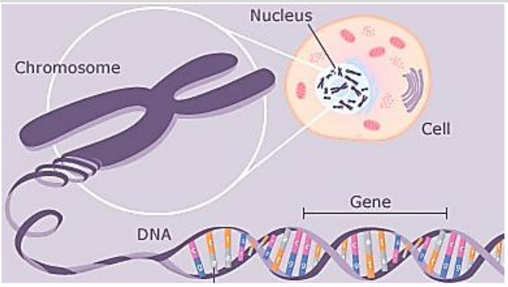
SCIENCE 10

NAME: ______________________________
BLOCK: _____ DATE: ____________________

Genetics & Mitosis – How Each New Cell Gets a Complete Genome[1]

GENES AND CHROMOSOMES

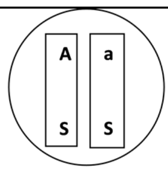


You probably already know that genes can influence a person's characteristics. For example, some people have genes that result in sickle cell anemia (a blood disease) or albinism (very pale skin and hair). In this section you will learn how genes in chromosomes influence our characteristics.

Each cell in your body contains chromosomes. Each **chromosome** contains a long molecule of DNA. Each DNA molecule contains many genes. A **gene** is a segment of a DNA molecule that gives the instructions for making a protein.

Different versions of the same gene are called **alleles**. Different alleles give the instructions for making different versions of a protein. The table to the right shows the alleles for two human genes.

Allele	→	Protein
A	→	Normal enzyme for producing melanin, a pigment molecule that gives color to our skin and hair
a	→	Defective enzyme that cannot make melanin
S	→	Normal hemoglobin
s	→	Sickle cell hemoglobin



Alleles for two genes in a pair of homologous chromosomes

Chromosomes come in pairs of **homologous chromosomes**. In each pair of homologous chromosomes, both chromosomes have the same genes at the same locations. A gene may have different alleles on the two homologous chromosomes (e.g. **Aa**) or a gene may have the same alleles (e.g. **SS**).

The table below shows how different **genotypes** (i.e. different combinations of alleles) result in the production of different proteins which in turn result in different **phenotypes** (i.e. different observable characteristics).

Genotype	→	Protein	→	**Phenotype** (characteristics)
AA or **Aa**	→	Enough normal enzyme to make melanin in skin and hair	→	Normal skin and hair color
aa	→	Defective enzyme for melanin production	→	Very pale skin and hair color; albino
SS or **Ss**	→	Enough normal hemoglobin to prevent sickle cell anemia	→	Normal blood; no sickle cell anemia
ss	→	Sickle cell hemoglobin, which can cause red blood cells to become sickle shaped	→	Sickle shaped red blood cells can block blood flow in the smallest blood vessels, causing pain, etc.; sickle cell anemia

1. Suppose that Jim has the alleles in the pair of homologous chromosomes shown in the above circle.

   What is Jim's genotype? (*circle your answer*) **aaSs** **AaSs** **AaSS**

   Is Jim an albino? (*circle your answer*) **yes** **no**

   Does Jim have sickle cell anemia? (*circle your answer*) **yes** **no**

2. Explain why a person with the **aa** genotype has very pale skin and hair color. Include the words **enzyme** and **melanin** in your explanation.

They have two copies of the gene that codes for a protein responsible for creating melanin (skin pigment). Because both copies of the gene are defective, the body can't produce the enzyme for melanin to be produced and the individual has no pigment.

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[1] Adapted from an activity By Drs. Ingrid Waldron, Jennifer Doherty, R. Scott Poethig, and Lori Spindler, Department of Biology, University of Pennsylvania, © 2015; Teachers are encouraged to copy this Student Handout for classroom use. A Word file for this Student Handout, a shorter Student Handout, and Teacher Preparation Notes with instructions for making the model chromosomes and background information are available at http://serendip.brynmawr.edu/exchange/waldron/mitosis.

3. Fill in the blanks of the following sentences using the following terms: **protein, homologous, DNA, alleles, chromosomes**

A chromosome contains one long ***DNA*** *molecule. Each gene in this* ***DNA*** *molecule gives the instructions for making a* ***protein****. Both chromosomes in a pair of* ***homologous*** *chromosomes have the same genes, but the genes in these two* ***homologous*** *chromosomes may have different* ***alleles****.*

Many of the genes on each chromosome give the instructions for making the large number of proteins that are needed for normal cell structure and function. Therefore, each cell needs to have a complete set of chromosomes with all of these genes.

CELL DIVISION – HOW NEW CELLS ARE MADE

Each of us began as a single cell, so one important question is:

How did that single cell develop into a body with more than a trillion cells?

The production of such a large number of body cells is accomplished by **cell division** repeated many many times. First, one cell divides to form two cells; then both of these cells divide to produce a total of four cells; then these four cells divide to produce eight cells, etc. Thus, repeated cell division is needed for growth.

4. Even in an adult, some cells continue to divide. Why is cell division useful even in an adult who is no longer growing? (Hint: Think about what happens when you have an injury that scrapes off some of your skin.)

To repair injured or old cells in tissues and to allow new tissues to grow (e.x. hair, nails, skin, etc.)

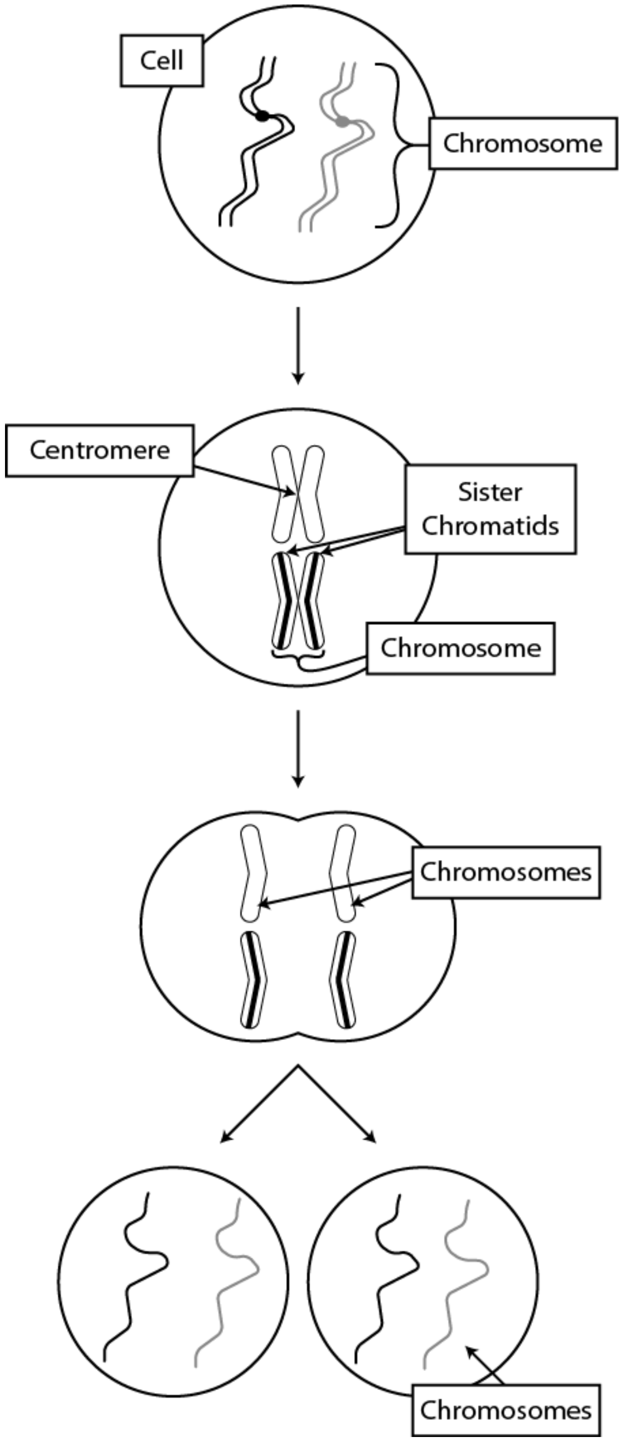
Almost all the cells in our bodies are produced by a type of cell division called mitosis. In mitosis, one cell divides to produce two daughter cells, each with a complete set of chromosomes. (It may seem odd, but the cells produced by cell division are called daughter cells, even in boys and men.)

5. Before mitosis begins, a cell makes a copy of all the DNA in each chromosome. What would go wrong if a cell did not make a second copy of all of its DNA before the cell divided into two daughter cells?

Daughter cells would only have half of a copy of DNA and the cell would not function properly

MITOSIS – HOW EACH DAUGHTER CELL GETS A COMPLETE SET OF CHROMOSOMES

This figure shows mitosis for a cell that has a single pair of homologous chromosomes. To indicate that these two homologous chromosomes have different alleles for many of their genes, one chromosome is shown as dark or striped.



Preparation for Mitosis
To prepare for mitosis, the cell makes a copy of the long DNA molecule in each chromosome; this is called **DNA replication**. DNA replication results in two identical copies of the DNA with the same alleles for each of the genes.

Beginning of Mitosis
Each copy of the long DNA molecule is wound tightly into a compact chromatid. The two chromatids in each chromosome are called **sister chromatids**; they are attached at a centromere.

The chromosomes are lined up in the center of the cell.

Mitosis continues
Next, the two sister chromatids of each chromosome are separated. After they separate, each chromatid is an independent chromosome.

Cytokinesis
The cell pinches together in the middle and separates into two daughter cells, each with a complete set of chromosomes. Thus, each daughter cell has a complete copy of all the genes in the original cell.

The DNA in each chromosome unwinds into a long thin thread.

6. Explain why the chromosomes in the second drawing have sister chromatids, but the chromosomes in the third drawing do not. What happened to the sister chromatids?

The third drawing depicts a cell after anaphase has occurred, which is when the sister chromatids are pulled apart by spindle fibres attached to centromeres at either end of the cell.

7. This fill-in-the-blank question reviews the information from the previous page and provides some additional information about six steps that are needed for mitosis to occur. Use the following terms: **chromatids, cytokinesis, daughter, replication**

   A. In preparation for mitosis, DNA is copied; this is called DNA ***replication***.

   B. Each copy of the DNA is wound tightly (condensed). Now each chromosome has two compact sister ***chromatids***. These compact chromosomes are easier to move than the long thin chromosomes in a cell which is not undergoing cell division. **Spindle fibers** which will move the chromosomes begin to form.

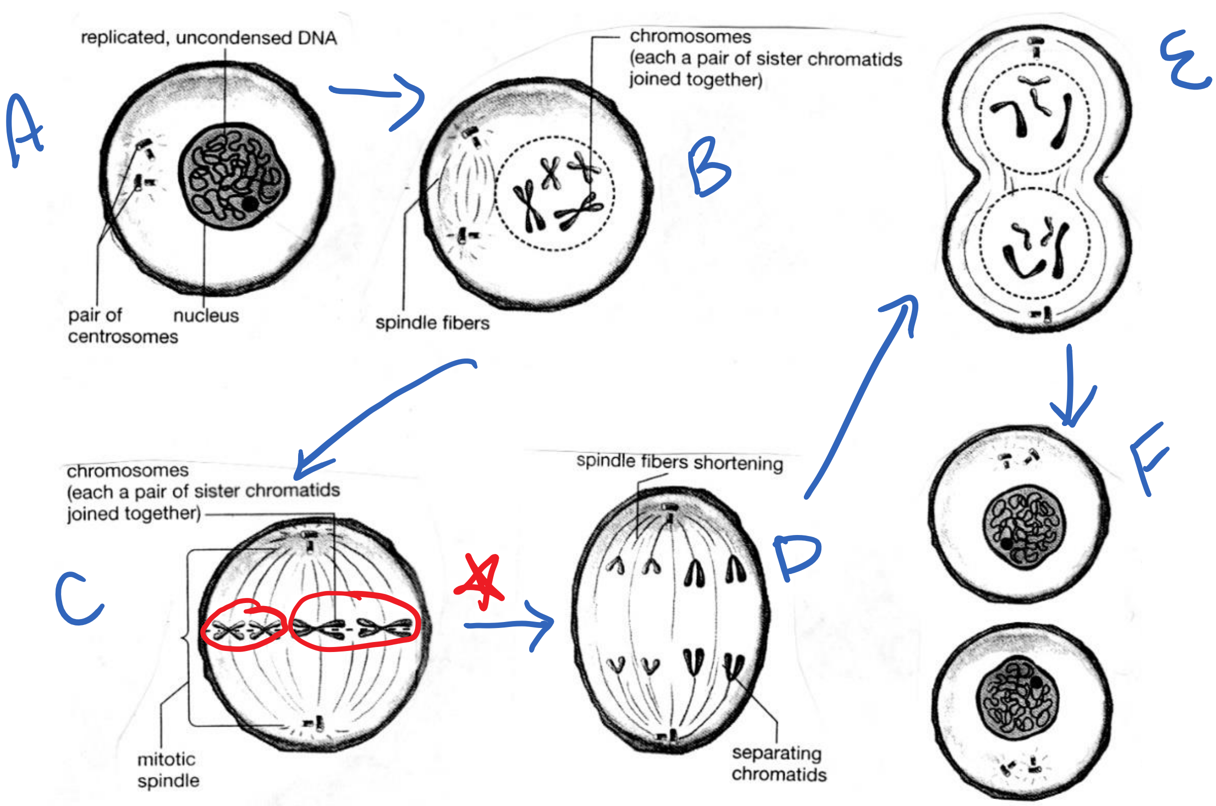
   C. Spindle fibers attach to the chromosomes and line up the chromosomes in the middle of the cell.

   D. Spindle fibers pull the sister ***chromatids*** apart to form separate chromosomes which are moved toward opposite ends of the cell.

   E. In a process called ***cytokinesis***, the cell pinches in half, with one complete set of chromosomes in each half.

   F. Two identical ***daughter*** cells are formed. Each ***daughter*** cell has received a complete set of chromosomes. The DNA in each chromosome unwinds into a long thin thread so that genes can become active and give the instructions for making proteins.

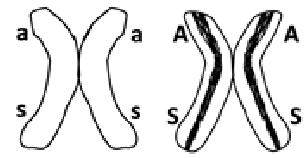
8. The diagram below shows mitosis for a cell that has only 4 chromosomes (2 pairs of homologous chromosomes). The basic process is the same in a human cell which has 46 chromosomes (23 pairs of homologous chromosomes). For each of the figures below,
   - **label the letter of the corresponding step described above**.
   - **Draw arrows to indicate the sequence of events during cell division.**



   - **Circle each pair of homologous chromosomes in step "C"**. Use a star (*) to mark the arrow you drew which **shows when sister chromatids separate** to form individual chromosomes.

Modeling Mitosis with One Pair of Homologous Chromosomes

i. Find a pair of model homologous chromosomes, one with the "**a**" and **"s"** alleles and the other with the "**A"** and "**S"** alleles. Both model chromosomes should be the same color, but one model chromosome will have a stripe on both chromatids to indicate that, although these two homologous chromosomes have the same genes, they have different alleles for many of their genes. The shape of the model chromosomes indicates that the DNA has already been copied and wound tightly into sister chromatids.



ii. Sit across from your desk partner. Use a piece of string laid out in a circle to represent the cell membrane that surrounds the cell that contains these chromosomes. Begin mitosis by lining up the model chromosomes in the middle of the cell (see figure below).

iii. Use your arms to represent the spindle fibers that move the chromosomes. Demonstrate how the sister chromatids of each chromosome are separated into two separate chromosomes which go to opposite ends of the cell.

iv. Now the cell is ready for cytokinesis which will produce two daughter cells, each with a complete set of chromosomes. Rearrange the string to demonstrate cytokinesis and then cut the string to form the cell membranes surrounding each daughter cell.

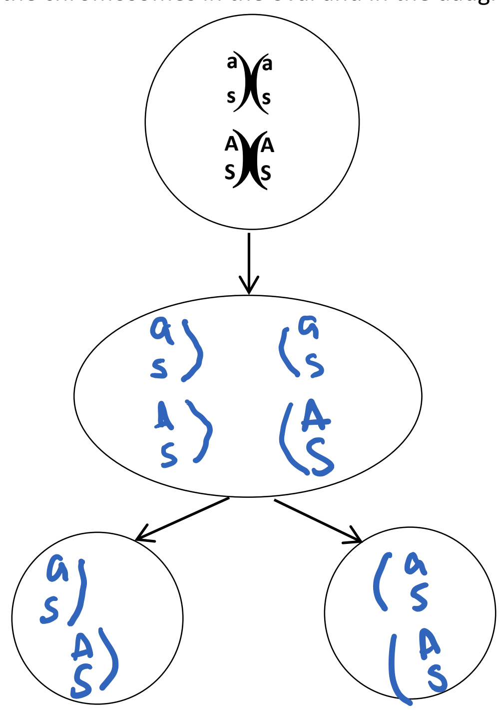
v. Model mitosis again and answer questions 9 & 10. (To do this, you will first need to put the sister chromatids of your model chromosomes back together. This does *not* correspond to any biological process – it is just necessary in order to continue your modeling activity.)

9. Record the results of your modeling in this figure. Draw and label the chromosomes in the oval and in the daughter cells.

Original cell at the beginning of mitosis (after DNA has been replicated and condensed into sister chromatids)

Sister chromatids have separated to form separate chromosomes.

Daughter cells



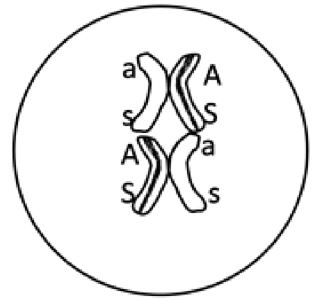
10. The original cell had the genetic makeup **AaSs**. What is the genetic makeup of the daughter cells? AaSs

Are there any differences in genetic makeup between the original cell and the daughter cells produced by mitosis? Explain your answer.

No. The daughter cells are genetically identical to the parent cells because the DNA was replicated (forming sister chromatids), and then those sister chromatids were separated (so each copy went to each daughter cell).

FOLLOW-UP QUESTIONS

Suppose that your partner has put the model chromosomes back together as shown in the diagram. What is wrong? Explain why, in a real cell, sister chromatids could not have different alleles.

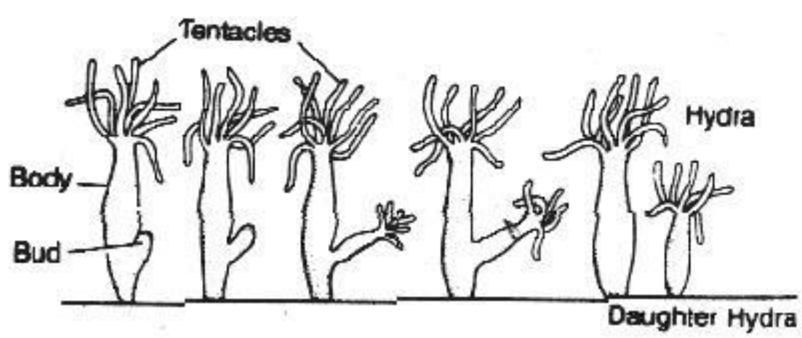


Sister chromatids are formed after DNA replication (when each chromosome makes a copy of itself). Sister chromatids must be exact duplicates of each other, so they could not have different alleles.

Each of the cells in your skin, brain, and other parts of your body has a complete set of chromosomes with the same genes and the same alleles that were present in the single cell that developed into your body. Explain how these billions of genetically identical cells were produced. Include the following terms in your explanation: chromosome, cytokinesis, daughter cell, DNA replication, genes, mitosis, sister chromatids, and spindle fibers.

When the egg was fertilized by the sperm cell, a single cell with a complete set of DNA was formed. Through many many many many many <u>mitosis</u> divisions, the cells were able to <u>replicate their DNA</u> to form <u>sister chromatids</u>, separate the chromatids using <u>spindle fibers</u>, and undergo <u>cytokinesis</u> to create <u>daughter cells</u> with a full copy of the original cell's DNA and <u>genes.</u> Over time, these many divisions created the multicellular organism that is a human.

Some animals and plants use a combination of mitosis and splitting off to reproduce. For example, a hydra can reproduce by budding. The bud is formed by many many repetitions of mitosis, and then the bud breaks off to form a daughter hydra. (A hydra is an animal that lives in the water and uses its tentacles to catch food.)



Will there be any genetic differences between the mother hydra and the daughter hydra? Explain your reasoning.

No. Mitosis generates cells that are genetically identical to their predecessors, so the new hydra that bud off have identical DNA to their parent hydra.