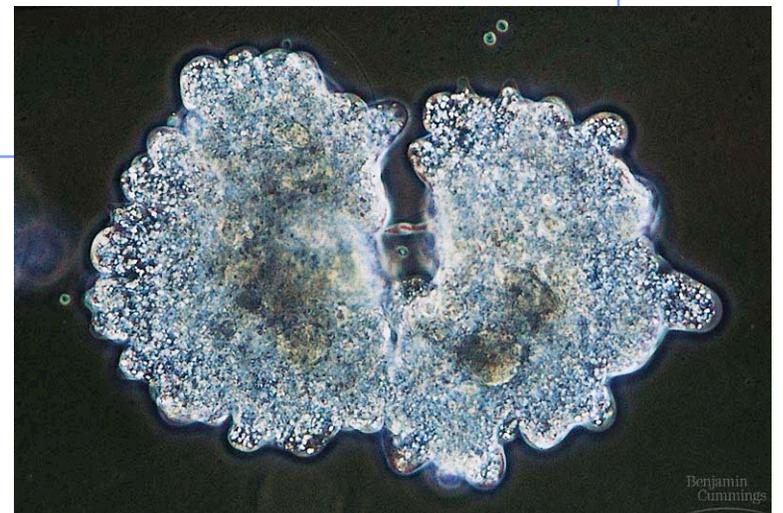
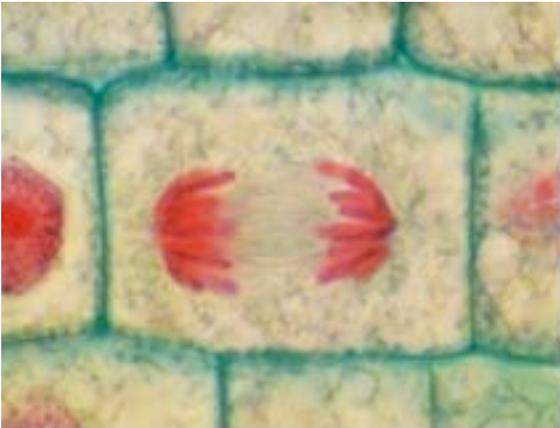
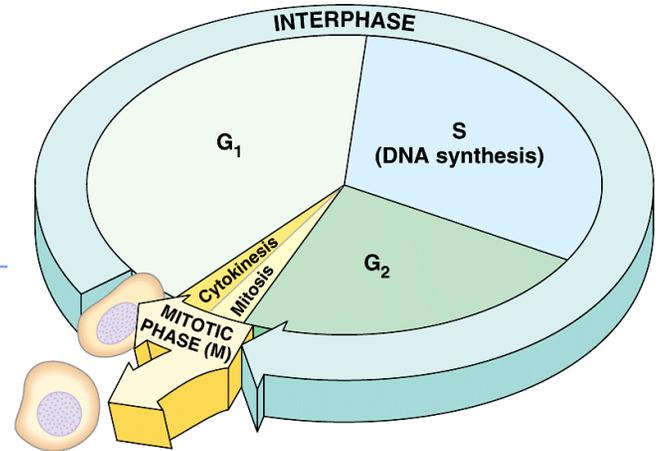


Biology is the only subject in which multiplication is the same thing as division...



# Chapter 12.

## The Cell Cycle: Cell Growth, Cell Division



## Where it all began...

- You started as a cell smaller than a period at the end of a sentence...



And now look at you...

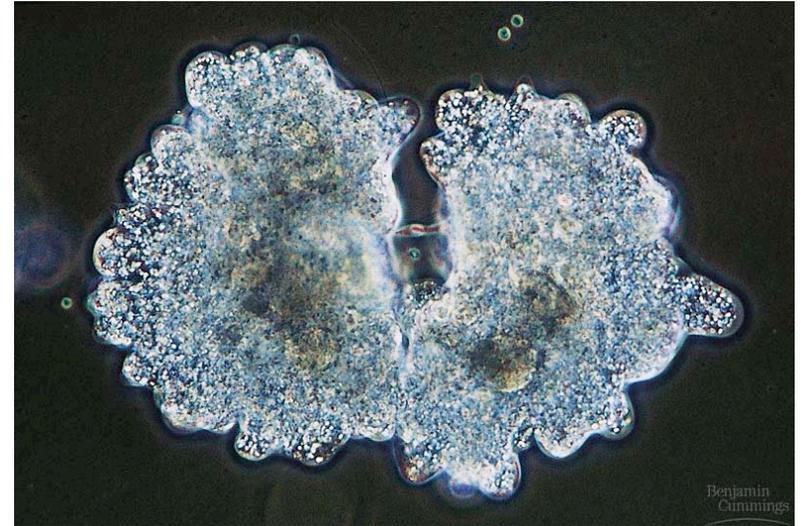


How did you  
get from there  
to here?

AP Biology

# Getting from there to here...

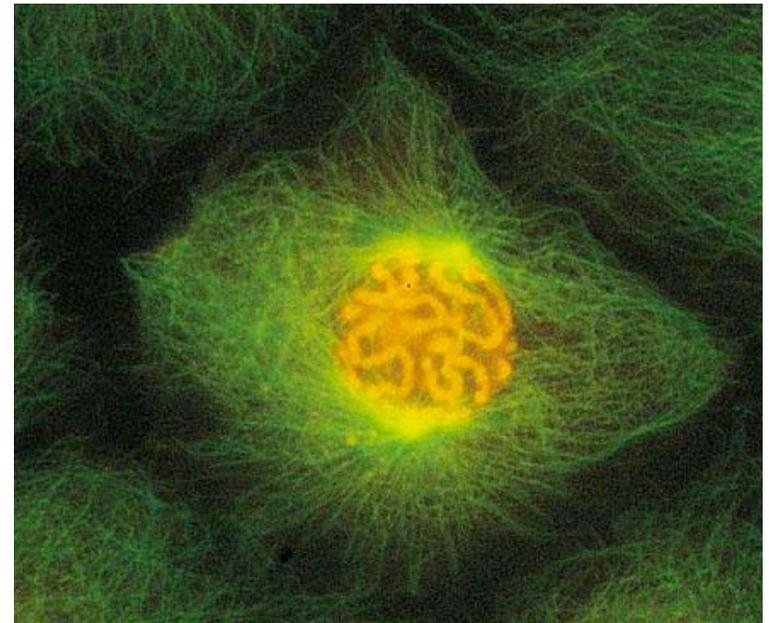
- **Cell division**
  - ◆ continuity of life = reproduction of cells
    - reproduction
      - ◆ unicellular organisms
    - growth
    - repair & renew
- **Cell cycle**
  - ◆ life of a cell from origin to division into 2 new daughter cells



# Getting the right stuff

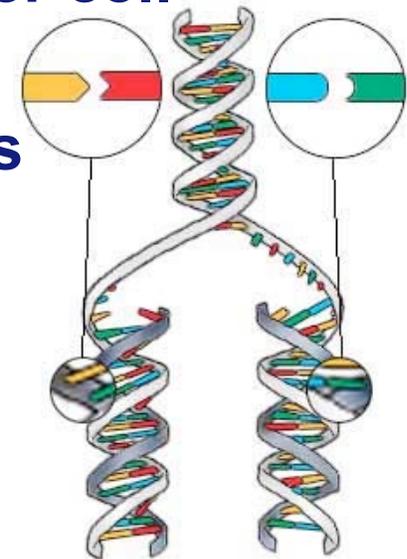
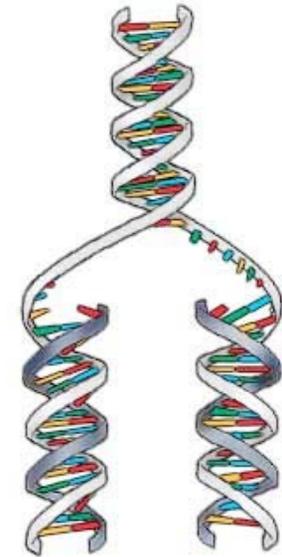
- What is passed to daughter cells?
  - ◆ exact copy of genetic material = DNA
    - this division step = mitosis
  - ◆ assortment of organelles & cytoplasm
    - this division step = cytokinesis

chromosomes (stained orange)  
in kangaroo rat epithelial cell



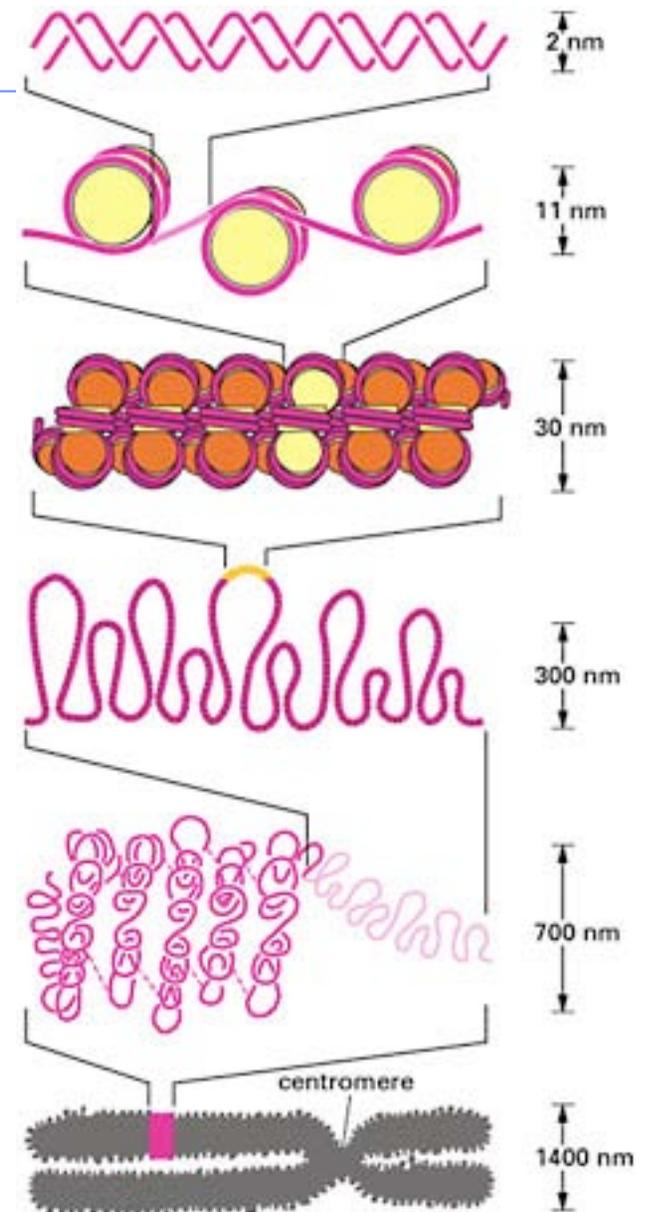
# Copying DNA

- **Dividing cell duplicates DNA**
  - ◆ separates each copy to opposite ends of cell
  - ◆ splits into 2 daughter cells
    - human cell duplicates ~3 meters DNA
    - separates 2 copies so each daughter cell has complete identical copy
    - error rate = ~1 per 100 million bases
      - ◆ 3 billion base pairs
        - mammalian genome
      - ◆ ~30 errors per cell cycle
        - mutations



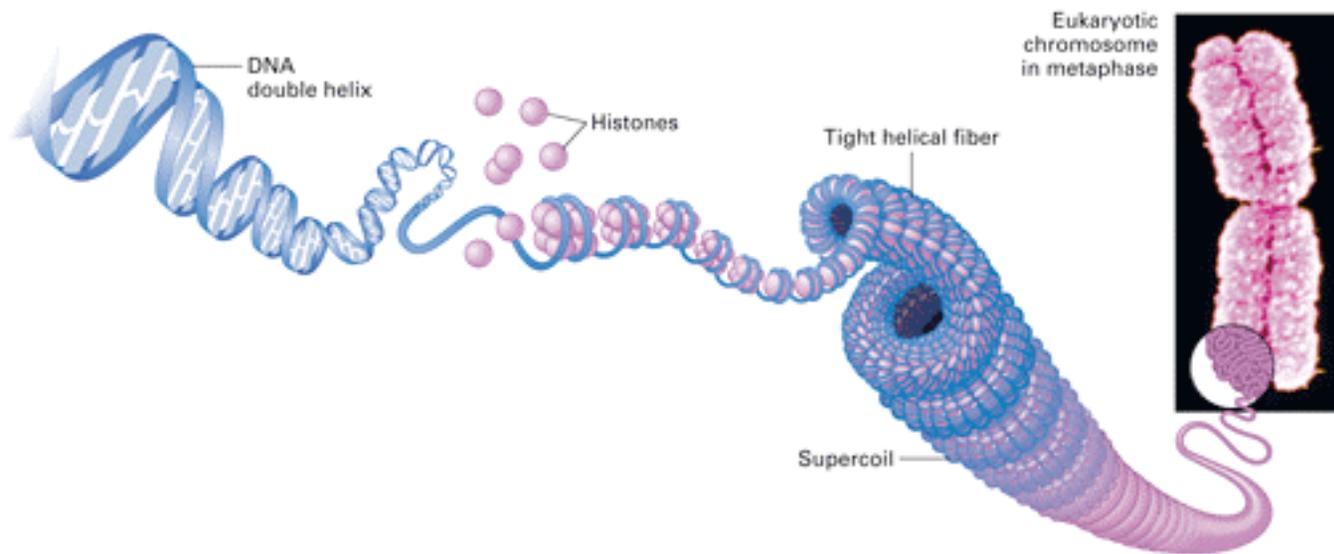
# A bit about DNA

- **DNA is organized in chromosomes**
  - ◆ double helix DNA molecule
  - ◆ associated proteins = histone proteins
  - ◆ DNA-protein complex = chromatin
    - organized into long thin fiber



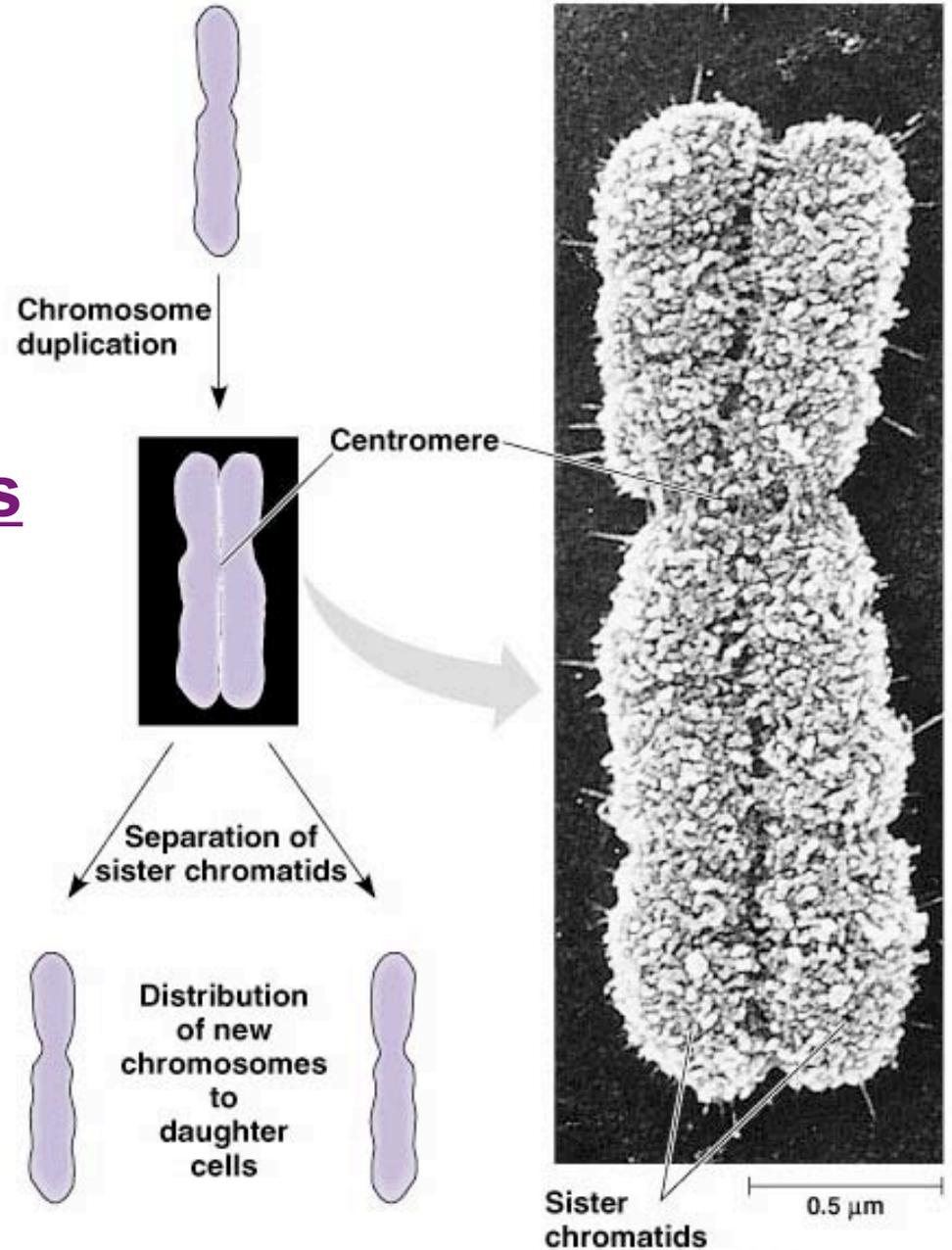
# Copying DNA with care...

- After DNA duplication chromatin condenses
  - ◆ coiling & folding to make a smaller package
  - ◆ from DNA to chromatin to highly condensed mitotic chromosome



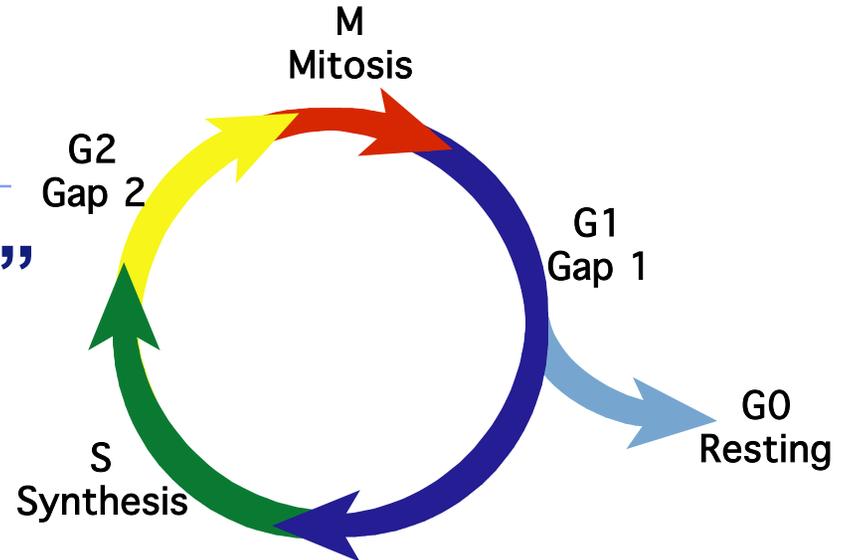
# Chromosome

- **Duplicated chromosome consists of 2 sister chromatids**
  - ◆ narrow at their centromeres
  - ◆ contain identical copies of the chromosome's DNA



# Cell cycle

- Cell has a “life cycle”



cell is formed from a mitotic division

cell grows & matures to divide again

cell grows & matures to never divide again

G<sub>1</sub>, S, G<sub>2</sub>, M

liver cells

G<sub>0</sub>

epithelial cells, blood cells, stem cells

brain nerve cells

# Cell Division cycle

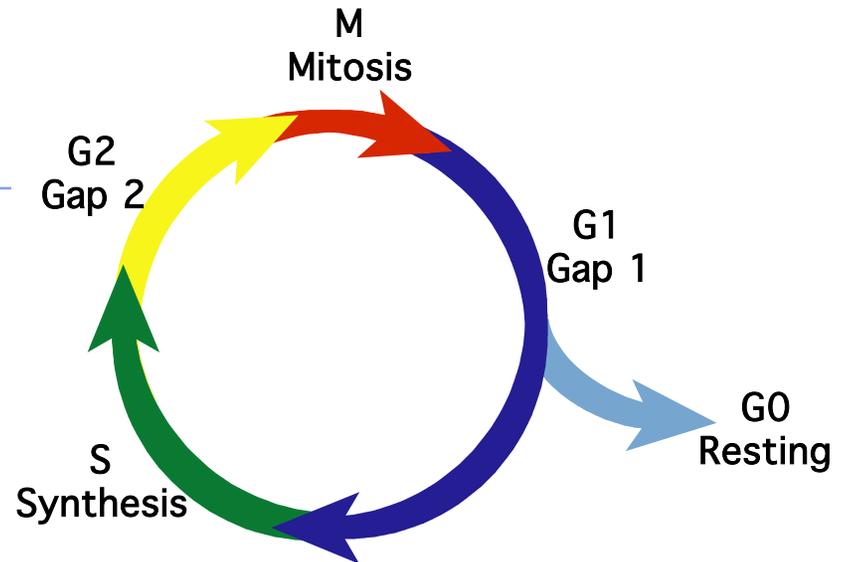
## ■ Phases of a dividing cell's life

### ◆ interphase

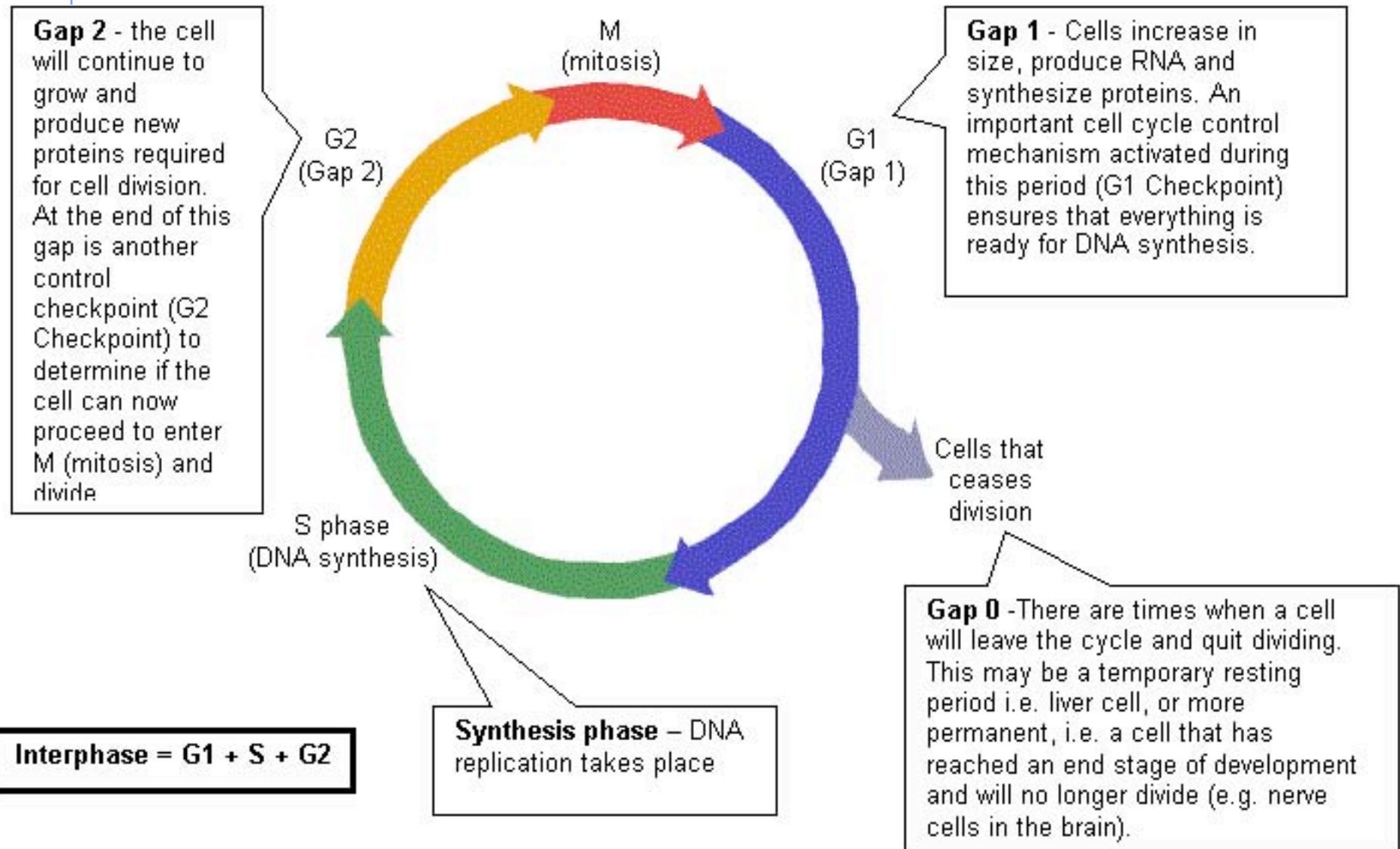
- cell grows
- replicates chromosomes
- produces new organelles & biomolecules

### ◆ mitotic phase

- cell separates & divides chromosomes
  - ◆ mitosis
- cell divides cytoplasm & organelles
  - ◆ cytokinesis

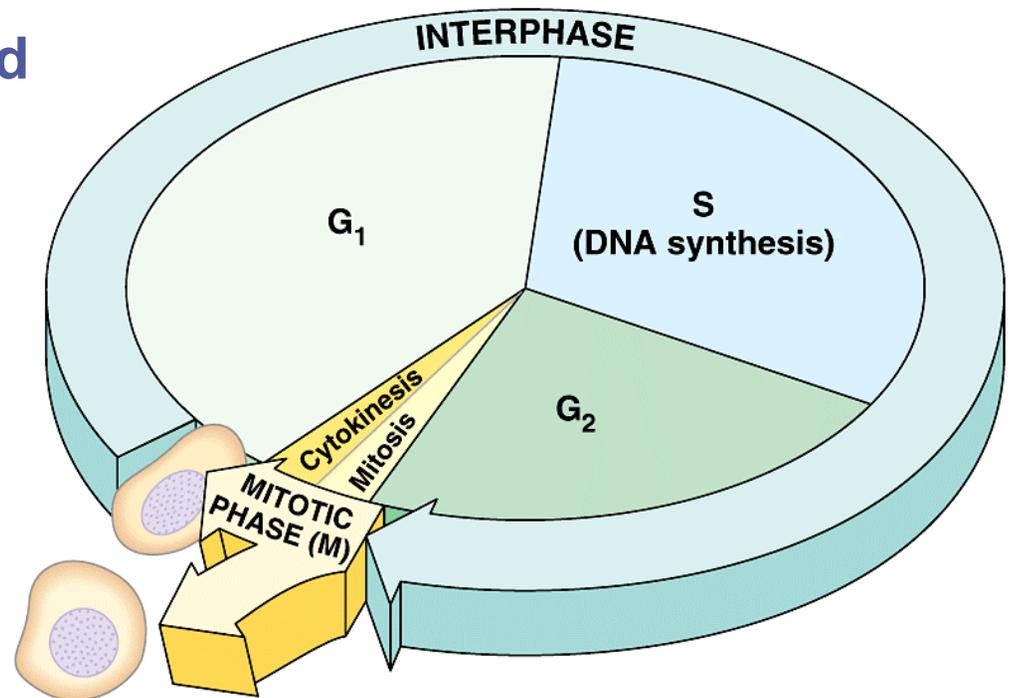


# Control of Cell Cycle



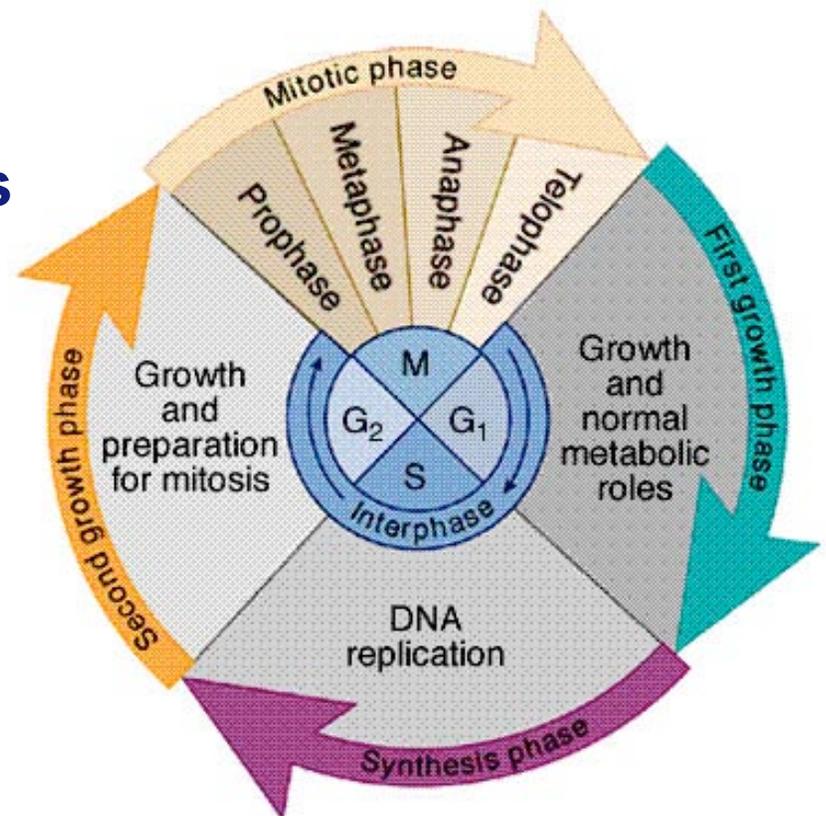
# Interphase

- **90% of cell life cycle**
  - ◆ cell doing its “everyday job”
    - produce RNA, synthesize proteins
  - ◆ prepares for duplication if triggered
- **Characteristics**
  - ◆ nucleus well-defined
  - ◆ DNA loosely packed in long chromatin fibers



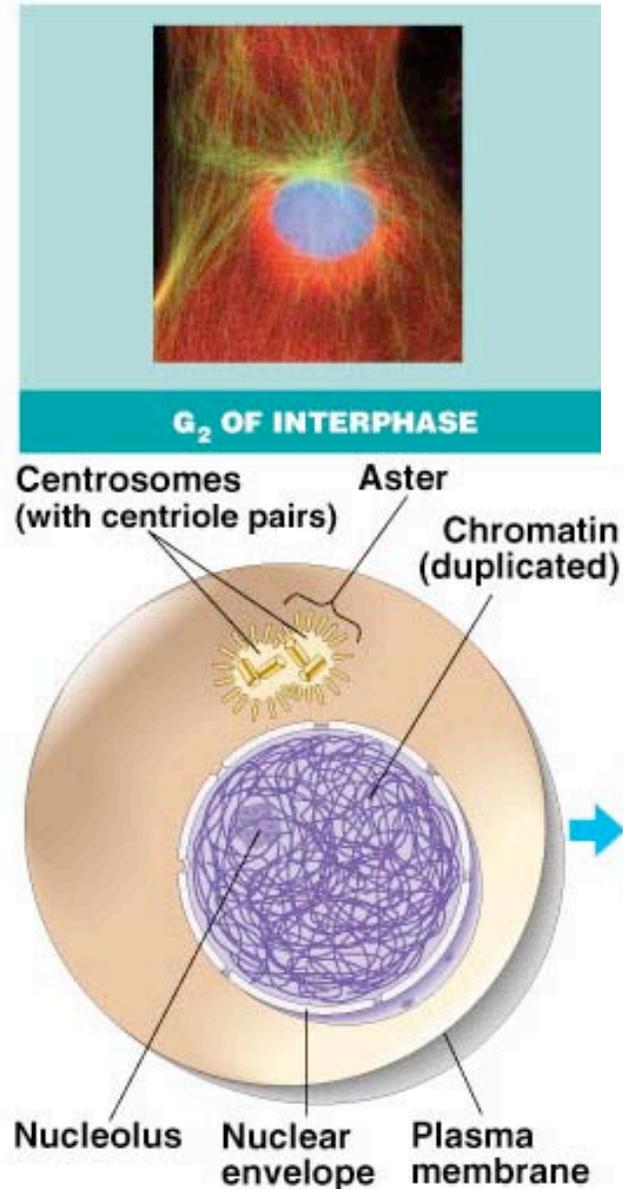
# Interphase

- Divided into 3 phases:
  - ◆  $G_1$  = 1<sup>st</sup> Gap
    - cell doing its “everyday job”
    - cell grows
  - ◆  $S$  = DNA Synthesis
    - copies chromosomes
  - ◆  $G_2$  = 2<sup>nd</sup> Gap
    - prepares for division
    - cell grows
    - produces organelles, proteins, membranes



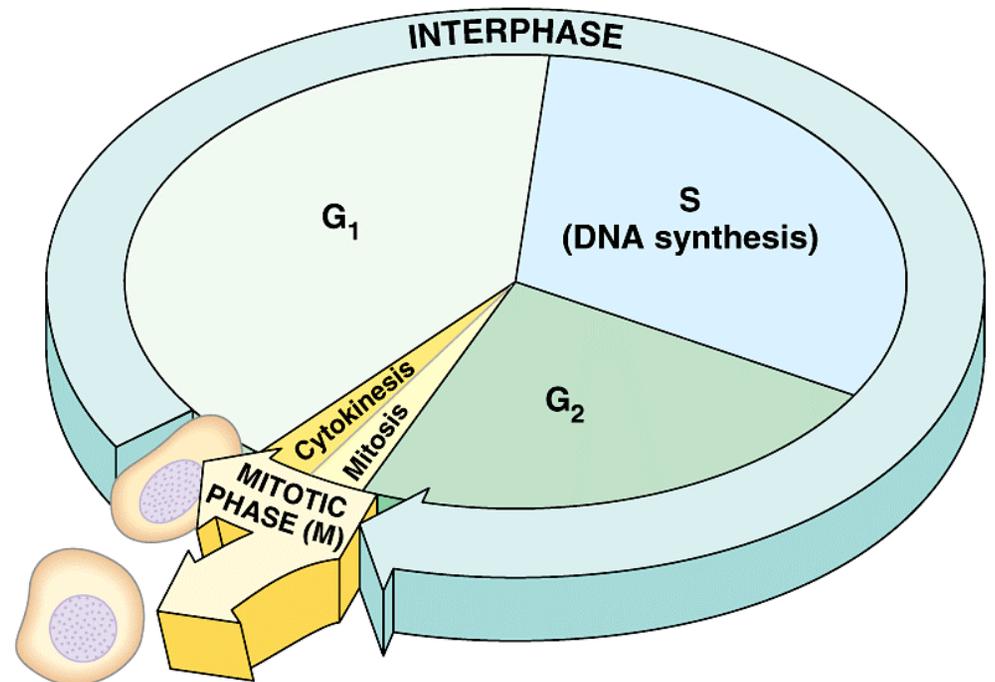
# Interphase G<sub>2</sub>

- **Nucleus well-defined**
  - ◆ chromosome duplication complete
  - ◆ DNA loosely packed in long chromatin fibers
- **Prepares for mitosis**
  - ◆ produces proteins & organelles

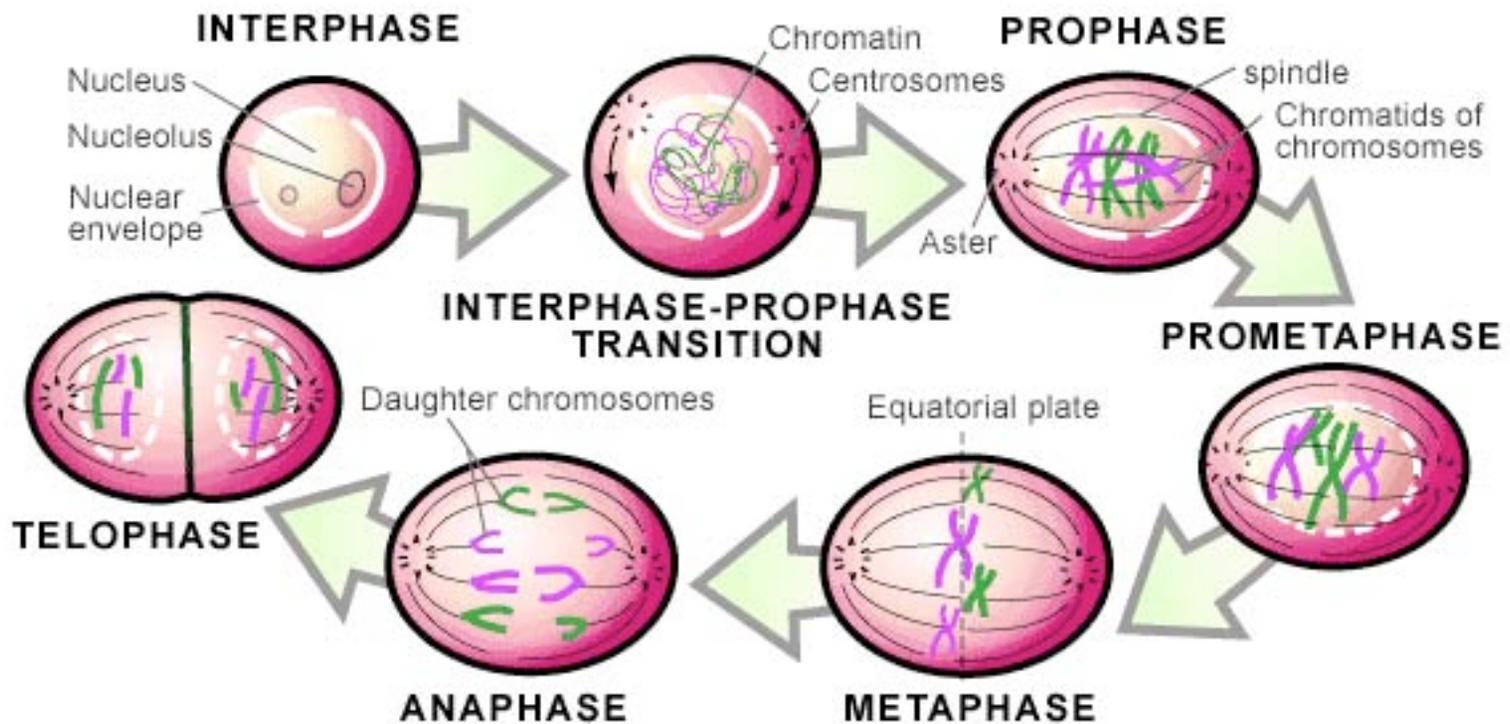


# Mitosis

- copying cell's DNA & dividing it between 2 daughter nuclei
- Mitosis is divided into 4 phases
  - ◆ prophase
  - ◆ metaphase
  - ◆ anaphase
  - ◆ telophase

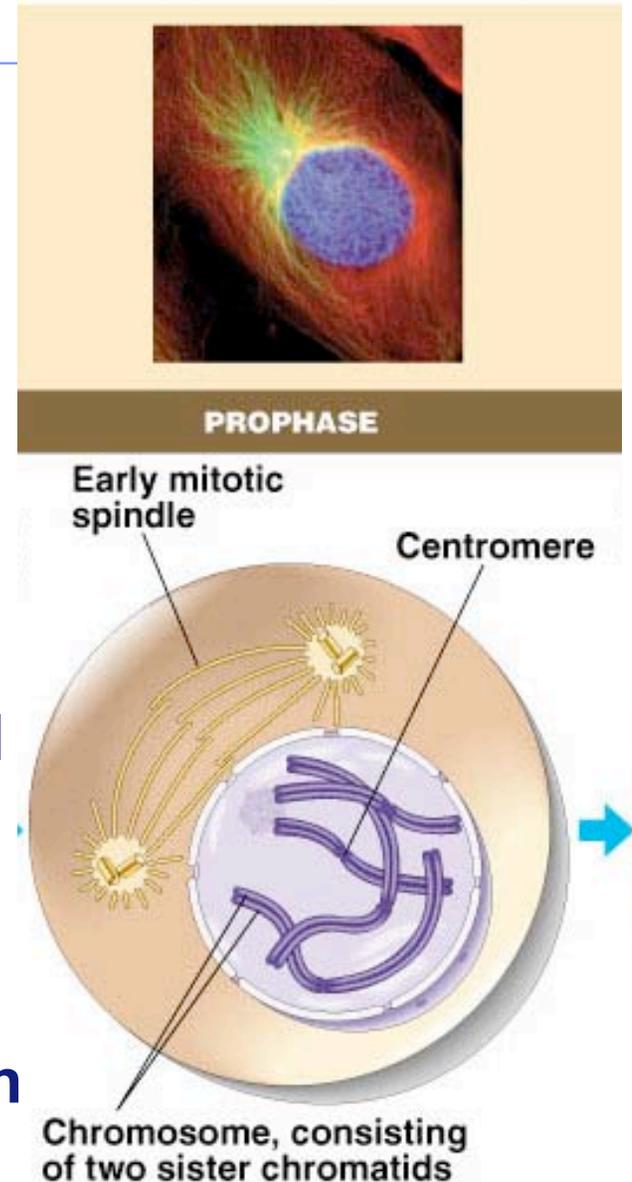


# Overview



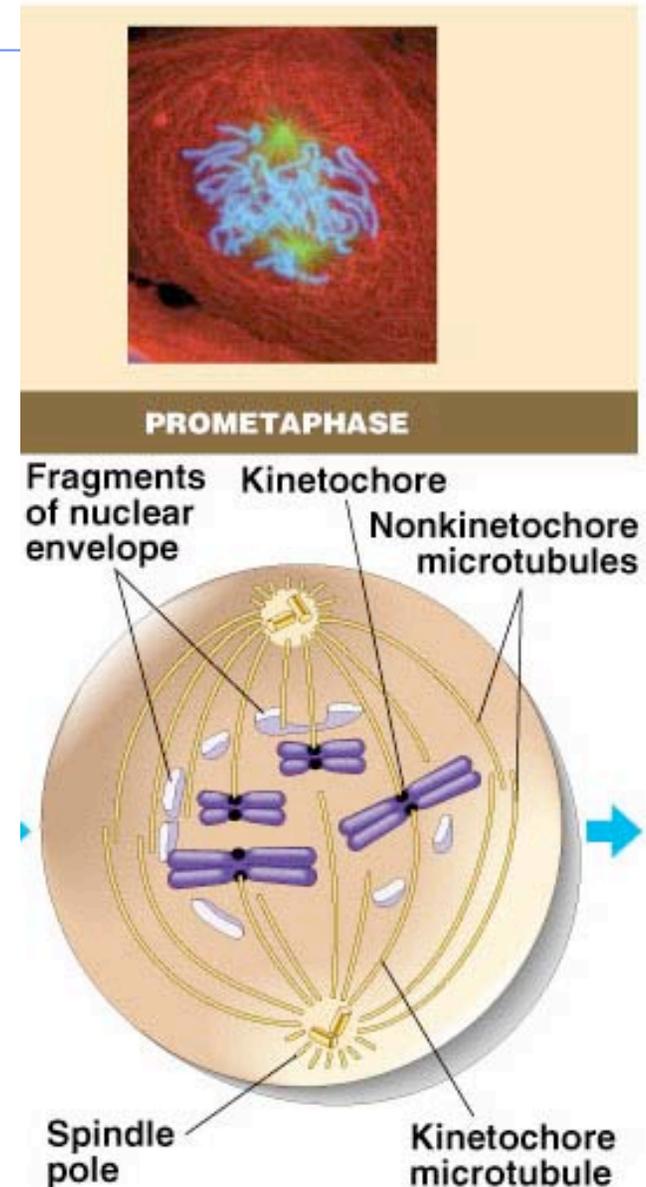
# Prophase

- **Chromatin (DNA) condenses**
  - ◆ visible as chromosomes
    - chromatids
  - ◆ fibers extend from the **centromeres**
- **Centrioles move to opposite poles of cell**
- **Fibers (microtubules) cross cell to form mitotic spindle**
  - ◆ actin, myosin
- **Nucleolus disappears**
- **Nuclear membrane breaks down**



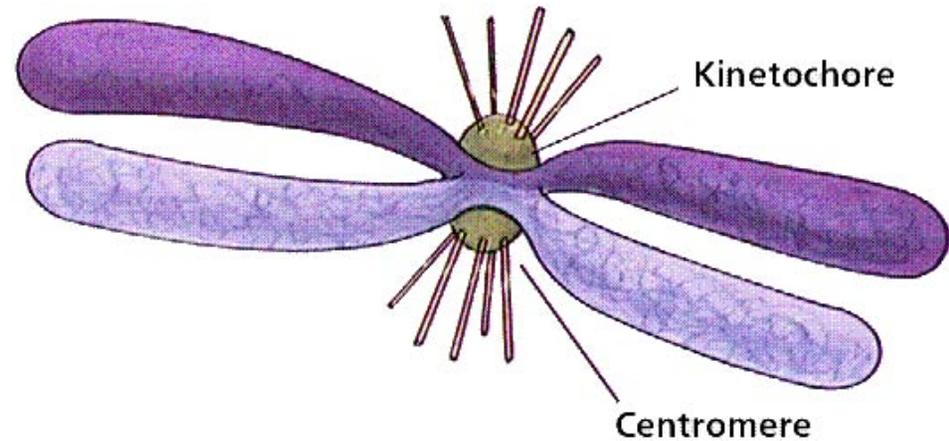
# Prometaphase

- Proteins attach to centromeres
  - ◆ creating kinetochores
- Microtubules attach at kinetochores
  - ◆ connect centromeres to centrioles
- Chromosomes begin moving



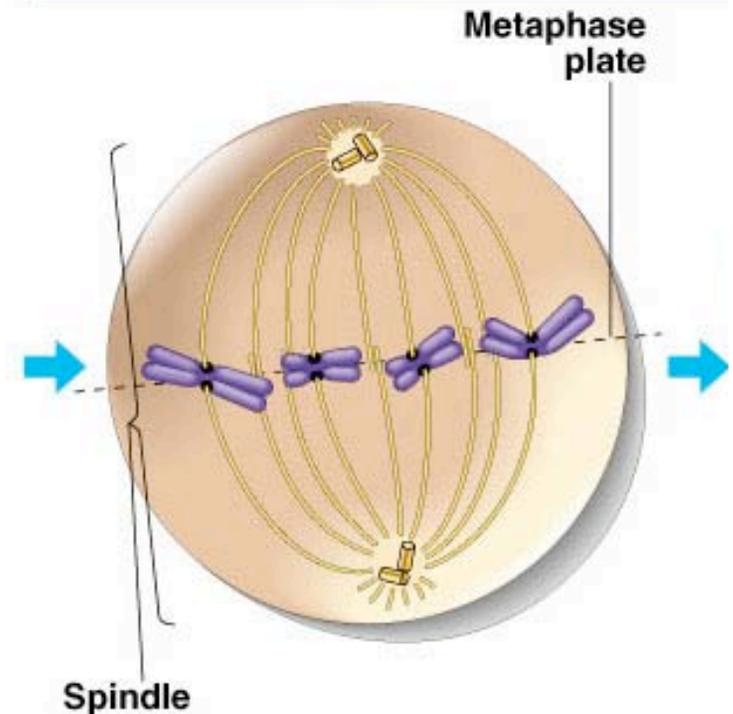
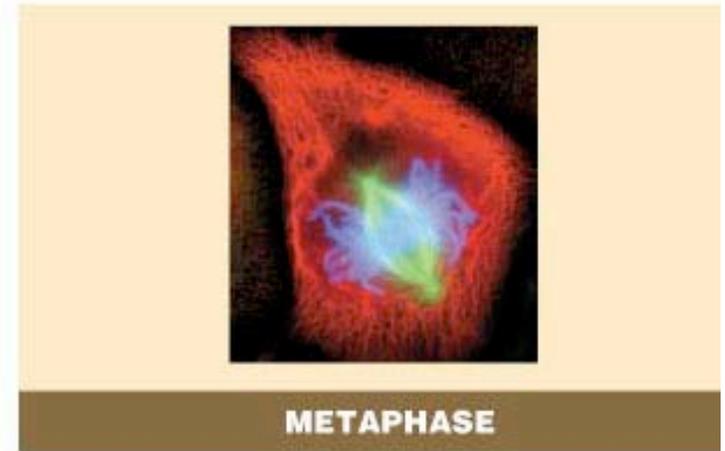
# Kinetochores

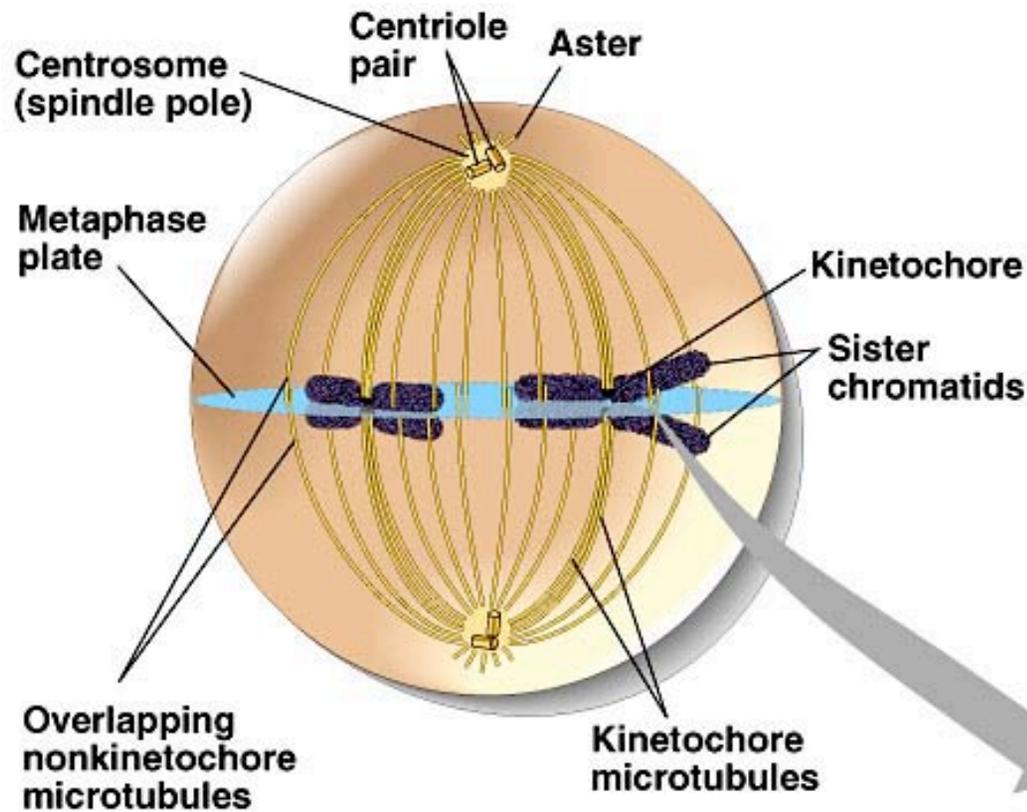
- Each chromatid has its own kinetochores
- ◆ microtubules attach to kinetochores



# Metaphase

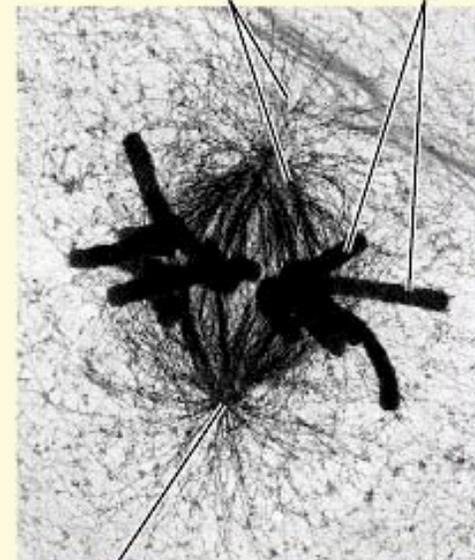
- Spindle fibers align chromosomes along the middle of cell
  - ◆ meta = middle
  - ◆ metaphase plate
  - ◆ helps to ensure chromosomes separate properly
    - so each new nucleus receives only 1 copy of each chromosome





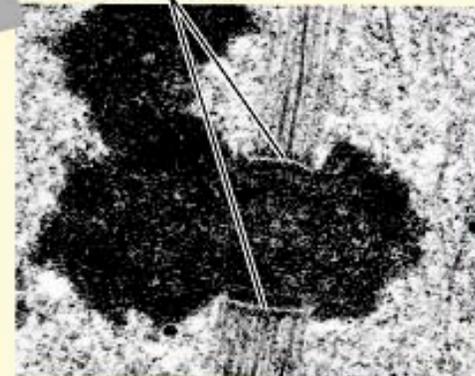
(a) Diagram of two duplicated chromosomes arrayed at the metaphase plate

Microtubules      Chromosomes



1 μm

Centrosome  
Kinetochores



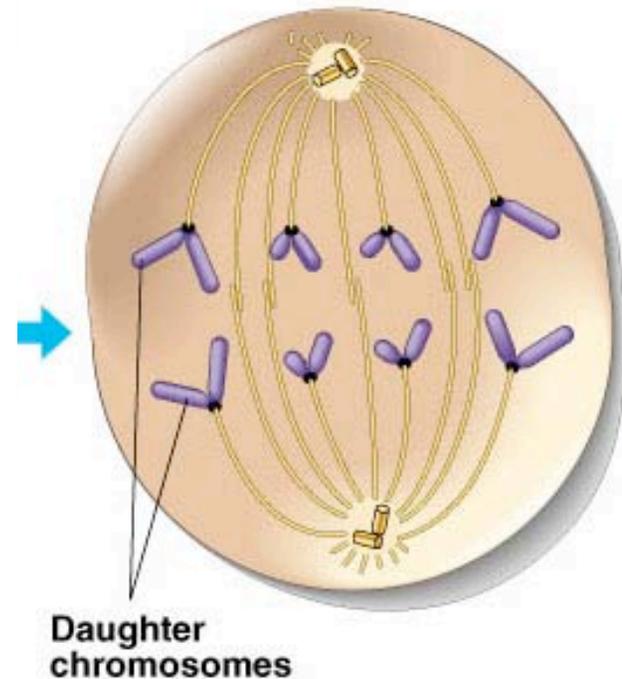
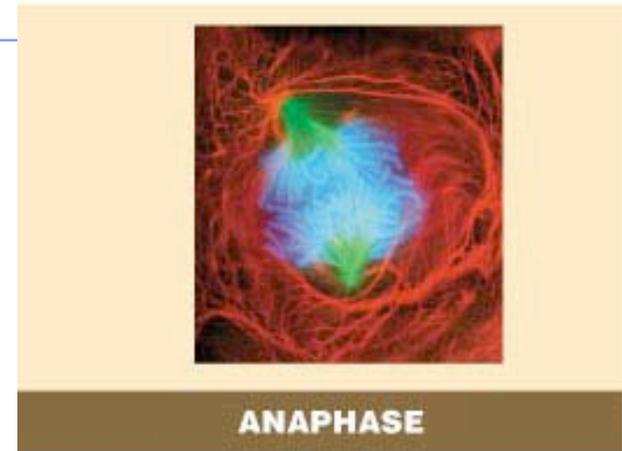
1 μm

(b) Transmission electron micrographs

From Dr. Matthew Schibler, *Photoplasma* 137 (1987):29-44.  
Reprinted by permission of Springer-Verlag.

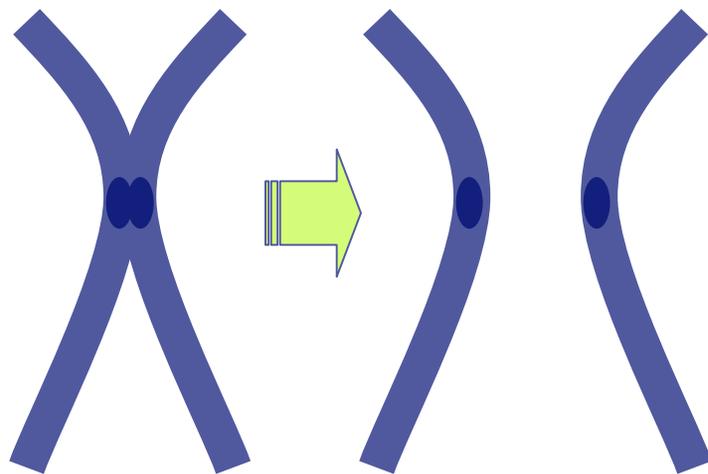
# Anaphase

- **Sister chromatids separate at kinetochores**
  - ◆ move to opposite poles
  - ◆ pulled at centromeres
  - ◆ pulled by motor proteins “walking” along microtubules
    - increased production of ATP by mitochondria
- **Poles move farther apart**
  - ◆ polar microtubules lengthen



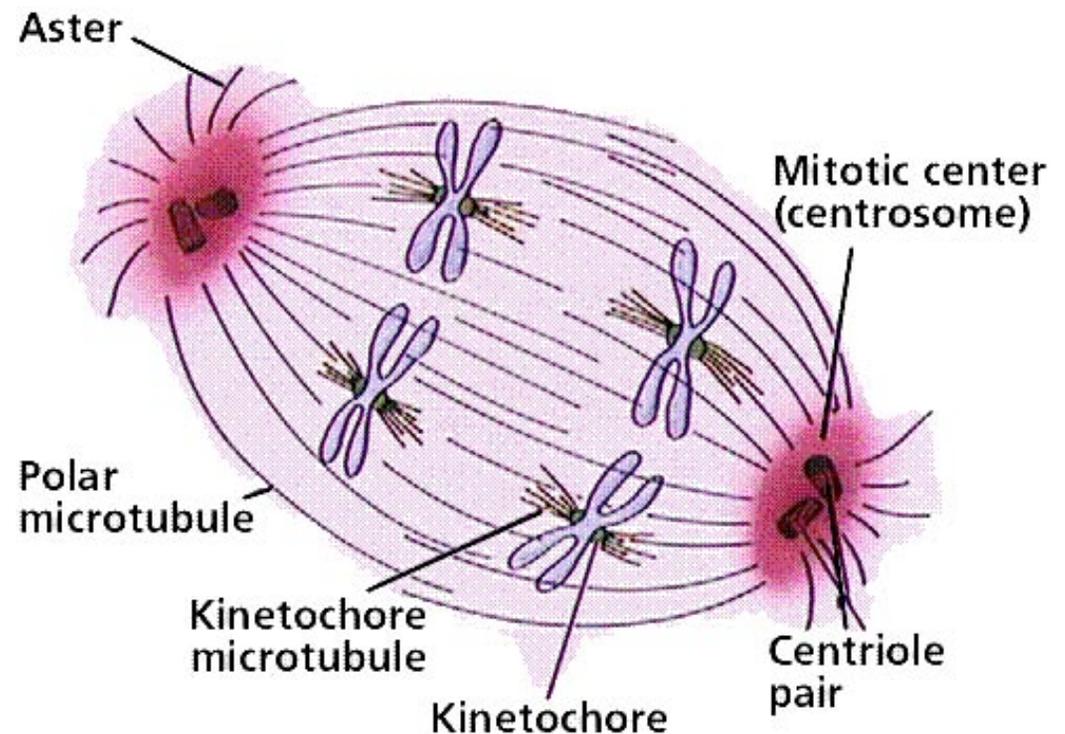
# Separation of chromatids

- In anaphase, proteins holding together sister chromatids are inactivated
  - ◆ separate to become individual chromosomes



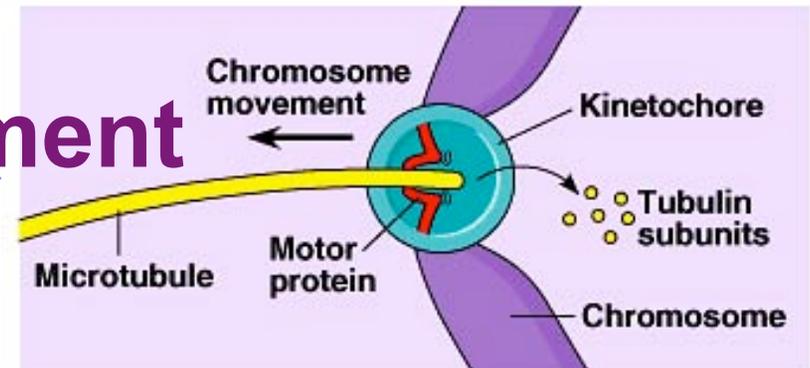
1 chromosome  
2 chromatids

2 chromosomes

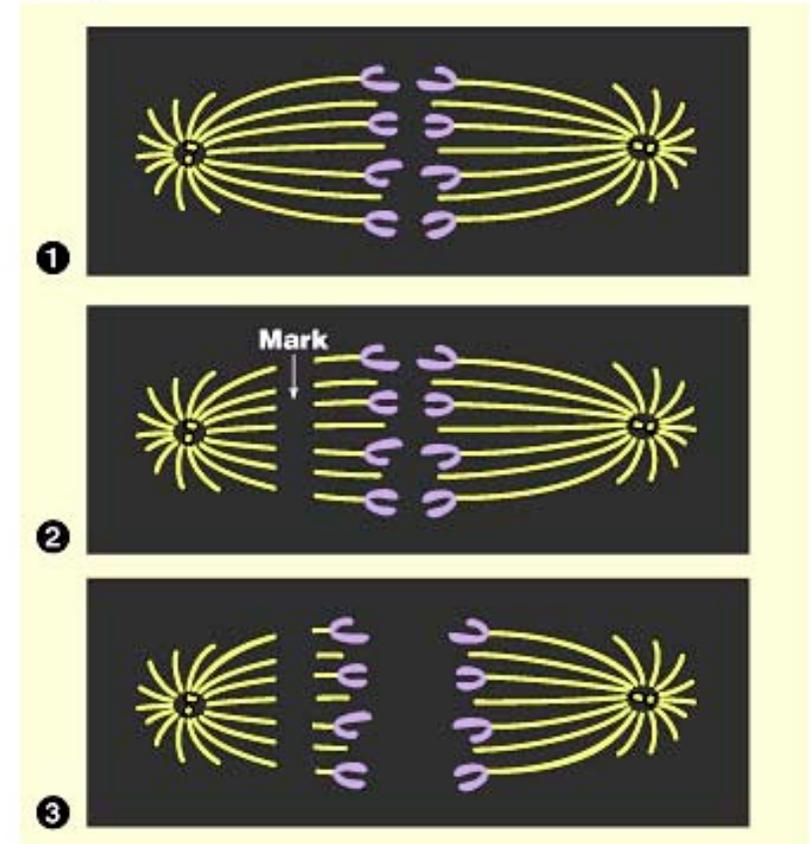


# Chromosome movement

- Kinetochore use motor proteins that “walk” chromosome along attached microtubule
  - ◆ microtubule shortens by dismantling at kinetochore (chromosome) end



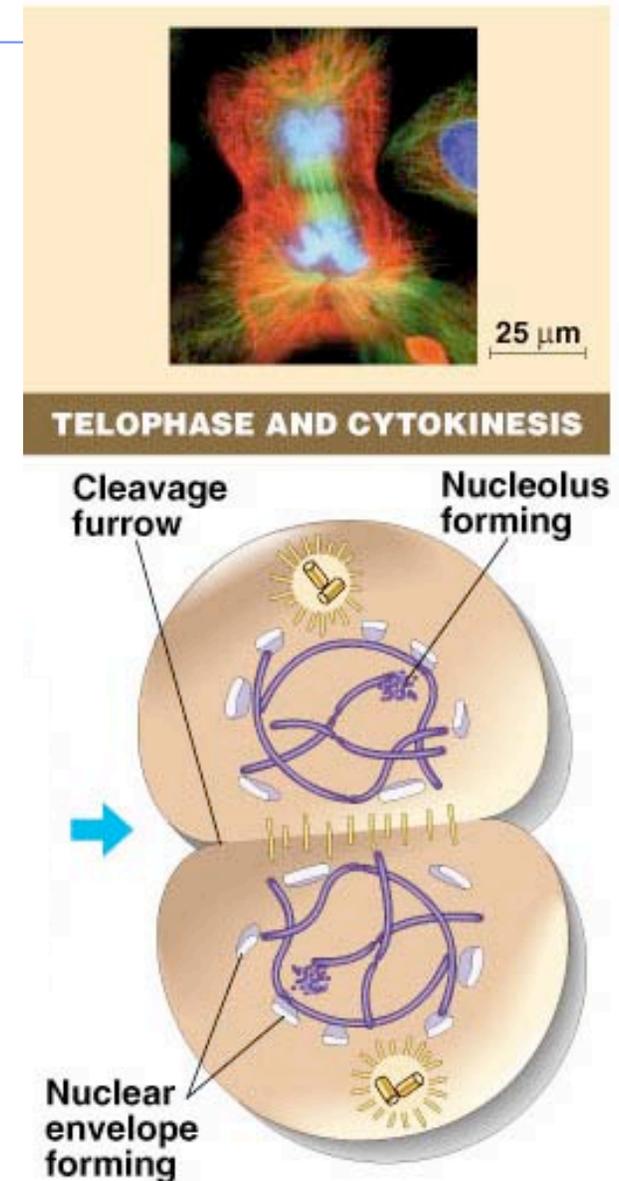
(a) Hypothesis



(b) Experiment

# Telophase

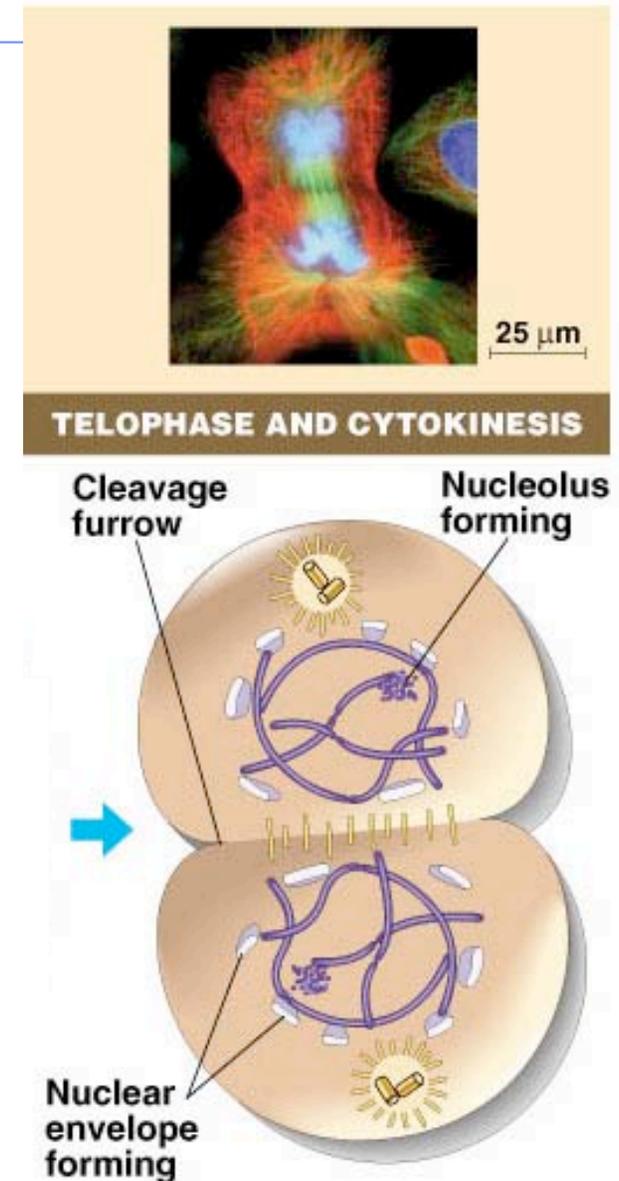
- Chromosomes arrive at opposite poles
  - ◆ daughter nuclei form
  - ◆ nucleoli form
  - ◆ chromosomes disperse
    - no longer visible under light microscope
- Spindle fibers disperse
- Cytokinesis begins
  - ◆ cell division



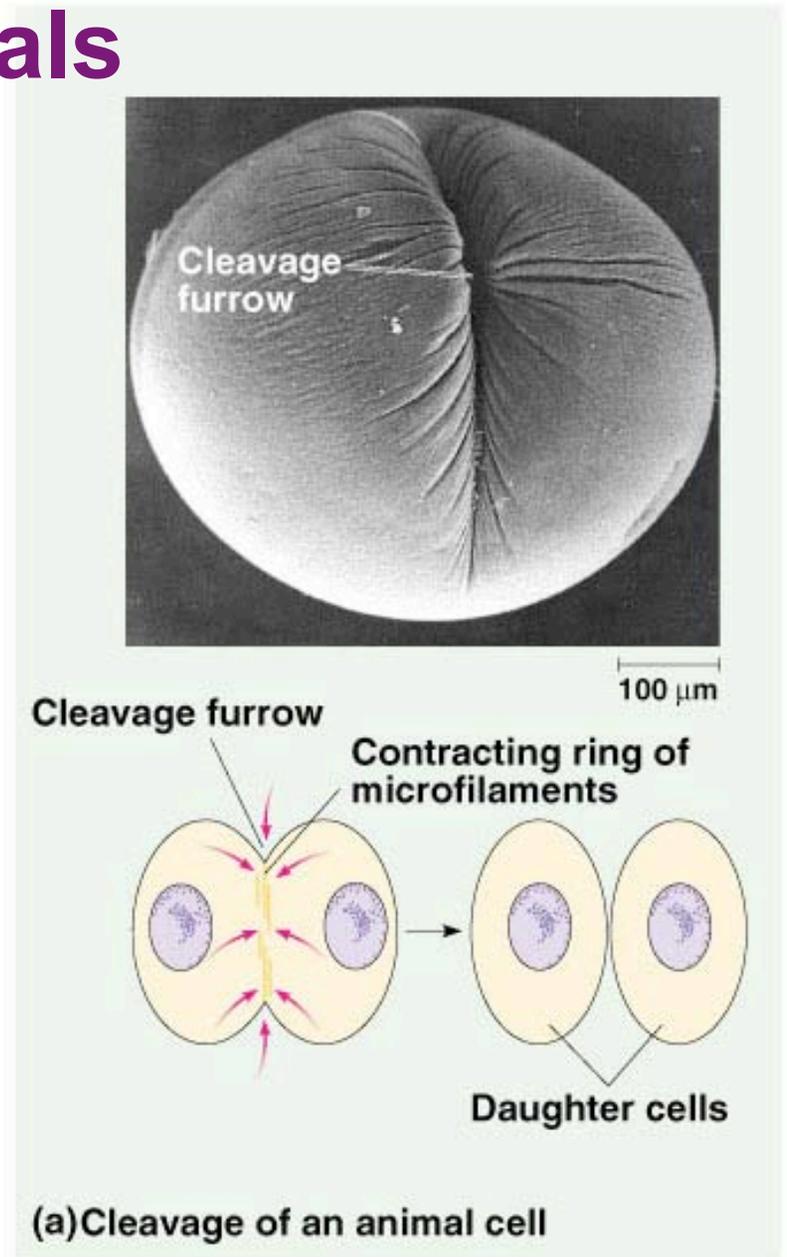
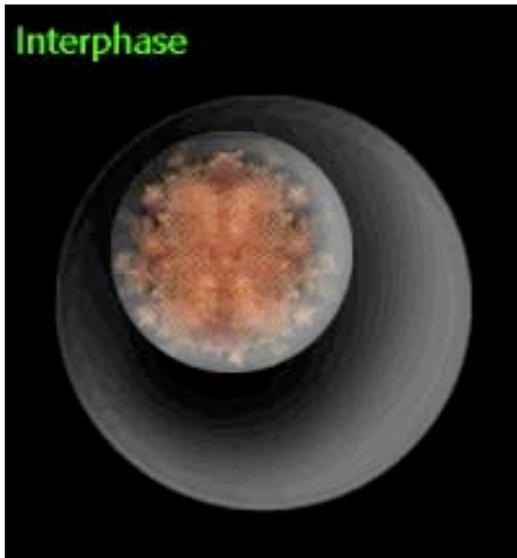
# Cytokinesis

## ■ Animals

- ◆ cleavage furrow forms
- ◆ ring of actin microfilaments forms around equator of cell
  - myosin proteins
- ◆ tightens to form a cleavage furrow, which splits the cell in two
  - like tightening a draw string

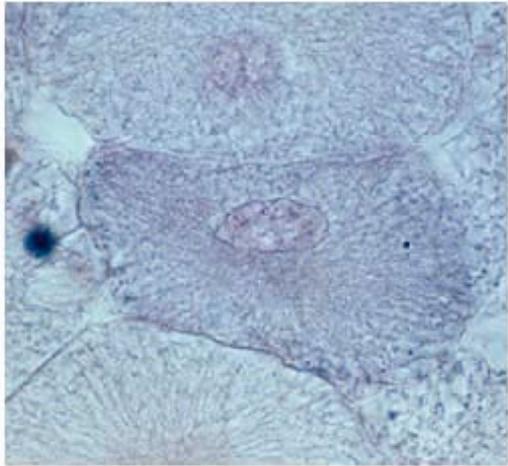


# Cytokinesis in Animals

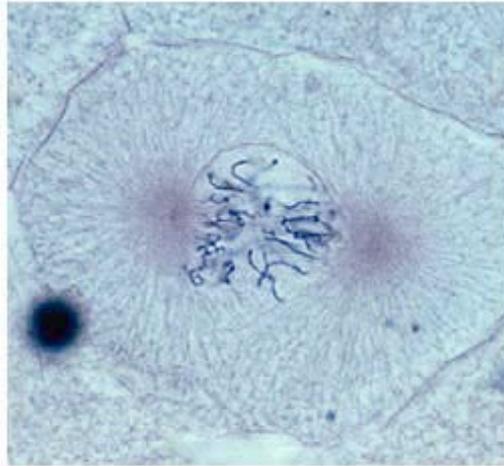


(play [Cells Alive](#) movie here)

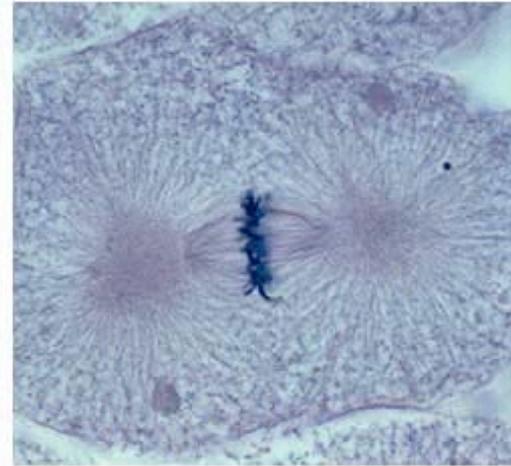
# Mitosis in whitefish blastula



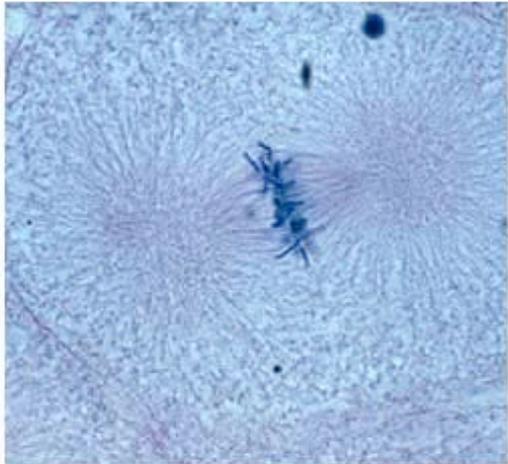
Interphase



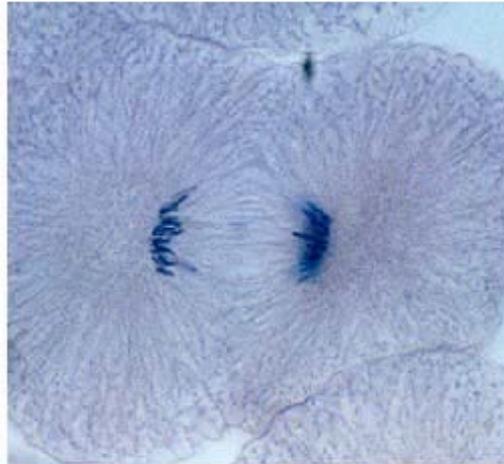
Prophase



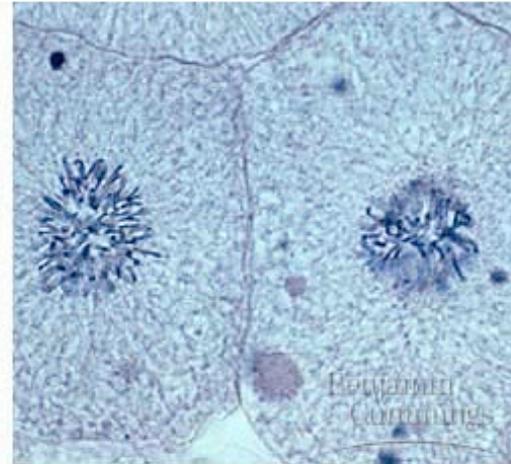
Metaphase



Anaphase

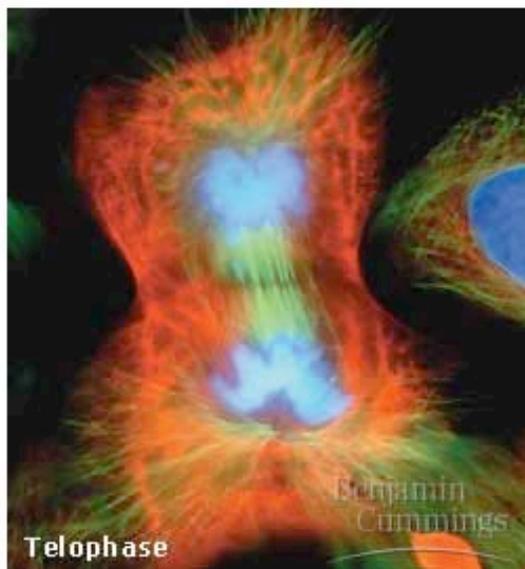
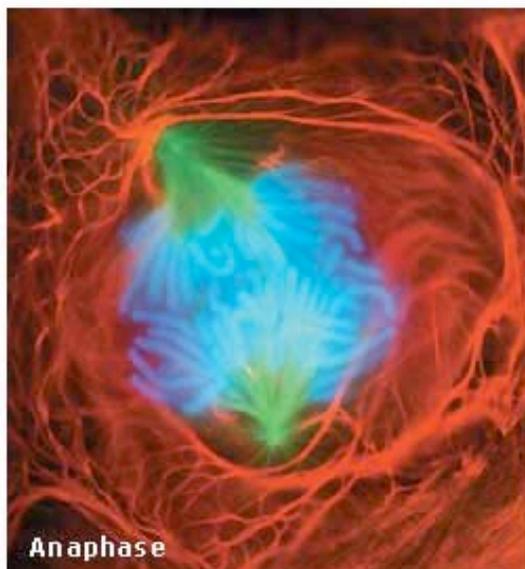
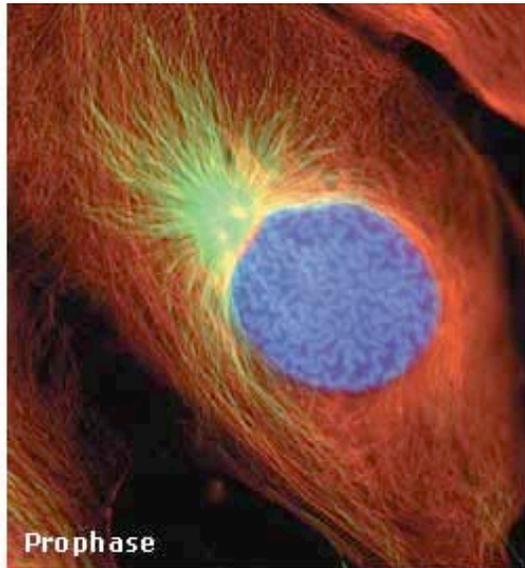
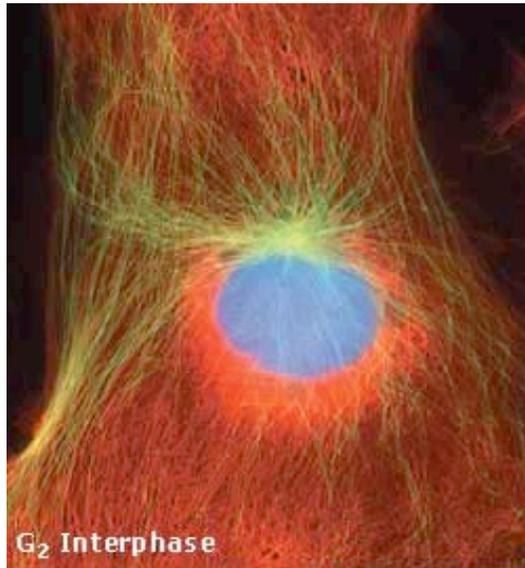


Early Telophase



Late Telophase

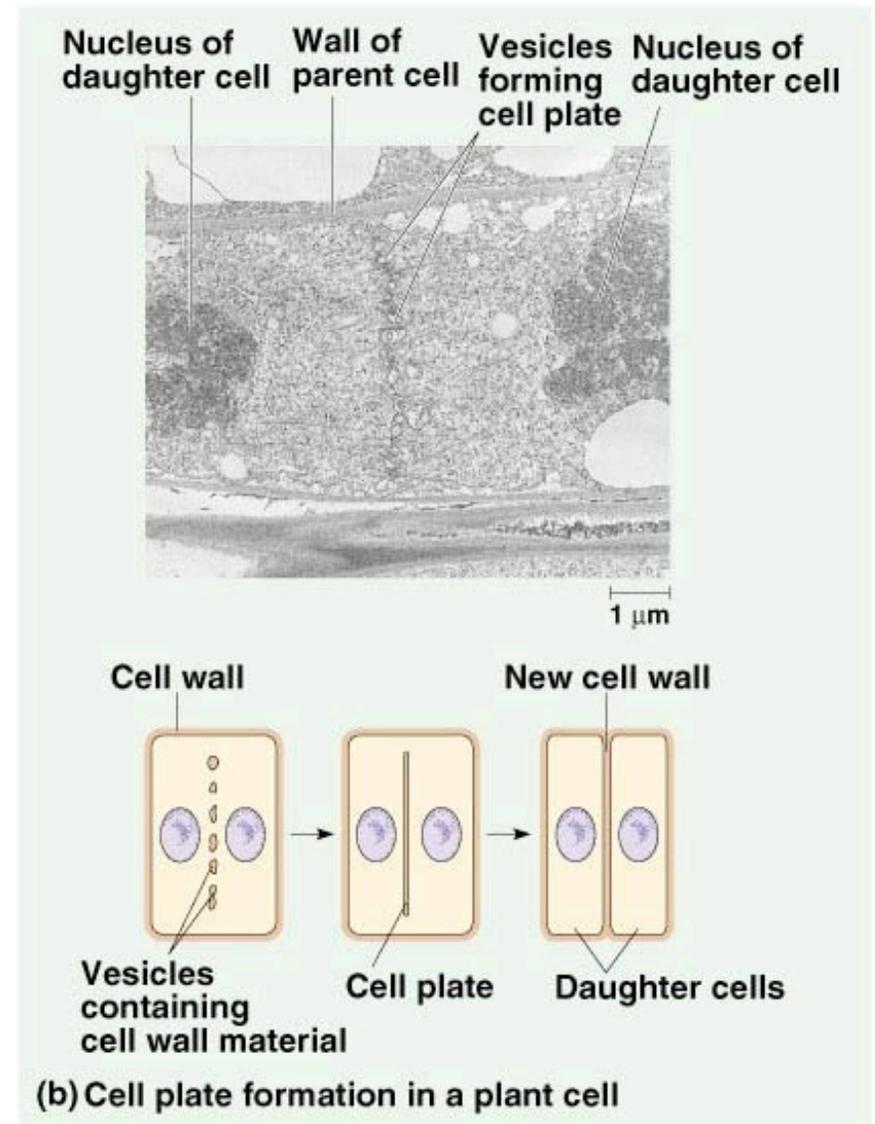
# Mitosis in animal cells



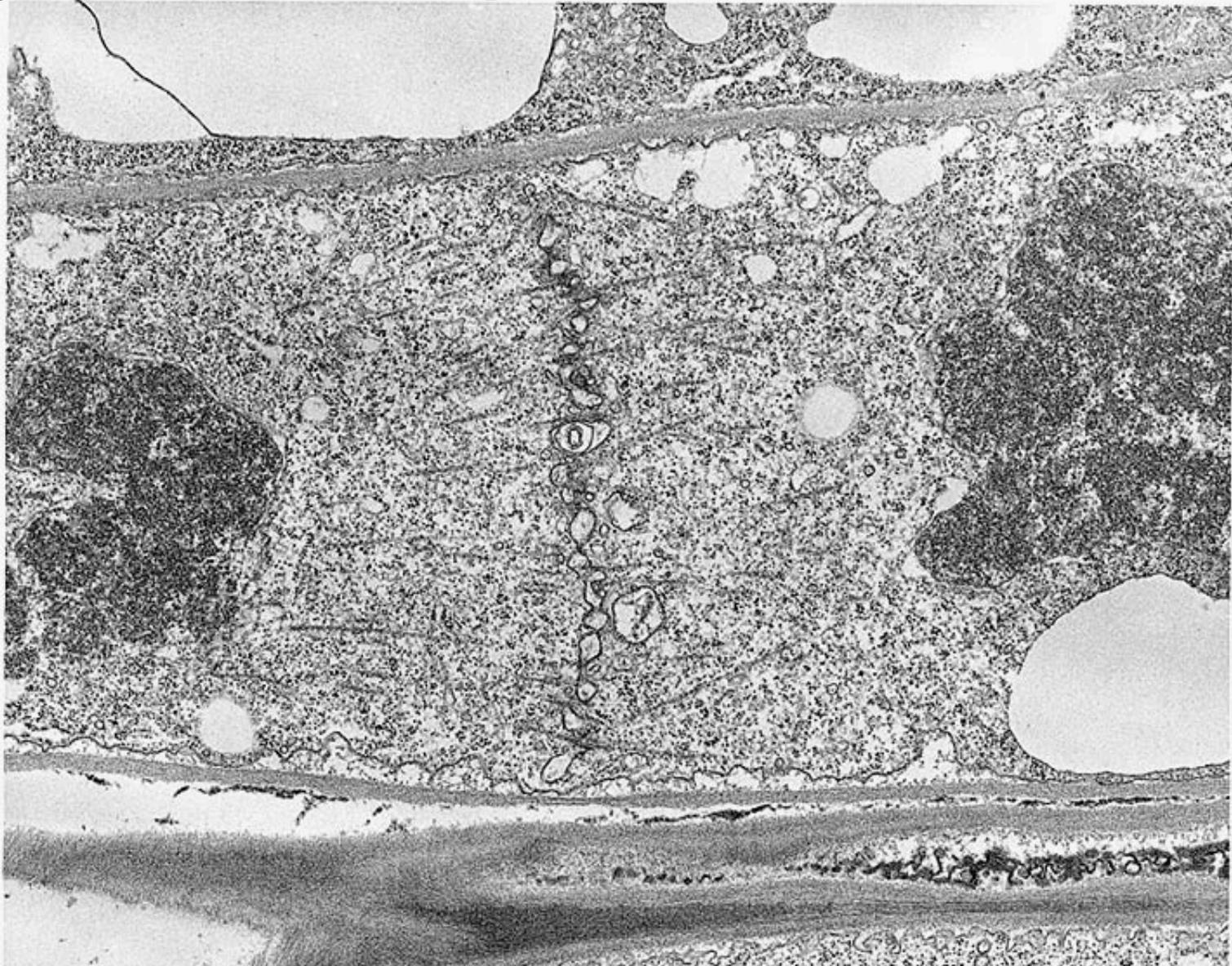
# Cytokinesis in Plants

## ■ Plants

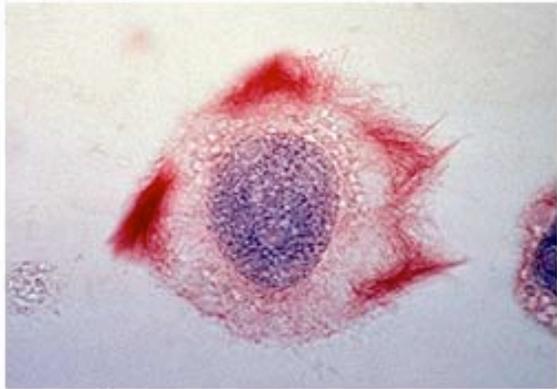
- ◆ vesicles move to equator line up & fuse to form 2 membranes = cell plate
  - derived from Golgi
- ◆ new cell wall is laid down between membranes
  - new cell wall fuses with existing cell wall



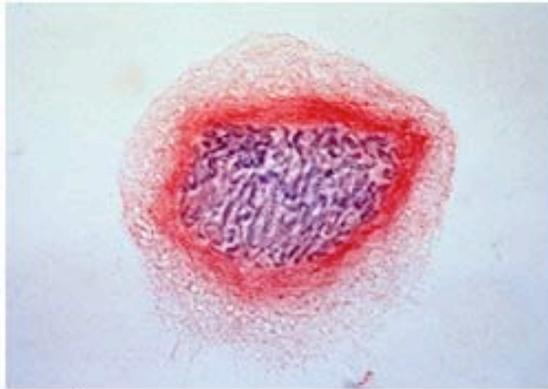
# Cytokinesis in plant cell



# Mitosis in plant cell



Interphase



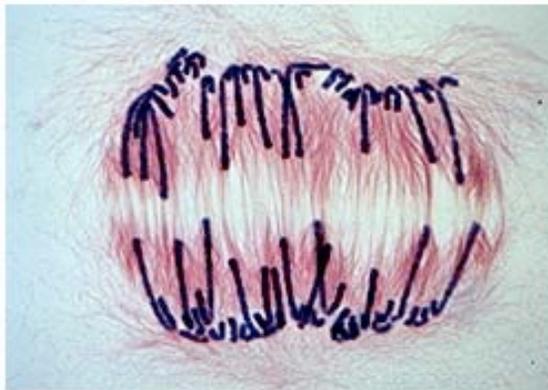
Prophase



Prometaphase



Metaphase

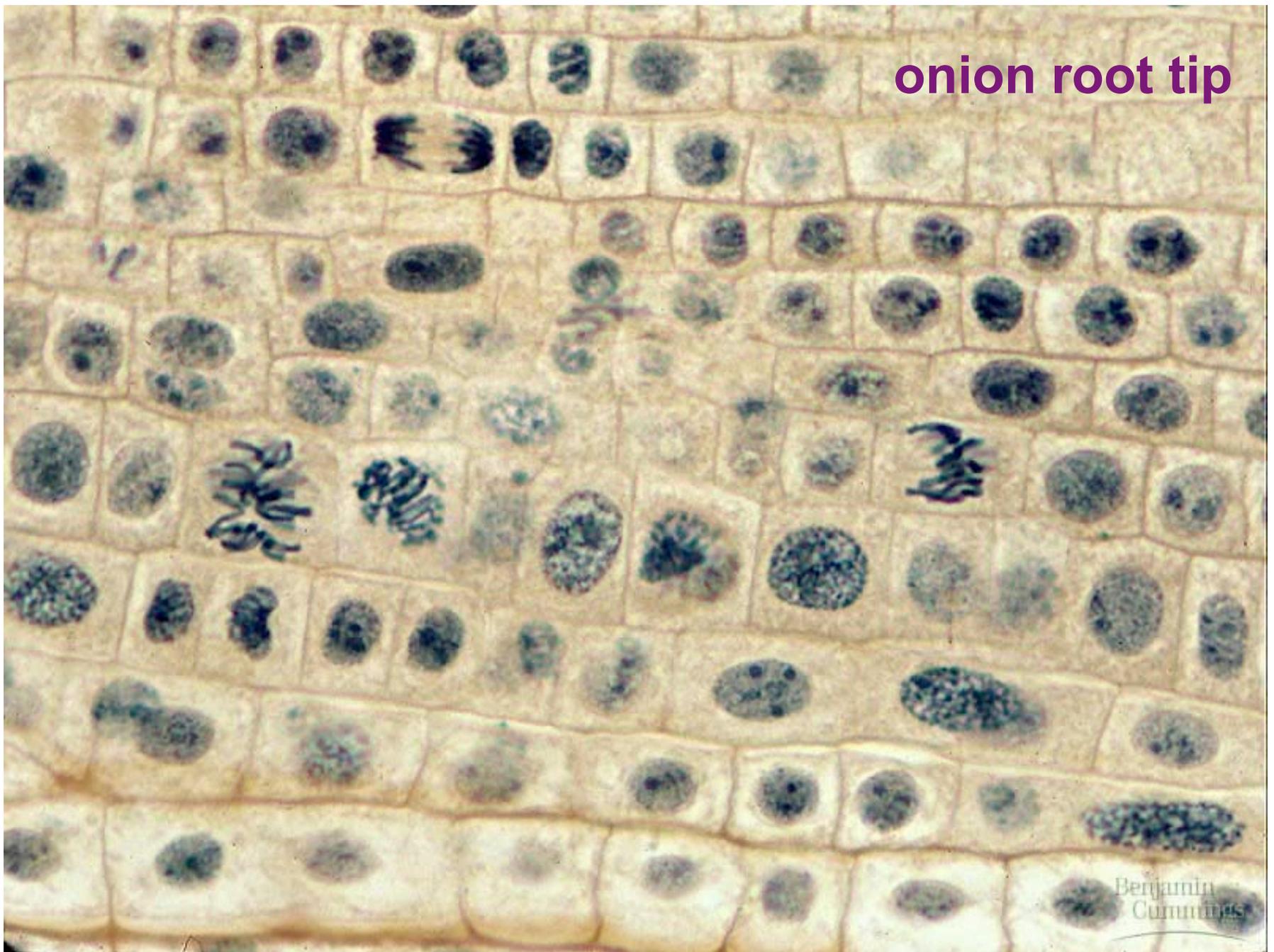


Anaphase



Telophase

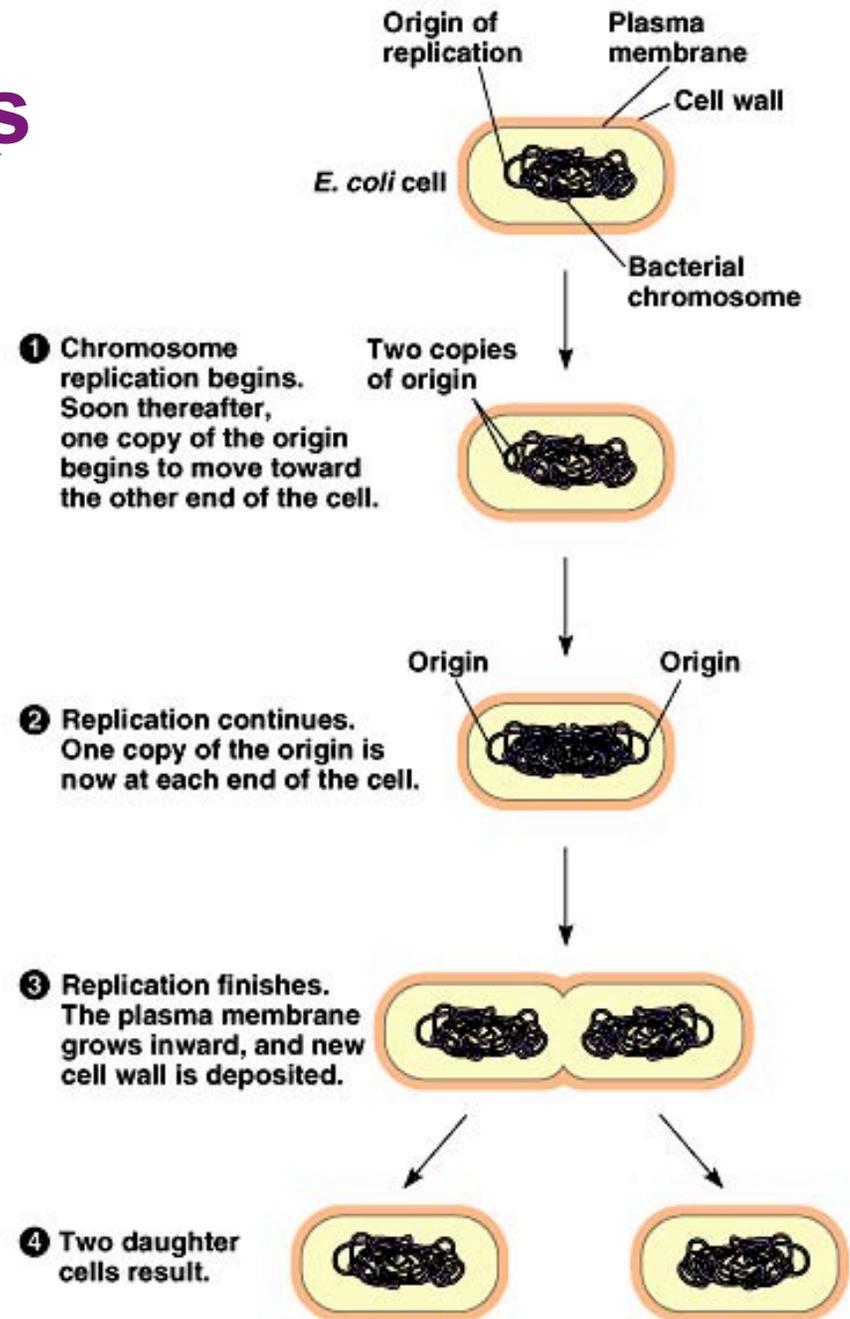
onion root tip



Benjamin  
Cummings

# Evolution of mitosis

- Mitosis in eukaryotes likely evolved from binary fission in bacteria
  - ◆ single circular chromosome
  - ◆ no membrane-bound organelles

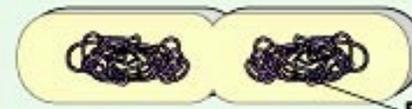


# Evolution of mitosis

- Mechanisms intermediate between binary fission & mitosis seen in modern organisms
  - ◆ protists

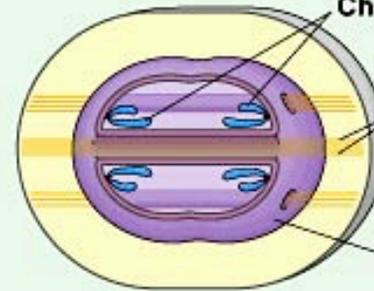
Hypothetical sequence

Evidence from modern organisms



Bacterial chromosome

(a) Prokaryotes

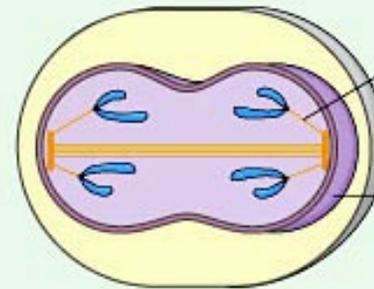


Chromosomes

Microtubules

Intact nuclear envelope

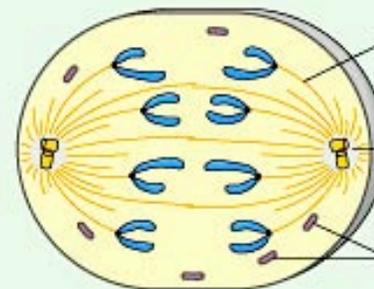
(b) Dinoflagellates



Kinetochore microtubules

Intact nuclear envelope

(c) Diatoms



Kinetochore microtubules

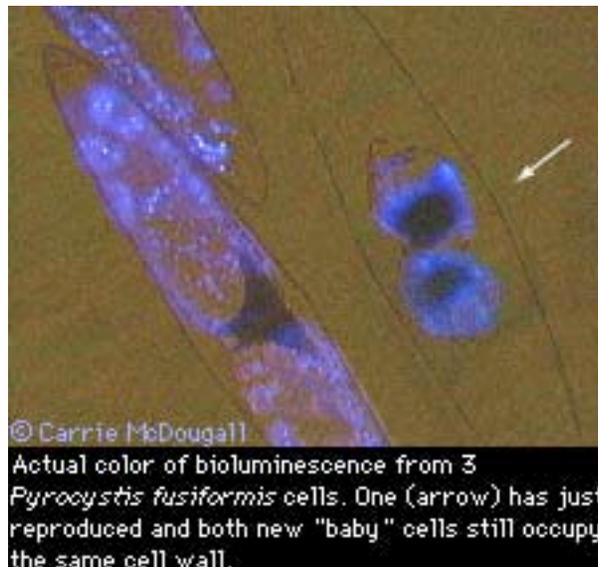
Centrosome

Fragments of nuclear envelope

(d) Most eukaryotes

# Dinoflagellates

- algae
  - ◆ “red tide”
  - ◆ bioluminescence



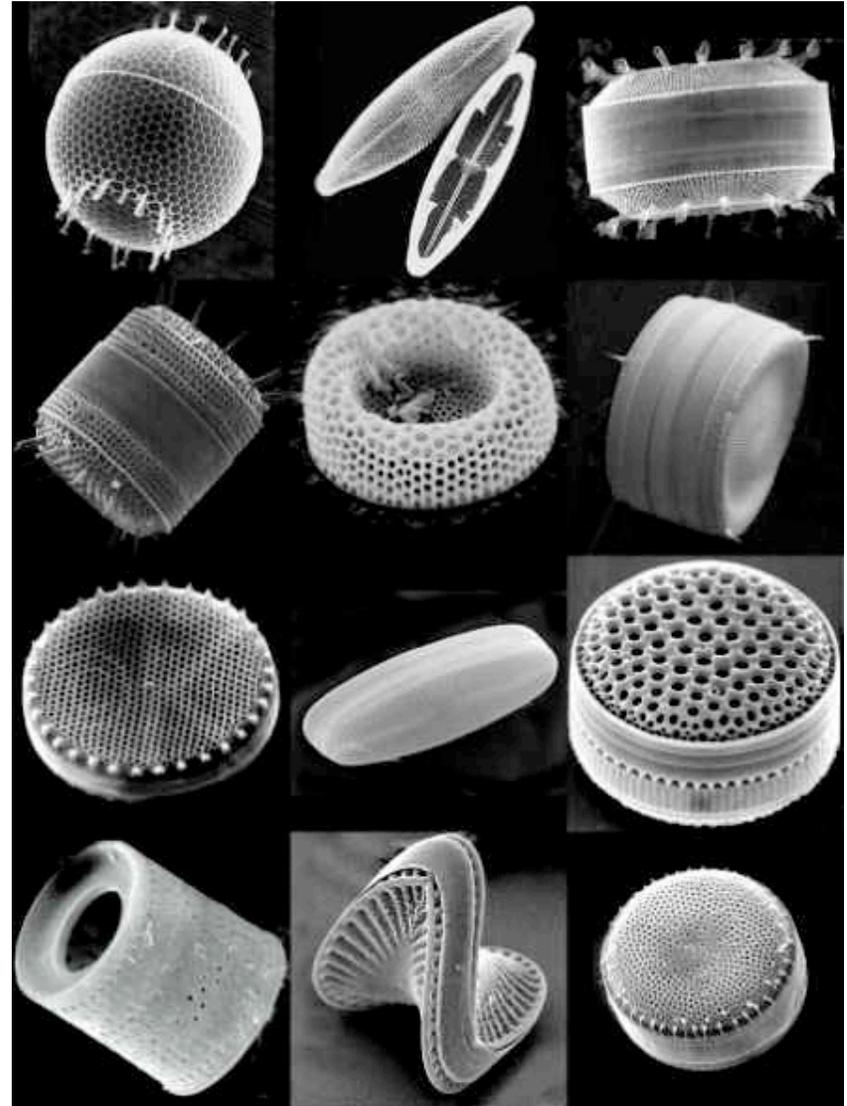
# Diatoms

- **microscopic algae**
  - ◆ **marine**
  - ◆ **freshwater**



Diatoms, one-celled algae, come in a variety of beautiful shapes and sizes.

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**Any Questions??**



**Any Questions??**

