

**Big Idea 3: Living  
systems store, retrieve,  
transmit and respond  
to information essential  
to life processes.**

Enduring understanding 3.A:  
Heritable information provides  
for continuity of life.

Essential knowledge 3.A.2: In eukaryotes, heritable information is passed to the next generation via processes that include the cell cycle and mitosis or meiosis plus fertilization.

a. The cell cycle is a complex set of stages that is highly regulated with checkpoints, which determine the ultimate fate of the cell.

Evidence of student learning is a demonstrated understanding of each of the following:

1. Interphase consists of three phases: growth, synthesis of DNA, preparation for mitosis.

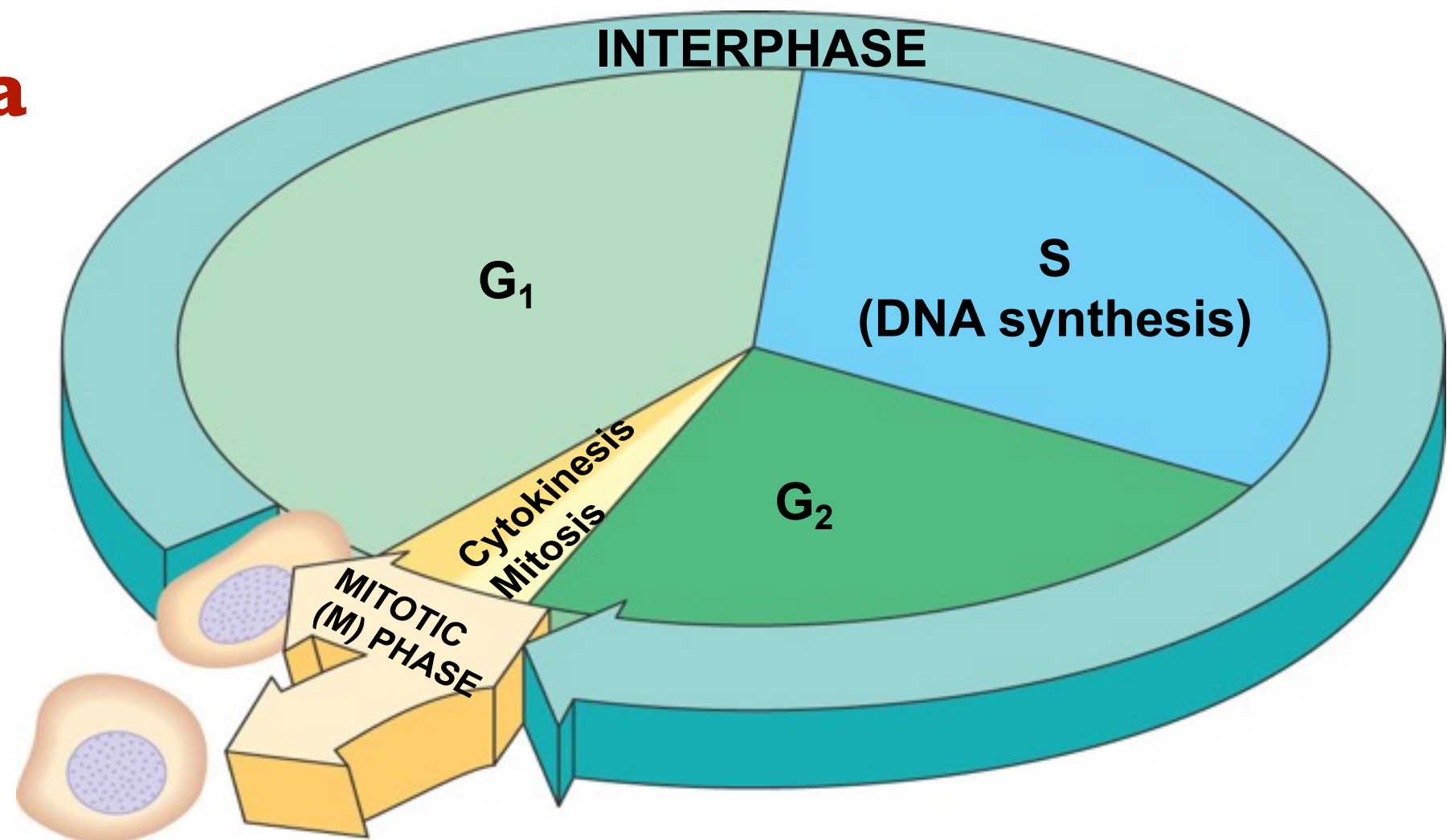
2. The cell cycle is directed by internal controls or checkpoints. Internal and external signals provide stop-and-go signs at the checkpoints.

# Phases of the Cell Cycle

- **Interphase**- growth and DNA replication but mostly the cell is functioning in its genetically determined capacity
- **Mitosis**- division of the nucleus
- **Cytokinesis**- division of the cytoplasm

**We will assume a cell cycle of 24 hours.**

The goal, is to develop a relative sense of time for each phase.

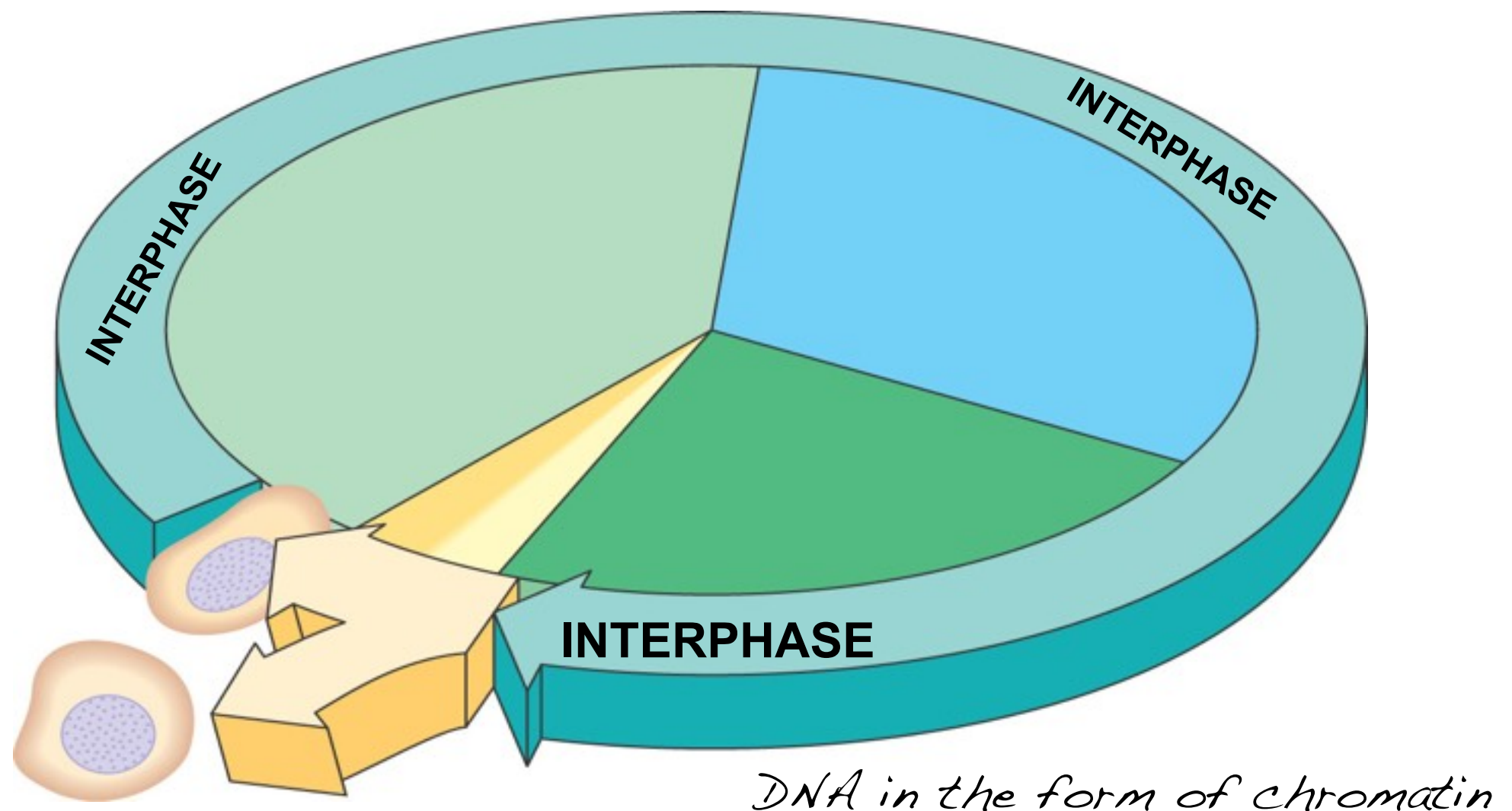




# Interphase

- Cells spend about 90% of their life in interphase
- **For the most part, unique cells “do what they do”**
- Interphase is split into three sub phases due to some specific activities that take place in a sequential manner

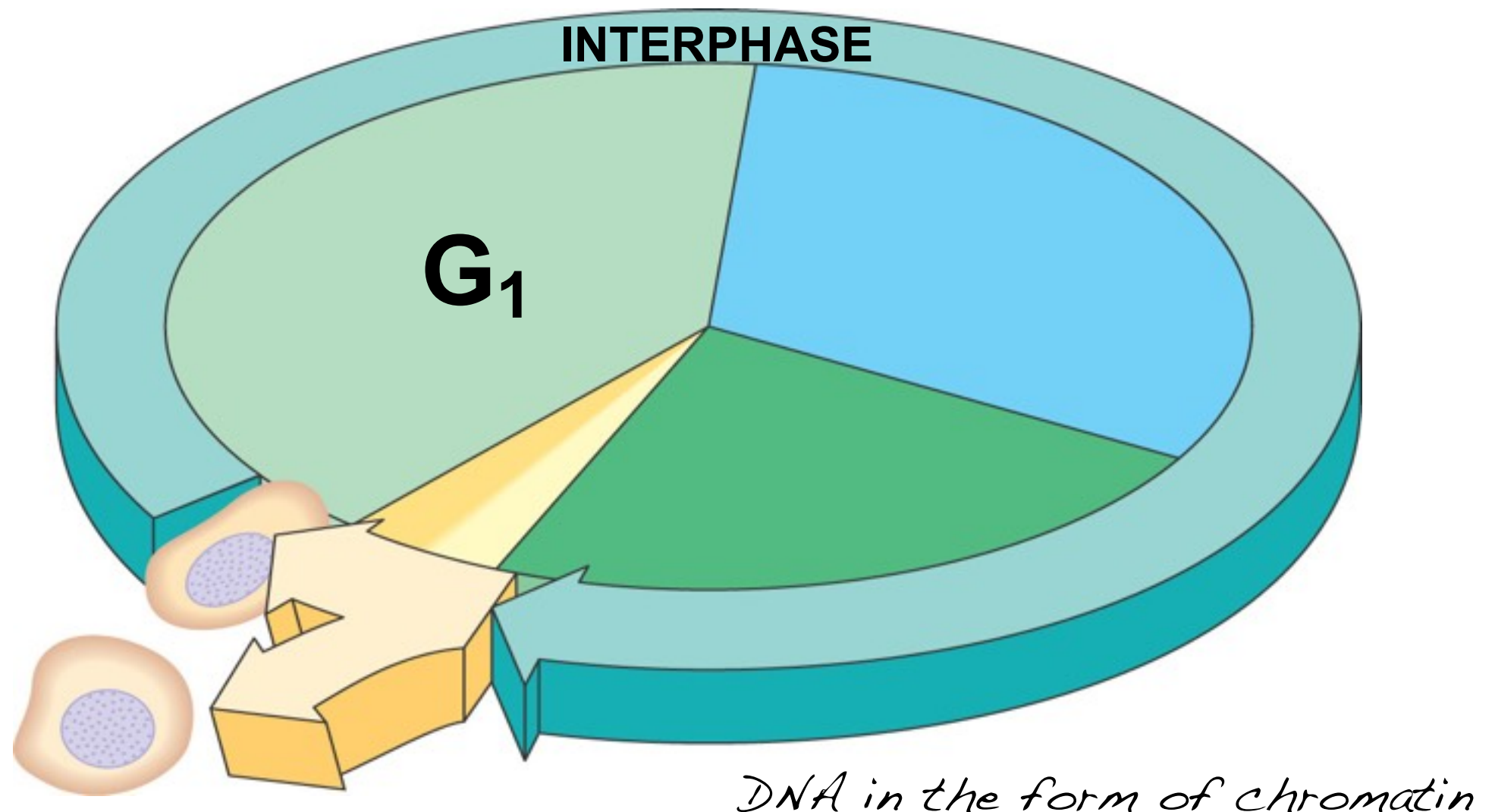
**~23 Hours**



# Interphase: G<sub>1</sub>

- New daughter cells are smaller than than parental cells.
- **..thus new cells experience tremendous growth (this includes the generation of more organelles)**
- And again cells continue to “do what they do”

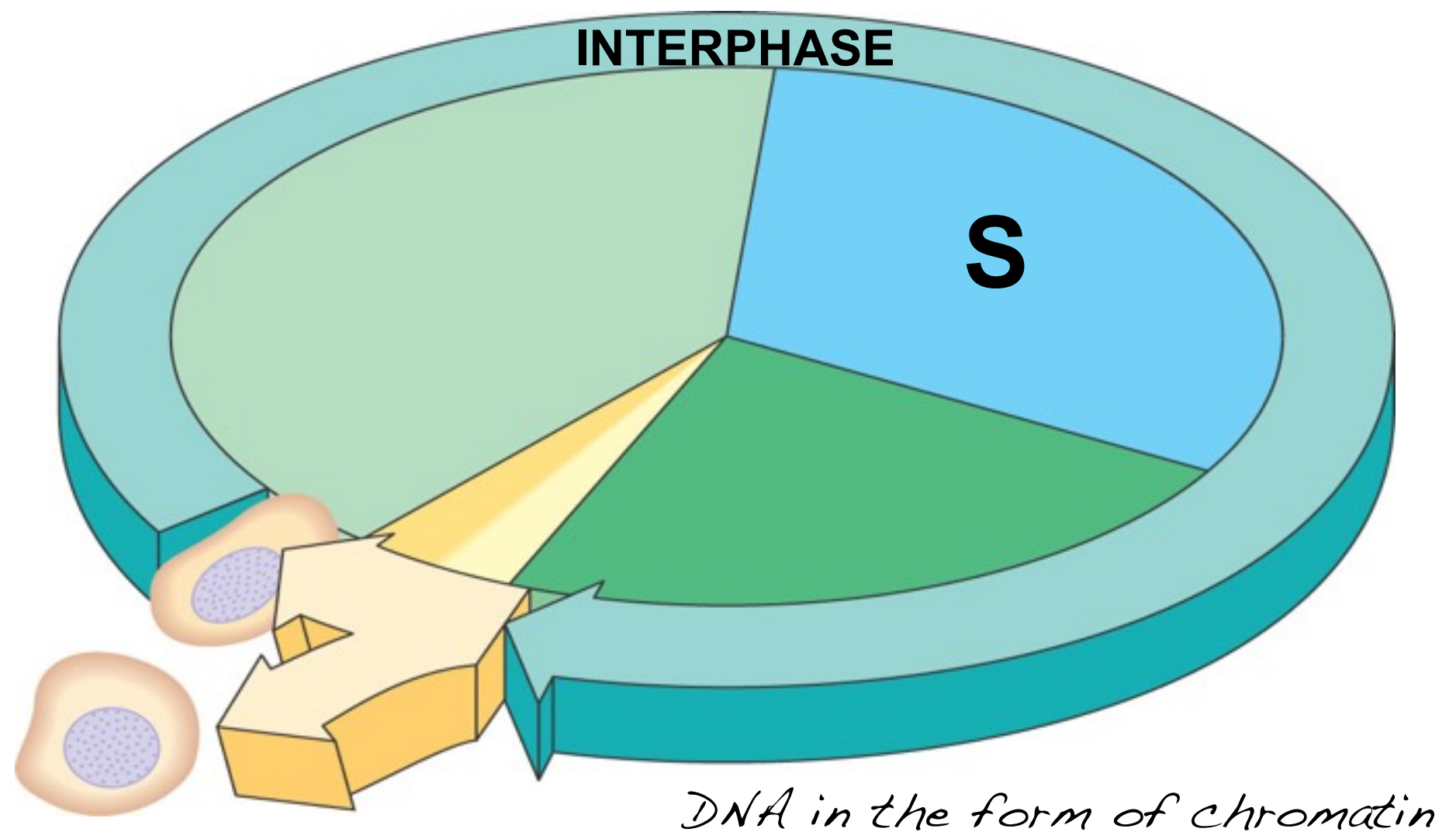
**~6 Hours**



# Interphase: S

- Anticipating and preparing for the next cell division...
- **DNA is replicated**
- And again cells continue to “do what they do”
- And they continue to grow

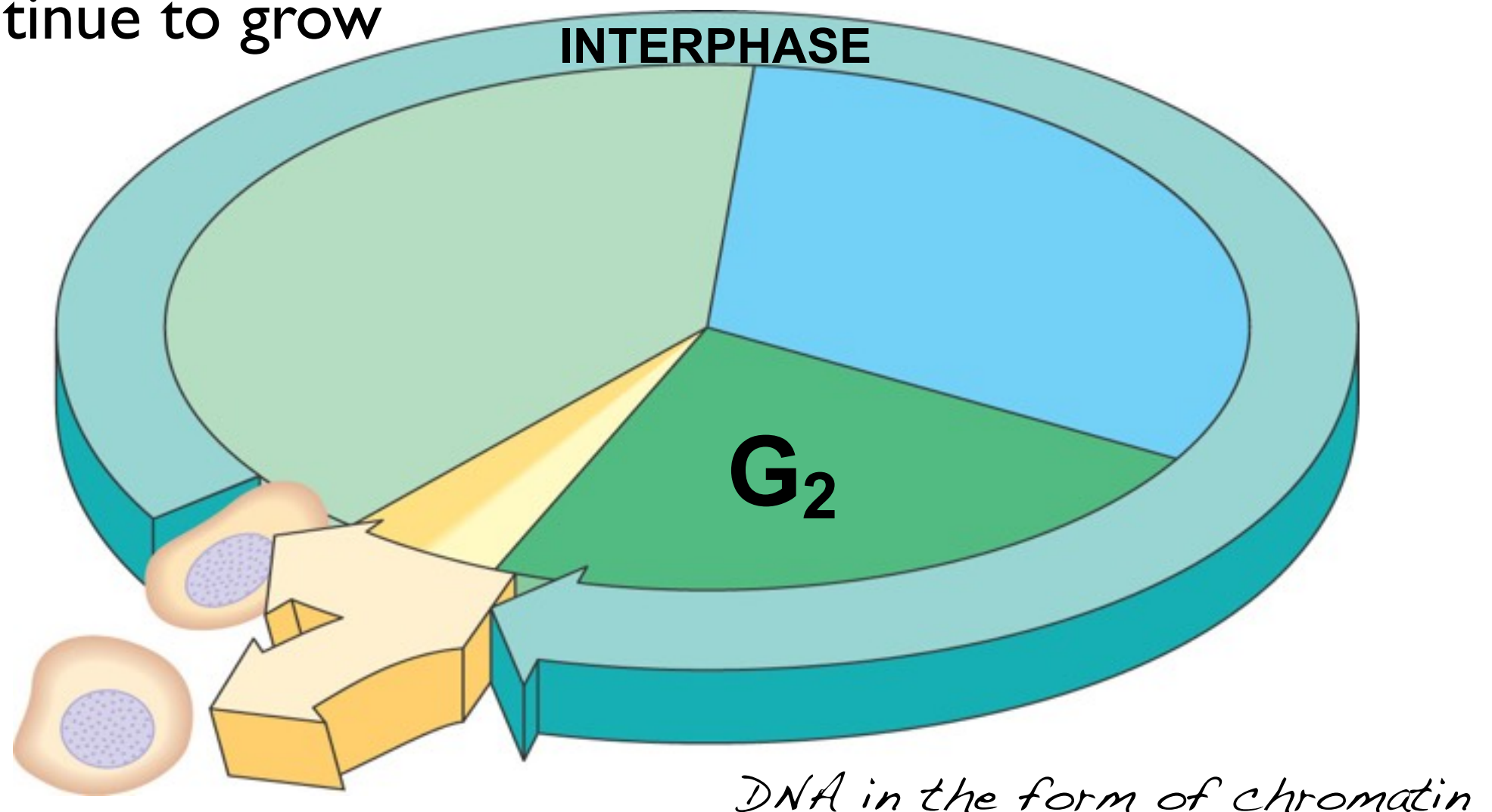
~ **11 Hours**



# Interphase: G<sub>2</sub>

- **Cells prepare for cell division.**
- **ex. at the end of G<sub>2</sub>, chromatin condenses into chromosomes**
- And again cells continue to “do what they do”
- They even continue to grow

**~6 Hours**

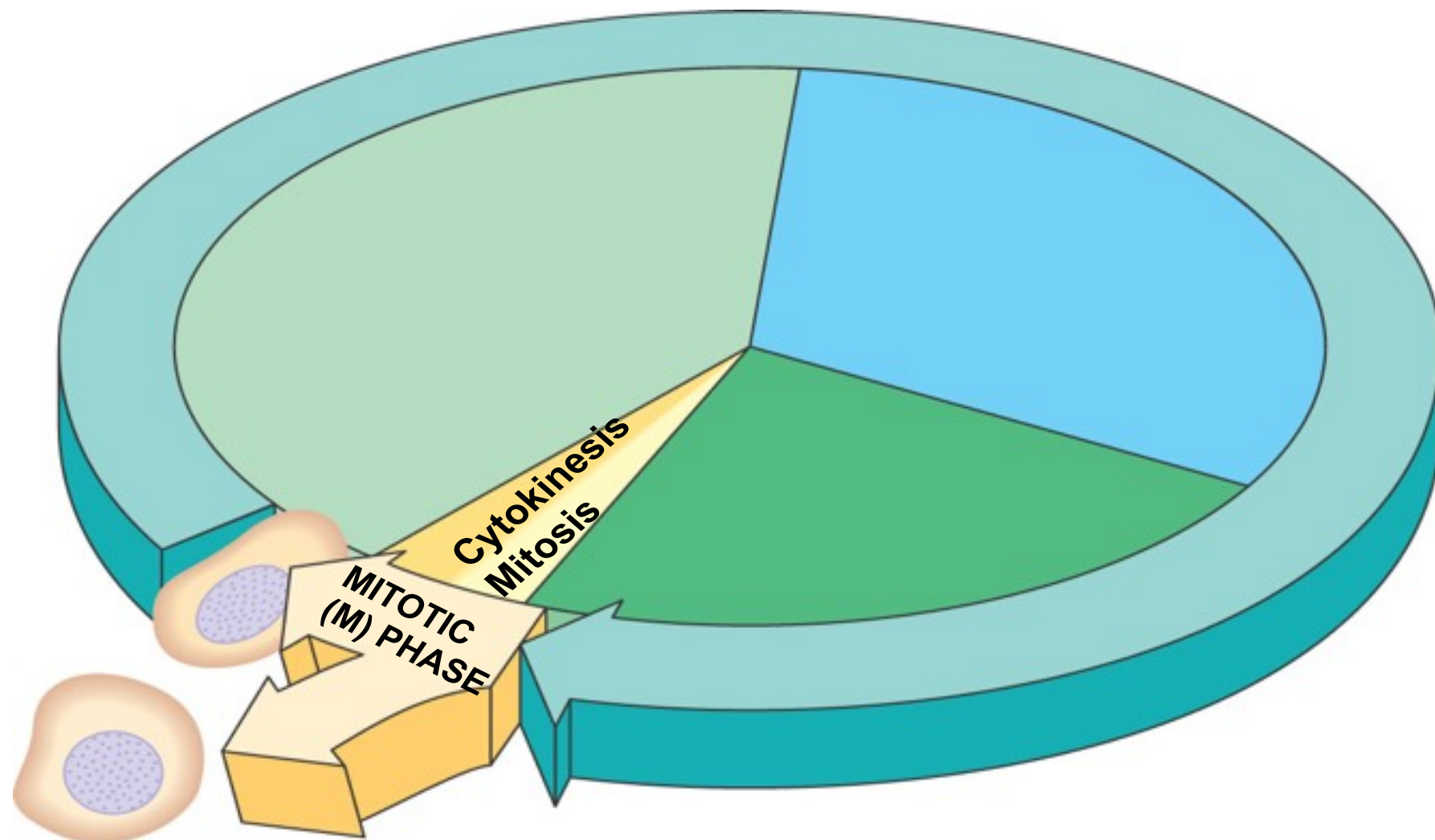




# Mitotic Phase: M

- The mitotic phase includes two divisional phases:
  - **Nuclear Division = Mitosis**
  - **Cytoplasmic Division = Cytokinesis**

**~ 1 Hour**

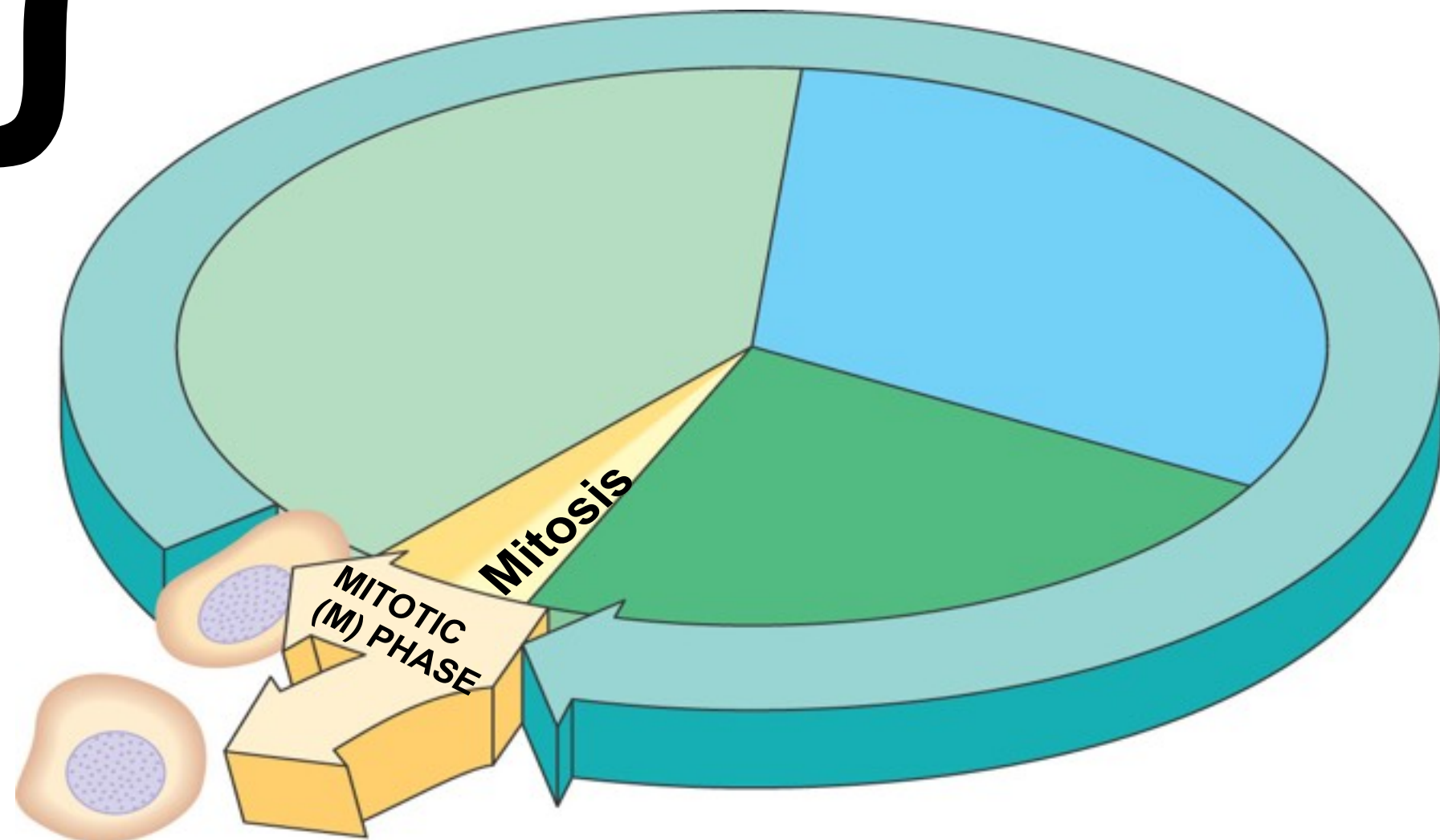


# Mitosis

- Mitosis is a fluid and dynamic process but to teach and better understand the process it is divided into 4 or more sub-phases:

- **Prophase**
- **Metaphase**
- **Anaphase**
- **Telophase**

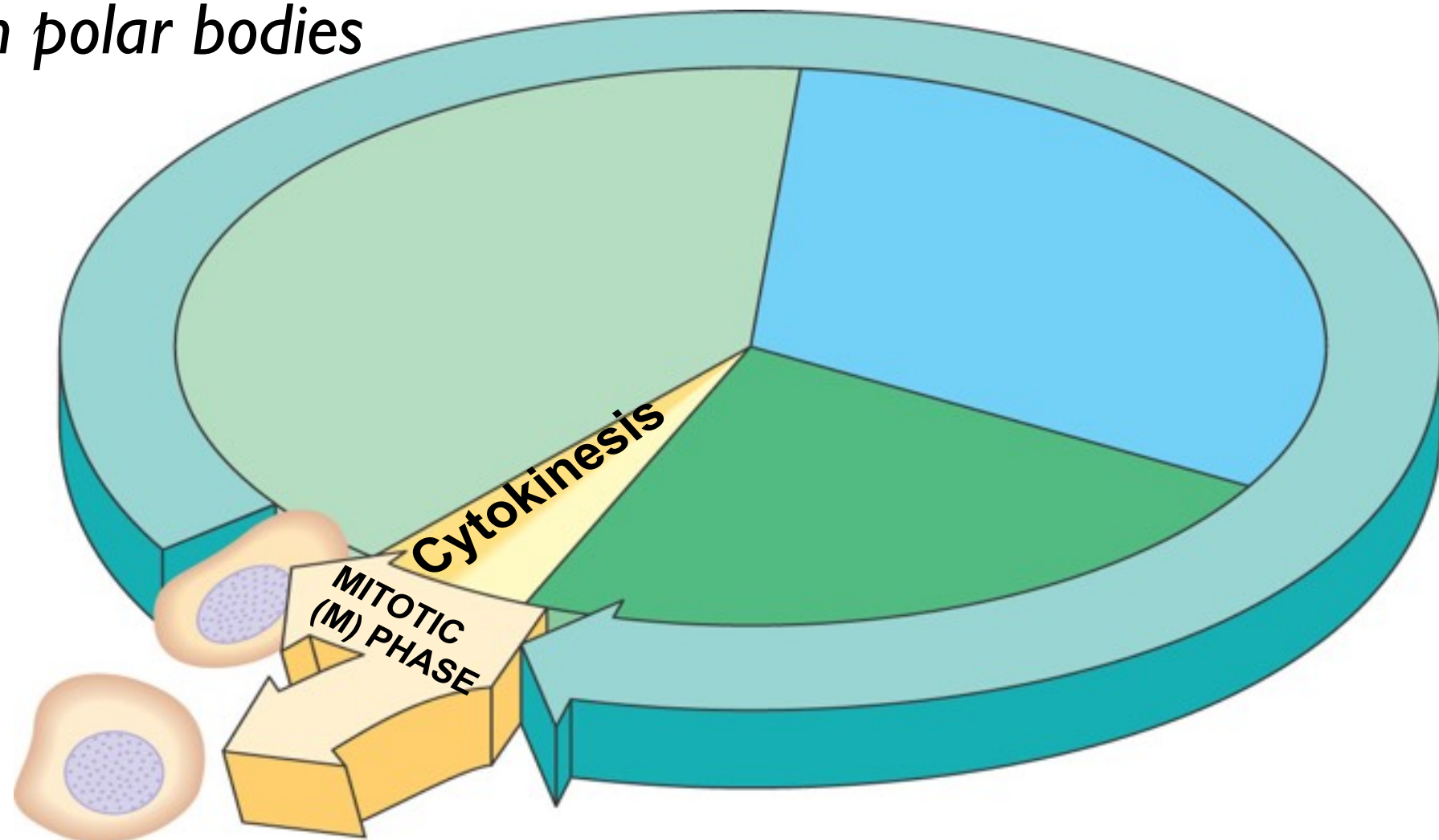
We will look these stages more closely in slides to follow



# Cytokinesis

- **Splits the cytoplasm into \*equal halves, creating 2 new daughter cells.**
- Cytokinesis begins while mitosis (telophase) is finishing.
- Differs in cells with and without cell walls.
  - *\*during the formation of ova in females there is an unequal split resulting in polar bodies*

We will look  
cytokinesis more  
closely in slides  
to follow



# A Cell's Biography

- **Interphase G<sub>1</sub>**

- cell grows
- organelles replicate
- carries out destined functions

- **Interphase S**

- replicates DNA
- replicates centrosomes
- cell grows
- organelles replicate
- carries out destined functions



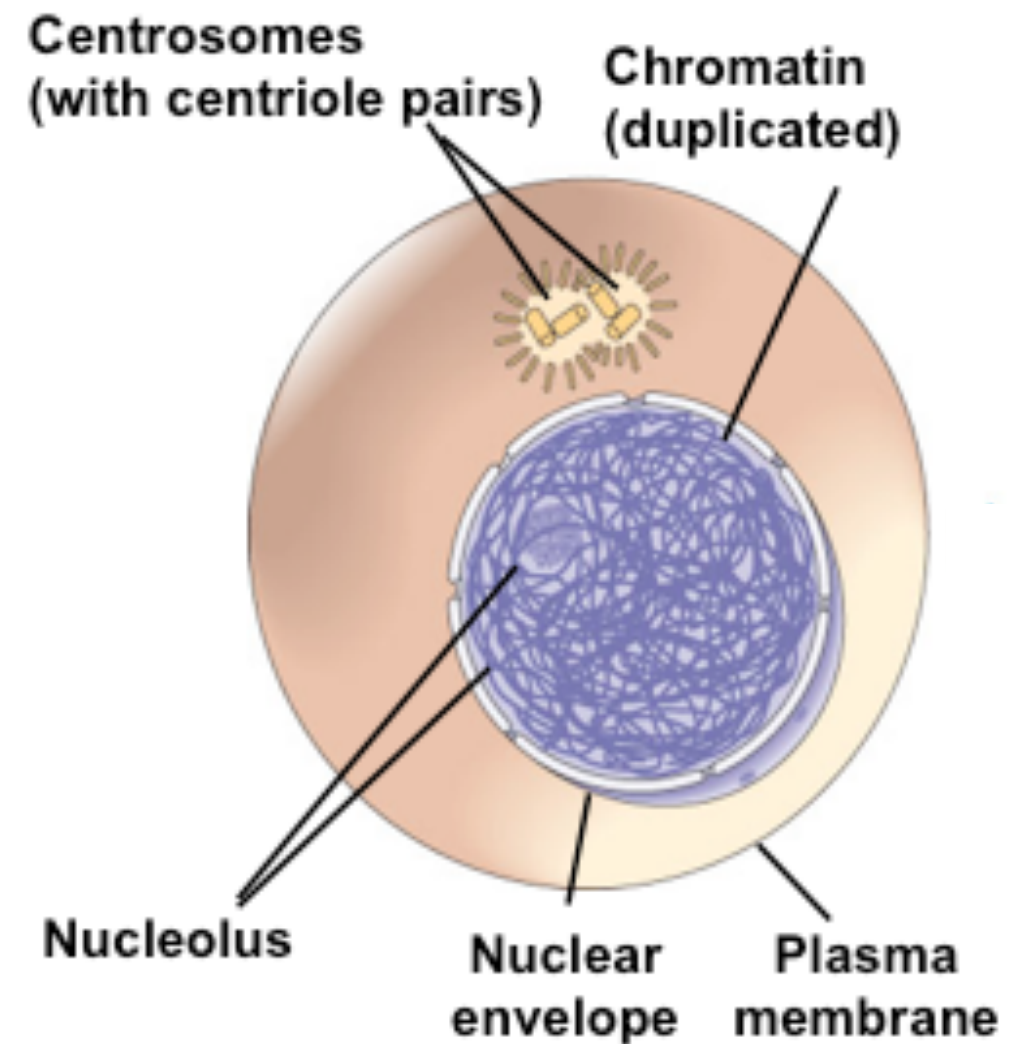
# A Cell's Biography

- **Interphase G<sub>2</sub>**

- cell grows
- organelles replicate
- carries out destined functions
- prepares for divisions
- condenses chromatin into chromosomes (at the very end of G<sub>2</sub> or start of prophase)

- **Mitosis (prophase)**

- Nuclear division



# The Cell Cycle

**Main Idea: The timing, rate and number of cell divisions in an organism is crucial to normal growth, development and maintenance.**



# Regulation of Cell Division

- For multicellular organisms to function properly cell division must be regulated and controlled, this includes
  - when cells divide
  - how fast they divide
  - how many times they will divide
- Consider the following cells...
  - once fully formed nerves and muscles NEVER divide
  - epithelial cells (skin) divide most of the time
  - liver cells only divide when they have to (if they are damaged)

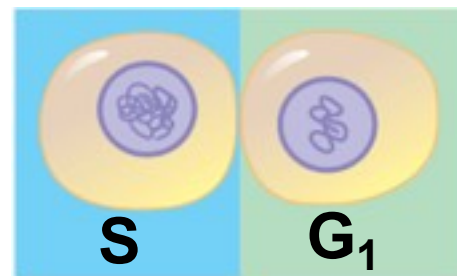
**But how?, How is this cell division regulated?**

# Evidence for Regulation

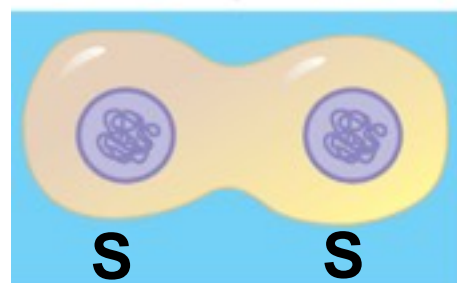
In each experiment, cultured mammalian cells at two different phases of the cell cycle were induced to fuse.

## EXPERIMENTS

Experiment 1

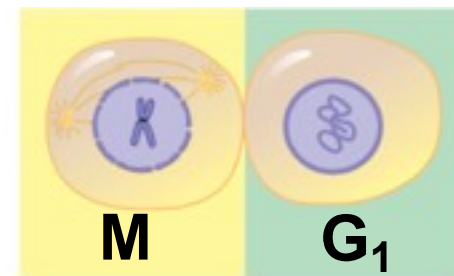


## RESULTS

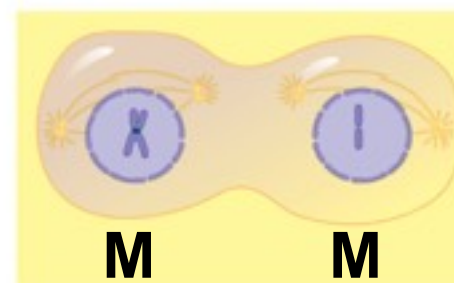


When a cell in the S phase was fused with a cell in  $G_1$ , the  $G_1$  cell immediately entered the S phase—DNA was synthesized.

Experiment 2



## RESULTS



When a cell in the M phase was fused with a cell in  $G_1$ , the  $G_1$  cell immediately began mitosis—a spindle formed and chromatin condensed, even though the

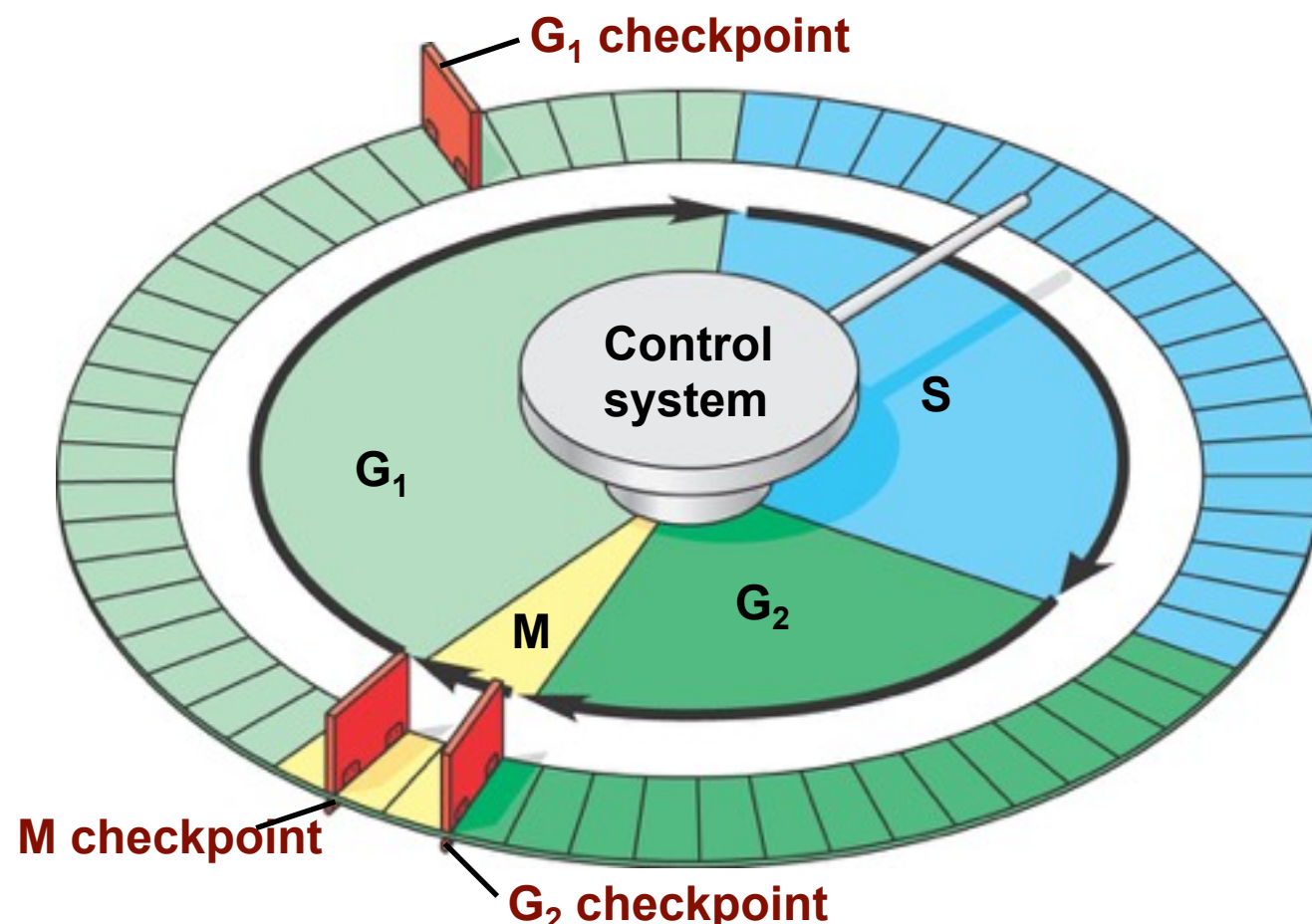
## CONCLUSION(S)

The results of fusing cells at two different phases of the cell cycle suggest that molecules present in the cytoplasm of cells in the S or M phase control the progression of phases.



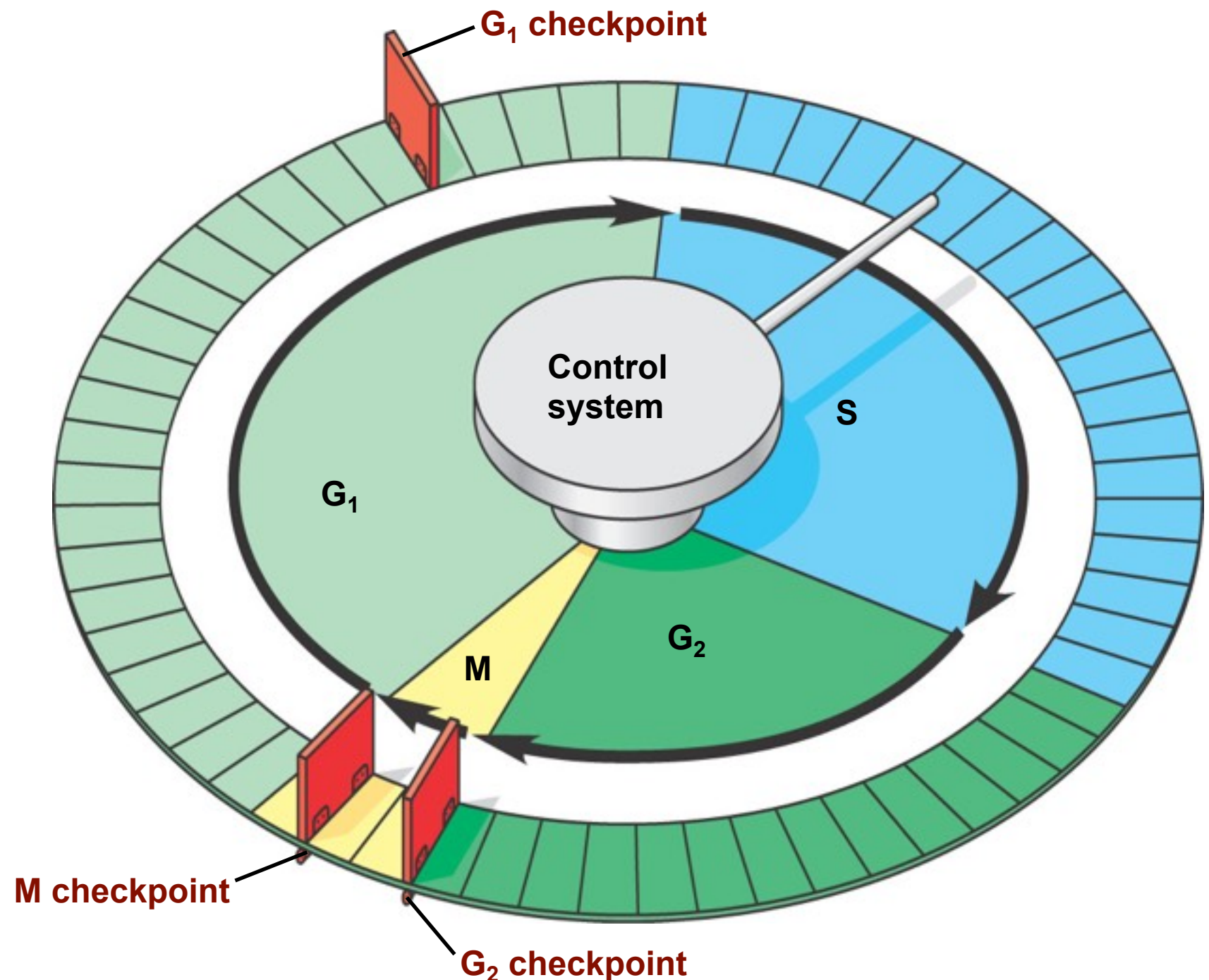
# Controlling the Cell Cycle

- **Cell Cycle Control System**- is a set of cyclical molecules that start and coordinate key sequential events in the cell cycle.
- Key **checkpoints** in the cell cycle stop the cycle at that point in the cycle.
- The cycle only continues if “Go” signals override the stop checkpoints.

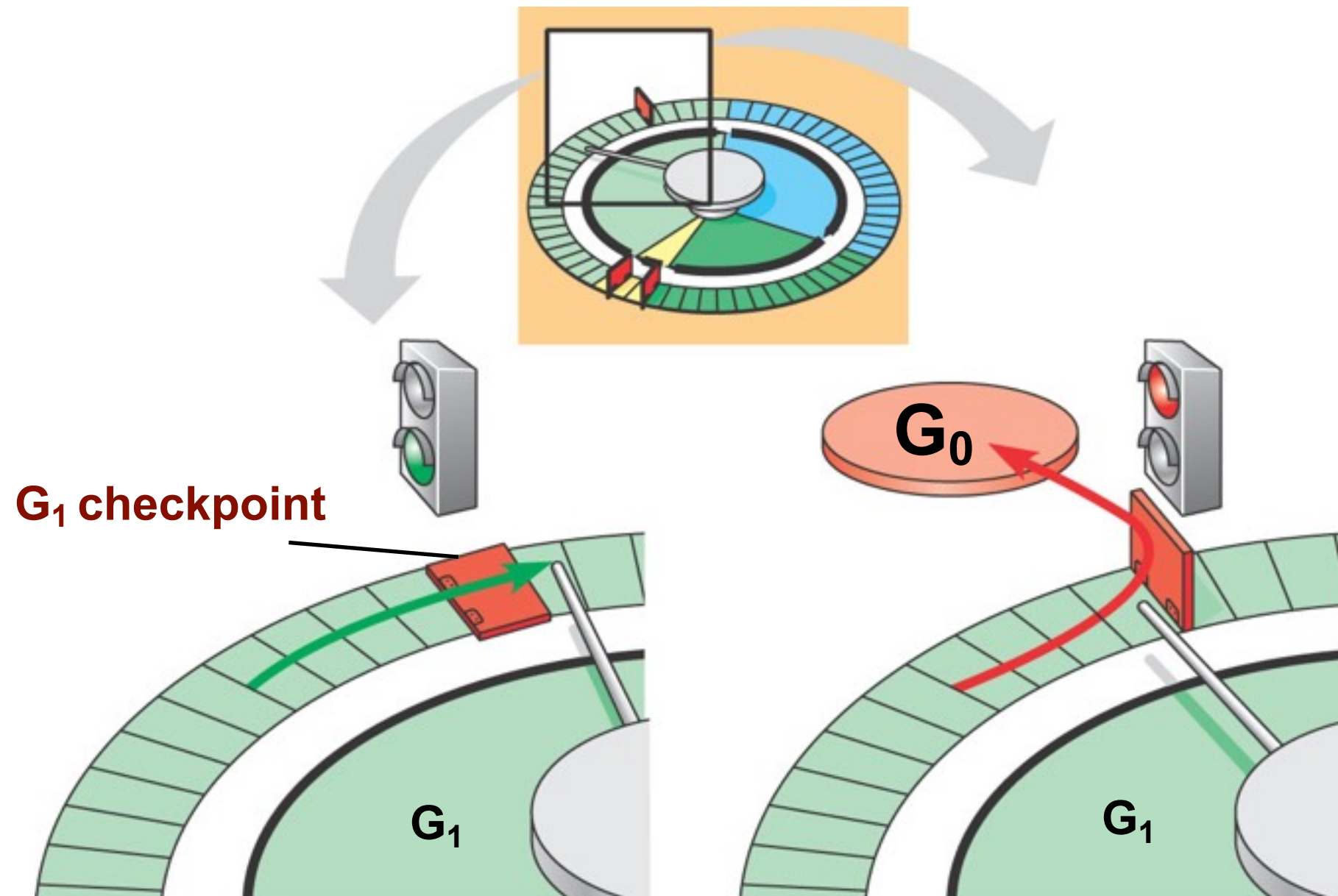


**These checkpoints can be regulated from internal mechanisms or from external signals.** *Think of washing machine that internally coordinates the different cycles but you can externally override the wash cycles by adjusting the dial as you choose.*

**The checkpoints allow the cell to make sure all crucial cellular processes that should have taken place, did indeed take place.**



**The  $G_1$  checkpoint appears to be the most important, when cells override this checkpoint almost all will continue through the entire cycle.**



**Most cells exist in the  $G_0$  state, the variability comes from the fact that some cells never leave the  $G_0$  state, some leave it only when necessary and yet some override the  $G_0$  state all the time.**

If a cell receives a go-ahead signal at the  $G_1$  checkpoint, the cell continues on in the cell cycle.

If a cell does not receive a go-ahead signal at the  $G_1$  checkpoint, the cell exits the cell cycle and goes into  $G_0$ , a nondividing state.



Essential knowledge 3.A.2: In eukaryotes, heritable information is passed to the next generation via processes that include the cell cycle and mitosis or meiosis plus fertilization.

To foster student understanding of this concept, instructors can choose an illustrative example such as:

- Mitosis-promoting factor (MPF)
- Action of platelet-derived growth factor (PDGF)
- Cancer results from disruptions in cell cycle control

3. Cyclins and cyclin-dependent kinases control the cell cycle.

**XX** Knowledge of any one cyclin-CdK pair or growth factor is beyond the scope of the course and the AP Exam.

4. Mitosis alternates with interphase in the cell cycle.

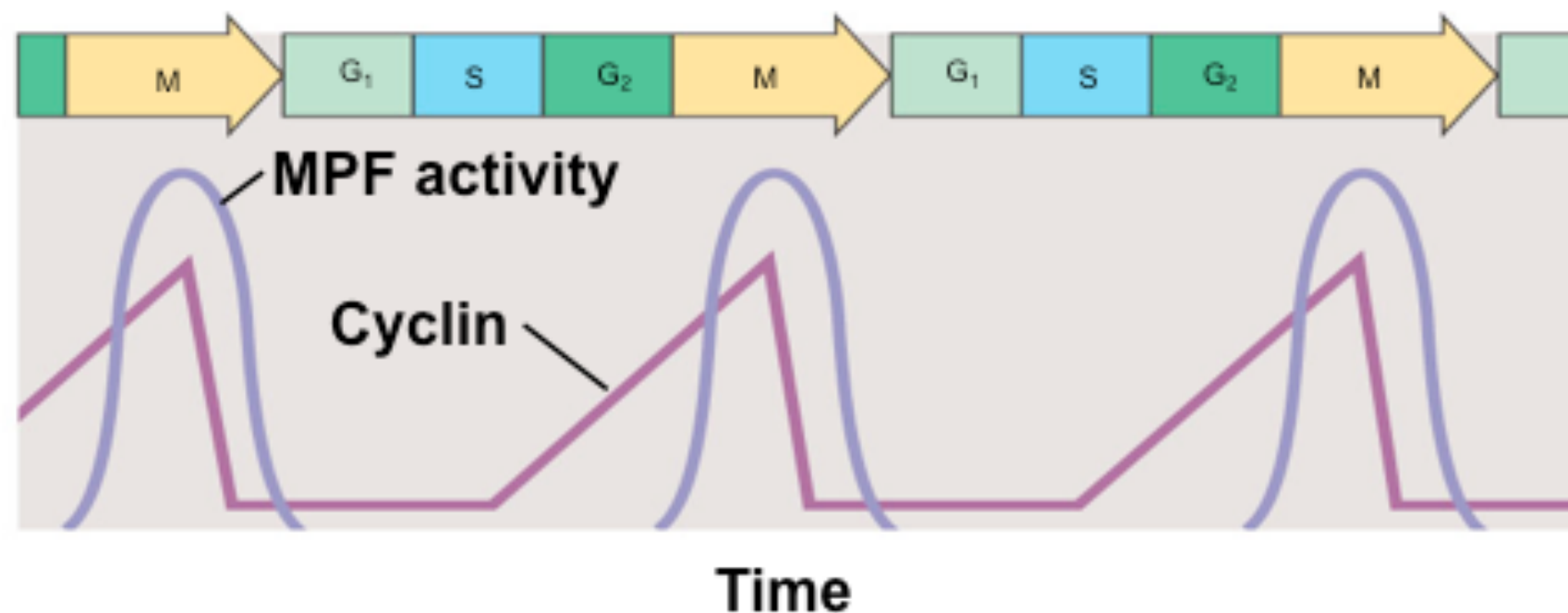
5. When a cell specializes, it often enters into a stage where it no longer divides, but it can reenter the cell cycle when given appropriate cues.

Nondividing cells may exit the cell cycle; or hold at a particular stage in the cell cycle.



# A Closer Look at Cell Cycle Control

- *Cell Cycle Control System*- specifically involves the fluctuations in the amount and activity of certain regulatory molecules that “pace” sequential events in the cell.
- These regulatory molecules are primarily **Kinases** and **Cyclins**.

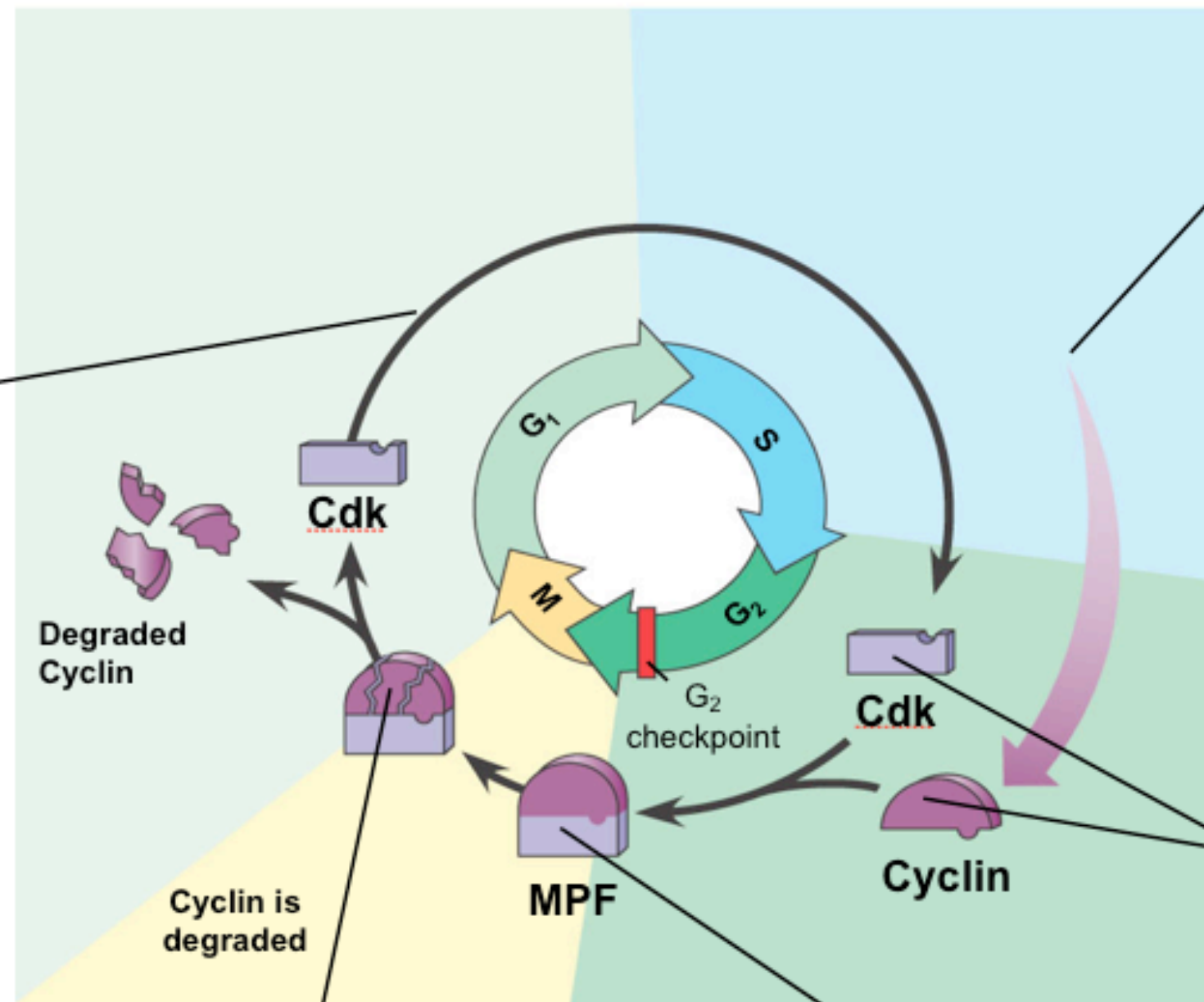


*MPF is the specific kinase in the active form*

# *MPF- maturation-promoting factor made of both cyclin and kinase*

*Cdk- is a cyclin dependent kinase*

**5.**  
During  $G_1$ , conditions in the cell favor degradation of cyclin, and the Cdk component of MPF is recycled.



**1.**

Synthesis of cyclin begins in late S phase and continues through  $G_2$ . Because cyclin is protected from degradation during this stage, it accumulates.

**2.**

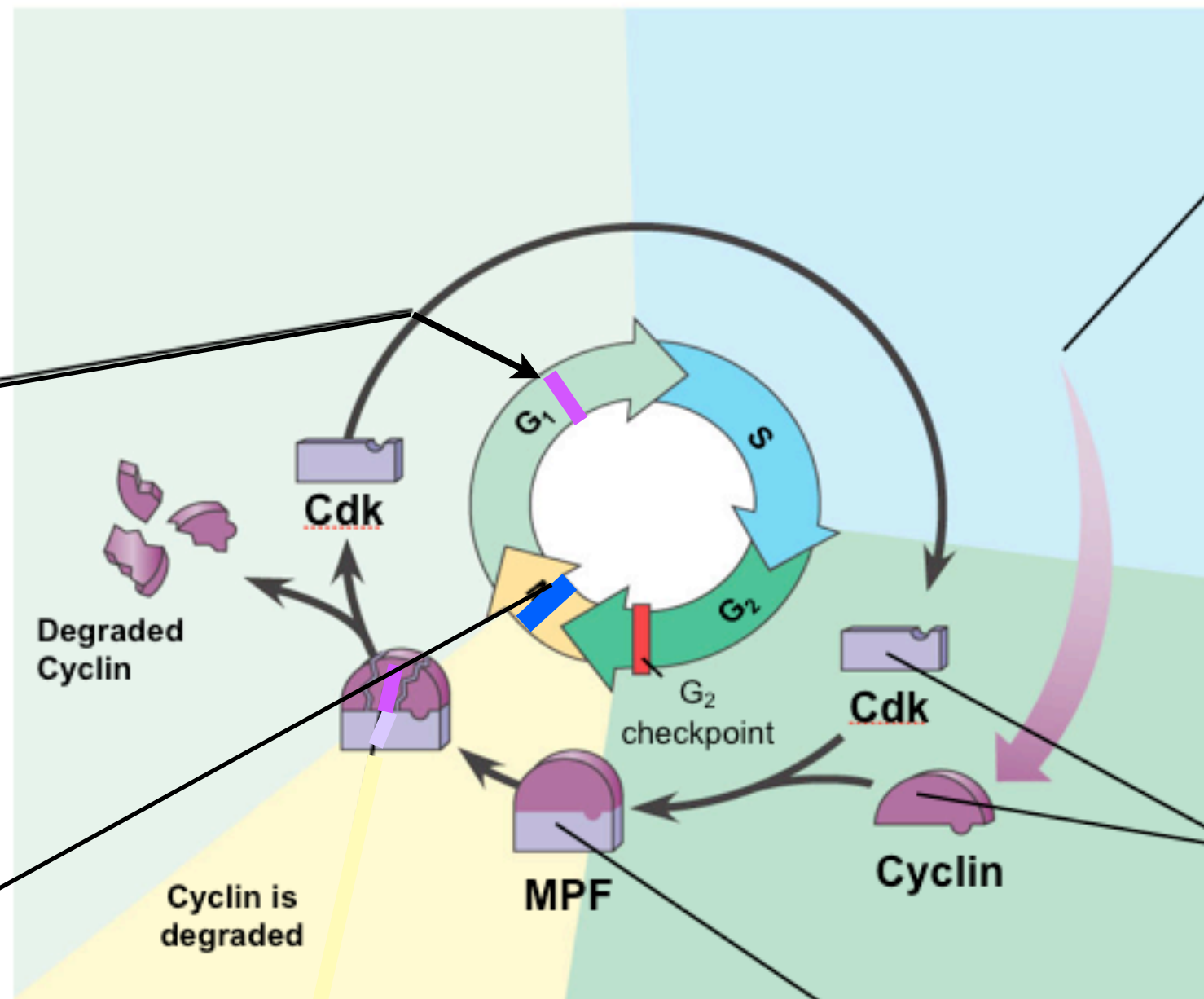
Accumulated cyclin molecules combine with recycled Cdk molecules, producing enough molecules of MPF to pass the  $G_2$  checkpoint and initiate the events of mitosis.

**4.** During anaphase, the cyclin component of MPF is degraded, terminating the M phase. The cell enters the  $G_1$  phase.

**3.** MPF promotes mitosis by phosphorylating various proteins. MPF's activity peaks during metaphase.

# Additional Points

The G<sub>1</sub> checkpoint is controlled a very similar manner using multiple Cdk's and cyclins.



Cyclin is always active but its concentration fluctuates.

Cdk is actually always present, its activity fluctuates.

M checkpoint occurs in anaphase using unique regulatory proteins. All spindles must attach to kinetochores before the “go” signal activates *seperase* which cuts cohesin proteins and pulls apart the sister chromatids

MPF also initiates the catabolism of the nuclear membrane and the condensation of chromatin into chromosomes.

# External Signals

- Recall that *Cell Cycle Control Systems* can be regulated internally as well as externally.
- The  $G_1$ ,  $G_2$ , and M checkpoints described at the last couple slides are involve internally regulated mechanisms.
- Three examples of externally regulated *Cell Cycle Control Systems* include **platelet derived growth factors (PDGF's)**, **density-dependent inhibition**, and **anchorage dependence**.
  - PDGF's stimulate cell division
  - While D.D.I and A.D. inhibit cell division



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What kind of receptor do PDGF's bind to?

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What kind of receptor do PDGF's bind to?

Tyrosine  
Kinase  
Receptors

# Platelet Derived Growth Factors

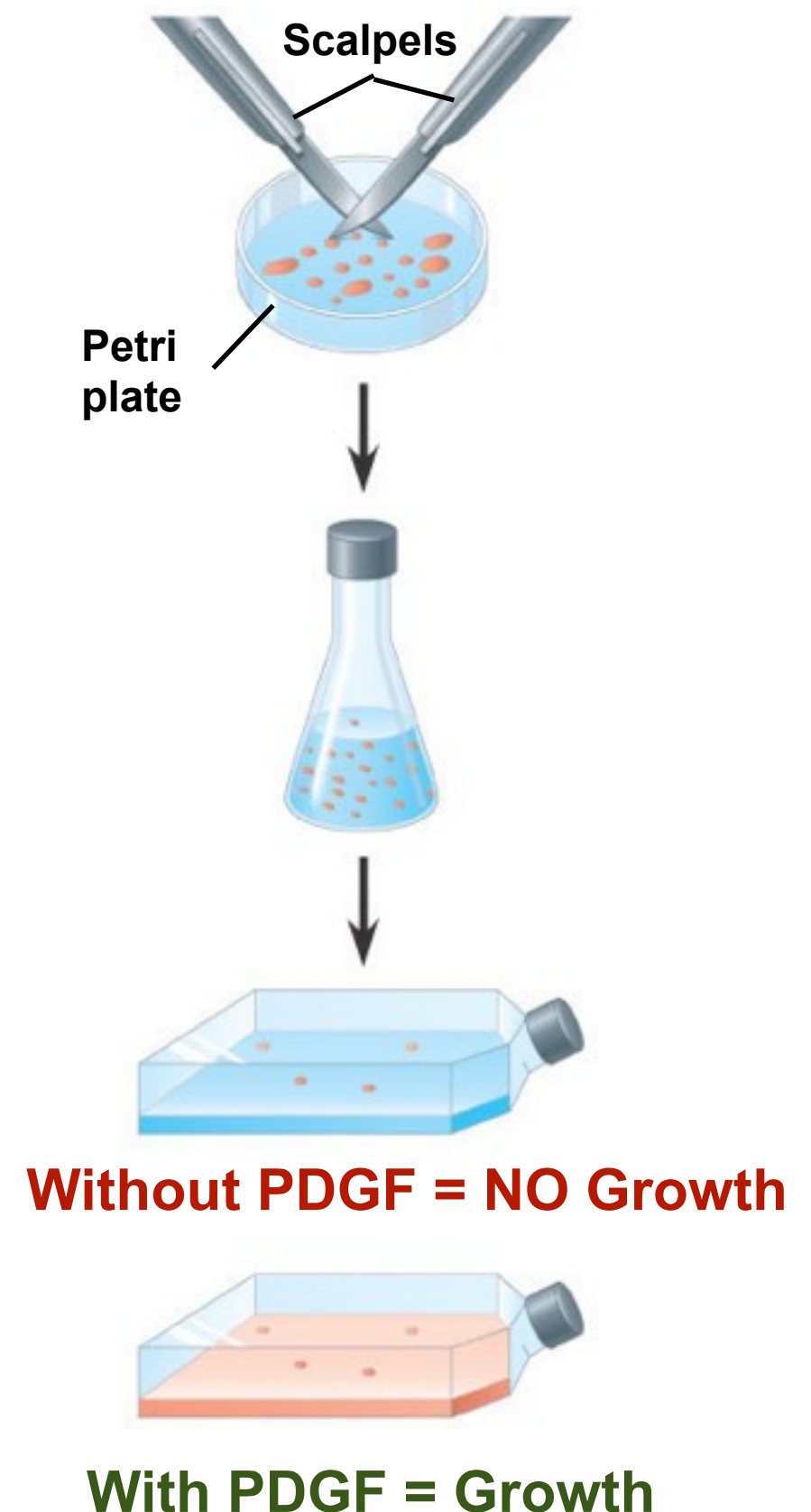
## EXPERIMENT

A sample of connective tissue was cut up into small pieces.

Enzymes were used to digest the extracellular matrix, resulting in a suspension of free fibroblast cells.

Cells were transferred to sterile culture vessels containing a basic growth medium consisting of glucose, amino acids, salts, and antibiotics (as a precaution against bacterial growth).

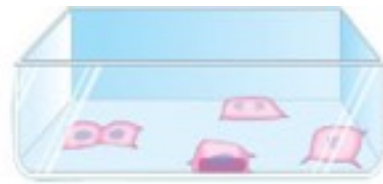
PDGF was added to half the vessels. The culture vessels were incubated at 37°C.



# Density-Dependent Inhibition & Anchorage Dependence

Many cells exhibit A.D., they must be attached to other cells or a surface of some kind in order to reproduce.

**Normal mammalian cells.**  
The availability of nutrients, growth factors, and a substratum for attachment limits cell density to a single layer.



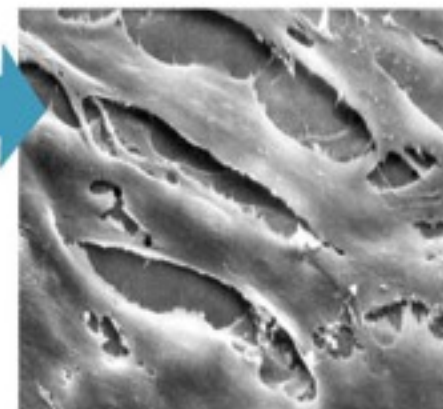
Cells anchor to dish surface and divide (anchorage dependence).



When cells have formed a complete single layer, they stop dividing (density-dependent inhibition).



If some cells are scraped away, the remaining cells divide to fill the gap and then stop (density-dependent inhibition).



25  $\mu\text{m}$

# Anchorage Dependence

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- The  $G_1$ ,  $G_2$ , and M checkpoints described at the last couple slides are involve internally regulated mechanisms.
- Three examples of externally regulated *Cell Cycle Control Systems* include **platelet derived growth factors (PDGF's)**, **density-dependent inhibition**, and **anchorage dependence**.
  - PDGF's stimulate cell division
  - While D.D.I and A.D. inhibit cell division



Essential knowledge 3.A.2: In eukaryotes, heritable information is passed to the next generation via processes that include the cell cycle and mitosis or meiosis plus fertilization.

b. Mitosis passes a complete genome from the parent cell to daughter cells.

Evidence of student learning is a demonstrated understanding of each of the following:

1. Mitosis occurs after DNA replication.
2. Mitosis followed by cytokinesis produces two genetically identical daughter cells.
3. Mitosis plays a role in growth, repair, and asexual reproduction
4. Mitosis is a continuous process with observable structural features along the mitotic process.

Evidence of student learning is demonstrated by knowing the order of the processes (replication, alignment, separation).

**XX** Memorization of the names of the phases of mitosis is beyond the scope of the course and the AP Exam.

# A Cell's Biography

- **Interphase G<sub>1</sub>**

- cell grows
- organelles replicate
- carries out destined functions

- **Interphase S**

- replicates DNA
- replicates centrosomes
- cell grows
- organelles replicate
- carries out destined functions

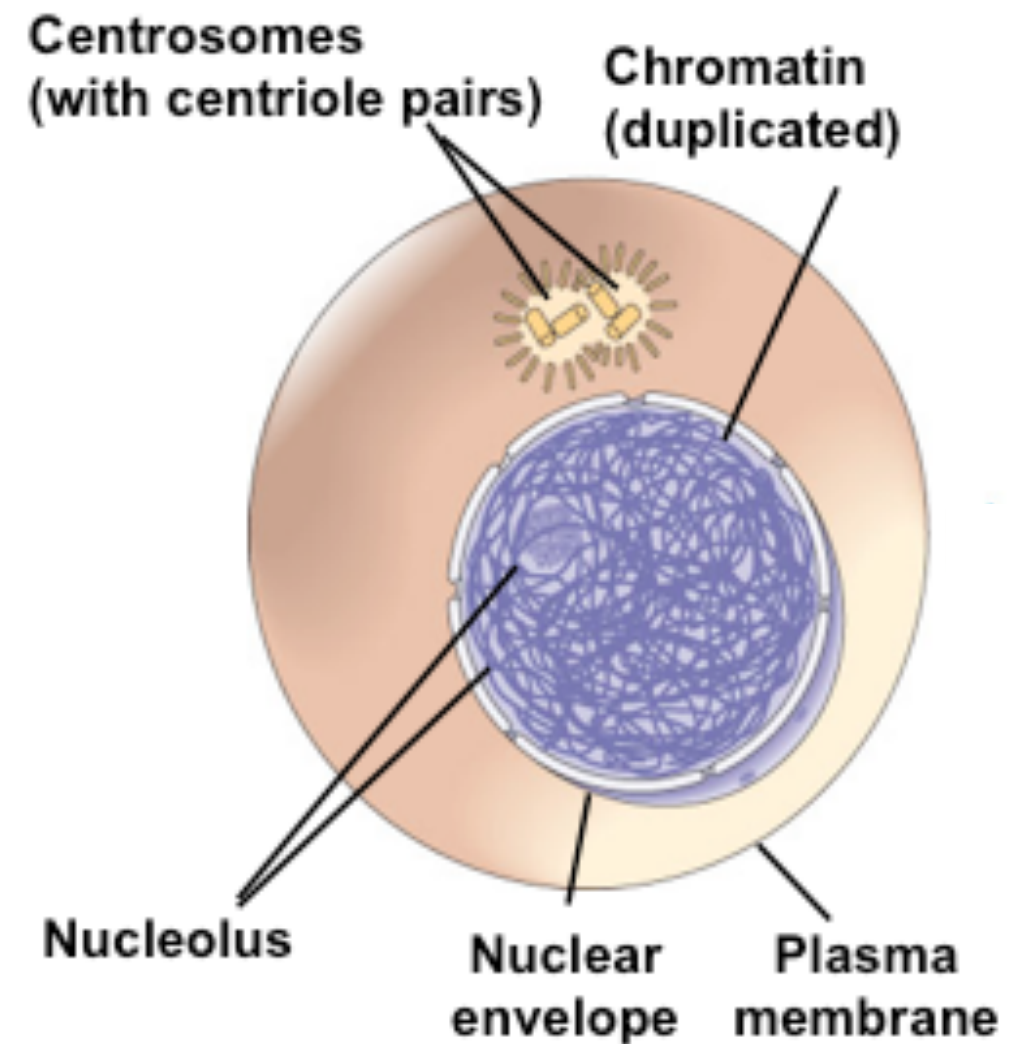
# A Cell's Biography

- **Interphase G<sub>2</sub>**

- cell grows
- organelles replicate
- carries out destined functions
- prepares for divisions
- condenses chromatin into chromosomes (at the very end of G<sub>2</sub> or start of prophase)

- **Mitosis (prophase)**

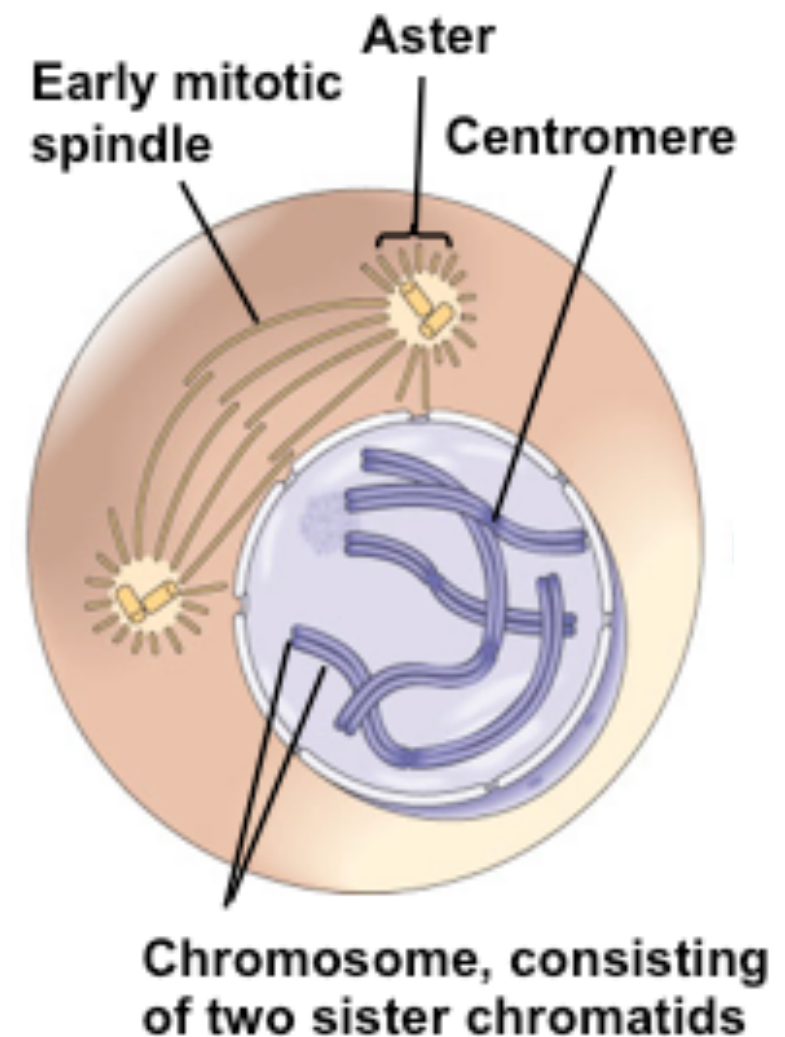
- chromatin condensed into chromosomes (by start of prophase)



# A Cell's Biography

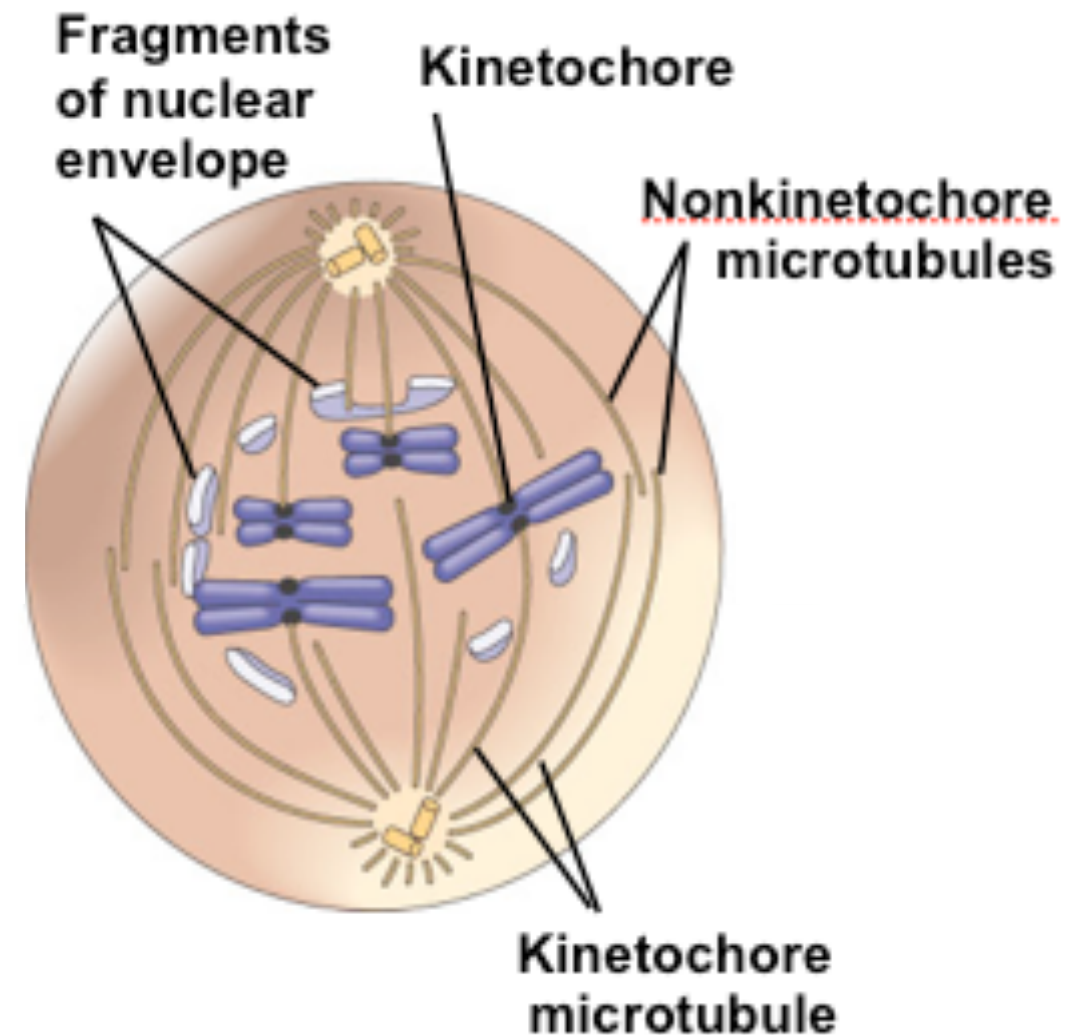
- **Mitosis (prophase)**

- nucleoli disappear
- sister chromatids joined at centromeres and visible
- mitotic spindle forms
  - *made of centrosomes and microtubules*
- mitotic spindle begins moving the opposite poles
- nuclear envelope begins to fragment



# A Cell's Biography

- **Mitosis (prometaphase)**
  - nuclear envelope continues to fragment
  - microtubules starting to reach nuclear area
  - chromosomes continue to condense
  - each sister chromatid now has a kinetochore
  - microtubules begin attaching to the kinetochores
  - other microtubules overlap each other

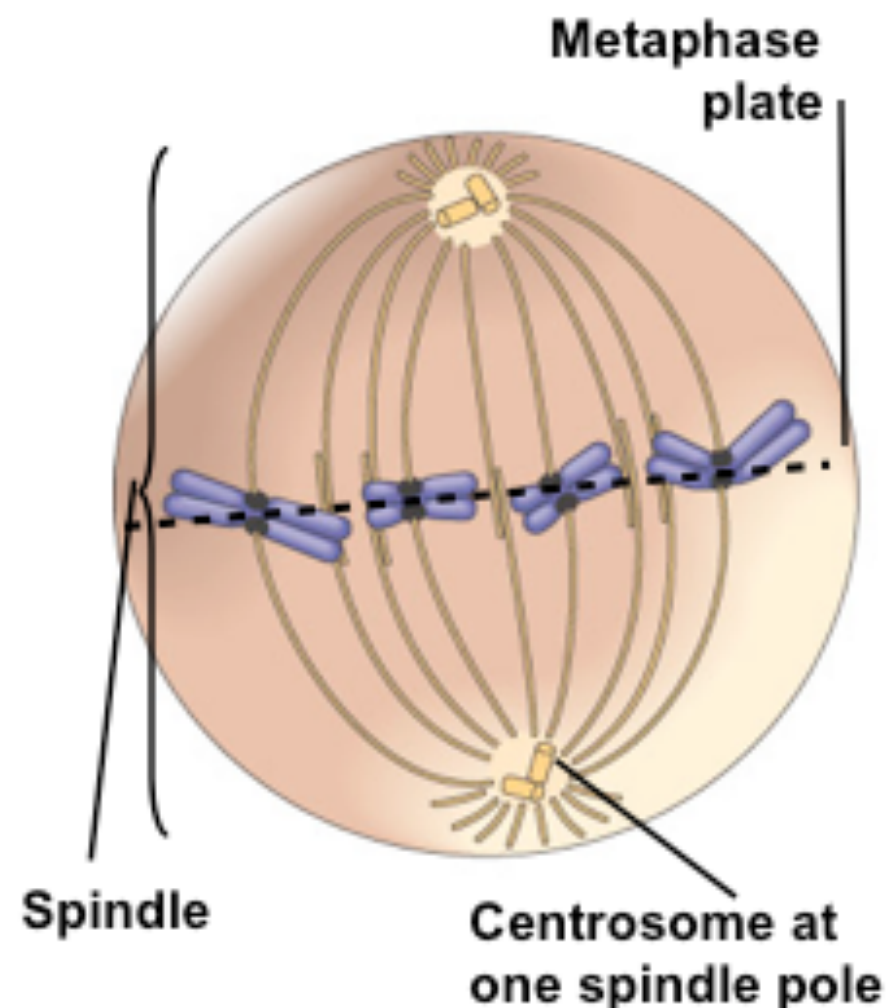




# A Cell's Biography

- **Mitosis (metaphase)**

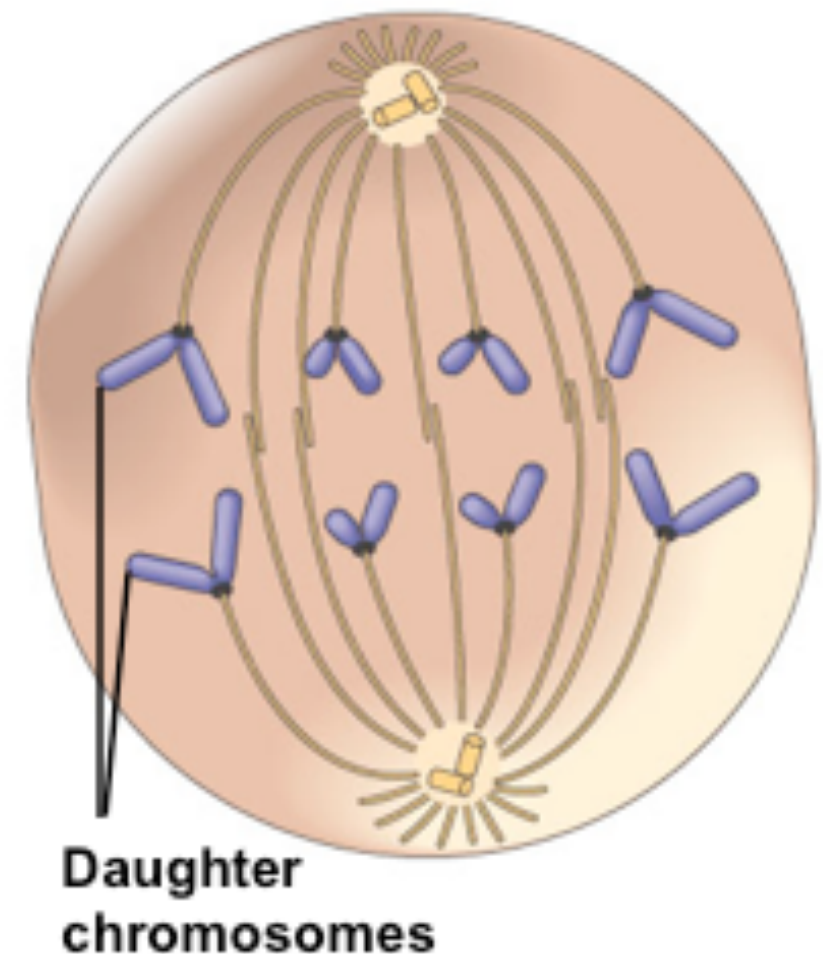
- centrosomes are now at cell's poles
- chromosomes are aligned at the cell's center
- all kinetochores are attached to microtubules



# A Cell's Biography

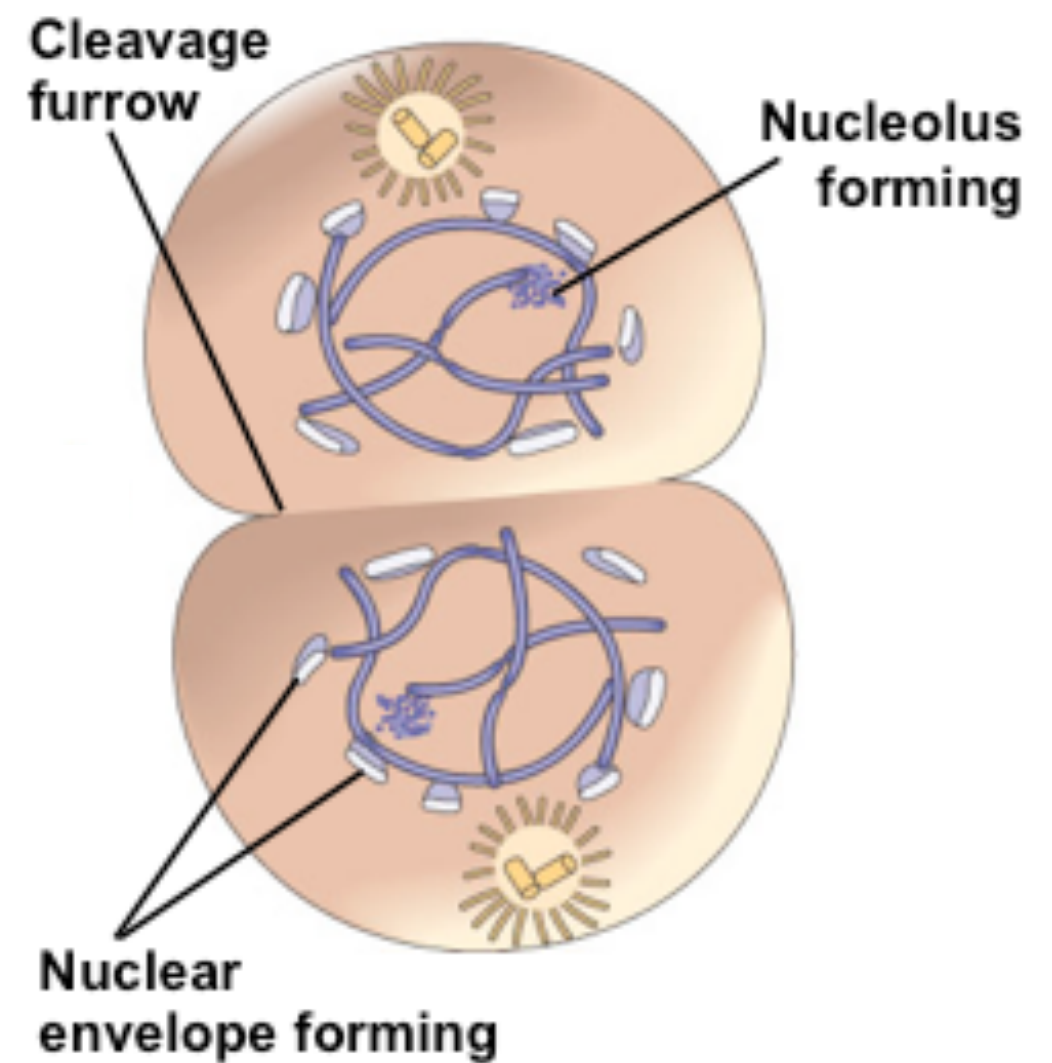
- **Mitosis (anaphase)**

- cohesin proteins cleave and sister chromatids separate
- kinetochore microtubules shorten
- chromosomes migrate away from each other move closer to the poles
- nonkinetochores microtubules lengthen and elongate cell
- each end of the cell have equivalent and complete collection of chromosomes



# A Cell's Biography

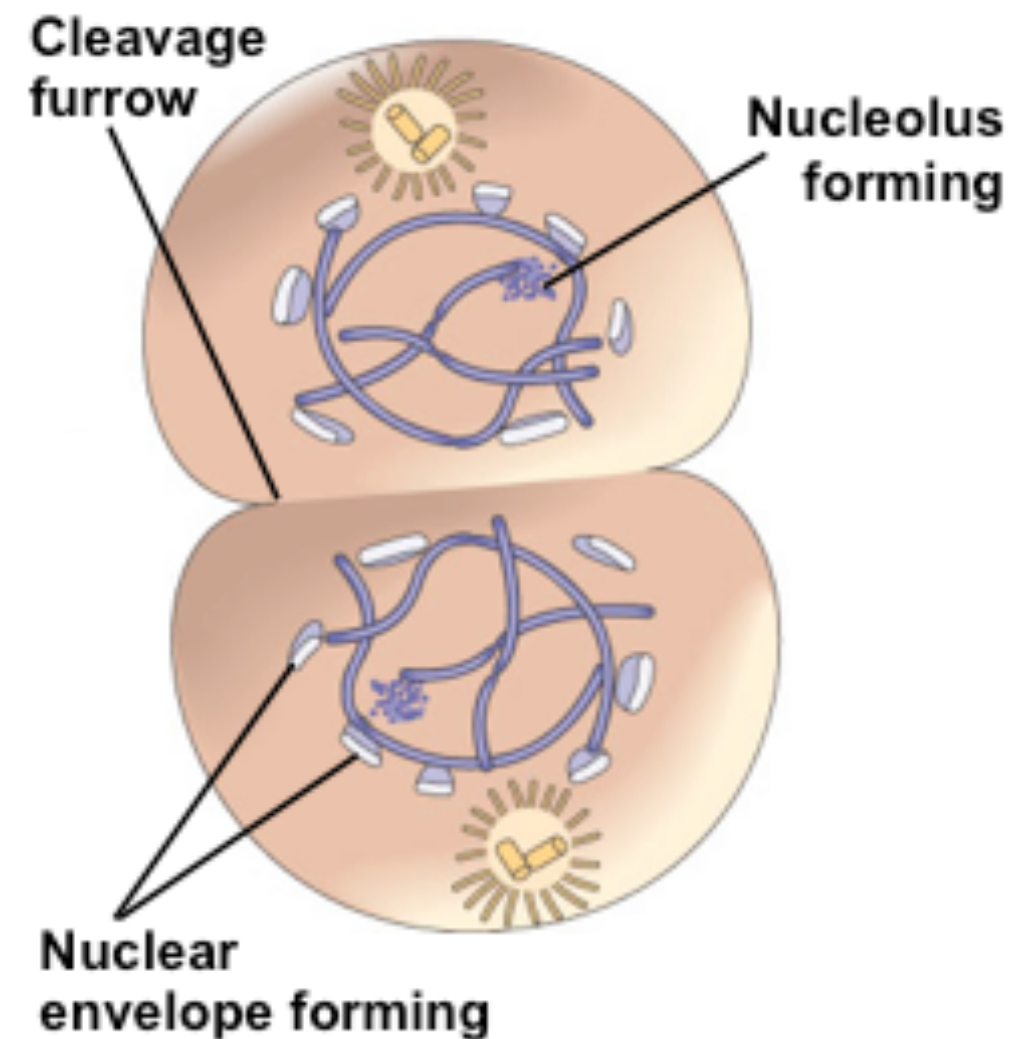
- **Mitosis (telophase)**
  - nuclear envelope begins to form
  - nucleolus begins to form
  - chromosomes begin to unravel into chromatin
  - all microtubules are starting to depolymerize
  - nuclear envelope are intact and chromatin is most abundant



# A Cell's Biography

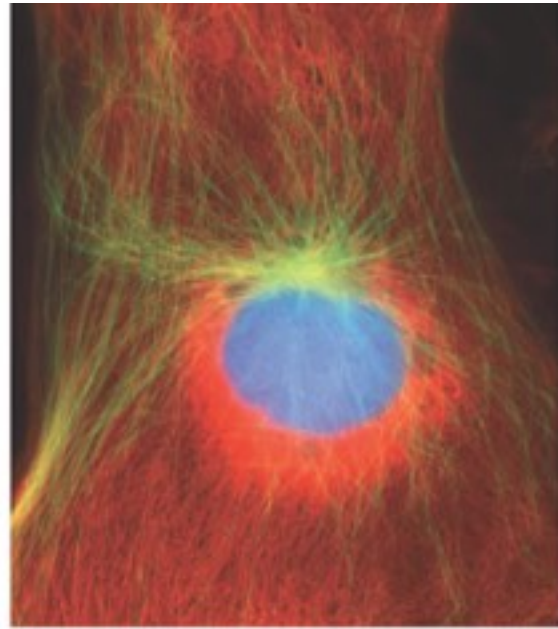
- **Cytokinesis**

- cell begins to pinch in half (animals) before mitosis is done
- cell begins to grow new cell wall (plants) through the middle of the cell even before mitosis is done

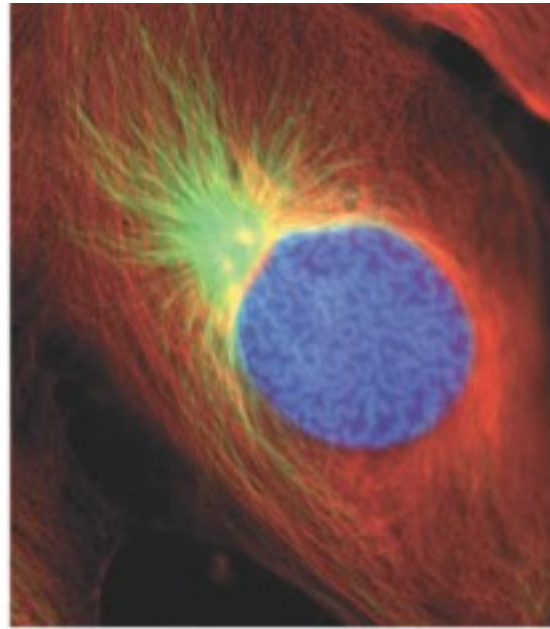




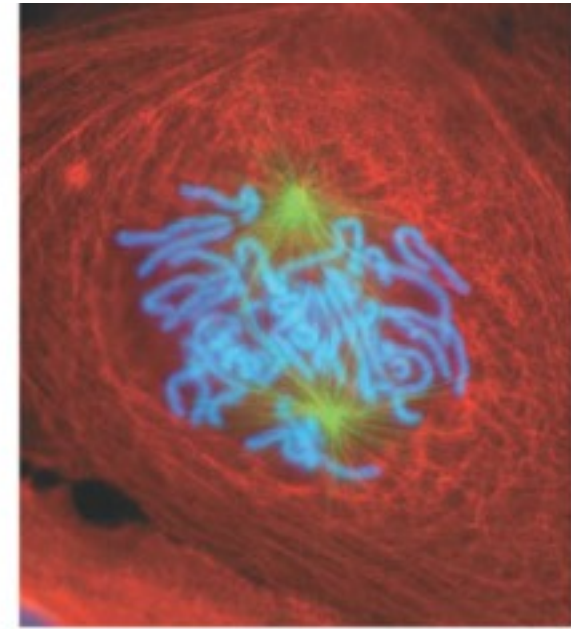
# Visual Tour of Mitosis



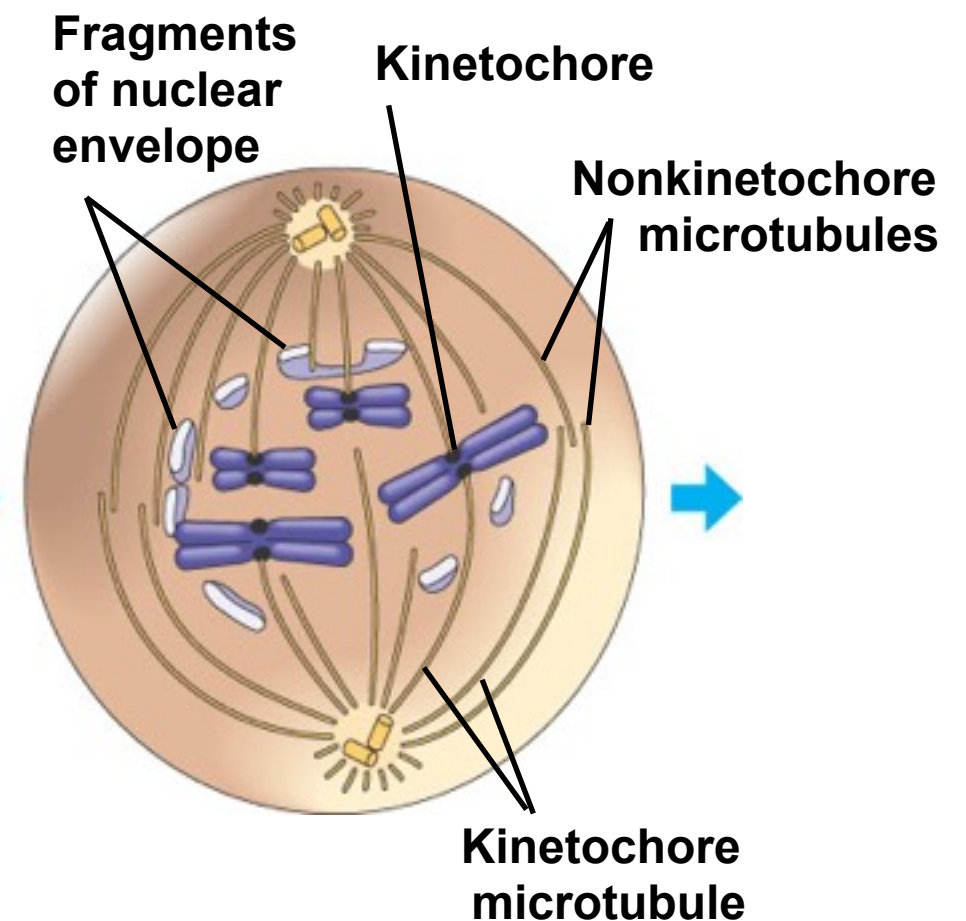
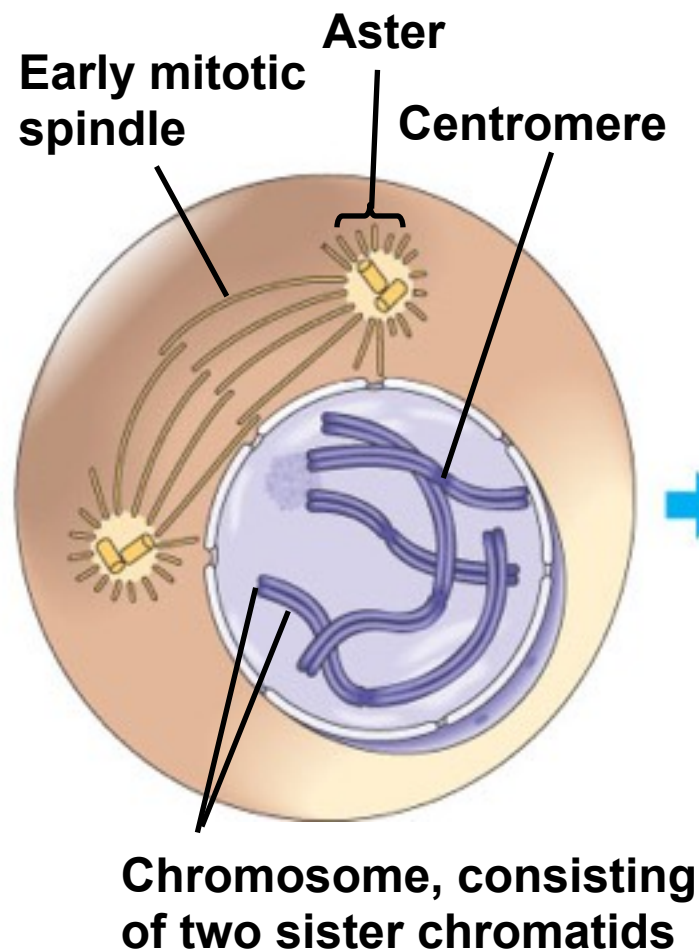
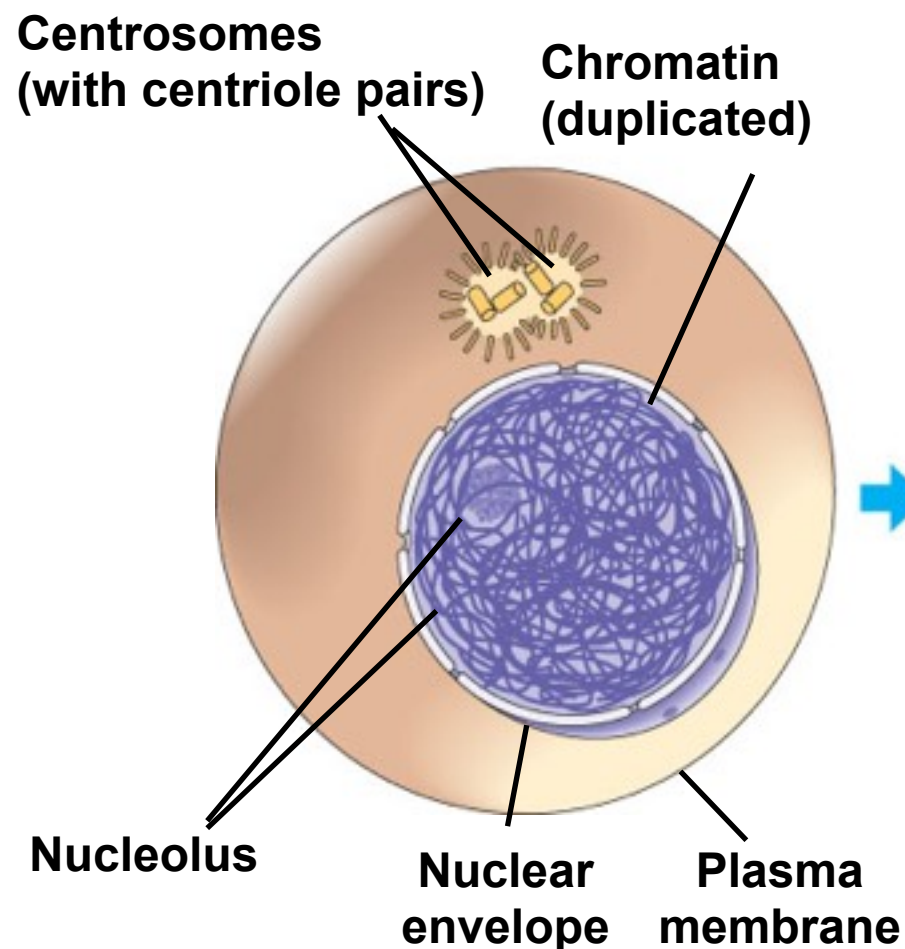
**G<sub>2</sub> OF INTERPHASE**



**PROPHASE**

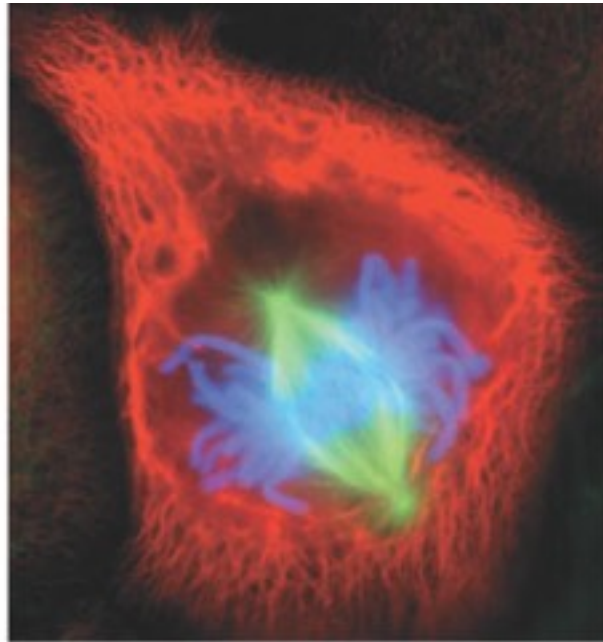


**PROMETAPHASE**

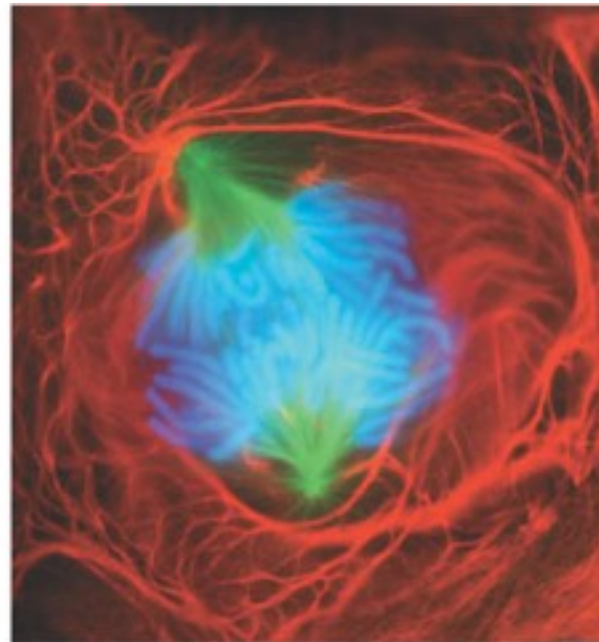




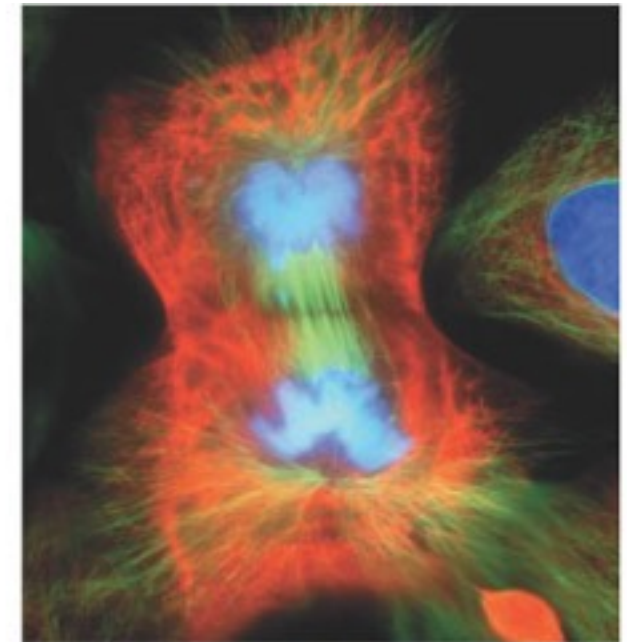
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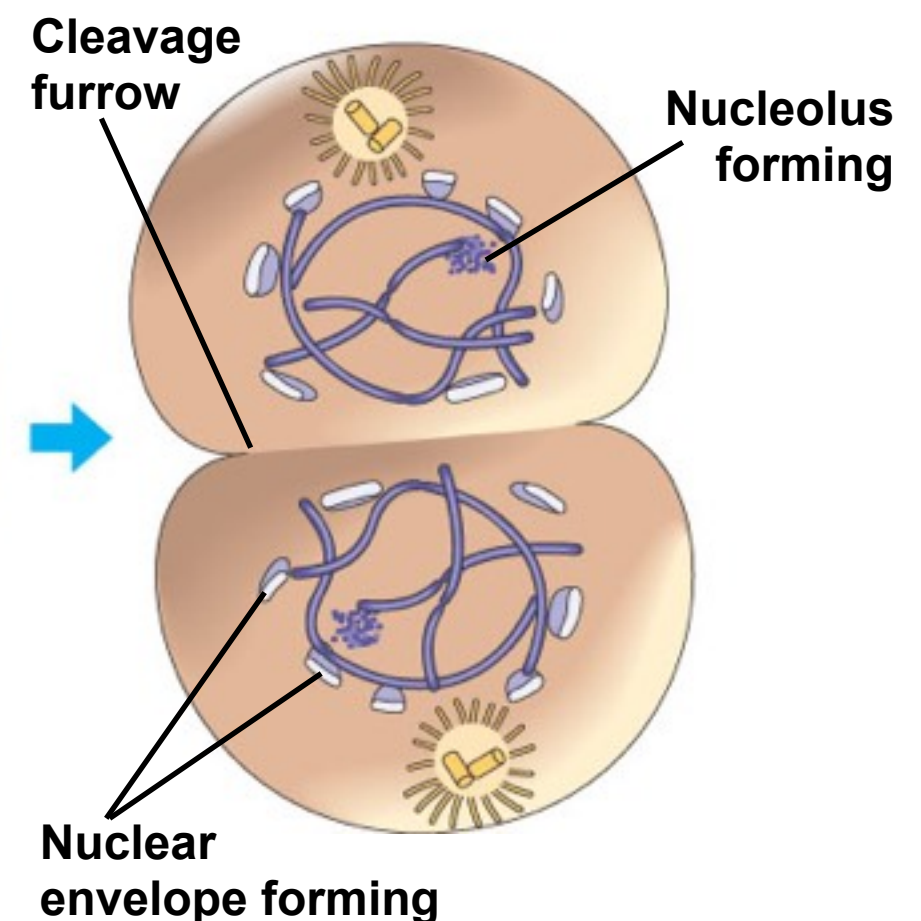
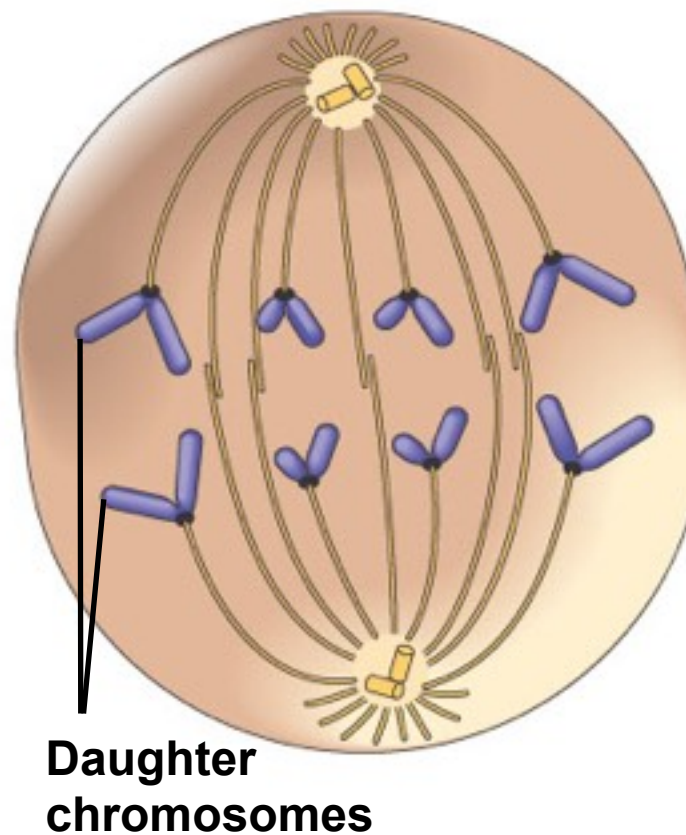
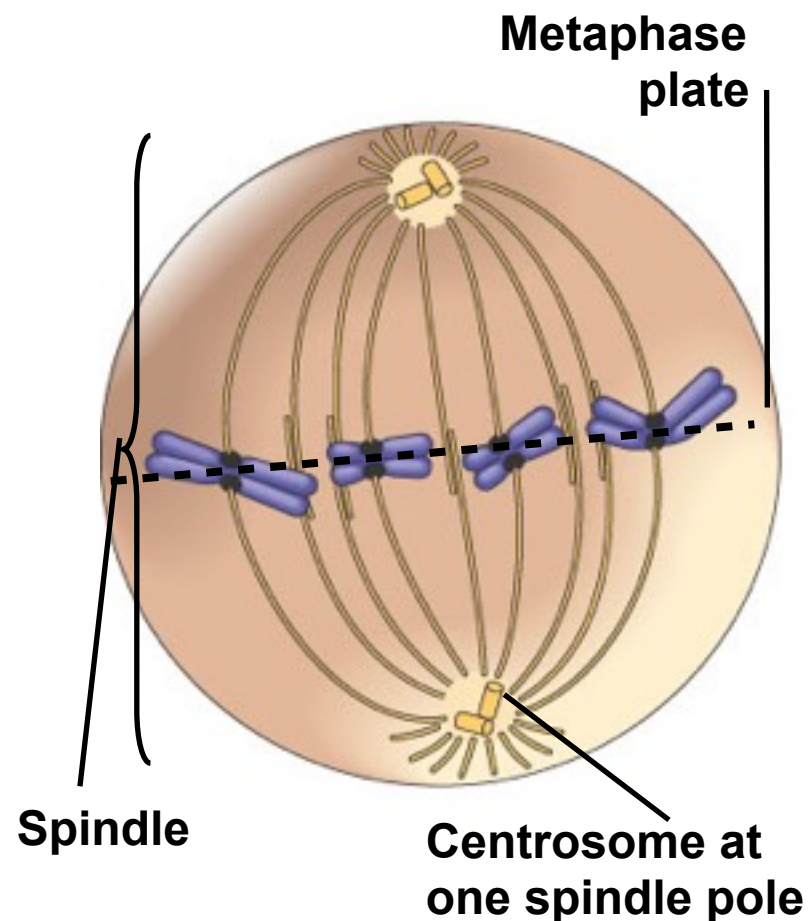
**METAPHASE**



**ANAPHASE**



**TELOPHASE & CYTOKINESIS**



Essential knowledge 3.A.2: In eukaryotes, heritable information is passed to the next generation via processes that include the cell cycle and mitosis or meiosis plus fertilization.

c. Meiosis, a reduction division, followed by fertilization ensures genetic diversity in sexually reproducing organisms.

Evidence of student learning is a demonstrated understanding of each of the following:

1. Meiosis ensures that each gamete receives one complete haploid ( $1n$ ) set of chromosomes.
2. During meiosis, homologous chromosomes are paired, with one homologue originating from the maternal parent and the other from the paternal parent. Orientation of the chromosome pairs is random with respect to the cell poles.
3. Separation of the homologous chromosomes ensures that each gamete receives a haploid set of chromosomes composed of both maternal and paternal chromosomes.
4. During meiosis, homologous chromatids exchange genetic material via a process called “crossing over,” which increases genetic variation in the resultant gametes. [See also 3.C.2]
5. Fertilization involves the fusion of two gametes, increases genetic variation in populations by providing for new combinations of genetic information in the zygote, and restores the diploid number of chromosomes.

# PREFACE

- **Genetics-** is the study of heredity and hereditary variation.
- **Heredity-** aka inheritance, is the transmission of traits one generation to another.
  - Innate to heredity is the passing of similar traits and the generation of variation.
- There are important and practical applications that come from our understanding of heredity and hereditary variation.
- **Your understanding of genetics requires a comprehensive understanding of meiosis, a special case of cell division.**

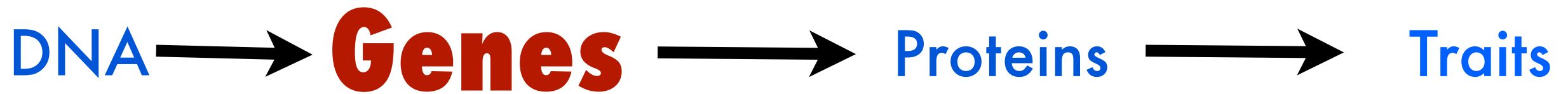


# Meiosis

**Main Idea: Parents pass chromosomes to their offspring, these chromosomes contain genes (the unit of heredity) that control traits.**



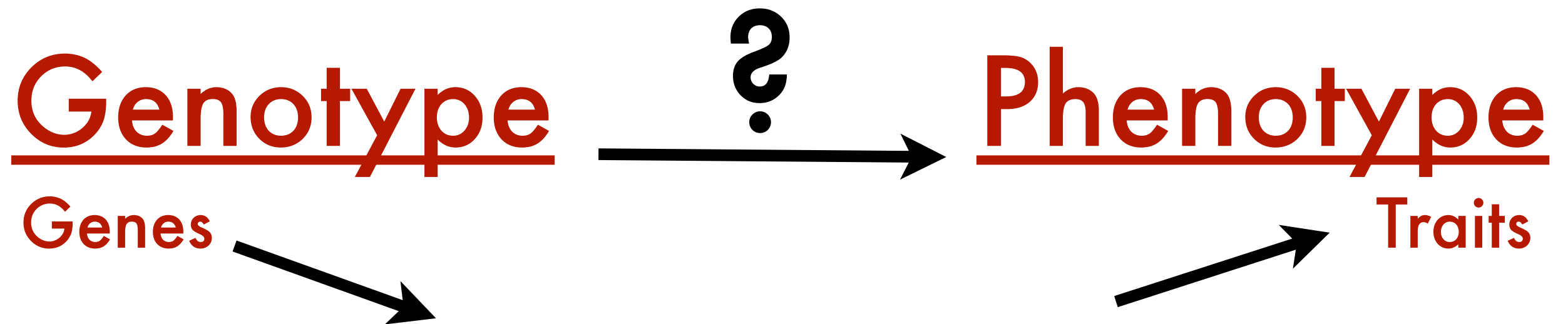
# Remember this?



## OK, What exactly is a gene?

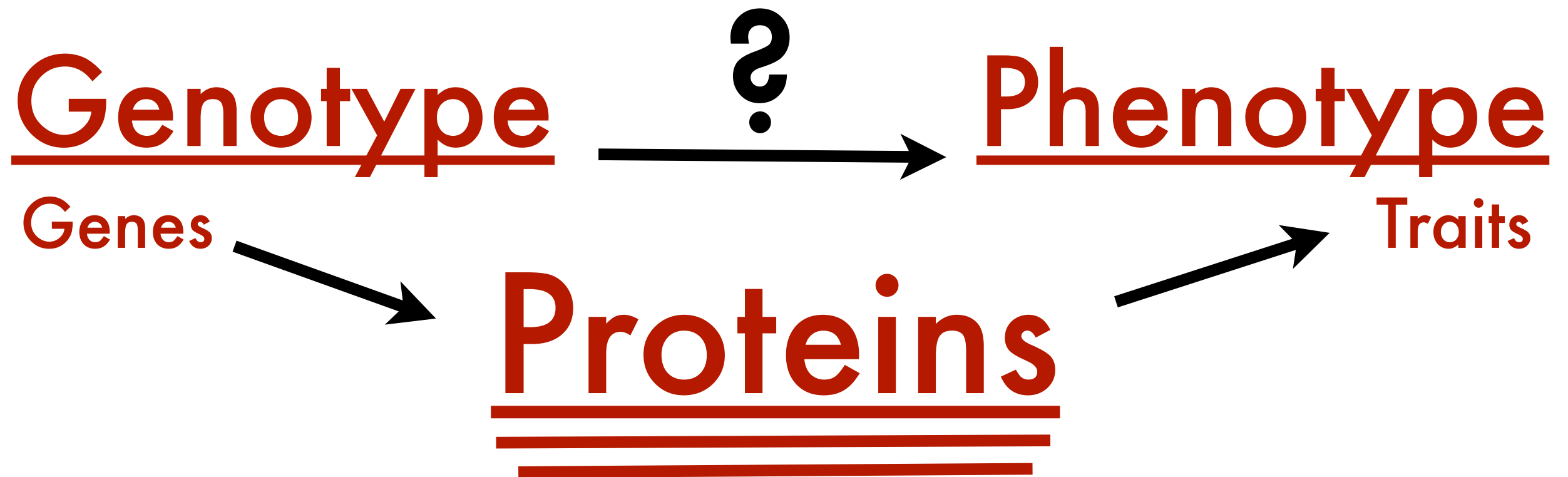
- (Basic Definition) A unit of inheritance that controls a phenotypic character.
- (Better Definition) A nucleotide sequence along a molecule of DNA that codes for a protein.
- **(Best Definition) A region of DNA that can be expressed to produce a final functional product that is either a polypeptide or an RNA molecule.**

# Review

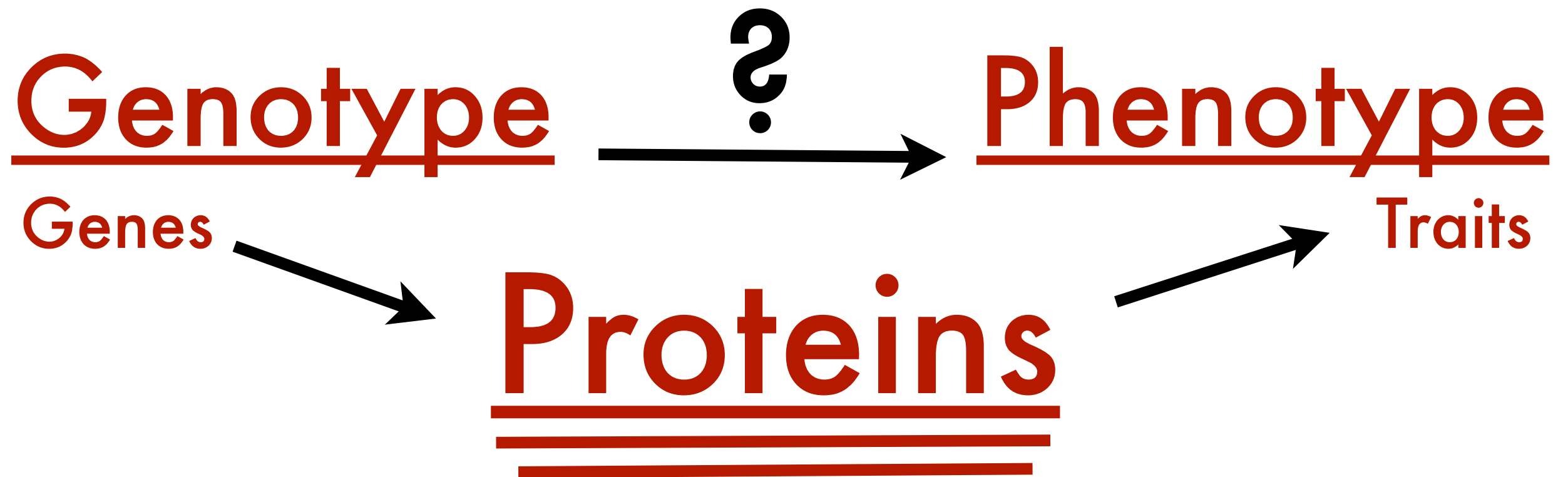


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# Review



# Review



Proteins are the link between genotypes and phenotypes  
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# Review

## Global Flow of Information



- The flow of genetic information involves two processes.
  - Transcription
  - Translation
- Together these two processes represent gene expression.

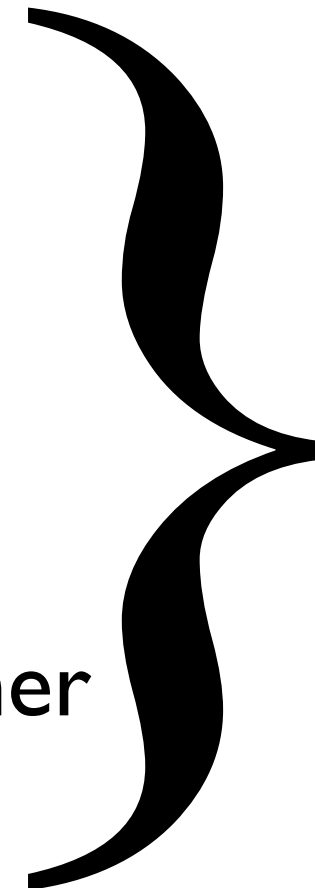
# Inheritance of Genes

- **Gametes-** are the vehicles that carry genes from one generation to another.
- Gametes are *haploid*, they carry only 50% a parent's genes (these genes are carried in 1 complete set of chromosomes).
- **Germ cells** are diploid cells (they contain 2 copies of every chromosome) that undergo a special type of cell division that produces unique haploid cells...gametes
- **Fertilization-** the union of gametes brings 1 set of chromosomes from each parent and produces a single unique cell called a *zygote* that is *diploid* .
- The *zygote* undergoes *mitosis* over and over again producing trillions of **somatic cells** (all diploid body cells except germ cells and gametes).

# Inheritance of Genes

- **Asexual Reproduction-**

- one parent
- no fusion of gametes
- daughter cells get all of parent's genes
- daughter cells are identical\* to each other and parent cell



*Mitosis*

*Binary Fission*

\* Unless of course a mutation occurs!

# Inheritance of Genes

- **Sexual Reproduction-**
  - two parents
  - fusion of gametes
  - daughter cells get half of parent's genes
  - daughter cells are completely unique (one of kind cells)

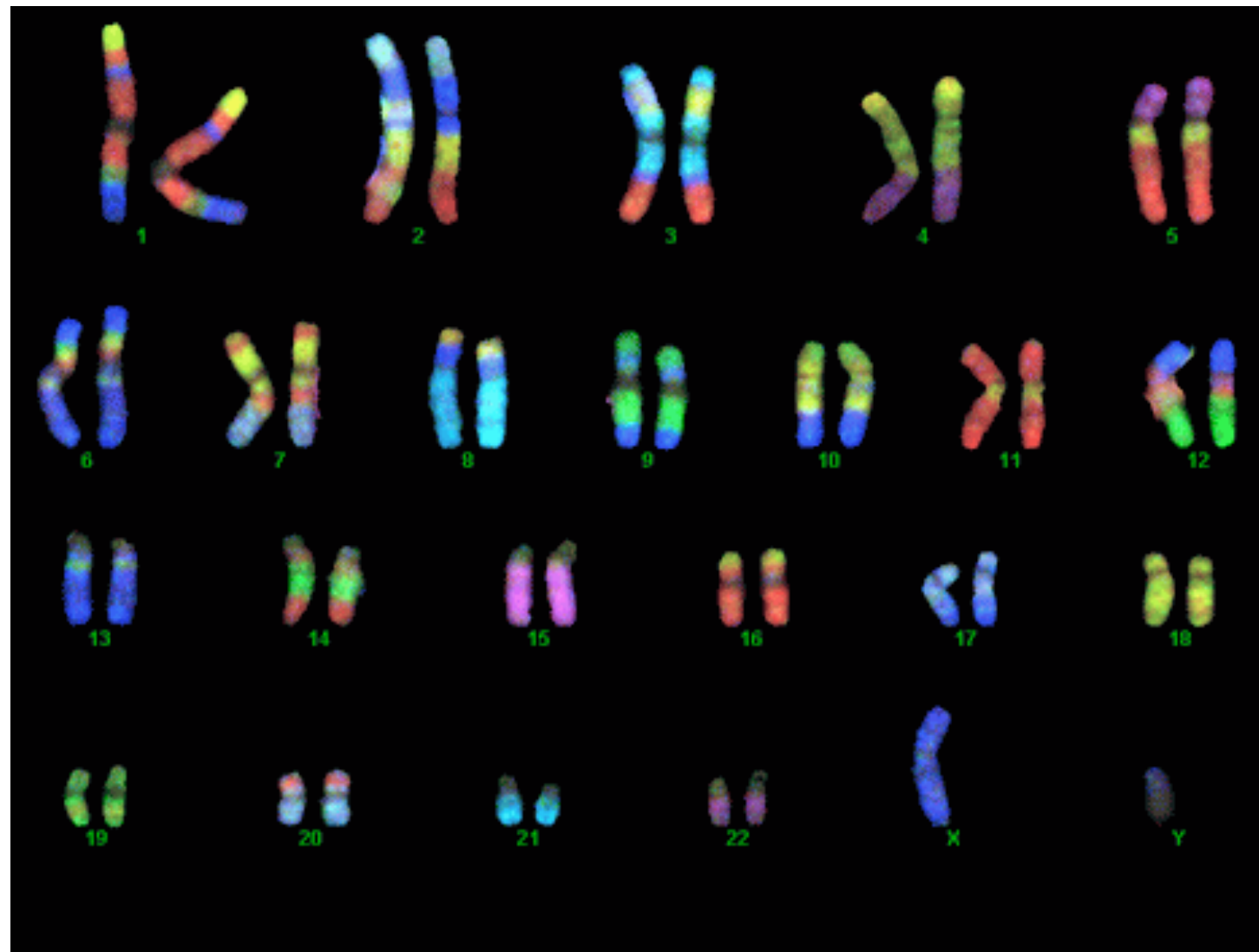
# Meiosis

**Main Idea: Fertilization and meiosis alternate in life cycles regardless of variations in life cycles.**



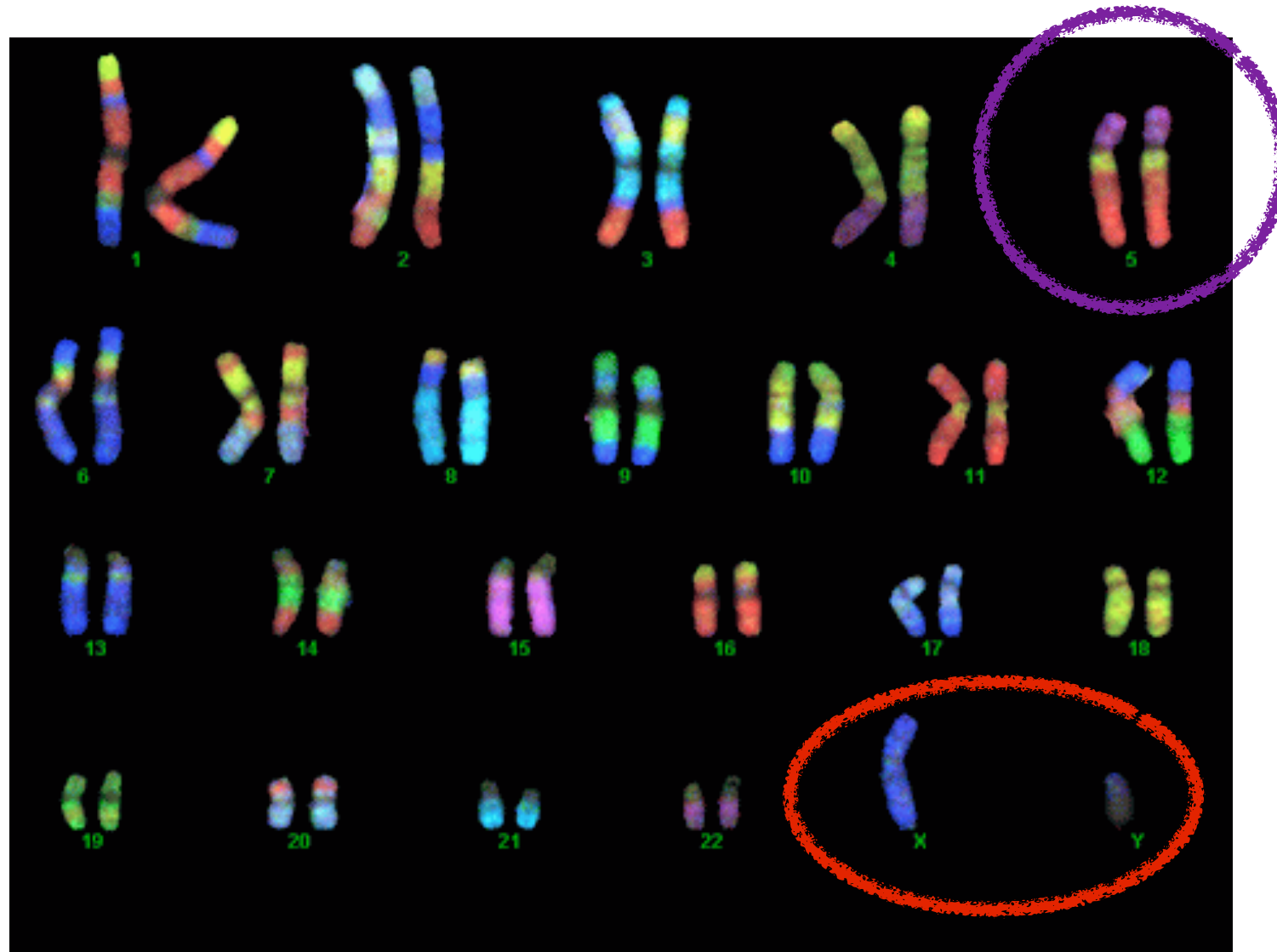


# Closer look at Chromosomes



This is a **karyotype**, an ordered display of chromosomes. Notice the 23 types (pairs) are numbered and arranged from long to short. The position of the centromere and the colored banded patterns are also used when arranging the chromosomes.

# Closer look at Chromosomes



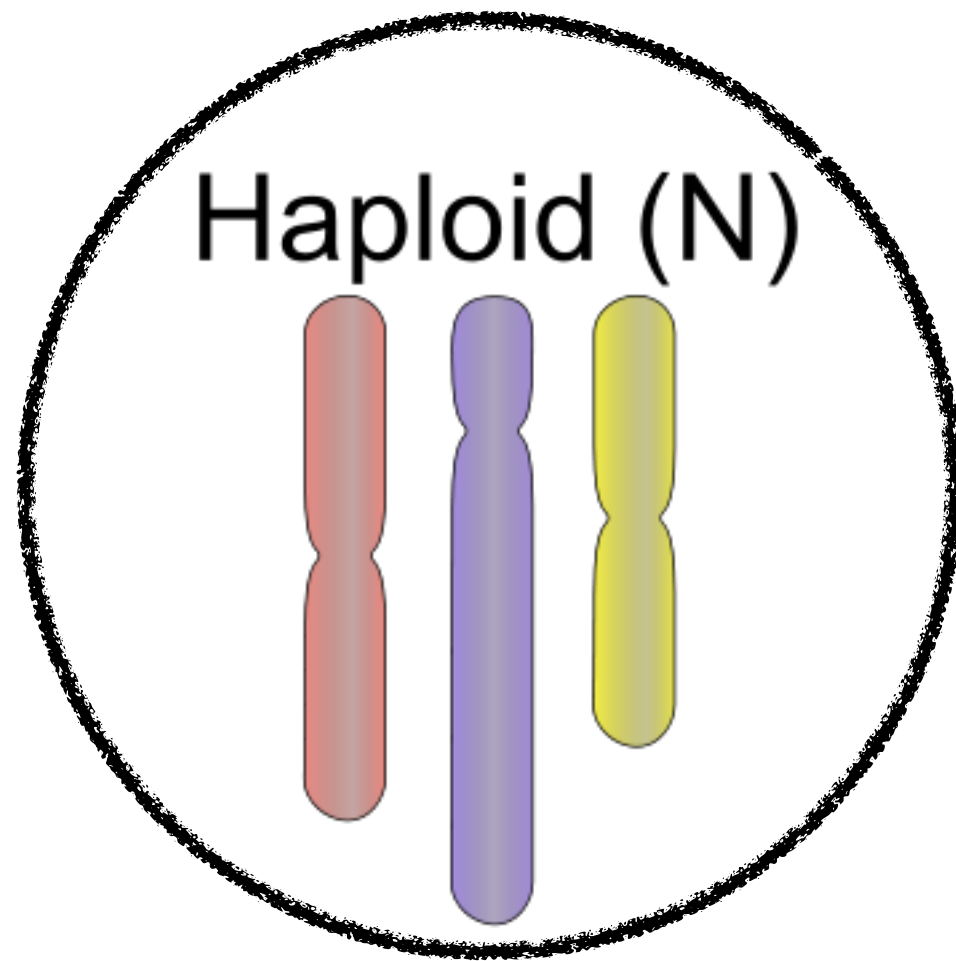
**Autosomes-** the first 22 pairs chromosomes (all except sex chromosomes)

## Homologous Chromosomes-

chromosomes with same, length, centromere position and they carry genes controlling the same traits

## Sex Chromosomes-

the X and Y chromosomes they are 23rd pair and they determine the sex of the offspring (XX=girl) (XY=boy)

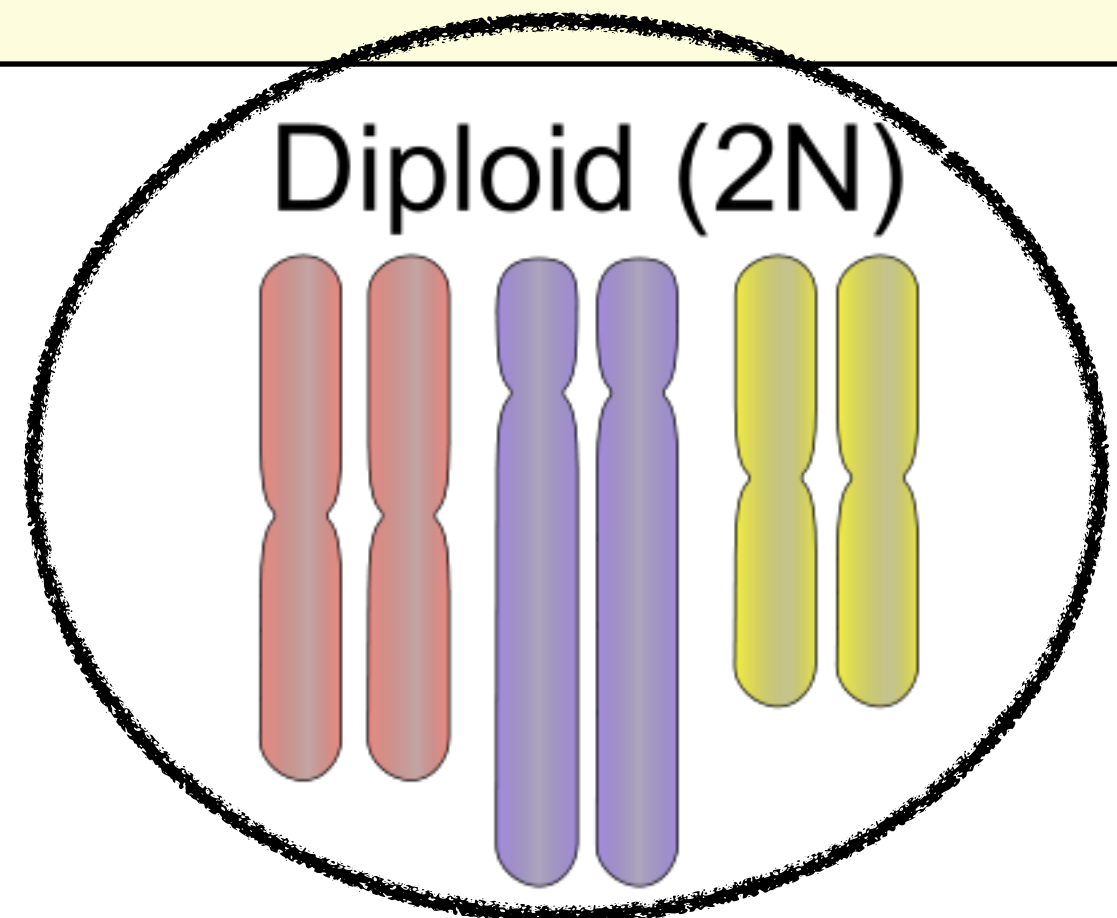


## Diploid

- symbol  $2n$
- two sets of chromosomes (maternal & paternal sets)
- includes almost all cells
- humans  $2n=46$



## Haploid

- symbol  $n$
- one set of chromosomes (maternal & paternal sets)
- only sperm and eggs
- humans  $n=23$



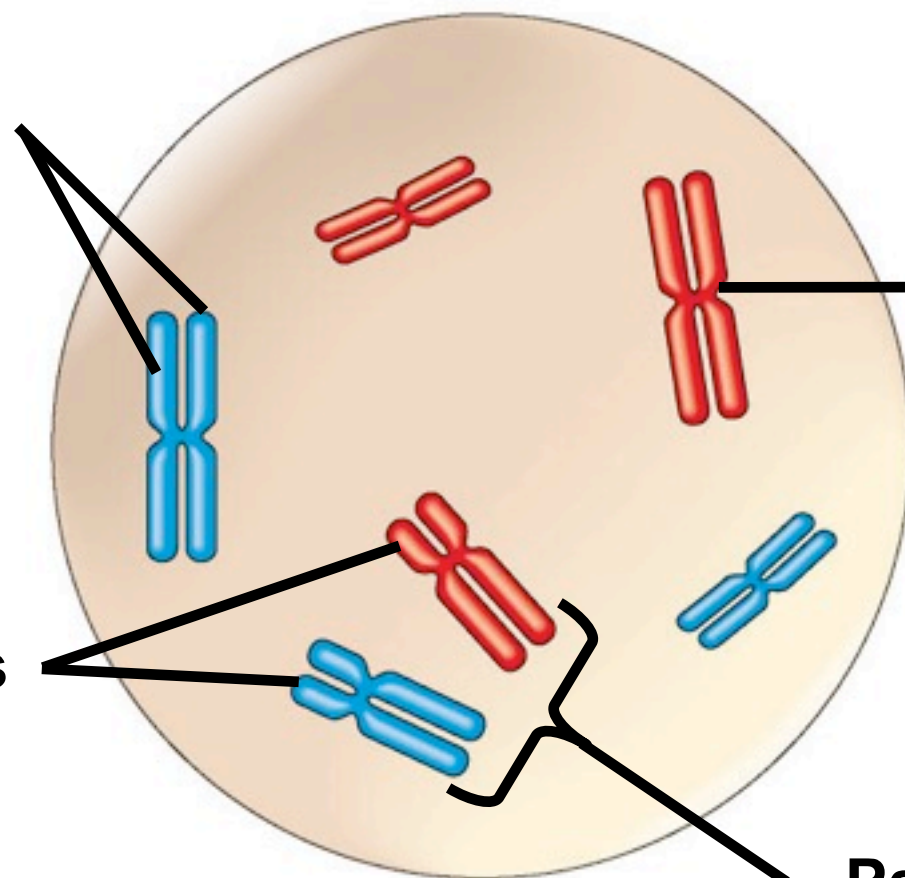
# Describing Chromosomes

## Key

$2n = 6$  {  Maternal set of chromosomes ( $n = 3$ )  
 Paternal set of chromosomes ( $n = 3$ )

Two sister chromatids of  
one replicated chromosome

Two nonsister chromatids  
in a homologous pair

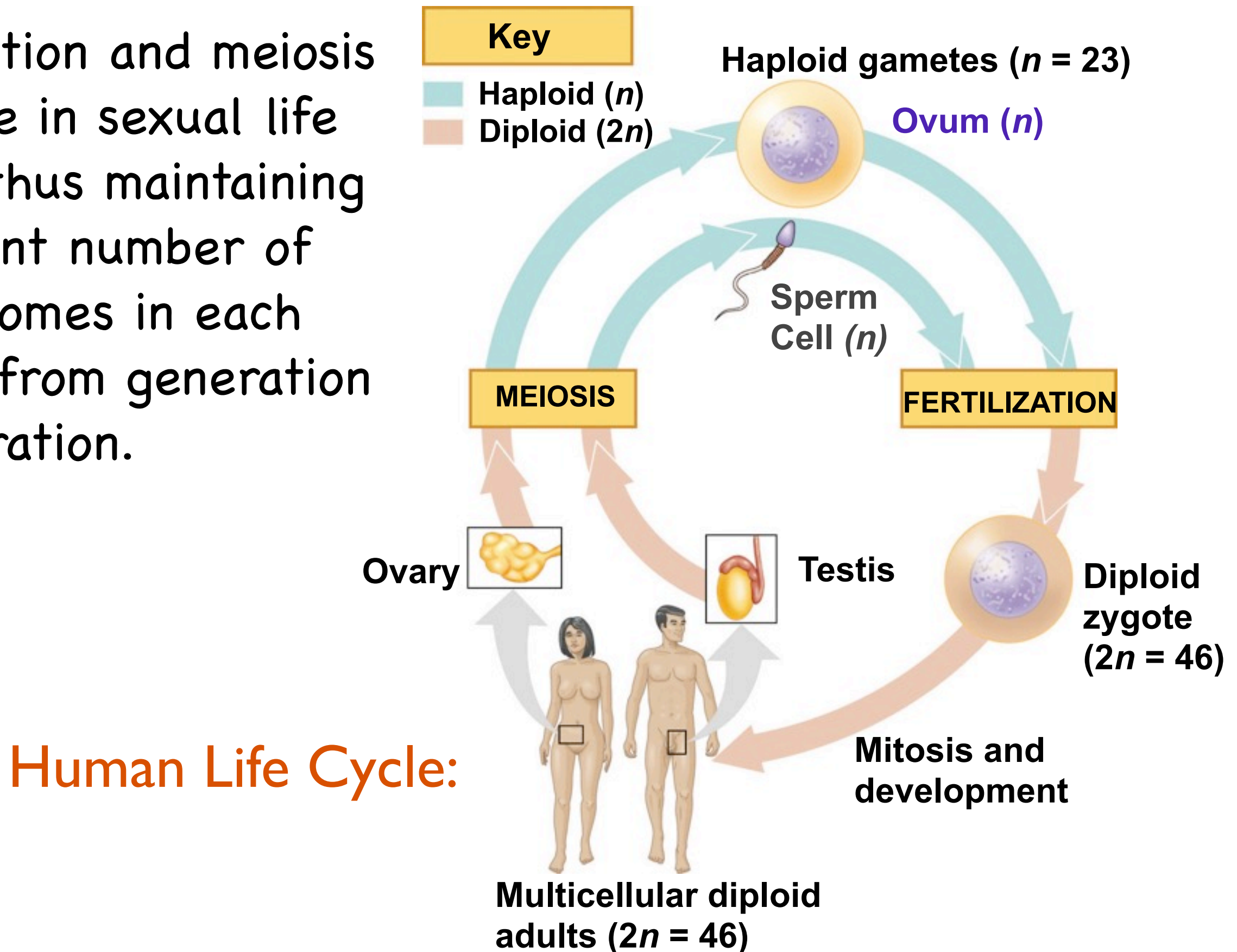


Centromere

Pair of homologous  
chromosomes  
(one from each set)

# Behavior of Chromosomes

Fertilization and meiosis alternate in sexual life cycles, thus maintaining a constant number of chromosomes in each species from generation to generation.





# Meiosis

**Main Idea: Meiosis reduces the number of chromosomes from 2 sets (diploid) to 1 set (haploid).**



# Mitosis and Meiosis

- There are many similarities and important differences between mitosis and meiosis.
- *Look for comparisons as we examine each stage of meiosis in slides that follow.*
- In the meantime lets begin our examination of meiosis with this fundamental difference between the two processes.

## Mitosis

**Produces 2 identical  
diploid cells**

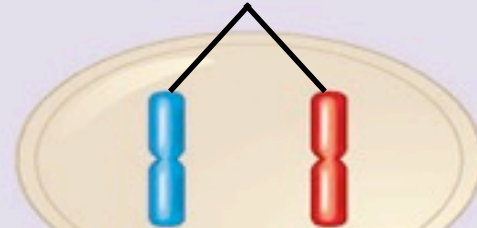
## Meiosis

**Produces 4 unique  
haploid cells**

# Meiosis Overview

## Interphase

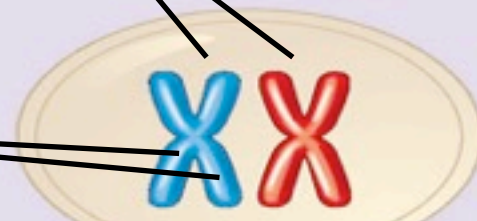
Homologous pair of chromosomes in diploid parent cell



Homologous pair of replicated chromosomes

Chromosomes replicate

Sister chromatids



Diploid cell with replicated chromosomes

## Meiosis I

Haploid cells with replicated chromosomes



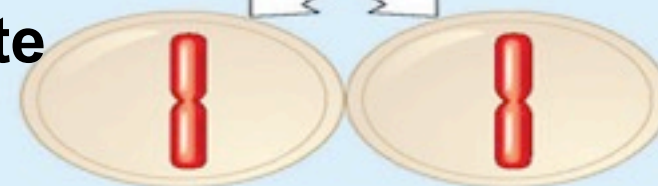
Homologous chromosomes separate



Haploid cells with replicated chromosomes

## Meiosis II

Sister chromatids separate



Haploid cells with unreplicated chromosomes



# Meiosis I

INTERPHASE

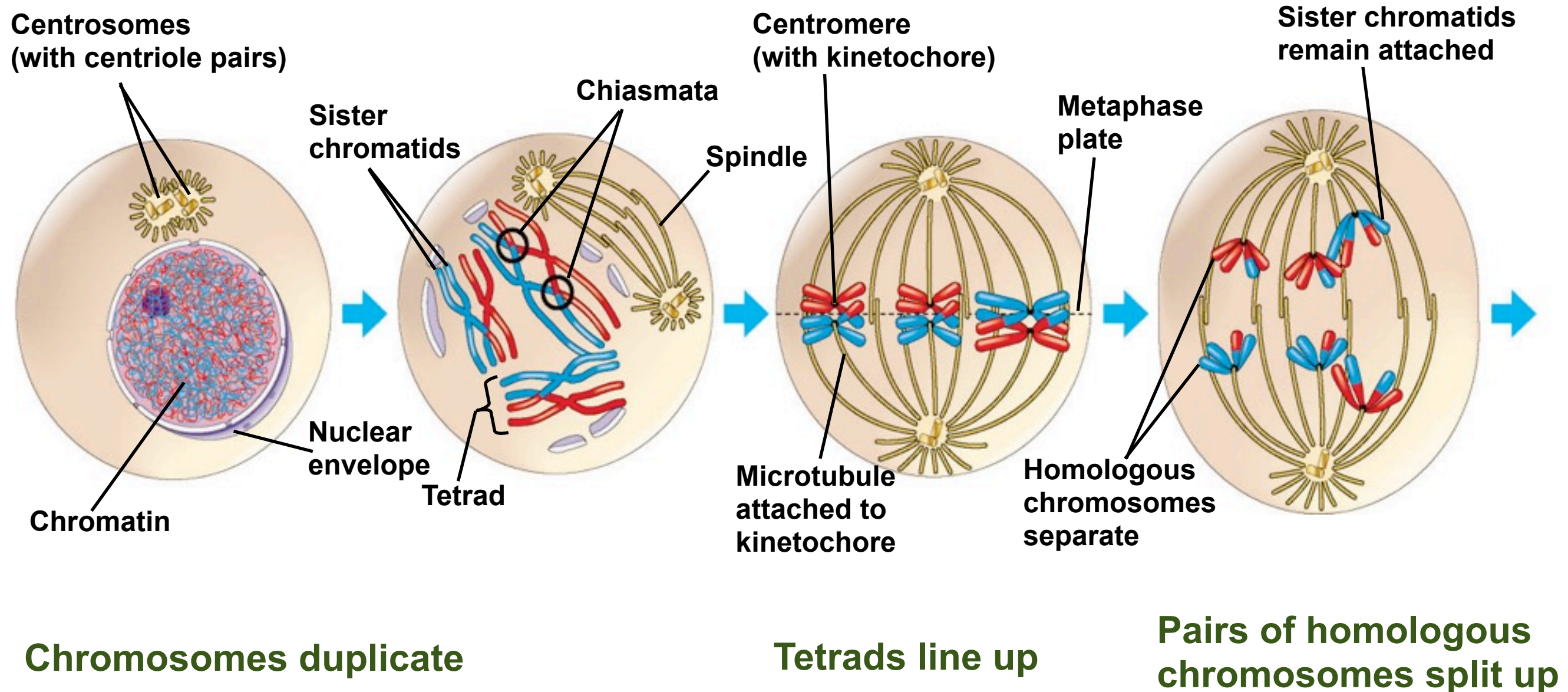
MEIOSIS I: Separates homologous chromosomes

PROPHASE I

METAPHASE I

ANAPHASE I

Homologous chromosomes (red and blue) pair and exchange segments;  
 $2n = 6$  in this example





# Meiosis II

## MEIOSIS II: Separates sister chromatids

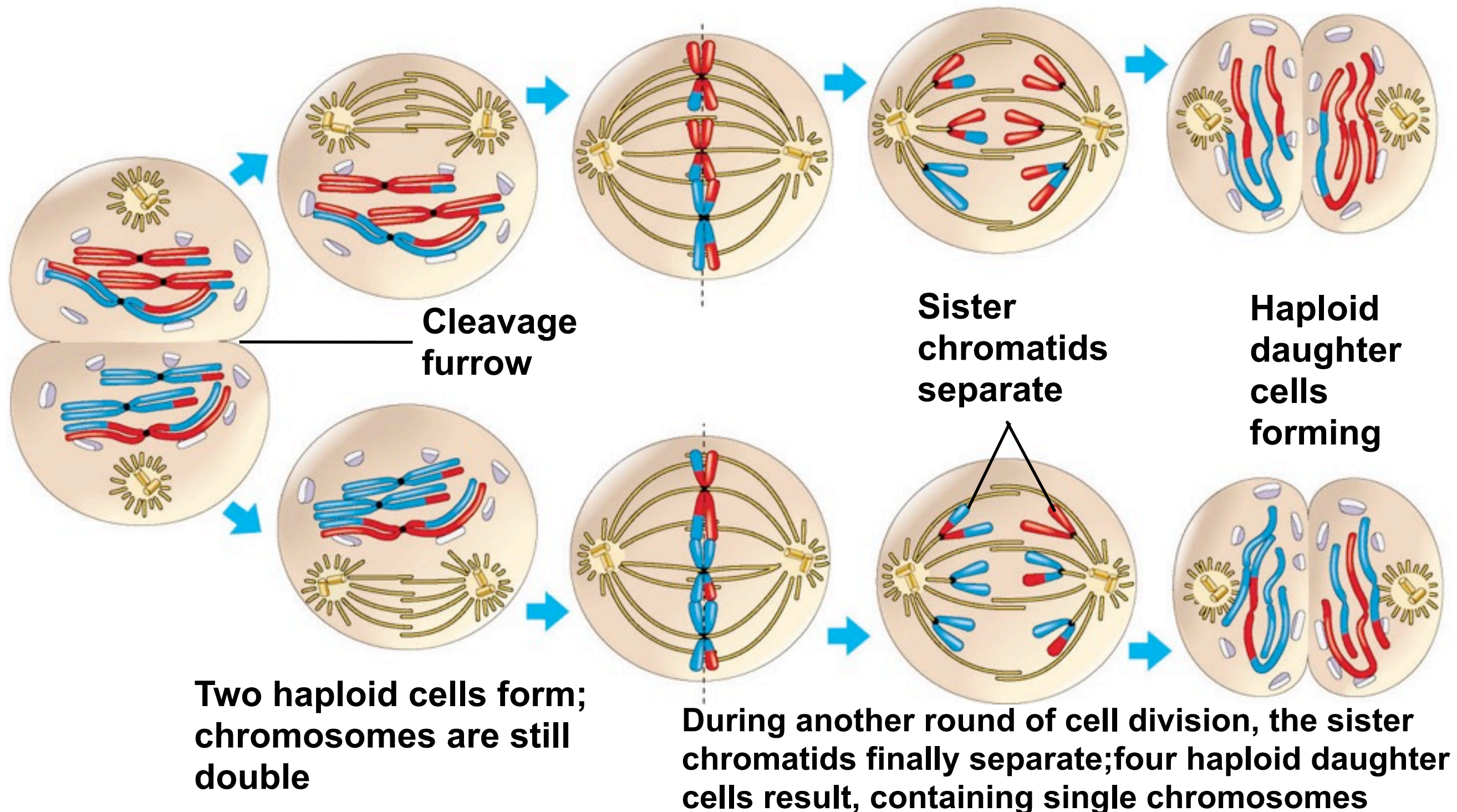
TELOPHASE I AND  
CYTOKINESIS

PROPHASE II

METAPHASE II

ANAPHASE II

TELOPHASE II AND  
CYTOKINESIS





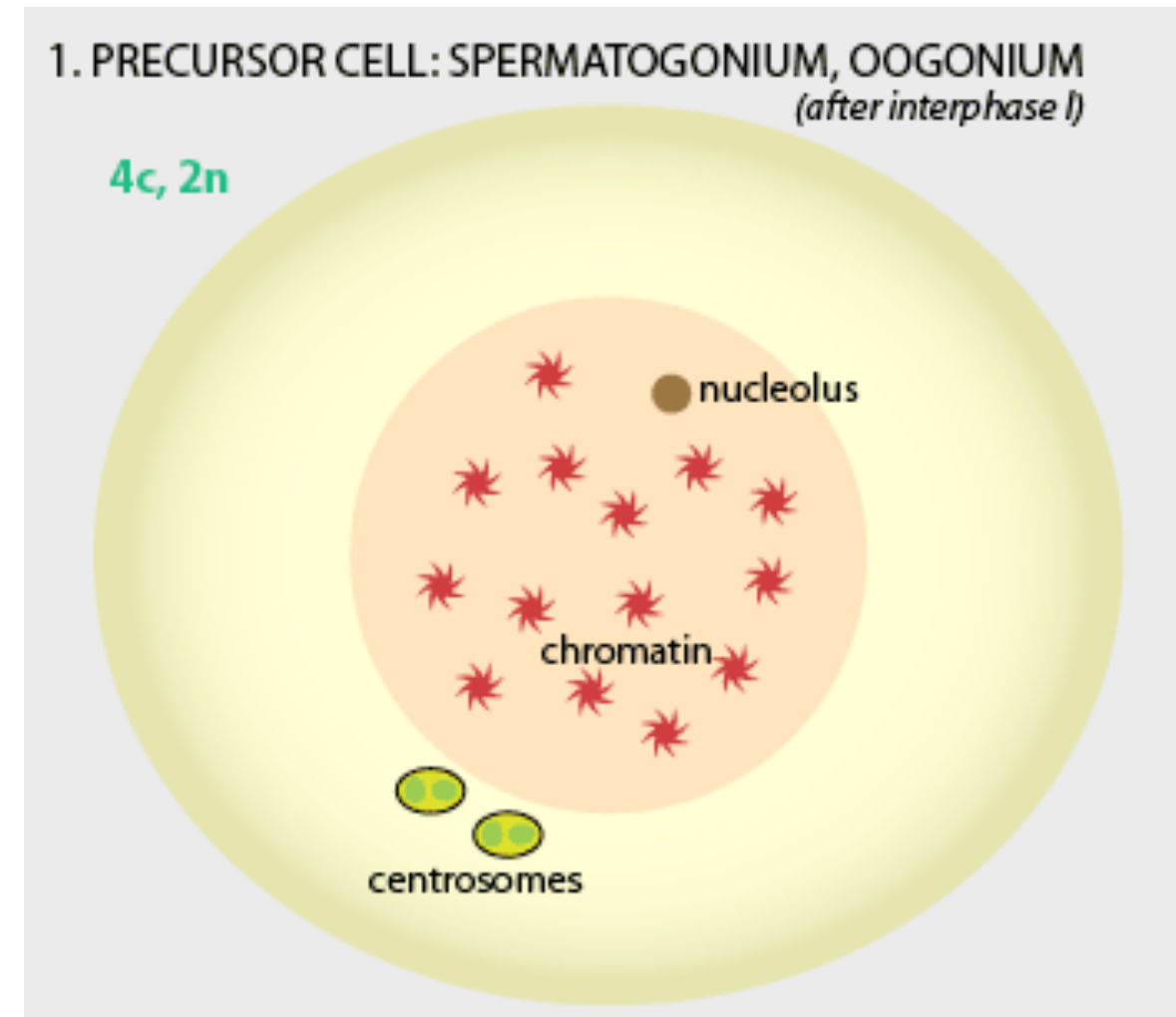
# Meiosis: A Closer Look

- **Interphase G<sub>1</sub>**

- cell grows
- organelles replicate
- carries out destined functions

- **Interphase S**

- replicates DNA
- replicates centrosomes
- cell grows
- organelles replicate
- carries out destined functions



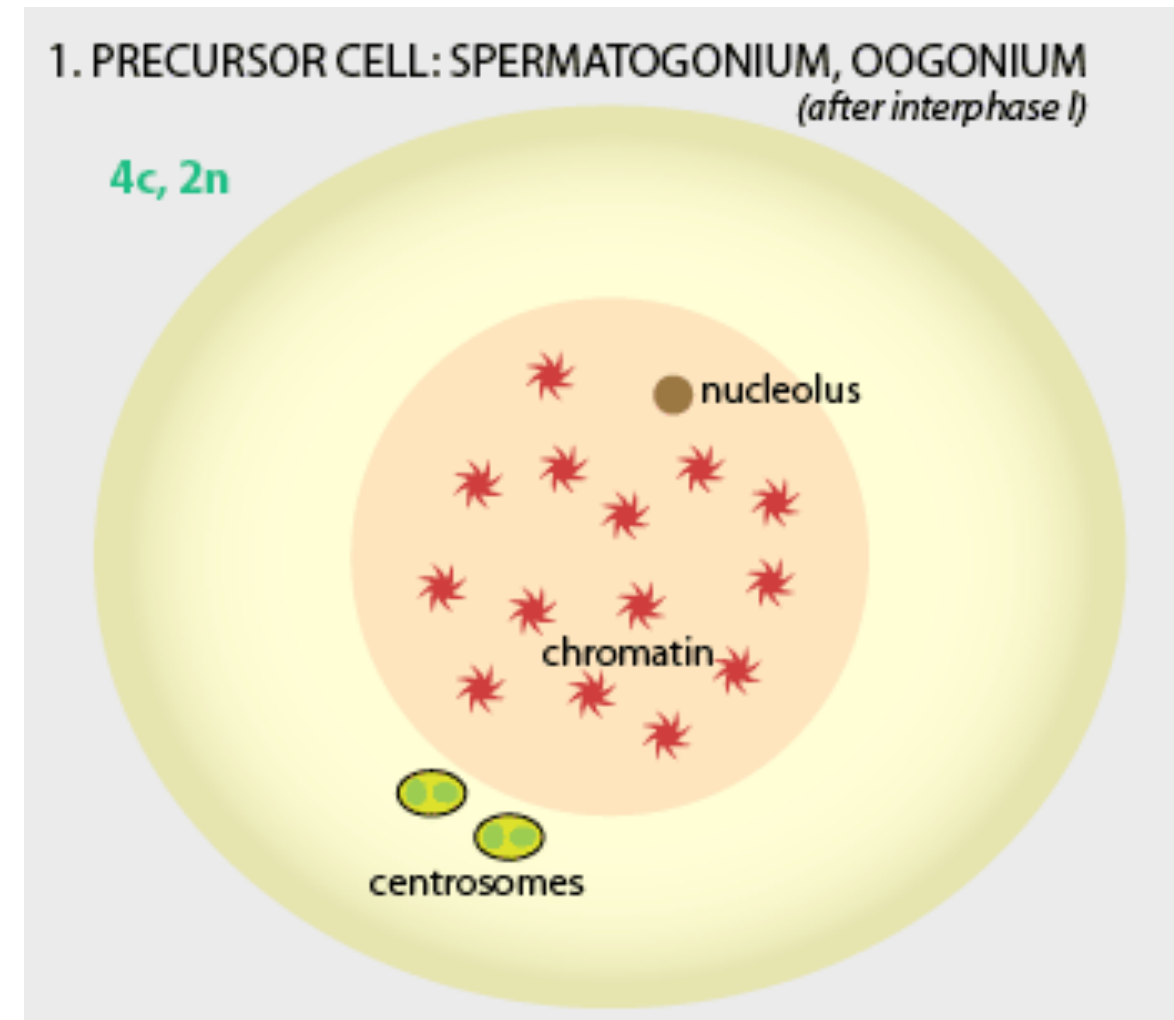
# Meiosis: A Closer Look

- **Interphase G<sub>2</sub>**

- cell grows
- organelles replicate
- carries out destined functions
- prepares for divisions
- condenses chromatin into chromosomes (at the very end of G<sub>2</sub> or start of prophase)

- **Prophase I**

- chromosomes begin to condense



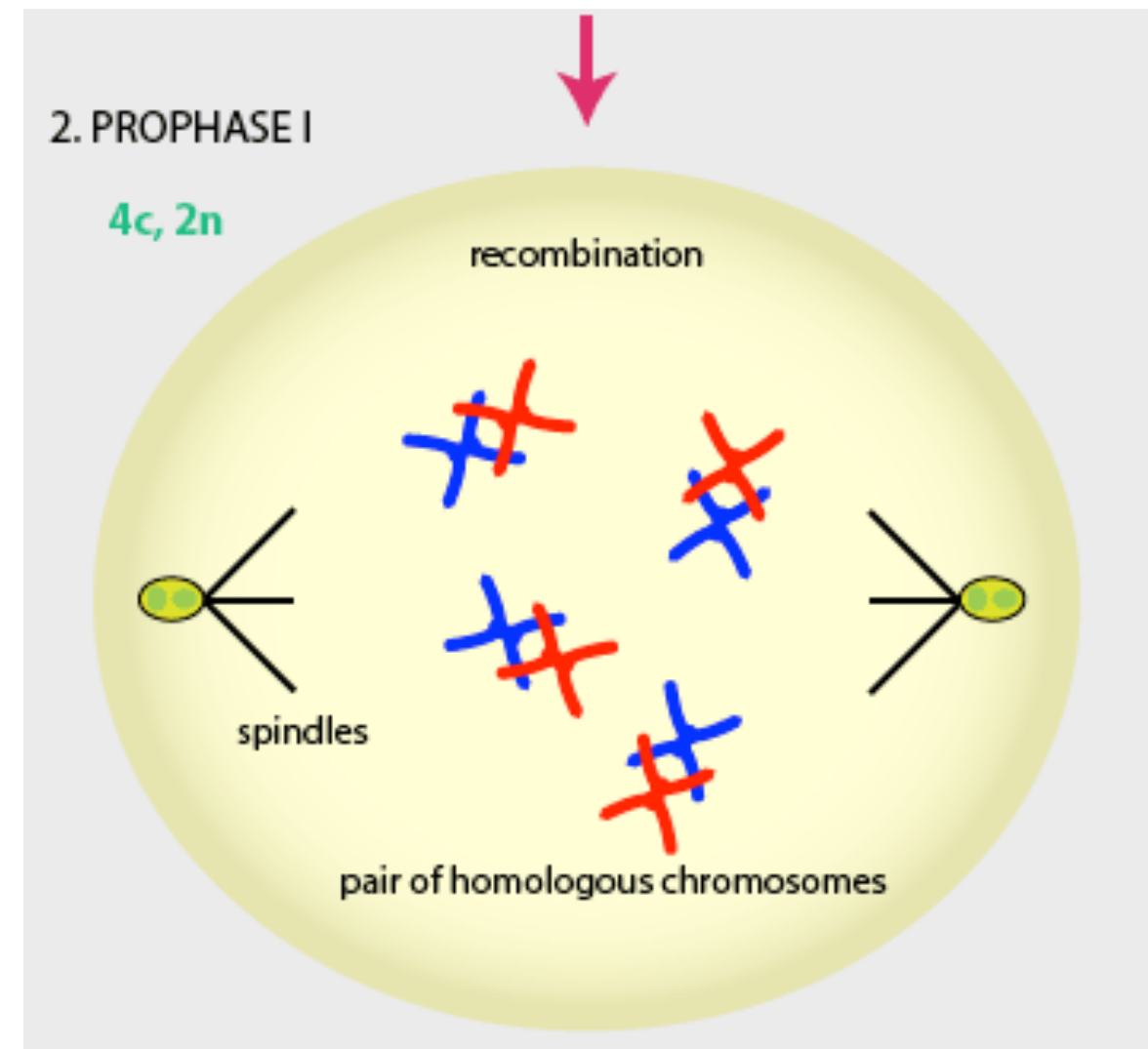
# Meiosis: A Closer Look

- **Prophase I (beginning)**

- homologs pair up lengthwise
- *synapsis*\* occurs, homologs connect at the synaptonemal complex
- *crossing over*\* occurs, genetic exchange between corresponding segments of the chromosomes

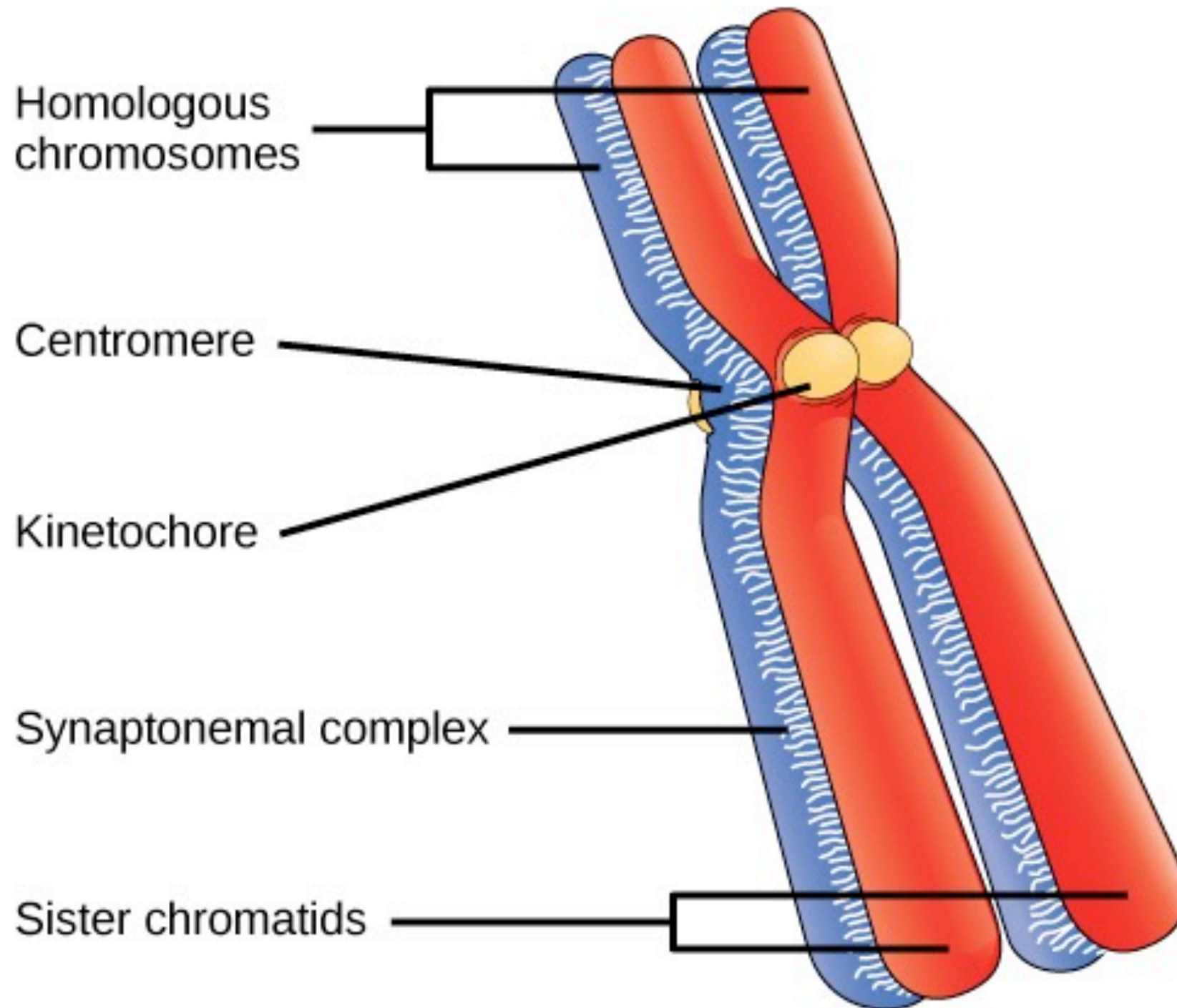
- **Prophase I (middle)**

- synaptonemal complex disassembles and homologs are loosely joined



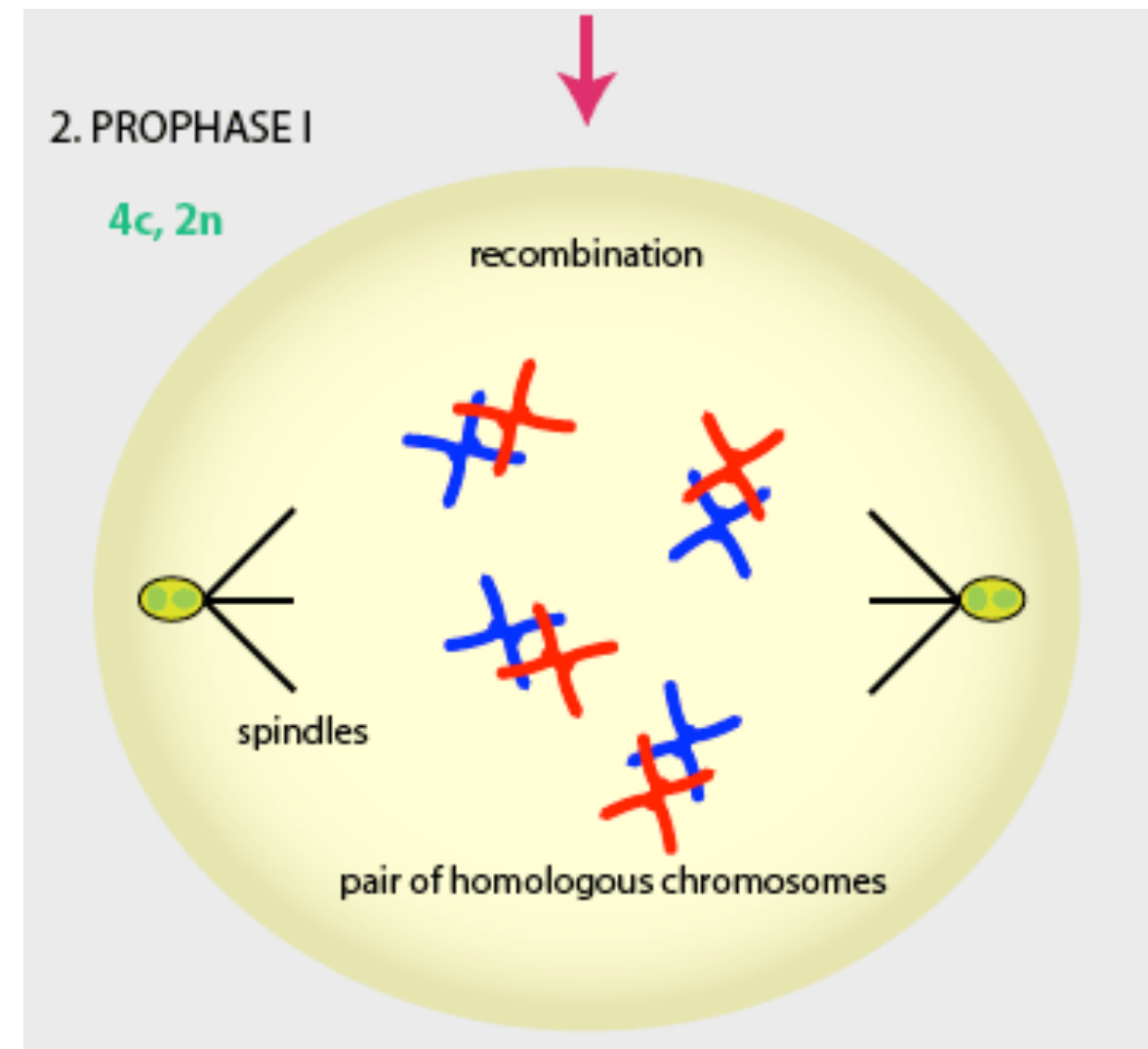
\*unique to meiosis

# Homologous Chromosomes Pairs (aka “tetrads”)



# Meiosis: A Closer Look

- **Prophase I (middle)**
  - each chromosome has an “X” shaped region called the chiasma. It is the point where crossing over has occurred
  - nuclear envelope breaks down
  - centrosomes migrate
  - spindle fibers form





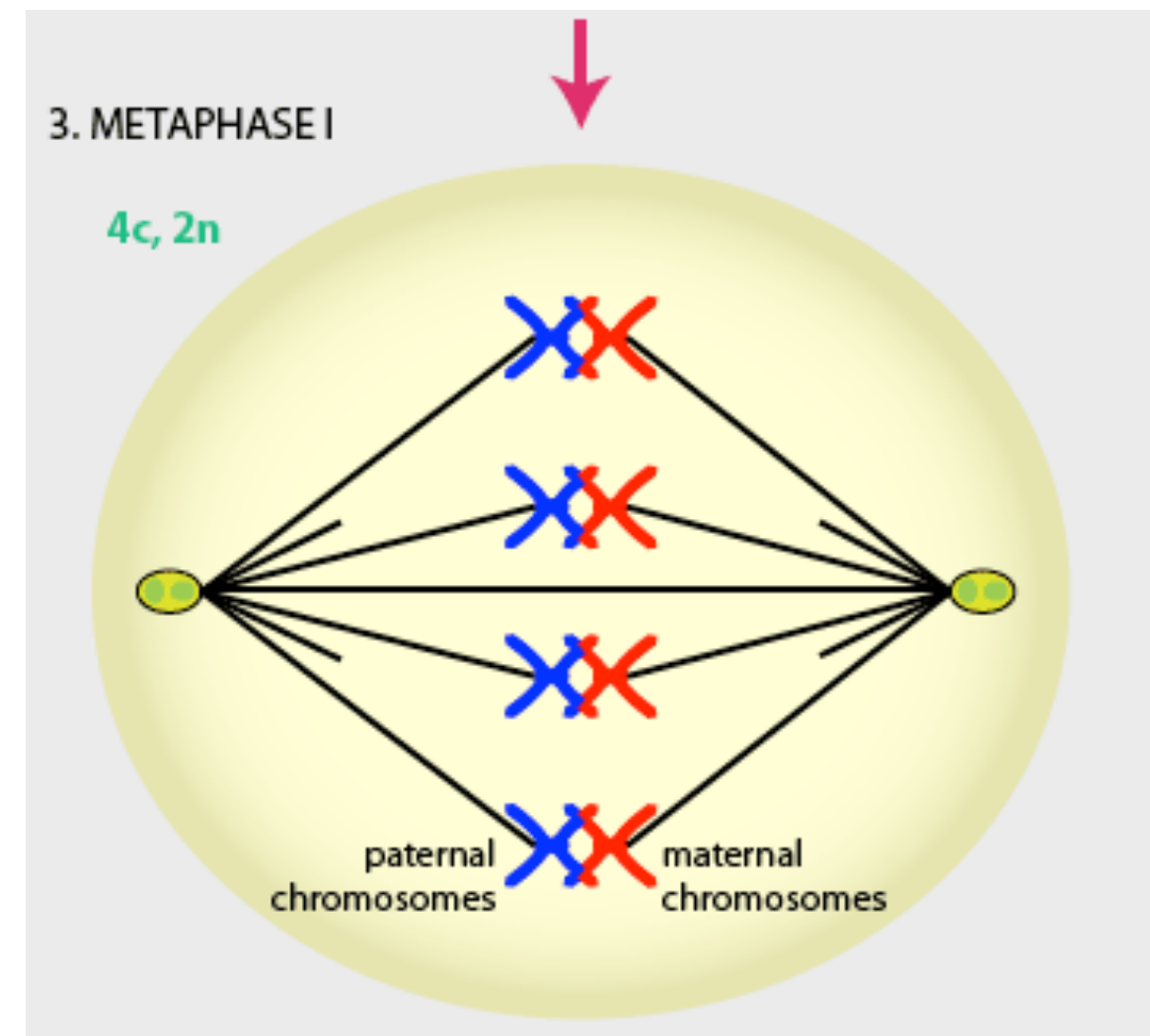
# Meiosis: A Closer Look

- **Prophase I (late)**

- microtubules attach to kinetochores and move the homologous pairs toward the middle of the cell

- **Metaphase I**

- homologous pairs (**tetrads\***) are now aligned at the metaphase plate
- both chromatids of each pair are attached to spindles from opposite poles

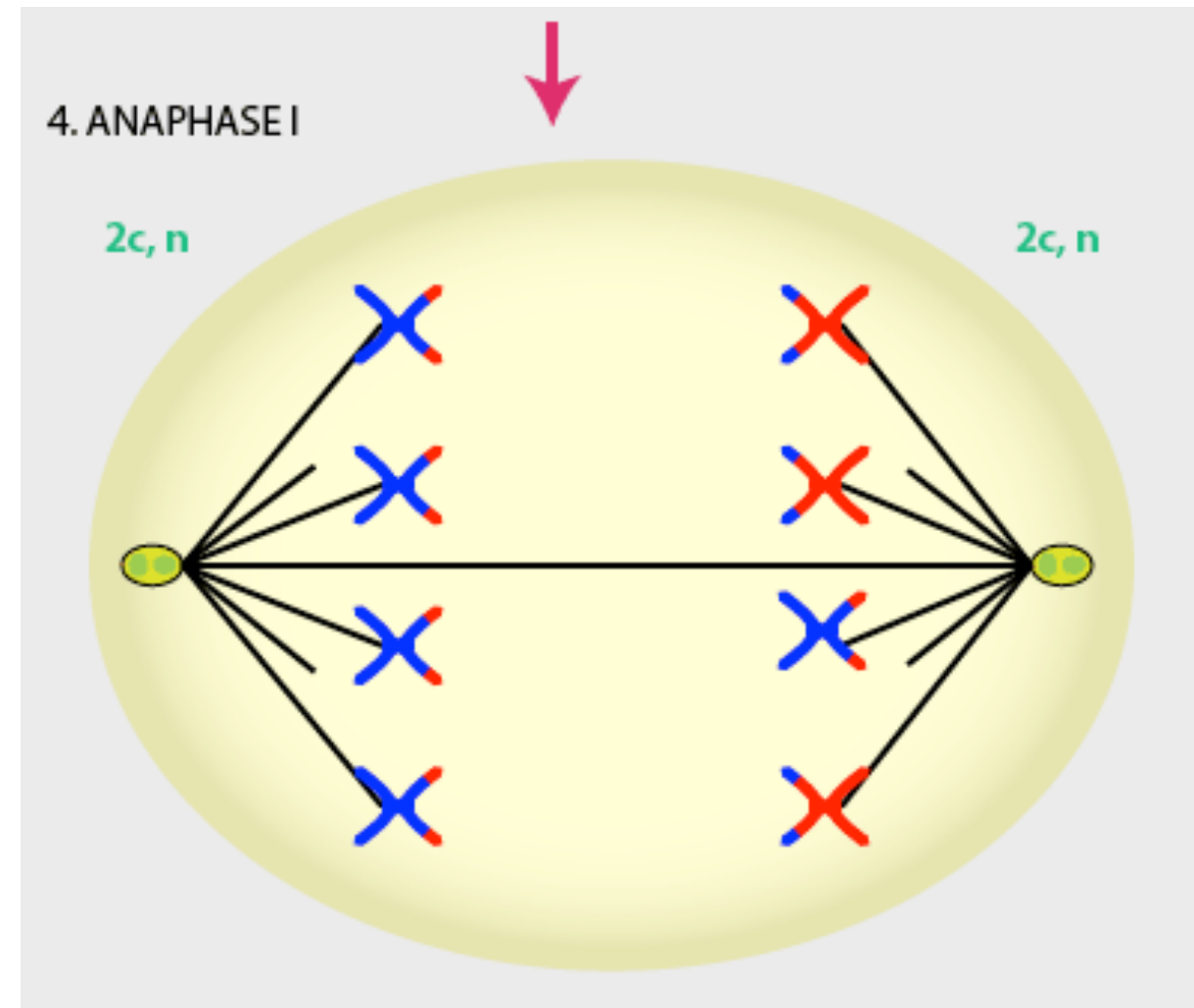


**\*unique to meiosis**

# Meiosis: A Closer Look

- **Anaphase I**

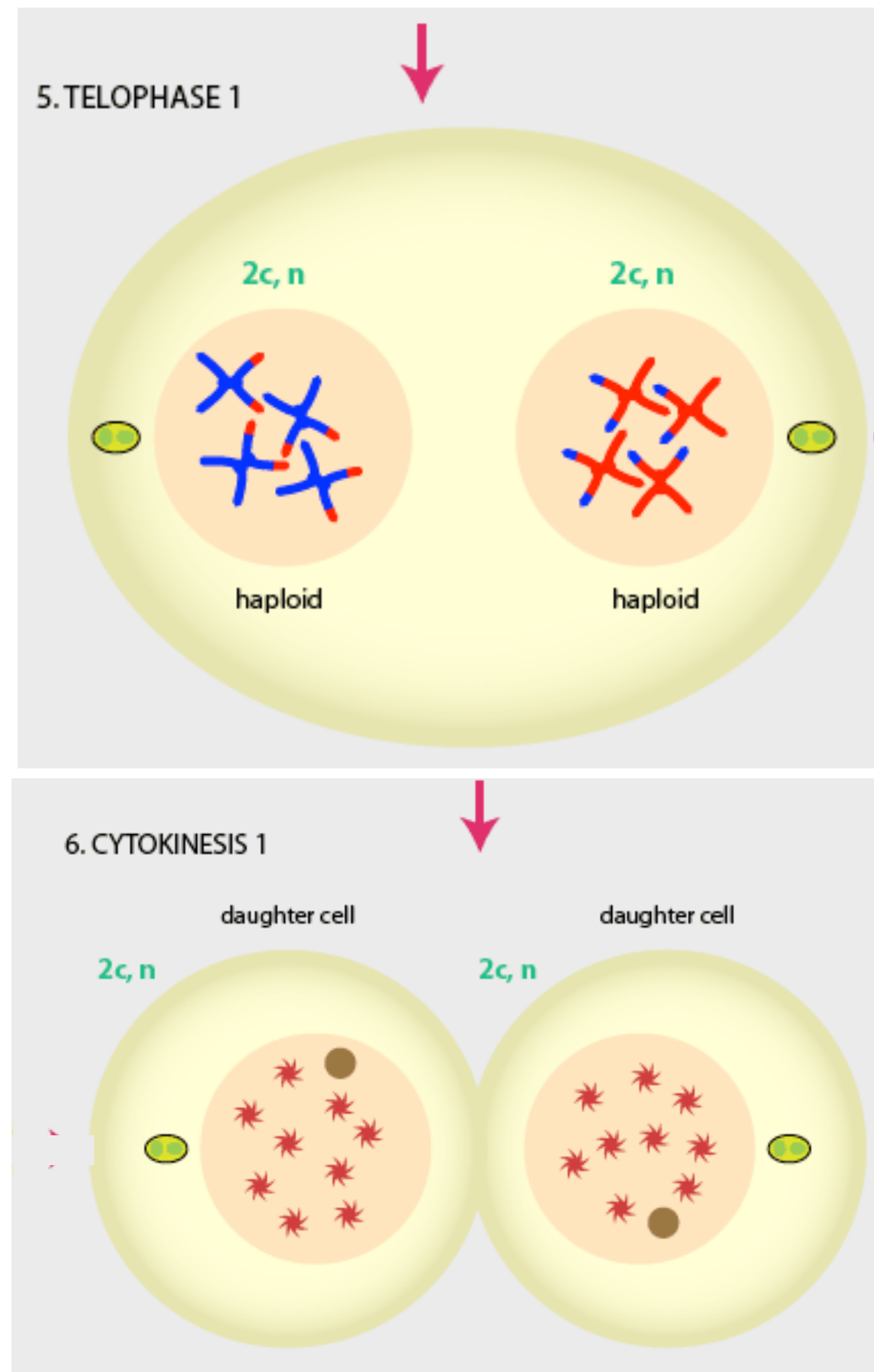
- proteins holding homologs together break down
- homologs separate and move toward each opposite pole
- cohesion remains between sister chromatids and they move as a unit



# Meiosis: A Closer Look

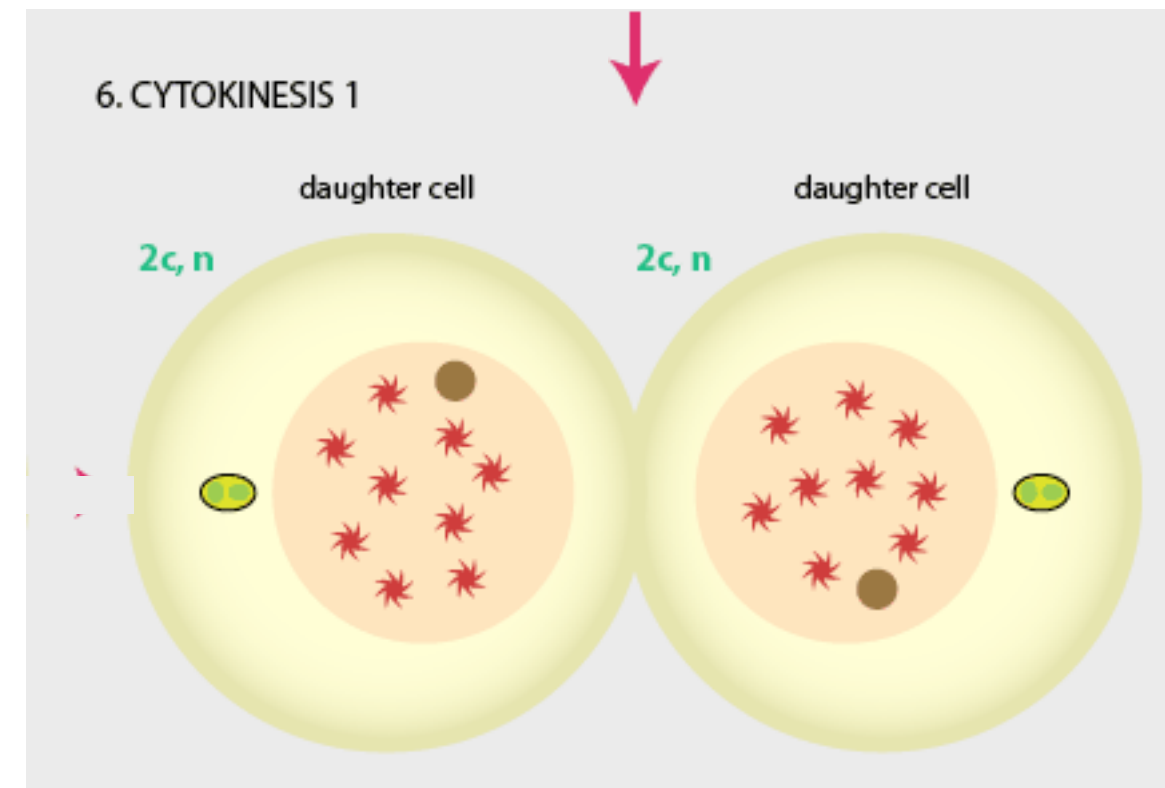
- **Telophase I & Cytokinesis**

- each set has a haploid set of chromosomes but amount of DNA is still that of a normal cell
- one of both sister chromatids contain regions of nonsister chromatid DNA
- Cytokinesis begins before telophase I is complete



# Meiosis: A Closer Look

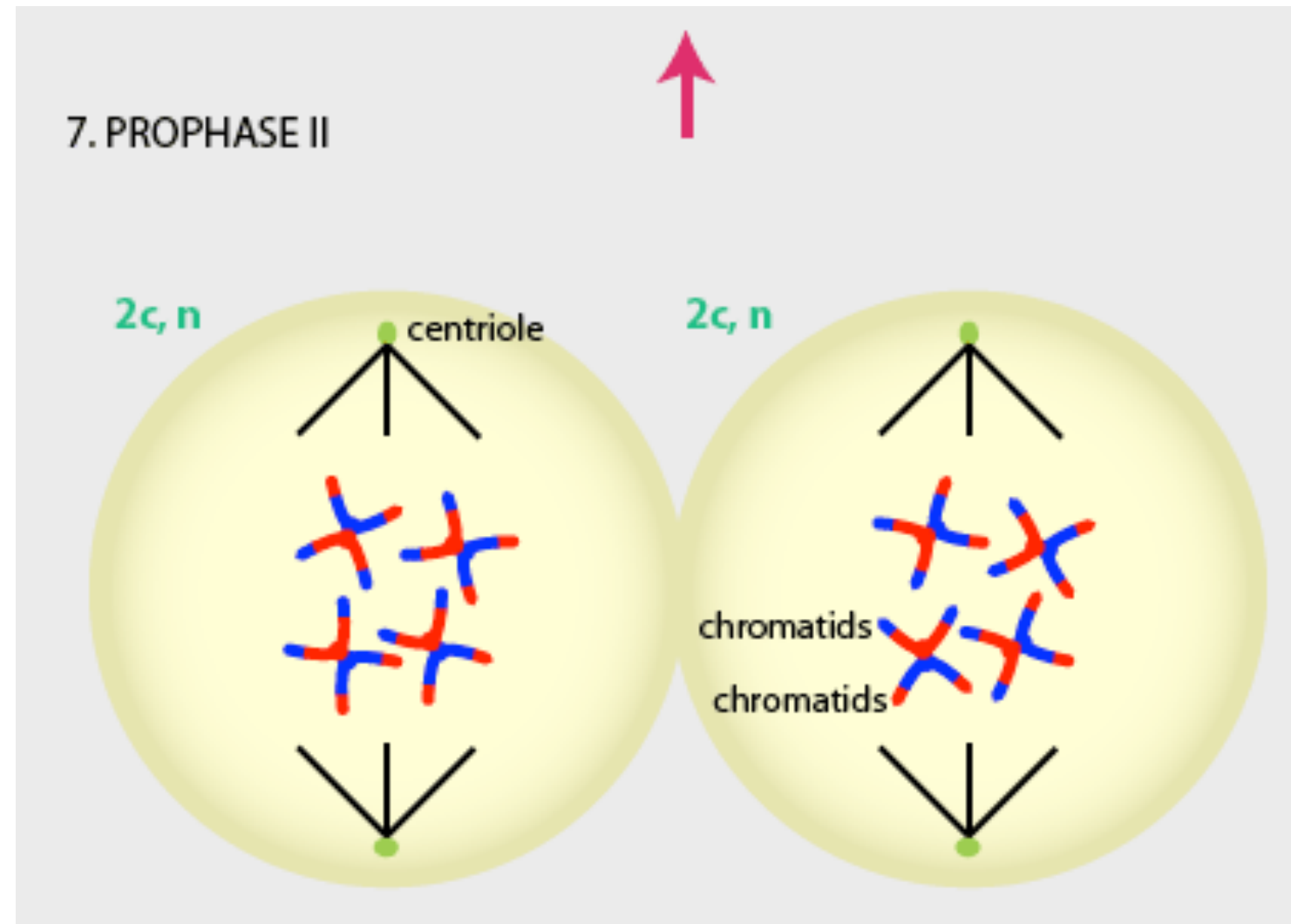
- **Cytokinesis**
  - animal cells create cleavage furrows and plant cells create cell plates
  - no DNA replication between meiosis I and II
  - In some species the chromosomes de-condense and reform a nuclear envelope



# Meiosis: A Closer Look

- **Prophase II**

- spindles form once again
- microtubules attach to kinetochores and move the sister chromatids toward the middle of the cell

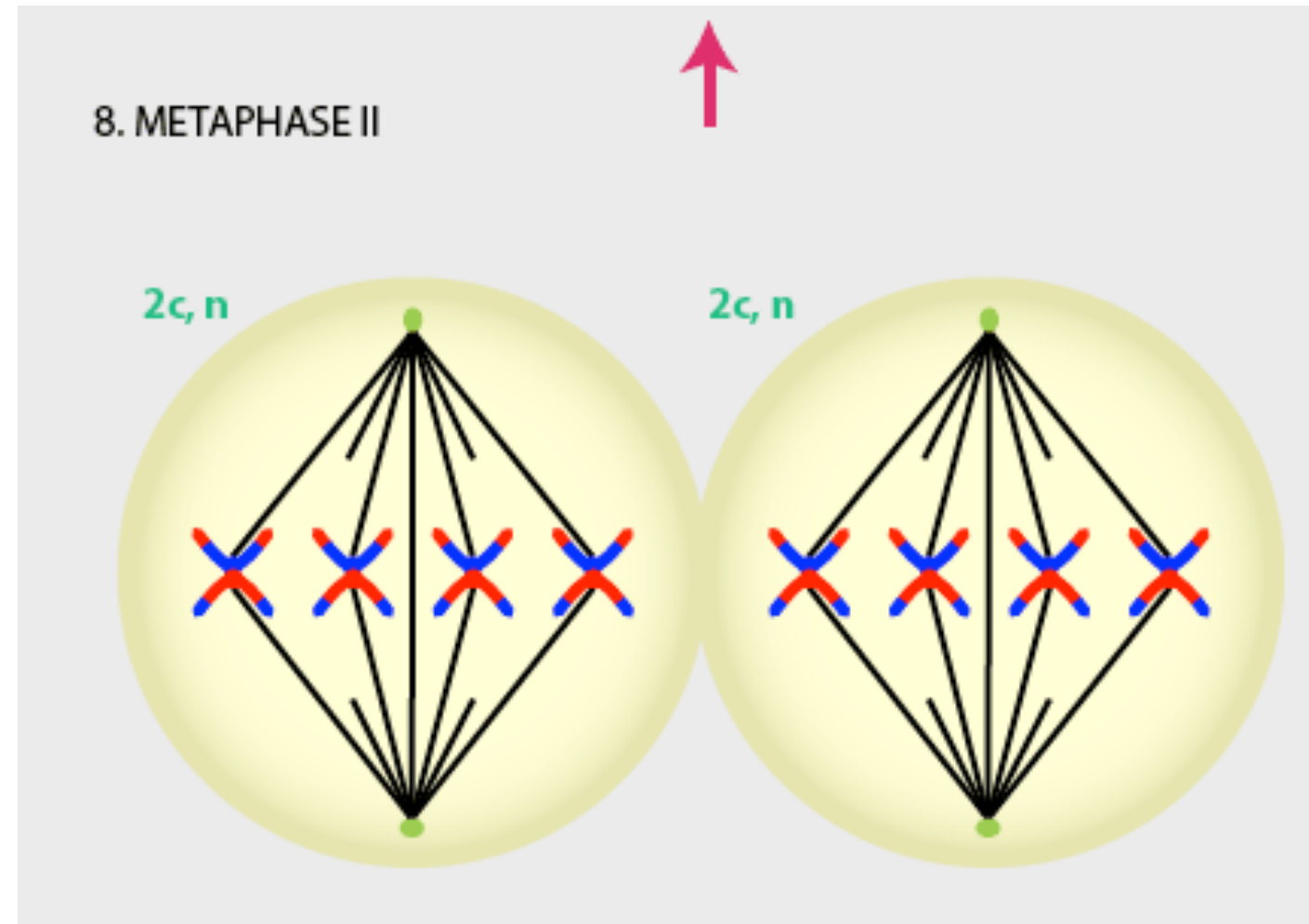




# Meiosis: A Closer Look

- **Metaphase II**

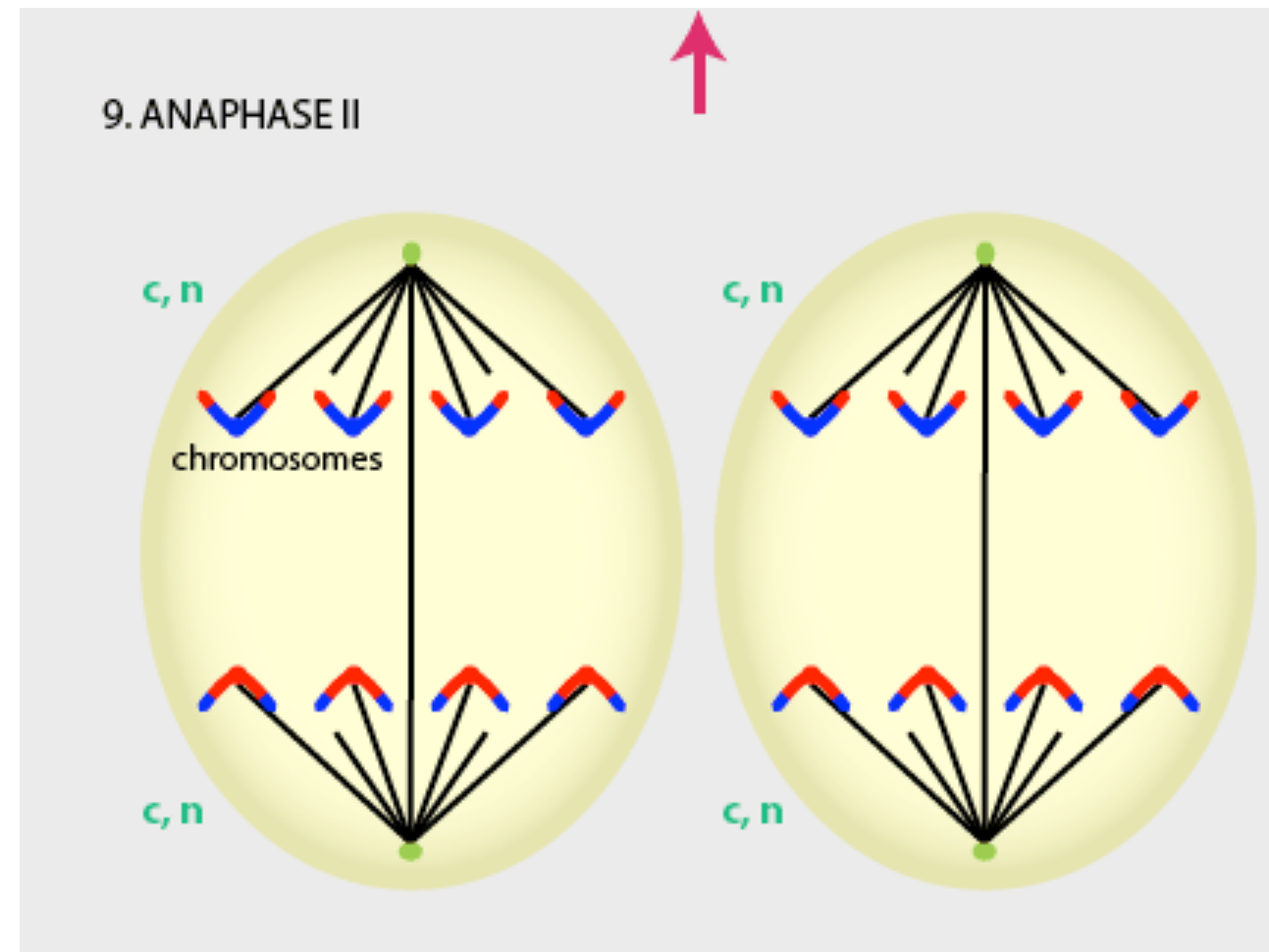
- sister chromatids are now aligned at the metaphase plate
- each chromatid of each pair are genetically unique because of crossing over



# Meiosis: A Closer Look

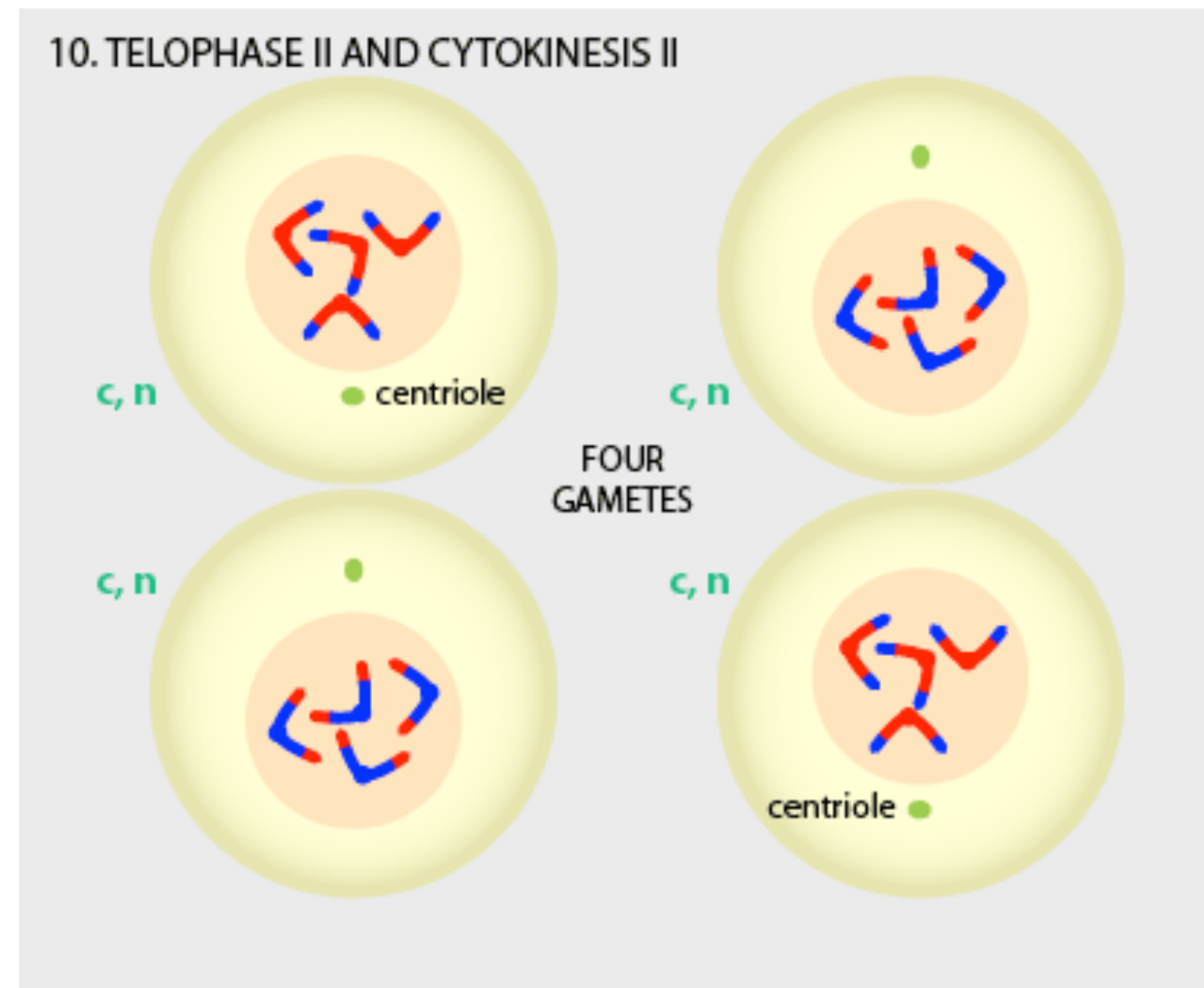
- **Anaphase II**

- proteins holding sister chromatids breakdown
- chromatids separate and move toward opposite poles as individual chromosomes



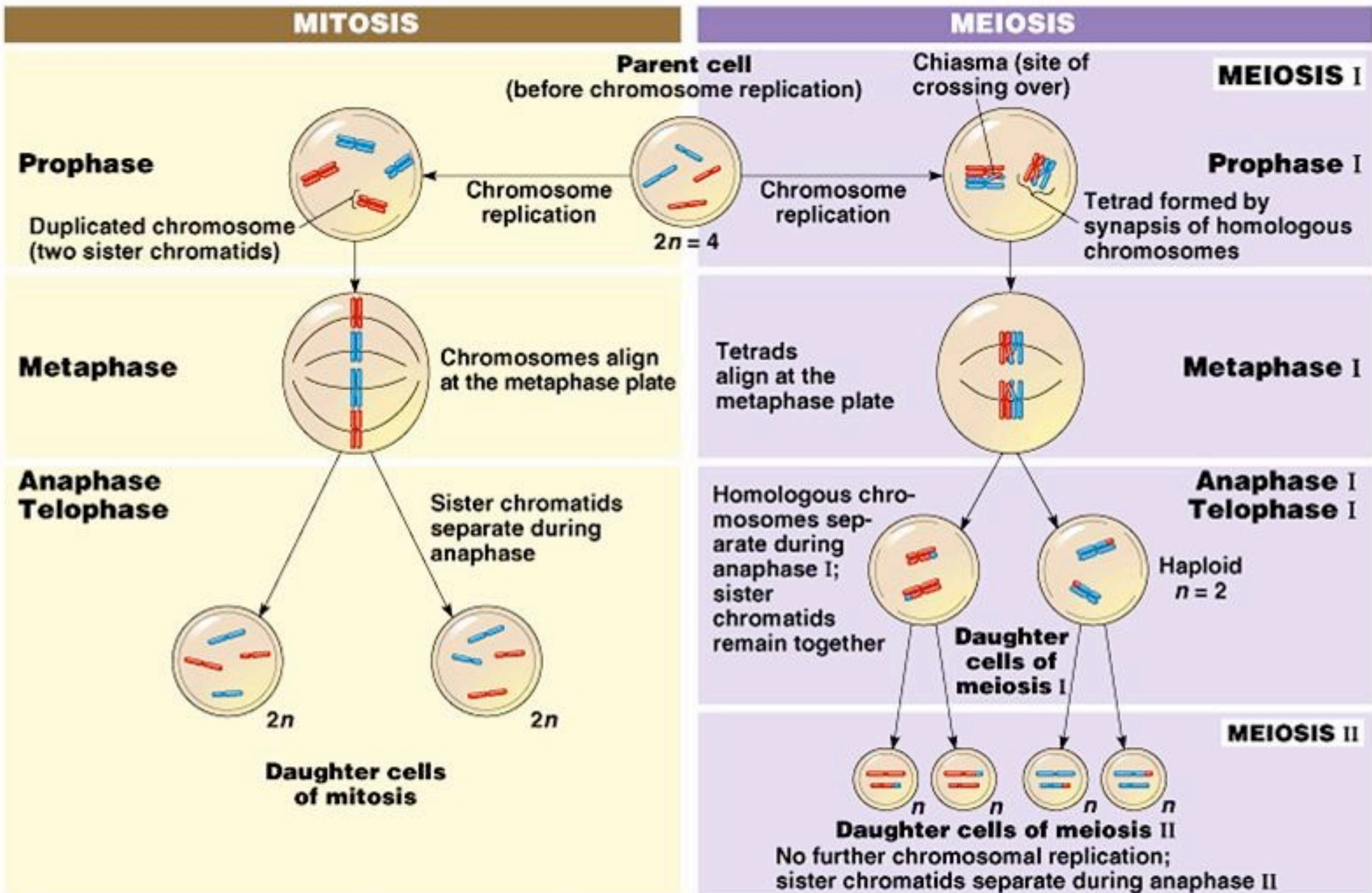
# Meiosis: A Closer Look

- **Telophase II & Cytokinesis**
  - chromosomes begin to de-condense
  - nuclear envelop reforms
  - cytokinesis results in 4 haploid cells
  - 4 cells are unique and haploid





# Illustrated Comparison



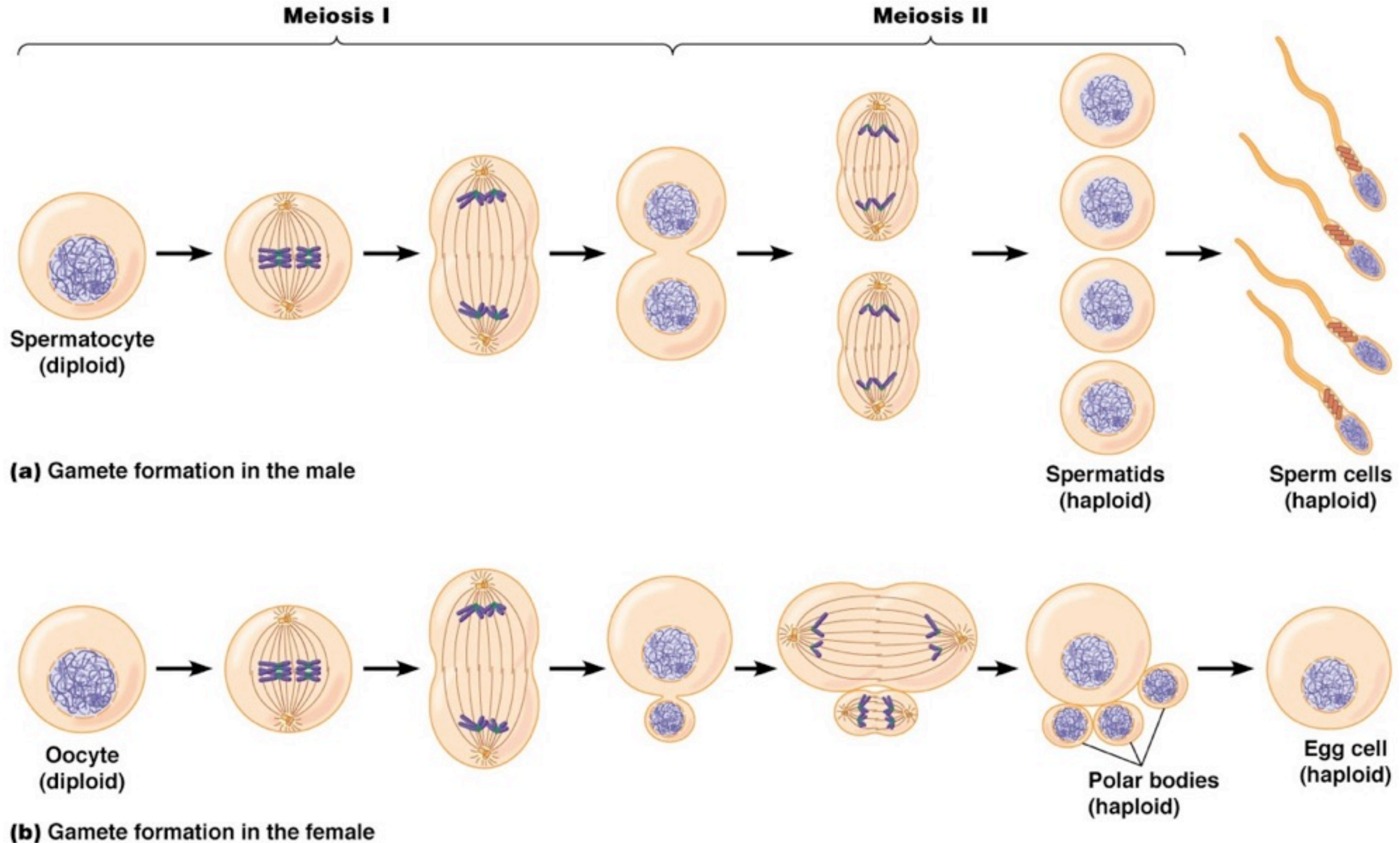


# Summary: Mitosis/Meiosis

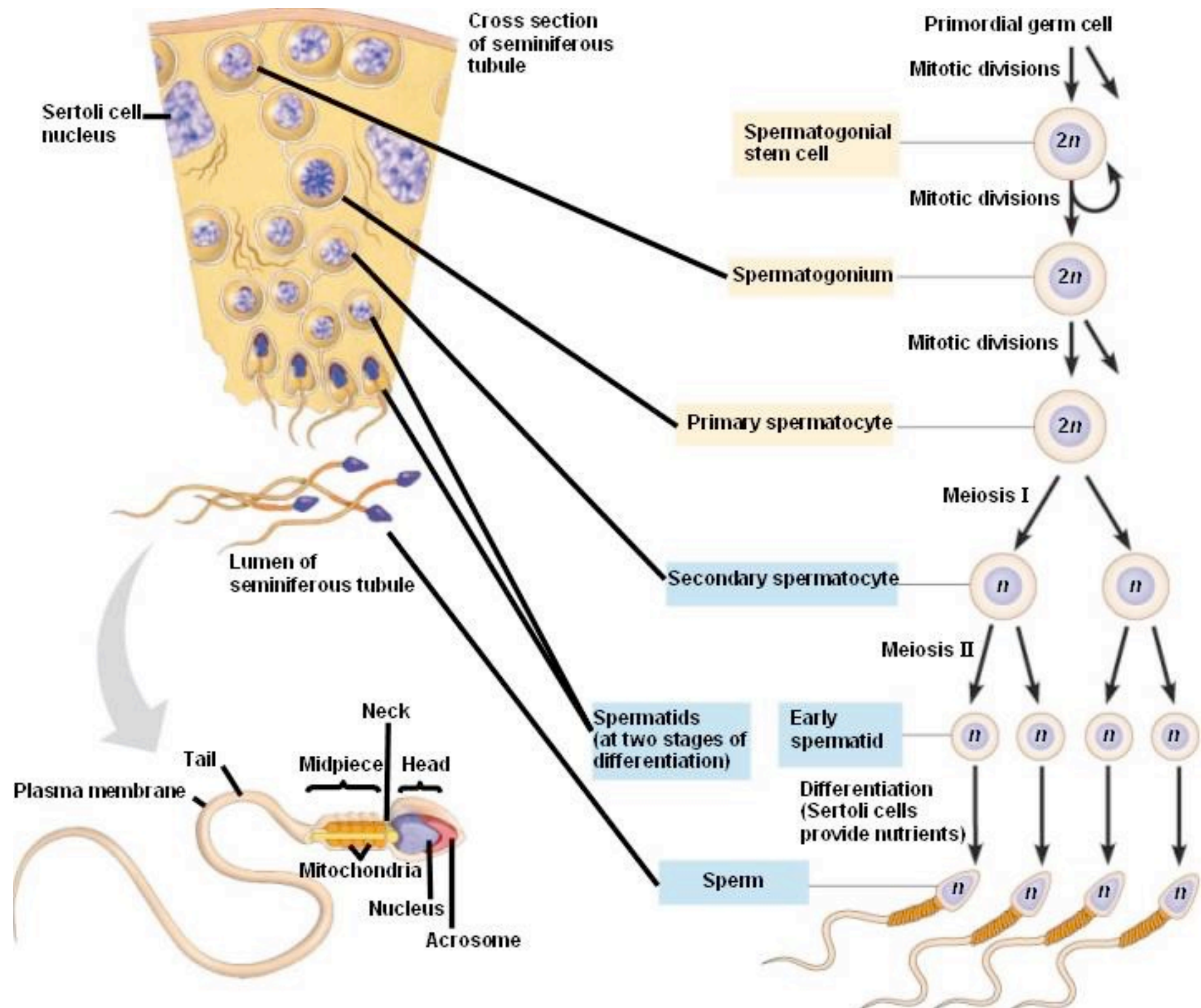
SUMMARY		
Event	Mitosis	Meiosis
DNA replication	Occurs during interphase before nuclear division begins	Occurs once, during the interphase before meiosis I begins
Number of divisions	One, including prophase, metaphase, anaphase, and telophase	Two, each including prophase, metaphase, anaphase, and telophase
Synapsis of homologous chromosomes	Does not occur	Synapsis is unique to meiosis: During prophase I, the homologous chromosomes join along their length, forming tetrads (groups of four chromatids); synapsis is associated with crossing over between nonsister chromatids
Number of daughter cells and genetic composition	Two, each diploid ( $2n$ ) and genetically identical to the parent cell	Four, each haploid ( $n$ ), containing half as many chromosomes as the parent cell; genetically nonidentical to the parent cell and to each other
Role in the animal body	Enables multicellular adult to arise from zygote; produces cells for growth and tissue repair	Produces gametes; reduces chromosome number by half and introduces genetic variability among the gametes



# Production of Gametes

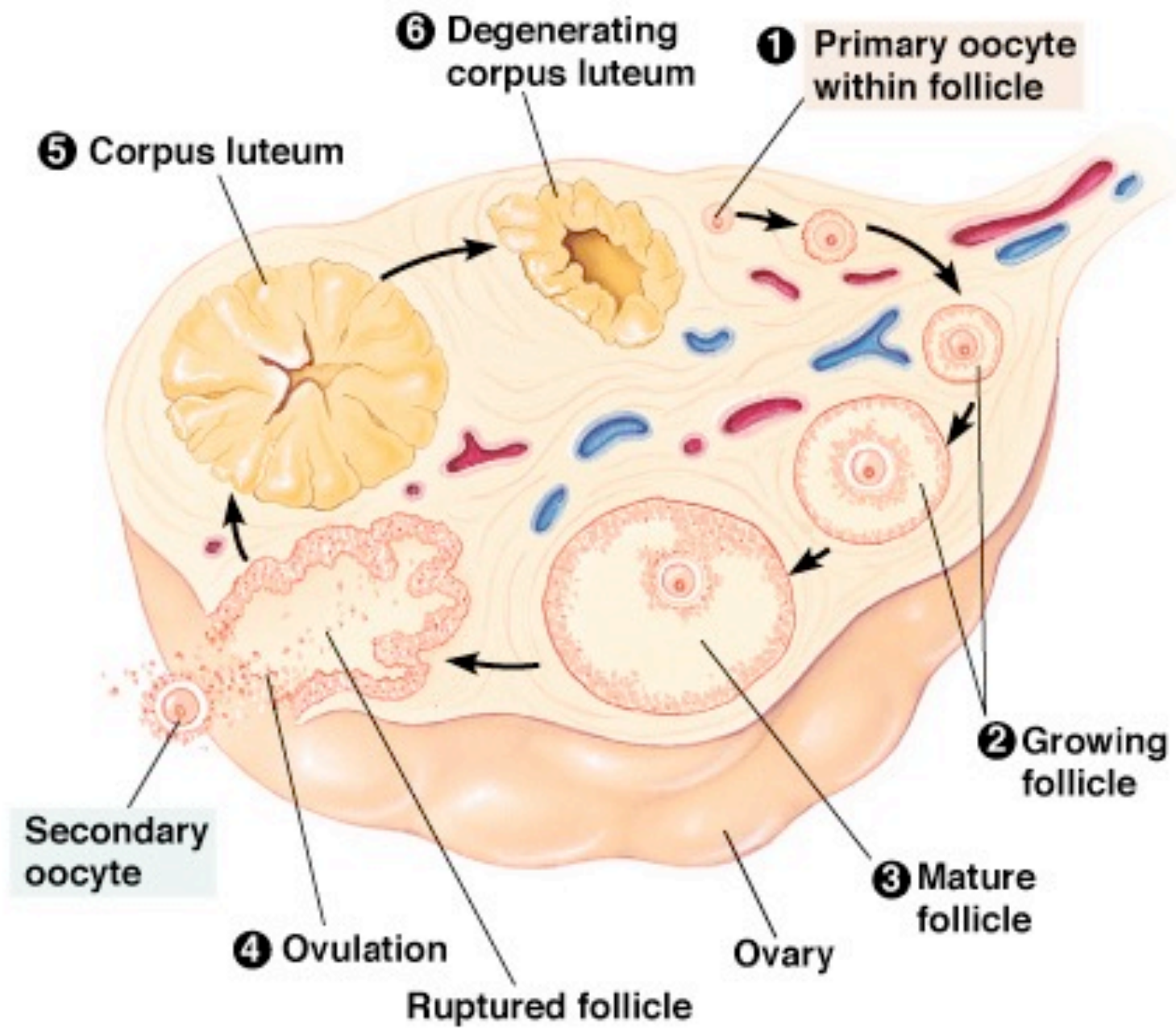
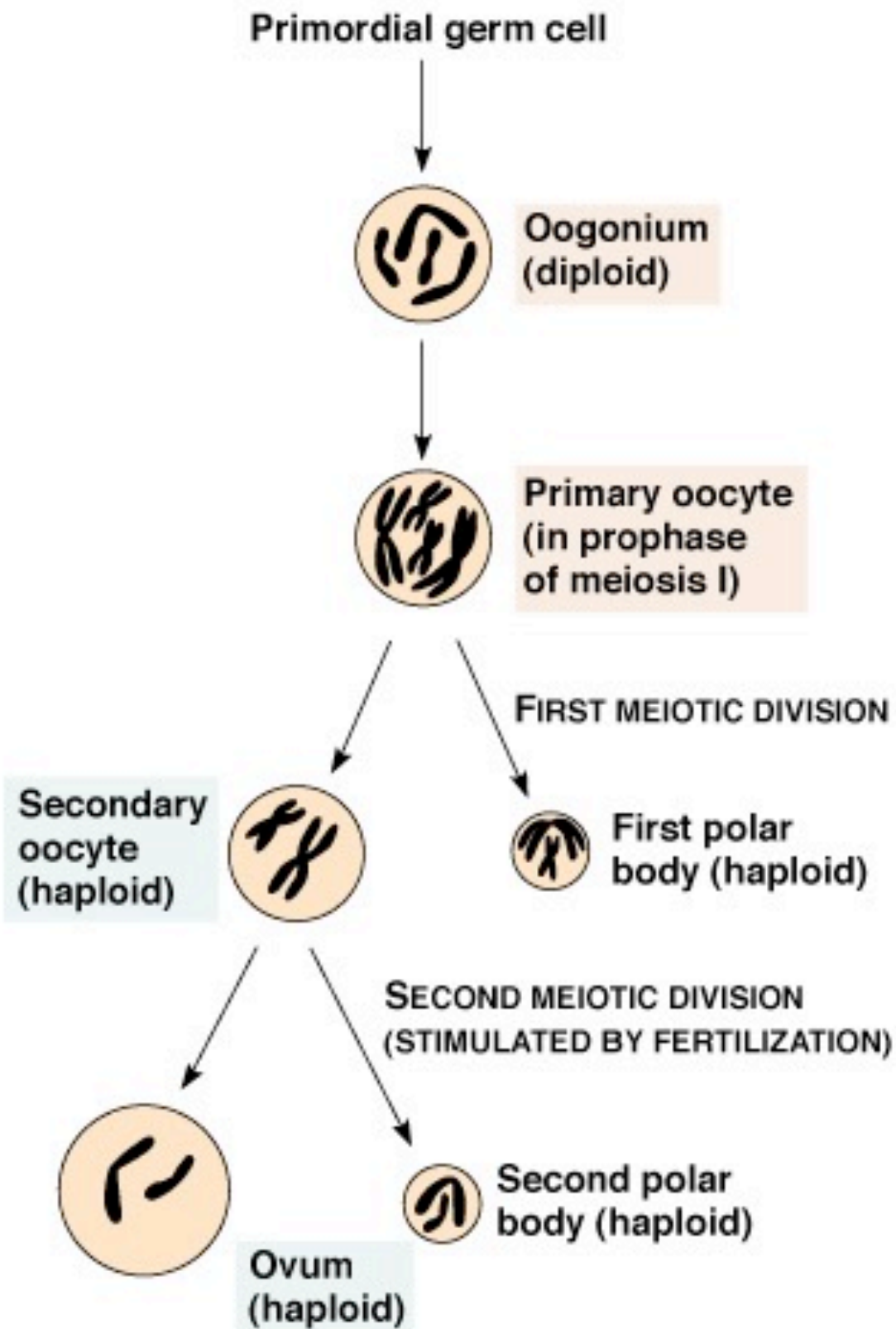


# Closer Look: Spermatogenesis



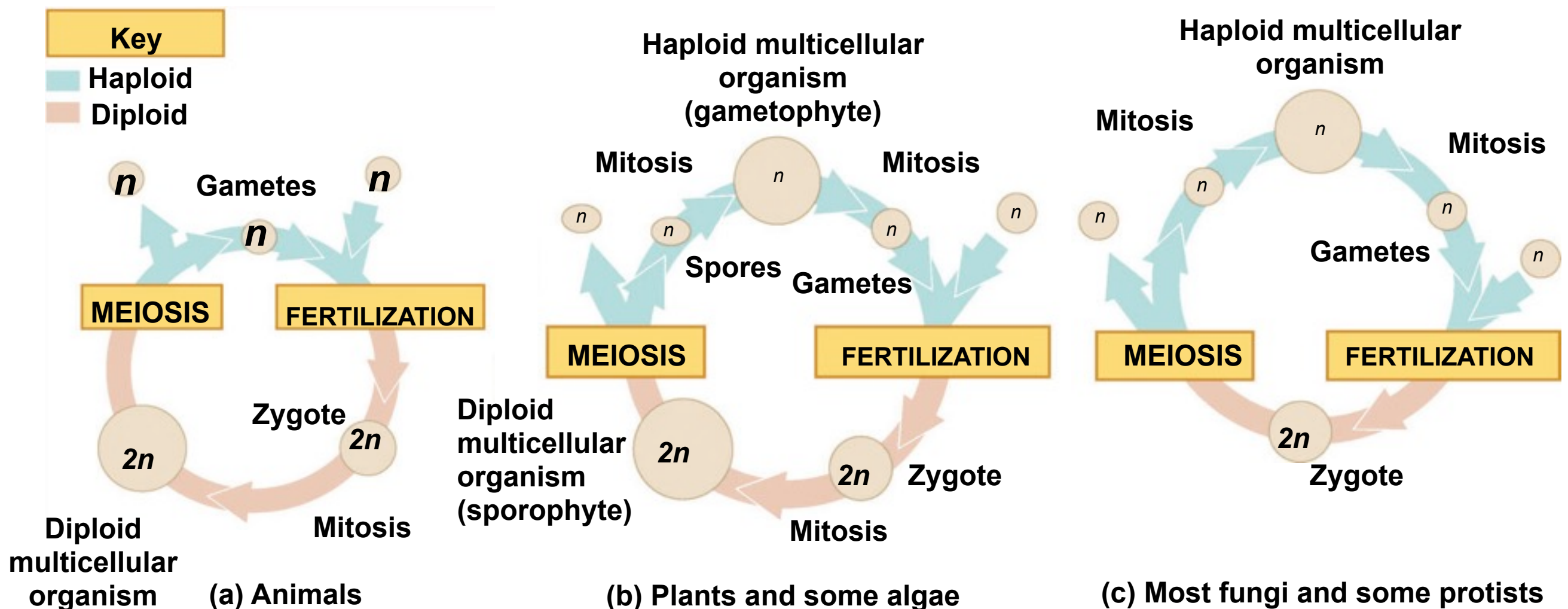


# Closer Look: Oogenesis



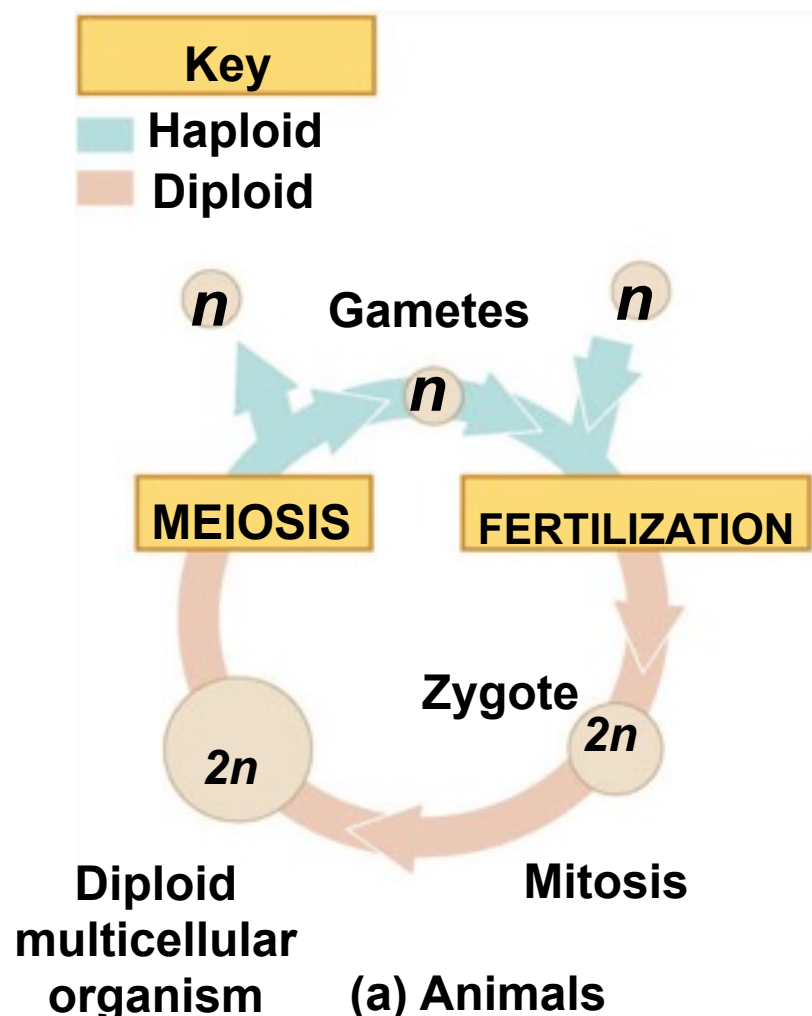
# Variation of Sexual Life Cycles

- Alternation of fertilization and meiosis is common in all cycles
- The timing of these two events differs in each cycle



- Meiosis occurs only in germ cells
- Germ cells produce gametes
- Gametes are the only haploid cells
- Zygote grows mitotically into a multicellular diploid organism

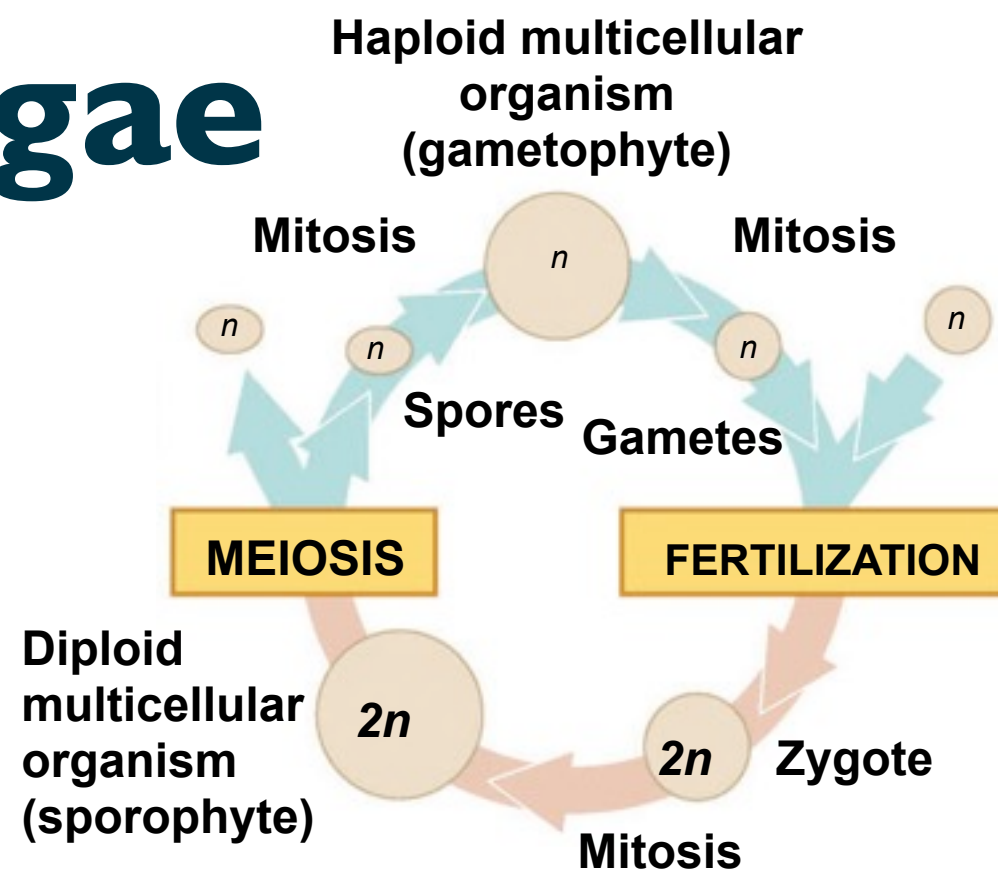
# Animal Life Cycle





- Exhibit *alternation of generations*-
- Gametophyte- a multicellular haploid organism/stage
  - produces haploid spores
- Sporophyte- a multicellular diploid organism/stage
  - produces haploid gametes

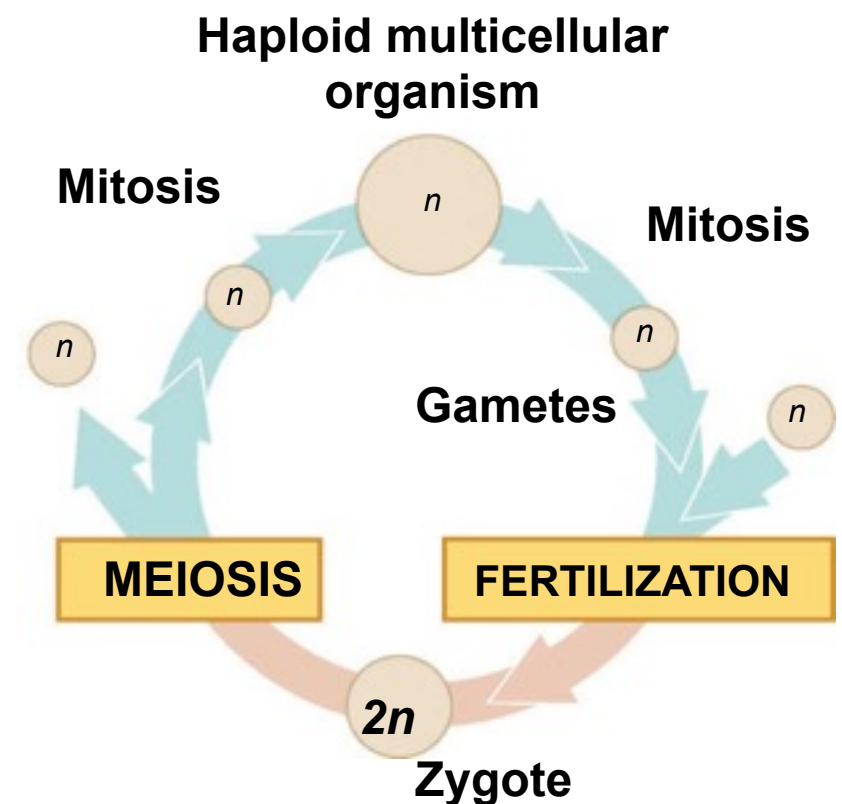
# Plant/Algae Life Cycle



(b) Plants and some algae

- Meiosis occurs in zygote
- Meiosis does not result in gametes
- Meiosis produces haploid cells that mitotically produce a multicellular haploid organism
- Mitosis produces gametes

# Fungi/Protists Life Cycles



(c) Most fungi and some protists

# Meiosis

**Main Idea: Meiosis creates the genetic variation associated with sexual reproduction.**



# Evolution & Genetics

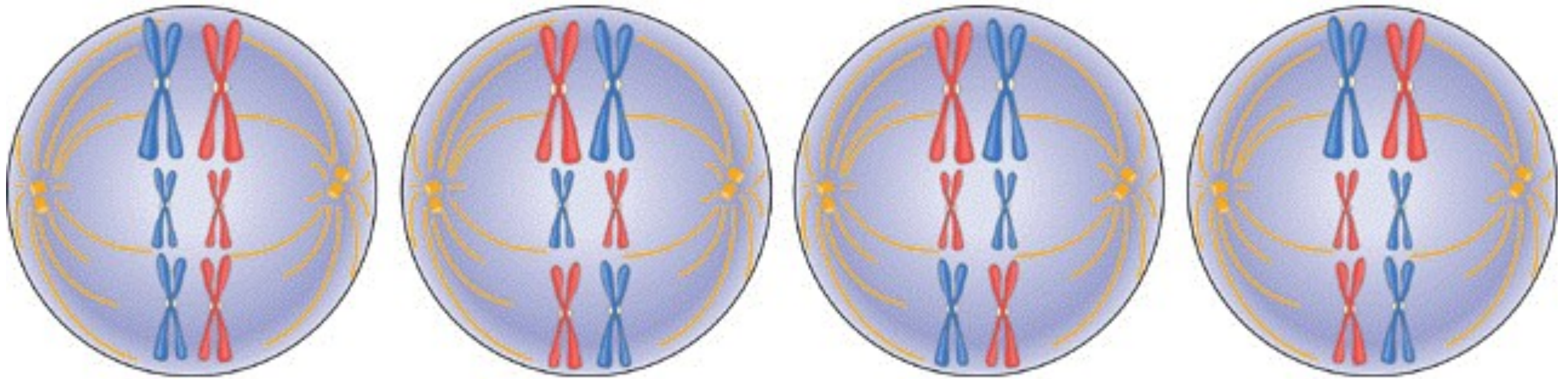
- Mutations created every allele, and will create every new allele in the future.
- *recall alleles are different genes*
- Sexual Reproduction/Meiosis shuffles those alleles to produce unique individuals and variation in gene pools
- Meiosis plays therefor a direct role in evolution by providing the necessary variation for natural selection to work on.
- **Also, understanding meiosis provides an understanding of the mechanics behind inheritance of traits (genetics)**

# Evolution & Genetics

- The following slides will explore 3 mechanisms that generate variation in sexual reproduction.
  - independent assortment,
  - crossing over and
  - random fertilization
- This exploration is important for two reasons:
  - First, it illuminates the sources of variation that evolution requires.
  - **Secondly, understanding meiosis and these same mechanisms and that generate variation will provide the foundation for our understanding of inheritance (genetics).**

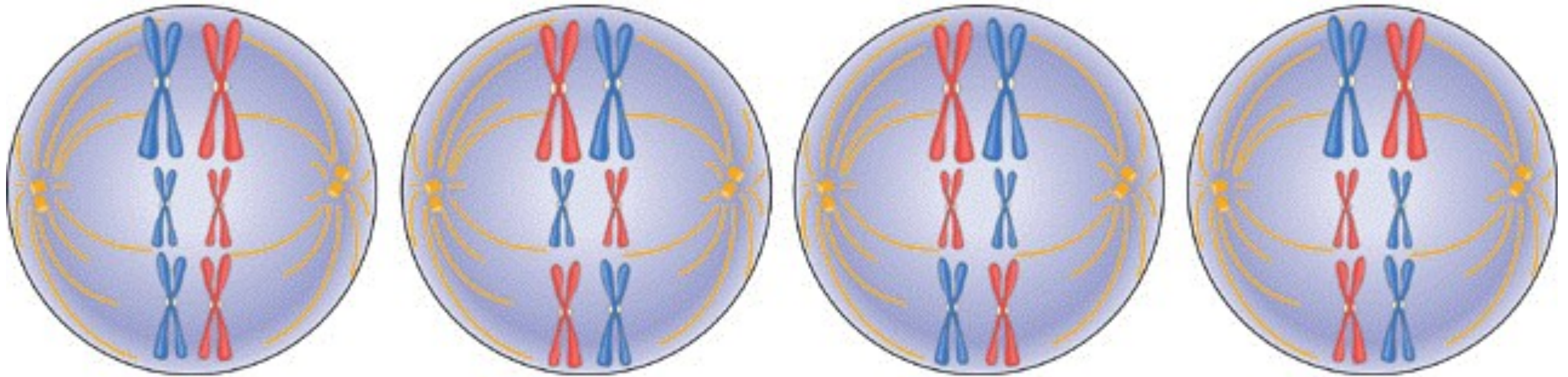


# Independent assortment



- In metaphase I, the homologous pairs (tetrads) align randomly at the cellular equator.
- The paternal and maternal chromosomes are randomly oriented towards one of the poles.
- *Notice above 3 homologous pairs (tetrads) can arrange themselves in 4 different ways.*

# Independent assortment

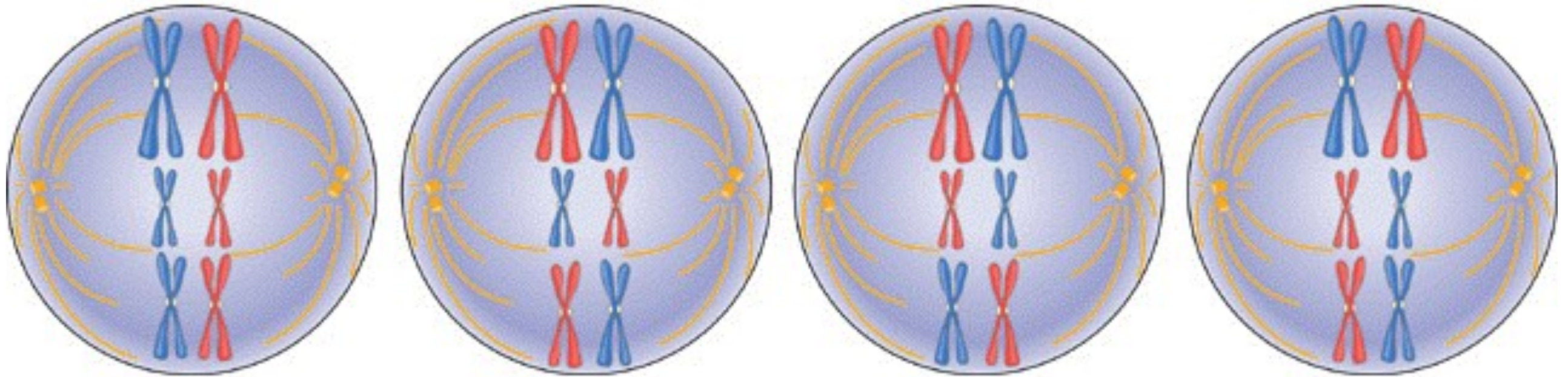


- Thus every gamete has a 50% chance of getting a paternal or maternal chromosome for each and number of chromosome pairs.

**How many different gametes are produced if this example of meiosis goes to completion?**



# Independent assortment

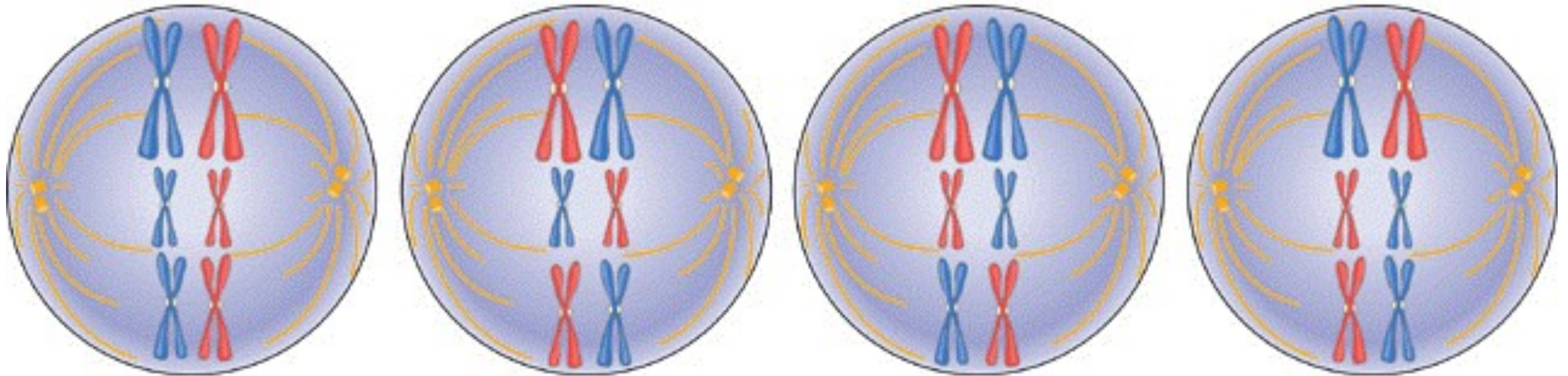


- Thus every gamete has a 50% chance of getting a paternal or maternal chromosome for each and number of chromosome pairs.

**How many different gametes are produced if this example of meiosis goes to completion?**

**8**

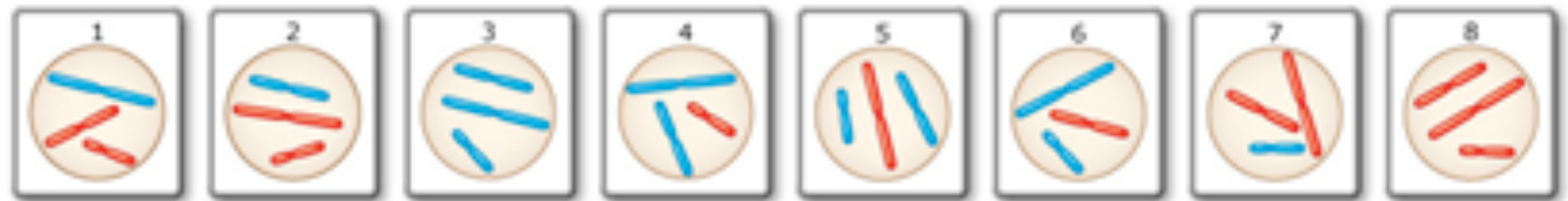
# Independent assortment



- Thus every gamete has a 50% chance of getting a paternal or maternal chromosome for each and number of chromosome pairs.

**How many different gametes are produced if this example of meiosis goes to completion?**

**8**





- Each daughter cell represents one outcome of all possible combinations of paternal and maternal chromosome combinations.
- Mathematically we can calculate the number of possible combinations by using the following equation:
  - $2^n$  where  $n$  is the haploid number of the organism.

## Humans:

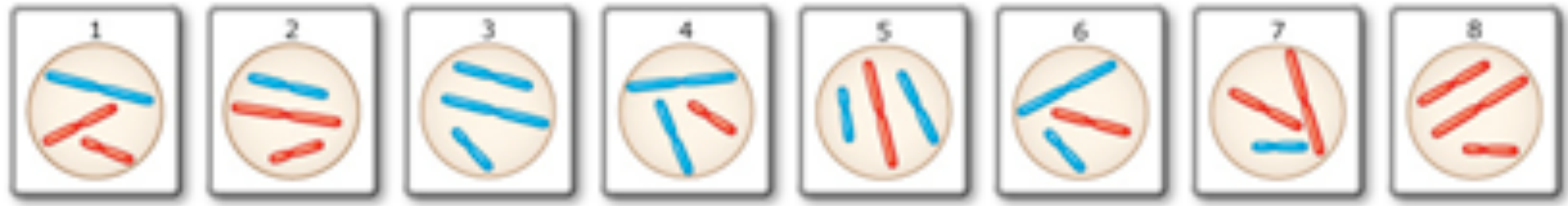
...haploid number is 23, so  $2^{23} = \sim 8.4$  million

## Bottom Line-

...humans can create  $\sim 8.4$  million different gametes from independent assortment alone



- Each daughter cell represents one outcome of all possible combinations of paternal and maternal chromosome combinations.



- Mathematically we can calculate the number of possible combinations by using the following equation:
  - $2^n$  where  $n$  is the haploid number of the organism.

## Humans:

...haploid number is 23, so  $2^{23} = \sim 8.4$  million

## Bottom Line-

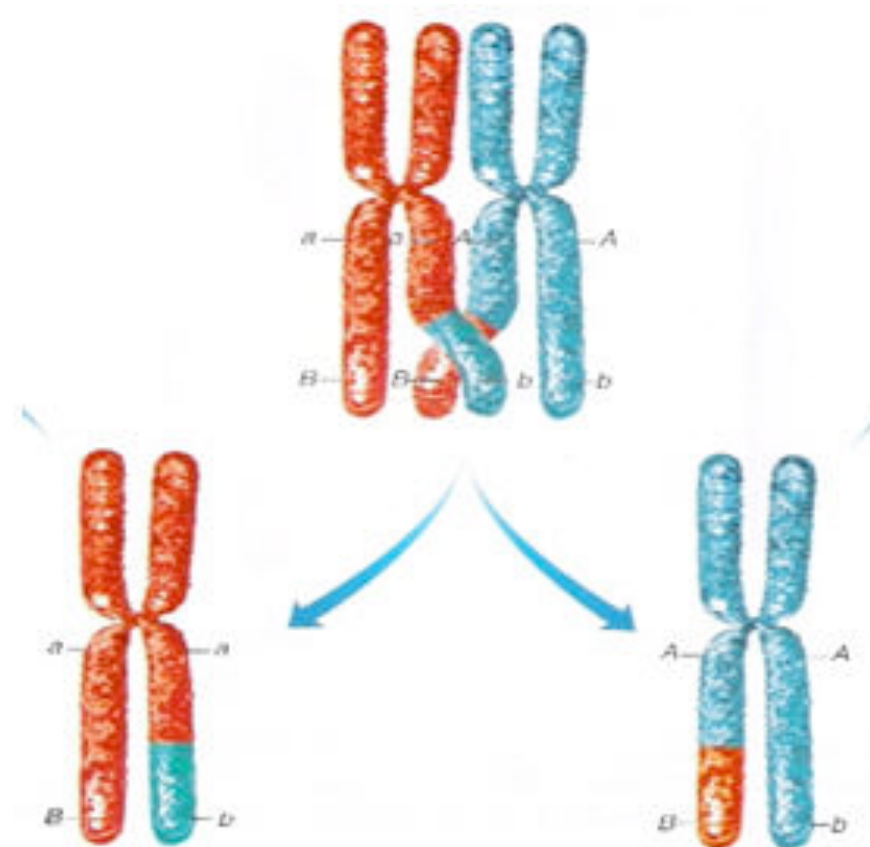
...humans can create  $\sim 8.4$  million different gametes  
from independent assortment alone

# Random Fertilization

- Although the process of ovulation is not random the actual oocyte that is ovulated is completely random.
- Although some sperm are more fit than others, the actual sperm that fertilizes the oocyte is completely random.
- This brings us back to the math...  $(8.4\text{million})(8.4\text{million})=$ 
  - *...if any of the 8.4 million different oocytes could be fertilized by any of the 8.4 million different sperm than we could in produce ~*  
**70 trillion different zygotes!**
- You can see that validity in the age old expression “you are one of a kind”
- But even this number does not tell the whole story of our truly unique nature, the fact is the actual number is far greater than 70 trillion.

# Crossing Over

- Our examination of independent assortment leads us to believe that we inherit strictly paternal or maternal chromosomes but this is not the case.
- As a consequence of independent assortment paternal and maternal chromosomes exchange segments creating unique chromosomes different than the one we inherited from our parents.



# Crossing Over

Chiasma

nonsister chromatids

synapsis

crossing-over between nonsister chromatids

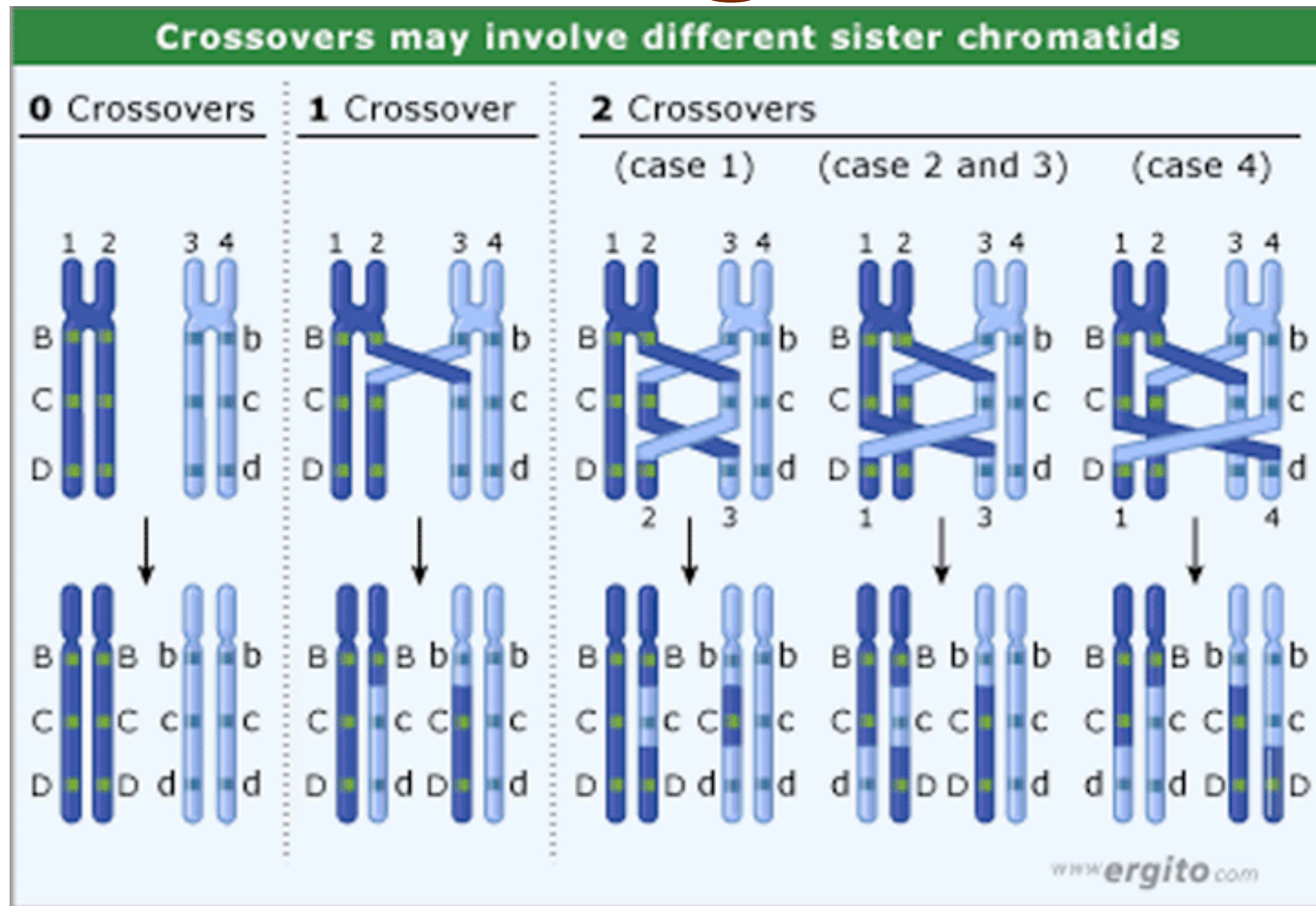
chromatids after exchange

chromosomes in four different gametes

Recombinant Chromosomes

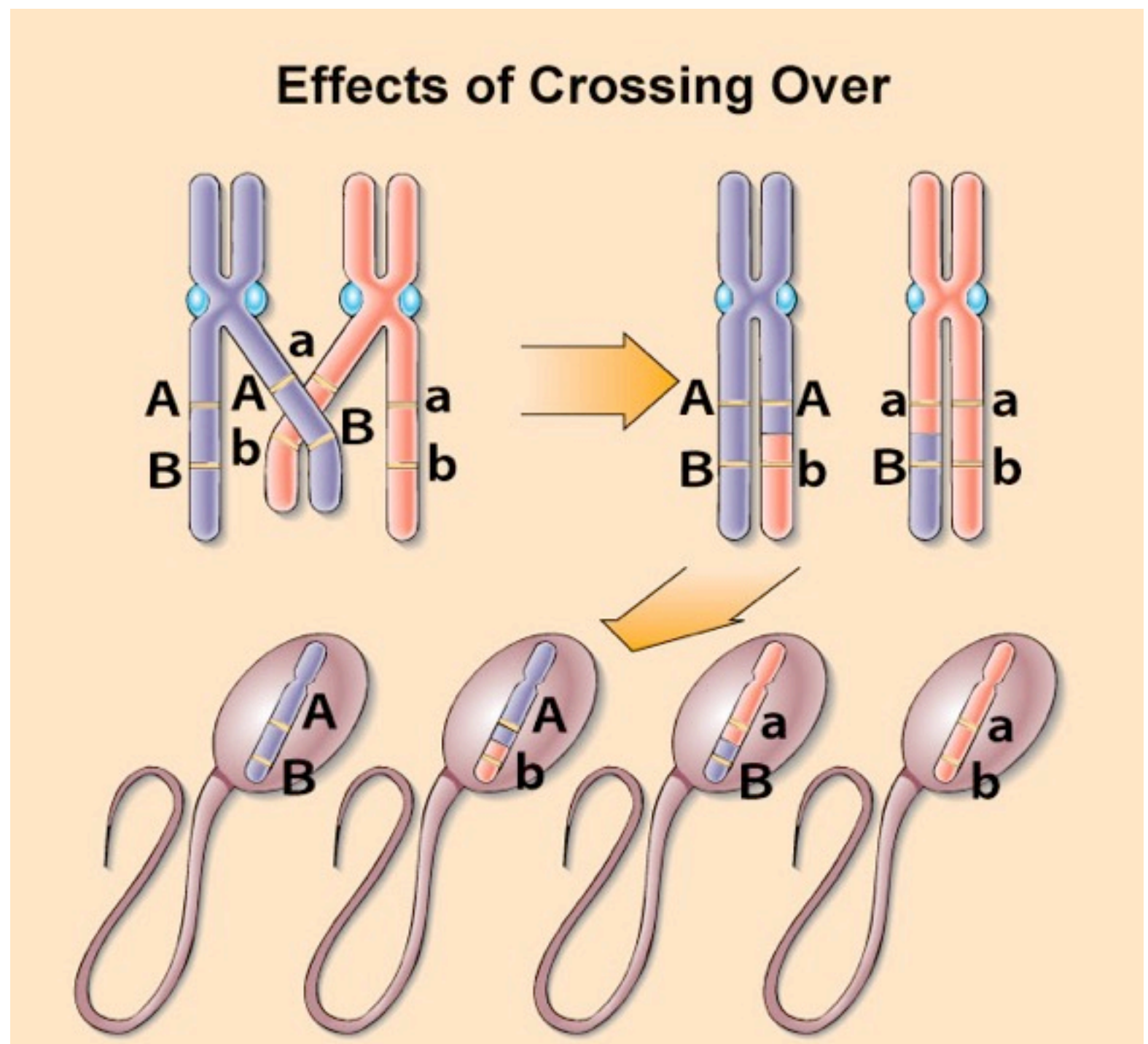


# Crossing Over



**Humans have on average 1-3 cross overs per chromosome pair, depending on the size of chromosome and the position of their centromere.**

**In this simple example crossing over has doubled the genetic variation possible.**



When we consider that crossing over takes place 1-3 times on 23 different pairs, multiply that by the variation that independent assortment and random fertilization create and you have an astronomically large number of possible individual offspring.

# Learning Objectives:

LO 3.7 The student can make predictions about natural phenomena occurring during the cell cycle. [See SP 6.2, 6.5]

LO 3.8 The student can describe the events that occur in the cell cycle. [See SP 1.2]

LO 3.9 The student is able to construct an explanation, using visual representations or narratives, as to how DNA in chromosomes is transmitted to the next generation via mitosis, or meiosis followed by fertilization. [See SP 6.2]

LO 3.10 The student is able to represent the connection between meiosis and increased genetic diversity necessary for evolution. [See SP 7.1]

LO 3.11 The student is able to evaluate evidence provided by data sets to support the claim that heritable information is passed from one generation to another generation through mitosis, or meiosis followed by fertilization. [See SP 5.3]