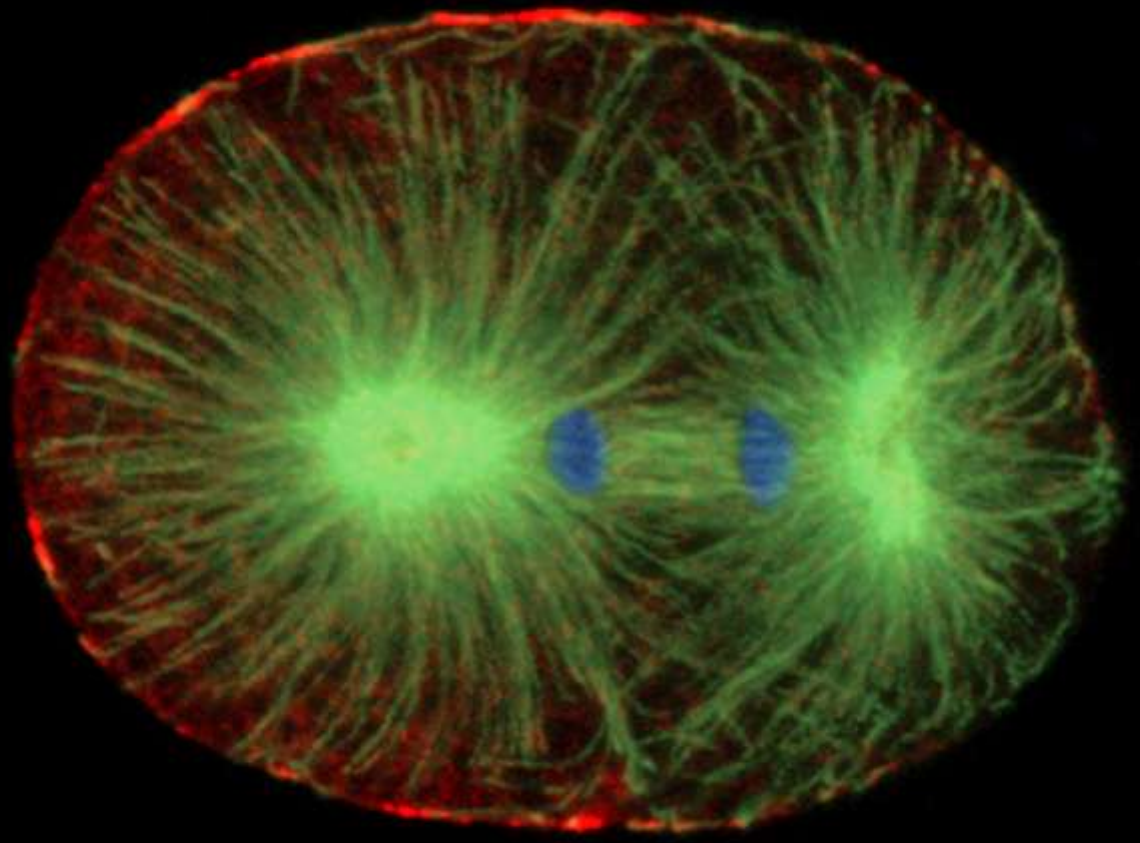
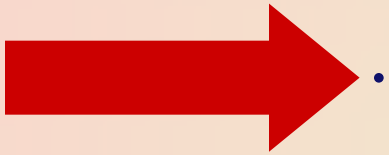
The Cell Cycle:
Cell Growth, Cell Division
(Ch. 12)



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?

Getting from there to here…

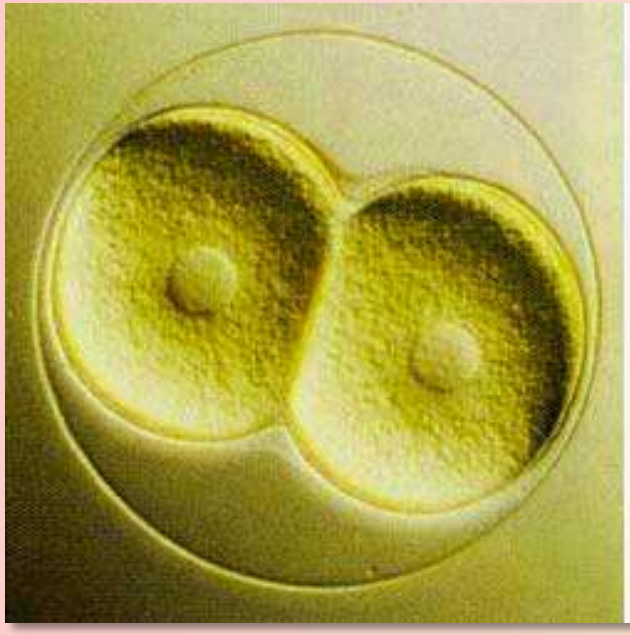
- Going from egg to baby….

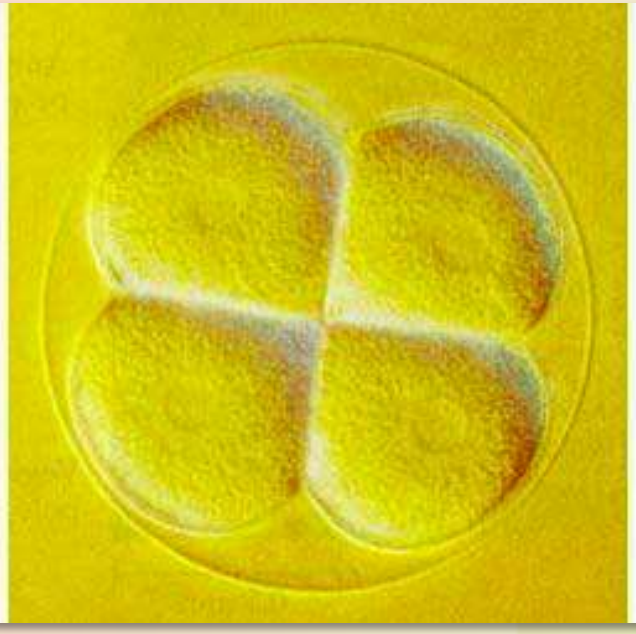
  the original fertilized egg has to divide…

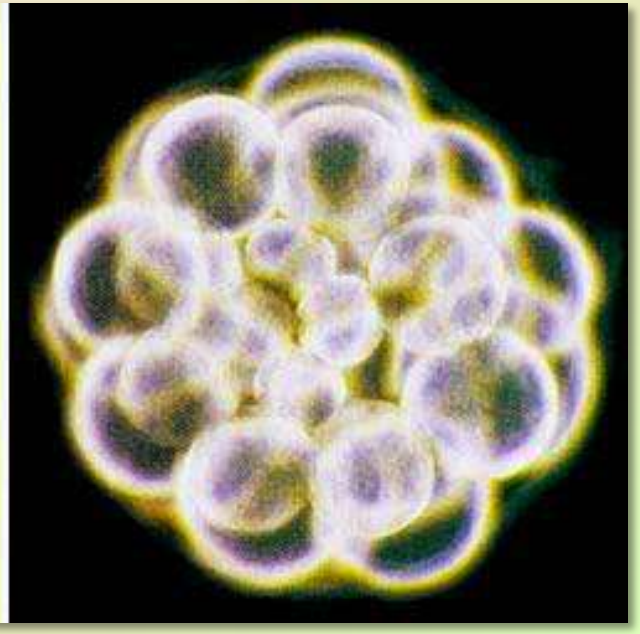
  and divide…

  and divide…

  and divide…

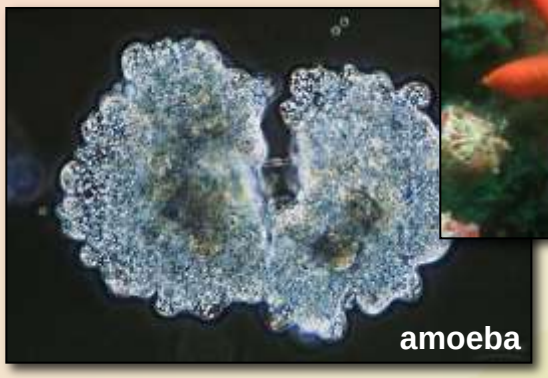






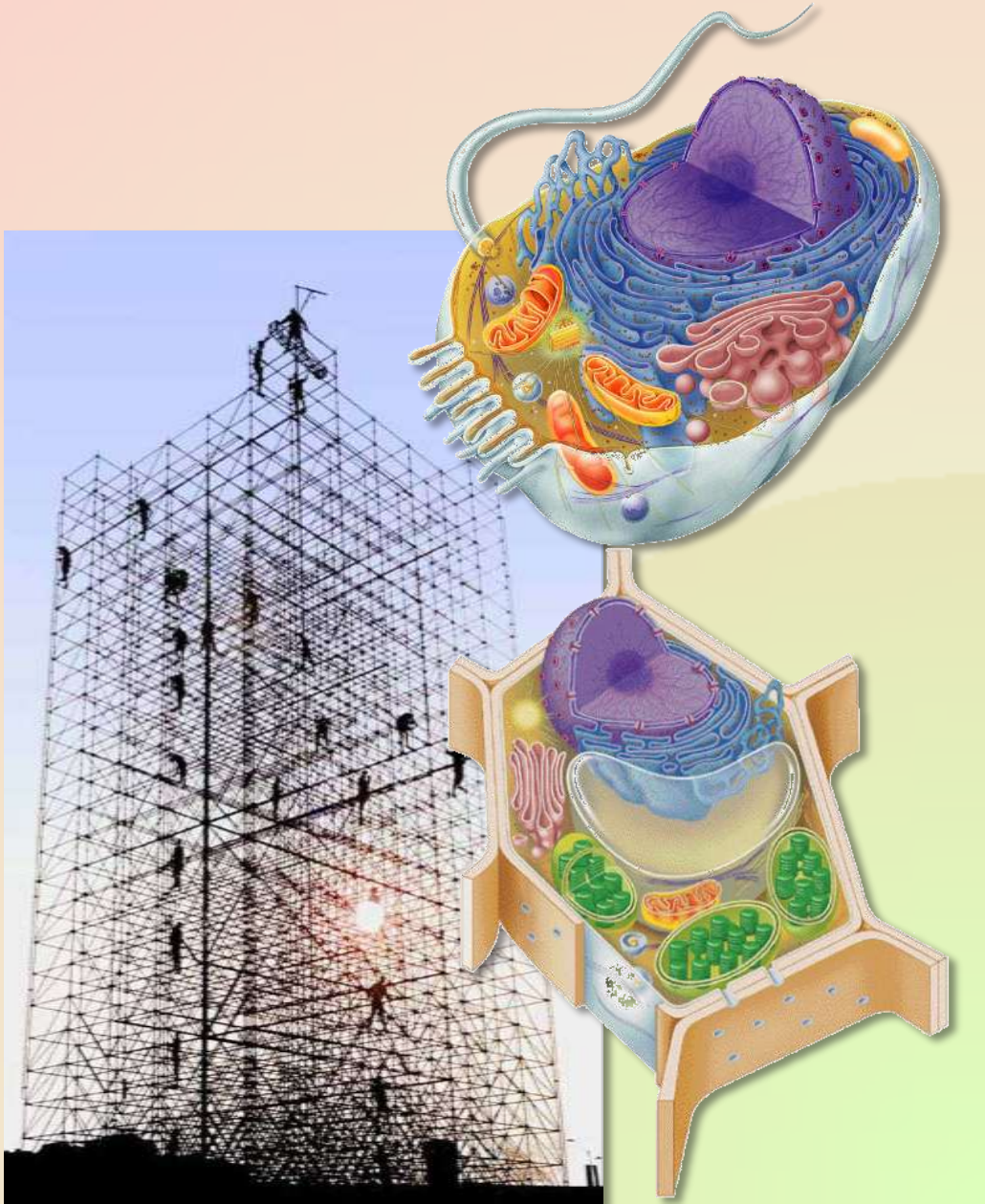
Why do cells divide?

- For reproduction
  - asexual reproduction
    - one-celled organisms
- For growth
  - from fertilized egg to multi-celled organism
- For repair & renewal
  - replace cells that die from normal wear & tear or from injury



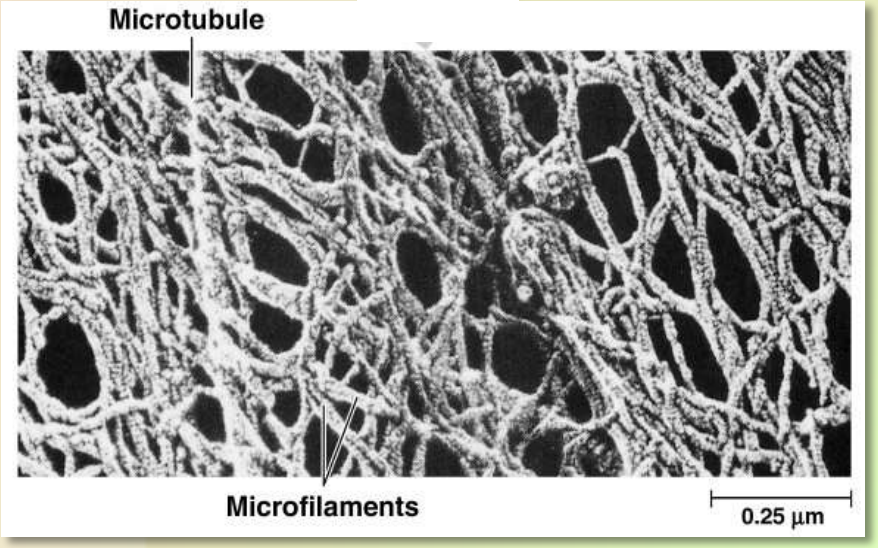
Making new cells

- Nucleus
  - chromosomes
  - DNA
- Cytoskeleton
  - centrioles
    - in animals
  - microtubule spindle fibers

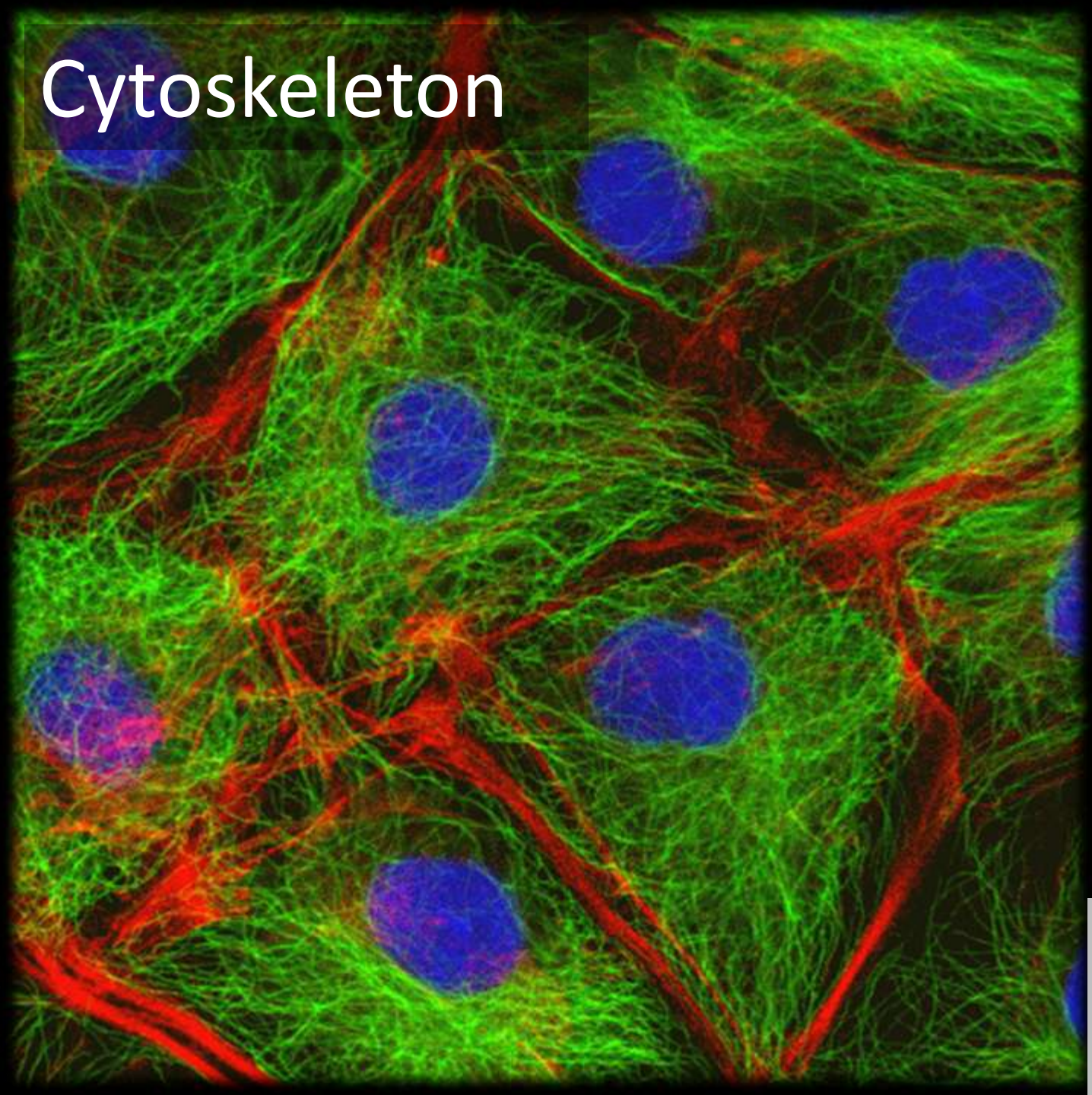


Cytoskeleton

- Function
  - structural support
    - maintains shape, provides anchorage
      - protein fibers
        - » microfilaments, intermediate filaments, microtubules
  - motility
    - cell locomotion
  - regulation
    - Organizes cell activities



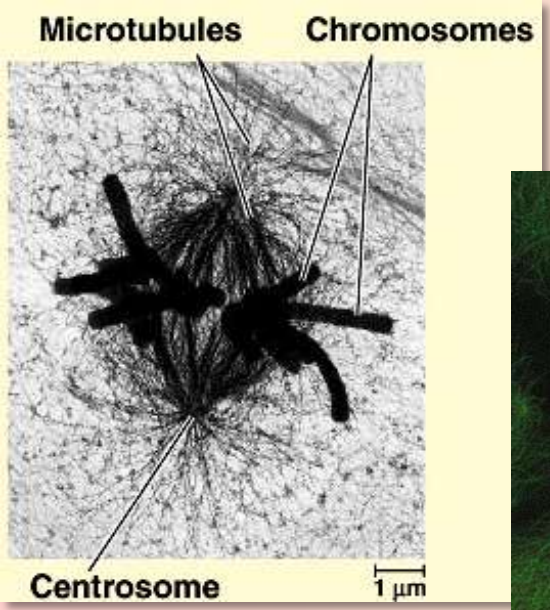
Cytoskeleton

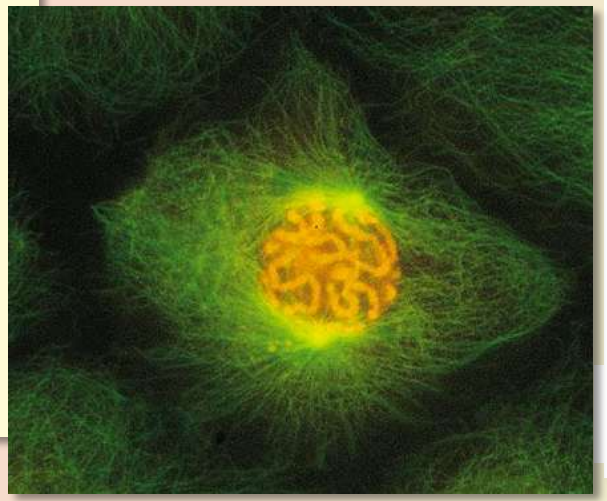


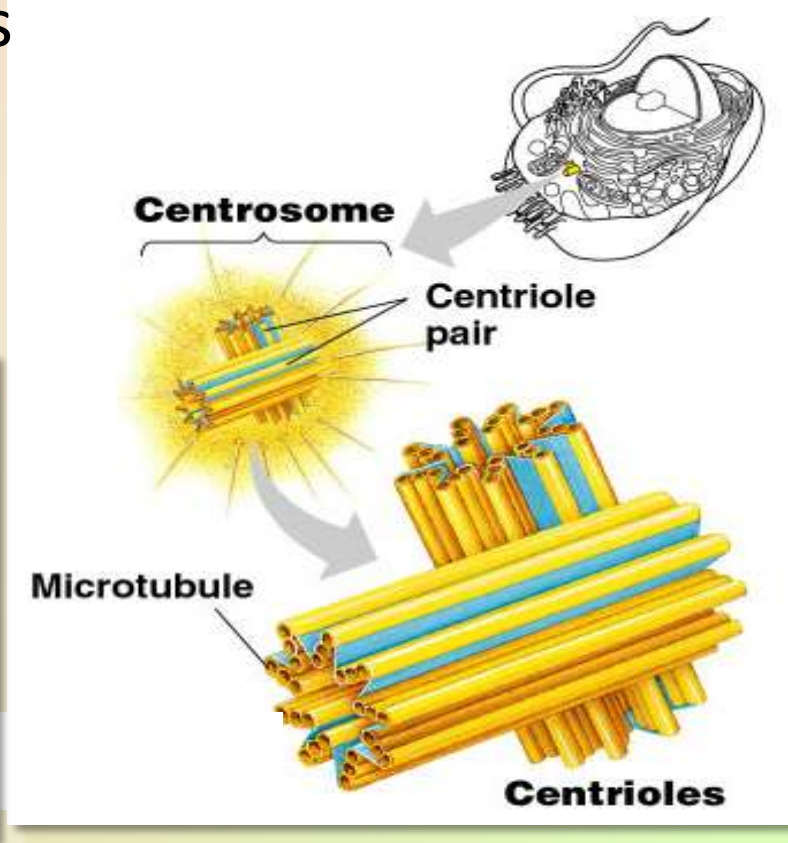
- actin
- microtubule
- nuclei

Centrioles

- Cell division
  - in animal cells, pair of centrioles organize microtubules
    - spindle fibers
  - guide chromosomes in mitosis

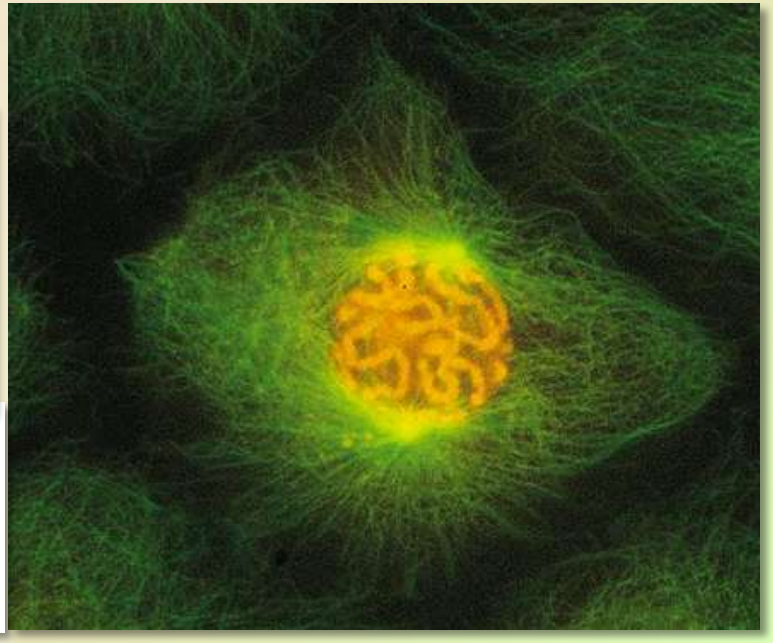






Getting the right stuff

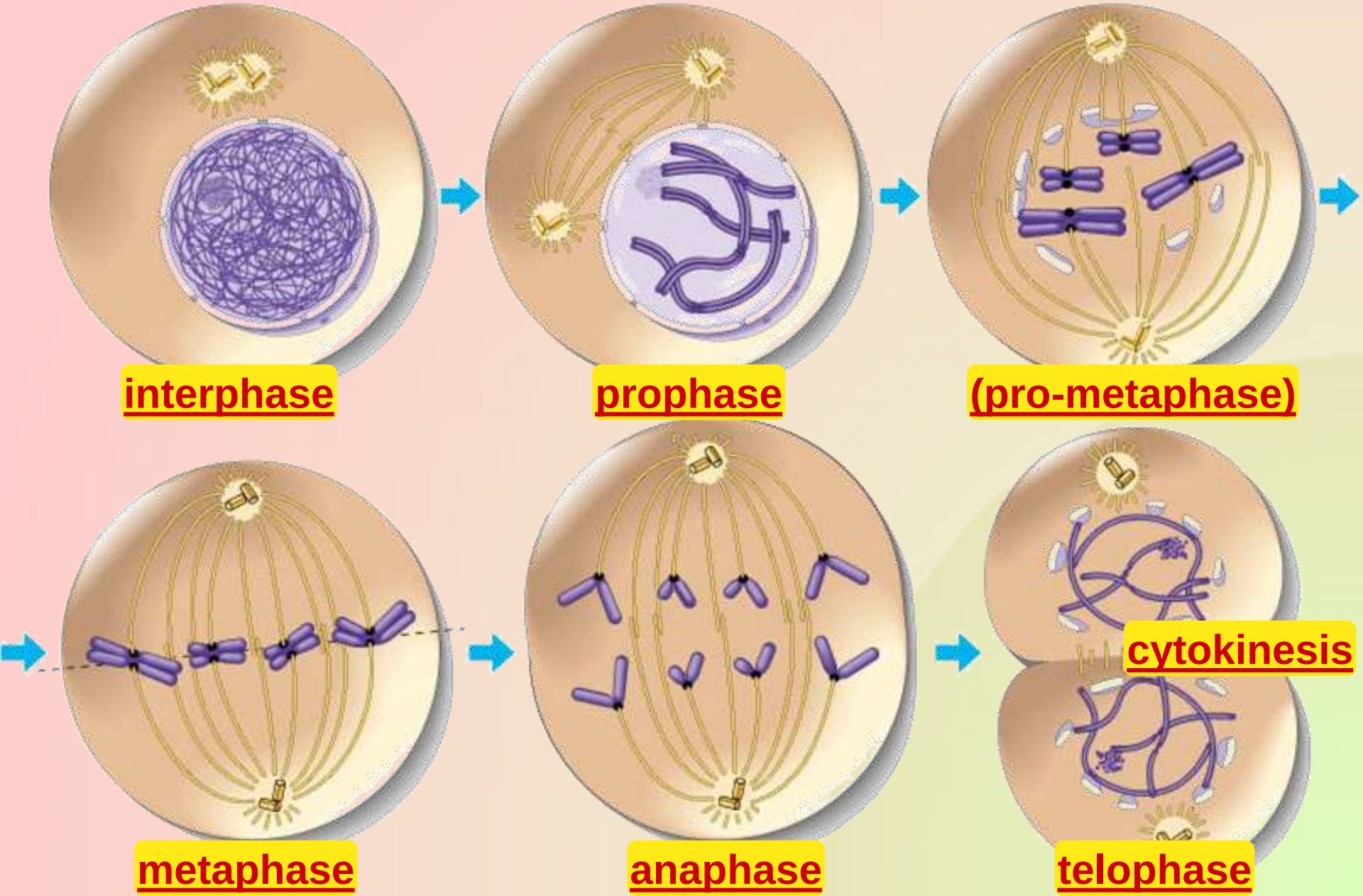
- What is passed on to daughter cells?
  - exact copy of genetic material = DNA
  - organelles, cytoplasm, cell membrane, enzymes



chromosomes (stained orange) in kangaroo rat epithelial cell
→notice cytoskeleton fibers

Overview of mitosis

I.P.M.A.T.

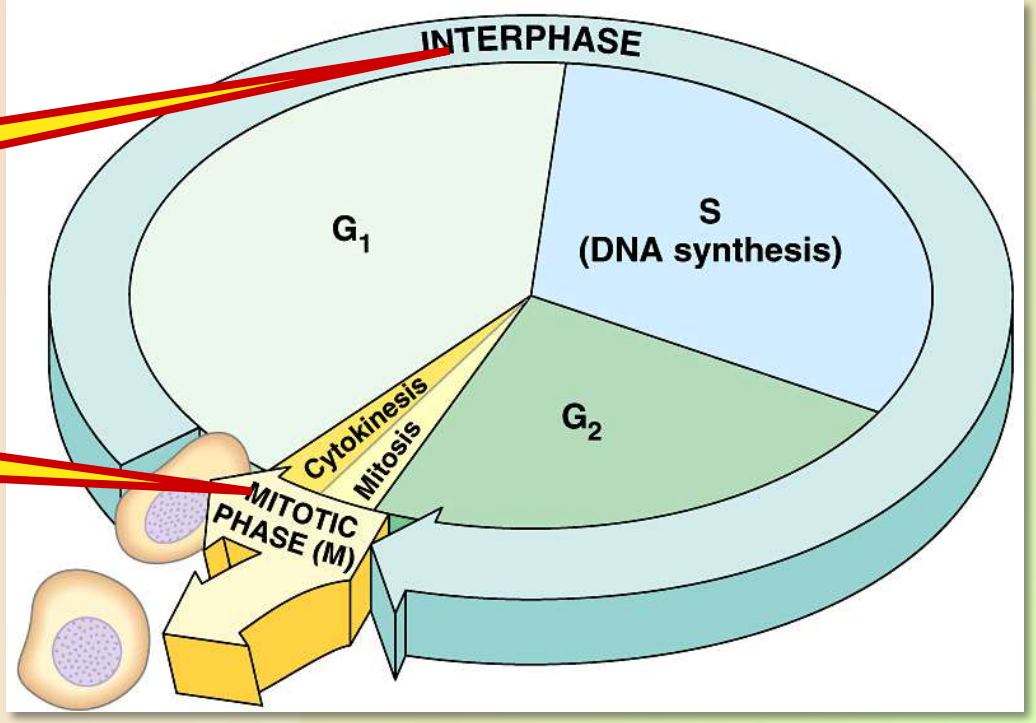


Interphase

- Most of a cell's life cycle (~95%)
  - cell doing its "everyday job"
    - synthesize proteins/enzymes, metabolism, etc.
  - prepares for duplication if triggered

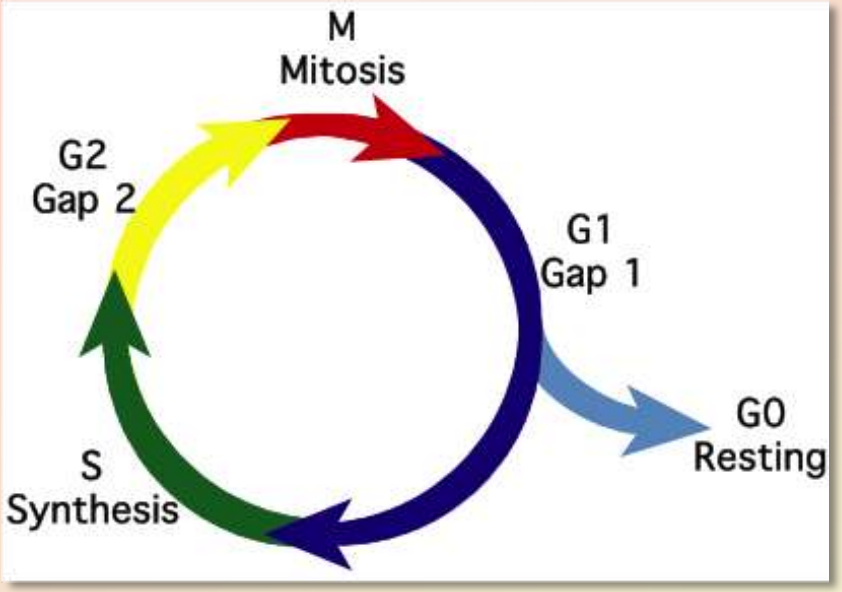
I'm working here!

Time to divide & multiply!



Cell cycle

- Cell has a “life cycle”



cell is formed from a mitotic division

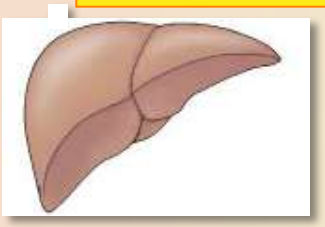
cell grows & matures to divide again

cell grows & matures to never divide again

G_1, S, G_2, M

liver cells

$G_1 \rightarrow G_0$



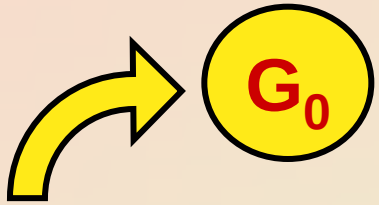
epithelial cells, blood cells, stem cells

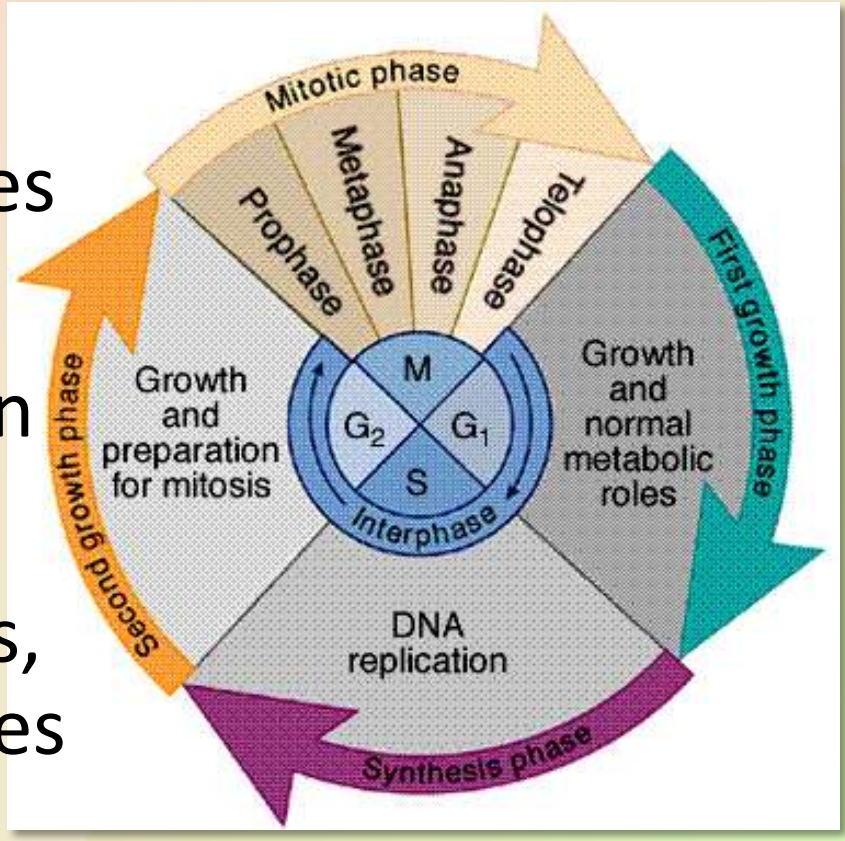
brain / nerve cells muscle cells

Interphase

- Divided into 3 phases:
  - G_1 = 1st Gap (Growth)
    - Non-dividing life
  - S = DNA Synthesis
    - copies chromosomes
  - G_2 = 2nd Gap (Growth)
    - prepares for division
    - cell grows (more)
    - produces organelles, proteins, membranes

signal to divide

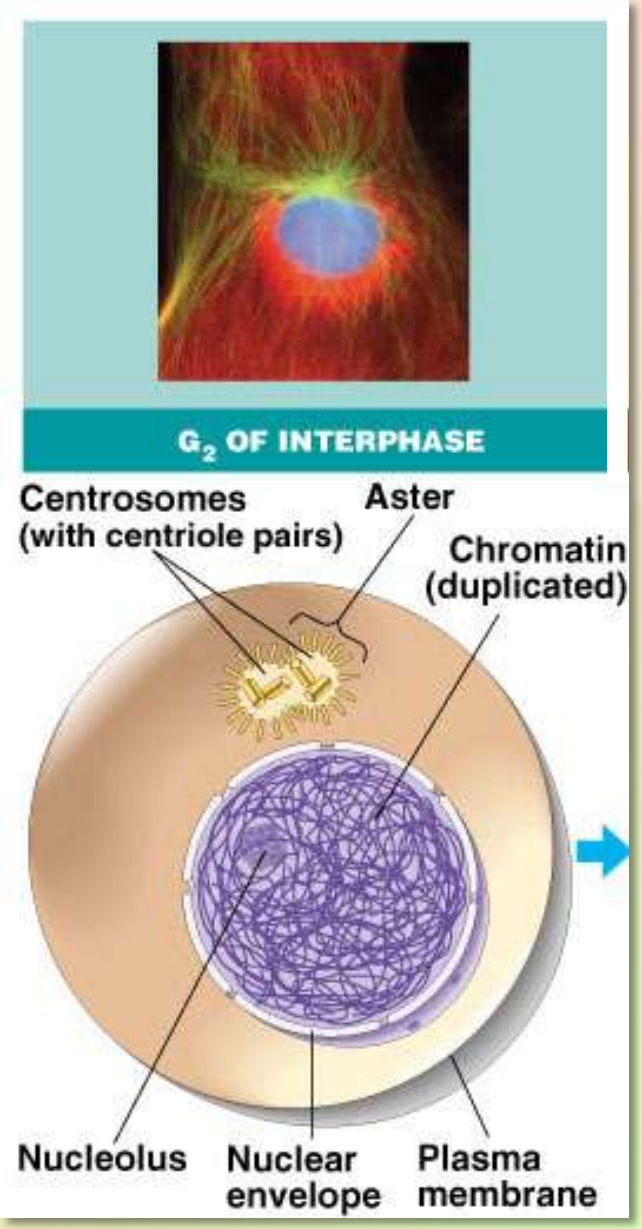




Red = key features

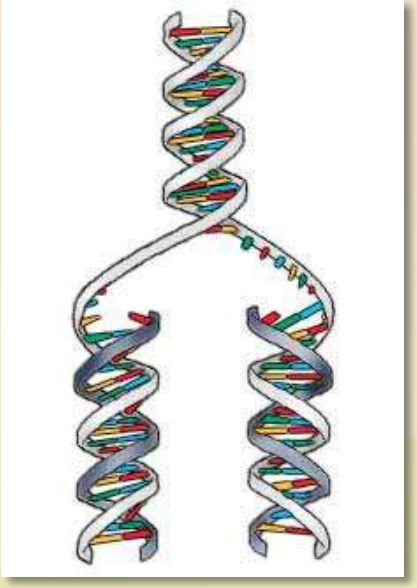
Interphase

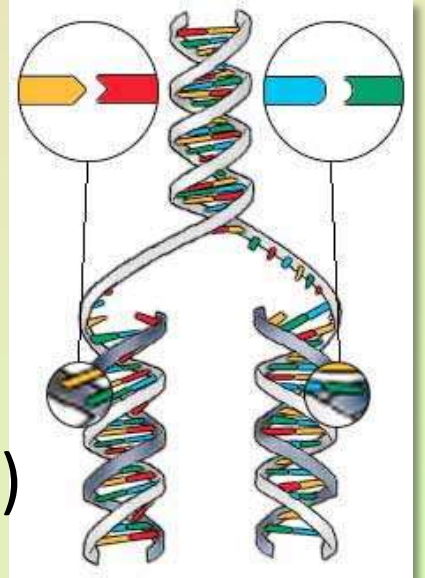
- Nucleus well-defined
  - DNA loosely packed in chromatin fibers
- Prepares for mitosis
  - replicates chromosome
    - DNA & proteins
  - produces proteins & organelles



S phase: Copying / Replicating DNA

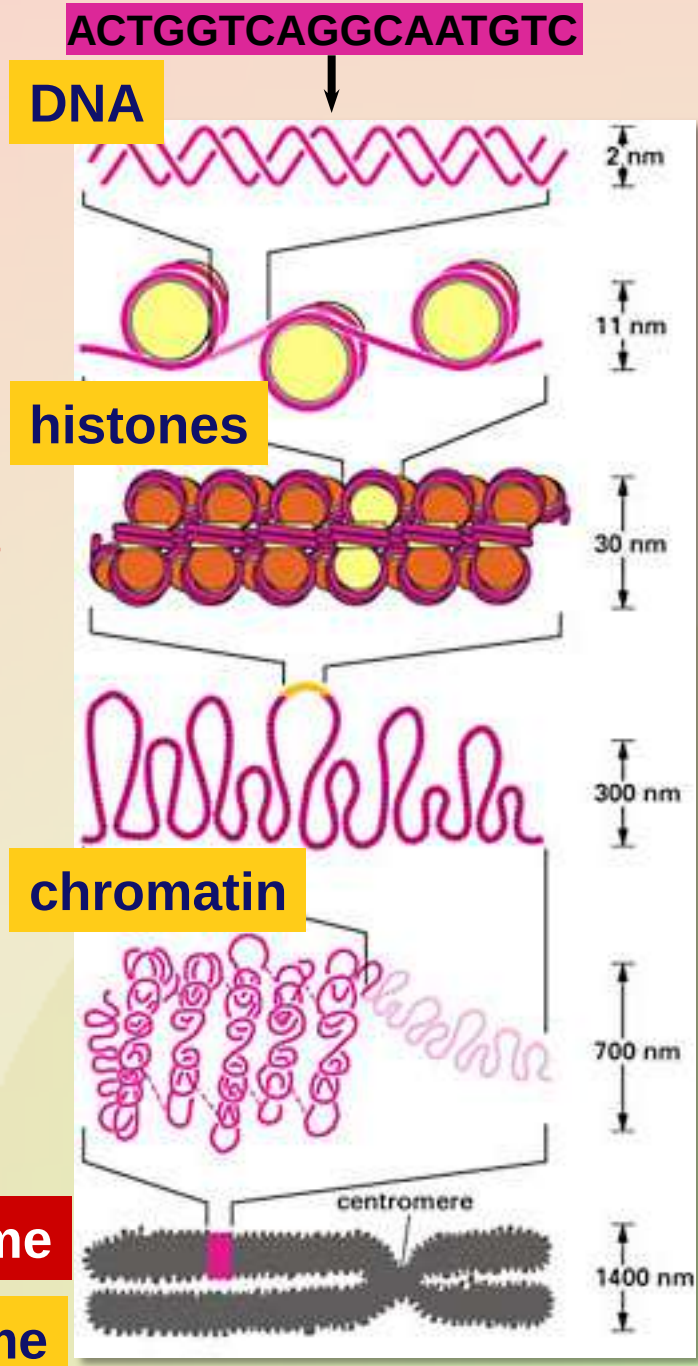
- Synthesis phase of Interphase
  - dividing cell replicates DNA
  - must separate DNA copies correctly to 2 daughter cells
    - human cell duplicates ~3 meters DNA
    - each daughter cell gets complete identical copy
    - error rate = ~1 per 100 million bases
      - 3 billion base pairs in mammalian genome
      - ~30 errors per cell cycle
        - » mutations (to somatic (body) cells)





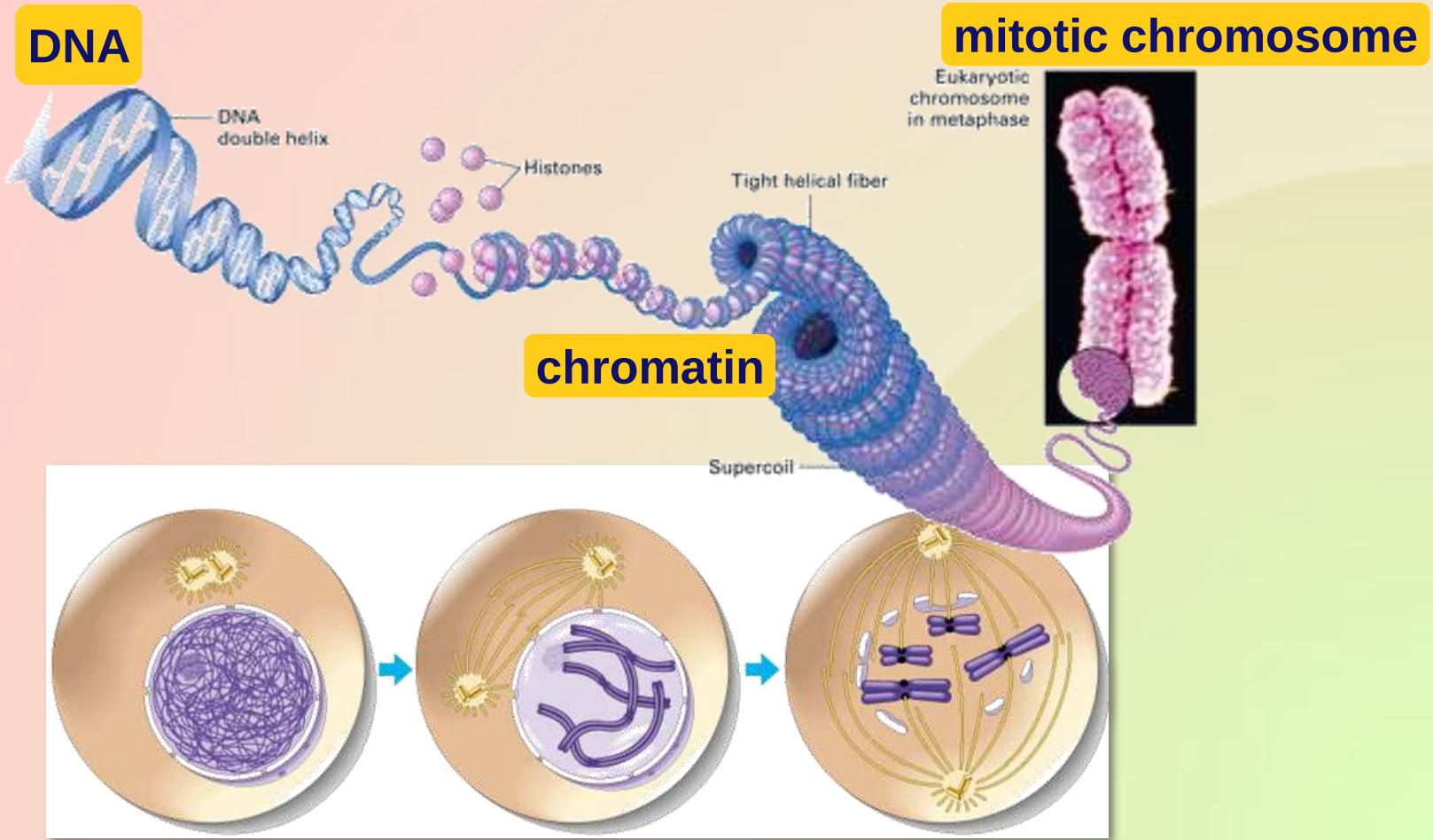
Organizing DNA

- DNA is organized in chromosomes
  - double helix DNA molecule
  - wrapped around histone proteins
    - like thread on spools
  - DNA-protein complex = chromatin
    - organized into long thin fiber
  - condensed further during mitosis



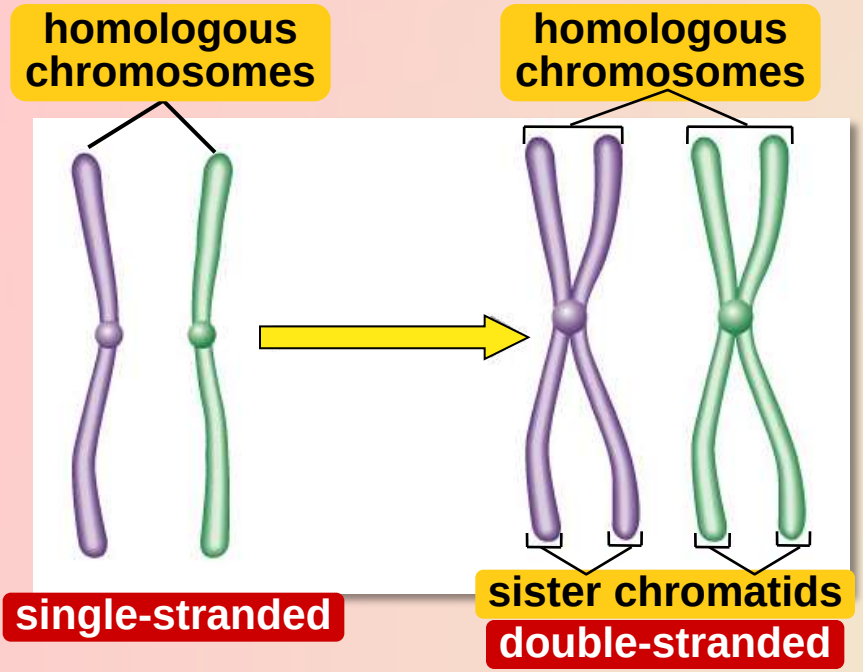
Copying DNA & packaging it…

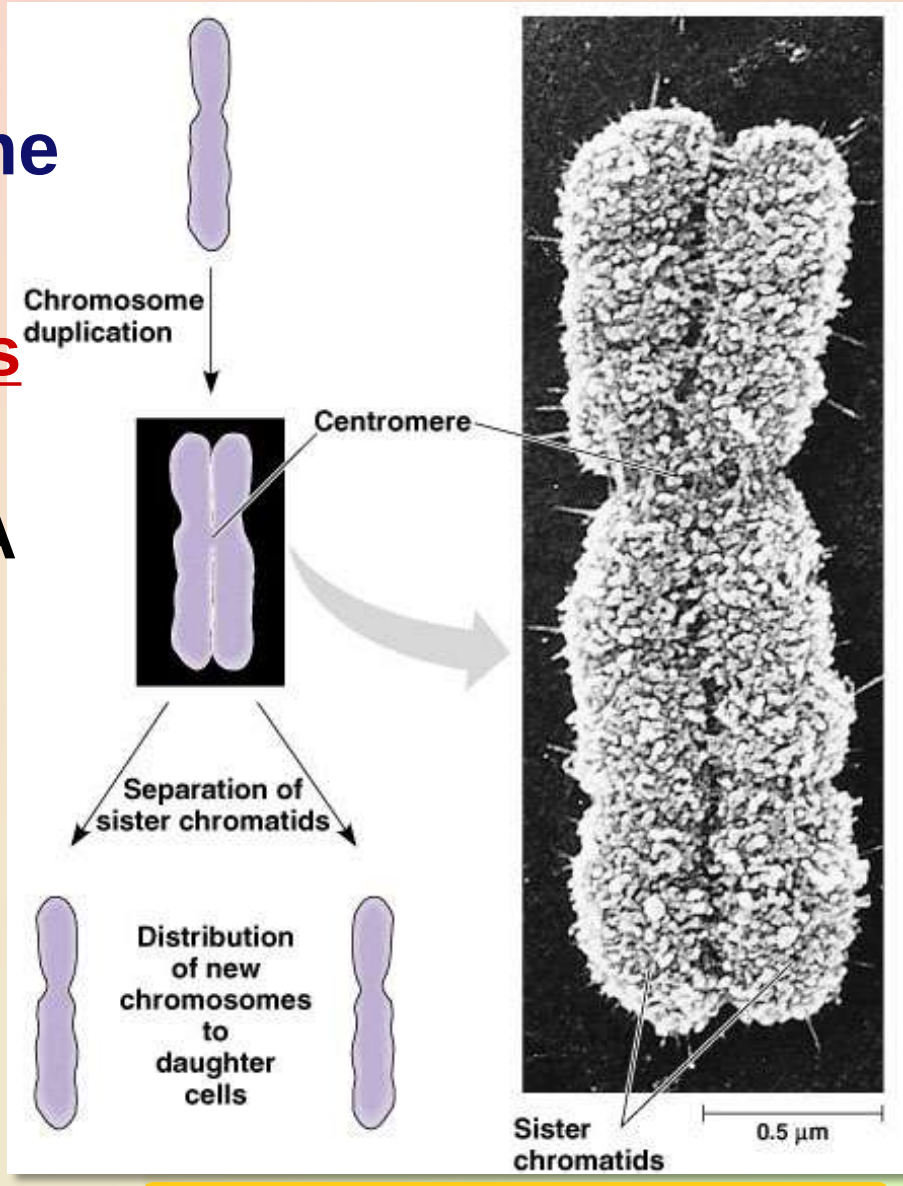
- After DNA duplication, chromatin condenses
  - coiling & folding to make a smaller package



Mitotic Chromosome

- **Duplicated chromosome**
  - **2 sister chromatids**
  - **narrow at centromeres**
  - **contain identical copies of original DNA**

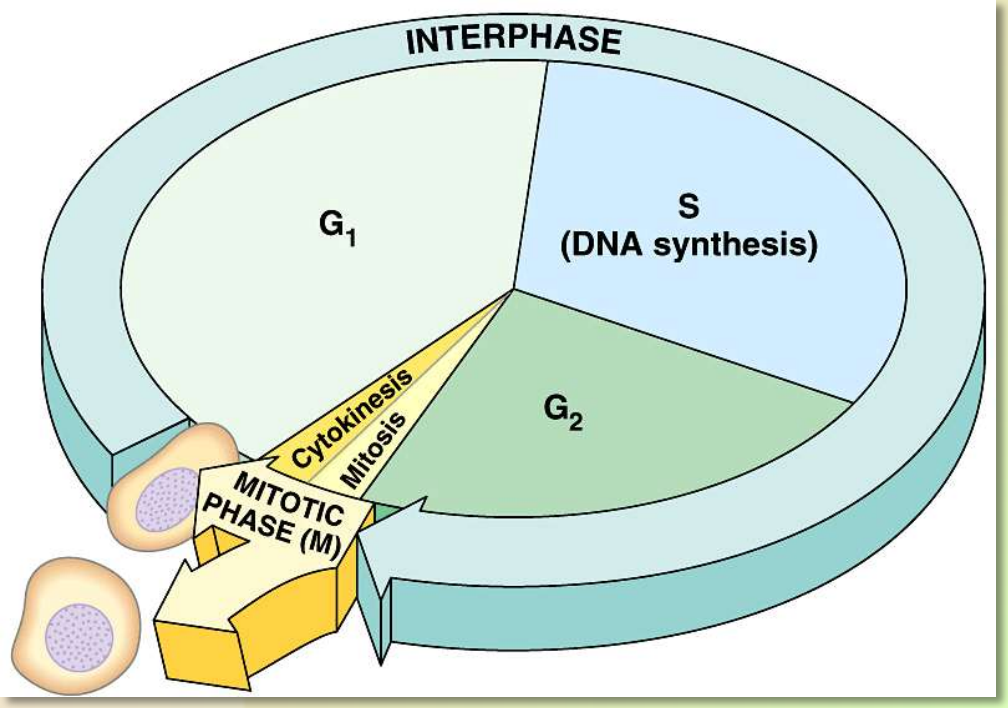




homologous = "same information"

Mitosis

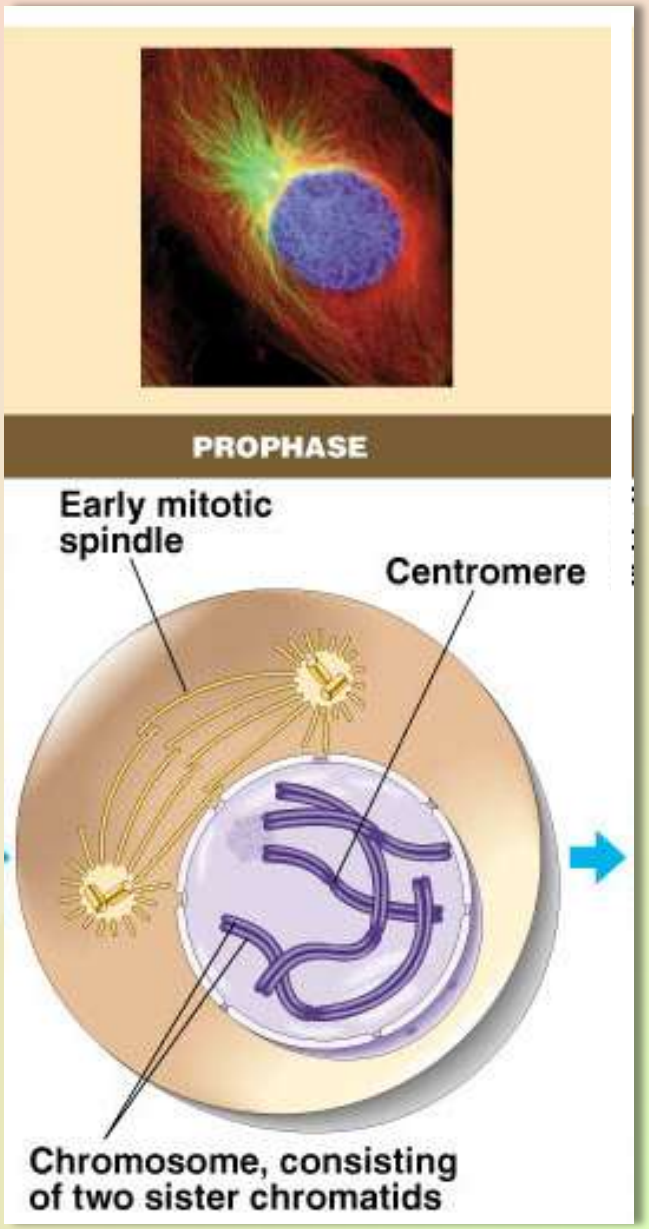
- Dividing cell's DNA between 2 daughter nuclei
  - "dance of the chromosomes"
- 4 phases
  - prophase
  - metaphase
  - anaphase
  - telophase



Prophase

Red = key features

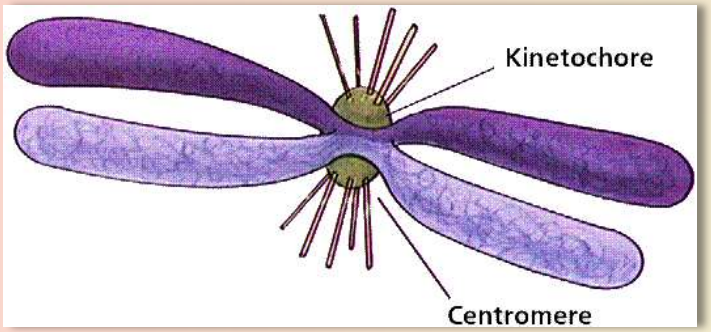
- Chromatin condenses
  - visible chromosomes
- Centrioles move to opposite poles of cell
  - animal cells only
- Protein fibers cross cell to form mitotic spindle
  - microtubules
  - coordinate movement of chromosomes
- Nucleolus disappears
- Nuclear membrane breaks down

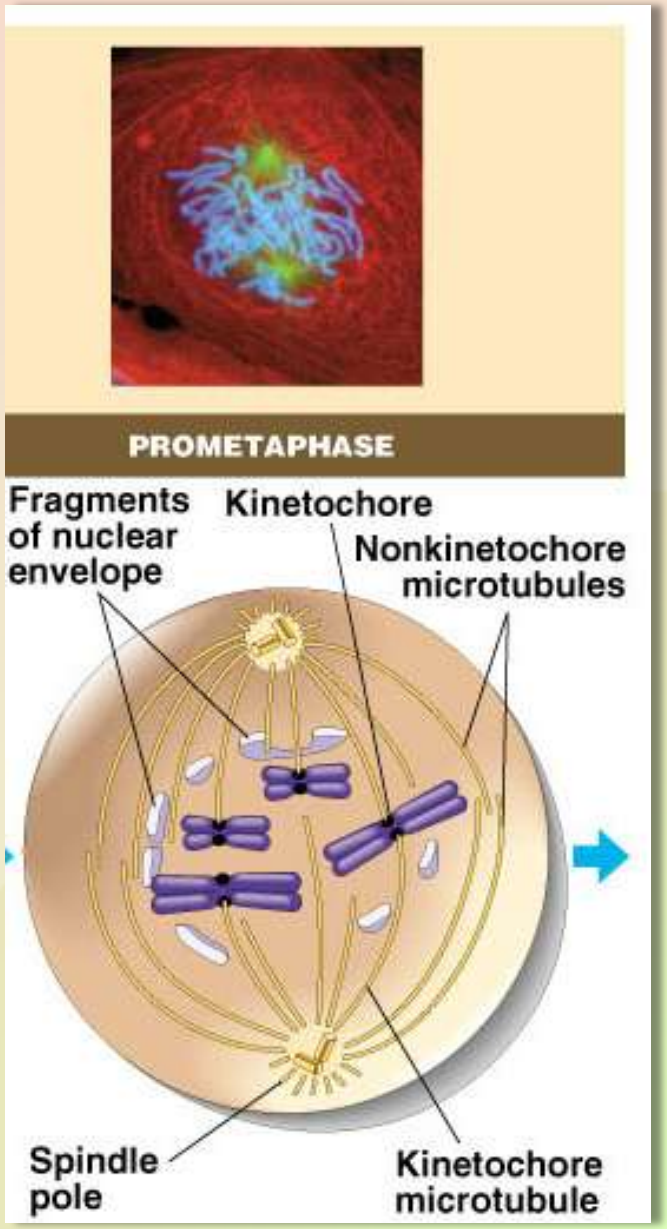


Red = key features

Transition to Metaphase

- Prometaphase
  - spindle fibers attach to centromeres
  - Kinetochores
    - connect centromeres to centrioles
  - chromosomes begin moving

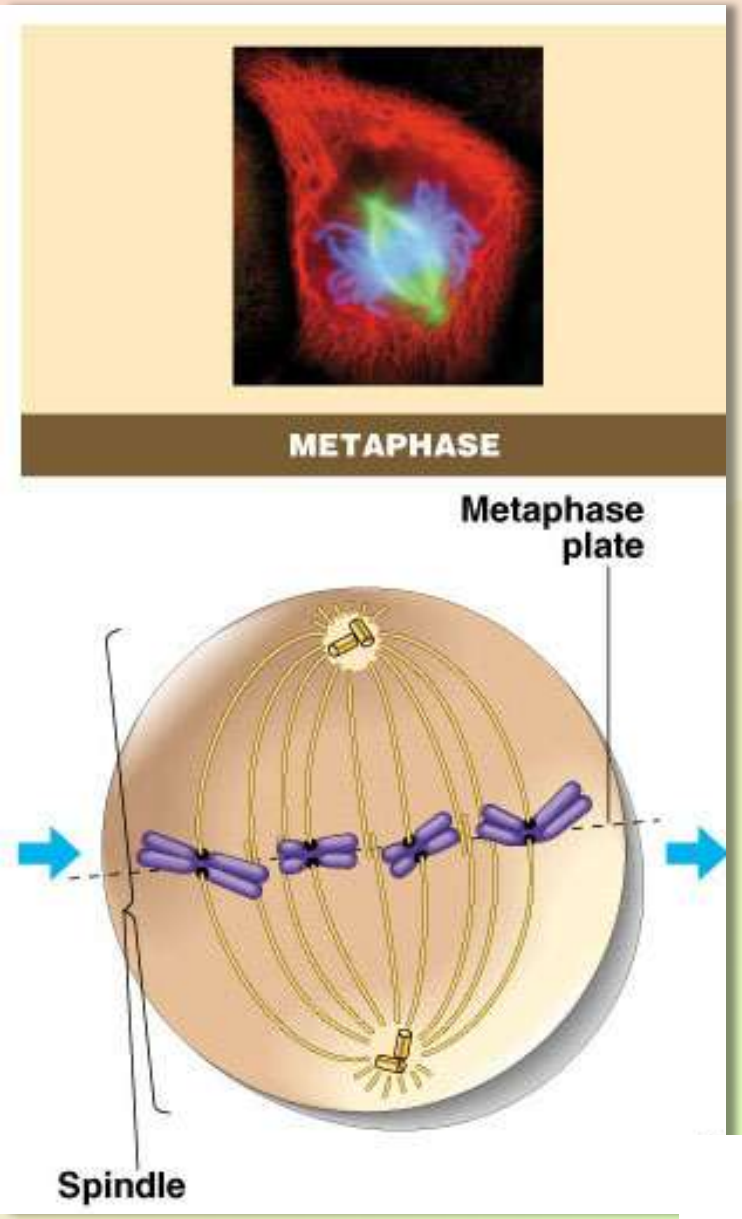


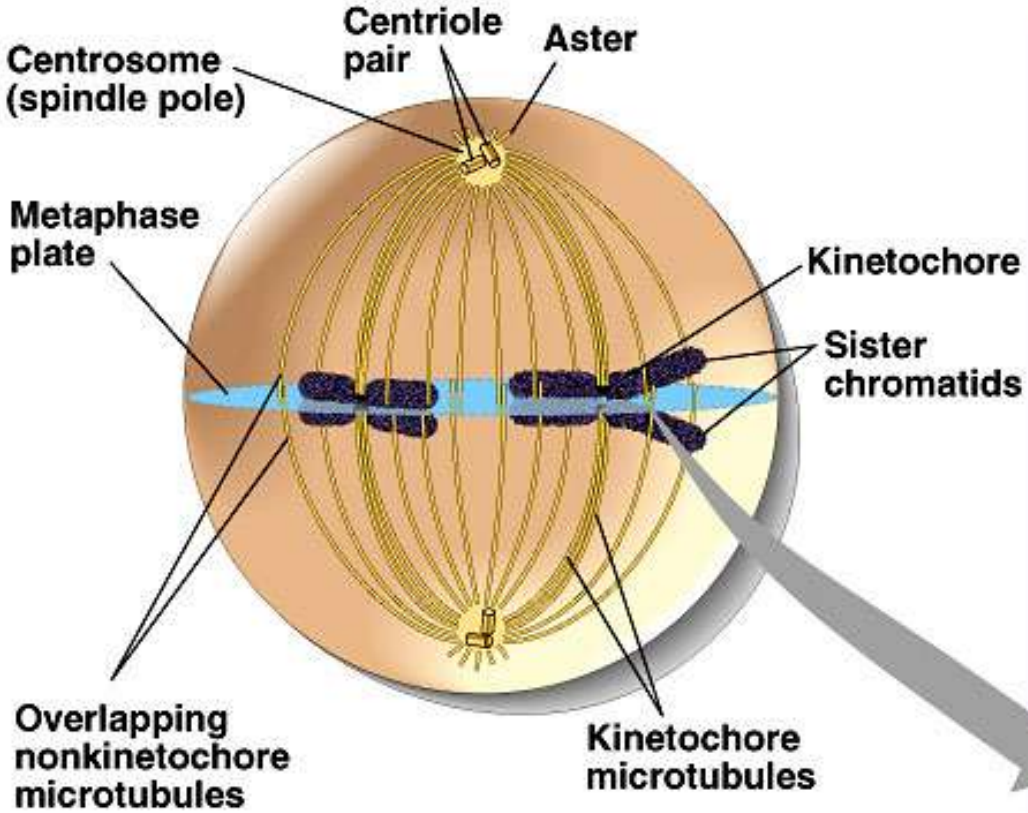


Red = key features

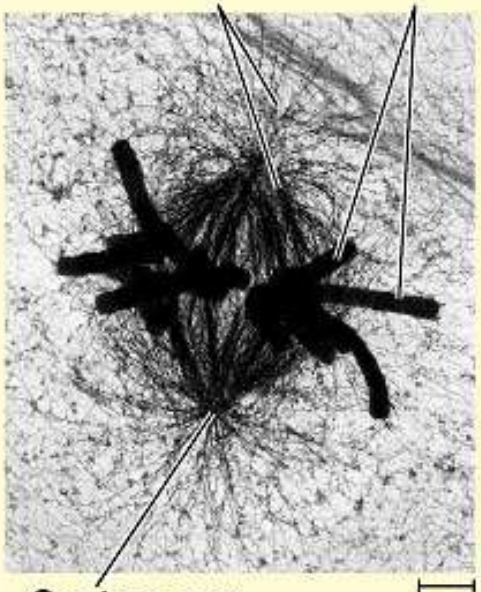
Metaphase

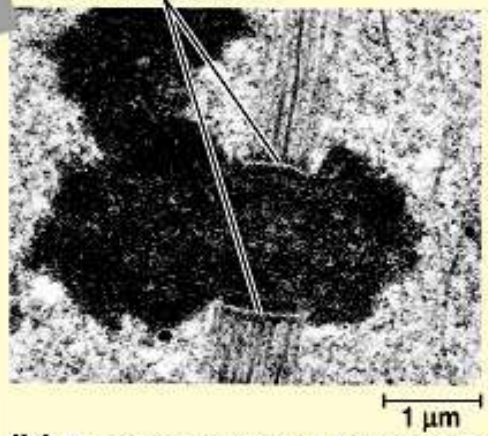
- Chromosomes align along middle of cell
  - metaphase plate
    - meta = middle
  - spindle fibers coordinate movement
  - ensure chromosomes separate properly
    - each new nucleus receives 1 copy of each chromosome





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





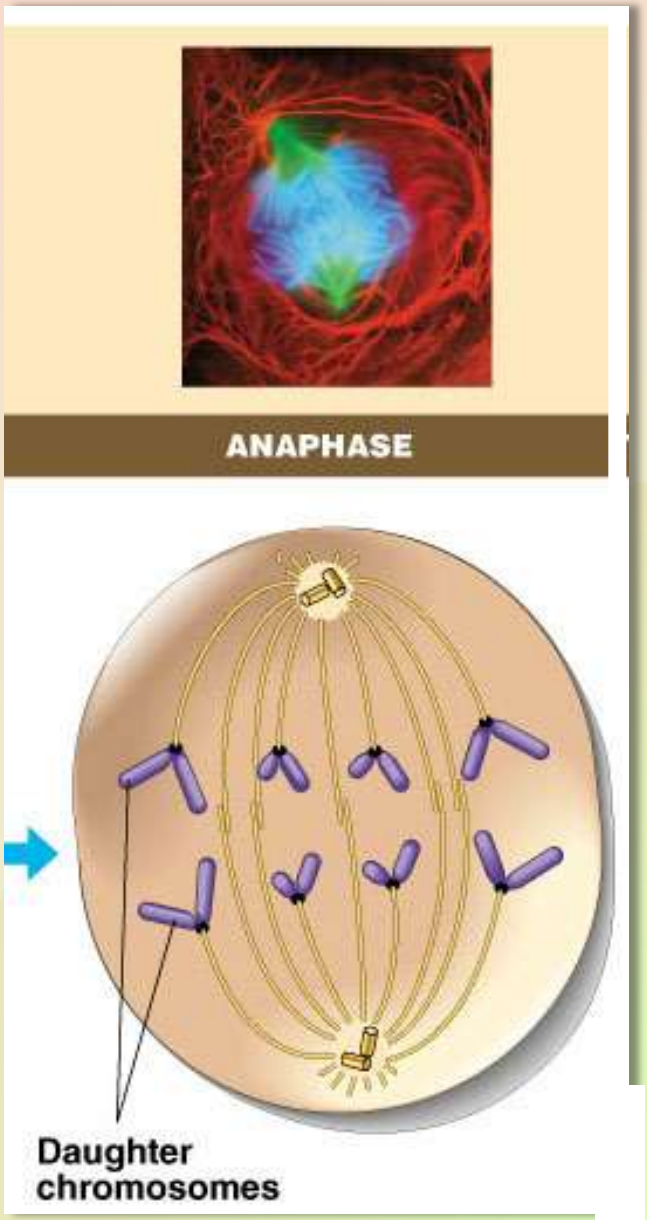
(b) Transmission electron micrographs

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

Red = key features

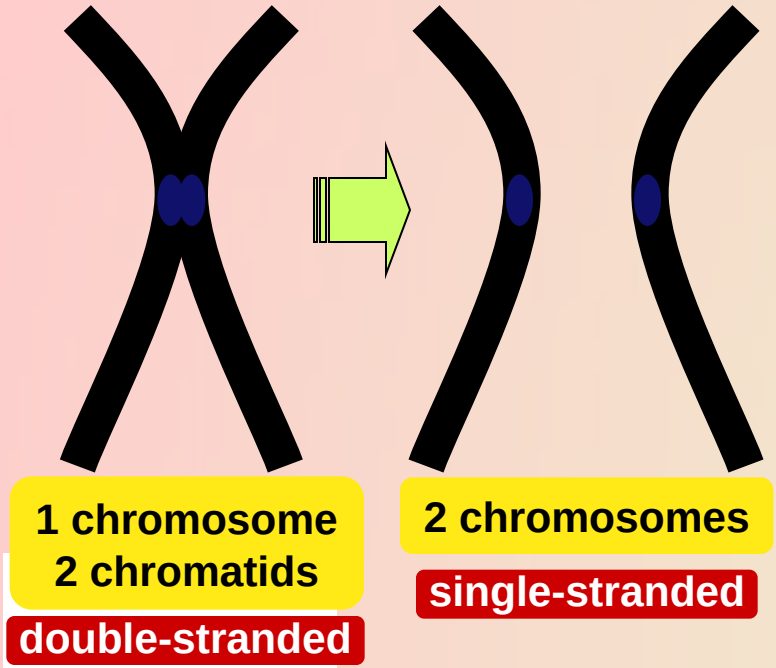
Anaphase

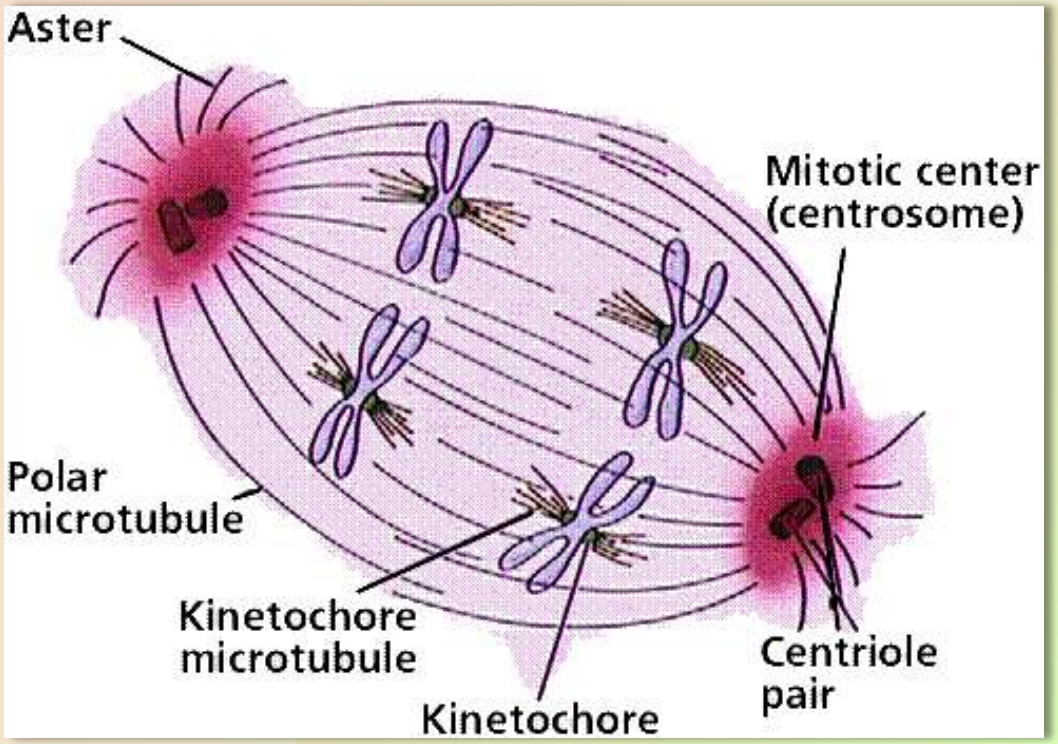
- Sister chromatids separate at centromere
  - move to opposite poles
  - pulled by motor proteins "walking"along microtubules
- Poles move farther apart
  - polar microtubules lengthen



Separation of chromatids

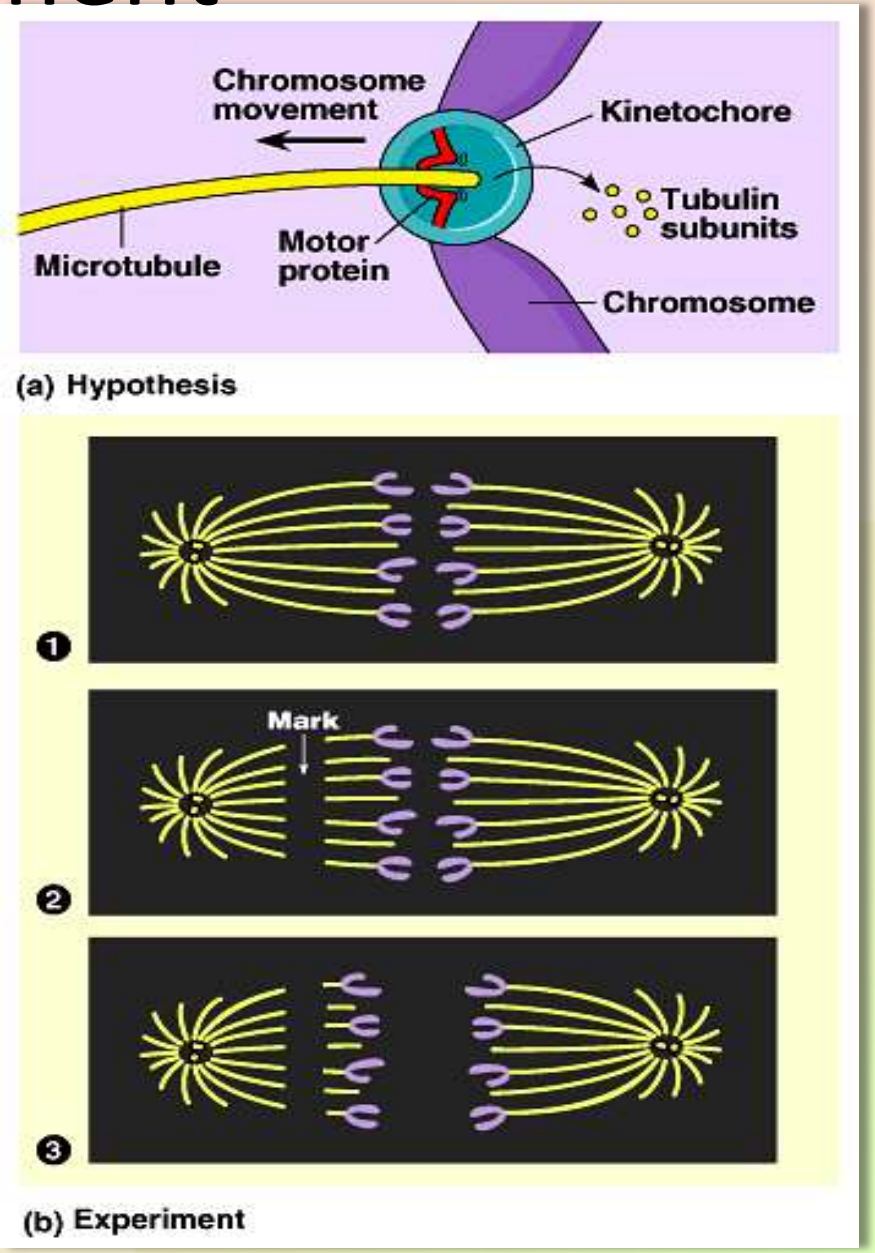
- In anaphase, proteins holding together sister chromatids are inactivated
  - separate to become individual chromosomes





Chromosome movement

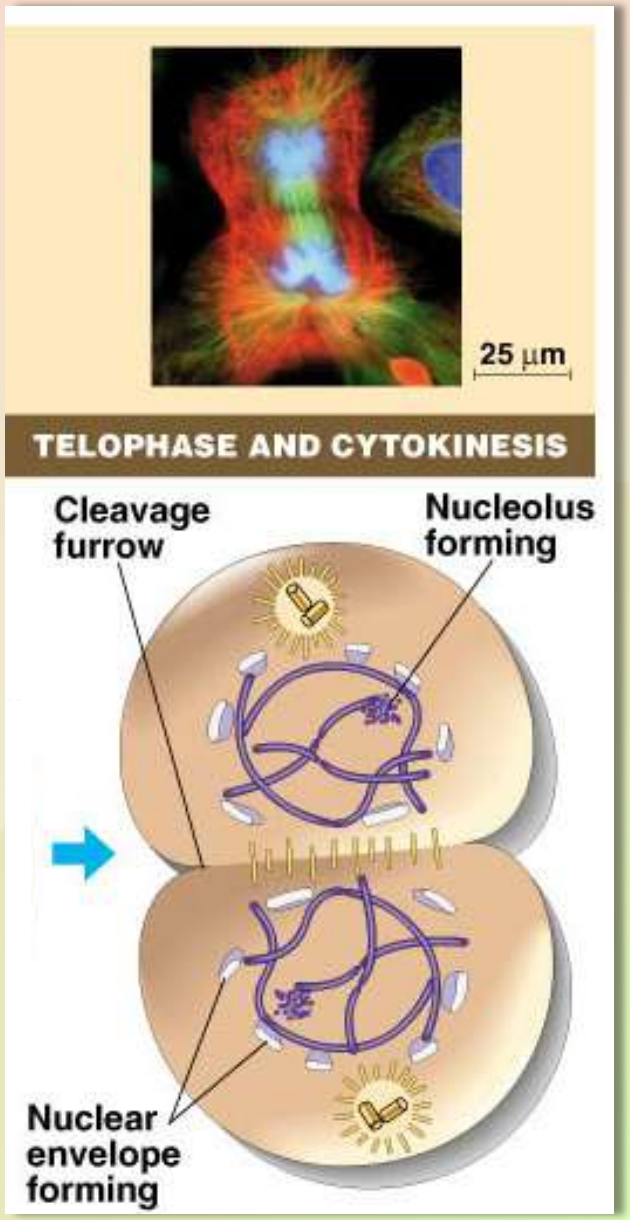
- Kinetochores use motor proteins that "walk" chromosome along attached microtubule
  - microtubule shortens by dismantling at kinetochore (chromosome) end



Red = key features

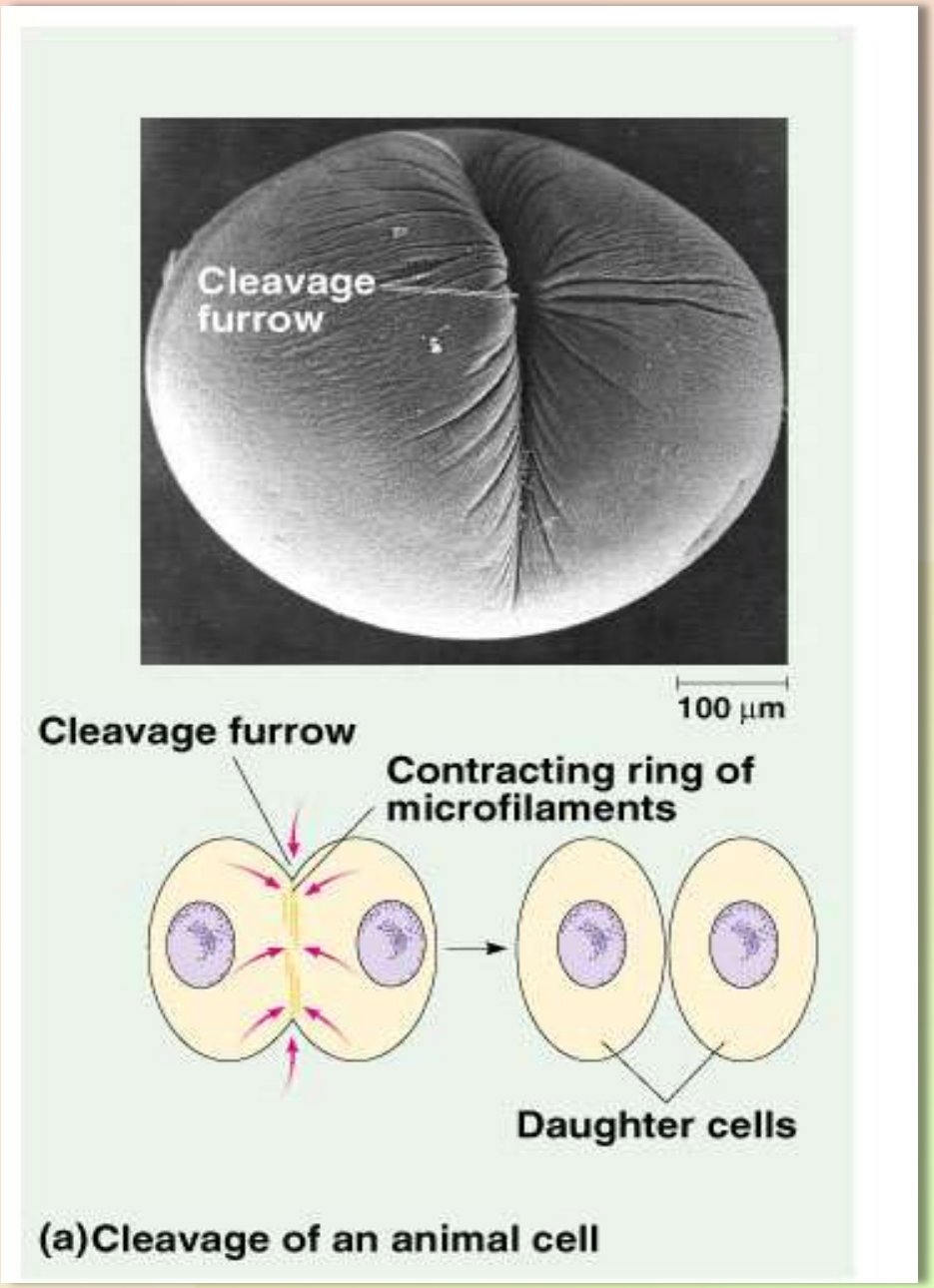
Telophase

- Chromosomes arrive at opposite poles
  - daughter nuclei form
  - chromosomes disperse
- Spindle fibers disperse
- Cytokinesis begins
  - cell division

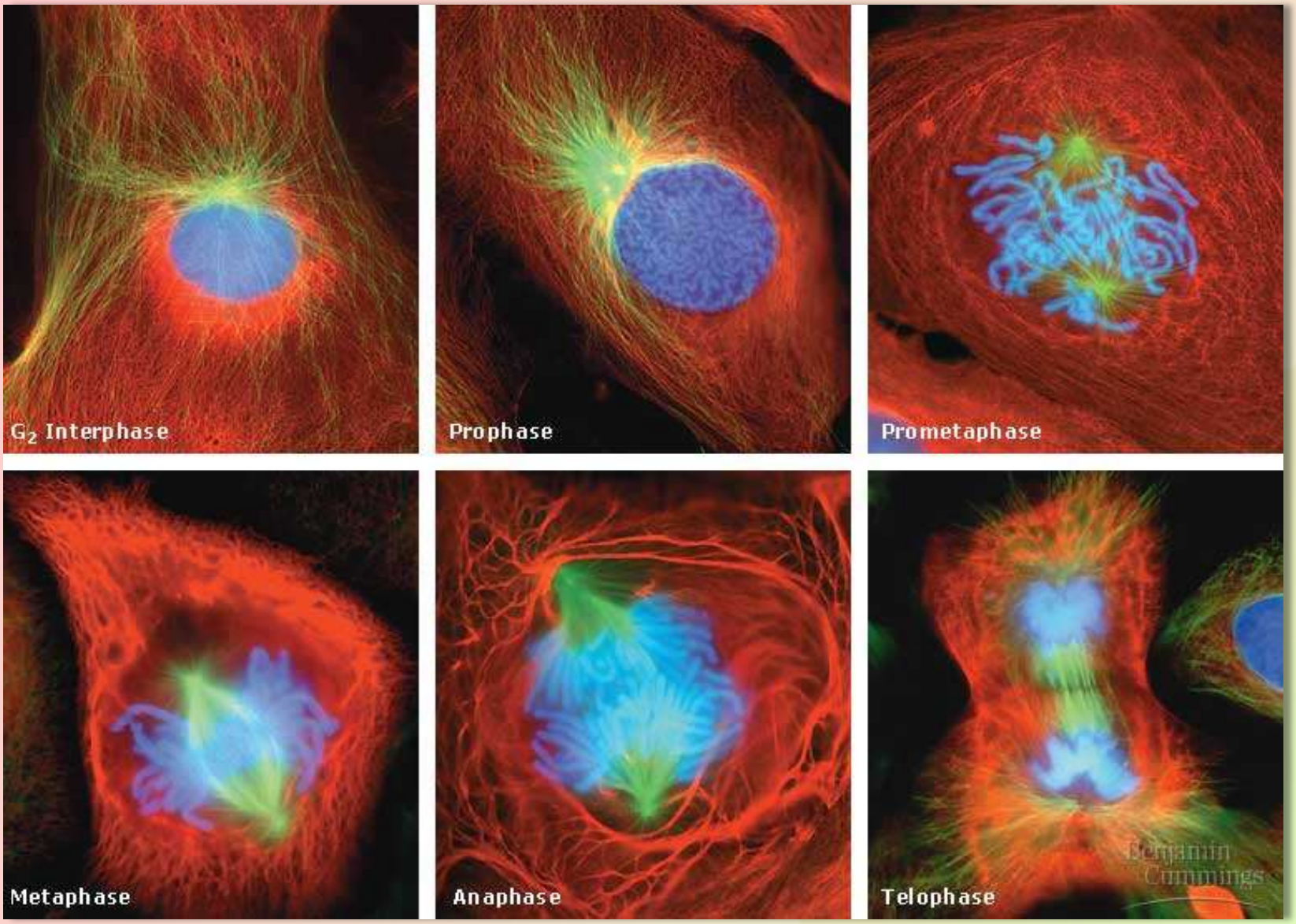


Cytokinesis

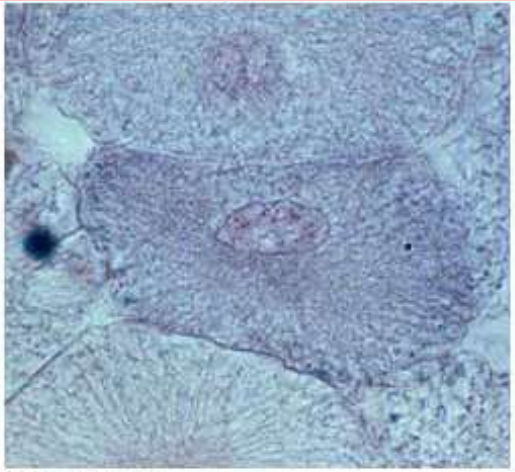
- Animals
  - constriction belt of actin microfilaments around equator of cell
    - cleavage furrow forms
    - splits cell in two
    - like tightening a draw string



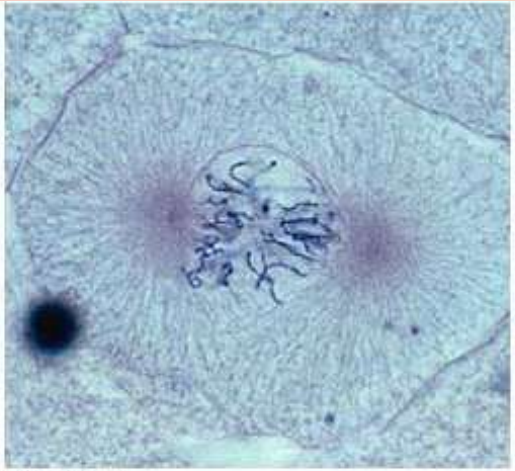
Mitosis in animal cells



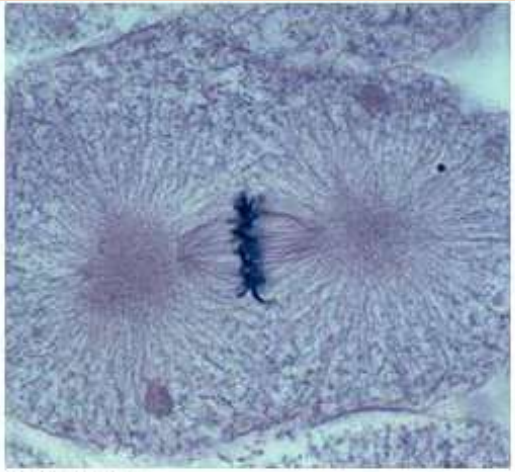
Mitosis in whitefish blastula



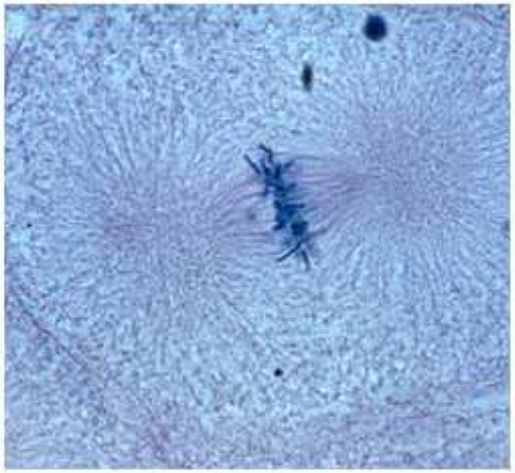
Interphase



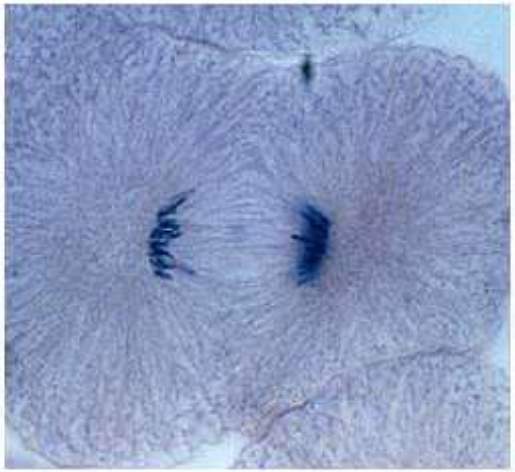
Prophase



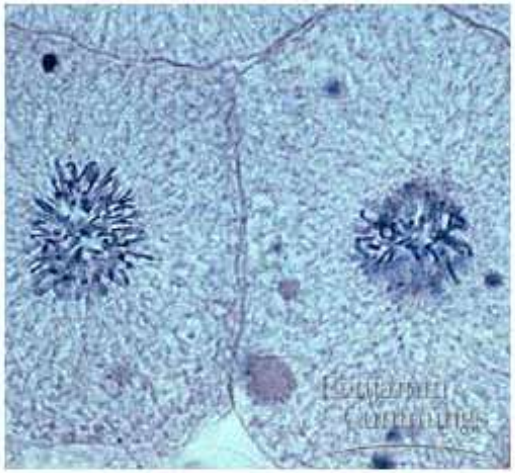
Metaphase



Anaphase



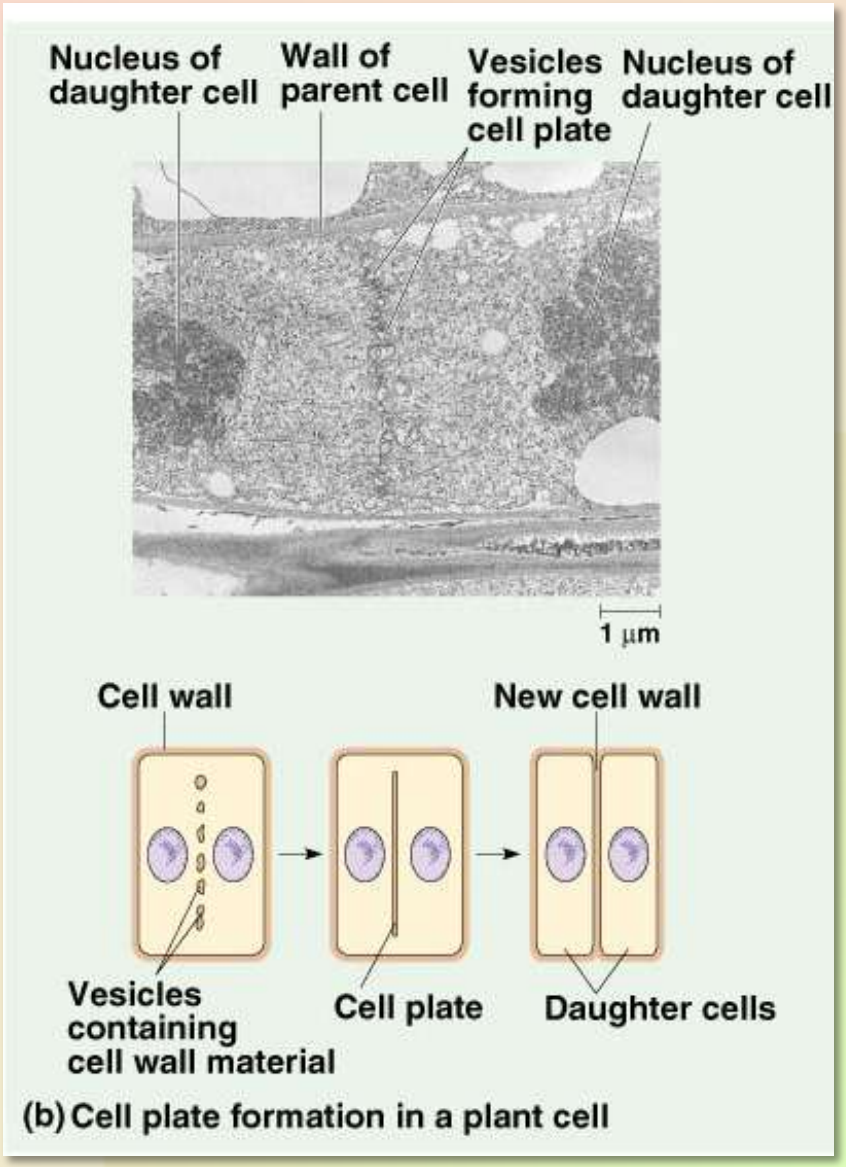
Early Telophase



Late Telophase

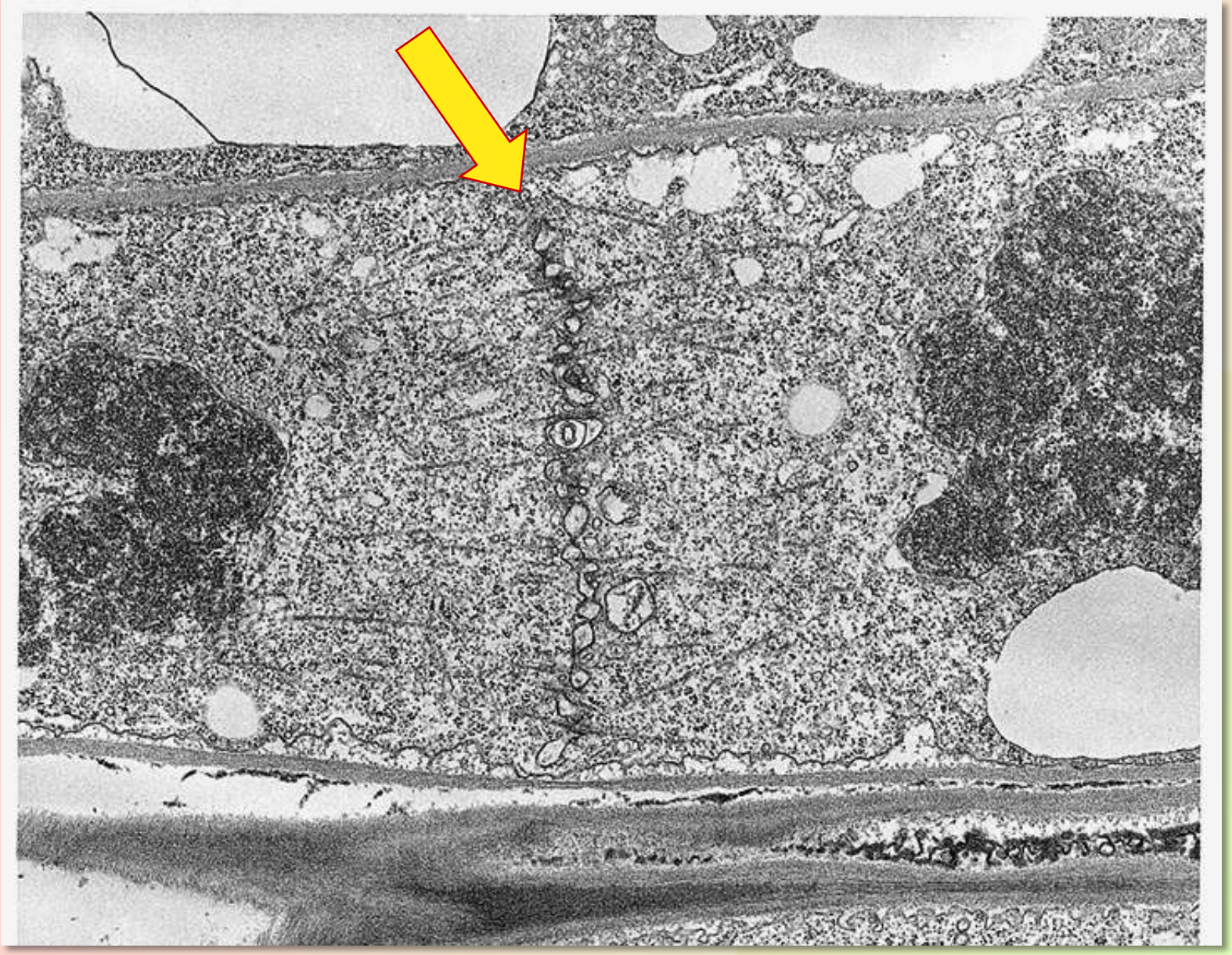
Cytokinesis in Plants

- Plants
  - cell plate forms
    - Vesicles (from golgi) line up at equator
    - vesicles fuse to form 2 cell membranes
  - new cell wall laid down between membranes
    - new cell wall fuses with existing cell wall



(b) Cell plate formation in a plant cell

Cytokinesis in plant cell



Mitosis in a plant cell

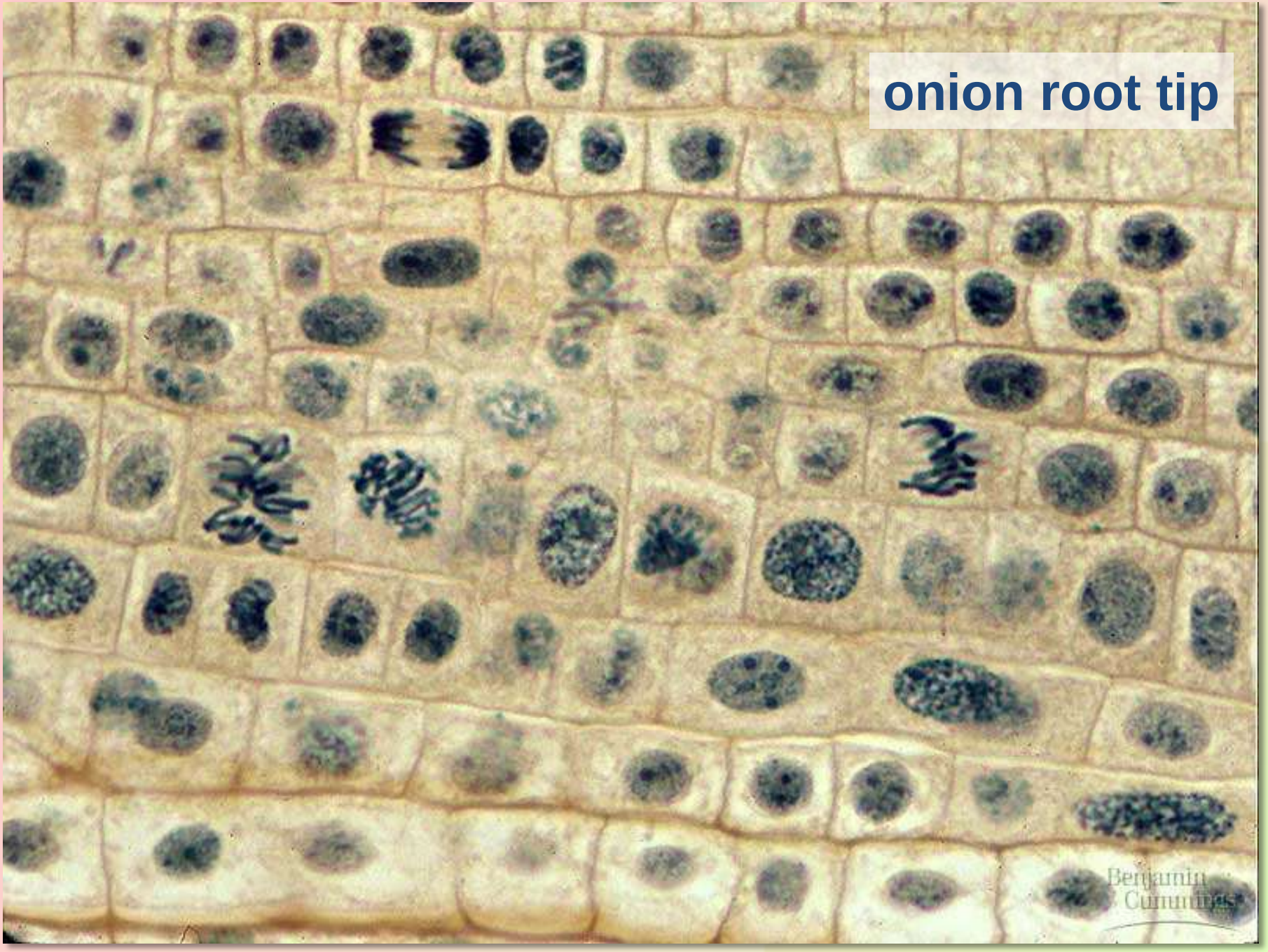
1 **Prophase.** The chromatin is condensing. The nucleolus is beginning to disappear. Although not yet visible in the micrograph, the mitotic spindle is staring to from.

2 **Prometaphase.** We now see discrete chromosomes; each consists of two identical sister chromatids. Later in prometaphase, the nuclear envelop will fragment.

3 **Metaphase.** The spindle is complete, and the chromosomes, attached to microtubules at their kinetochores, are all at the metaphase plate.

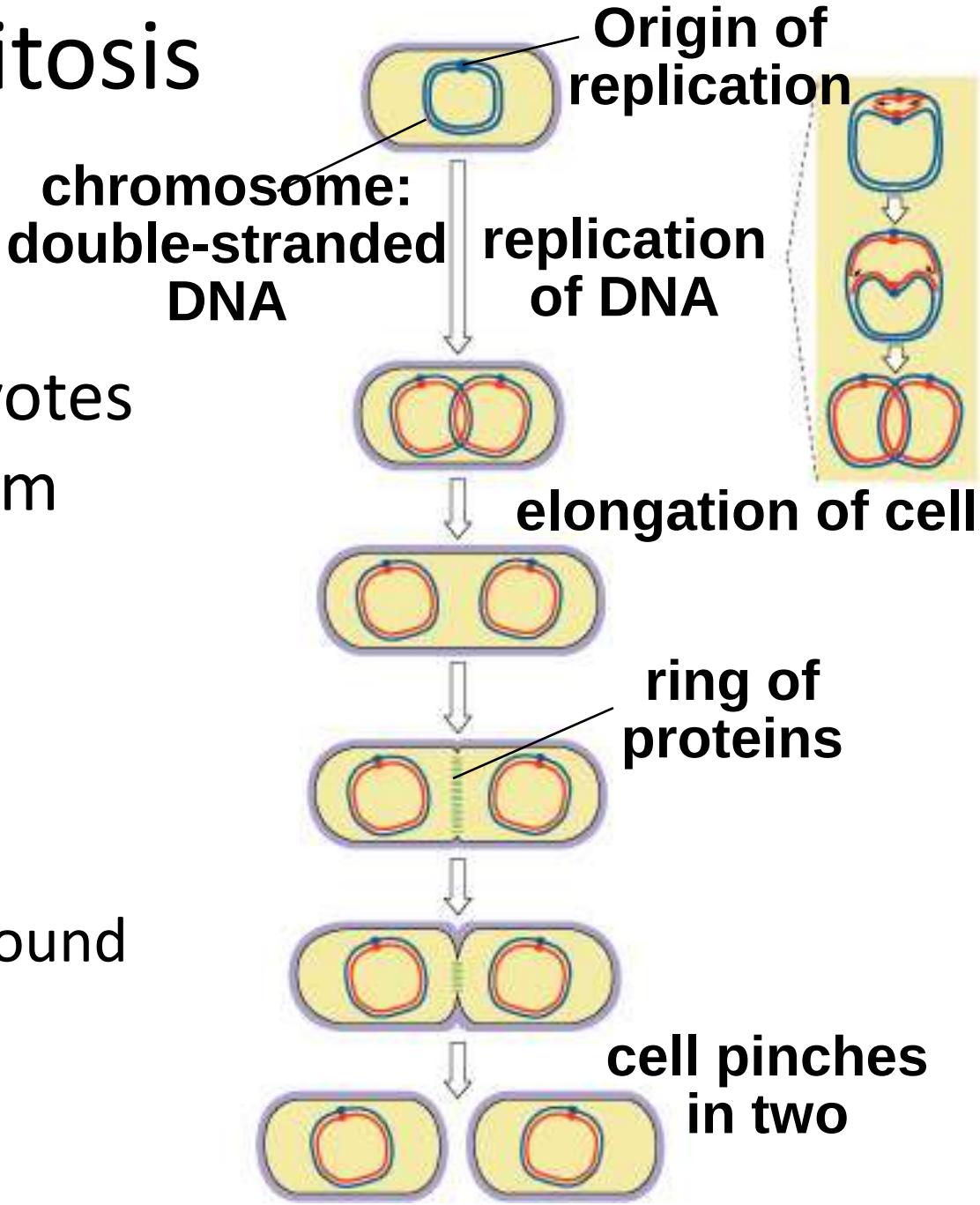
4 **Anaphase.** The chromatids of each chromosome have separated, and the daughter chromosomes are moving to the ends of cell as their kinetochore microtubles shorten.

5 **Telophase.** Daughter nuclei are forming. Meanwhile, cytokinesis has started: The cell plate, which will divided the cytoplasm in two, is growing toward the perimeter of the parent cell.

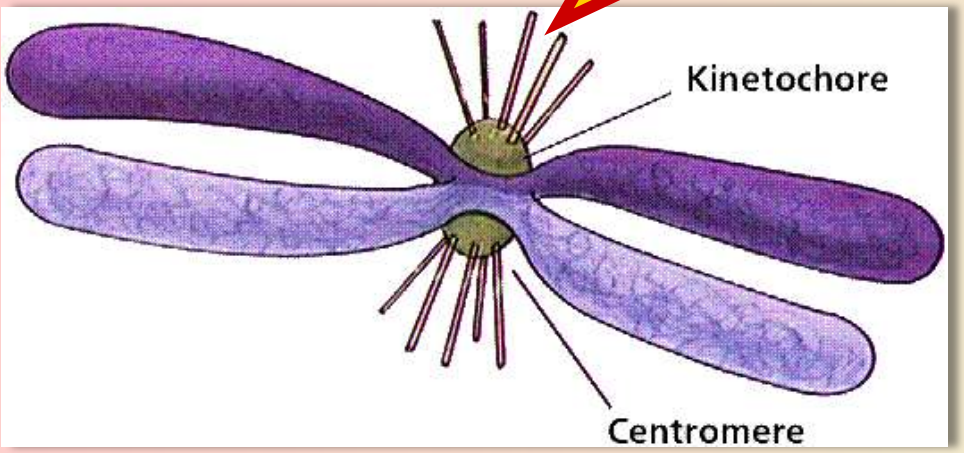

onion root tip
Benjamin Cummings

Evolution of mitosis

- Mitosis in eukaryotes likely evolved from <u>binary fission</u> in bacteria
  - single circular chromosome
  - no membrane-bound organelles



Any Questions??



Review Questions

1. Cytokinesis usually, but not always, follows mitosis. If a cell completed mitosis but not cytokinesis, what would be the result?
   A. a cell with a single large nucleus
   B. a cell with high concentrations of actin and myosin
   C. a cell with two abnormally small nuclei
   D. a cell with two nuclei
   E. a cell with two nuclei but with half the amount of DNA

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2. Taxol is an anticancer drug extracted from the Pacific yew tree. In animal cells, taxol disrupts microtubule formation by binding to microtubules and accelerating their assembly from the protein precursor, tubulin. Surprisingly, this stops mitosis. Specifically, taxol must affect

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   E. the S phase of the cell cycle.

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3. A group of cells is assayed for DNA content immediately following mitosis and is found to have an average of 8 picograms of DNA per nucleus. Those cells would have _____ picograms at the end of the S phase and _____ picograms at the end of G_2.

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C. 16 … 8
D. 16 … 16
E. 12 … 16

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4. A particular cell has half as much DNA as some of the other cells in a mitotically active tissue. The cell in question is most likely in

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