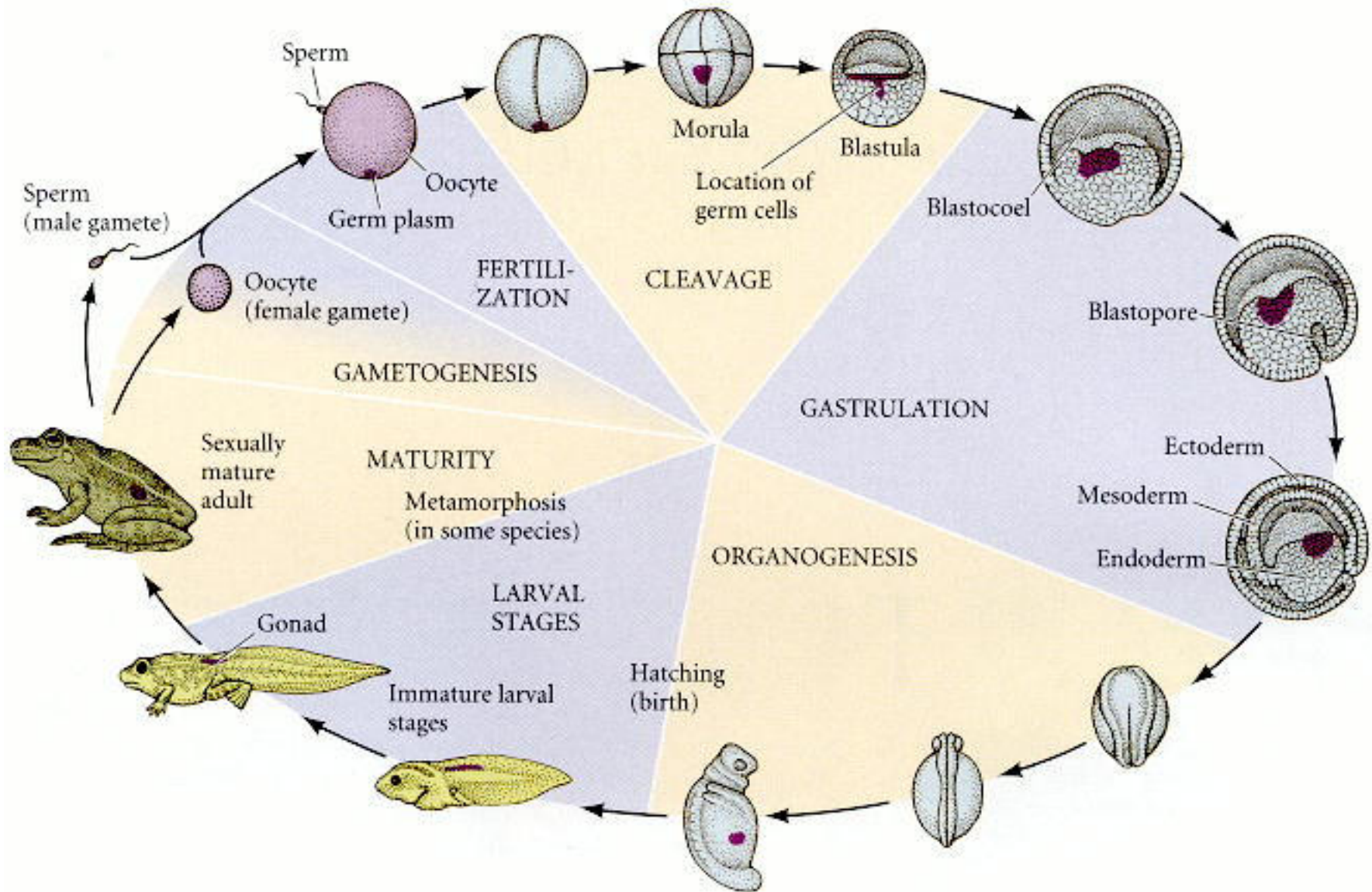


# Frog Life Cycle



# How did multicellular organism evolve?

Two examples:

Volvox – colony of organisms evolved specialized cells

Dictyostelium – individual cells for cell aggregates that act like a multicellular organism

# Volvocales

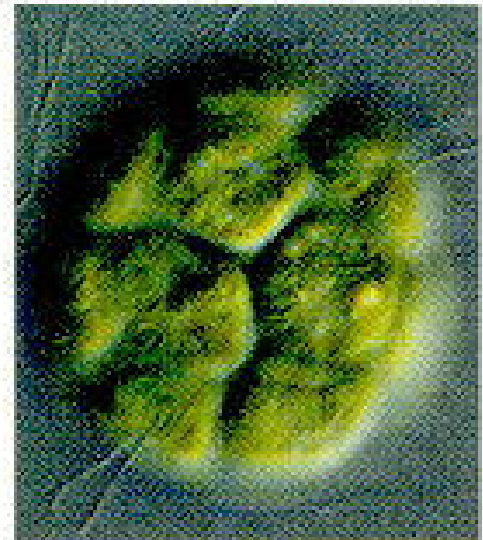
(A)



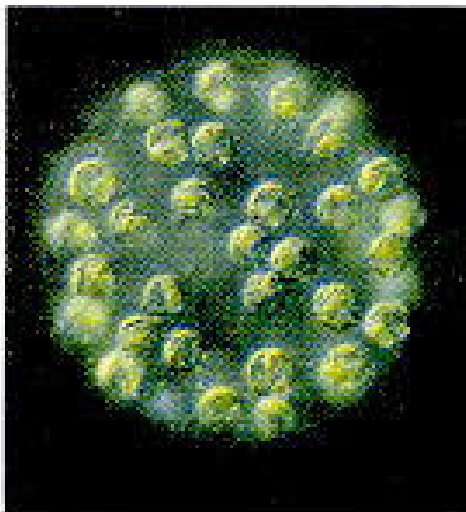
(B)



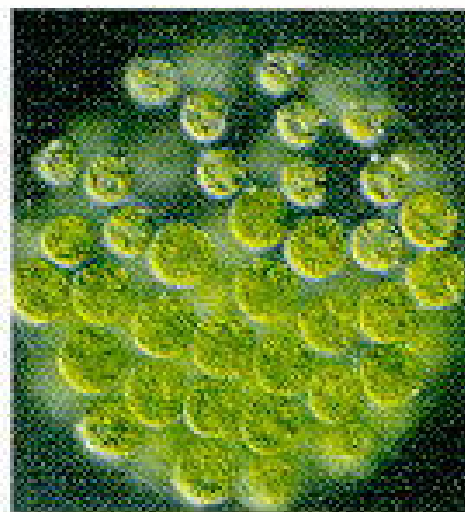
(C)



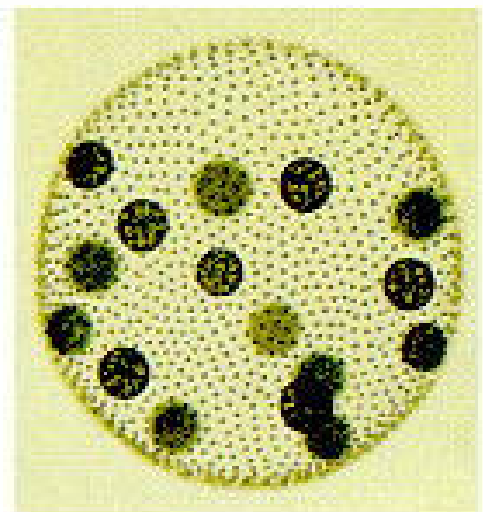
(D)



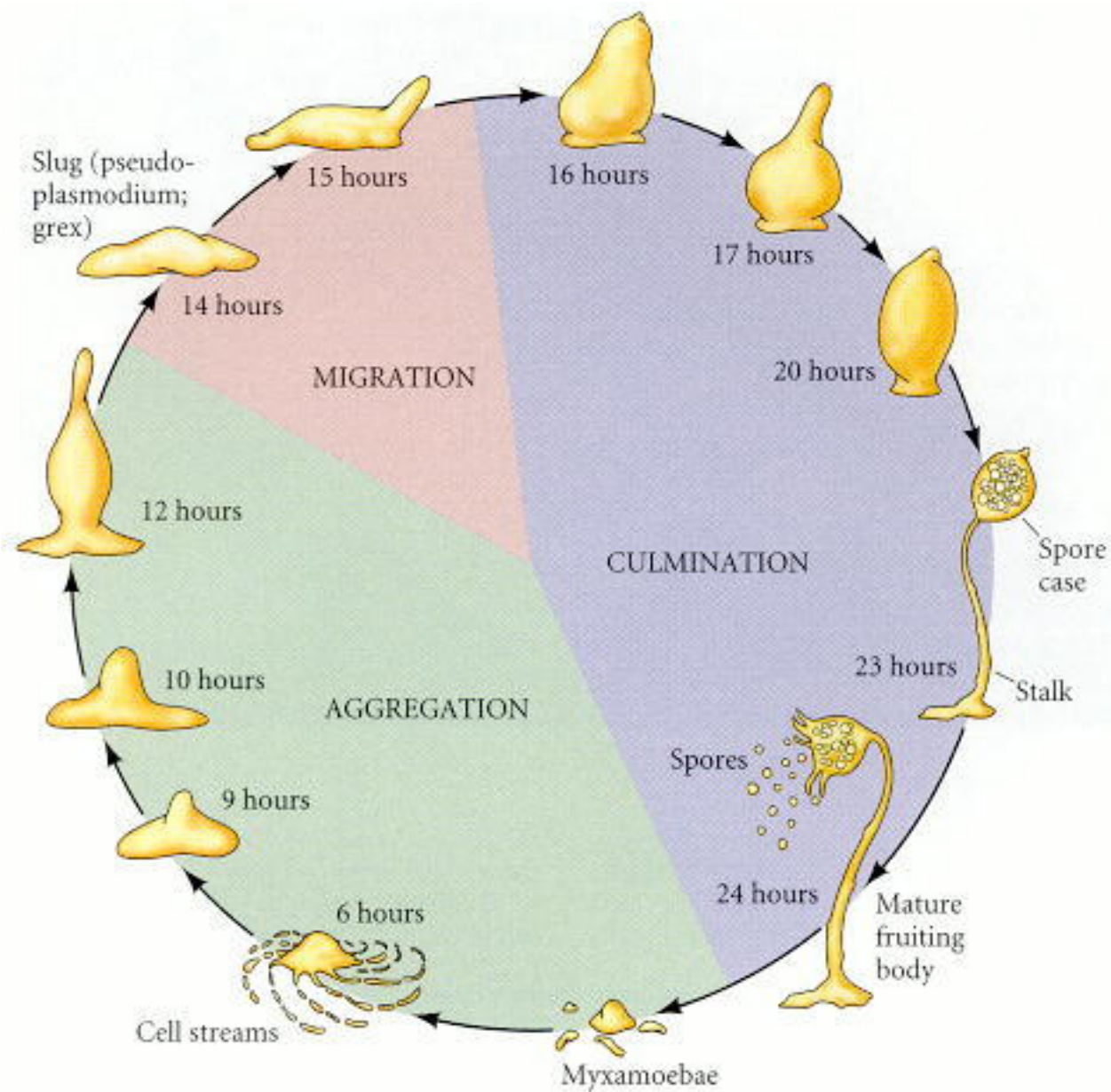
(E)



(F)

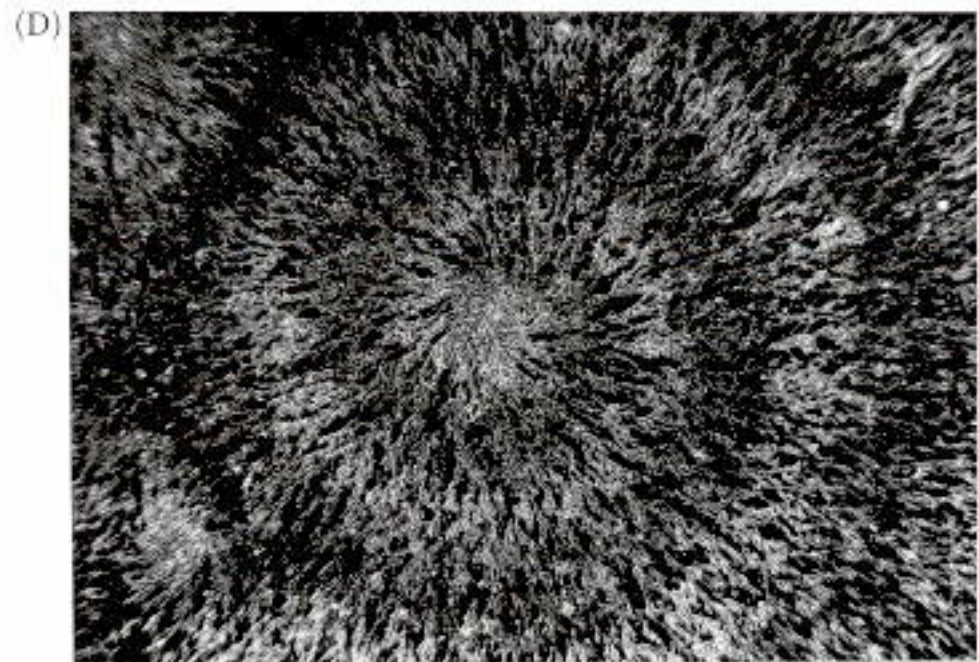
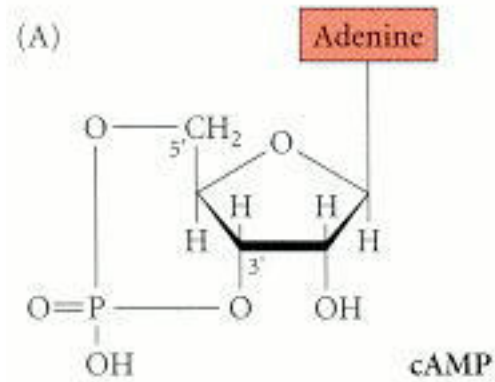


# Life cycle of *Dictyostelium*

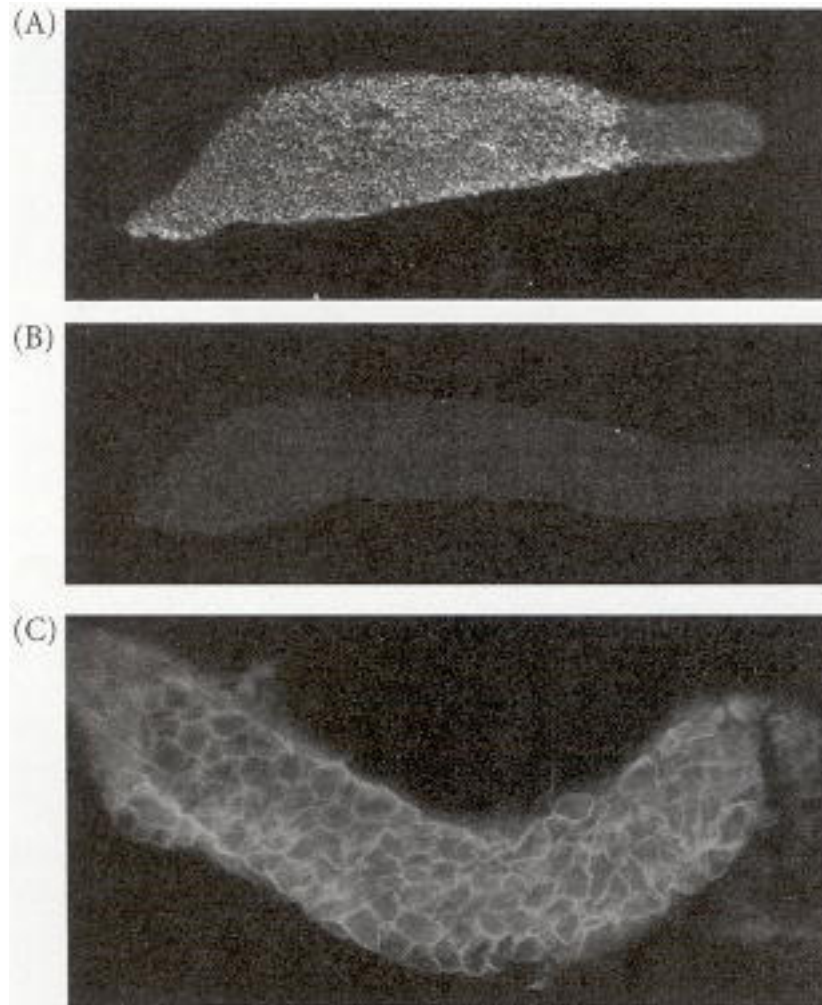




# Chemotaxis of *Dictyostelium*



# *Dictyostelium* “Slug”







CNRI/Photo Researchers Inc.

# Eukaryotic Chromosomes

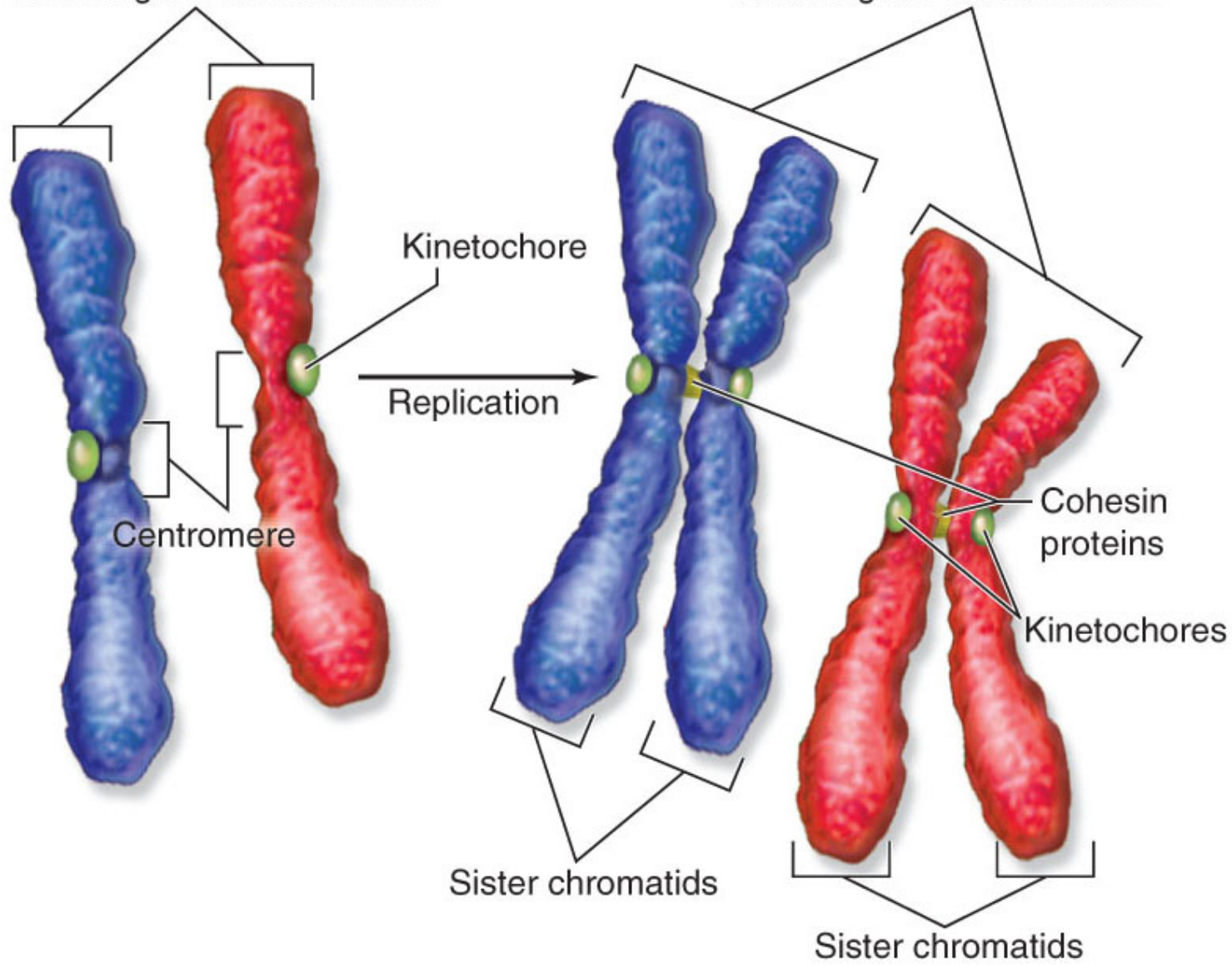
Chromosomes must be replicated before cell division.

- Replicated chromosomes are connected to each other at their **kinetochores**
- cohesin** – complex of proteins holding replicated chromosomes together
- sister chromatids**: 2 copies of the chromosome within the replicated chromosome



Homologous chromosomes

Homologous chromosomes



# Eukaryotic Cell Cycle

The eukaryotic cell cycle has 5 main phases:

- 1.  $G_1$  (gap phase 1)
  - 2. S (synthesis)
  - 3.  $G_2$  (gap phase 2)
  - 4. M (mitosis)
  - 5. C (cytokinesis)
- } interphase

The length of a complete cell cycle varies greatly among cell types.

# Interphase

Interphase is composed of:

$G_1$  (gap phase 1) – time of cell growth

S phase – synthesis of DNA (DNA replication)

- 2 sister chromatids are produced

$G_2$  (gap phase 2) – chromosomes condense

# Interphase

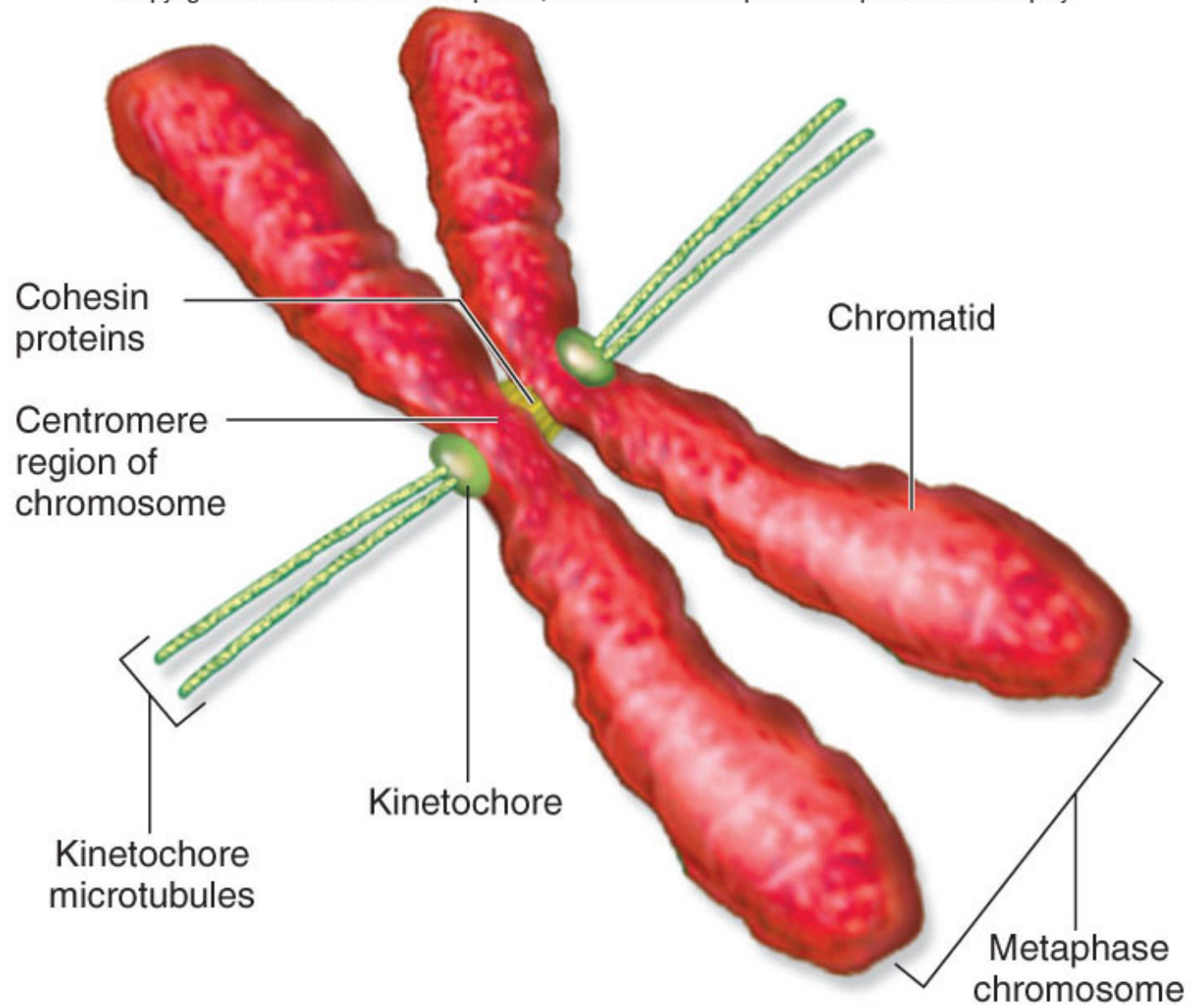
Following S phase, the sister chromatids appear to share a centromere.

In fact, the centromere has been replicated but the 2 centromeres are held together by cohesin proteins.

Proteins of the kinetochore are attached to the centromere.

Microtubules attach to the kinetochore.





# Interphase

During  $G_2$  the chromosomes undergo **condensation**, becoming tightly coiled.

**Centrioles** (microtubule-organizing centers) replicate and one centriole moves to each pole.

# Mitosis

Mitosis is divided into 5 phases:

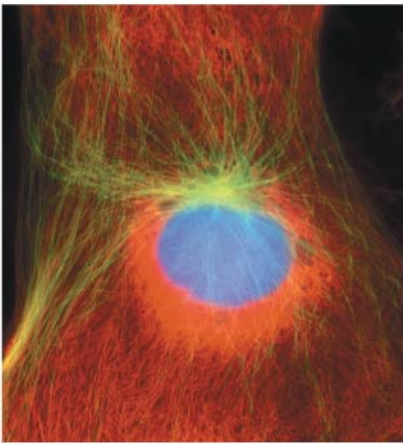
1. prophase
2. prometaphase
3. metaphase
4. anaphase
5. telophase

# Mitosis

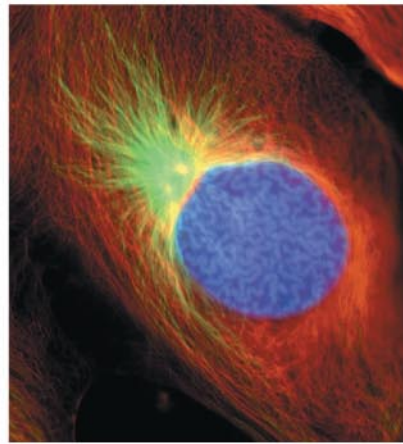
## Prophase:

- chromosomes continue to condense
- centrioles move to each pole of the cell
- spindle apparatus is assembled
- nuclear envelope dissolves

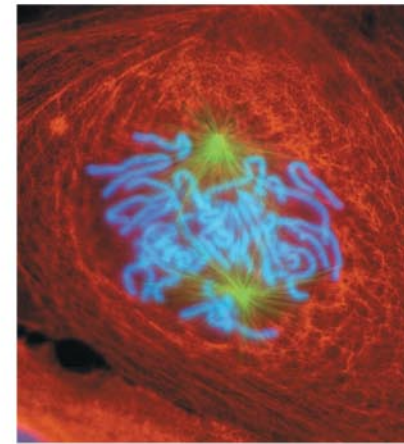




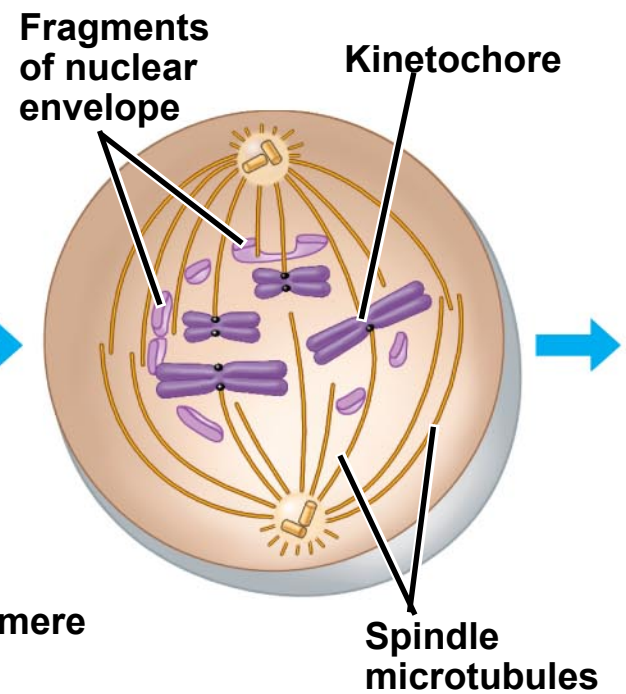
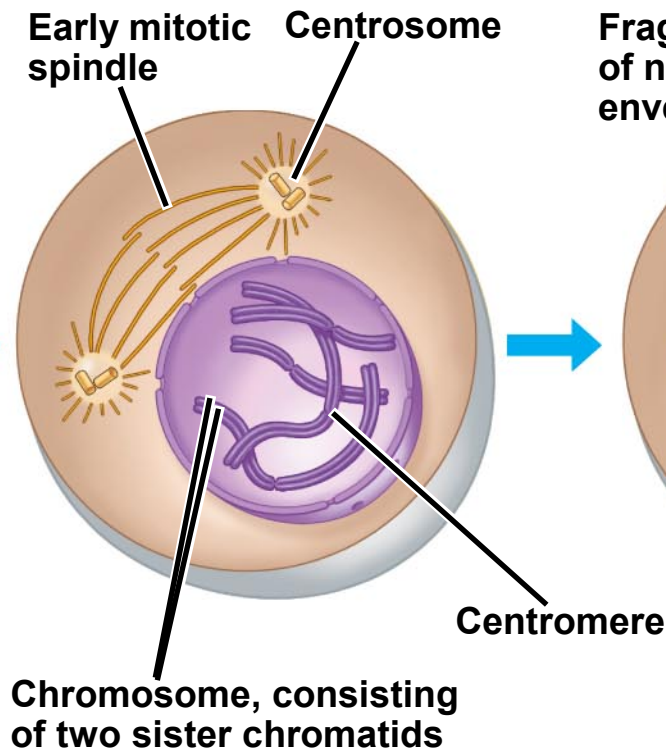
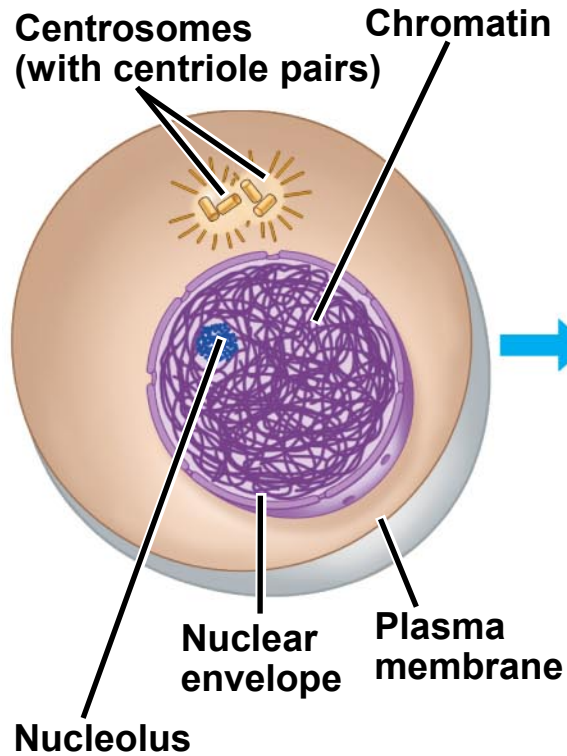
**INTERPHASE**

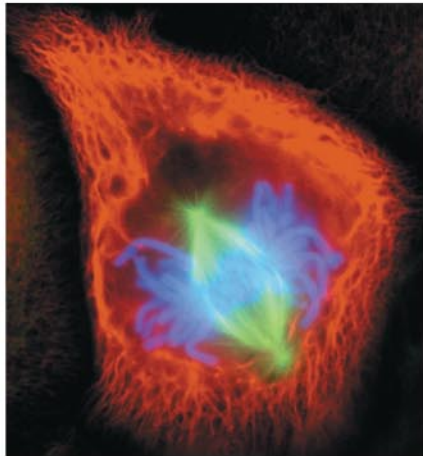


**PROPHASE**

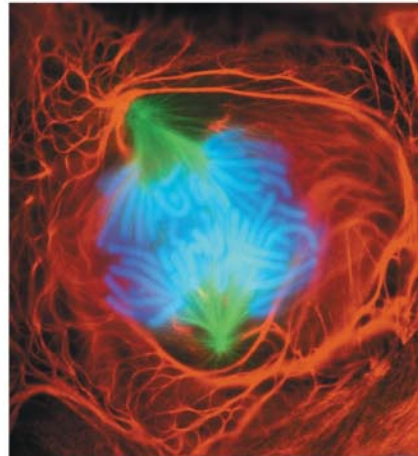


**PROMETAPHASE**

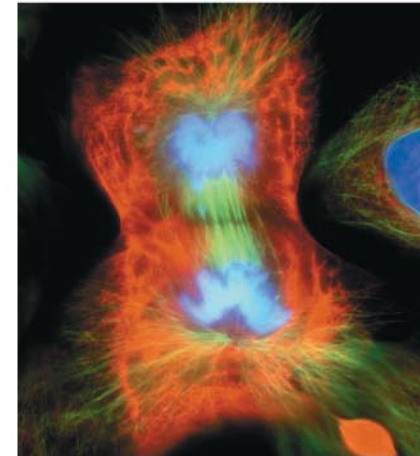




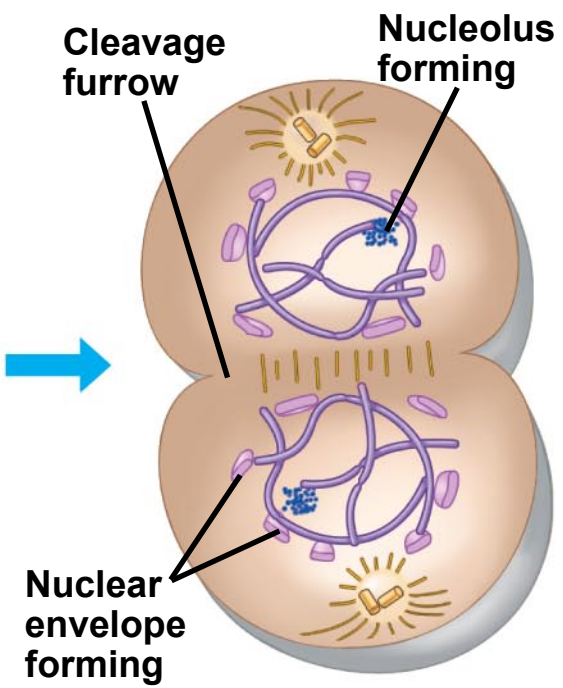
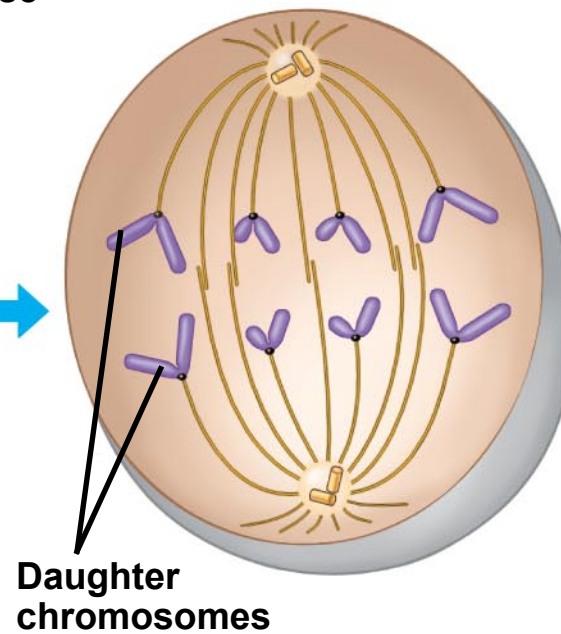
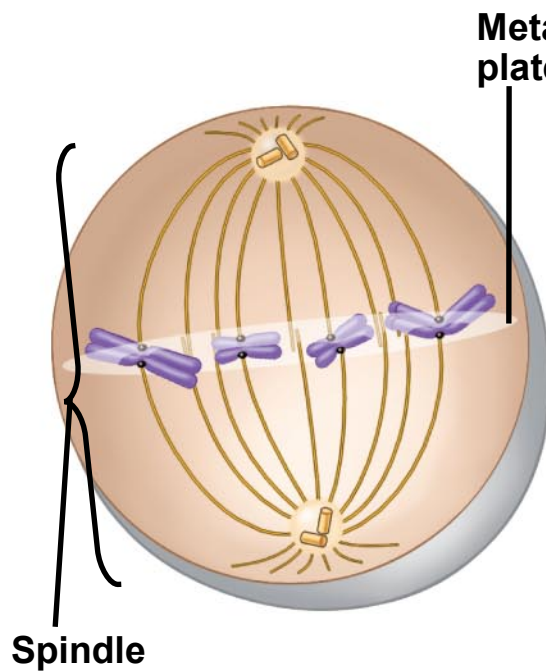
**METAPHASE**



**ANAPHASE**



**TELOPHASE AND CYTOKINESIS**



# Mitosis

## Prometaphase:

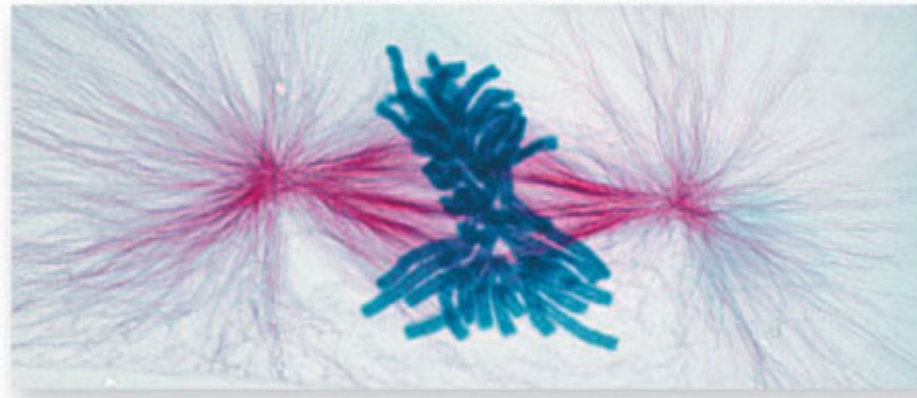
- chromosomes become attached to the spindle apparatus by their kinetochores
- a second set of microtubules is formed from the poles to each kinetochore
- microtubules begin to pull each chromosome toward the center of the cell

# Mitosis

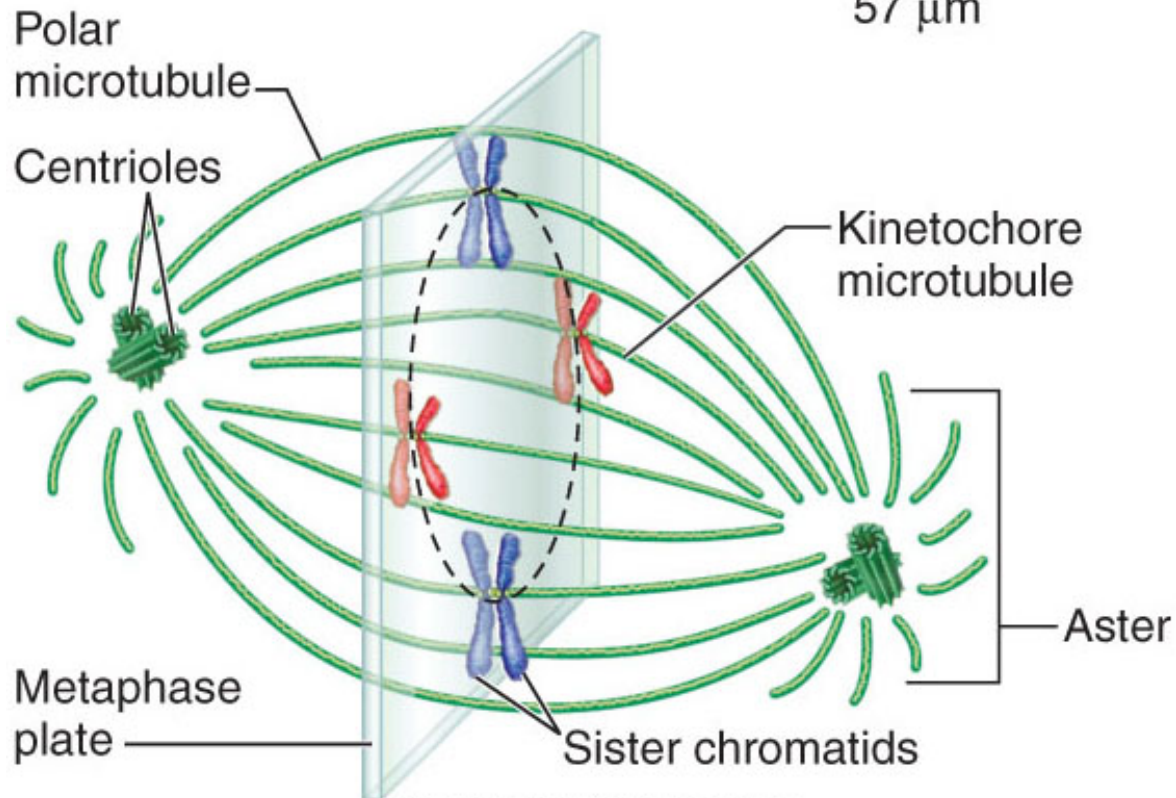
Metaphase:

- microtubules pull the chromosomes to align them at the center of the cell
- metaphase plate**: imaginary plane through the center of the cell where the chromosomes align





57  $\mu\text{m}$



© Andrew S. Bauer, University of Oregon

# Mitosis

## Anaphase:

- removal of cohesin proteins causes the centromeres to separate
- microtubules pull sister chromatids toward the poles
- in anaphase A the kinetochores are pulled apart
- in anaphase B the poles move apart

# Mitosis

## Telophase:

- spindle apparatus disassembles
- nuclear envelope forms around each set of sister chromatids
- chromosomes begin to uncoil
- nucleolus reappears in each new nucleus

# Cytokinesis

**Cytokinesis** – cleavage of the cell into equal halves

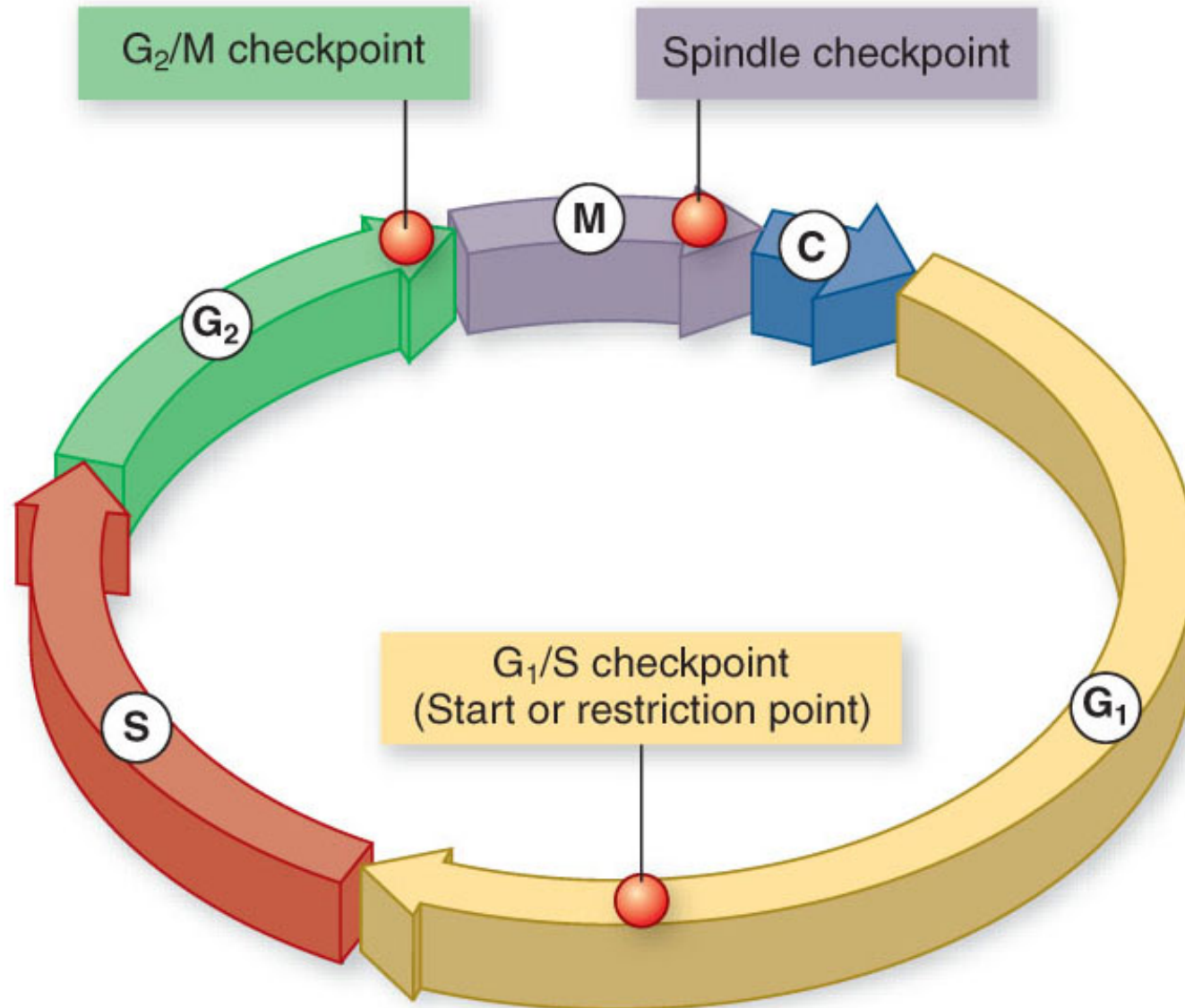
-in animal cells – constriction of actin filaments produces a **cleavage furrow**

# Control of the Cell Cycle

The cell cycle is controlled at three checkpoints:

1.  $G_1/S$  checkpoint
  - the cell “decides” to divide
2.  $G_2/M$  checkpoint
  - the cell makes a commitment to mitosis
3. late metaphase (spindle) checkpoint
  - the cell ensures that all chromosomes are attached to the spindle





# Control of the Cell Cycle

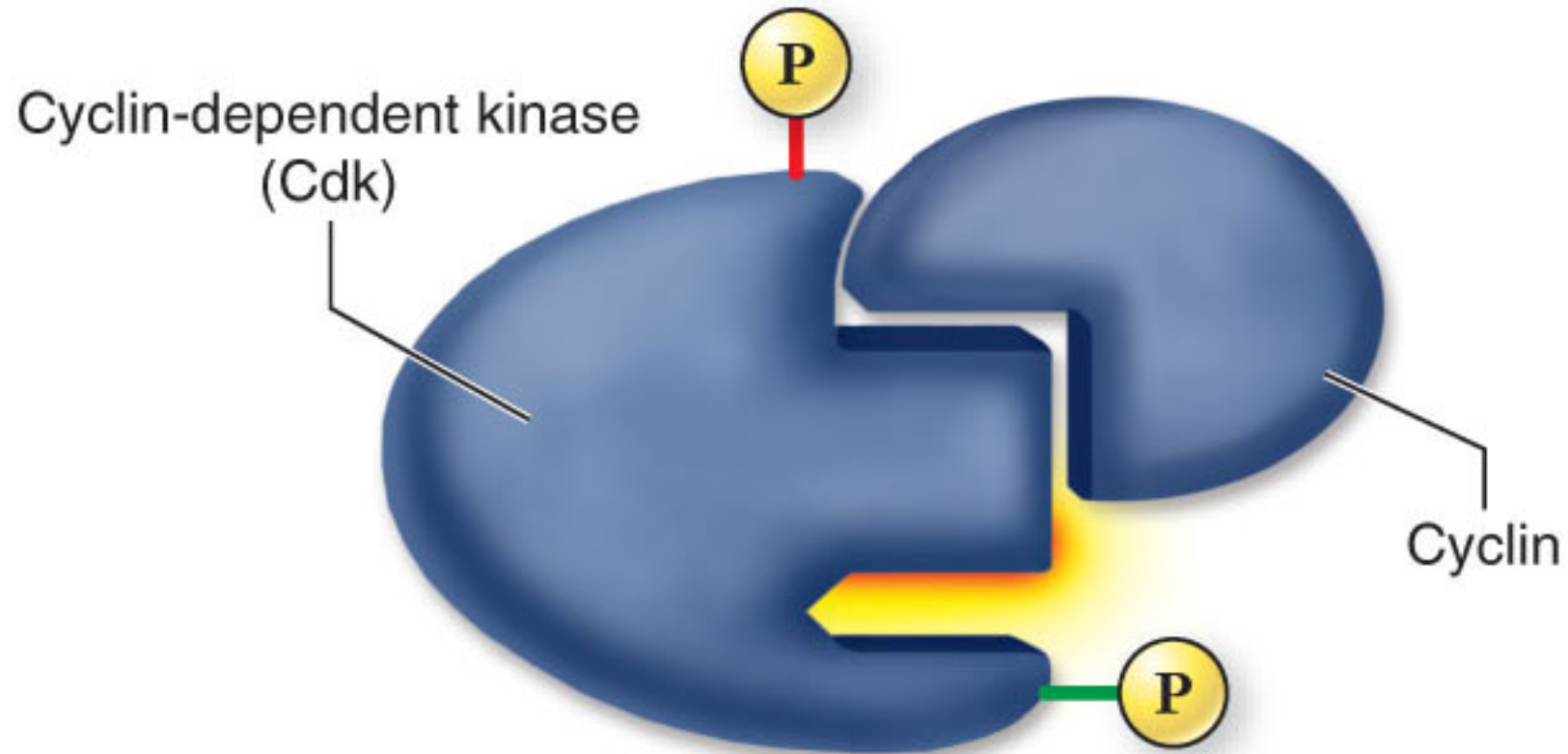
**cyclins** – proteins produced in synchrony with the cell cycle

- regulate passage of the cell through cell cycle checkpoints

**cyclin-dependent kinases (Cdks)** – enzymes that drive the cell cycle

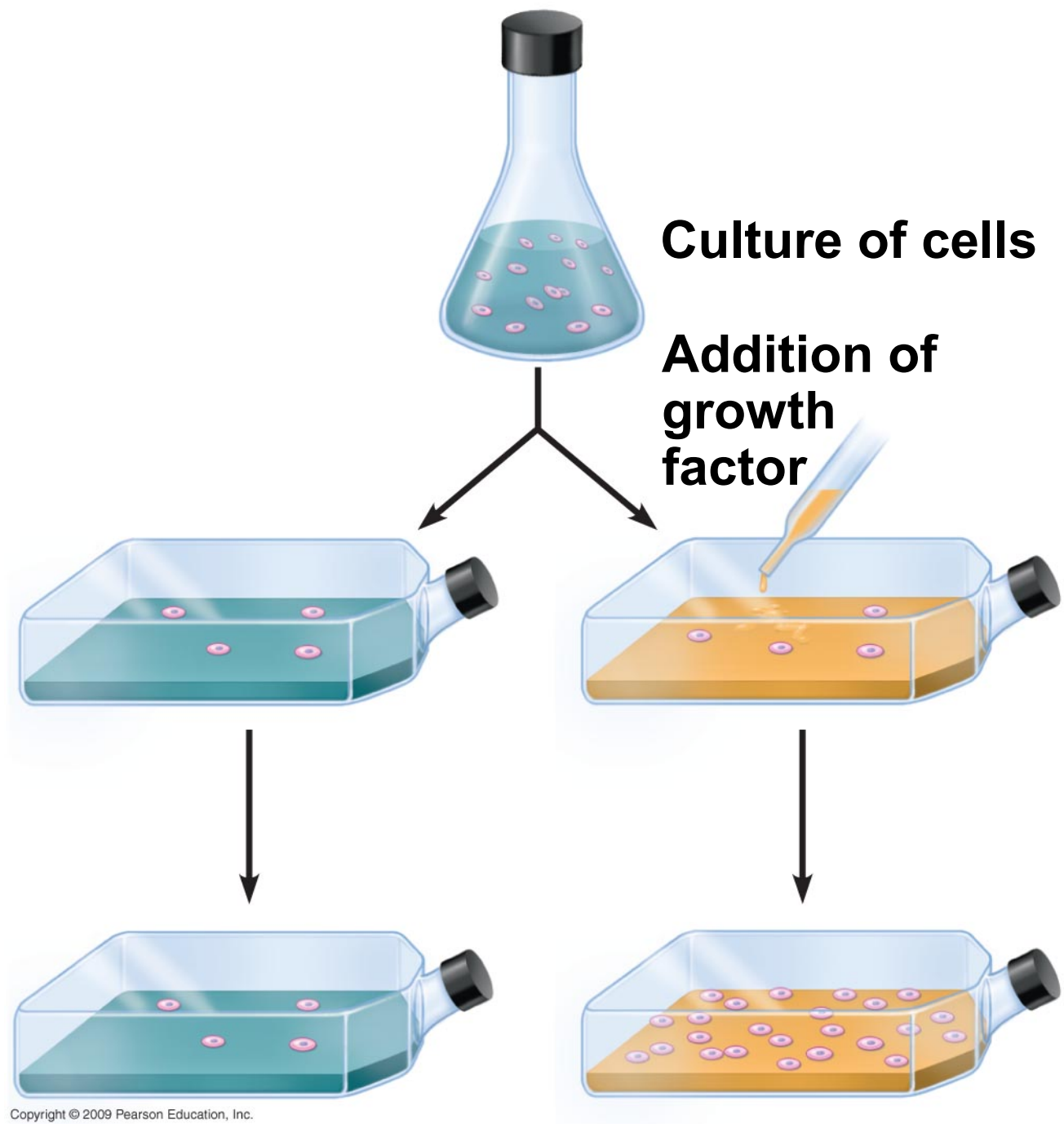
- activated only when bound by a cyclin

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# Anchorage, cell density, and chemical growth factors affect cell division

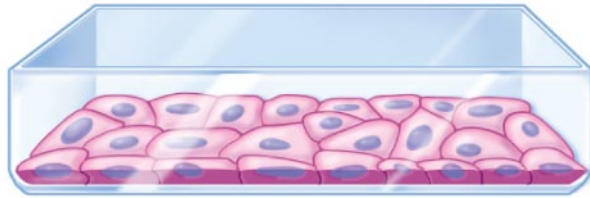
- Factors that control cell division
  - Presence of essential nutrients
  - **Growth factors**, proteins that stimulate division
  - Presence of other cells causes **density-dependent inhibition**
  - Contact with a solid surface; most cells show **anchorage dependence**



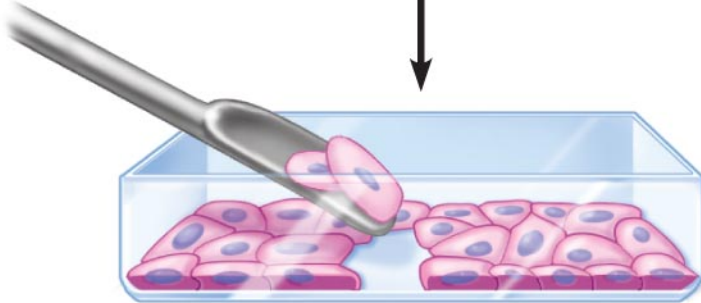




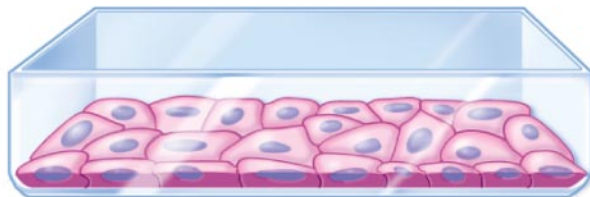
**Cells anchor to dish surface and divide.**



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

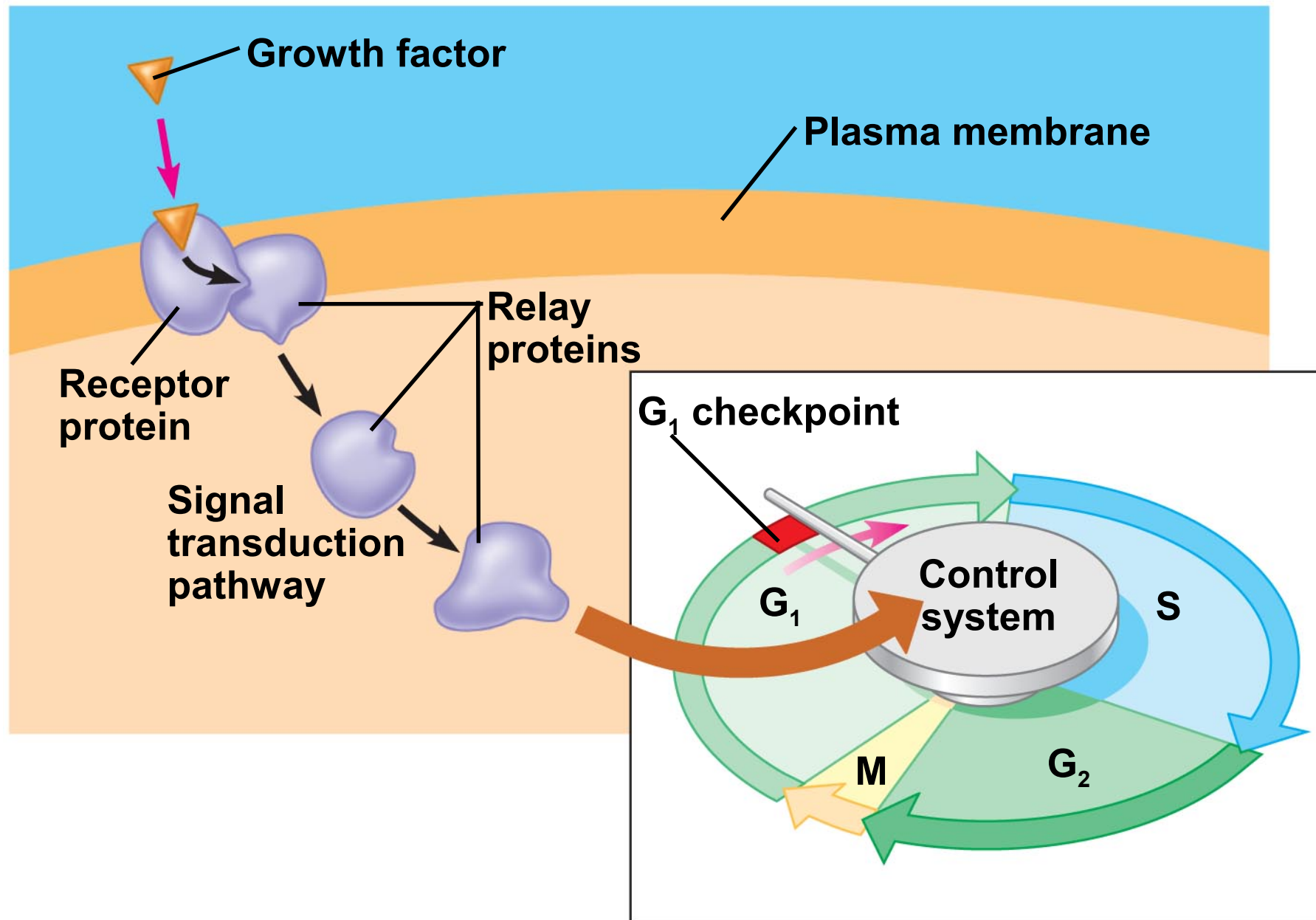


**If some cells are scraped away, the remaining cells divide to fill the dish with a single layer and then stop (density-dependent inhibition).**



# Growth factors signal the cell cycle control system

- Effects of a growth factor at the  $G_1$  checkpoint
  - A growth factor binds to a receptor in the plasma membrane
  - Within the cell, a signal transduction pathway propagates the signal through a series of relay molecules
  - The signal reaches the cell cycle control system to trigger entry into the S phase



# Control of the Cell Cycle

At G<sub>1</sub>/S checkpoint:

- G<sub>1</sub> cyclins accumulate
- G<sub>1</sub> cyclins bind with Cdc2 to create the active G<sub>1</sub>/S Cdk
- G<sub>1</sub>/S Cdk phosphorylates a number of molecules that ultimately increase the enzymes required for DNA replication

# Control of the Cell Cycle

At the spindle checkpoint:

- the signal for anaphase to proceed is transmitted through **anaphase-promoting complex (APC)**
- APC activates the proteins that remove the cohesin holding sister chromatids together



# Control of the Cell Cycle

Growth factors:

- can influence the cell cycle
- trigger intracellular signaling systems
- can override cellular controls that otherwise inhibit cell division

**platelet-derived growth factor (PDGF)**

triggers cells to divide during wound healing

# Control of the Cell Cycle

Cancer is a failure of cell cycle control.

Two kinds of genes can disturb the cell cycle when they are mutated:

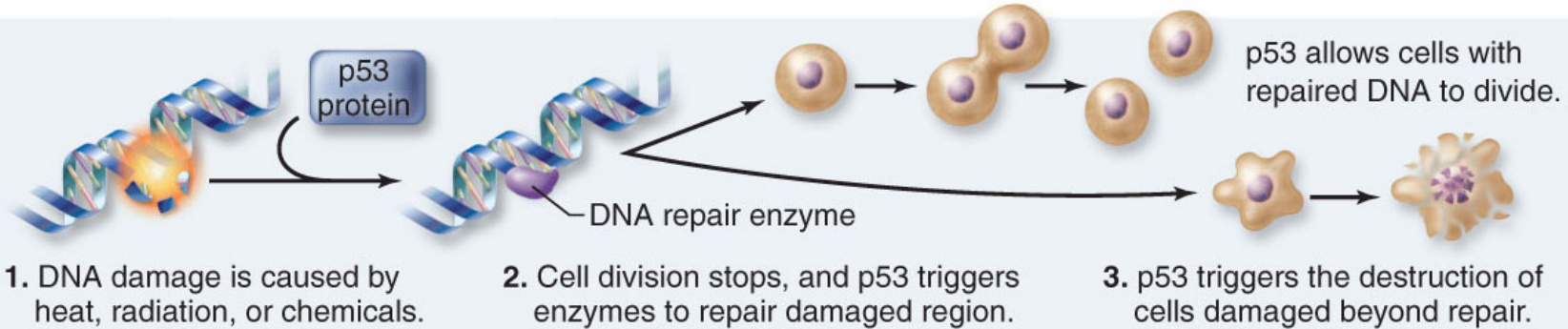
1. **tumor-suppressor genes**
2. **proto-oncogenes**

# Control of the Cell Cycle

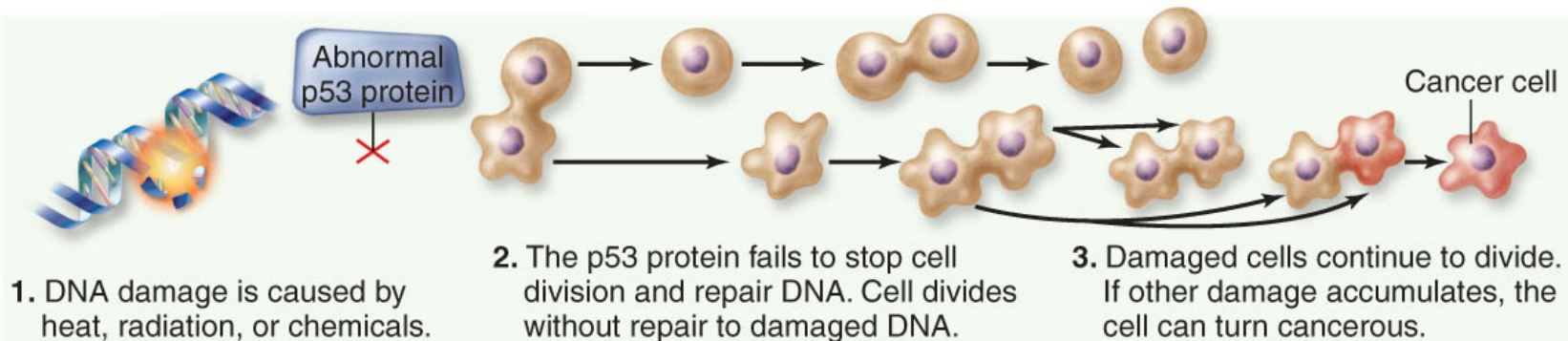
Tumor-suppressor genes:

- prevent the development of many cells containing mutations
- for example, *p53* halts cell division if damaged DNA is detected
- p53* is absent or damaged in many cancerous cells

Normal p53



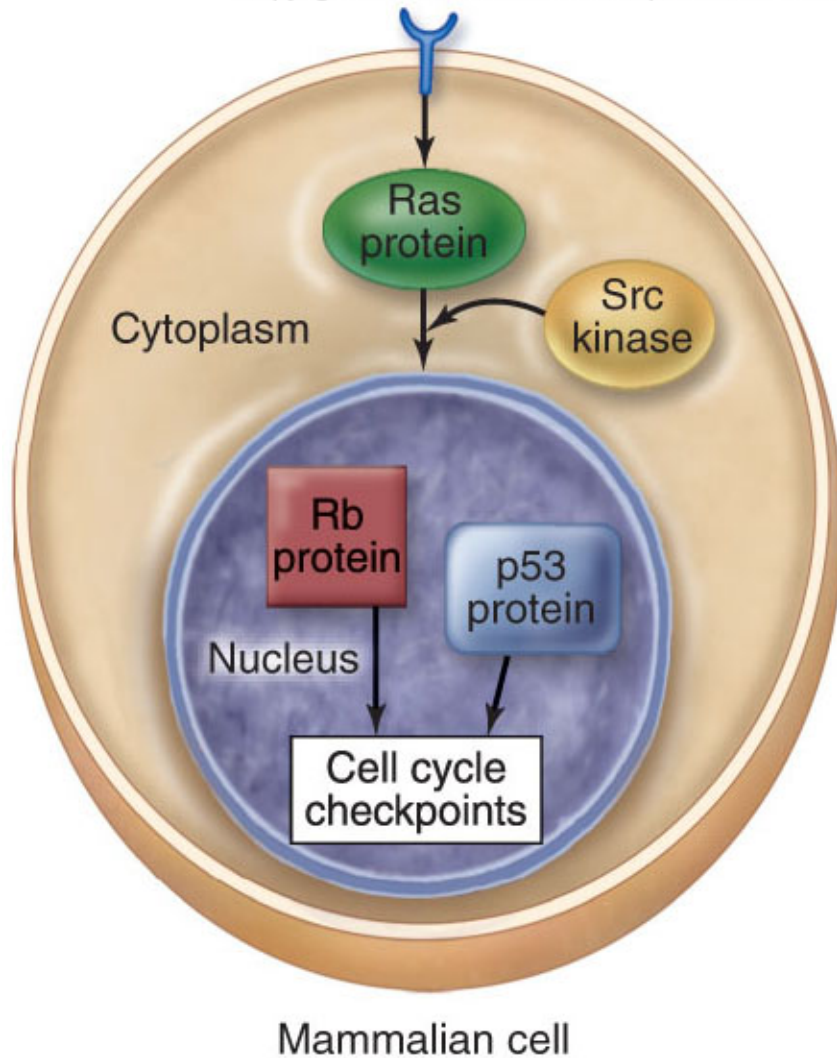
Abnormal p53



# Control of the Cell Cycle

Proto-oncogenes:

- some encode receptors for growth factors
- some encode signal transduction proteins
- become **oncogenes** when mutated
- oncogenes can cause cancer when they are introduced into a cell



### Proto-oncogenes

**Growth factor receptor:**  
more per cell in many breast cancers.

**Ras protein:**  
activated by mutations in 20–30% of all cancers.

**Src kinase:**  
activated by mutations in 2–5% of all cancers.

### Tumor-suppressor Genes

**Rb protein:**  
mutated in 40% of all cancers.

**p53 protein:**  
mutated in 50% of all cancers.



# Overview of Meiosis

Meiosis is a form of cell division that leads to the production of **gametes**.

**gametes**: egg cells and sperm cells

- contain half the number of chromosomes of an adult body cell

Adult body cells (**somatic cells**) are **diploid**, containing 2 sets of chromosomes.

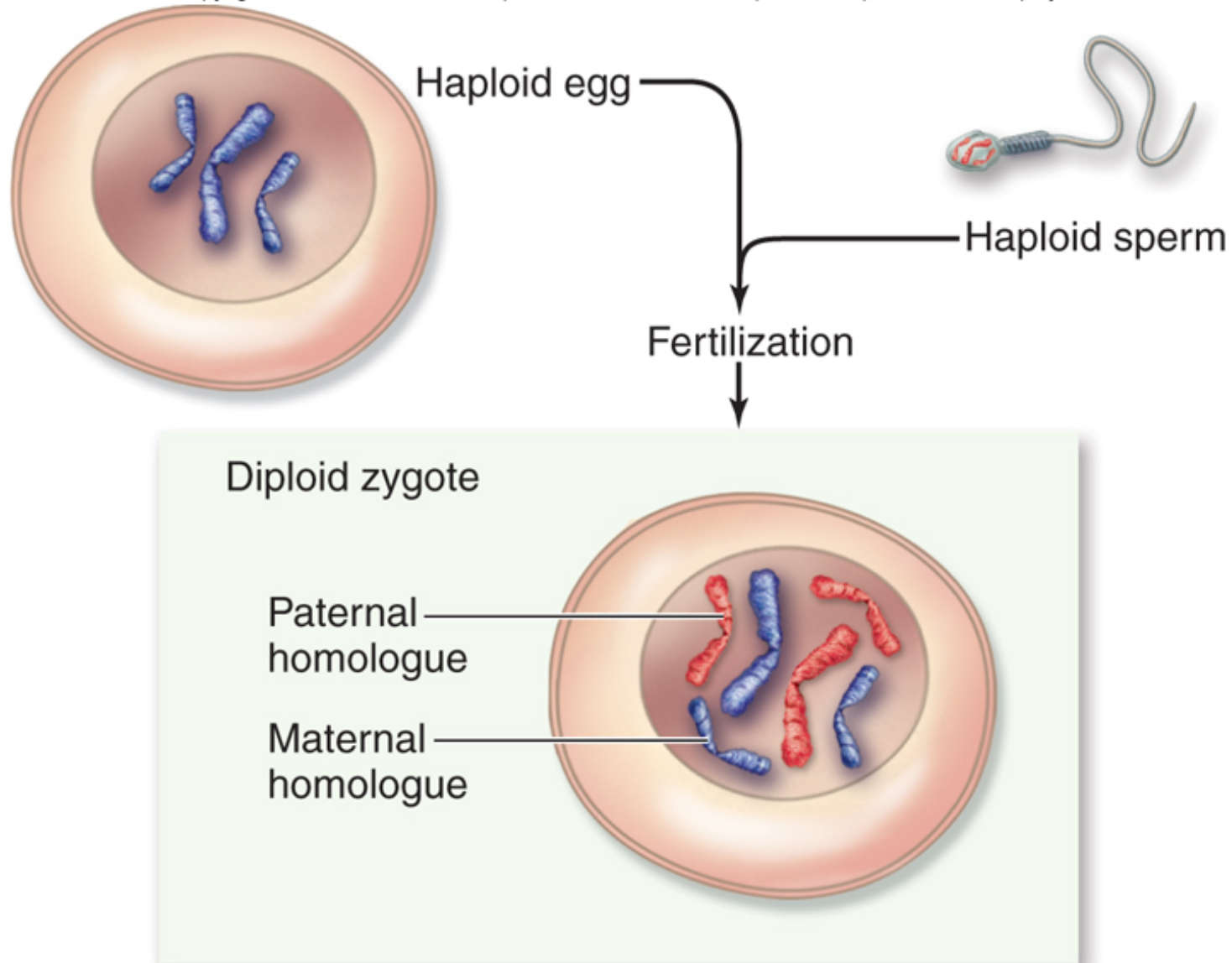
Gametes are **haploid**, containing only 1 set of chromosomes.

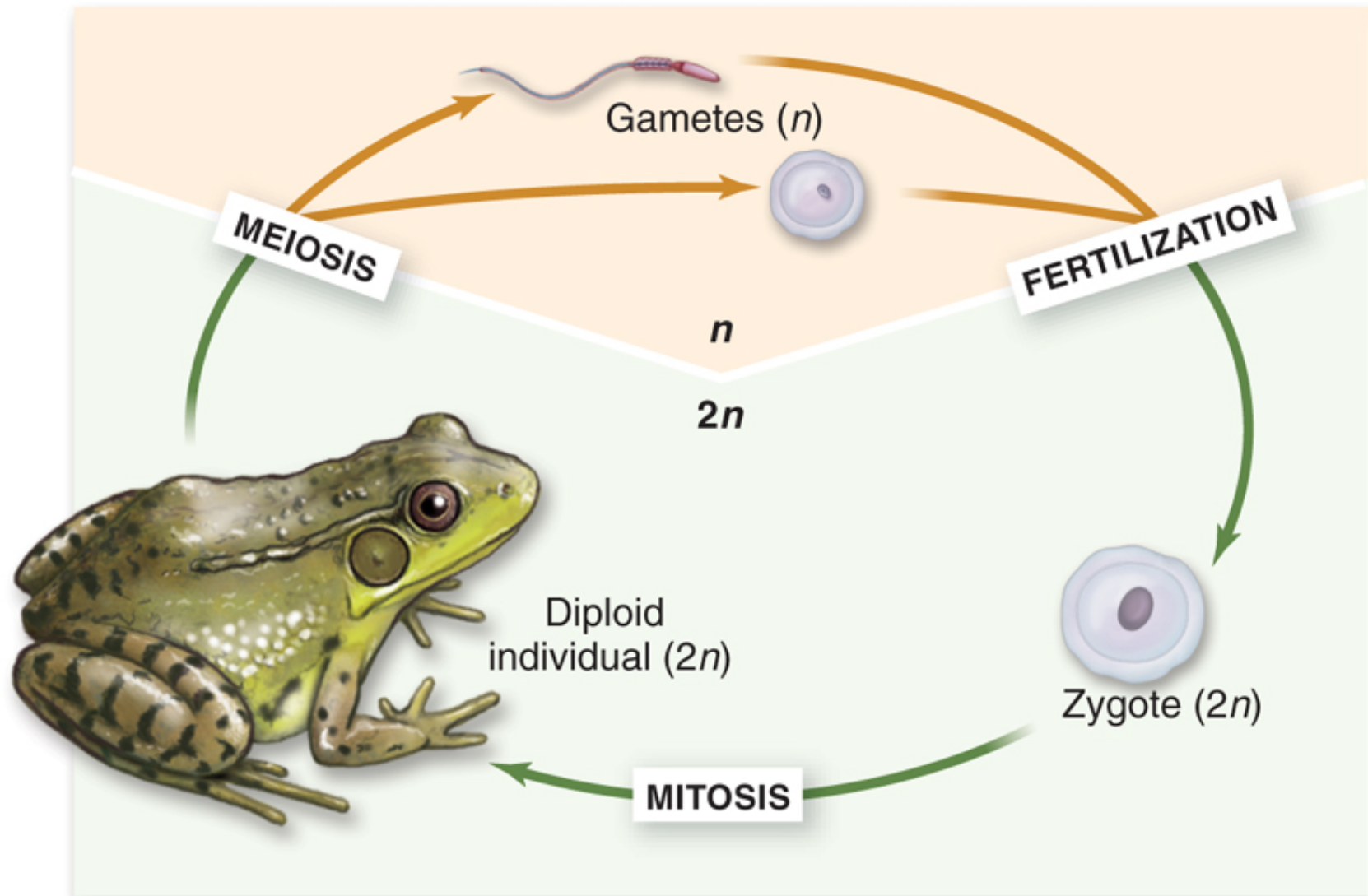
# Overview of Meiosis

**Sexual reproduction** includes the fusion of gametes (**fertilization**) to produce a diploid **zygote**.

Life cycles of sexually reproducing organisms involve the alternation of haploid and diploid stages.

Some life cycles include longer diploid phases, some include longer haploid phases.





**b.** Most animals

# Features of Meiosis

Meiosis includes two rounds of division – **meiosis I** and **meiosis II**.

During meiosis I, homologous chromosomes (**homologues**) become closely associated with each other. This is **synapsis**.

Proteins between the homologues hold them in a **synaptonemal complex**.

# The Process of Meiosis

## Prophase I:

- chromosomes coil tighter
- nuclear envelope dissolves
- homologues become closely associated in synapsis
- crossing over occurs between non-sister chromatids



## MEIOSIS I: Homologous chromosomes separate

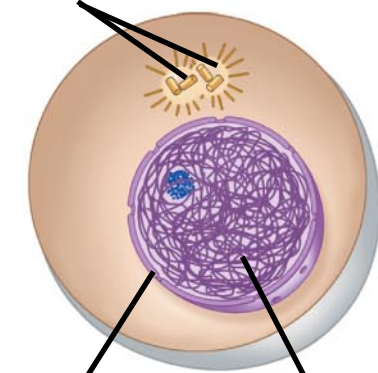
### INTERPHASE

### PROPHASE I

### METAPHASE I

### ANAPHASE I

Centrosomes  
(with centriole  
pairs)

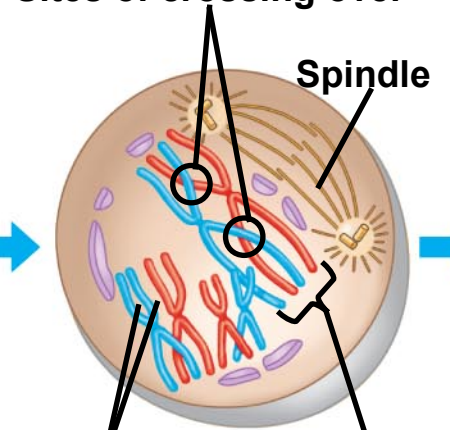


Nuclear  
envelope

Chromatin

Sites of crossing over

Spindle



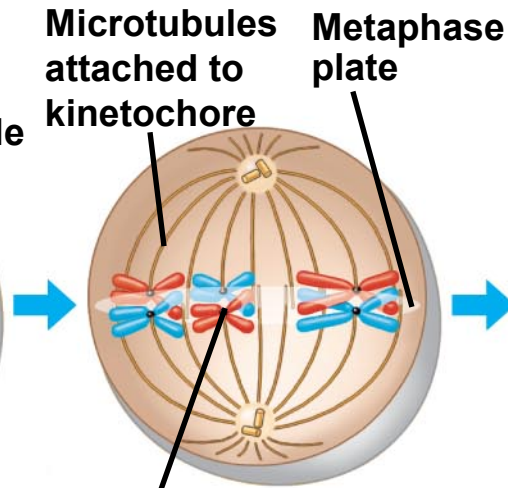
Sister  
chromatids

Tetrad

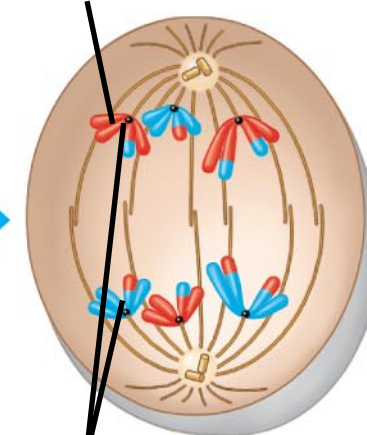
Microtubules  
attached to  
kinetochore

Metaphase  
plate

Centromere  
(with kinetochore)



Sister chromatids  
remain attached



Homologous  
chromosomes separate

**MEIOSIS II: Sister chromatids separate**

**TELOPHASE II  
AND CYTOKINESIS**

**PROPHASE I**

**METAPHASE II**

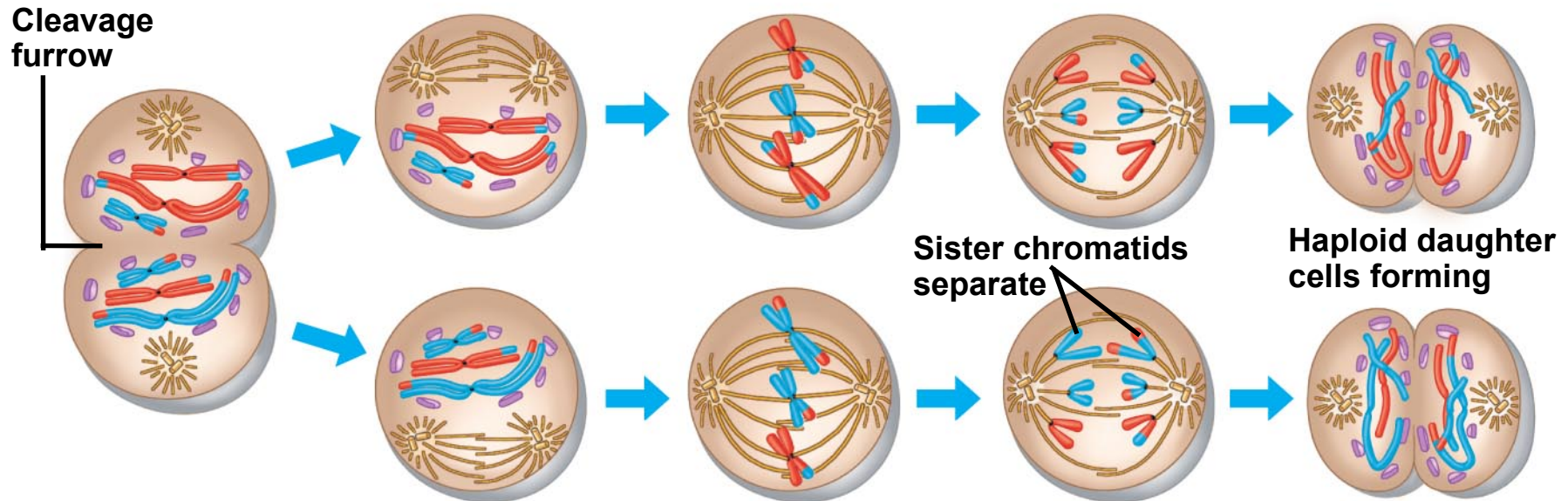
**ANAPHASE II**

**TELOPHASE II  
AND CYTOKINESIS**

**Cleavage  
furrow**

**Sister chromatids  
separate**

**Haploid daughter  
cells forming**



# The Process of Meiosis

## Metaphase I:

- terminal chiasmata hold homologues together following crossing over
- microtubules from opposite poles attach to each *homologue*, not each sister chromatid
- homologues are aligned at the metaphase plate side-by-side
- the orientation of each pair of homologues on the spindle is random

# The Process of Meiosis

## Anaphase I:

- microtubules of the spindle shorten
- homologues are separated from each other
- sister chromatids remain attached to each other at their centromeres

# The Process of Meiosis

## Telophase I:

- nuclear envelopes form around each set of chromosomes
- each new nucleus is now haploid
- sister chromatids are no longer identical because of crossing over

# The Process of Meiosis

Meiosis II resembles a mitotic division:

- prophase II: nuclear envelopes dissolve and spindle apparatus forms
- metaphase II: chromosomes align on metaphase plate
- anaphase II: sister chromatids are separated from each other
- telophase II: nuclear envelope re-forms; cytokinesis follows



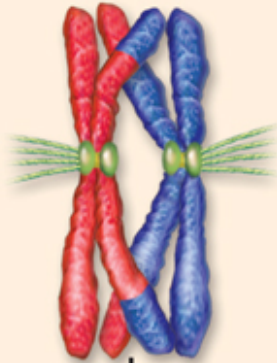
# Meiosis vs. Mitosis

Meiosis is characterized by 4 features:

1. Synapsis and crossing over
2. Sister chromatids remain joined at their centromeres throughout meiosis I
3. Kinetochores of sister chromatids attach to the same pole in meiosis I
4. DNA replication is suppressed between meiosis I and meiosis II.

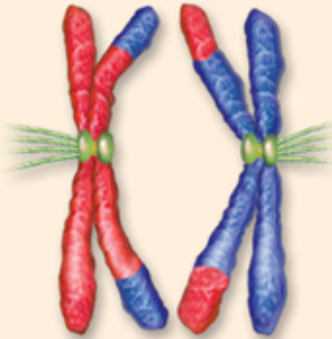
## Meiosis I

### Metaphase I



Chiasmata hold homologues together. The kinetochores of sister chromatids fuse and function as one. Microtubules can attach to only one side of each centromere.

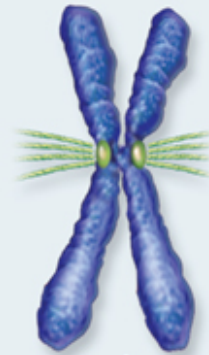
### Anaphase I



Microtubules pull the homologous chromosomes apart, but sister chromatids are held together.

## Mitosis

### Metaphase



Homologues do not pair; kinetochores of sister chromatids remain separate; microtubules attach to both kinetochores on opposite sides of the centromere.

### Anaphase



Microtubules pull sister chromatids apart.

# Meiosis vs. Mitosis

Meiosis produces haploid cells that are not identical to each other.

Genetic differences in these cells arise from:

- crossing over
- random alignment of homologues in metaphase I (independent assortment)

Mitosis produces 2 cells identical to each other.