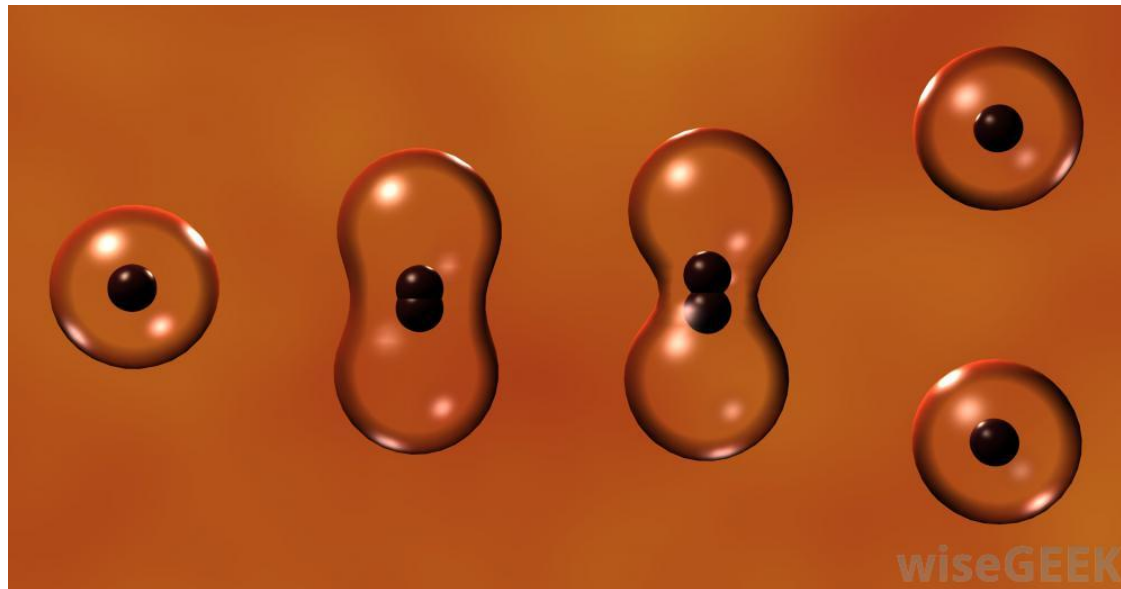


Chapter 5: Chromosomes and Inheritance

Part 1: Mitosis and Meiosis

Where do cells come from?

- Cell division
 - All cells come from other cells
 - One cell (parent) becomes two cells (daughters)
 - Daughter cells are identical to parent cell

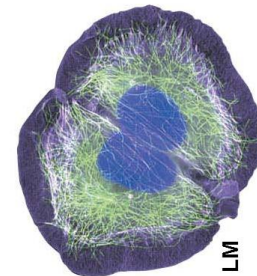


Why do organisms need cell division?

1. Repair and replacement of cells
2. Growth of multicellular organisms
3. Asexual reproduction
4. Sexual reproduction (production of sperm and eggs)
**requires a special version of cell division*

FUNCTIONS OF CELL DIVISION BY MITOSIS

Cell Replacement



Human kidney cell

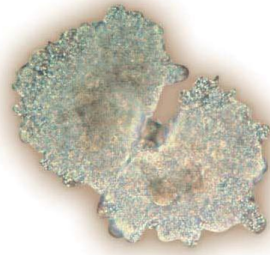
Growth via Cell Division



Colorized SEM

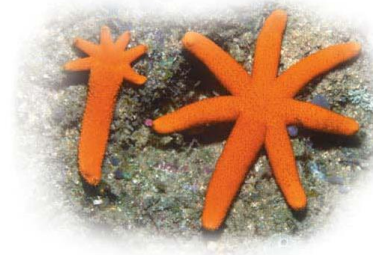
Early human embryo

Asexual Reproduction



LM

Reproduction of an amoeba



Regeneration of a sea star



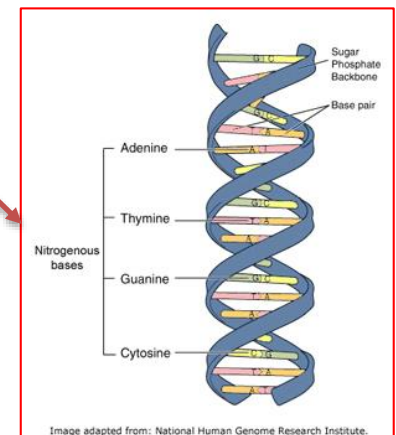
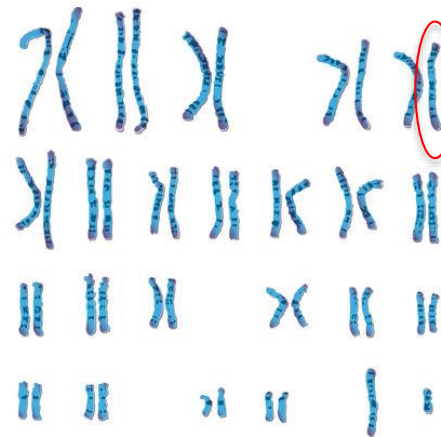
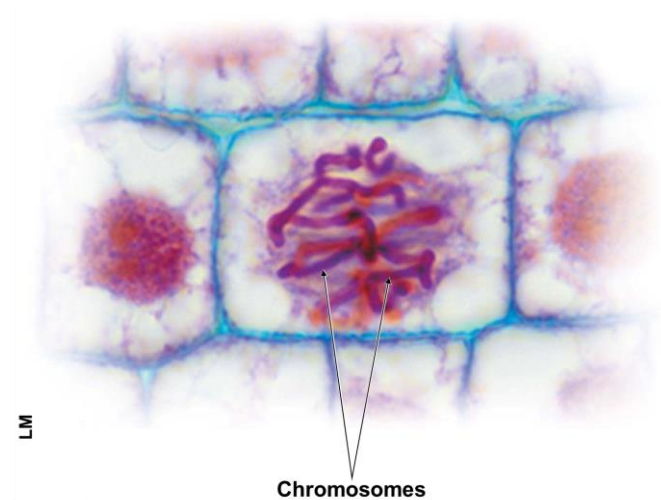
Growth of a clipping

Goals of Cell Division

1. Grow parent cell so it is big enough to divide in two
2. Duplicate chromosomes so each daughter cell receives a copy of the genetic instructions
3. Divide up the chromosomes and cellular contents between the two daughter cells so that they are the same

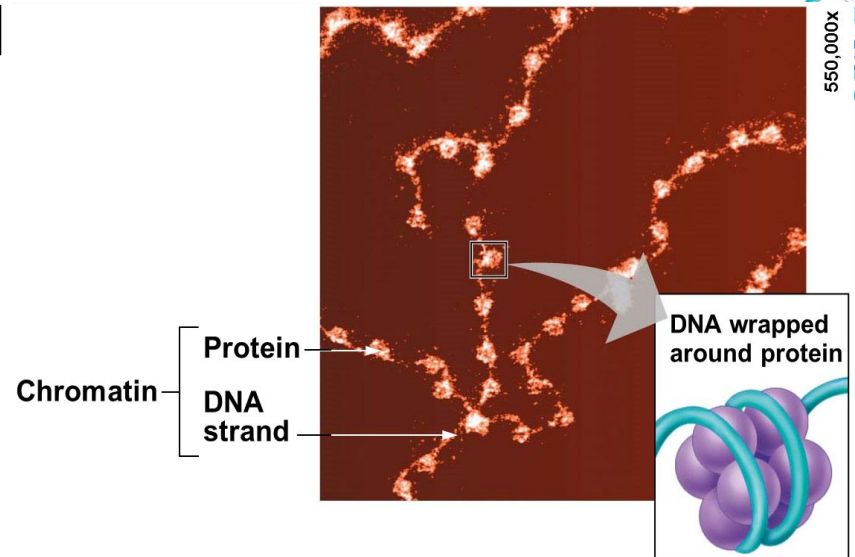
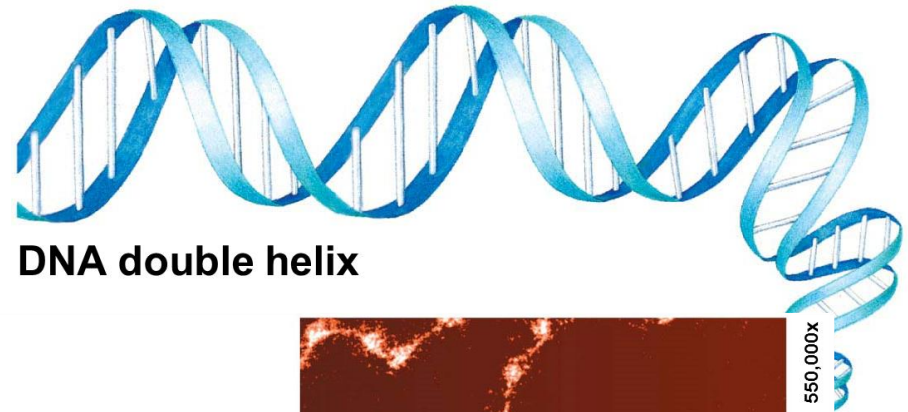
Chromosomes are DNA Molecules

- DNA in a cell is organized into pieces called **chromosomes**
 - Each chromosome is a DNA molecule (DNA double helix)
 - Human cells have 46 chromosomes, or 46 pieces of DNA



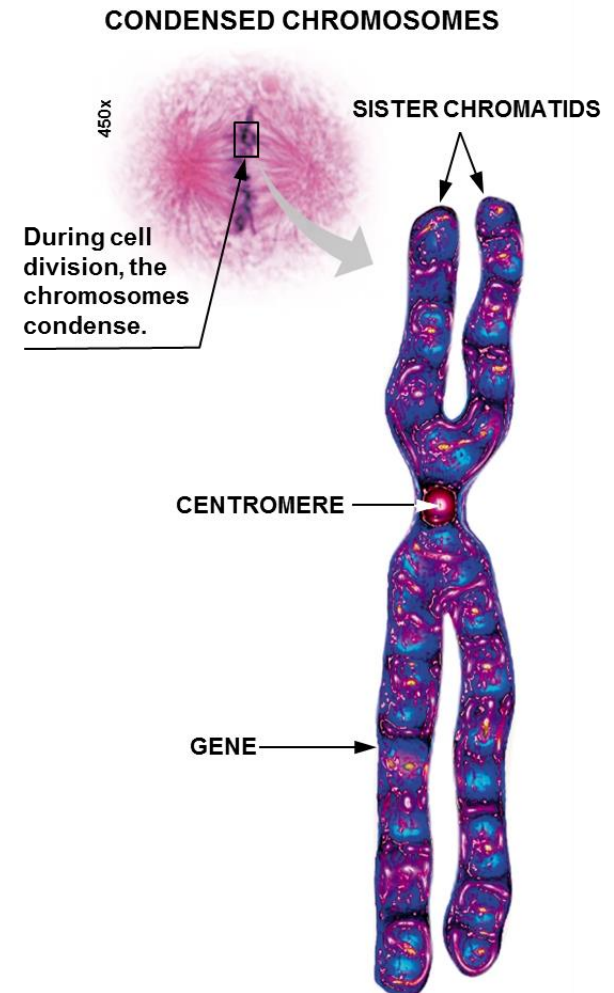
Chromosome Organization

- Chromosomes must be organized in order to fit into the nucleus
- DNA “thread” is wrapped around proteins that act like a “spool”



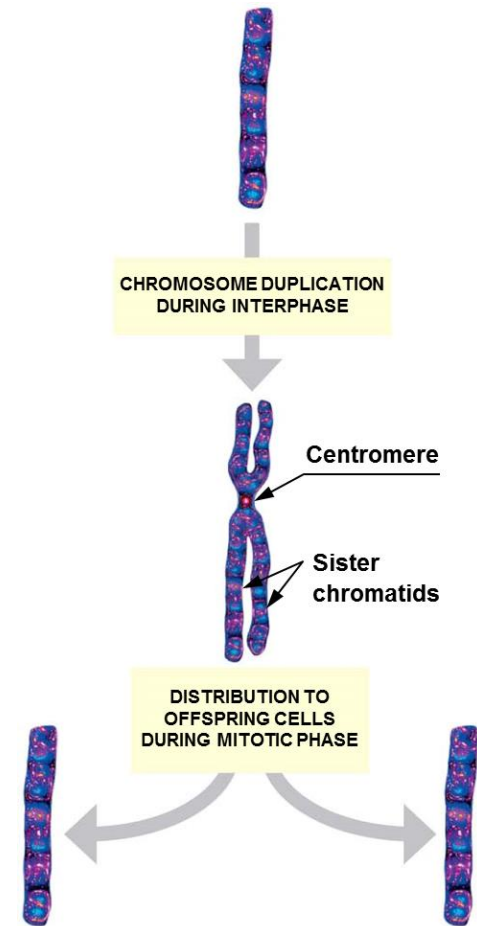
Chromosome Structure

- Chromosomes are thick and condensed during cell division
- DNA is copied by the process of **Chromosome Duplication**
 - DNA replication will produce two identical daughter DNA strands called **sister chromatids**
 - Sister chromatids are attached to one another at the **centromere**
 - Sister chromatids can be separated so that one copy of the DNA goes to one cell and one copy to the other

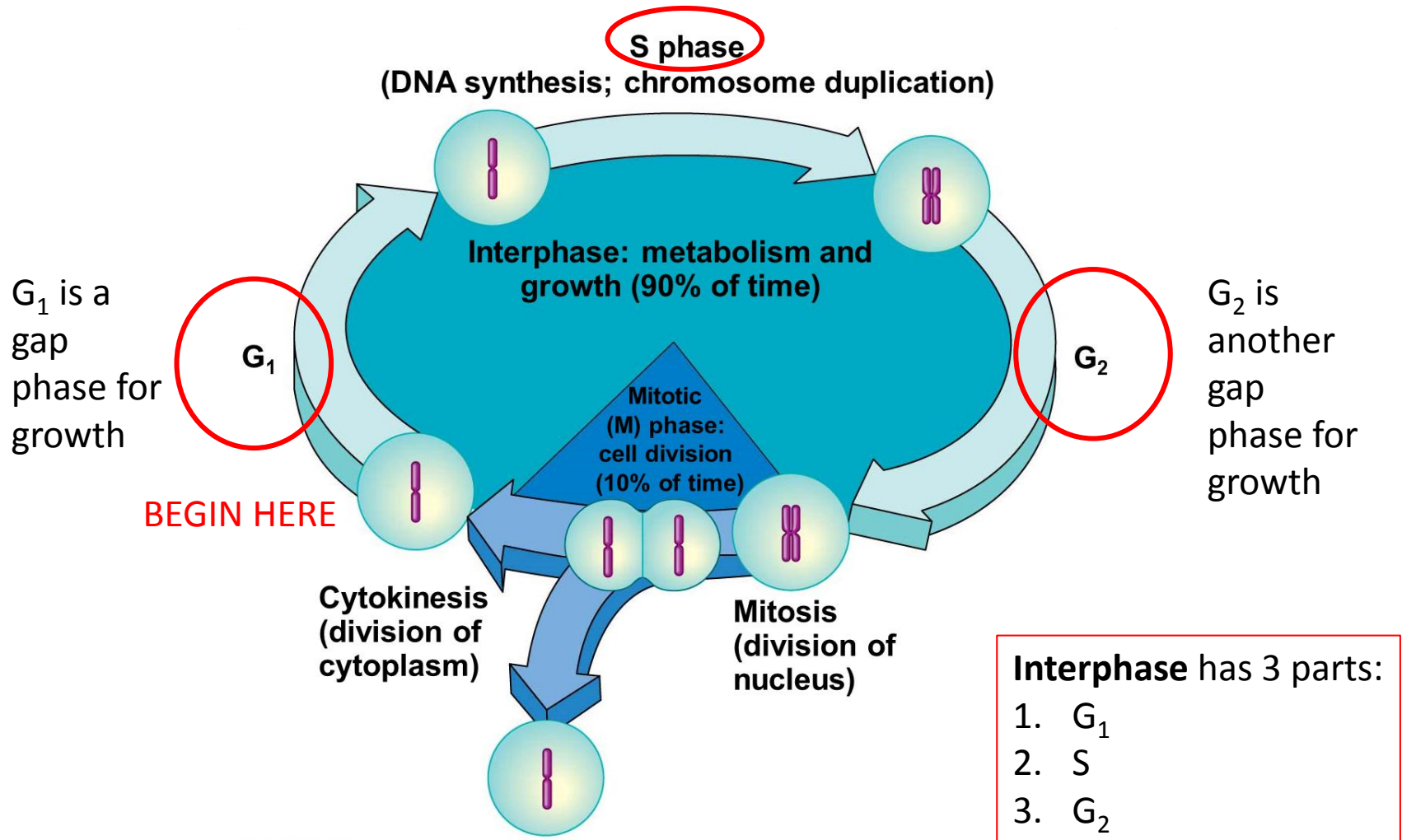


Chromosome Duplication

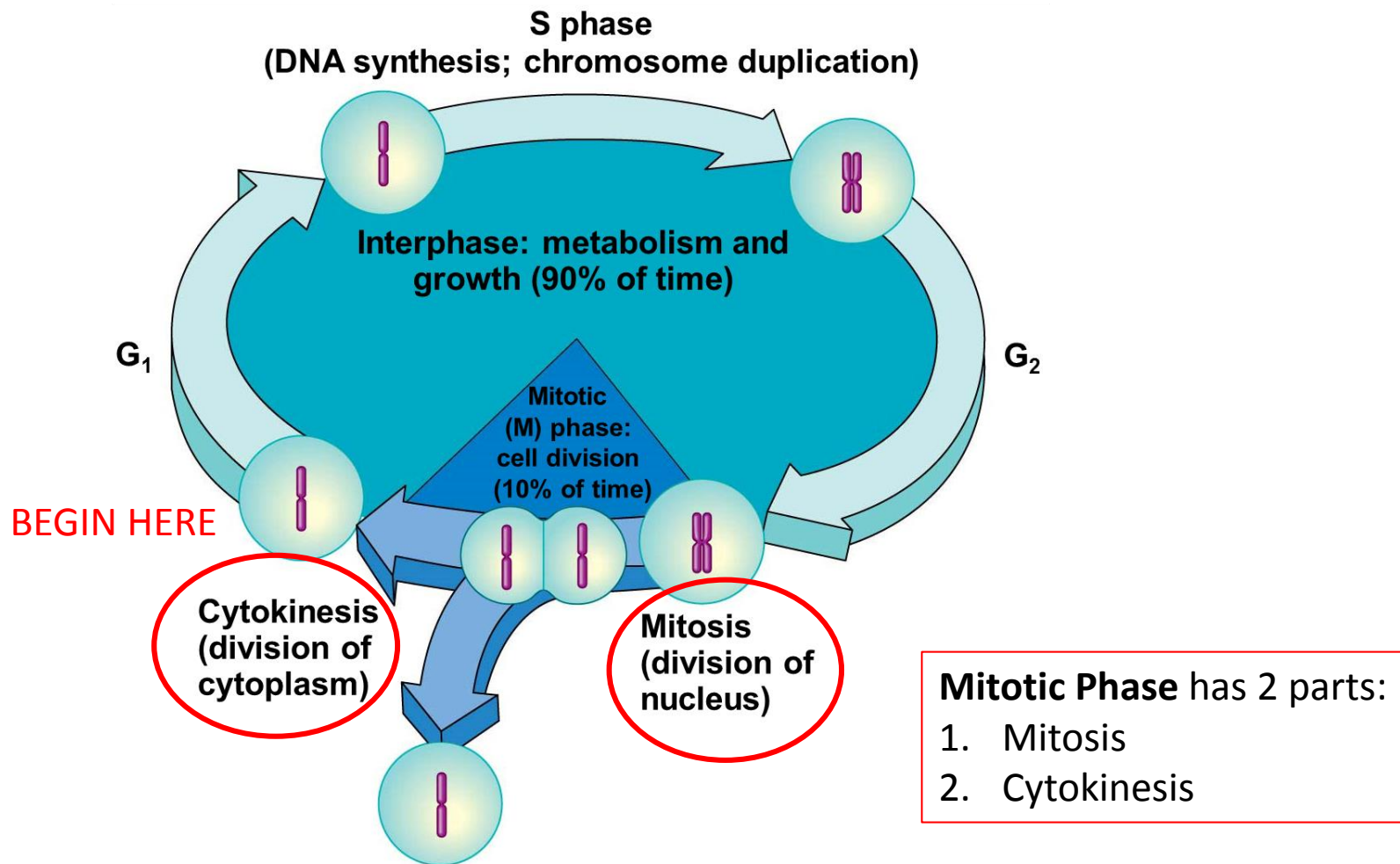
- An extra copy of DNA must be made so that each daughter cell contains the same genetic information



The Cell Cycle: Interphase

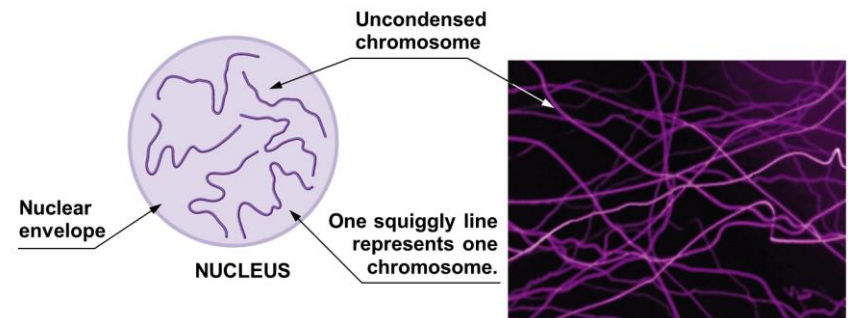
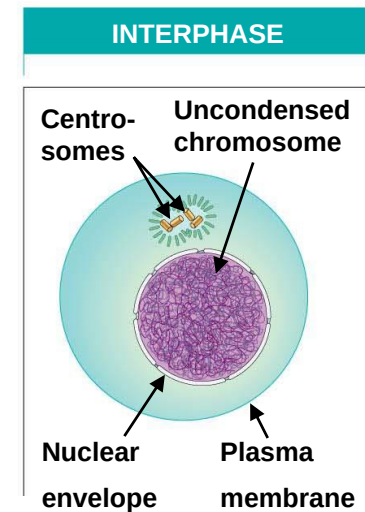


The Cell Cycle: Mitotic Phase



Interphase

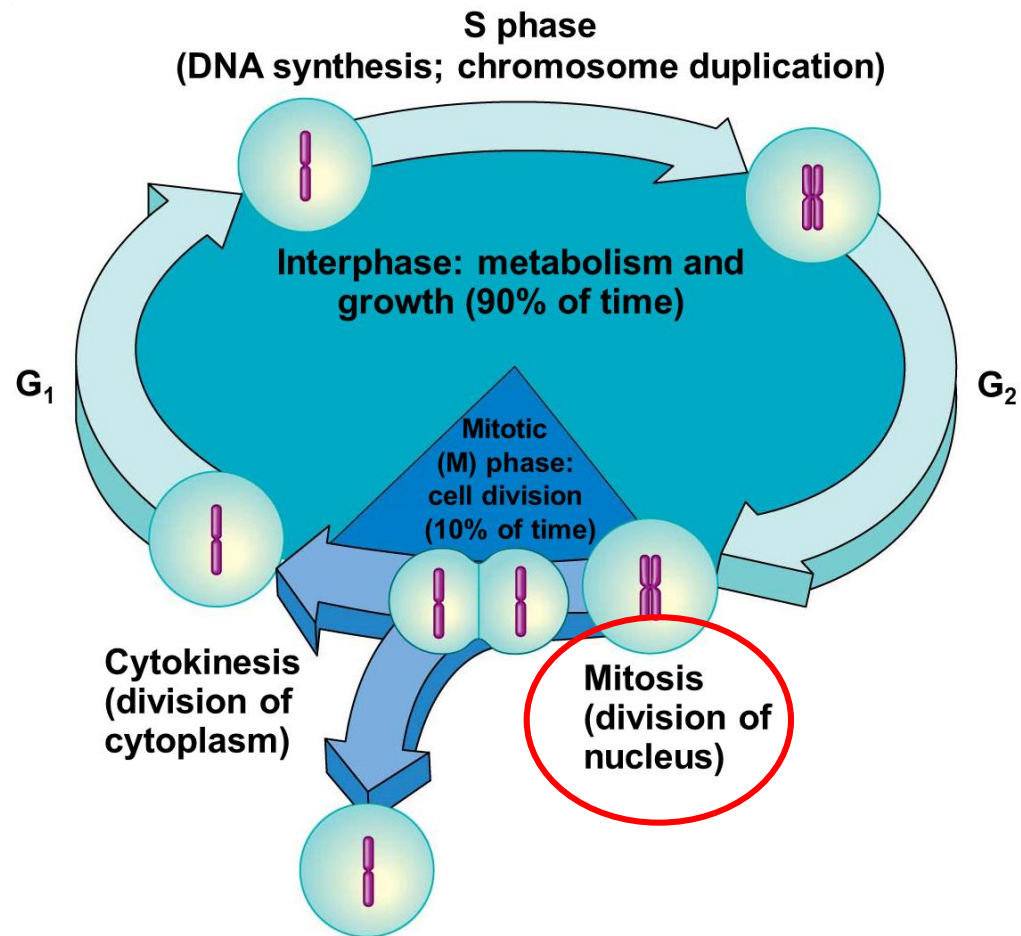
- During interphase (G_1 , S, and G_2) the cell looks the same under a microscope
- Two **centrosomes** form
 - Organelle that will be used to help divide the chromosomes
- Chromosomes duplicate during S phase



Mitosis Stages

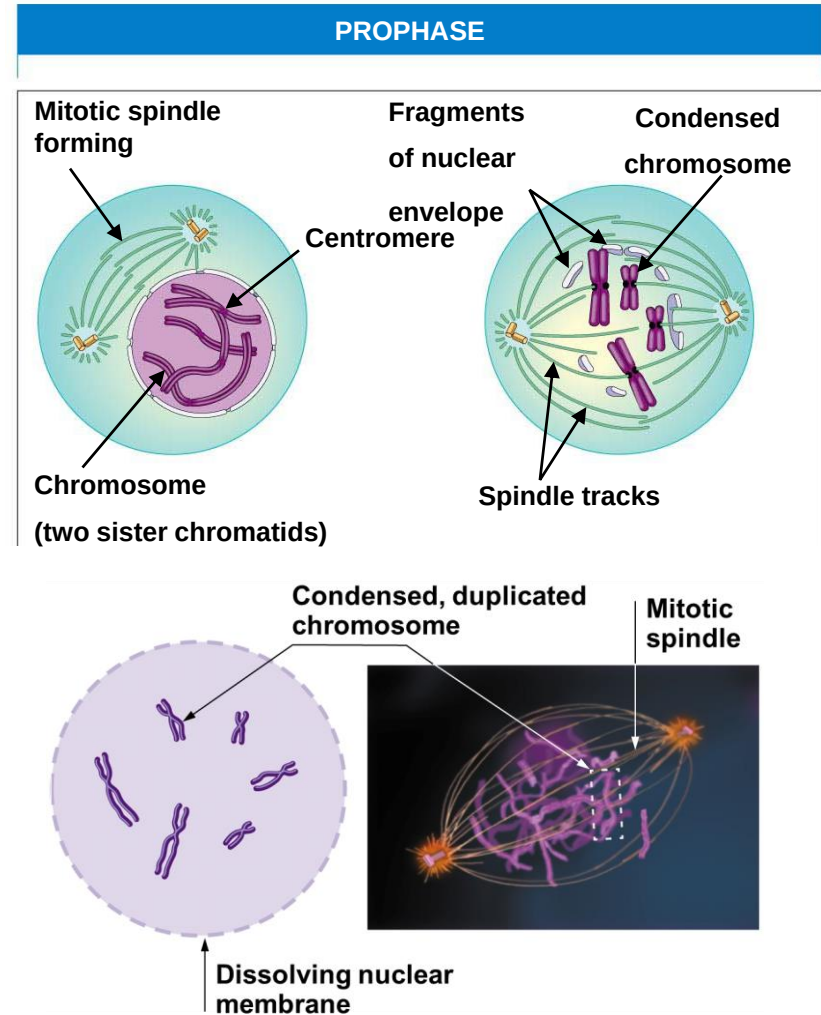
1. Prophase
2. Metaphase
3. Anaphase
4. Telophase
(cytokinesis overlaps with telophase)

PMAT



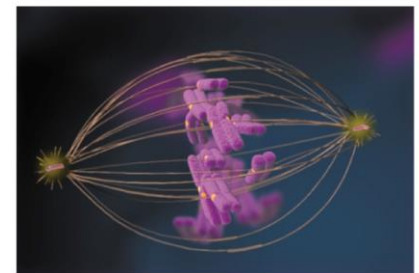
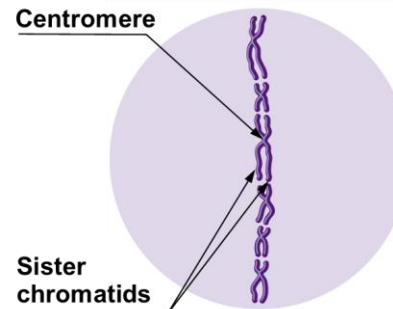
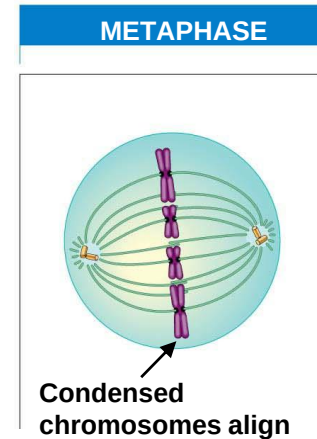
Prophase

- Chromosomes condense (become short and thick)
- Nuclear envelope breaks down
- **Mitotic spindle** forms
 - Like a web of tracks that spreads between the two centrosomes
- Chromosomes attach to the spindle fibers by their centromeres



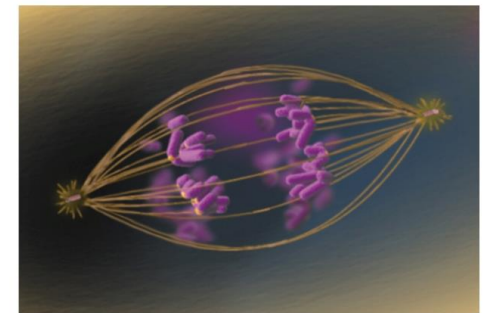
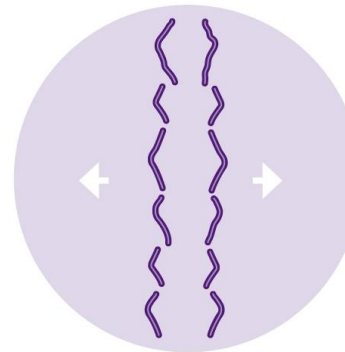
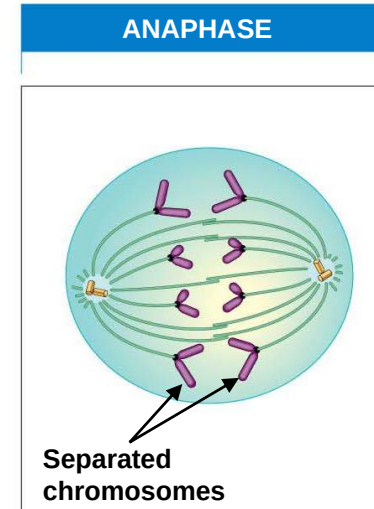
Metaphase

- Chromosomes align at the **metaphase plate**
 - The middle of the cell between the two centrosomes
 - Like an equator where the centrosomes are the poles



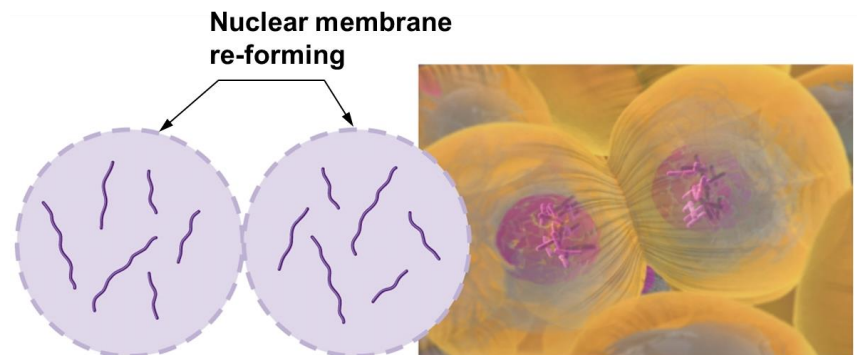
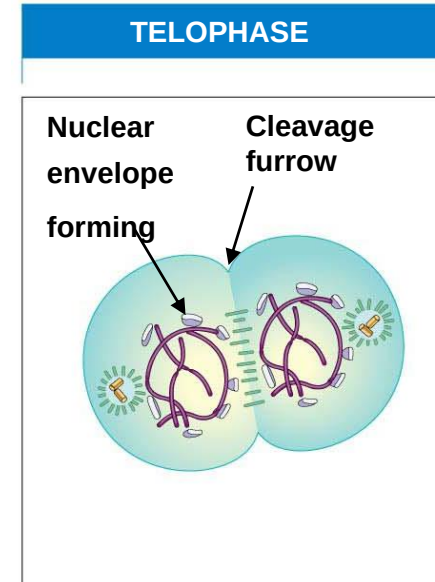
Anaphase

- Sister chromatids separate at the centromeres
- Chromosomes move to opposite sides of the cell
 - Travel on the spindle fibers like tracks
 - One set of chromosomes moves toward each centrosome



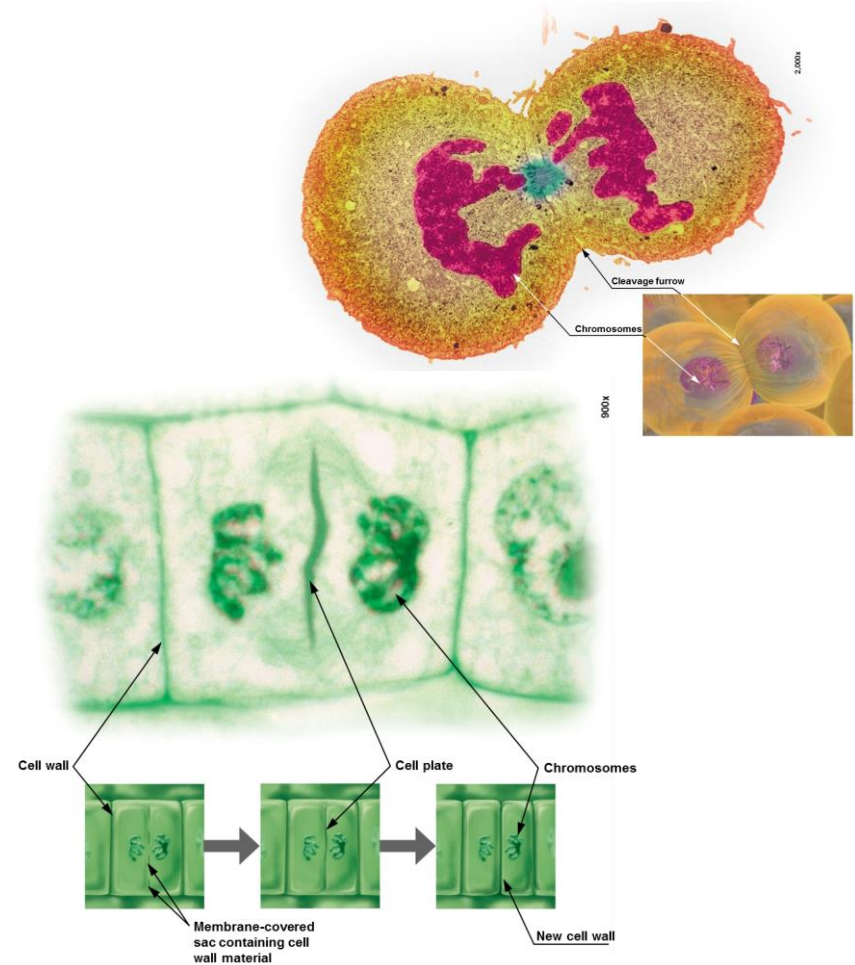
Telophase

- Nuclear envelopes form around chromosomes to establish daughter nuclei
- Chromosomes uncoil
- Mitotic spindle disappears



Cytokinesis

- **Cytokinesis** divides the cytoplasm
 - **Cleavage furrow** begins dividing two daughter cells (animals)
 - **Cell plate** forms between two daughter cells (plants)



Practice Question

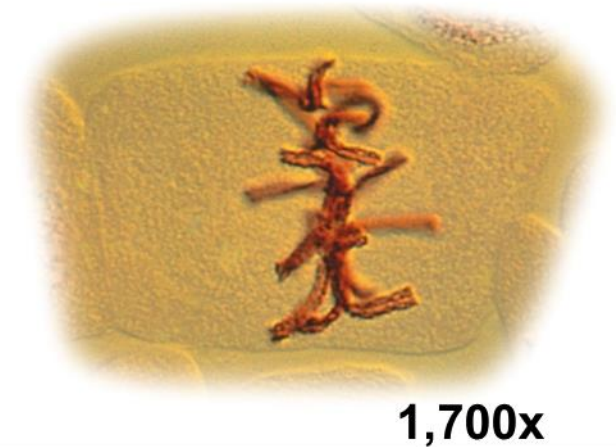
- What phase of mitosis is pictured?
 - a. Prophase
 - b. Metaphase
 - c. Anaphase
 - d. Telophase



1,700x

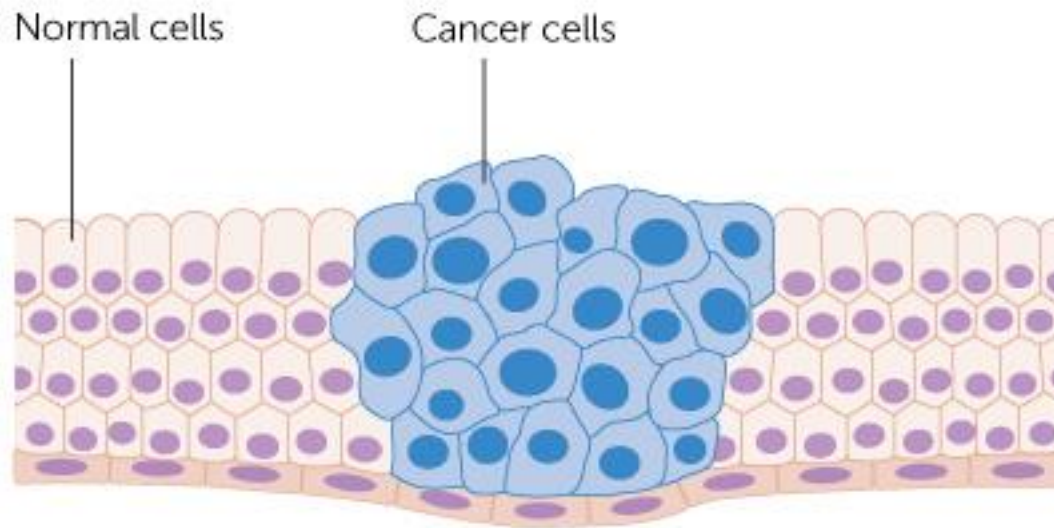
Practice Question

- What phase of mitosis is pictured?
 - a. Prophase
 - b. Metaphase
 - c. Anaphase
 - d. Telophase



The Cell Cycle and Cancer

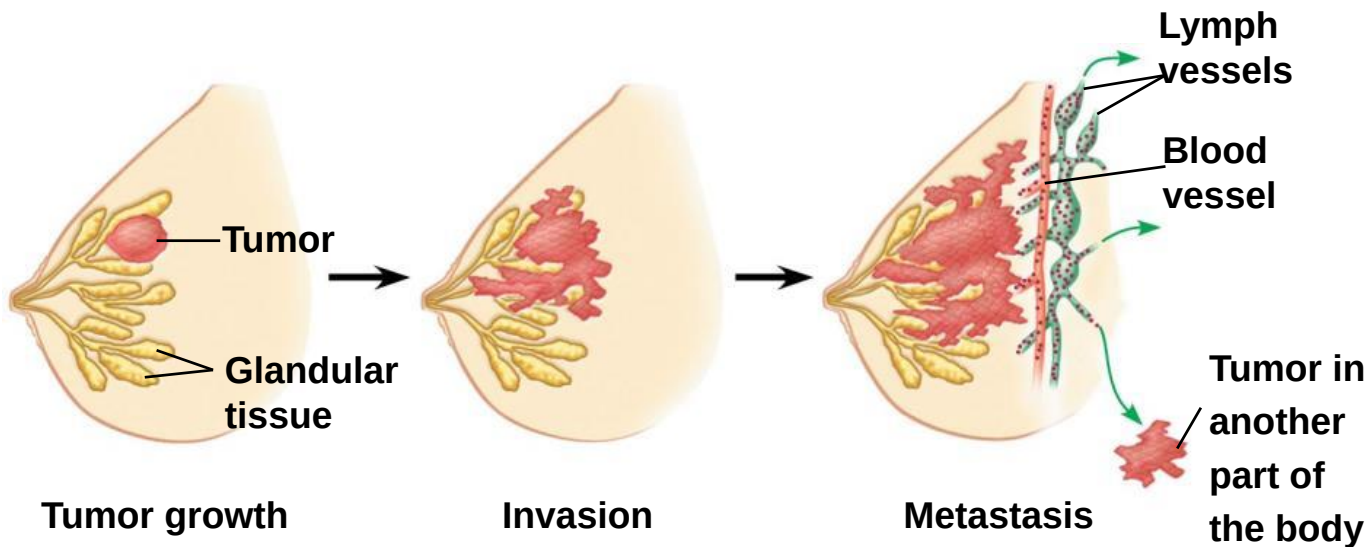
- Cancer cells escape control of the cell cycle
 - Cells divide excessively and form tumors, invade other body tissues



Cancer Research UK

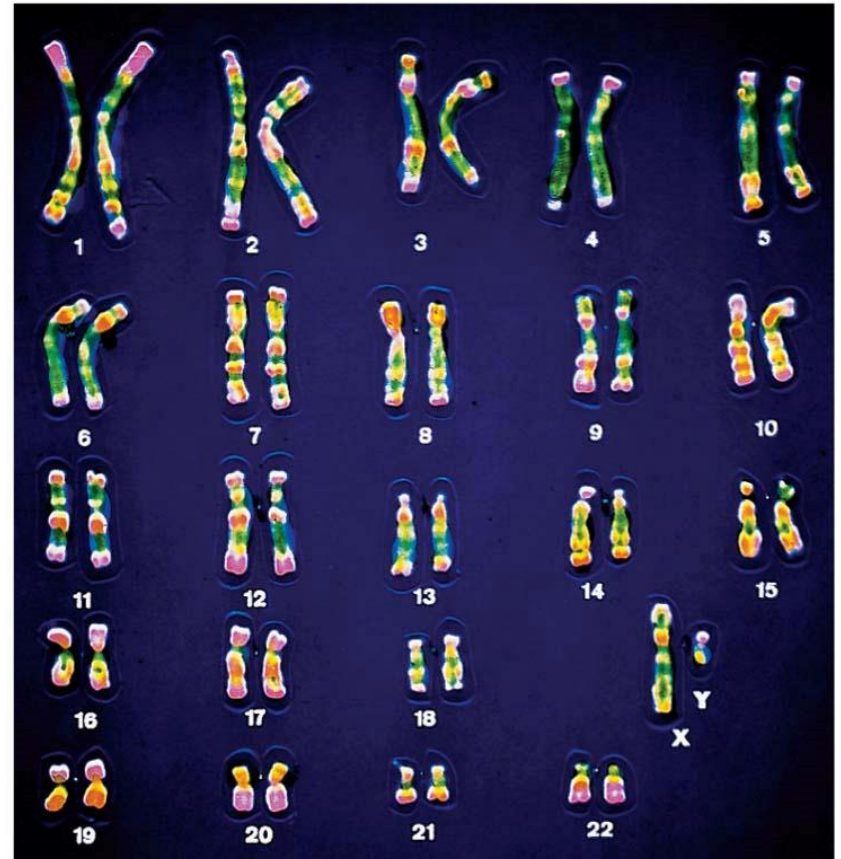
The Cell Cycle and Cancer

- Benign tumors stay at the original site
- Malignant tumors spread to other areas of the body (metastasis)



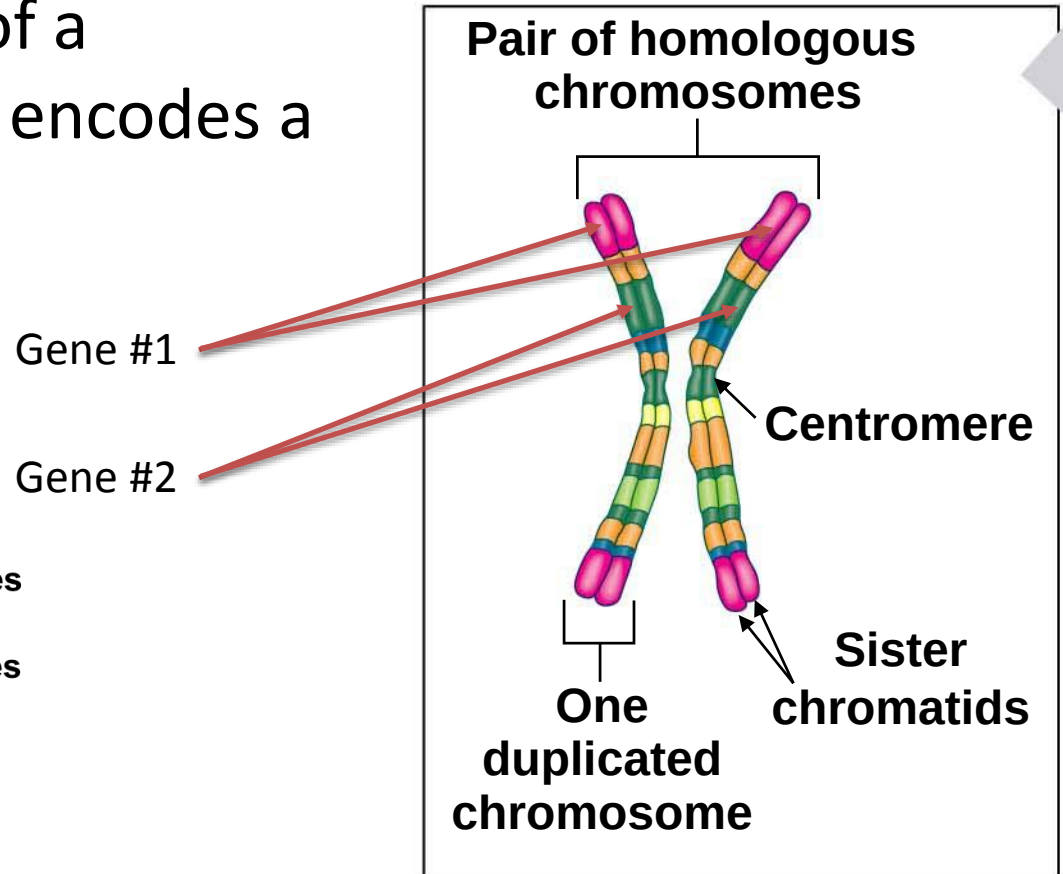
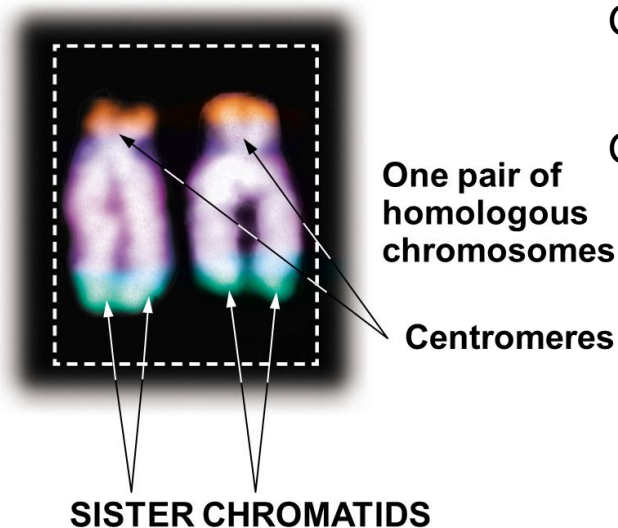
Homologous Chromosomes

- Human body cells (**somatic cells**) have 46 chromosomes
 - 23 **homologous pairs**
 - 1 set of 23 chromosomes inherited from father (paternal) 1 set of 23 chromosomes inherited from mother (maternal)



Homologous Chromosomes Contain the Same Genes in the Same Order

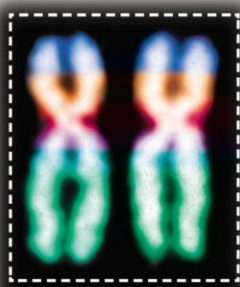
- **Gene** – a section of a chromosome that encodes a specific trait



Homologous Chromosomes Contain the Same Genes in the Same Order

- NOTE: only 22 of the 23 human pairs of homologous chromosomes are truly homologous
- Sex chromosomes (X, Y) do not contain the same genes in the same order
 - Females XX (homologous pair)
 - Males XY (not really a homologous pair)

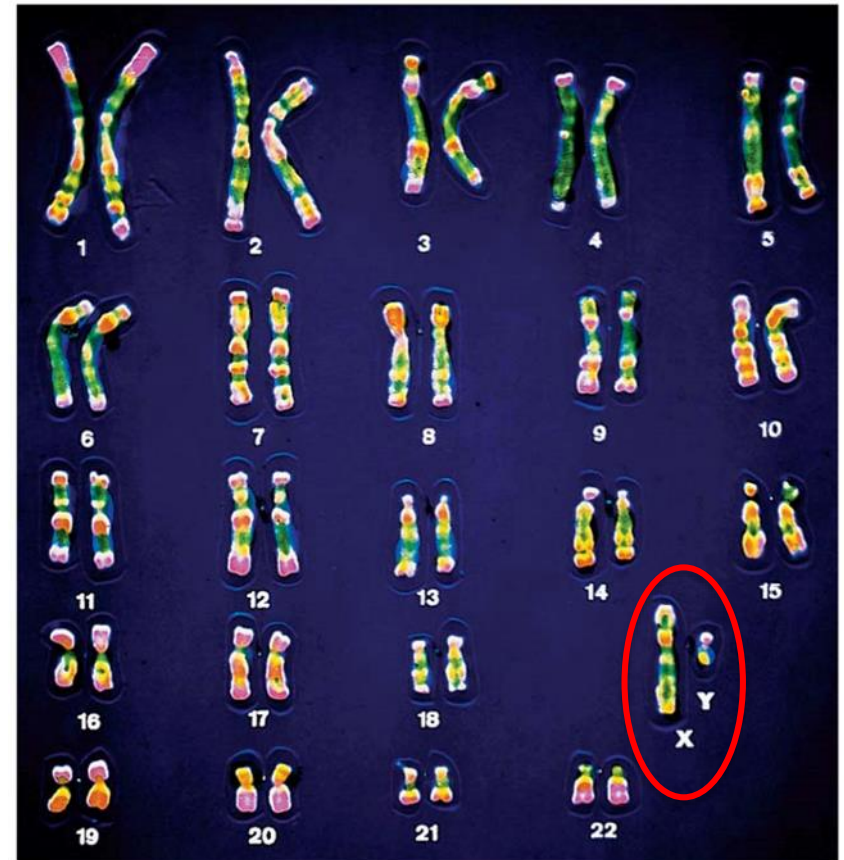
SEX CHROMOSOMES



XX sex chromosomes
of a human female

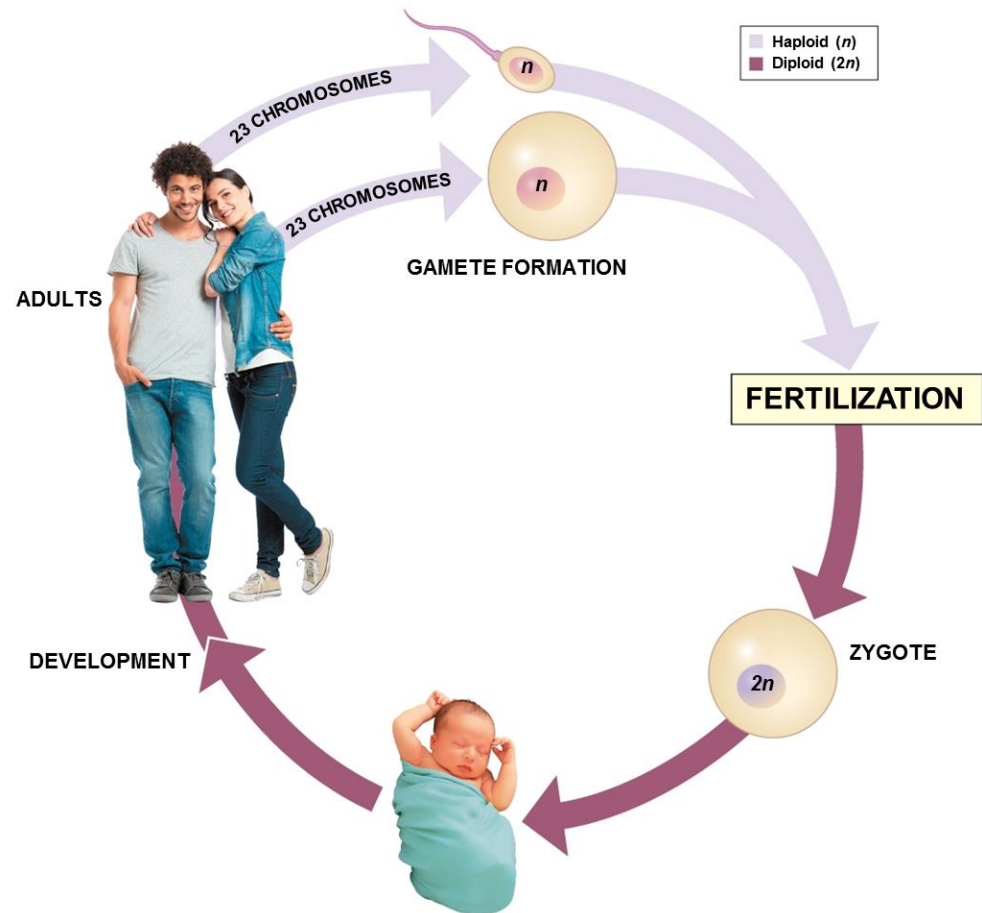


XY sex chromosomes
of a human male



Sexual Life Cycle: Diploid vs. Haploid

- Normal human body cells are **diploid**
 - Contain 2 sets of chromosomes (paternal and maternal)
 - 46 total chromosomes, 23 homologous pairs
- Human sex cells (**gametes**) are **haploid**
 - Contain 1 set of chromosomes
 - 23 total chromosomes

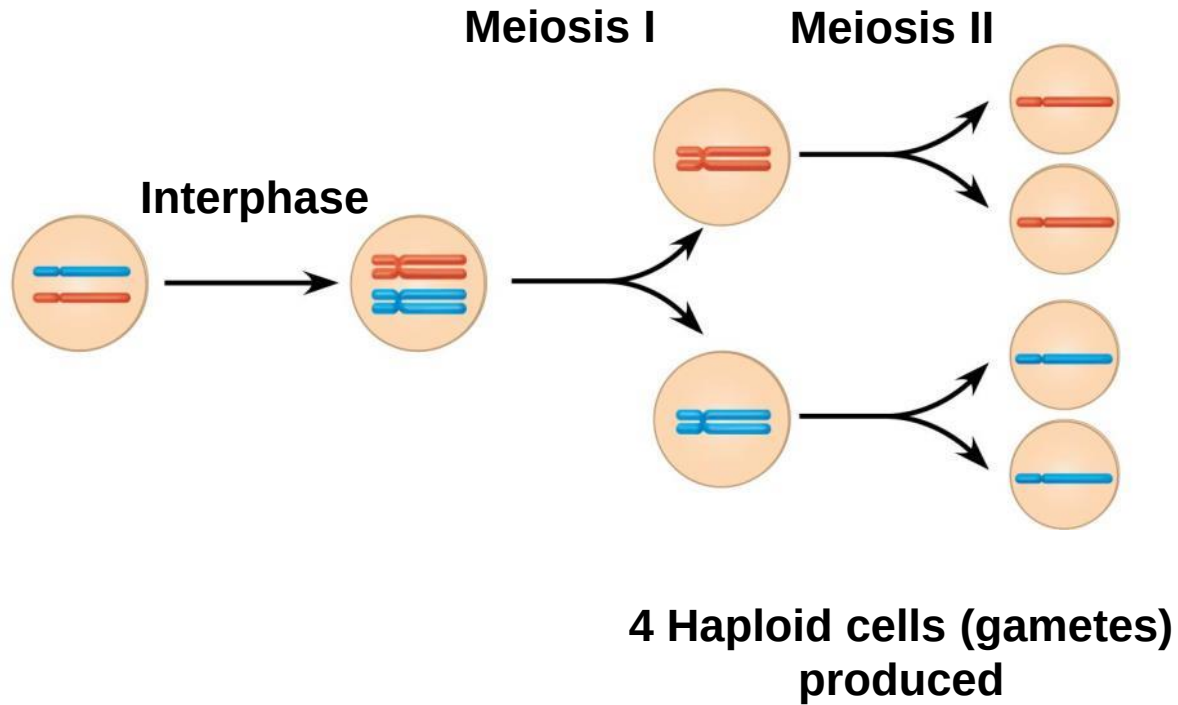


Meiosis

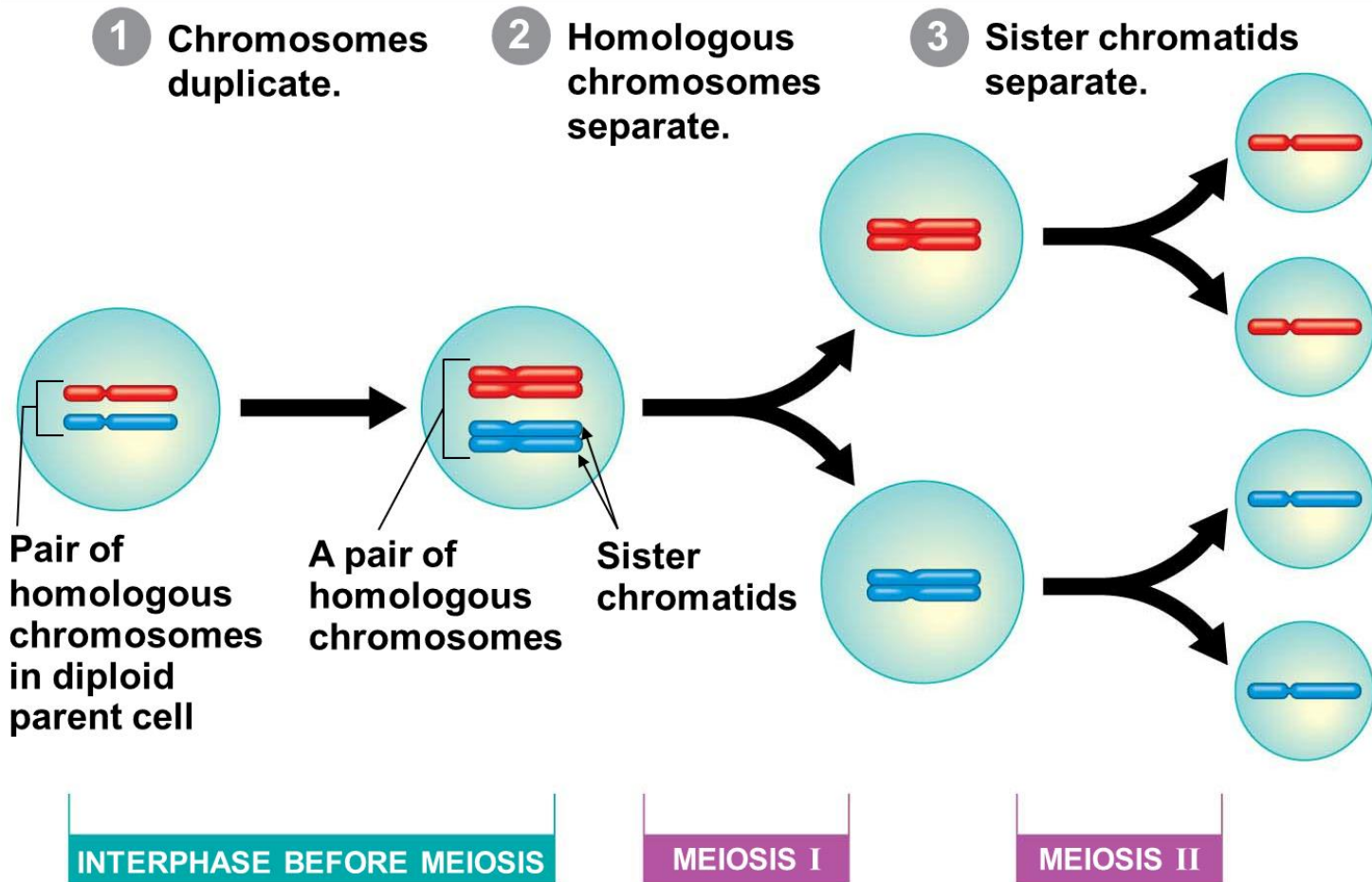
- Gametes are made by a special form of cell division called **meiosis**
- Occurs in the ovaries and testes to make eggs and sperm
- Goal: reduce the number of chromosomes by half
 - $2n \rightarrow n$
 - 46 chromosomes $\rightarrow$ 23 chromosomes
 - 2 sets (homologous pairs) $\rightarrow$ 1 set

Meiosis Overview

- Interphase
 - G_1
 - S
 - G_2
- Meiosis I
 - Prophase I
 - Metaphase I
 - Anaphase I
 - Telophase I
- Meiosis II
 - Prophase II
 - Metaphase II
 - Anaphase II
 - Telophase II

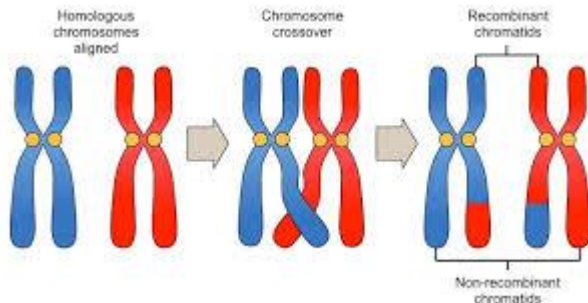


Meiosis Overview

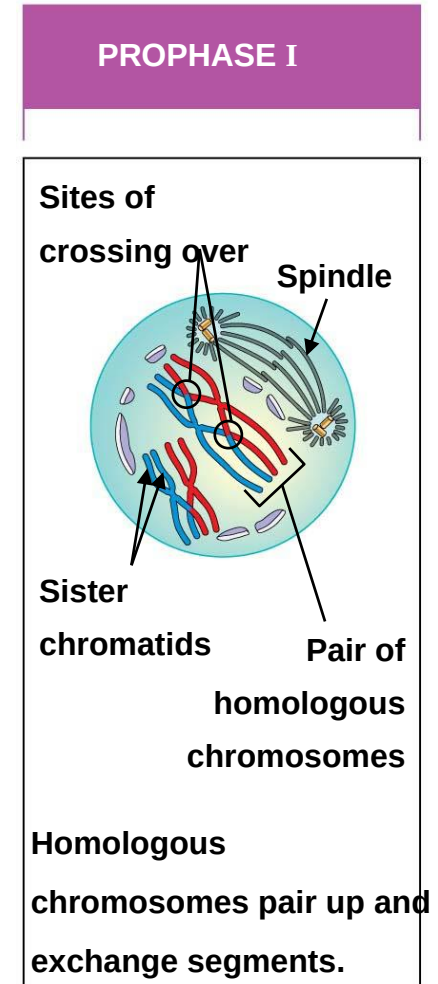


Prophase I

- Similarities to mitosis:
 - Chromosomes condense
 - Nuclear envelope breaks down
 - Spindle begins to form
- Specific to meiosis:
 - **Homologous chromosomes pair up**
 - **Crossing over:** segments of DNA are exchanged between chromatids

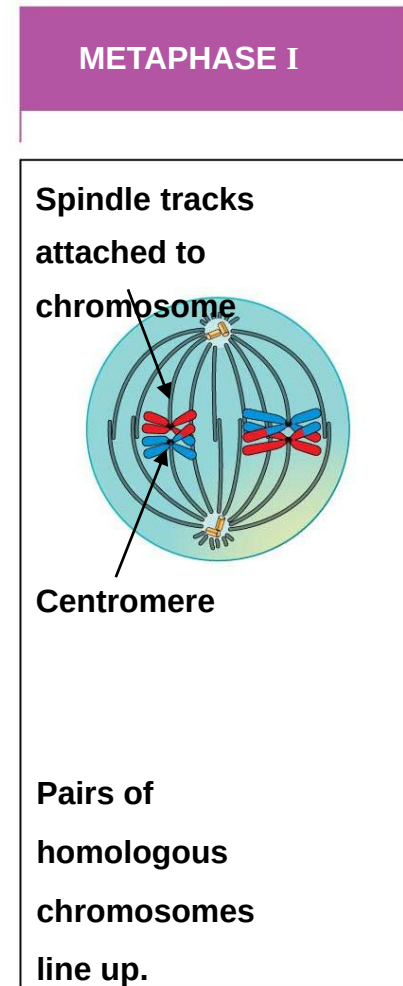


Section 5.8



Metaphase I

- Similarities to mitosis:
 - Chromosomes line up at the center of the cell
- Specific to meiosis:
 - **Homologous pairs align** at the metaphase plate (instead of individual chromosomes)

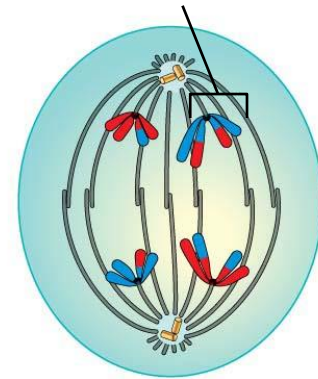


Anaphase I

- Similarities to mitosis:
 - Chromosomes move to opposite ends of the cell along spindle fiber tracks
- Specific to meiosis:
 - **Homologous pairs separate**
 - Sister chromatids stay together at the centromere

ANAPHASE I

Sister chromatids remain attached



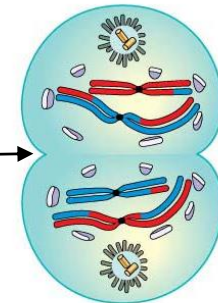
Pairs of homologous chromosomes split up.

Telophase I and Cytokinesis

- Similarities to mitosis:
 - Nuclear envelope reforms around two daughter nuclei
- Specific to meiosis:
 - Each daughter cell is **haploid** (only contains 1 set of chromosomes, no homologous pairs)
 - **Sister chromatids are still attached at the centromere**

TELOPHASE I AND CYTOKINESIS

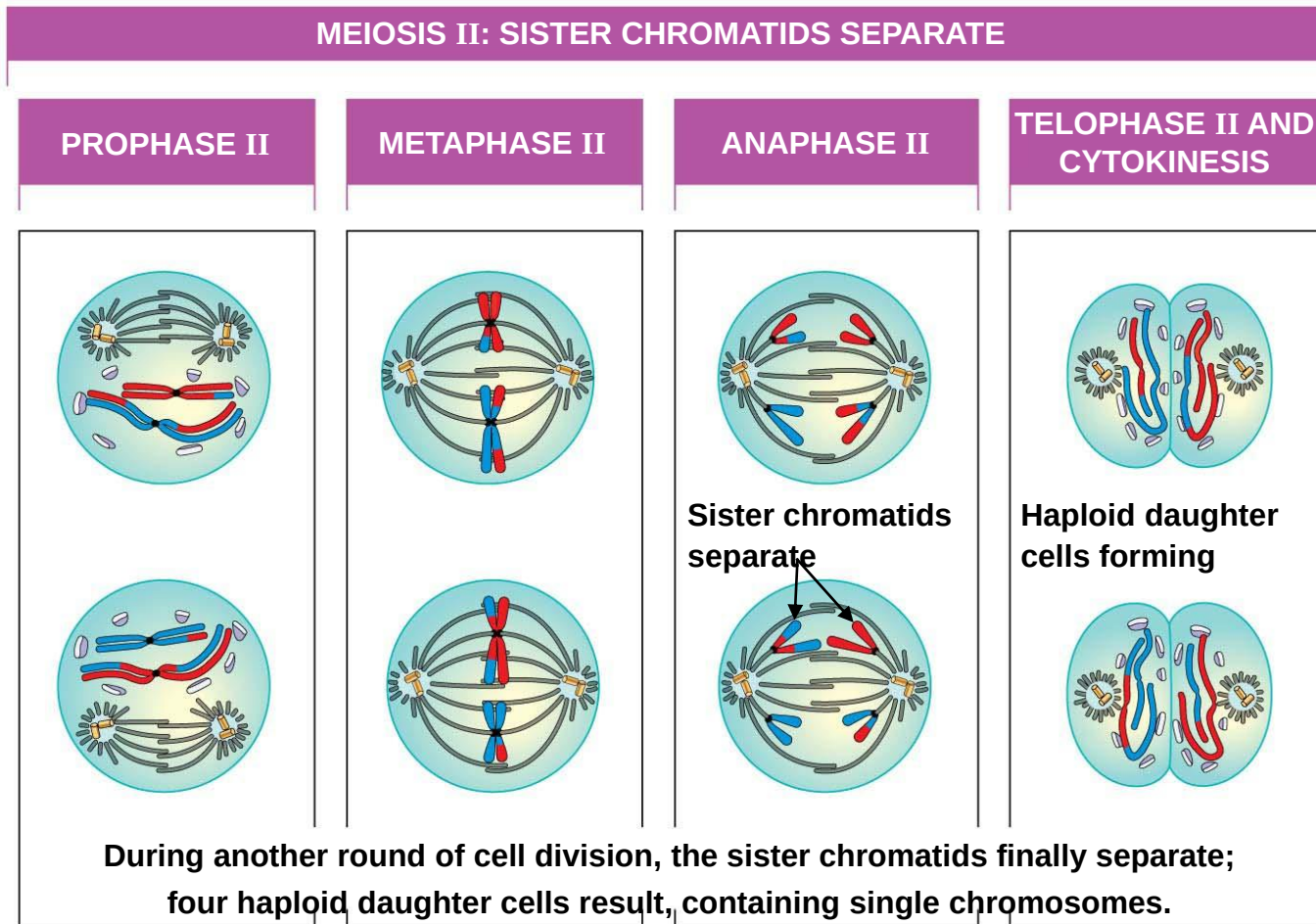
Cleavage
furrow



Two haploid
cells form;
chromosomes
are still doubled.

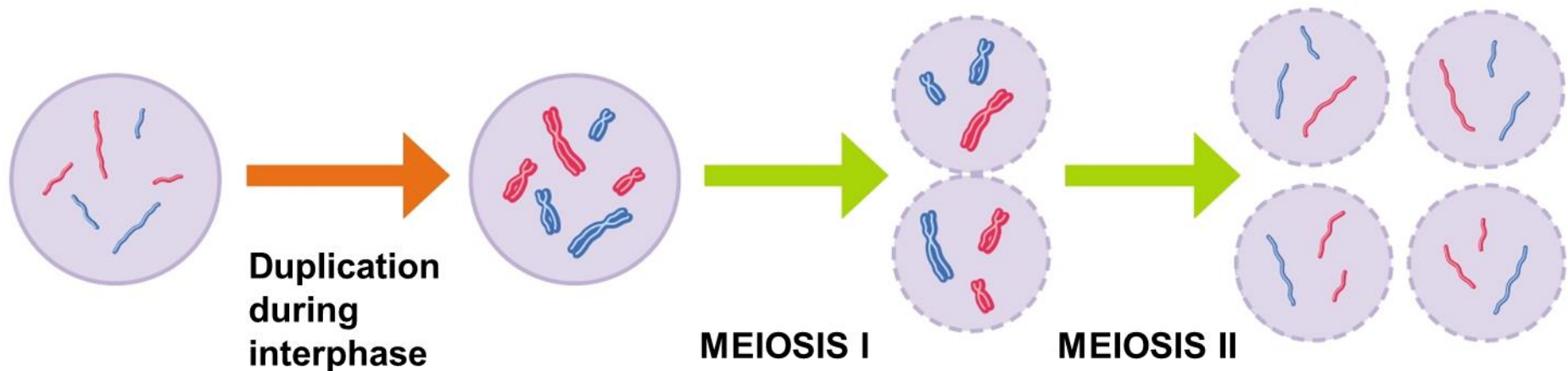
Meiosis II

- Looks like regular mitosis BUT starts with only 1 set of chromosomes



Meiosis Summary

- 4 haploid gametes produced from each round of meiosis



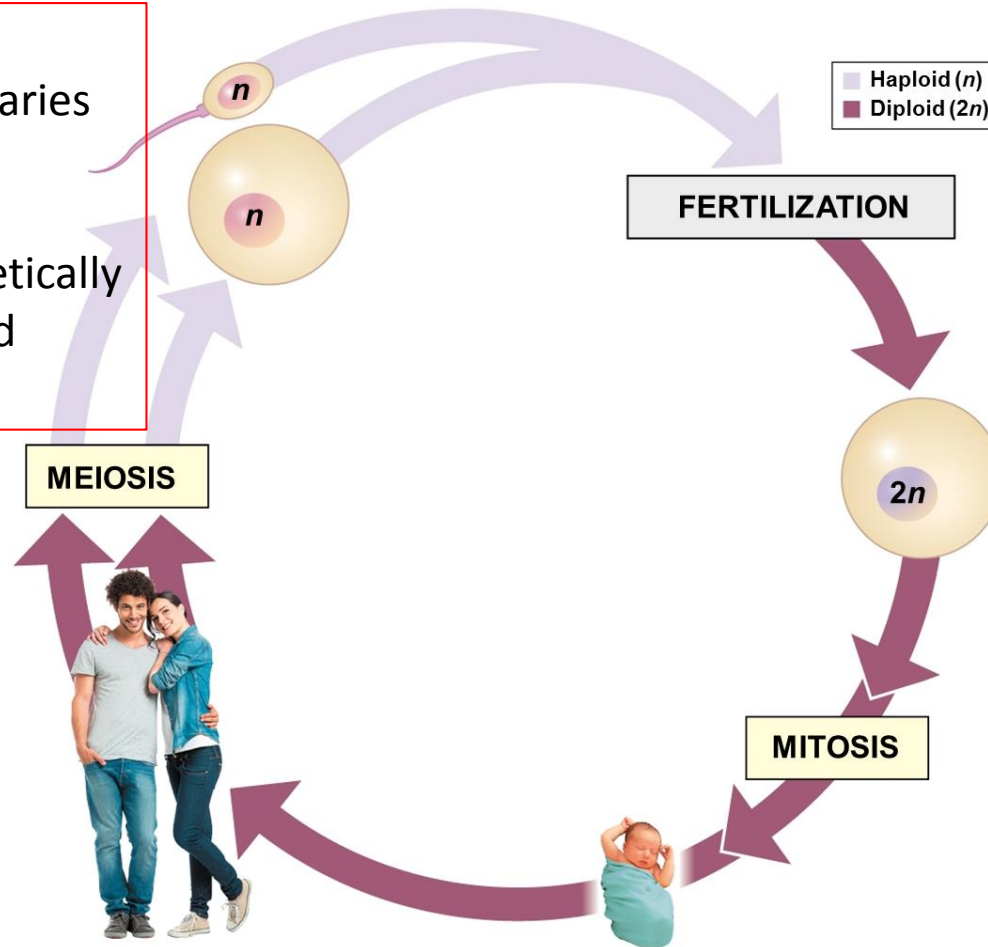
Mitosis vs. Meiosis

	Mitosis	Meiosis
Interphase	DNA duplicated during S phase	DNA duplicated during S phase
Prophase	Duplicated chromosomes condense	Prophase I – duplicated chromosomes pair up, crossing over Prophase II – same as mitosis
Metaphase	Chromosomes align at the metaphase plate	Metaphase I – homologous pairs align at metaphase plate Metaphase II – same as mitosis
Anaphase	Sister chromatids separate	Anaphase I – homologous pairs separate Anaphase II – same as mitosis
Telophase and Cytokinesis	2 daughter cells formed identical to original cell	4 unique haploid gametes formed

Mitosis vs. Meiosis

MEIOSIS

- In testes or ovaries for sexual reproduction
- Produces genetically unique haploid gametes



MITOSIS

- Throughout the body over whole lifetime
- Produces genetically identical diploid body cells

Genetic Variation

- Sexual reproduction produces unique offspring
- Due to three factors:
 - Random fertilization
 - Crossing Over (during Prophase I of Meiosis)
 - Independent Assortment (during Metaphase I of Meiosis)

1. Random Fertilization



600x

SPERM

This sperm contains one of 8 million possible combinations of chromosomes.



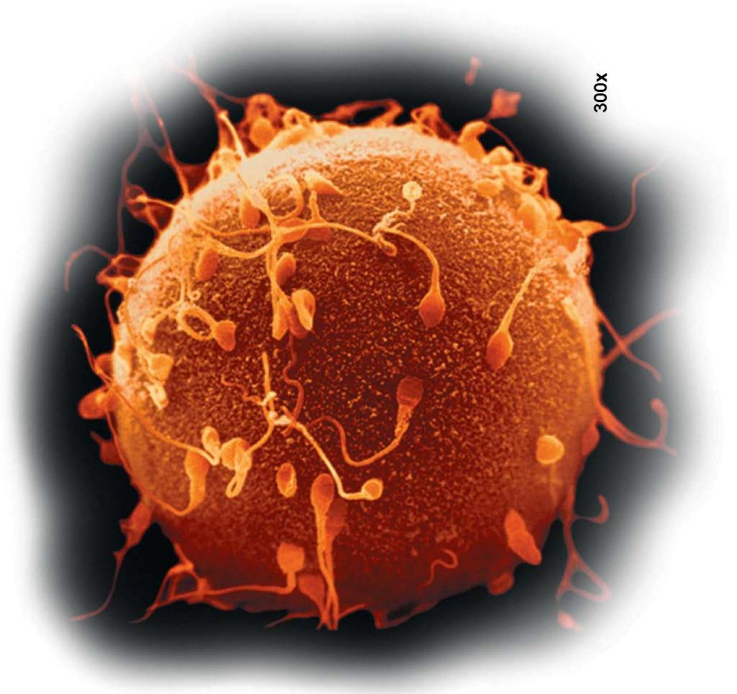
75x

EGG

This egg contains one of 8 million possible combinations of chromosomes.

ZYGOTE

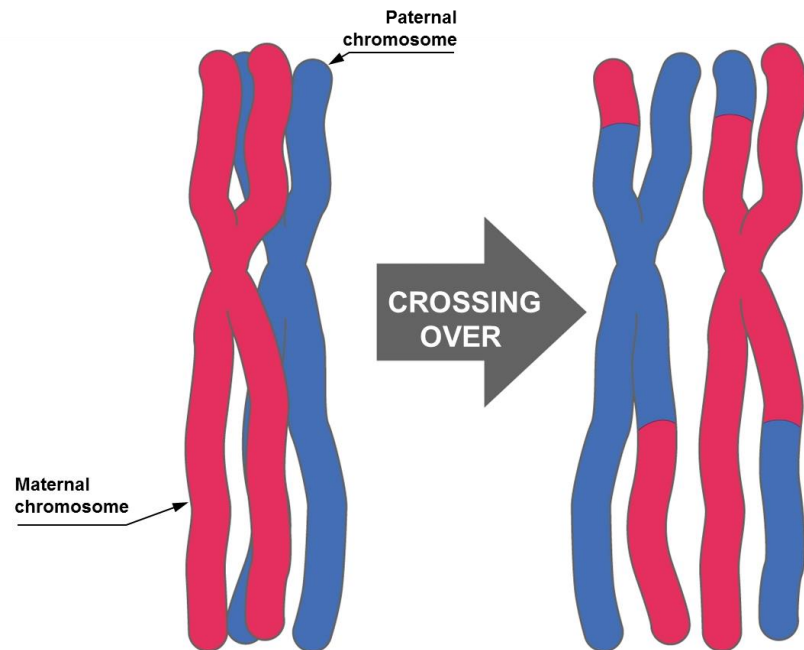
$8 \text{ million} \times 8 \text{ million} = 64 \text{ trillion}$ possible combinations of chromosomes in the zygote



300x

2. Crossing Over

- Crossing over during Prophase I produces new combinations of chromosomes (**recombinant chromosomes**)
- The recombinant chromosomes are distributed to gametes during meiosis

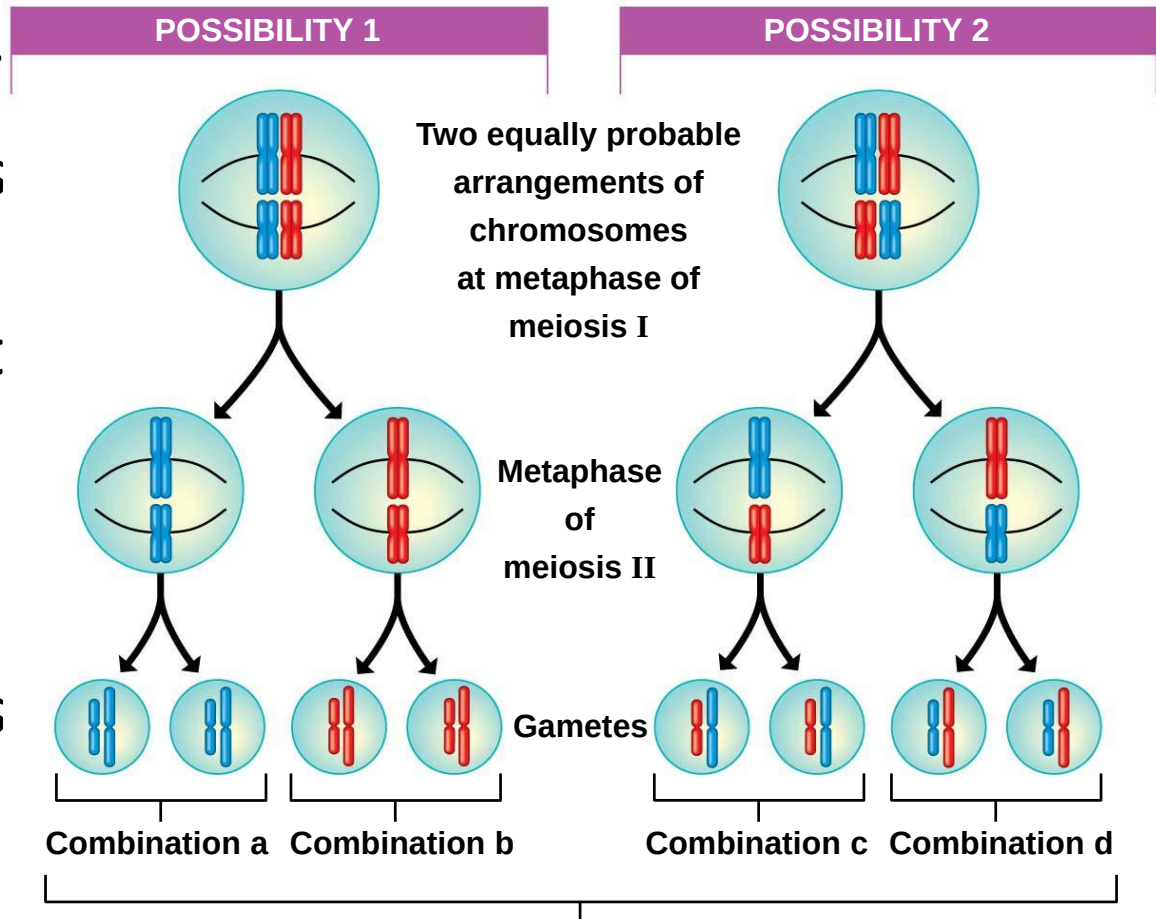


Hybrid chromosomes produced via crossing over

Recombinant chromosomes = new versions of chromosomes made up of maternal and paternal chromosomes

3. Independent Assortment

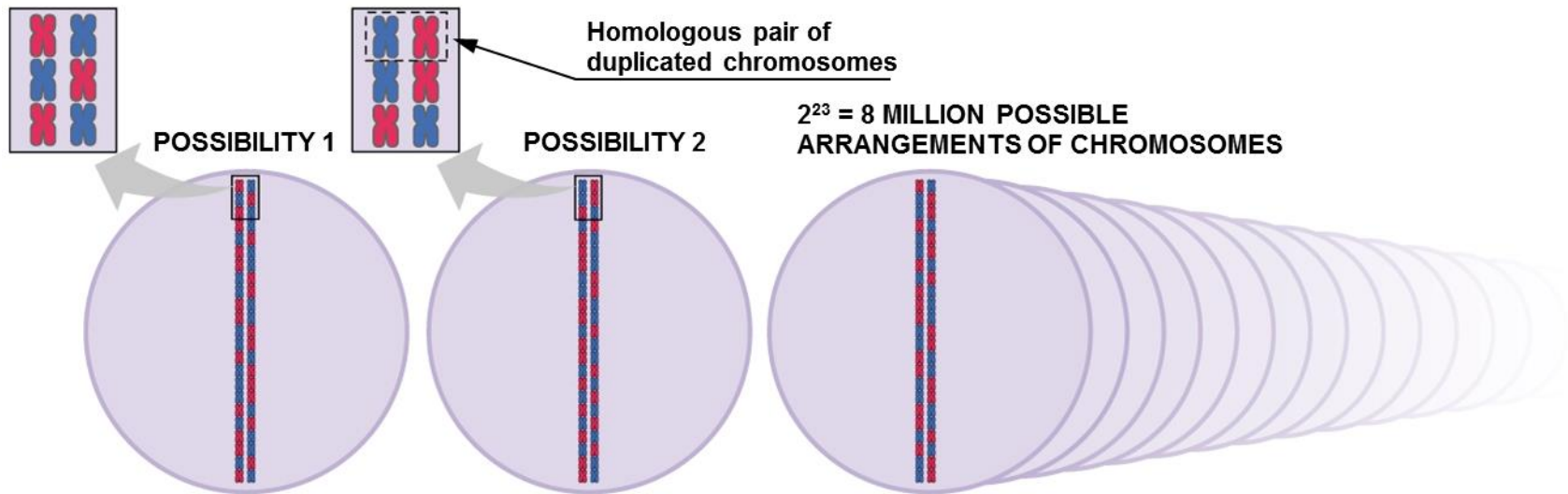
- Haploid set of chromosomes can be made from different combinations of maternal and paternal chromosomes



Because possibilities 1 and 2 are equally likely, the four possible types of gametes will be made in approximately equal numbers.

3. Independent Assortment

- Humans have 23 homologous pairs and each pair can line up during Metaphase I in two different orientations
 - The orientations are random and equally likely
 - Creates many, many possible chromosome combinations for the gametes!



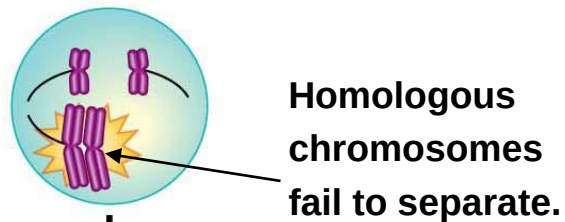
Chromosomes line up by homologous pairs during meiosis I.

Meiosis Errors: Nondisjunction

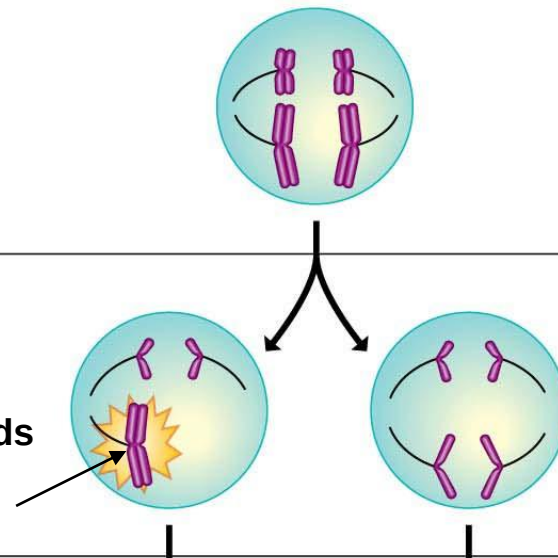
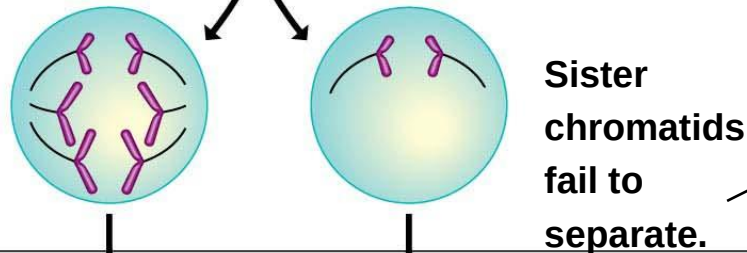
NONDISJUNCTION IN MEIOSIS I

NONDISJUNCTION IN MEIOSIS II

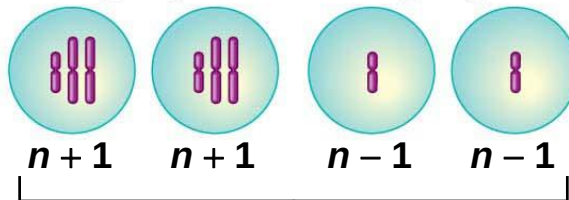
Meiosis I



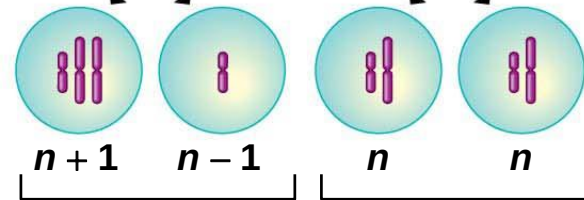
Meiosis II



Gametes



Abnormal



Abnormal

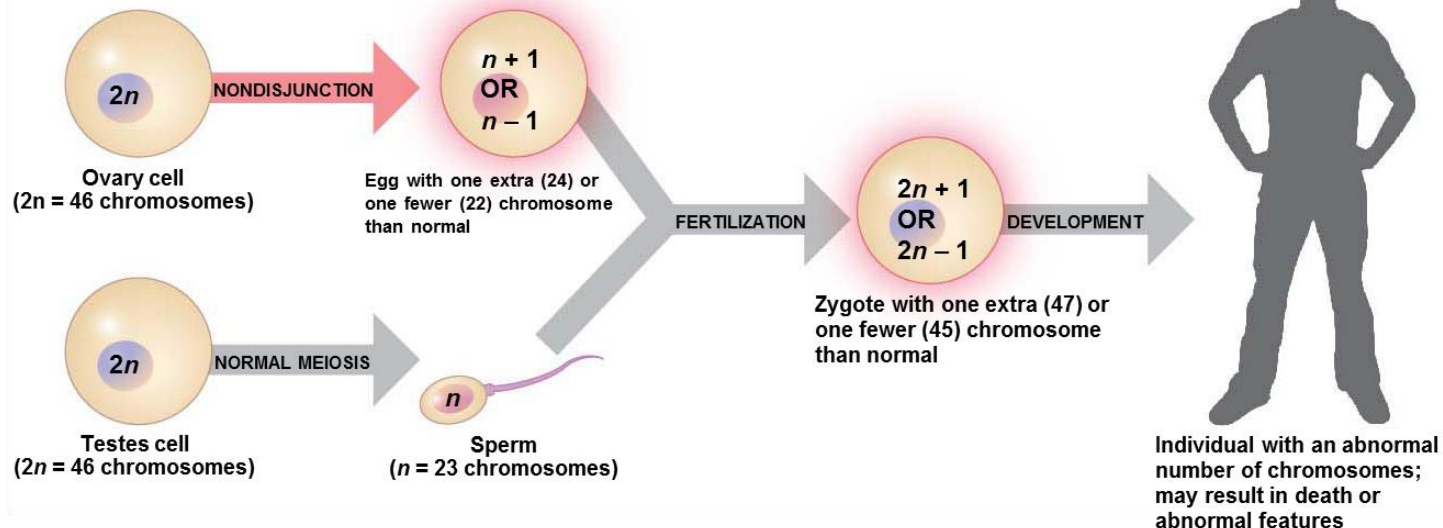
Normal

Meiosis Errors: Nondisjunction

- Nondisjunction produces gametes with the incorrect number of chromosomes
- When the gamete is fertilized, it produces a zygote with the incorrect number of chromosomes

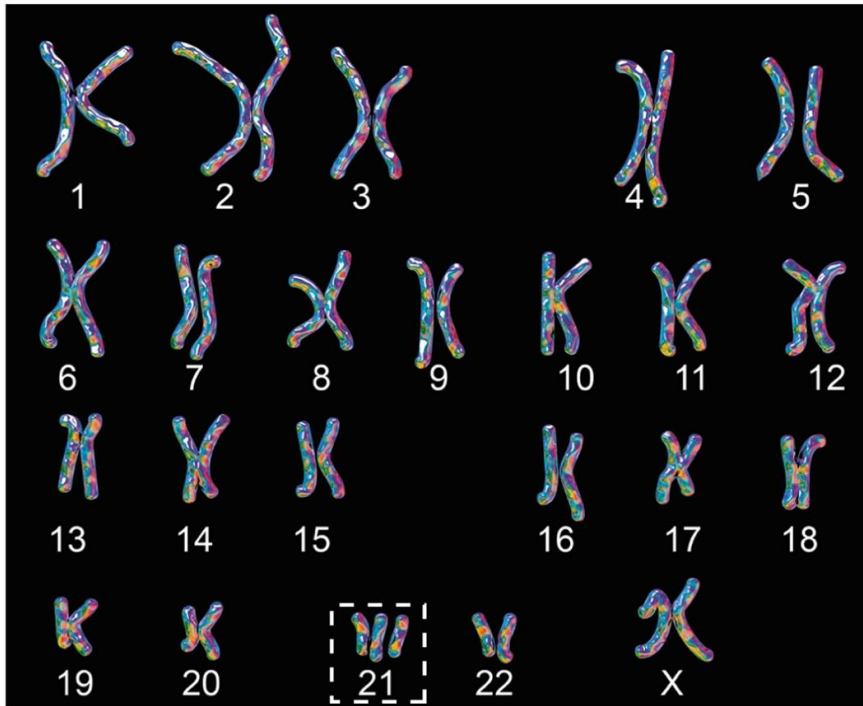
NONDISJUNCTION

Errors during meiosis within the ovaries (shown here) or testes (not shown) may occur.



Meiosis Errors: Nondisjunction

- Too many or too few chromosomes can result in miscarriage or chromosome abnormalities



SEX CHROMOSOME ABNORMALITIES (IN ORDER OF FREQUENCY)			
Sex chromosomes	Syndrome	Sex	Symptoms
XXX	Triple-X syndrome	Female	Slightly taller than average; slight risk of learning delays
XYY	Jacob's syndrome	Male	Normal individual, but may be slightly taller than average
XXY	Klinefelter syndrome	Male	Sterile; underdeveloped testes; some feminine features
XO	Turner syndrome	Female	Sterile; immature sex organs

You should now be able to:

- Define cell division and explain why it is essential for life
- Label the parts of a chromosome (sister chromatids, centromere, gene)
- Describe the stages of the cell cycle
- List the phases of mitosis and describe the events in each phase, be able to draw/identify from pictures
 - Prophase
 - Metaphase
 - Anaphase
 - Telophase

You should now be able to:

- Describe the difference between animal and plant cytokinesis
- Explain what homologous pairs are
- Understand the human life cycle and how it uses mitosis and meiosis to create diploid and haploid cells

You should now be able to:

- List the phases of meiosis and describe the events in each phase
- Compare and contrast mitosis and meiosis
- Explain the three sources of genetic variation
 - Random fertilization
 - Crossing over
 - Independent assortment
- Describe nondisjunction and how it affects gametes and offspring