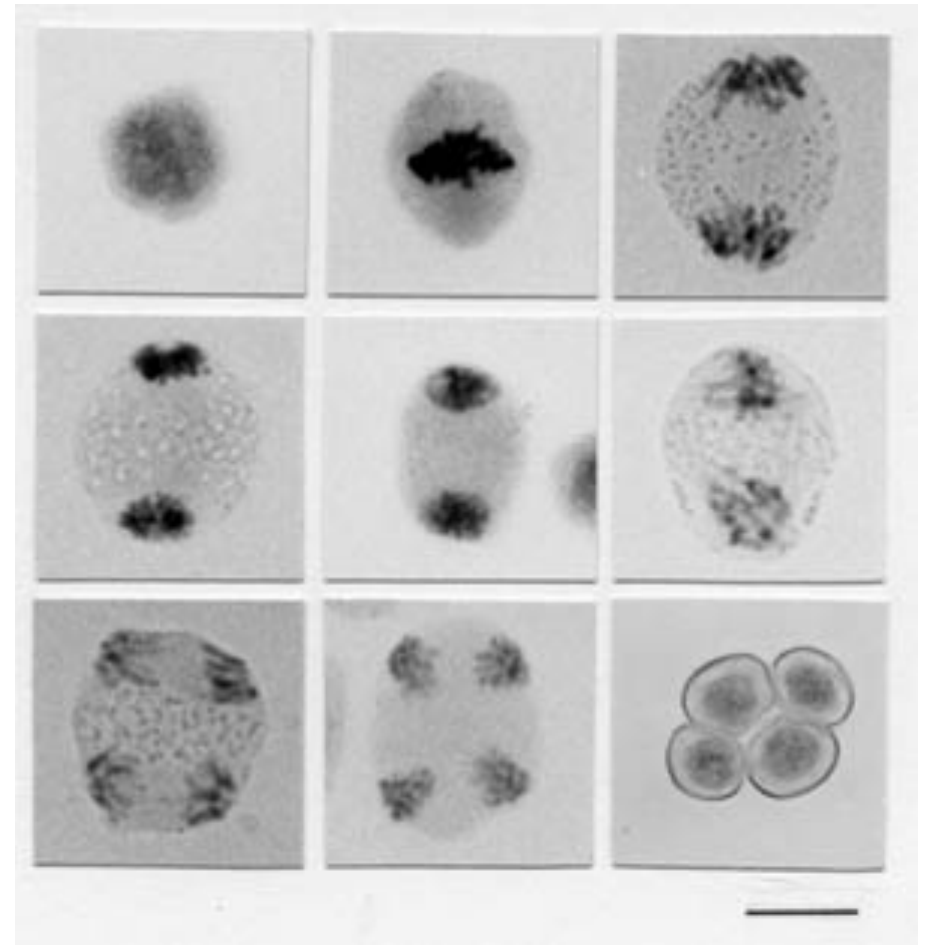
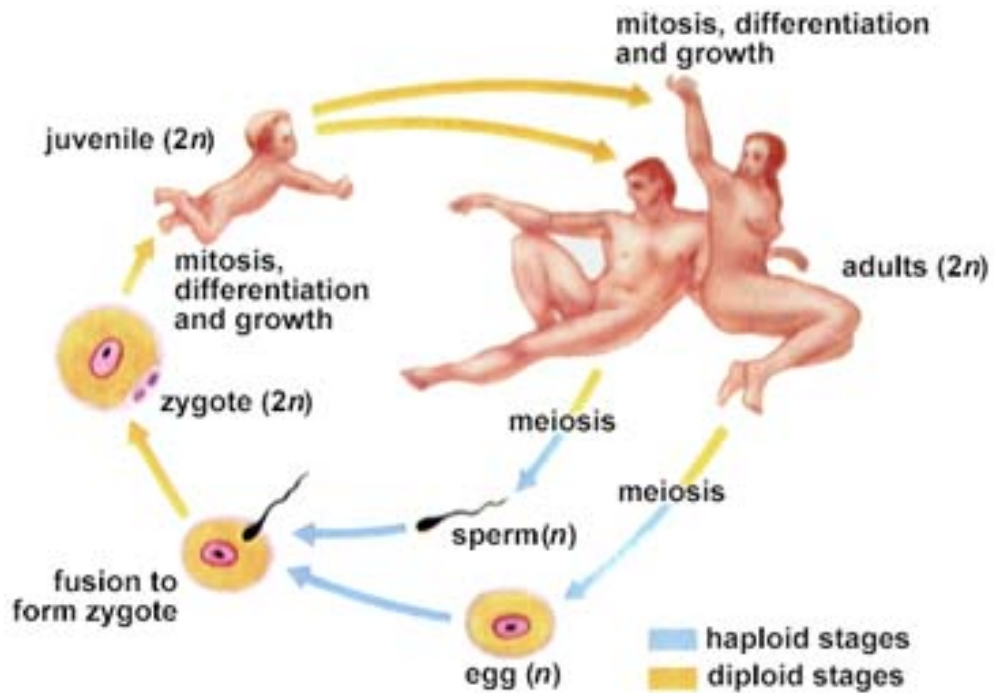


- What did one cell say to his sister cell that stepped on his toe?

MITOSIS

# Topic 2 Cell Division – Meiosis



# Meiosis

## Meiosis Tutorial: The Biology Project!

A second type of cell division designed to make haploid (n) cells called gametes

### **“GAMETOGENESIS”**

- Gametes include sperm (from testes) and egg (from ovaries)
- $2n \rightarrow n$
- Meiosis occurs in 2 stages to produce a total of 4 haploid cells



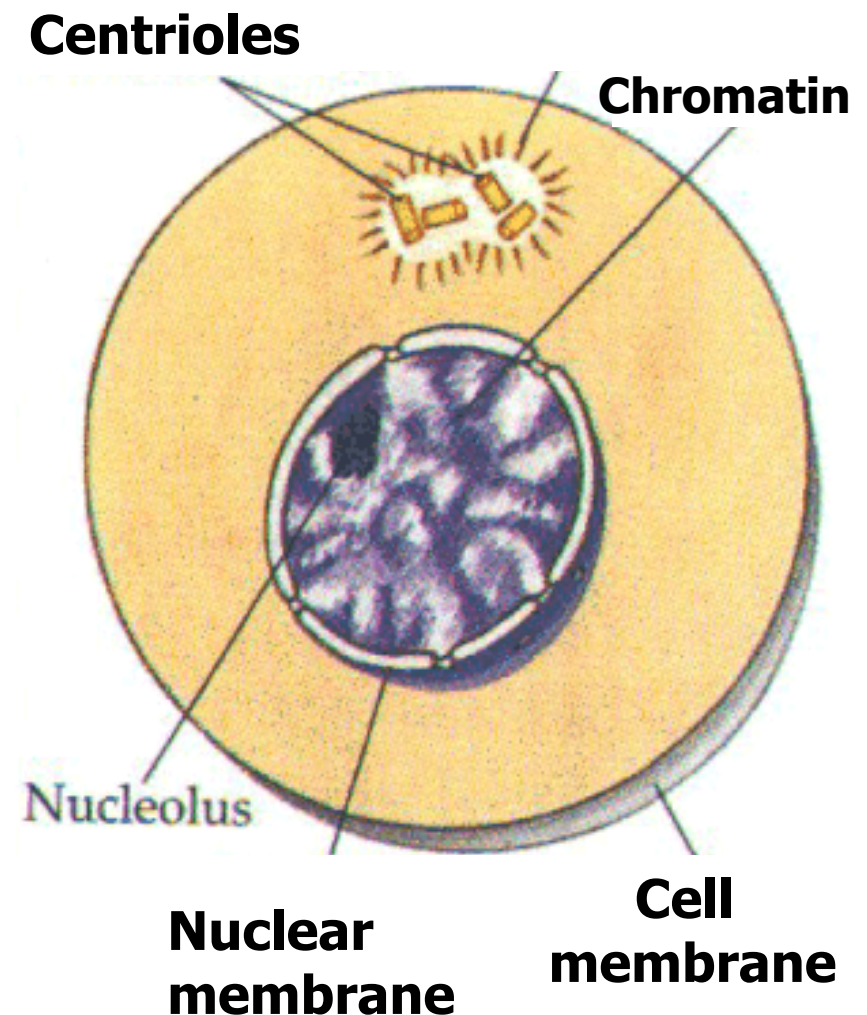
**Why are haploid cells necessary?**

# Interphase: Stage Prior to Meiosis I

- Similar to **mitosis**, germ cells will go through interphase
  - During this phase, chromosomes are **replicated (DNA synthesis)**
  - The cell prepares for meiosis

Great Meiosis animation  
(McGraw-Hill)

[http://highered.mcgraw-hill.com/sites/0072495855/student\\_view0/chapter28/animation\\_how\\_meiosis\\_works.html](http://highered.mcgraw-hill.com/sites/0072495855/student_view0/chapter28/animation_how_meiosis_works.html)





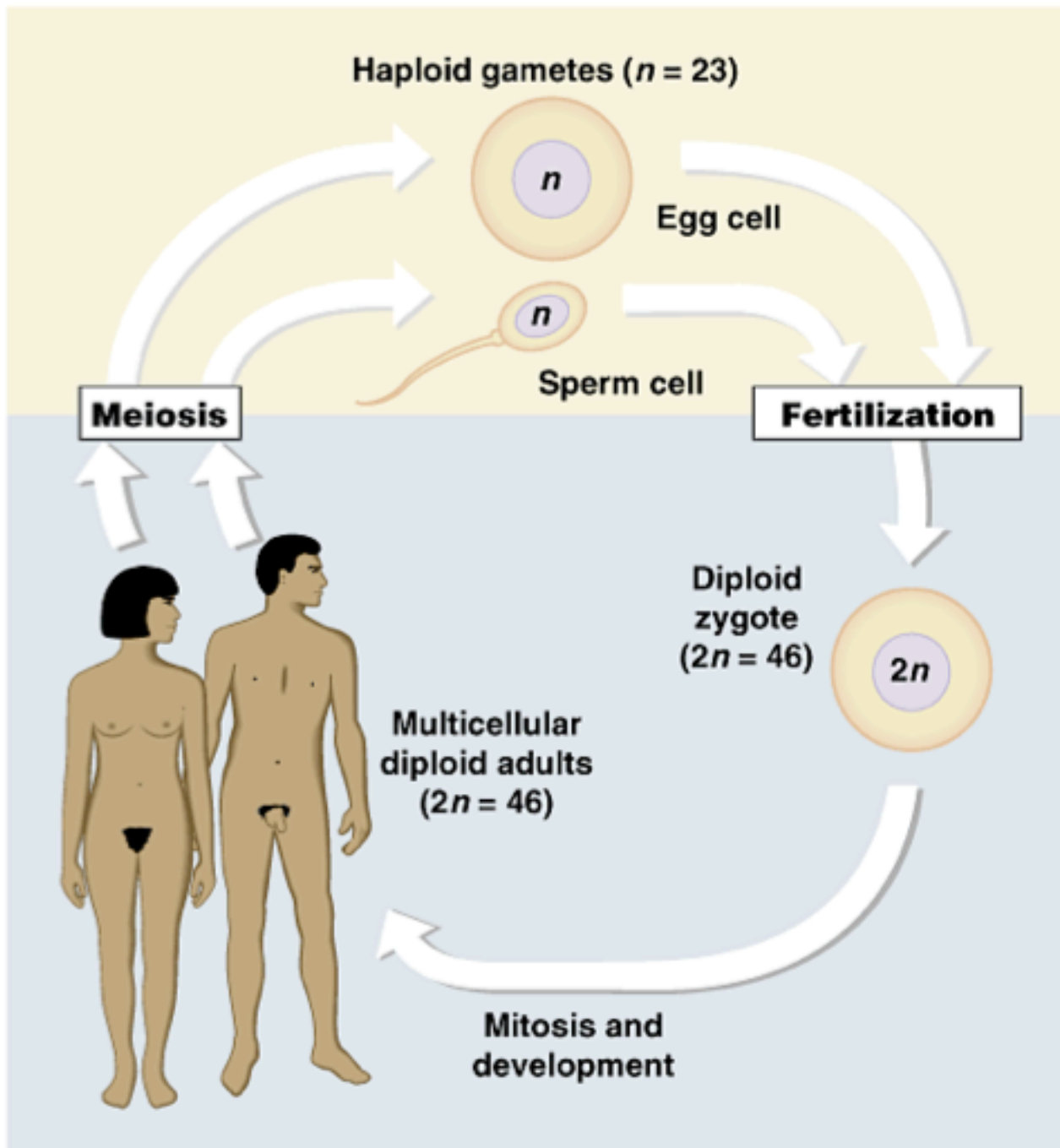
# Outcomes of Meiosis:

## 1. Reductive Division

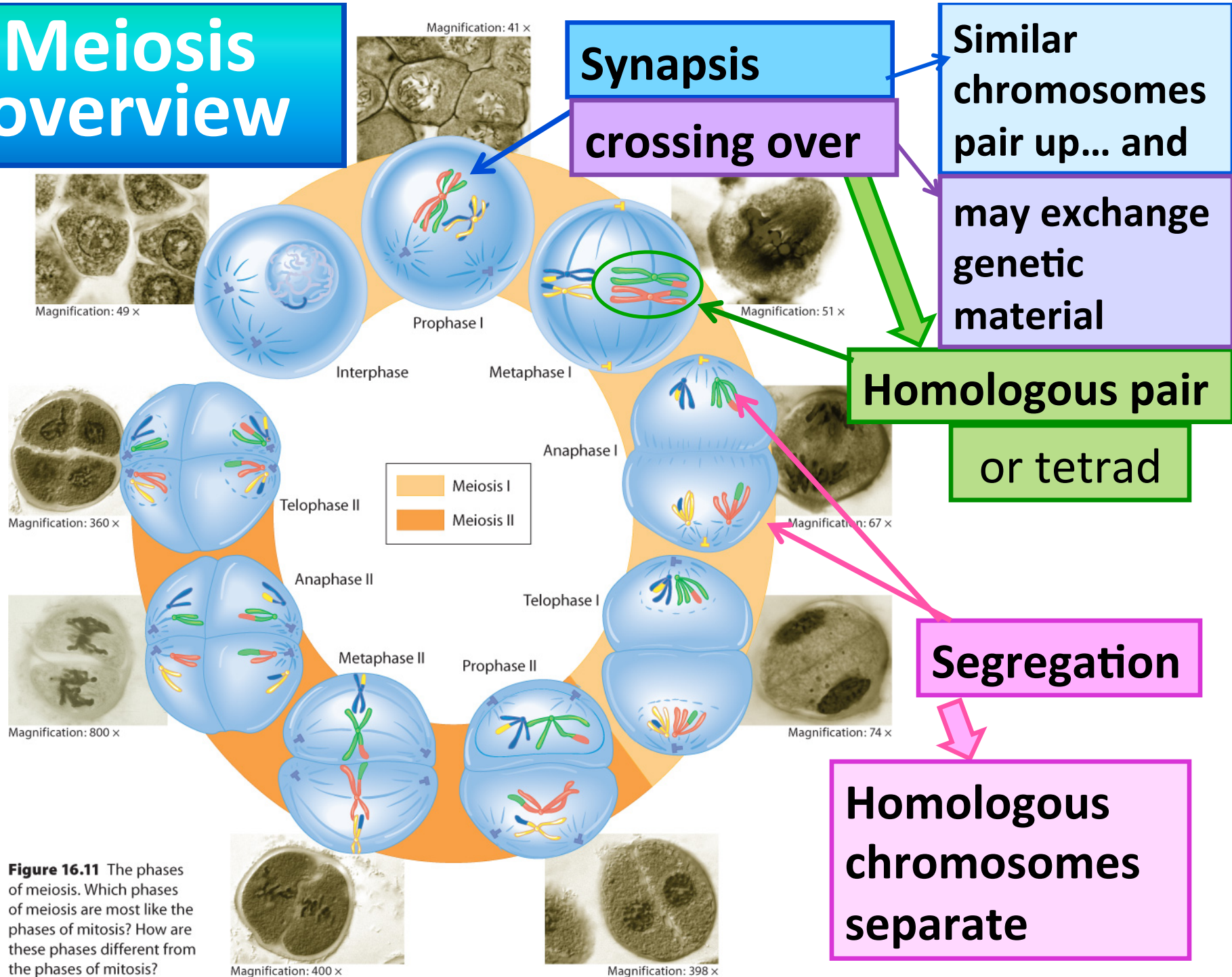
(reduce # of chromosomes from 46 to 23)

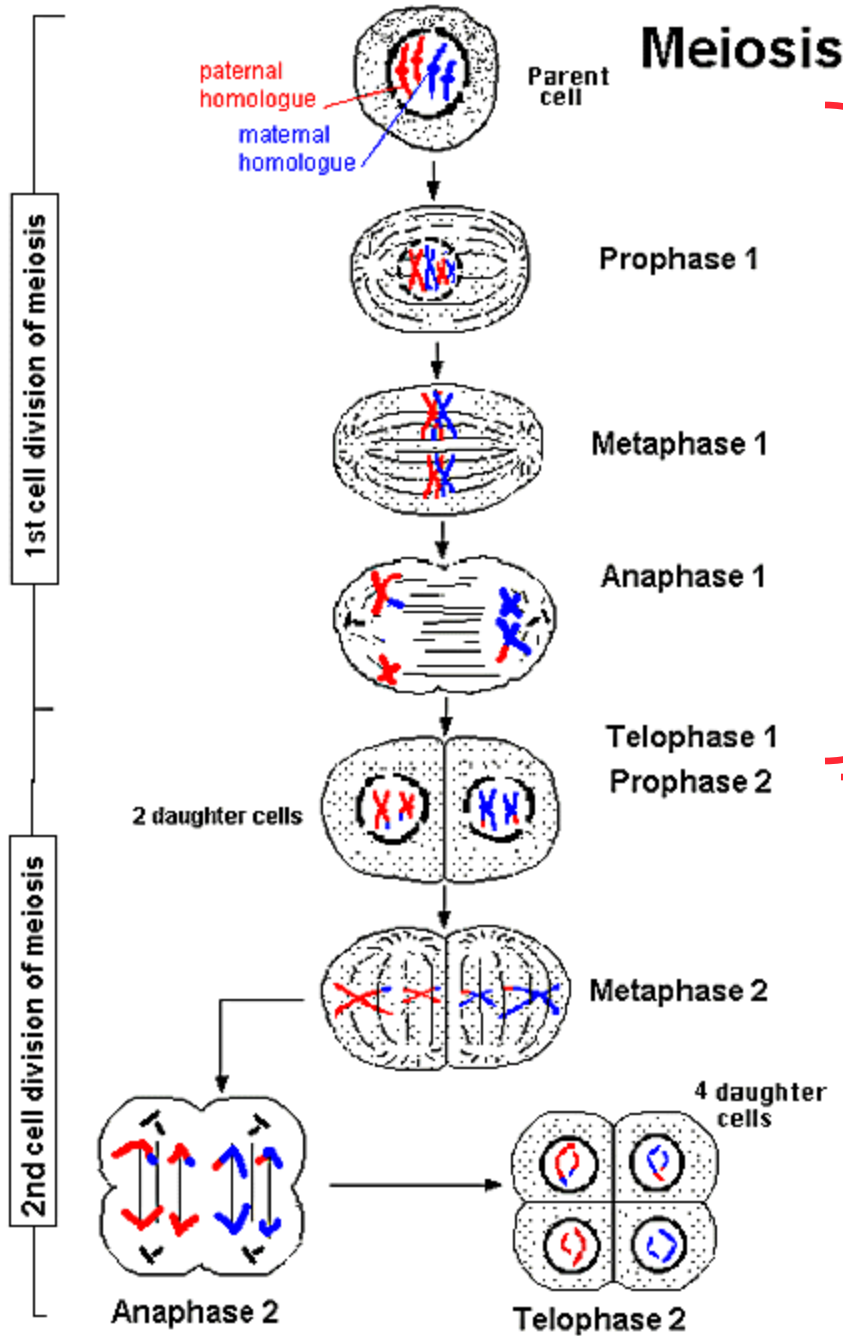
## 2. Recombination

(creating genetic diversity)



# Meiosis overview





## Meiosis I

**AKA : Reduction  
division** since  
chromosome number  
is **reduced ( $2n \rightarrow n$ )**

## Meiosis II

# Synapsis

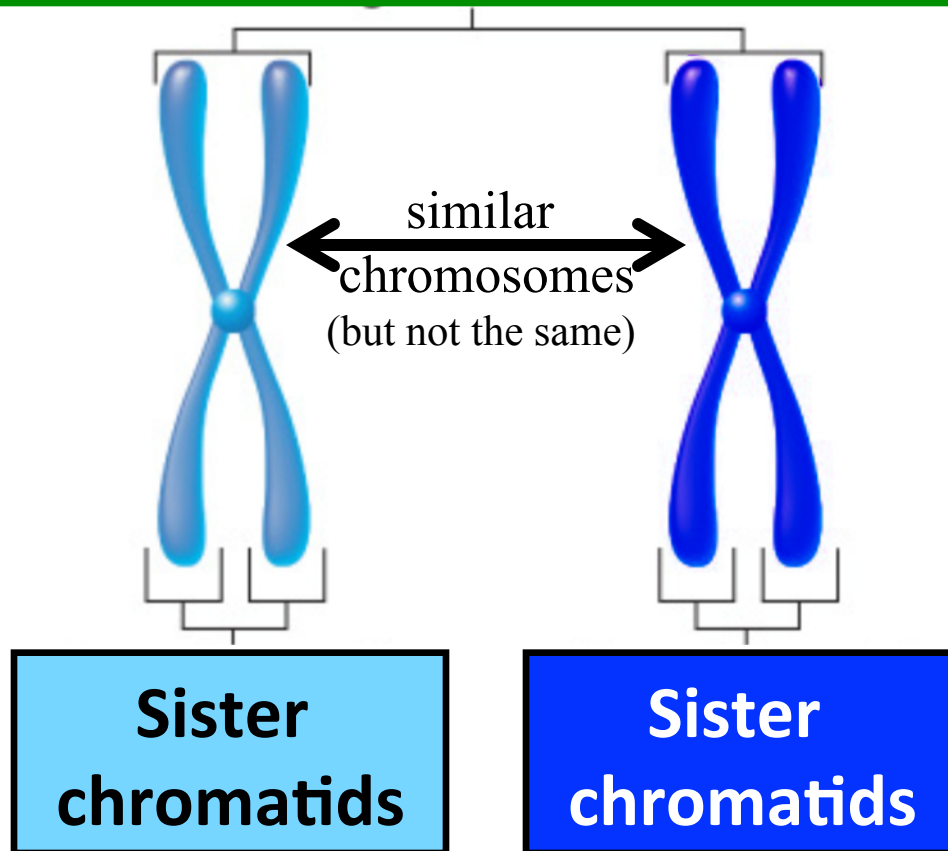
**HOMOLOGOUS** = chromosomes containing similar info.

Pronounced: "ho mol o gus"

-maternal and paternal

are **NOT** a duplicated chromosome!!

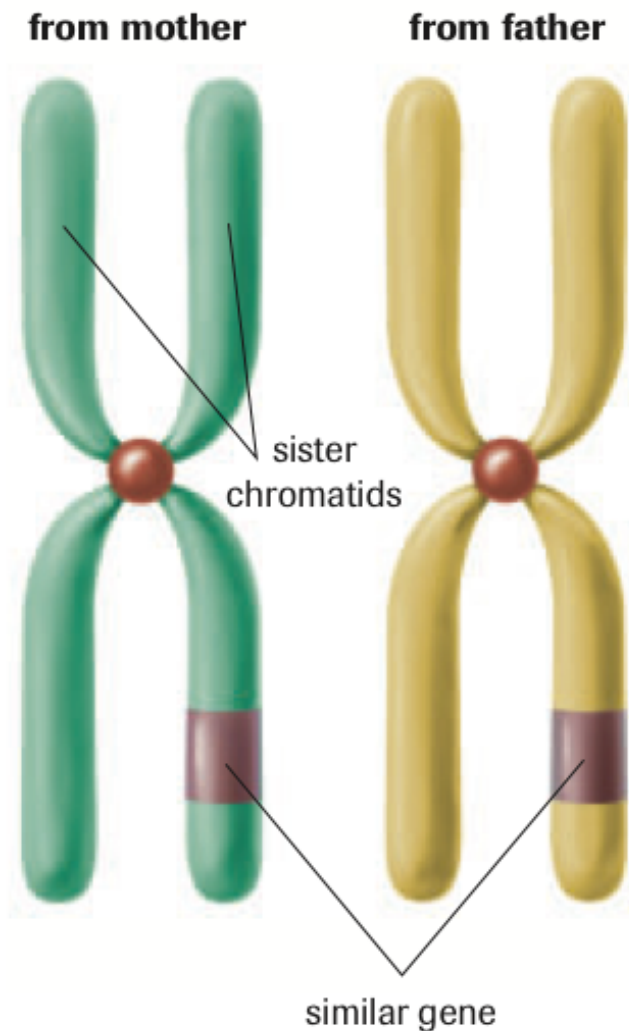
homologous replicated chromosomes = Tetrads



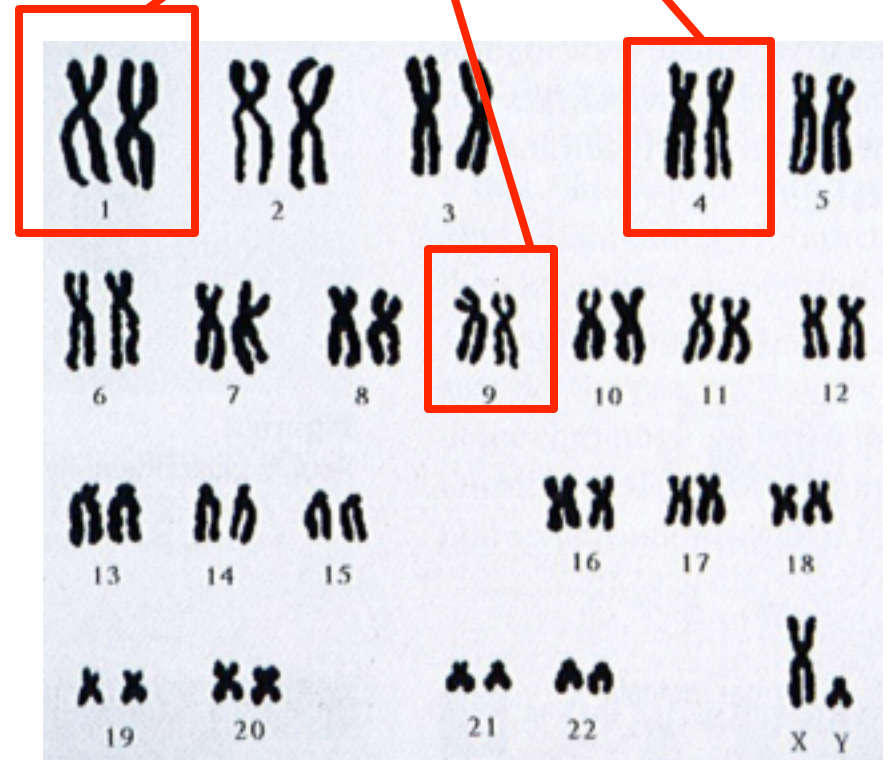
4 chromatids that contain similar information

# CROSSING OVER – in Prophase 1

## Homologous Chromosomes

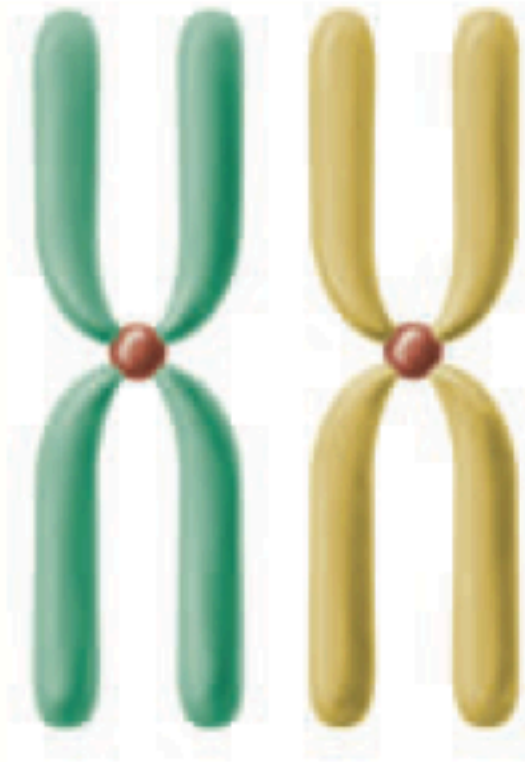


## Various Homologous Chromosomes

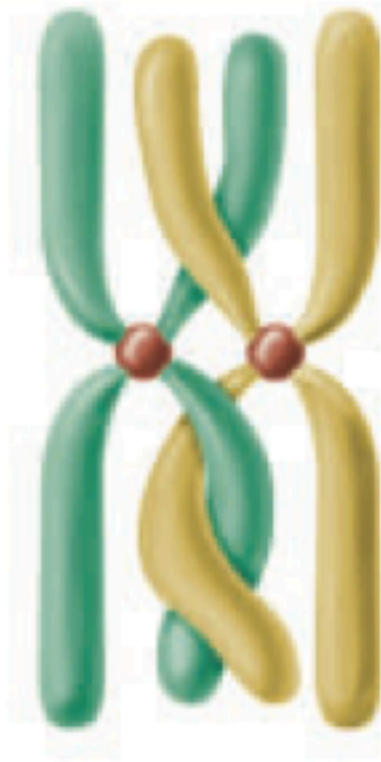




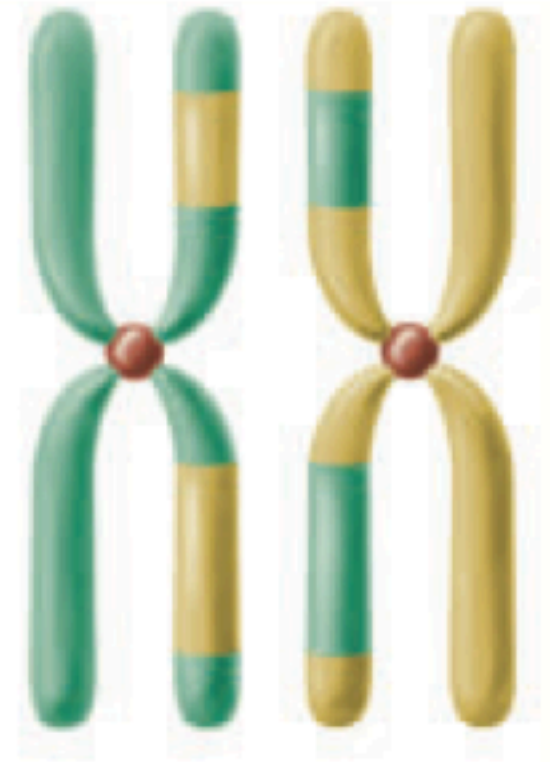
# CROSSING OVER – in Prophase 1



homologous  
chromosome pair



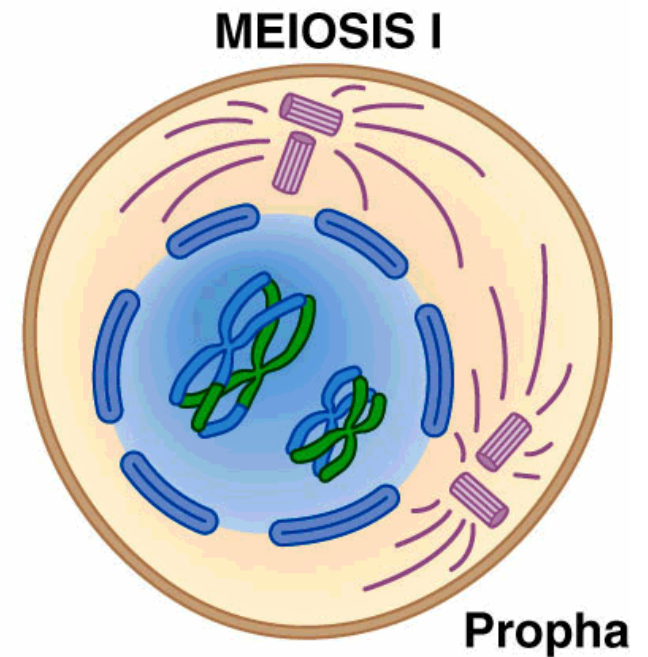
As the chromosomes  
move closer together,  
synapsis occurs.



Chromatids break,  
and genetic information  
is exchanged.

# Prophase 1

- Nuclear membrane disintegrates and spindle fibers start to form
- Chromatin coils up into chromosomes
- Two homologous (similar) chromosomes come together to form a tetrad
- This process is called **synapsis**(coming together)
- A tetrad consists of 2 replicated homologous chromosomes or 4 chromatids



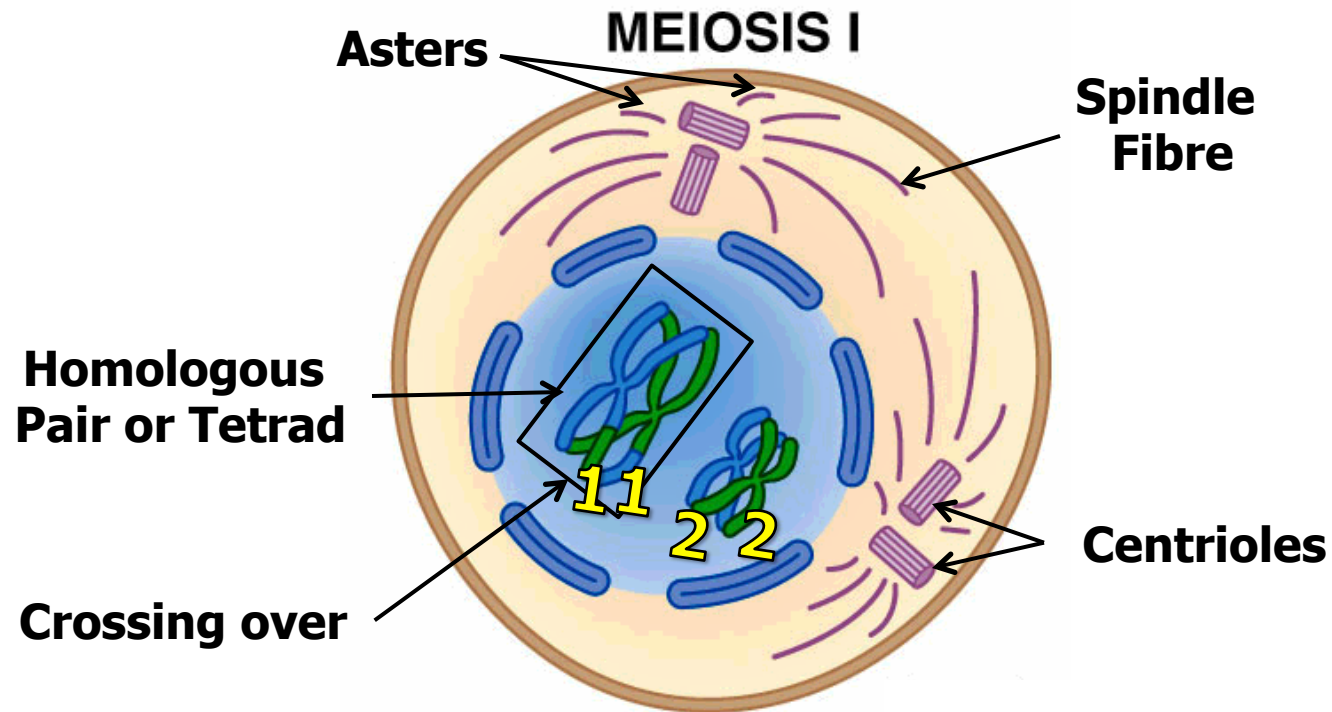
**\*\*Diagram on next page!**

## RECOMBINATION

- During this time, chromosomes are so close together, **crossing over** can occur between non-sister chromatids

The result is entirely new genetic combinations not seen in the parents

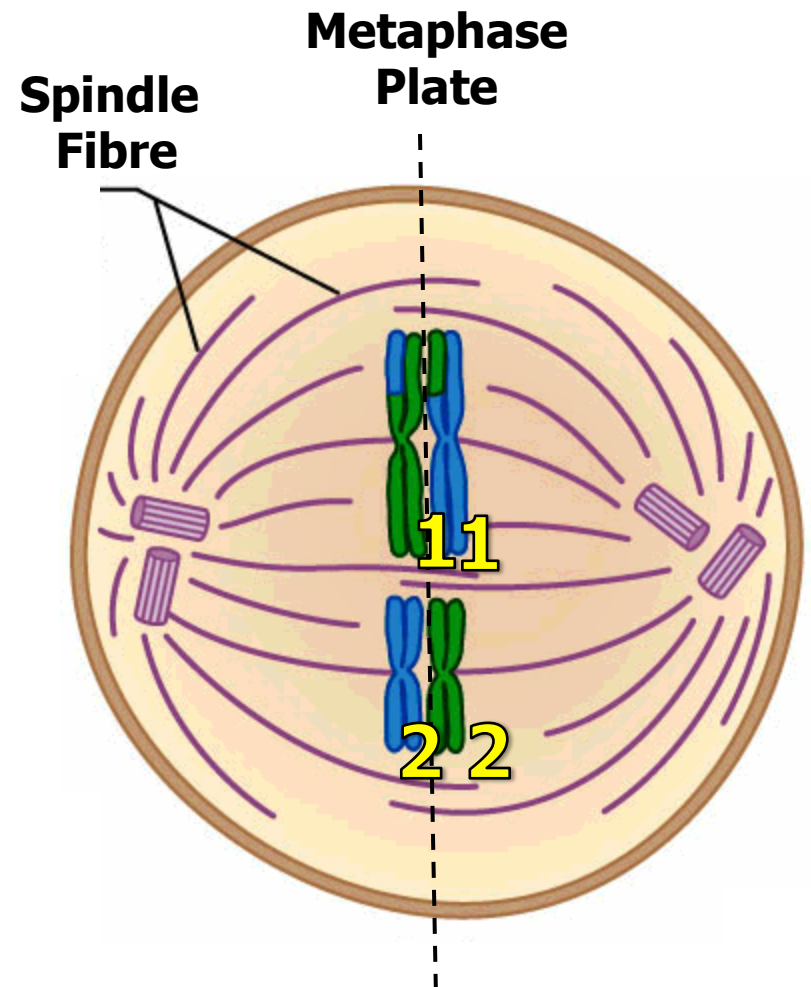
# Prophase 1



# Metaphase I

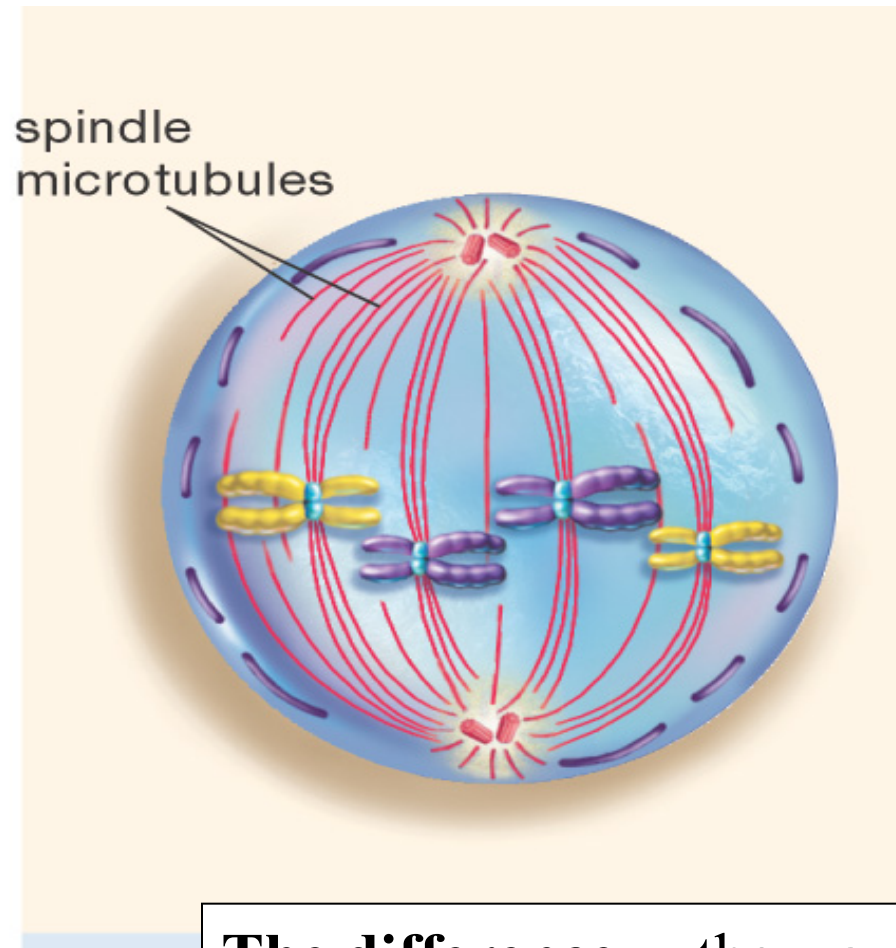
- Homologous replicated chromosomes line up at the equator on the metaphase plate on the same spindle fiber
- spindle fibers attach to chromosomes

Recall in metaphase of mitosis, all chromosomes lined up at the middle

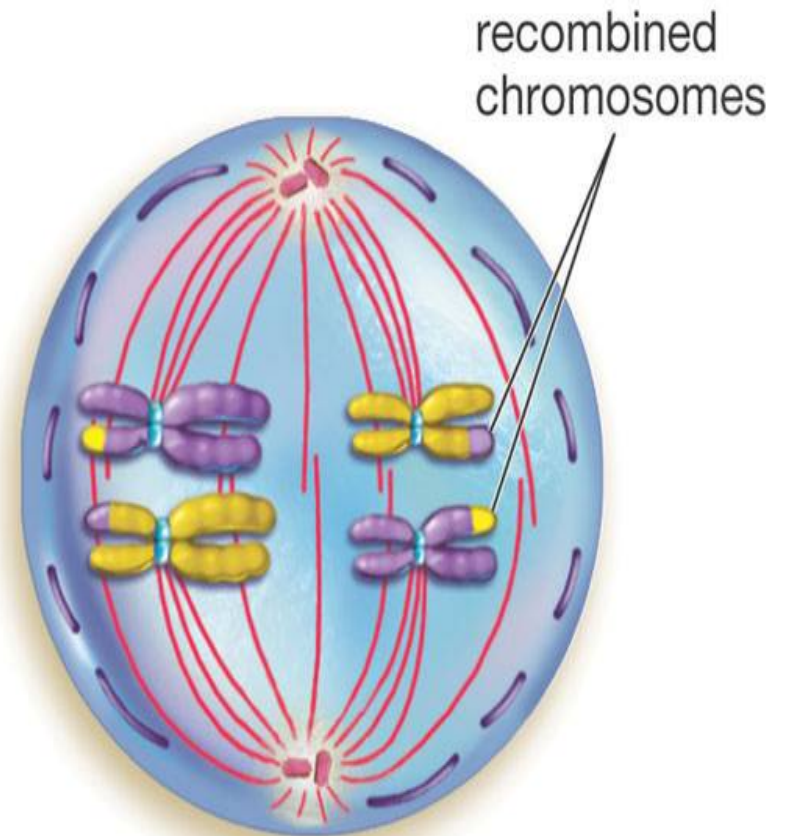


# Metaphase – what's different?

Mitosis – Metaphase



Meiosis – Metaphase I

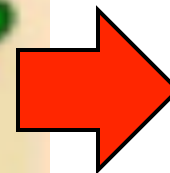
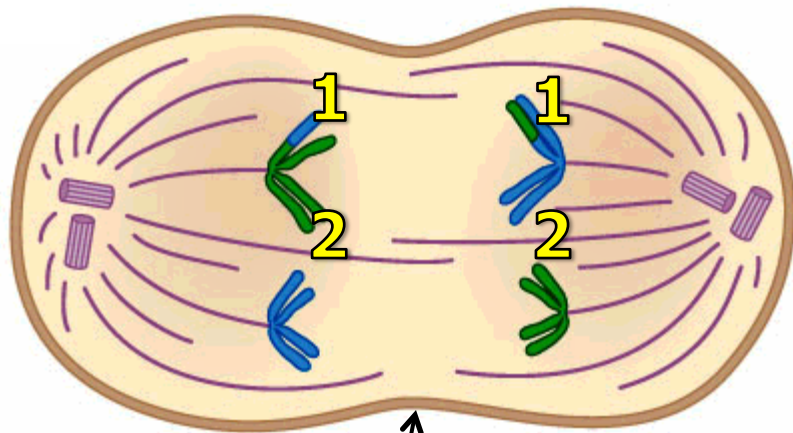


**The difference...** the way chromosomes line up  
(in a row in middle vs paired up either side of middle)



# Anaphase I

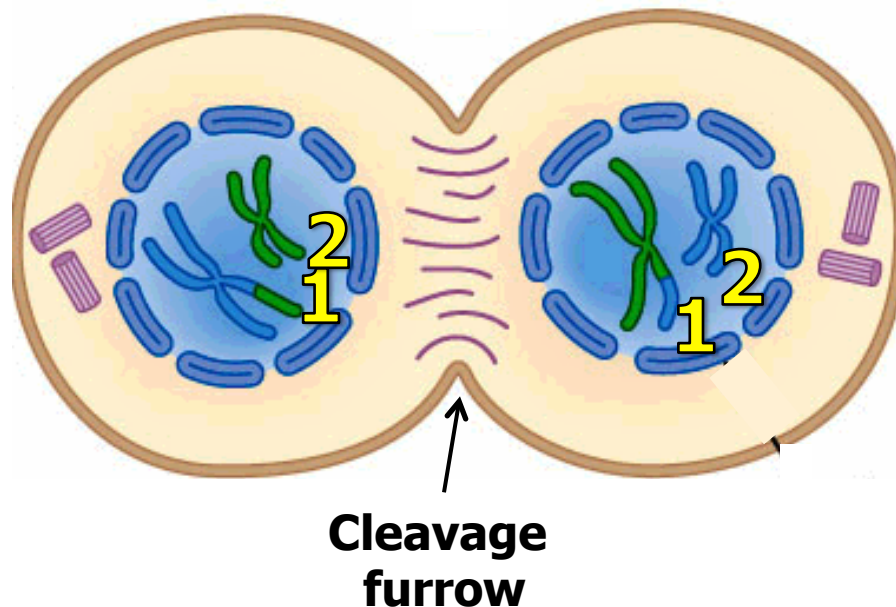
- Apart!
- Homologous chromosomes separate to opposite poles
- This is known as **segregation**  $2n \rightarrow n$  or  $46 \rightarrow 23$
- Each new cell will now have HALF the number of chromosomes as the parent cell
- Even though the sister chromatids are still connected, they have essentially the same genetic information but are half of the original parent



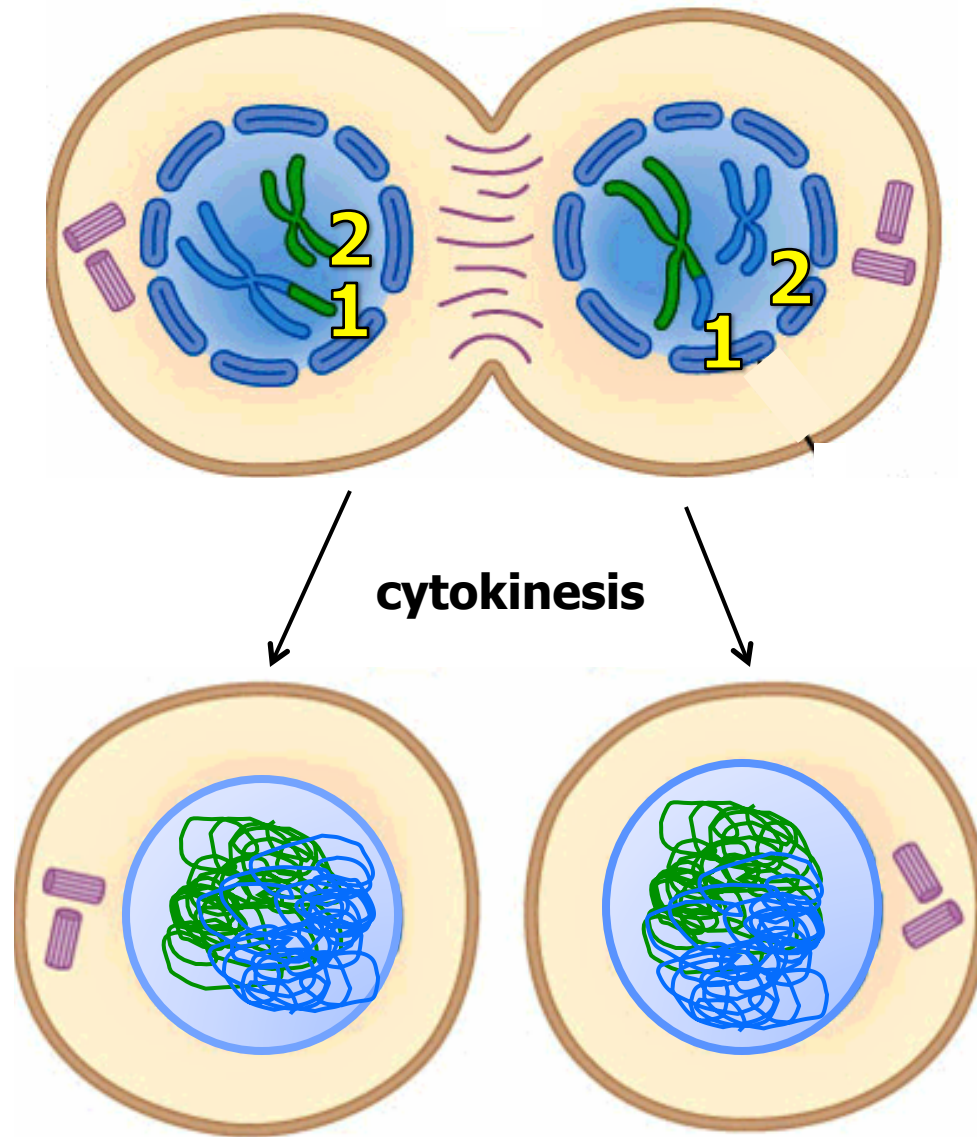
2 attached sister chromatids have similar genetic information

# Telophase 1

- Chromosomes arrive at opposite poles
- Cytokinesis occurs in animal cells
- 2 **haploid** cells form
- Each cell will now have  $\frac{1}{2}$  the amount of chromosomes
- Chromosomes may become chromatin and enter an interphase 2 in some cells
- Haploid cells now go into Meiosis II (similar to Mitosis)

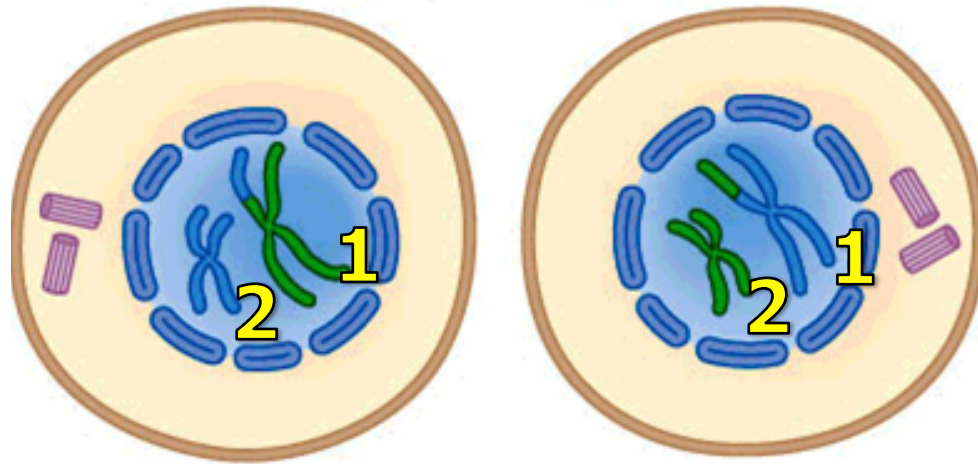


# Telophase 1



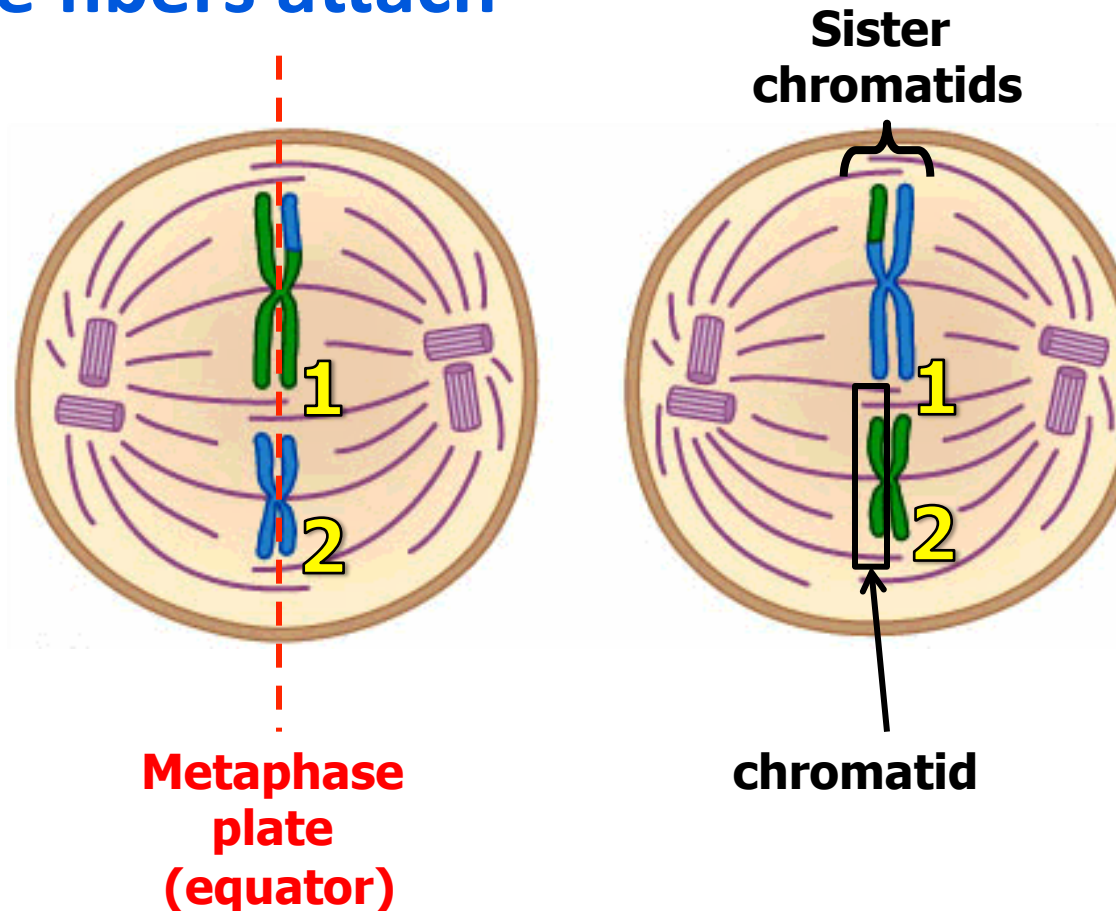
# Prophase II

- New spindle fibers start to form
- Nuclear membrane dissolves
- Chromatin becomes visible chromosomes
- **NOTE: NO REPLICATION OF CHROMOSOMES BEFORE THIS STAGE**



# Metaphase II

- Chromosome line up at the metaphase plate
- Chromosomes here are made up of 2 chromatids
- Spindle fibers attach



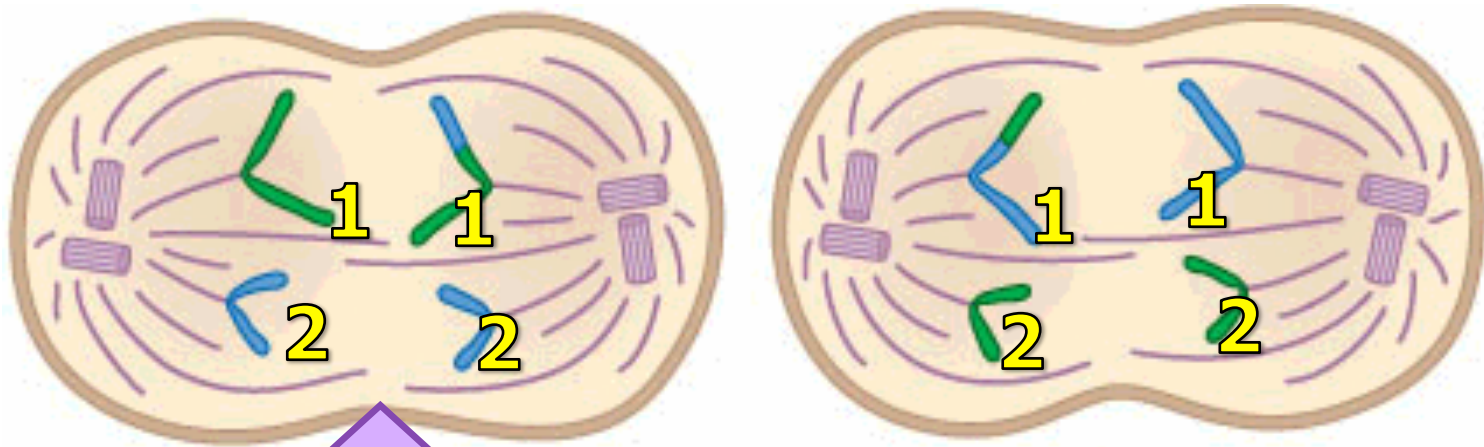


# Anaphase II

- Centromeres **split**
- The paired sister chromatids separate

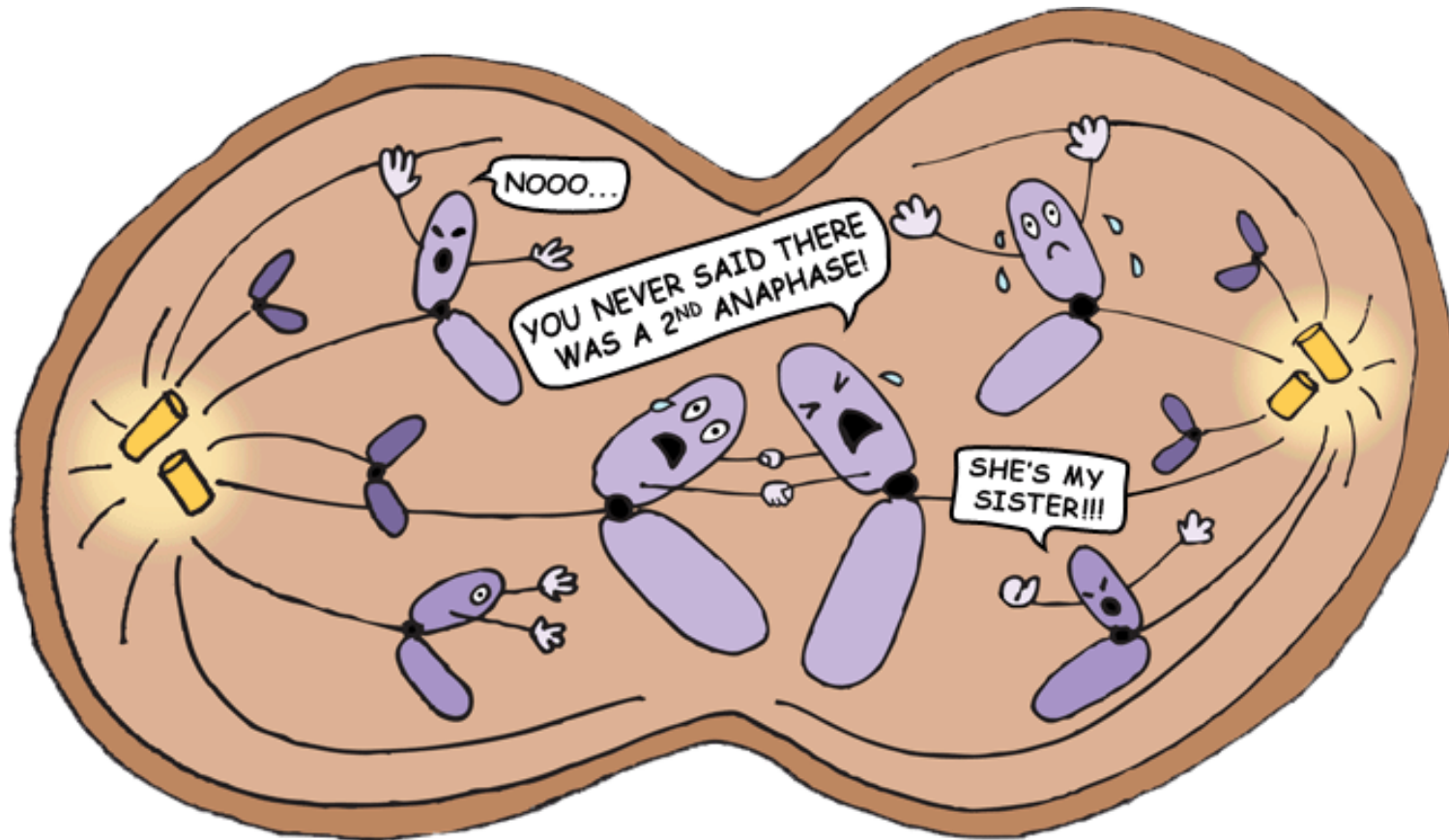
**NOTE:** each cell will still be “n” because the sisters were already half the original parents genetic information

- **Chromosomes** move to the poles



No cleavage furrow yet!  
(Indent should not be there!)

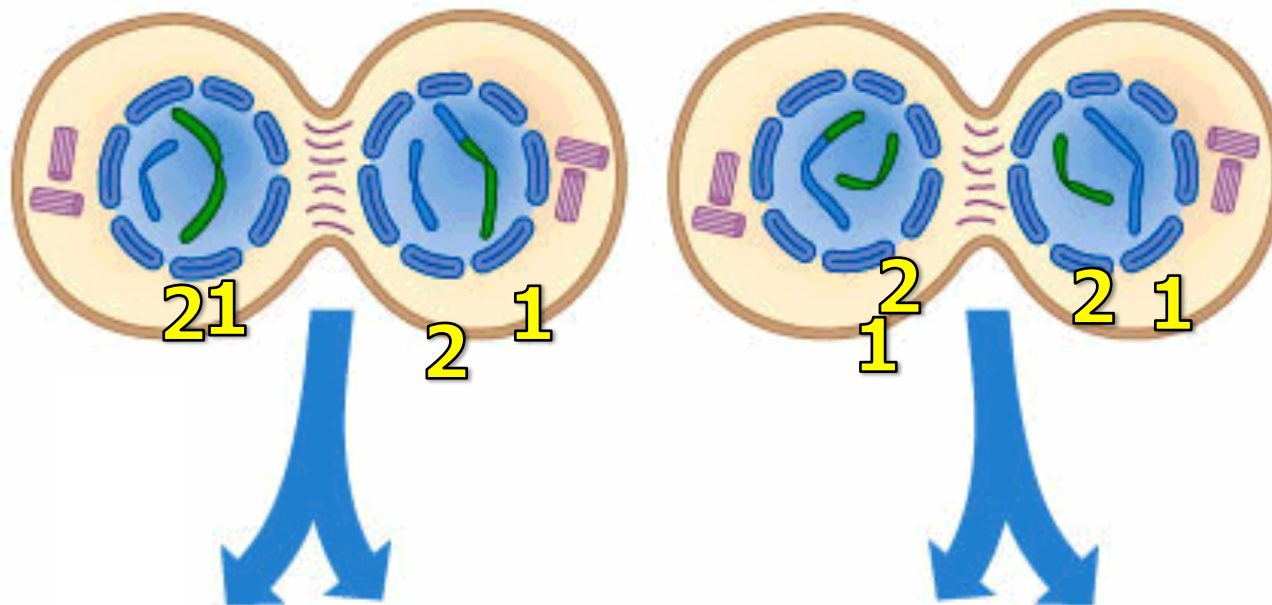
# Anaphase II



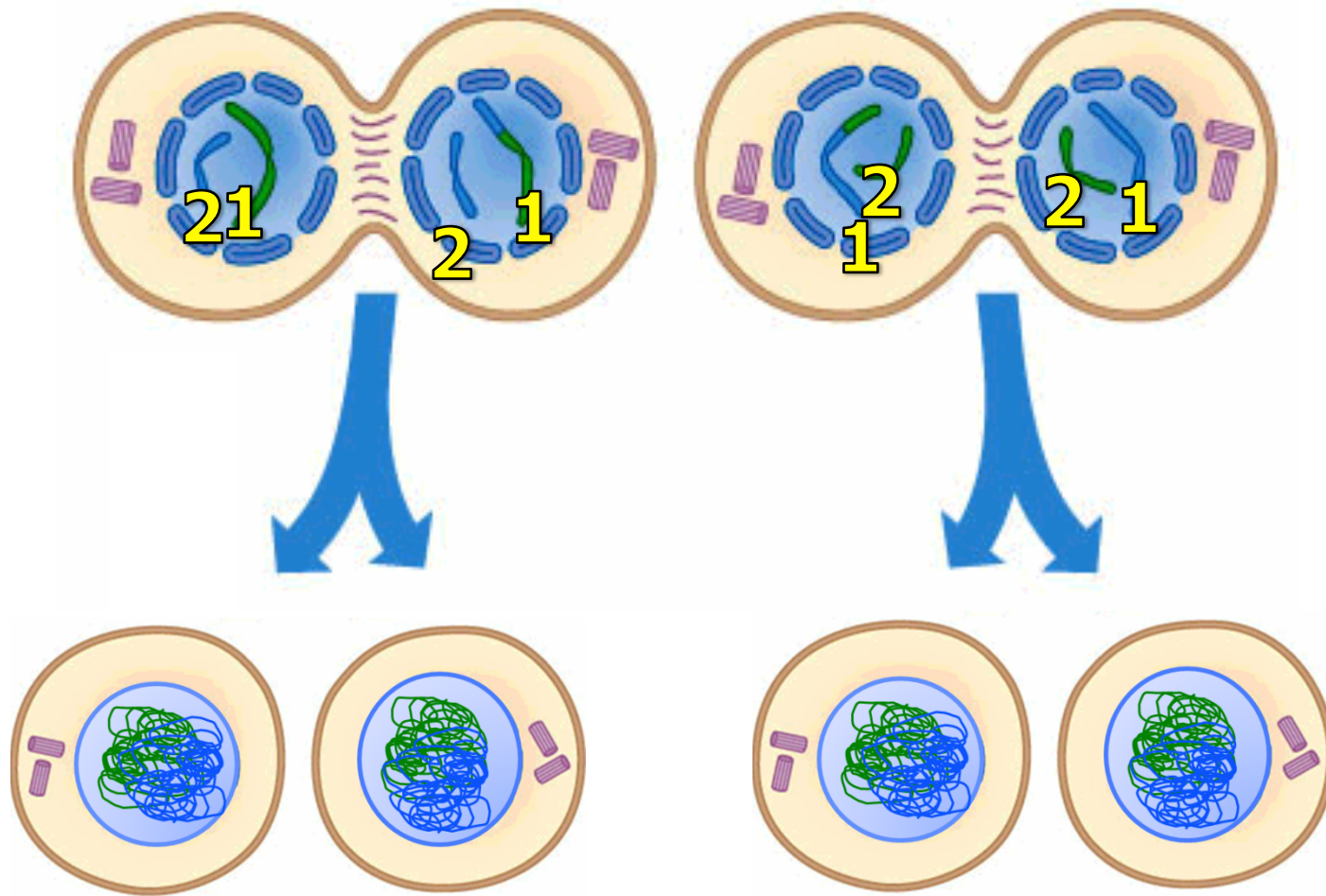
# Telophase II

[Excellent Narrated  
Movie of Meiosis](#)

- Chromosomes arrive at poles
- Cytoplasm starts to pinch in
- **Cytokinesis** occurs
- End result is **4 haploid cells**



# Cytokinesis

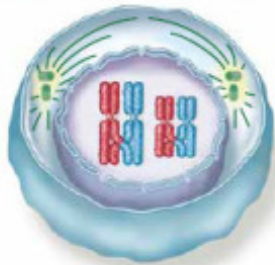
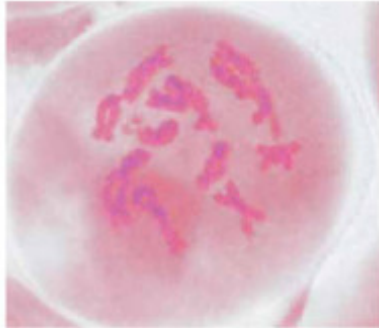


Meiosis Square Dance

<http://www.youtube.com/watch?v=iCL6d0OwKt8>

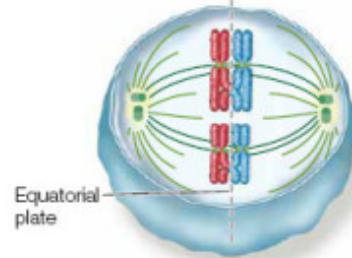
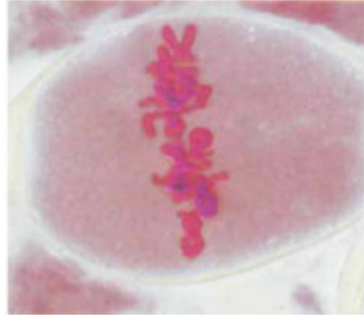
# Meiosis I

Late prophase I-prometaphase



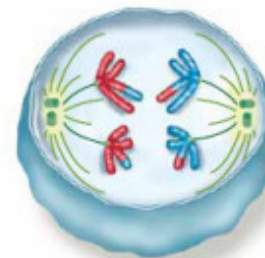
**3** The chromosomes continue to coil and shorten. Crossing over results in an exchange of genetic material. In prometaphase the nuclear envelope breaks down.

Metaphase I



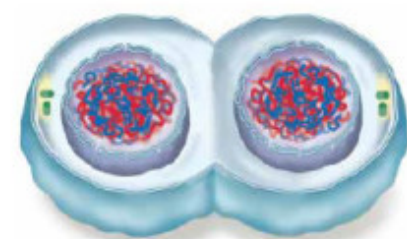
**4** The homologous pairs line up on the equatorial (metaphase) plate.

Anaphase I



**5** The homologous chromosomes (each with two chromatids) move to opposite poles of the cell.

Telophase I



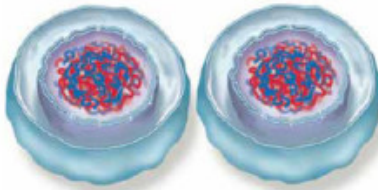
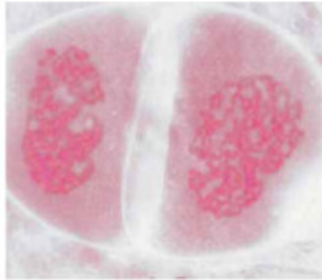
**6** The chromosomes gather into nuclei, and the original cell divides.



# Meiosis II

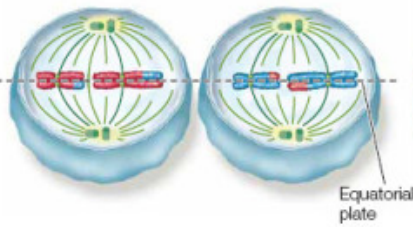
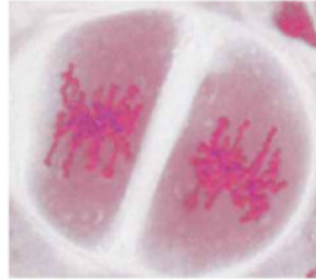
## MEIOSIS II

Prophase II



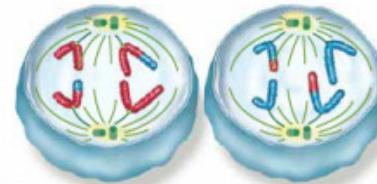
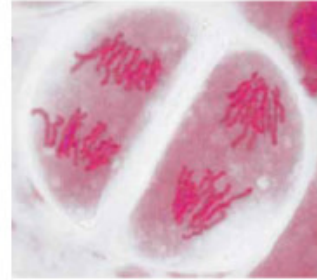
7 The chromosomes condense again, following a brief interphase (interkinesis) in which DNA does not replicate.

Metaphase II



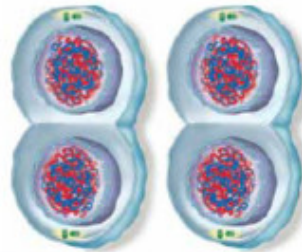
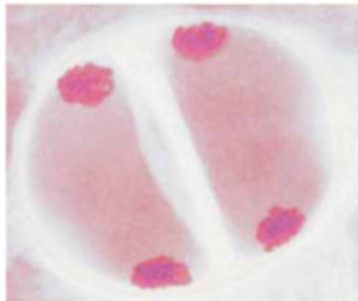
8 The centrosomes of the paired chromatids line up at the equatorial plates of each cell.

Anaphase II



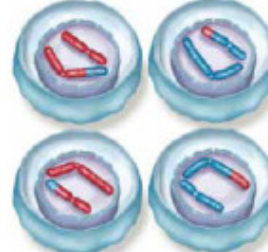
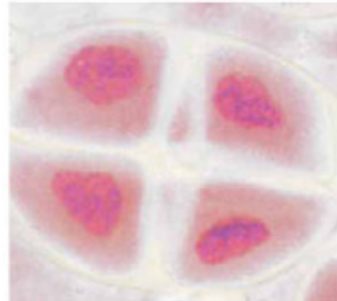
9 The chromatids finally separate, becoming chromosomes in their own right, and are pulled to opposite poles. Because of crossing over in prophase I, each new cell will have a different genetic makeup.

Telophase II



10 The chromosomes gather into nuclei, and the cells divide.

Products

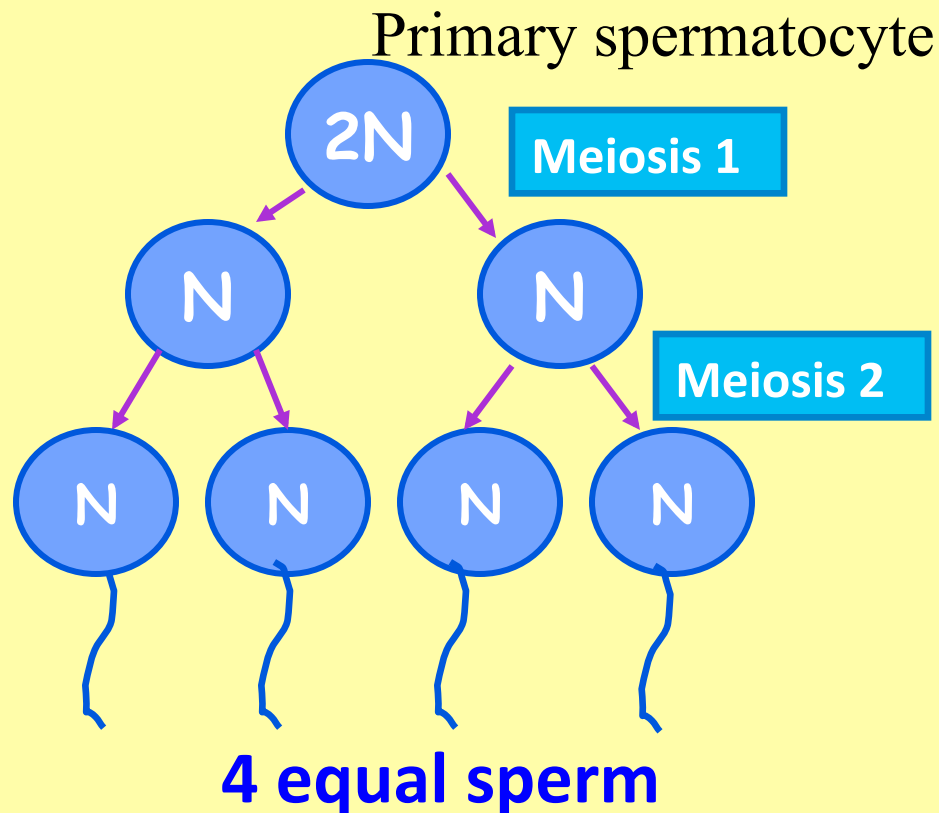


11 Each of the four cells has a nucleus with a haploid number of chromosomes.

# Meiosis in Males and Females

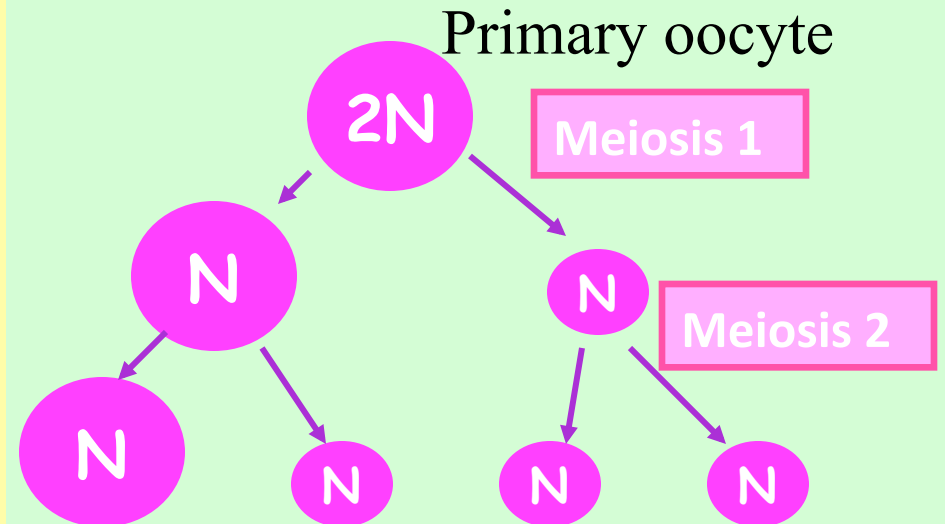
## Males - Spermatogenesis

Location : **testes**



## Females - Oogenesis

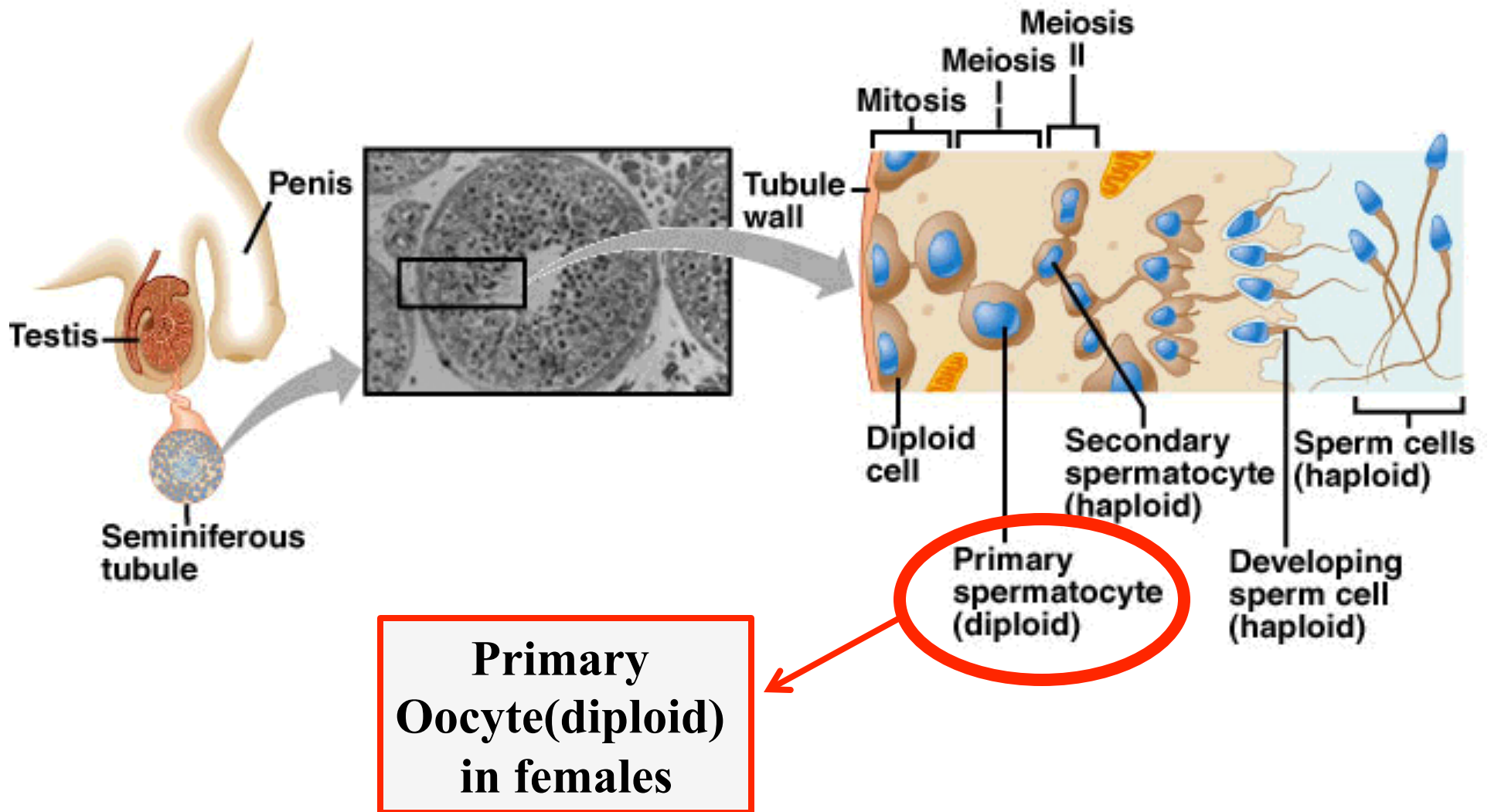
Location: **ovaries**



**1 egg and 3 polar bodies**

Egg (ootid) gets most of the cytoplasm. Polar bodies die and are absorbed by body.

# Meiosis Produces Sperm Cells



# Meiosis

## Spermatogenesis

## Oogenesis

Sperm (n)

Egg (Ovum) (n)

Zygote(2n)

## Fertilization

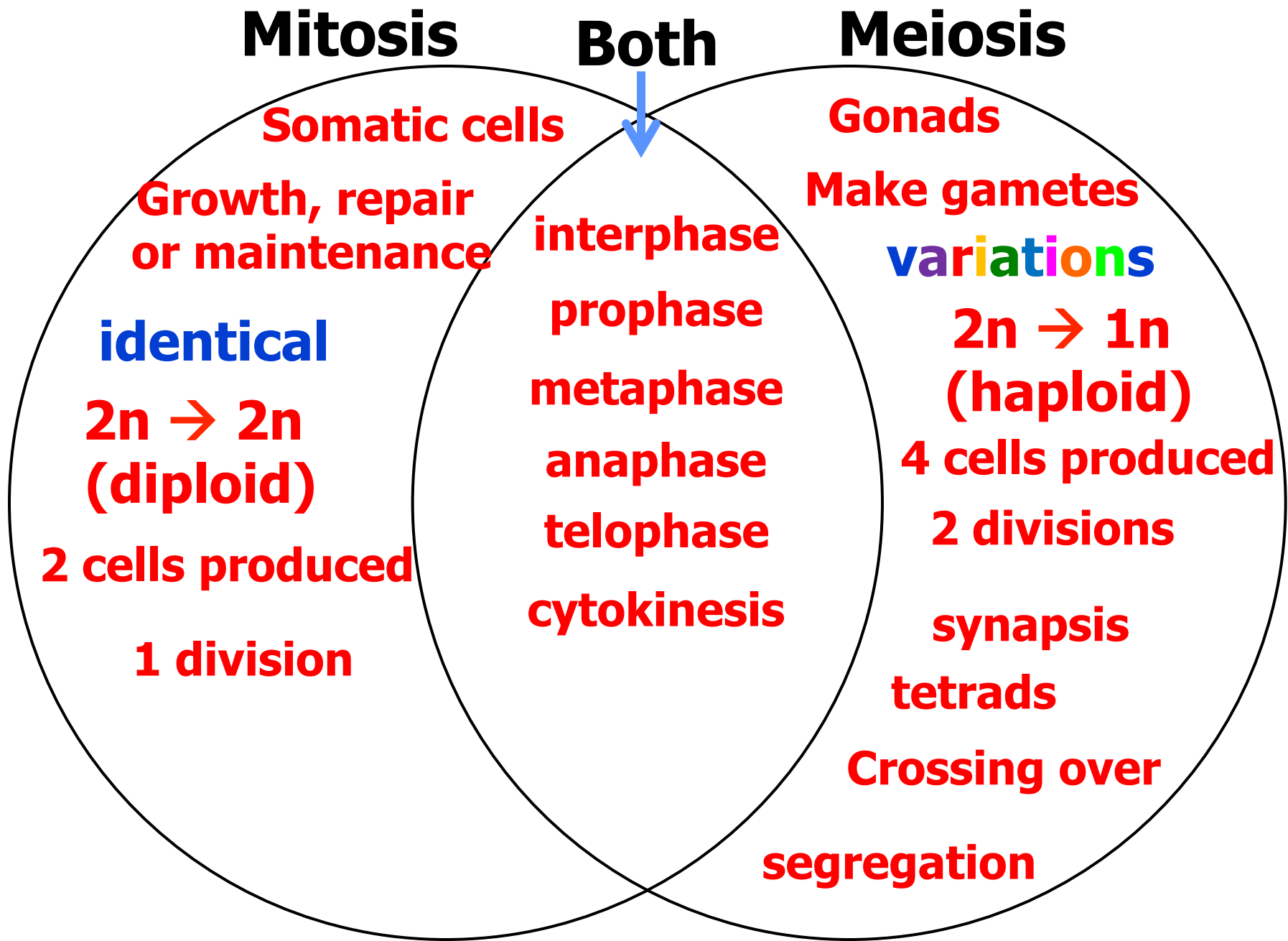
## Mitosis

Embryo  
(2n) Fetus  
Child

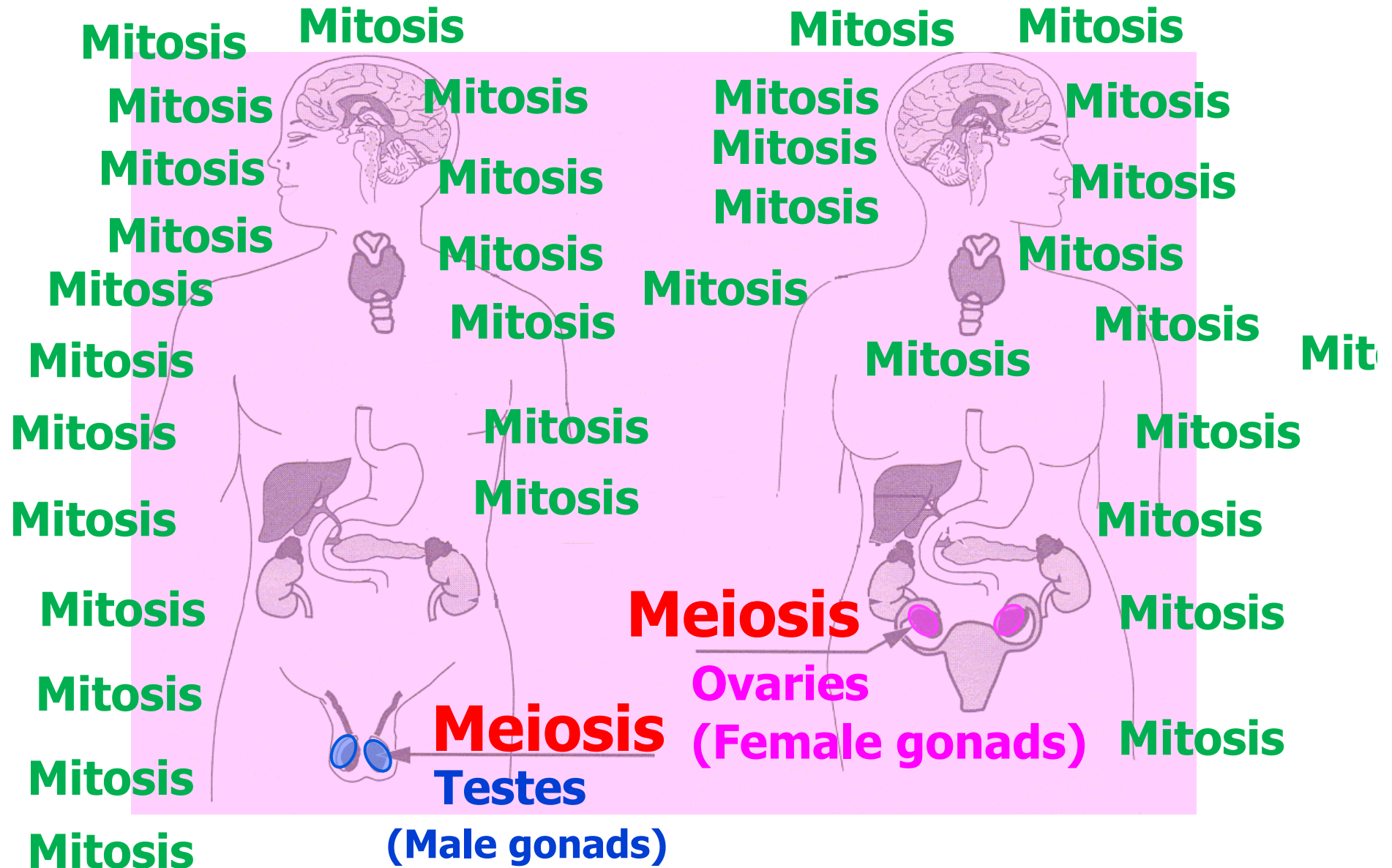


FYI: males  
make approx  
 $10^9$  sperm  
cells every  
day

FYI: females are  
born with approx  
400 000 egg  
cells. 1000  
mature every  
month, but only  
one leaves  
ovary.







Do the questions in your workbook



"Well, here we go again. ... Did anyone here *not* eat his or her homework on the way to school?"

## I Didn't Do My Homework Because...

- I didn't do my history homework because I don't believe in dwelling on the past.
- I didn't want the other kids in the class to look bad.
- A sudden gust of wind blew it out of my hand and I never saw it again.
- Another pupil fell in a lake and I jumped in to rescue him. Unfortunately, my homework drowned.
- Our furnace broke and we had to burn it to keep ourselves from freezing.
- I'm not at liberty to say why.
- I wanted to frame the detention letter you're about to give me.
- It was destroyed in a freak accident involving a hippo, a toaster and a bag of frozen peas. You don't want to know the details.
- I have a solar powered calculator and it was cloudy.
- My mom used it as a dryer sheet.
- My agent won't allow me to publish my homework until the movie deal is finalized.
- I lost it fighting this kid who said you weren't the best teacher in the school.
- I was abducted by green-skinned, three-eyed, pig-snouted space aliens and they incinerated my homework with their death rays.
- I felt it wasn't challenging enough.
- My parents were sick, and unable to do my homework last night. Don't worry, they have been suitably punished.
- We had homework?!
- I see your lips moving but all I am hearing is "blah, blah, blah."
- I didn't want to add to your already heavy workload.
- I spent the night at a rally supporting higher pay for our hard-working teachers.

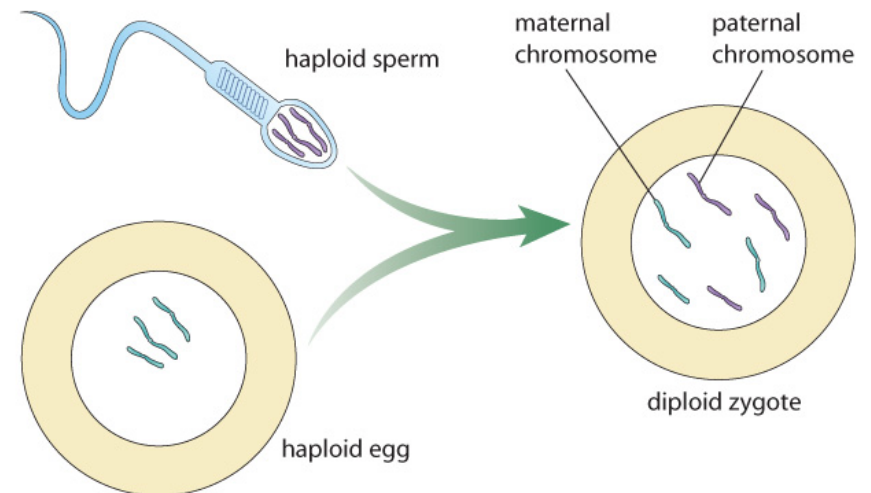
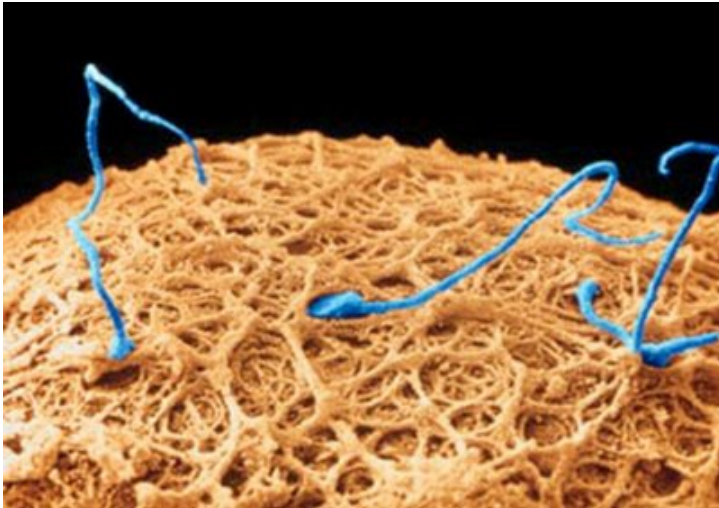
# Meiosis - Sources of Variation

**Mitosis produces daughter cells that are genetically IDENTICAL**

- Meiosis produces daughter cells with different **combinations** of genes.

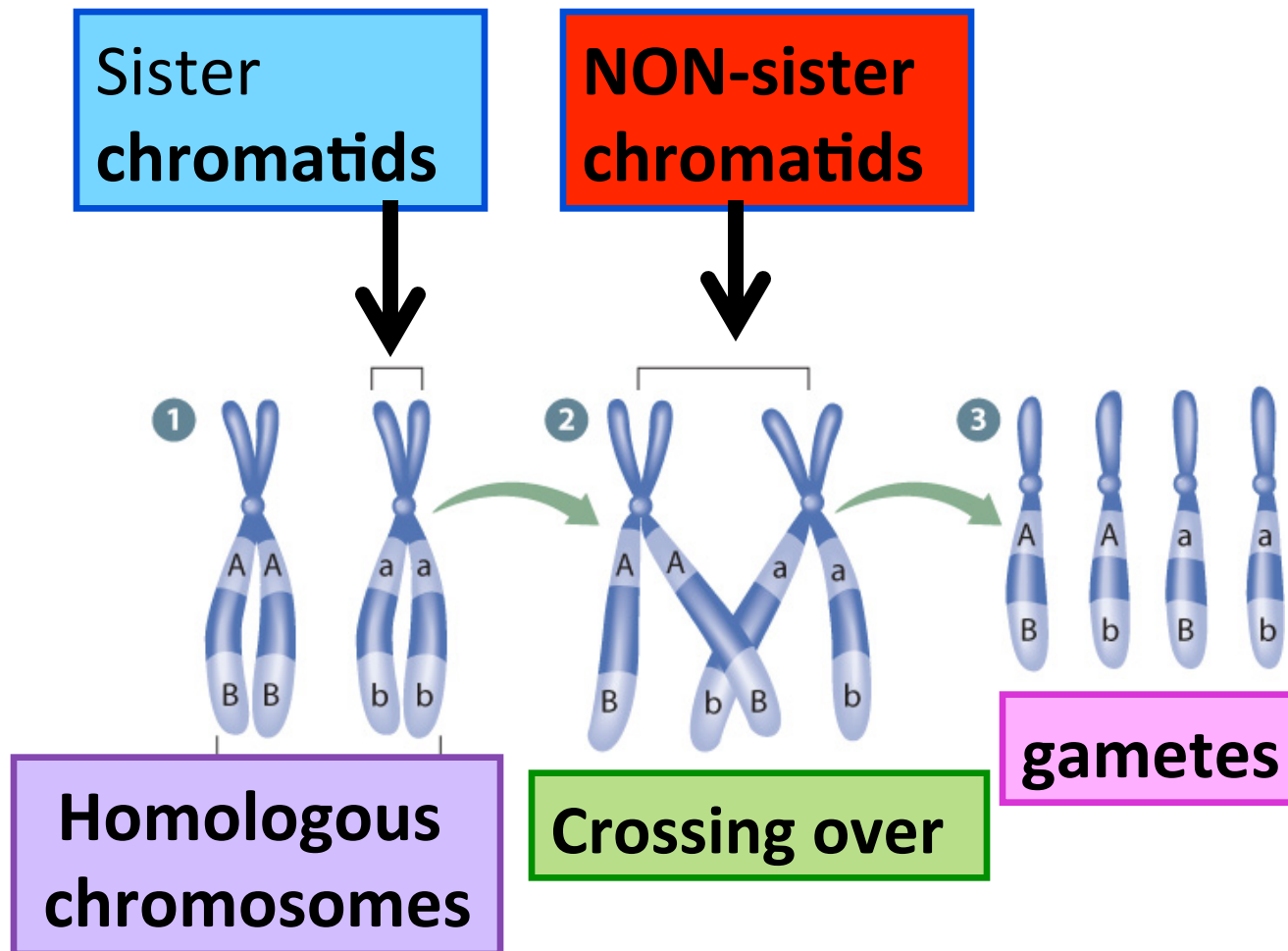
**This GENETIC VARIATION is accomplished by:**

1. **Gamete success** - only one sperm can fertilize the egg
2. **Crossing over** – exchange of genetic material between chromosomes
3. **Independent Assortment**- chromosomes line up randomly before being separated (in Anaphase)



# Crossing Over

2. **Crossing Over** – occurs between non-sister chromatids

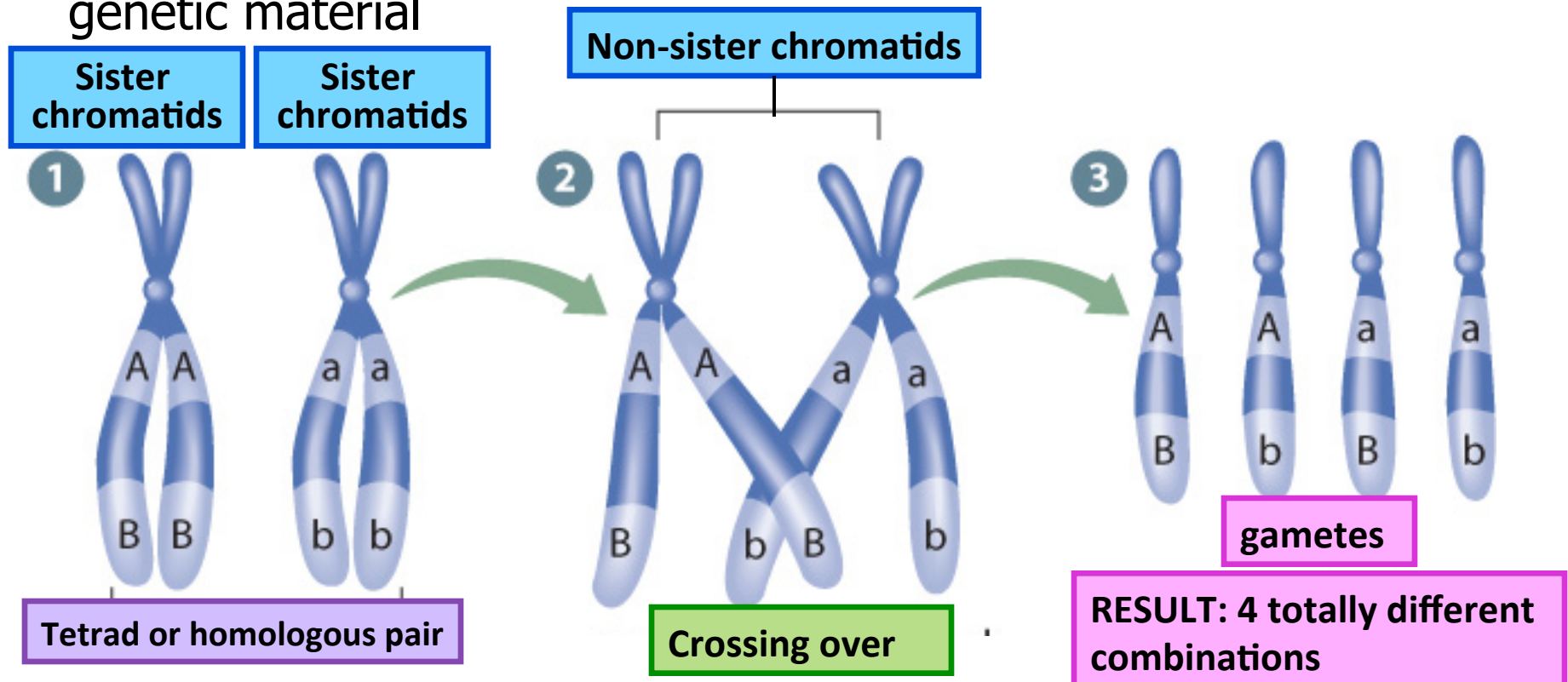




# Crossing Over

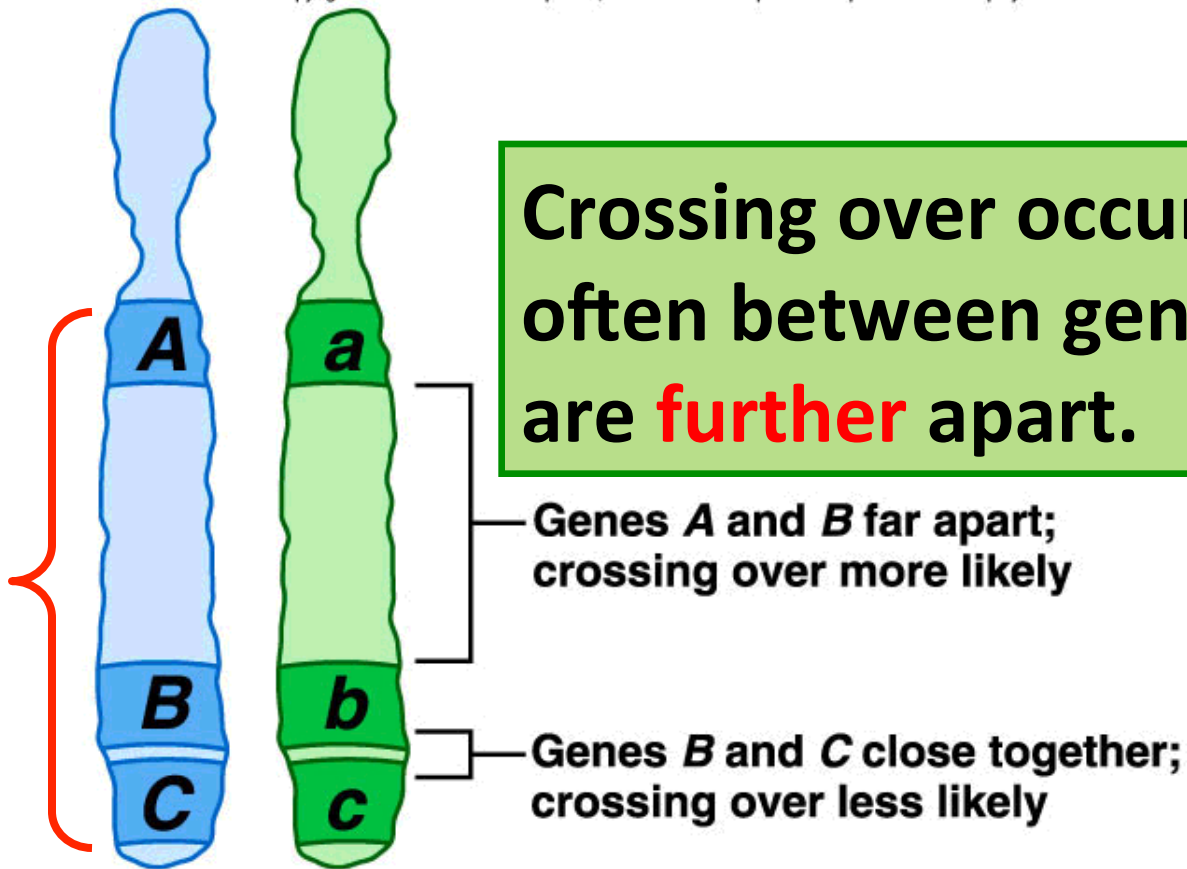
Crossing over occurs at random between pairs of **homologous chromosomes**.

- (1) During **prophase I**, homologous chromosomes form pairs.
- (2) Non-sister chromatids cross over each other and exchange segments of chromosomes.
- (3) Chromosomes in the gametes contain **new combinations** of genetic material





# Linked Genes

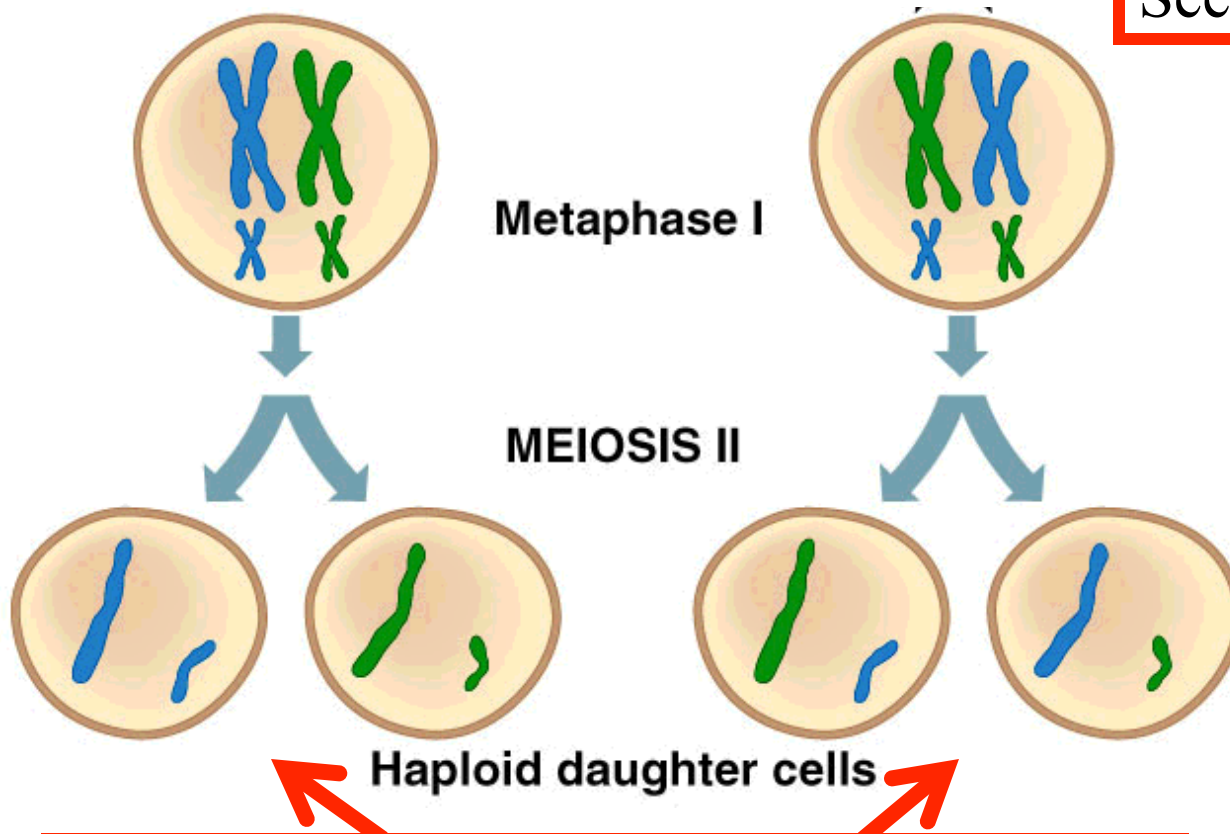


Crossing over occurs more often between genes that are **further** apart.

# Independent Assortment

## 3. Independent assortment – chromosomes line up randomly in Metaphase I

See next page illustration...



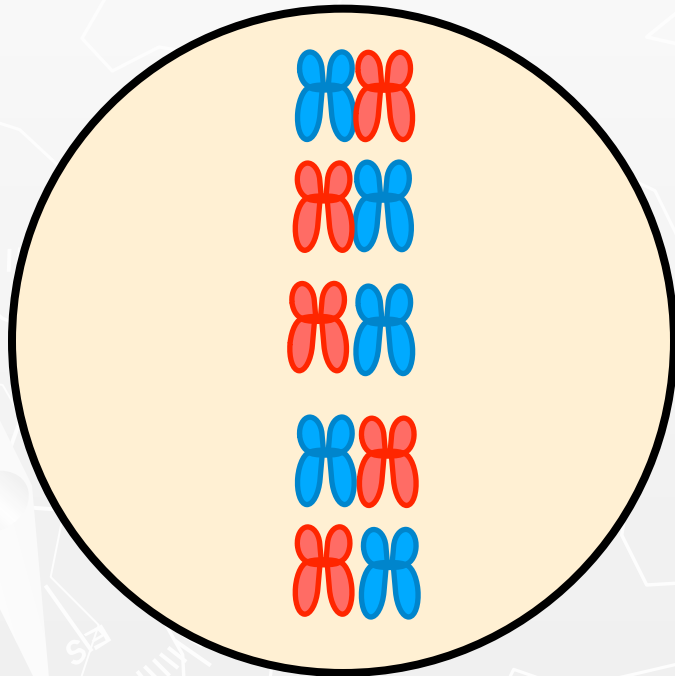
Bozeman Meiosis Video: (9:35)  
[http://www.youtube.com/watch?v=rB\\_8dTuh73c&safety\\_mode=true&safe=active](http://www.youtube.com/watch?v=rB_8dTuh73c&safety_mode=true&safe=active)

The result could (depending on how the pairs line up) be either of these combinations in this example

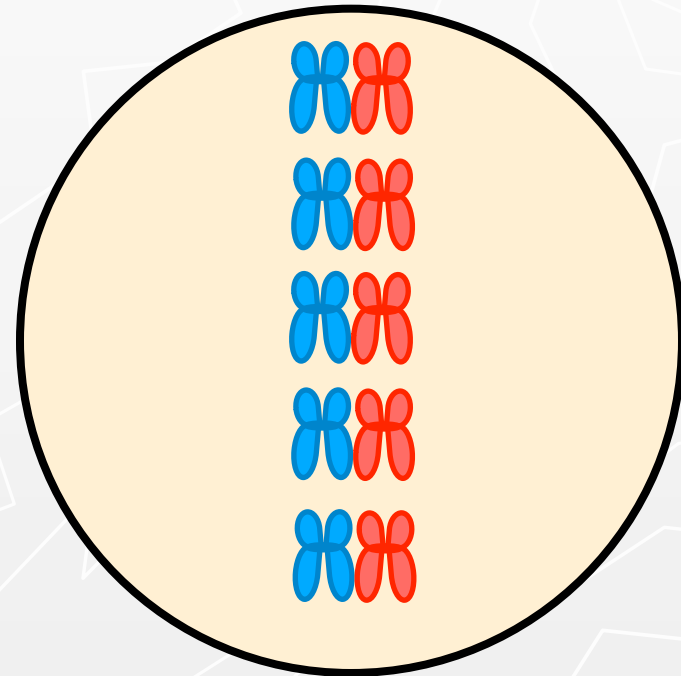
# Law of Independent Assortment

- Different pairs of chromatids line up independently of each other (completely random!)

**Independent Assortment**

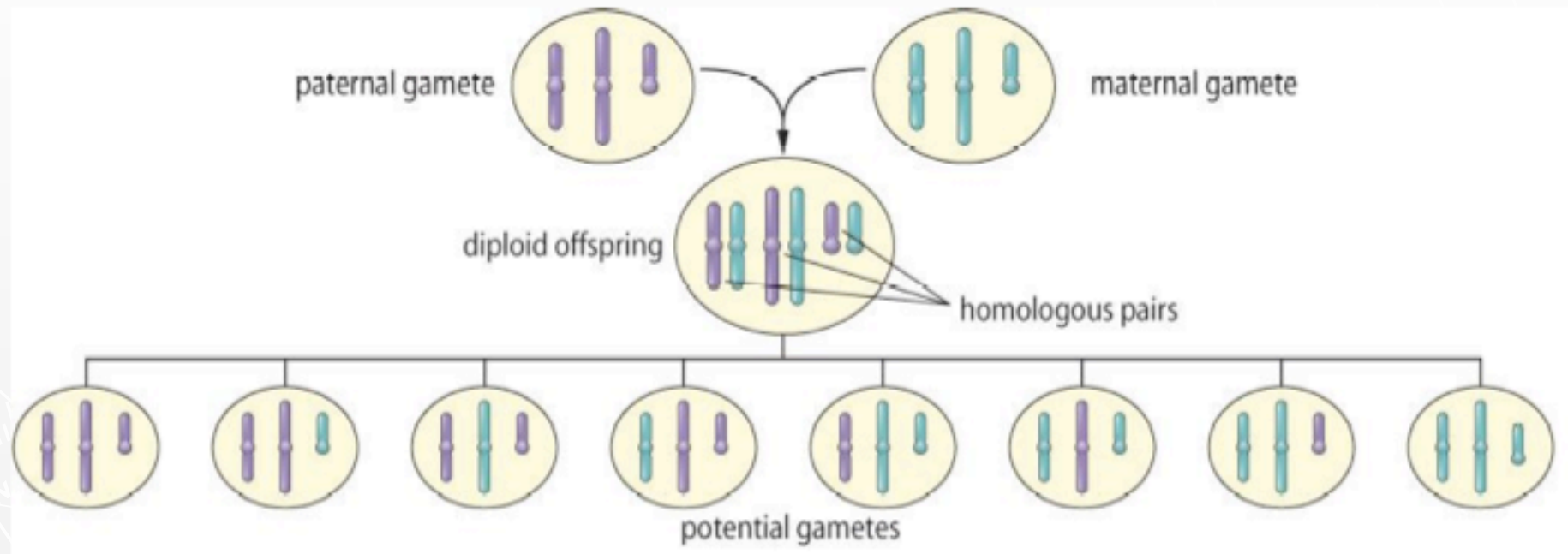


**Very unlikely according to Independent Assortment**



# Independent Assortment

**FYI: How much variation will this provide?**



3 pairs of chromosomes: -->  $2^3$  produce 8 genetically different gametes  
7 pairs of chromosomes -->  $2^7$  or 128 different gametes  
23 pairs of chromosomes -->  $2^{23}$  = (lots) 8,388,608 gametes

**Pair this with crossing over and the genetic possibilities are enormous!**

# MEIOSIS ABNORMALITY

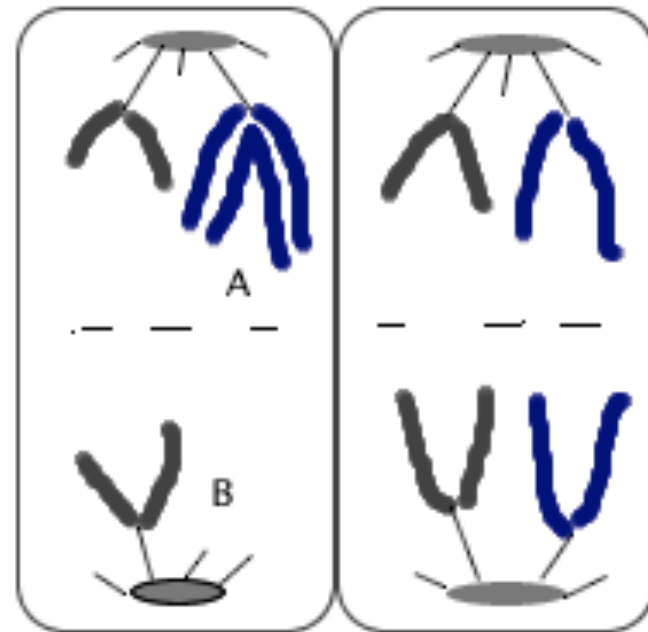
Occasionally abnormalities can occur as meiosis undergoes its divisions. This is called **Nondisjunction**.

-**Nondisjunction** occurs when chromosomes fail to separate properly in ANAPHASE I or II

-This results in some cells having not enough information and others having too much  
-can occur in mitosis as well but **most devastating** in meiosis

**Example-** Down syndrome, where there is an extra chromosome in the 21<sup>st</sup> set of chromosomes

Nondisjunction (at A) During Meiosis II



In the end, 4 haploid cells will be created. Two will have 2 chromosomes (normal), one with 3 chromosomes (at A), and one with one chromosome (at B).



**Nondisjunction  
in meiosis I**

**Normal  
meiosis II**

**Gametes**

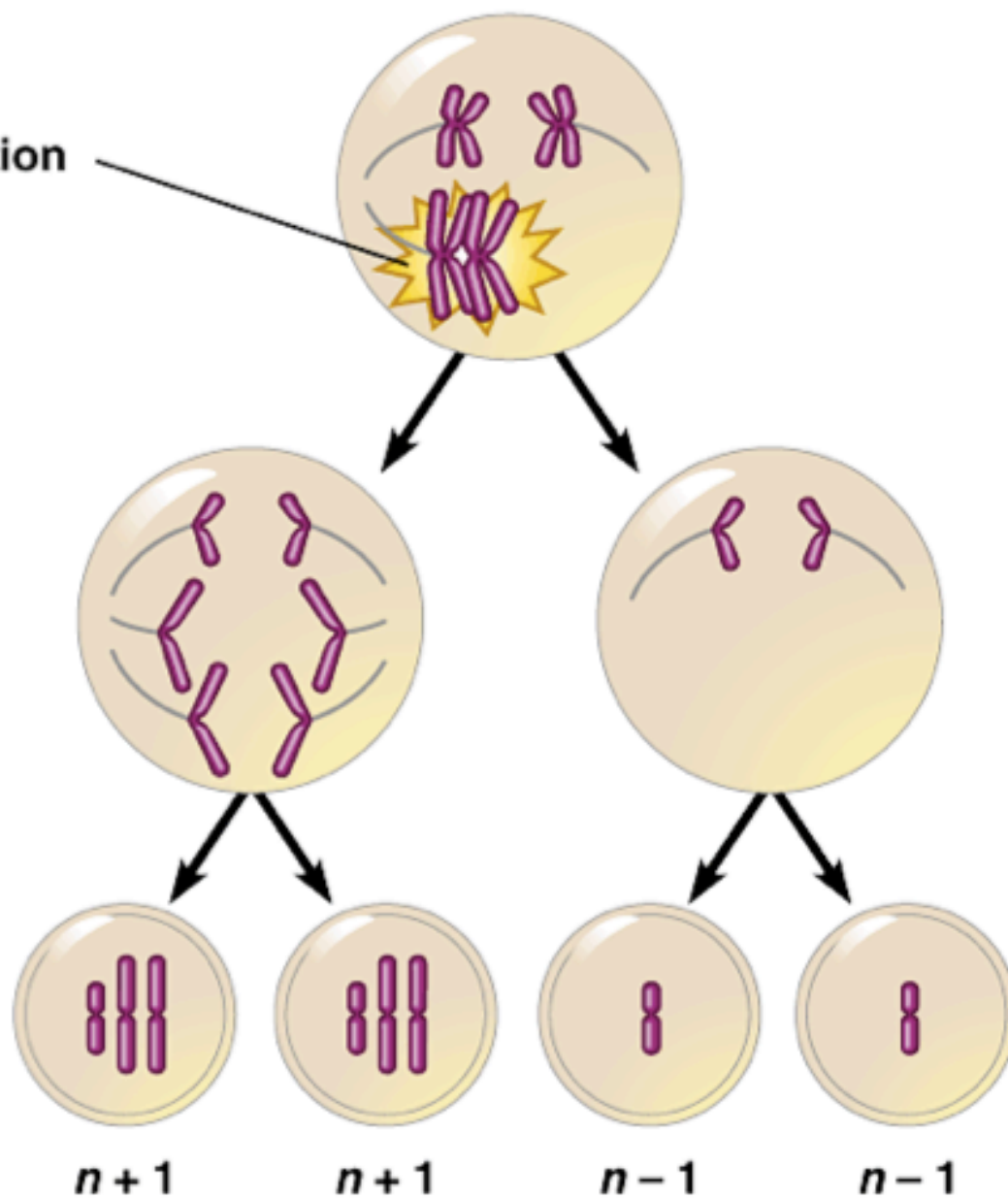
$n + 1$

$n + 1$

$n - 1$

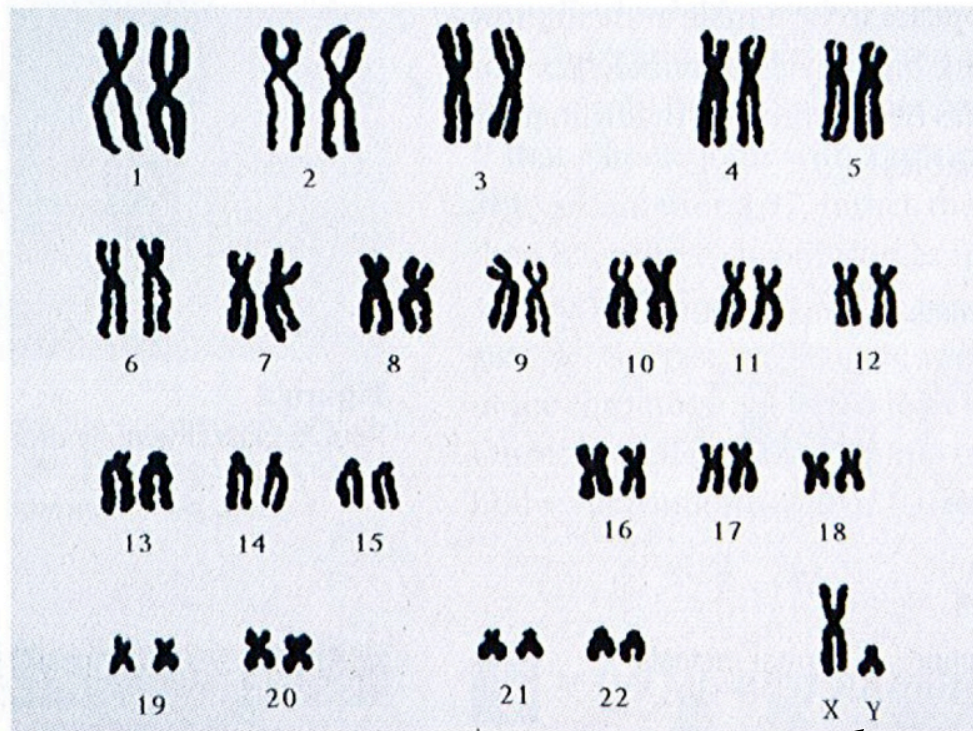
$n - 1$

**Number of chromosomes**



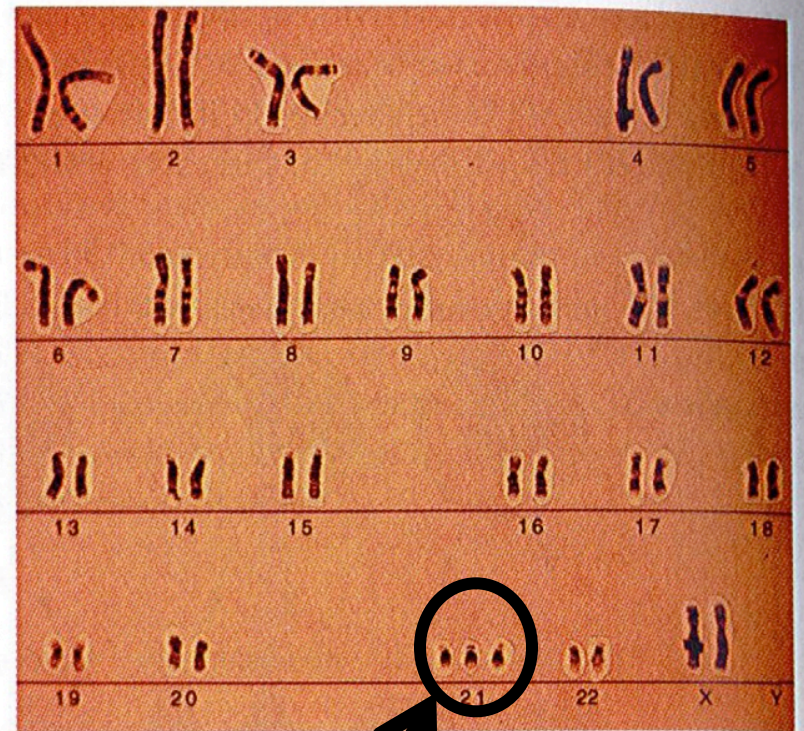
**Karyotype Chart** – used to see individual chromosomes and see possible abnormalities

Normal Male



Notice how small the “Y” chromosome is

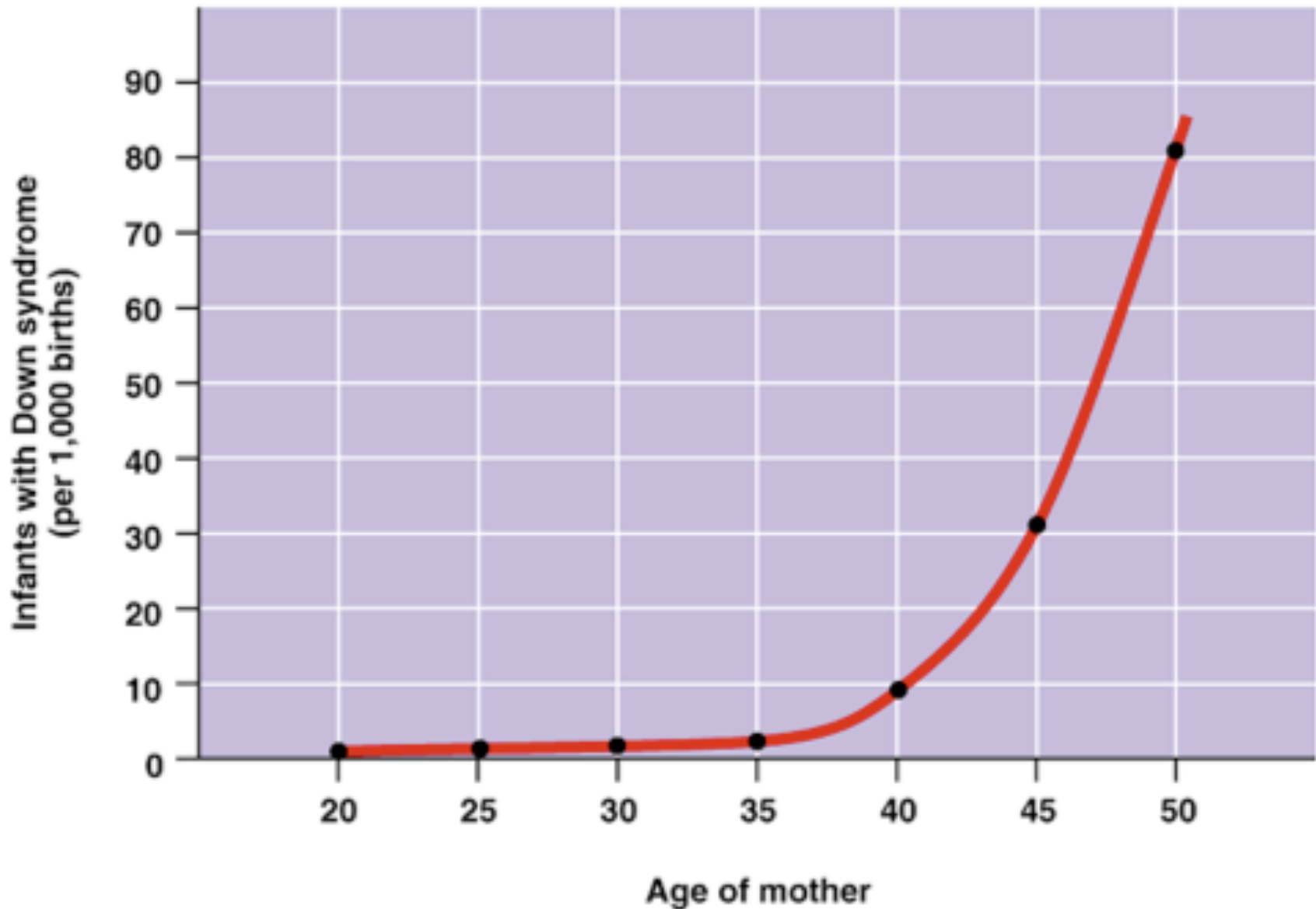
Abnormal Female



Female with Down syndrome (notice extra chromosome in set #21)

**FYI**

## Risk of Down Syndrome in relation to maternal age



# Meiosis

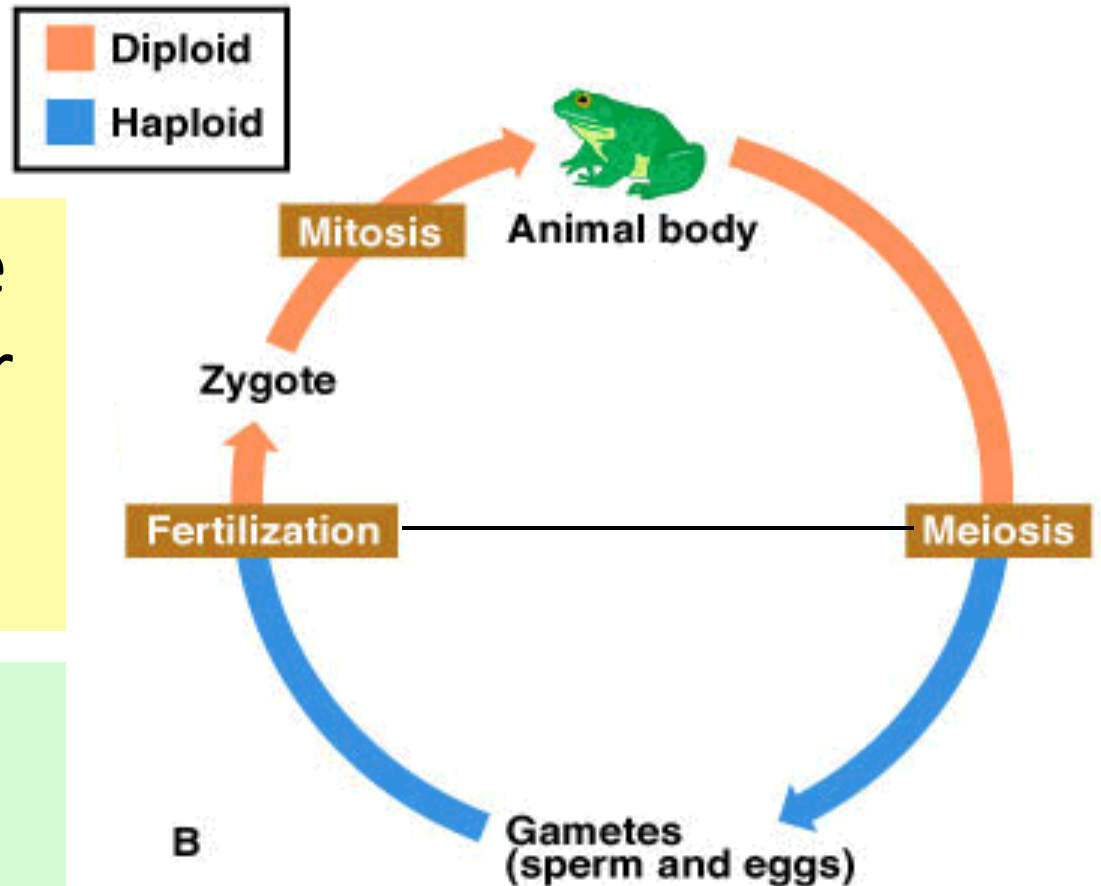
**Test yourself! 10 interactive questions:**

[http://www.biology.arizona.edu/cell\\_bio/tutorials/meiosis/01q.html](http://www.biology.arizona.edu/cell_bio/tutorials/meiosis/01q.html)

# Animal Life Cycle

The animal life cycle is based on a regular pattern of mitosis and meiosis

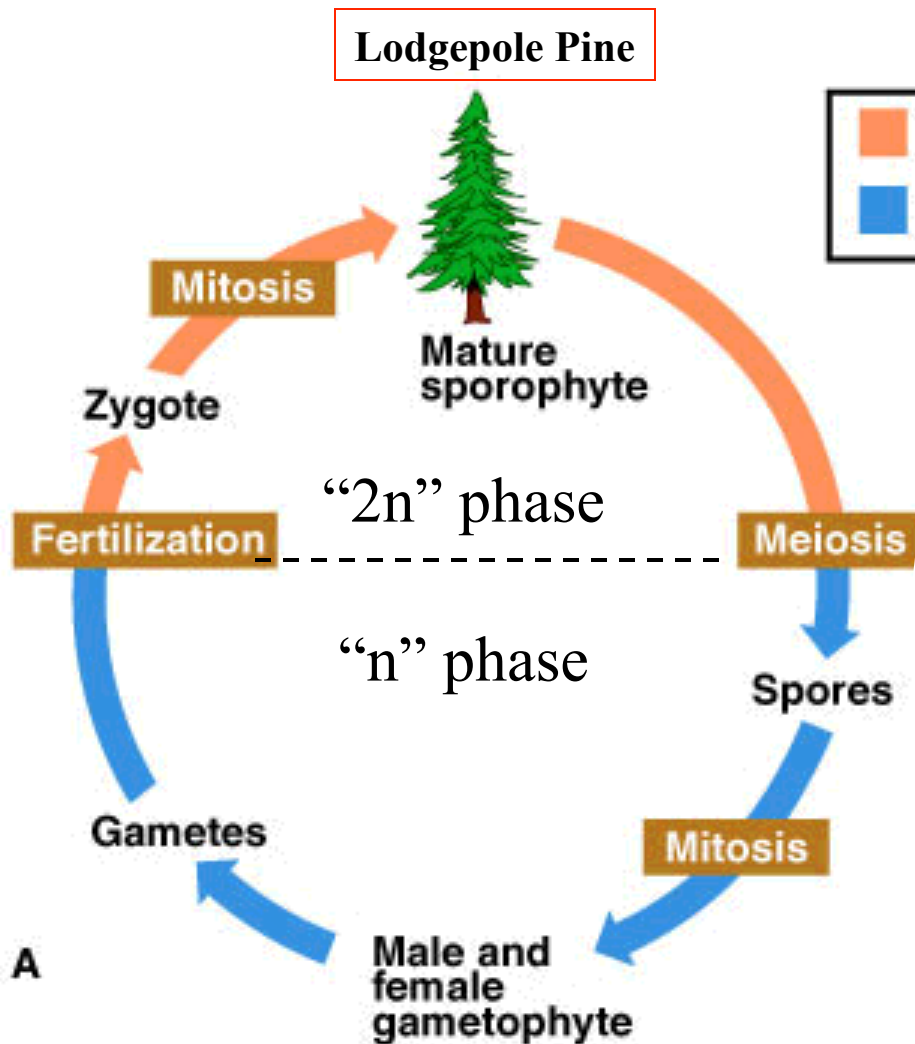
Humans reproduce sexually and live in the **diploid** stage





# Plant Life Cycle

## ALTERNATION OF GENERATIONS



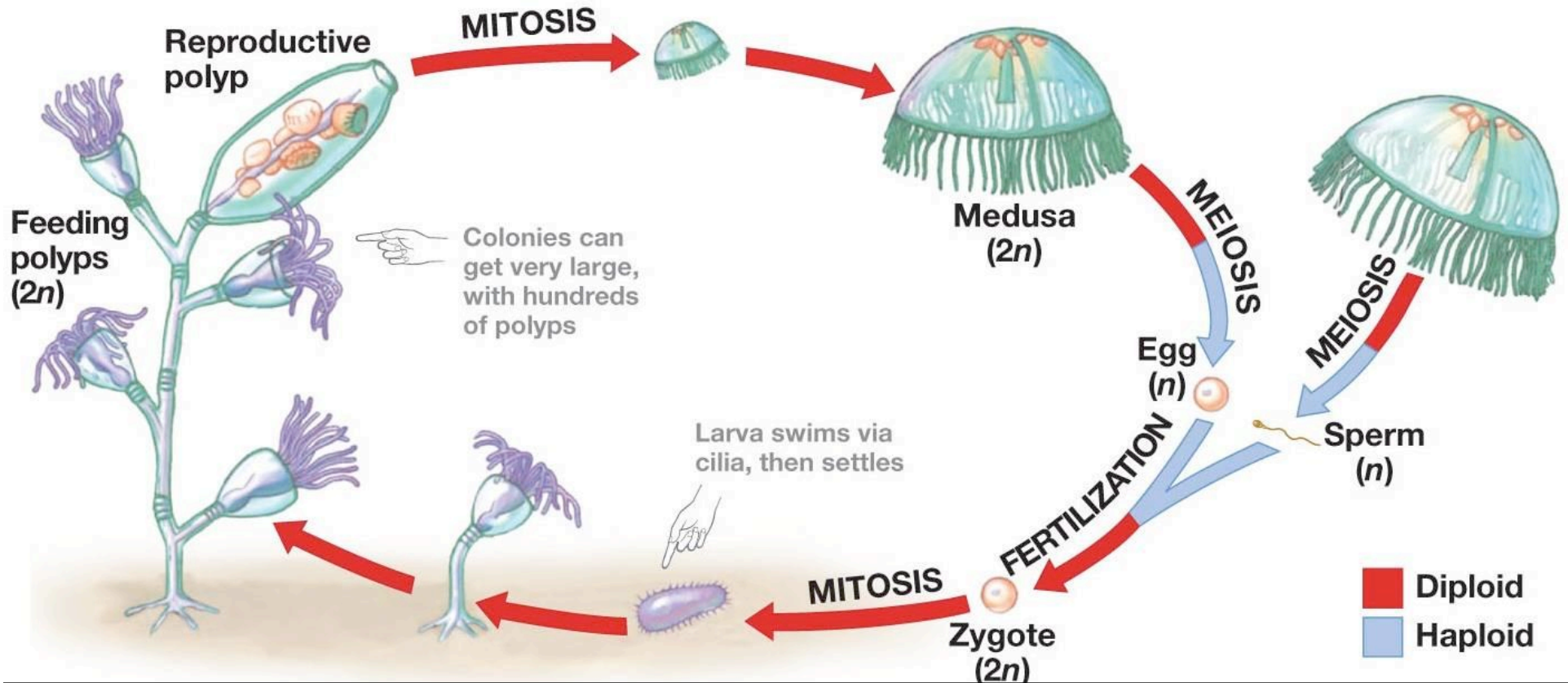
Plants can exist in haploid & Diploid stages known as **Alternation of Generations**

**Sporophyte:** asexual and usually **diploid (2n)** phase (plant growing), **producing spores** from which the gametophyte arises.

**Gametophyte:** the **gamete-producing** and usually **haploid (n)** phase

# ALTERNATION OF GENERATIONS

## Sea Sponge Life Cycle

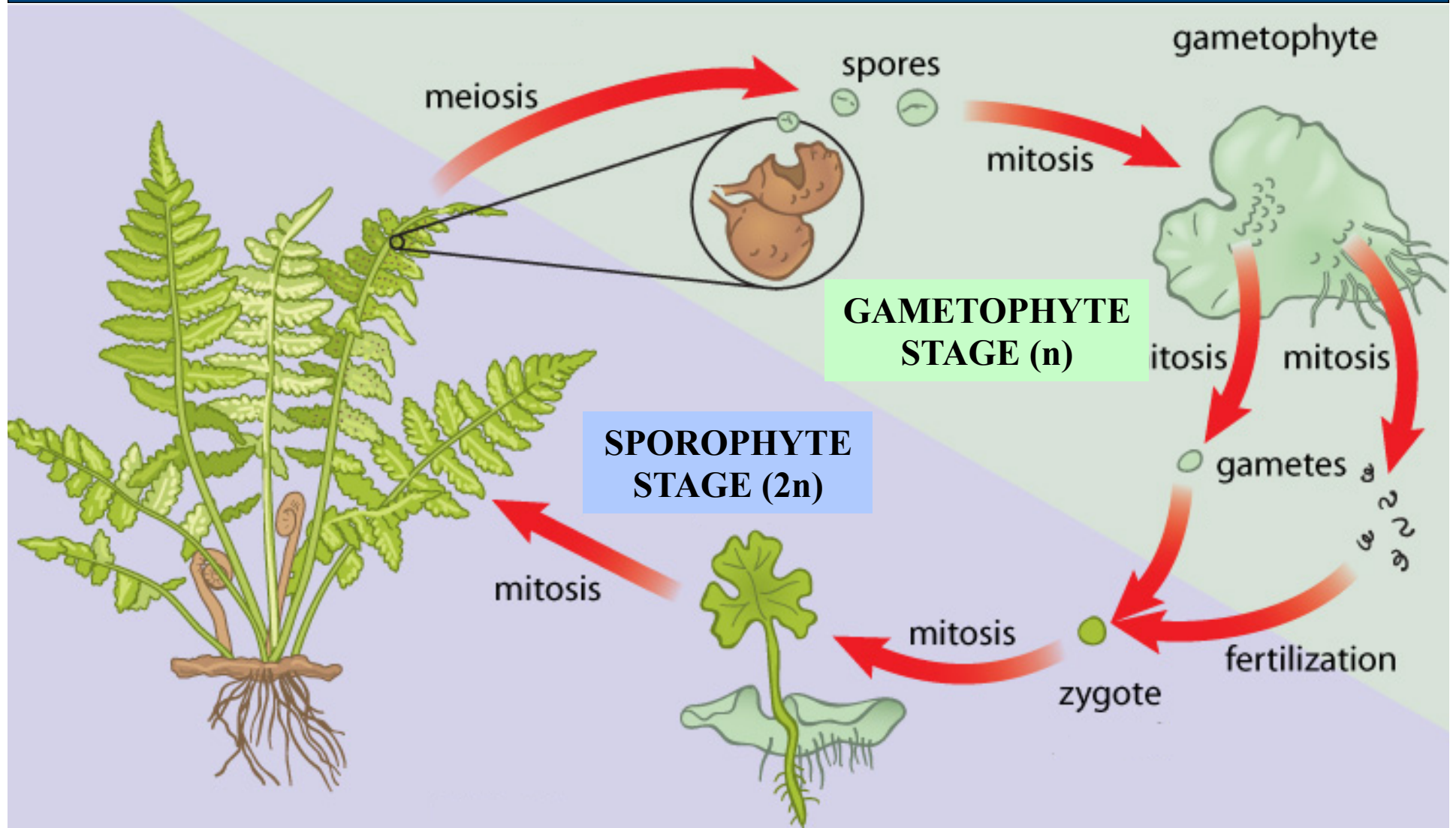


**Compare this life cycle to a human one. What is a major difference?**

There is an extra stage/organism (medusa) that eventually produces gametes. We don't have a stage like this as we individually produce our gametes.

# ALTERNATION OF GENERATIONS

## Fern Life Cycle





# Alteration of Generations



1. Is the dominant stage of a fern a gametophyte or a sporophyte?  
**sporophyte**
2. Are the cells of a fern diploid or haploid?  
**diploid (2n)**
3. Do ferns produce gametes or spores for reproduction?  
**gametes** – produced from gametophyte which was grown from a spore
4. Are spores produced by meiosis or mitosis?  
**meiosis**
5. Does the heart-shaped gametophyte produce gametes or spores?  
**gametes** though mitosis because is already in haploid stage
6. Does the zygote grow into a sporophyte or a gametophyte?  
**Sporophyte (fern)**

Use the following information to answer the next four questions.

Interleukin-4 is a polypeptide that causes the body's immune system to destroy cancer cells. Researchers have genetically engineered neural stem cells of rats to produce interleukin-4. Previous studies have shown that when neural stem cells are injected into the brain, they migrate throughout it. The researchers hypothesized that the genetically engineered stem cells would carry the interleukin-4 to a brain tumour. When the genetically engineered neural stem cells were injected into rats with malignant brain tumours, the rats survived longer than untreated rats and their tumours became smaller.

Malignant brain tumours form as a result of

- ☒ A. abnormal mitosis
- ☐ B. abnormal meiosis
- ☐ C. a long interphase stage of the cell cycle
- ☐ D. a long cytokinesis stage of the cell cycle

The process that occurs to form an eight-cell embryo from a zygote is

- ☒ A. mitosis of diploid cells
- ☐ B. mitosis of haploid cells
- ☐ C. meiosis of diploid cells
- ☐ D. meiosis of haploid cells



In the embryos of most animals, cytokinesis immediately follows mitosis and, therefore, the embryo grows as a ball of cells. However, *Drosophila* (fruit fly) embryos develop in an unusual manner. In *Drosophila*, separating membranes do not appear until after several thousand nuclei have been produced. This development trait has led researchers to use fruit fly embryos to study development.

In most animals, cytokinesis occurs at the end of the mitotic phase known as

- A. anaphase
- B. prophase
- C. telophase**
- D. metaphase

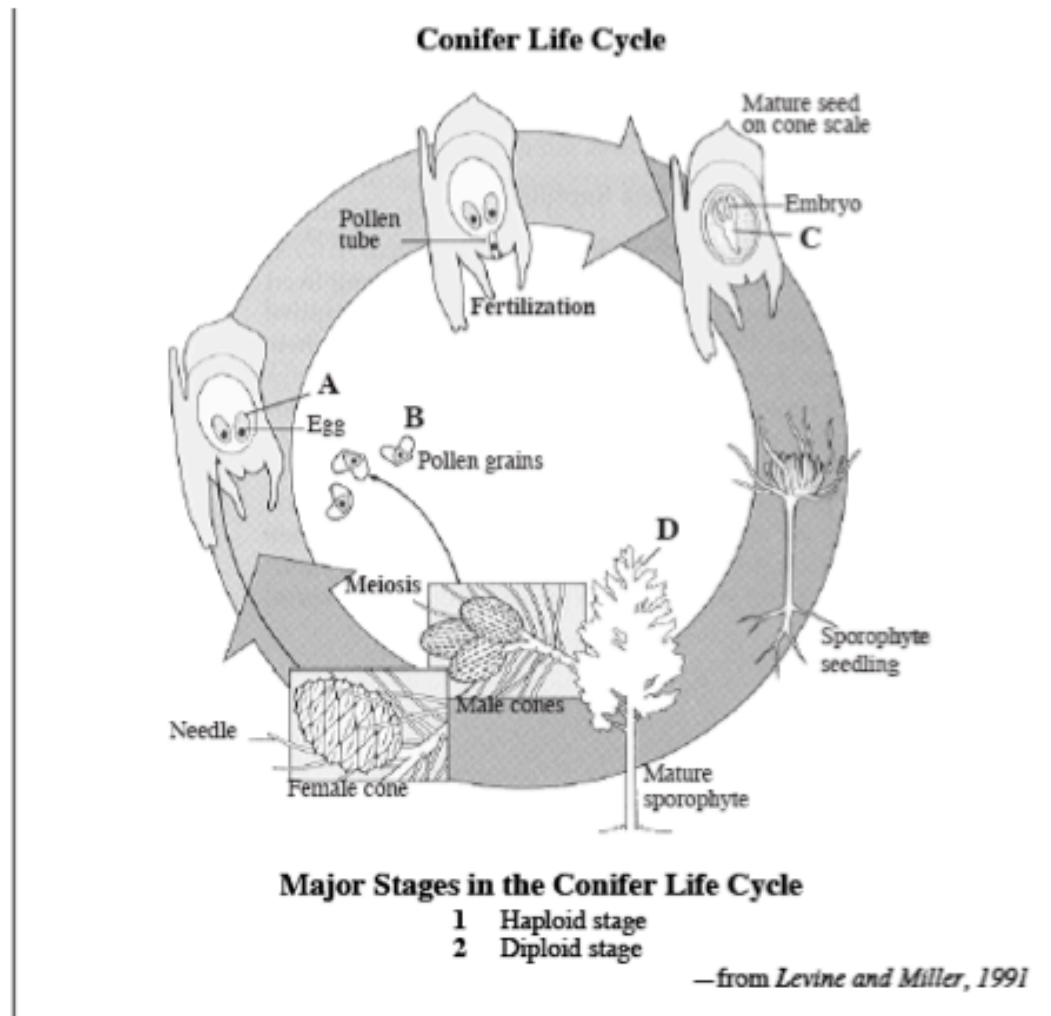
Use the following information to answer the next question.

**Some Events That Occur in Various Stages of Oogenesis**

- 1 DNA replication takes place.
- 2 Centromeres split; sister chromatids pull apart.
- 3 Homologous chromosomes align at the equator of the cell.
- 4 Homologous chromosomes separate; members of each chromosome pair move to opposite poles.

Match each of the events that occur in oogenesis numbered above with the stage at which it occurs, as given below.

Event:	<u>1</u>	<u>3</u>	<u>4</u>	<u>2</u>
Stage:	Interphase	Metaphase I	Anaphase I	Anaphase II



### erical Response

Identify the stages in the conifer life cycle, as numbered above, that correspond with the letters that represent these stages on the diagram.

Stages: 1      1      2      2  
Diagram: A      B      C      D

*Use the following information to answer the next three questions.*

Researchers have found a gene known as p53. It codes for a protein that binds to specific areas of DNA and activates them. This causes the production of a set of proteins that halts cell division or, in some cells, activates the cell's suicide program (apoptosis). The p53 gene is activated when a cell is damaged and/or undergoes a DNA mutation.

—from *Seachrist, 1996*

The normal function of the p53 gene is likely to

- A. encourage a cell to undergo mitosis
- B. encourage a cell to undergo meiosis
- ☒ C. prevent an abnormal cell from reproducing
- D. prevent the transcription of a cell suicide gene

*Use the following additional information to answer the next two questions.*

Research on the p53 gene was initially done with cancer cells obtained from a laboratory animal. These cells were grown in a petri dish. A cell with two normal *p53* alleles was found to have normal cell division. Cells with one normal and one mutated *p53* allele were also found to have normal cell division. Cells that had mutations in both *p53* alleles were unable to control cell division and were associated with cancer.

The initial research findings described above

- A. demonstrate that the activated p53 gene causes cancer in lab animals
- B. demonstrate that the p53 protein causes the formation of cancer cells
- C. indicate that the normal p53 gene is responsible for preventing cancer in all mammals
- ☒ D. indicate that the normal p53 gene is responsible for preventing cancer under laboratory conditions

Gene therapy that might stop uncontrolled cell division due to the mutant *p53* allele would require

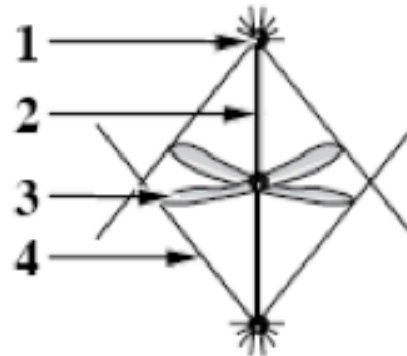
- ☒ A. one functional *p53* allele to be successfully inserted into cancer cells
- ☐ B. two functional *p53* alleles to be successfully inserted into cancer cells
- ☐ C. one functional *p53* allele to be successfully removed from cancer cells
- ☐ D. two functional *p53* alleles to be successfully removed from cancer cells



Use the following information to answer the next three questions.

Investigators were interested in determining the role chromosomes play in the formation of the mitotic spindle. Using extracts of eggs from the African frog *Xenopus laevis*, they monitored spindle assembly in a test tube. The researchers replaced the chromosomes with beads coated with random sequences of DNA. The beads served as substitute genetic material, but centrosomes (centrioles) were absent. As well, a part of the centromere was missing.

**Simplified Diagram of Normal Mitotic Cell**



—from *Travis, 1996*

Which of the structures numbered above was replaced by the beads in the experimental setup?

- A. 1
- B. 2
- C. 3**
- D. 4

*Use the following additional information to answer the next question.*

Other studies showed that the phase that involves pulling chromosomes to the two poles of mitotic cells can be delayed for up to 4.5 h by pulling a chromosome out of line from the centre of the cell.

—from *Travis, 1996*

The phase that is delayed and the phase where the chromosomes line up at the equator are, respectively,

- A. telophase and anaphase
- B. metaphase and prophase
- C. interphase and telophase
- ☒ D. anaphase and metaphase