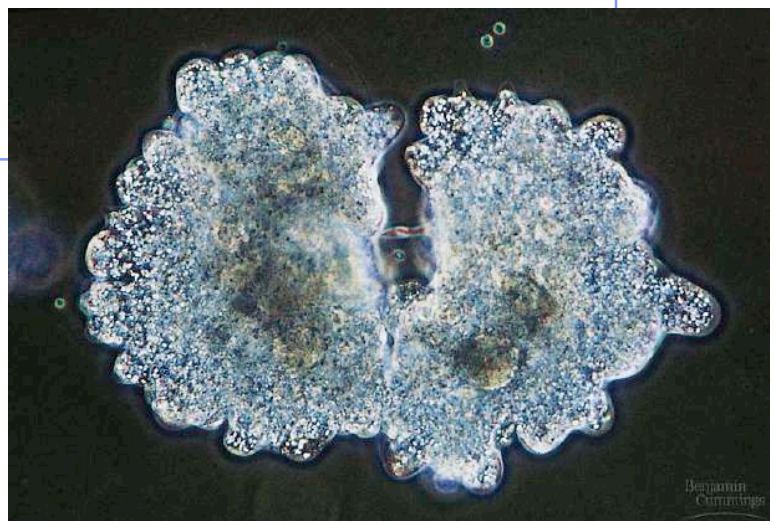
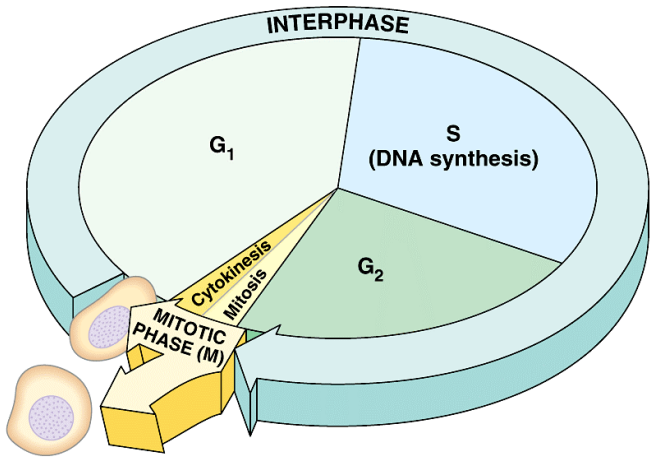
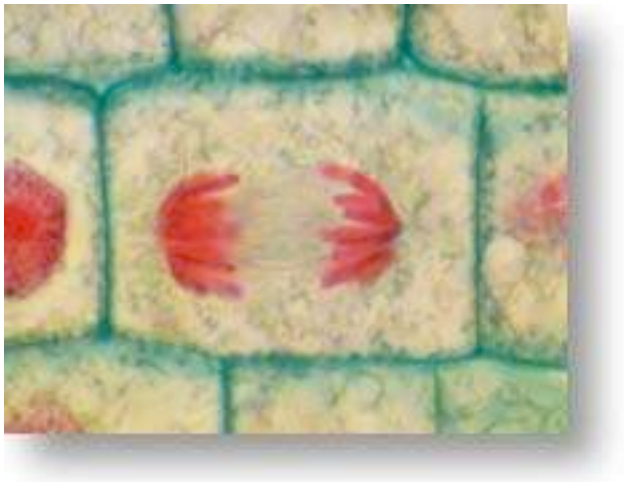
Biology is the only subject in which multiplication is the same thing as division…





Chapter 12.

The Cell Cycle:
Cell Growth, Cell Division



2005-2006

Where it all began…

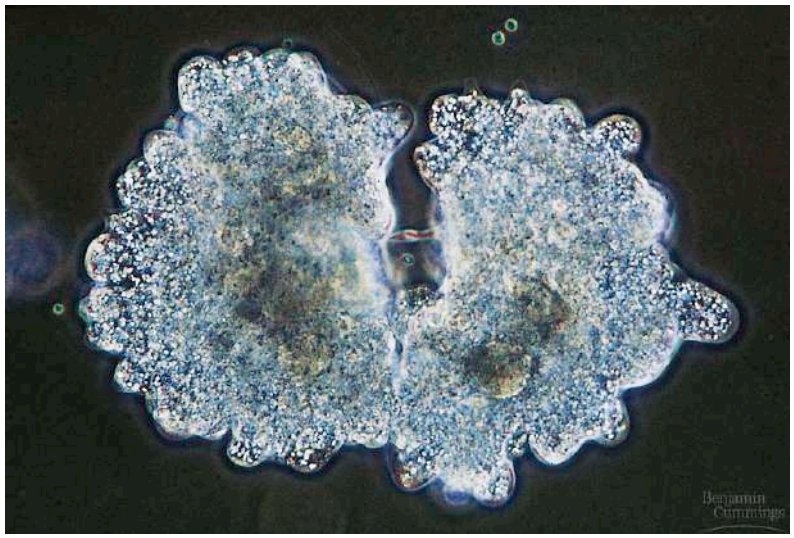
- You started as a cell smaller than a period at the end of a sentence…

And now look at you…

How did you get from there to here?

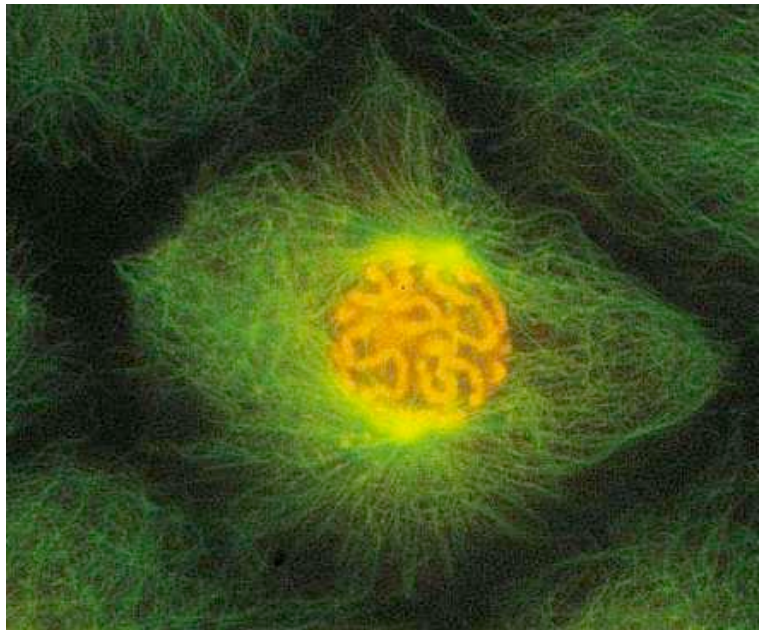
Getting from there to here…

- 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



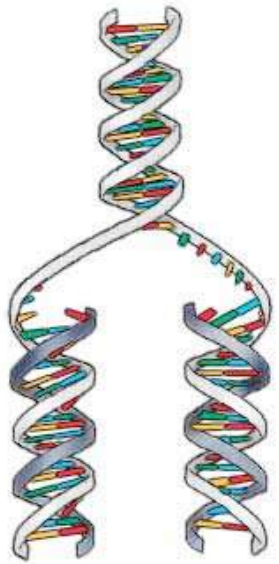
Getting the right stuff

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

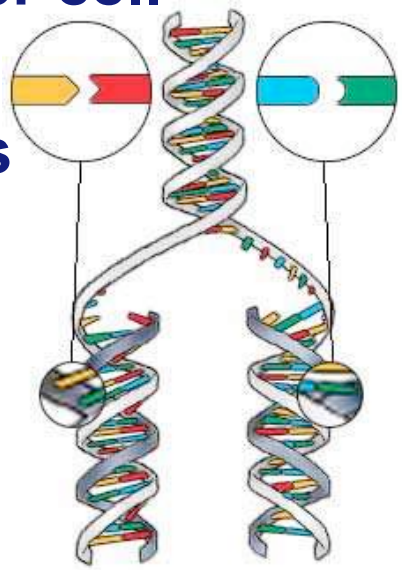


chromosomes (stained orange) in kangaroo rat epithelial cell

Copying DNA

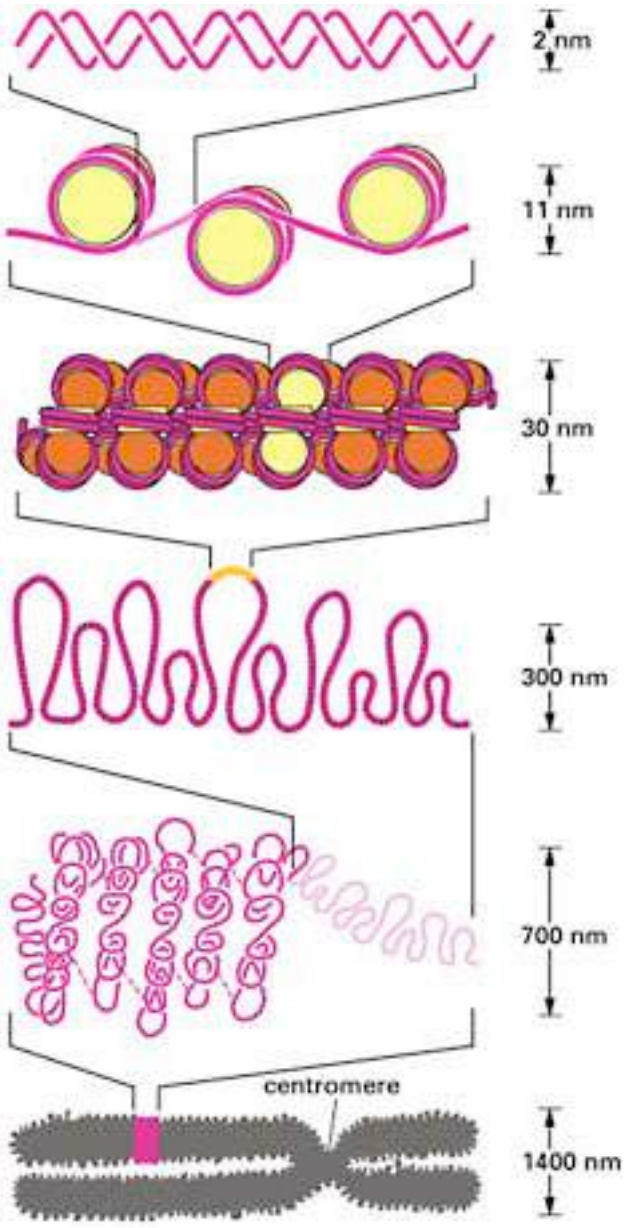


- Dividing cell duplicates DNA
  - separates each copy to opposite ends of cell
  - splits into 2 daughter cells
    - human cell duplicates ~3 meters DNA
    - separates 2 copies so each daughter cell has complete identical copy
    - error rate = ~1 per 100 million bases
      - 3 billion base pairs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



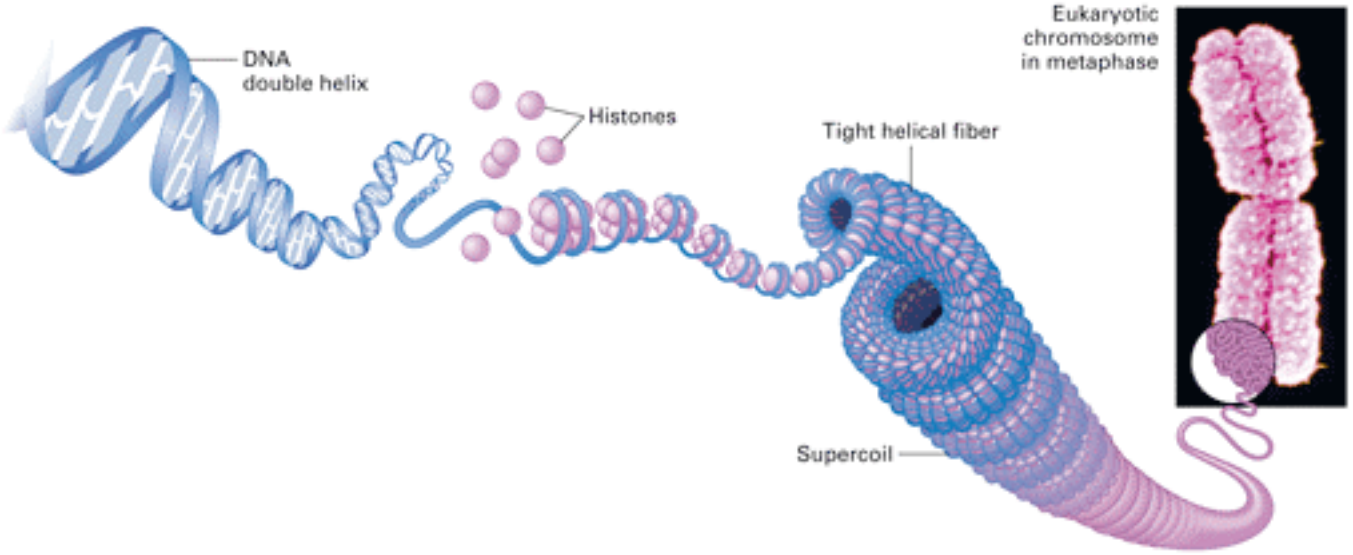
A bit about DNA

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



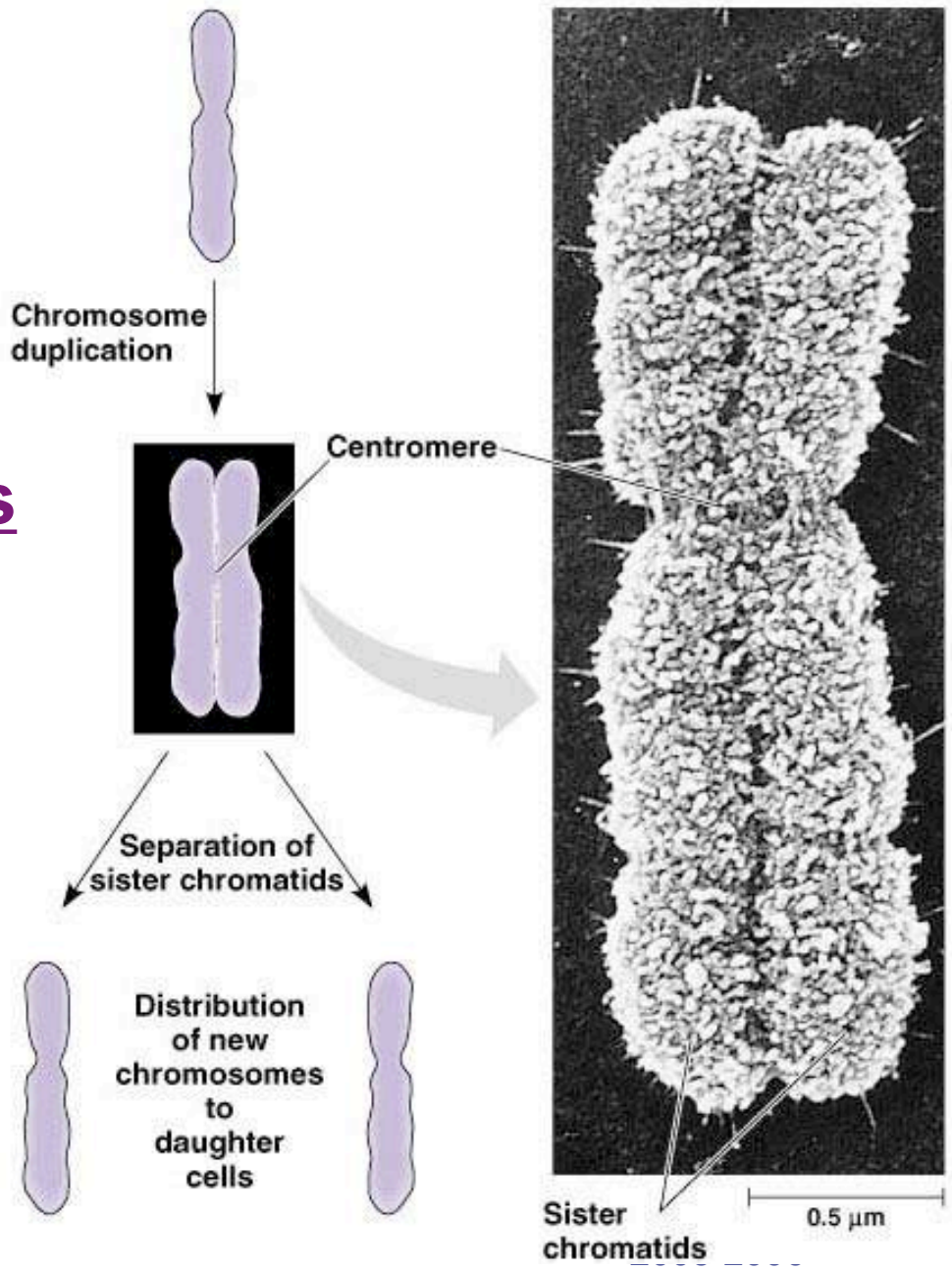
Copying DNA with care…

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



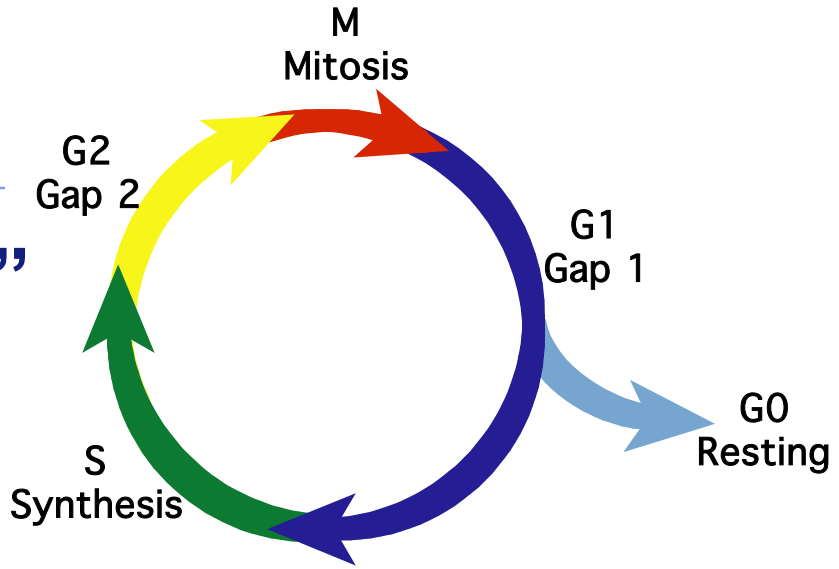
Chromosome

- 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_1, S, G_2, M

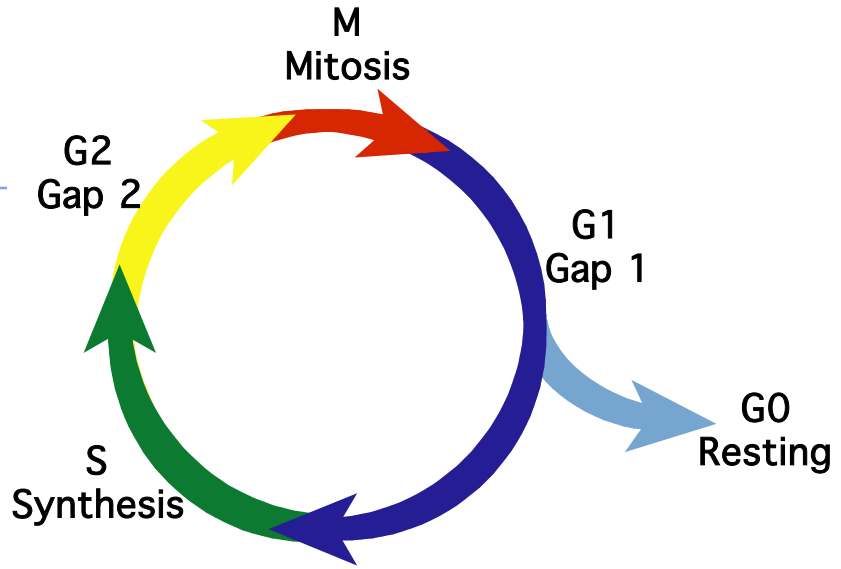
liver cells

G_0

epithelial cells, blood cells, stem cells

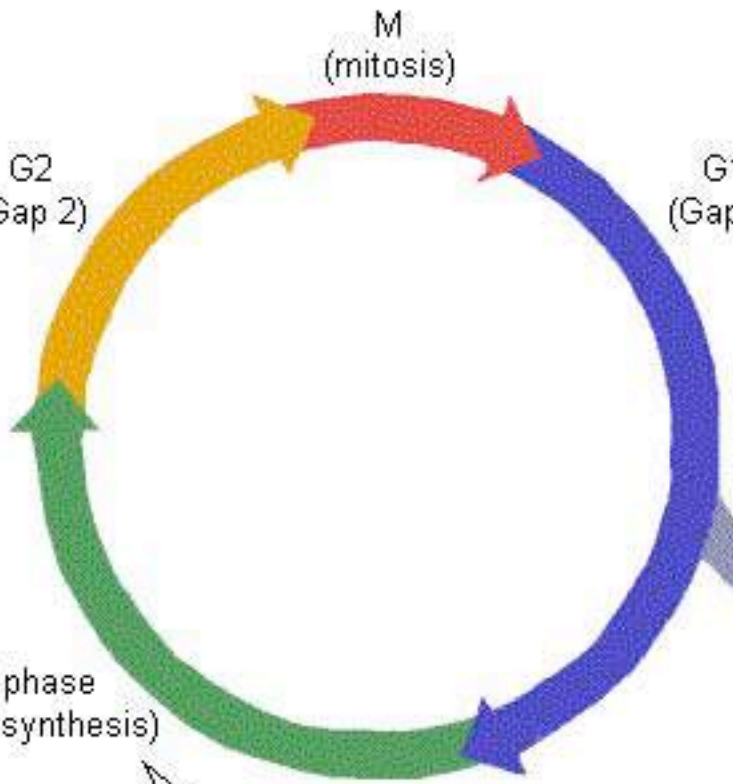
brain nerve cells

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



Gap 2 - the cell will continue to grow and produce new proteins required for cell division. At the end of this gap is another control checkpoint (G2 Checkpoint) to determine if the cell can now proceed to enter M (mitosis) and divide

Gap 1 - Cells increase in size, produce RNA and synthesize proteins. An important cell cycle control mechanism activated during this period (G1 Checkpoint) ensures that everything is ready for DNA synthesis.

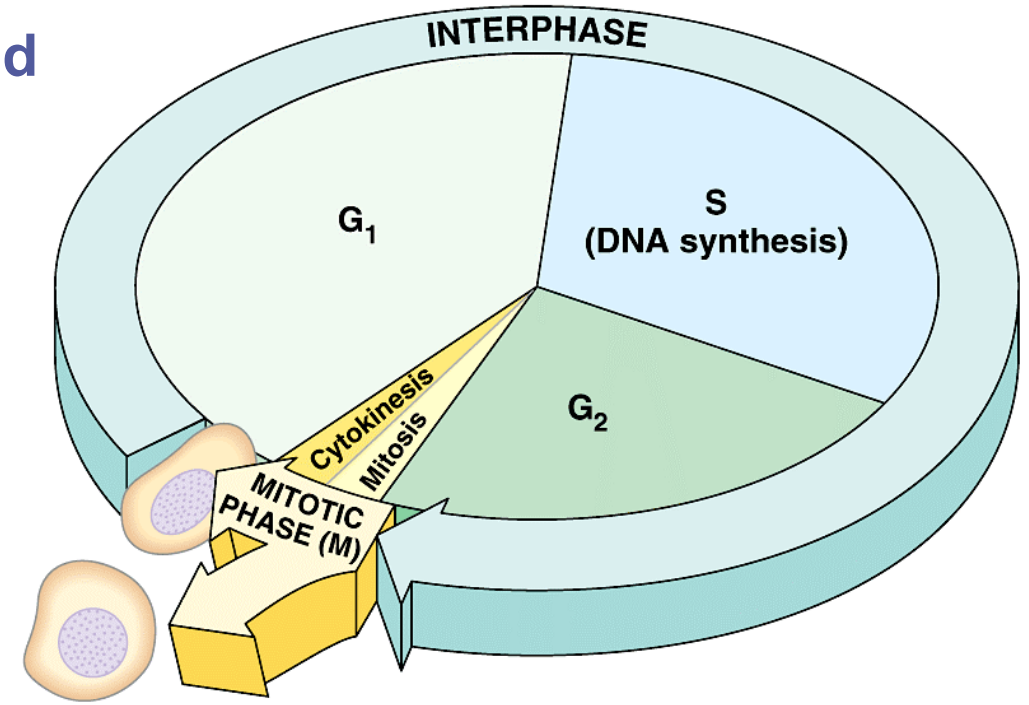
Gap 0 -There are times when a cell will leave the cycle and quit dividing. This may be a temporary resting period i.e. liver cell, or more permanent, i.e. a cell that has reached an end stage of development and will no longer divide (e.g. nerve cells in the brain).

Synthesis phase – DNA replication takes place

Interphase = G1 + S + G2

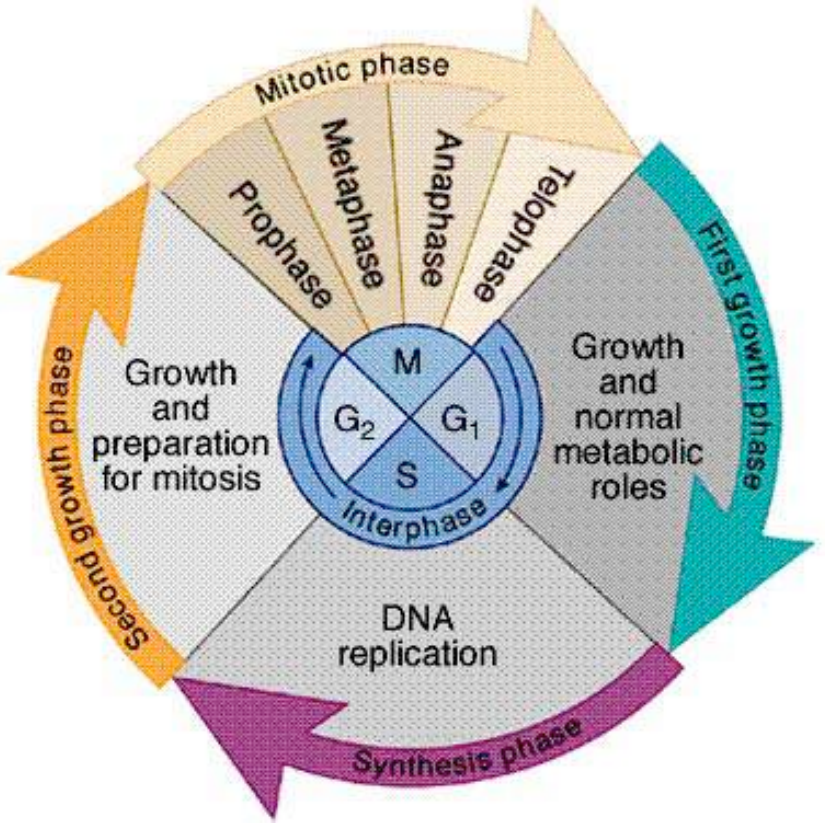
Interphase

- 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



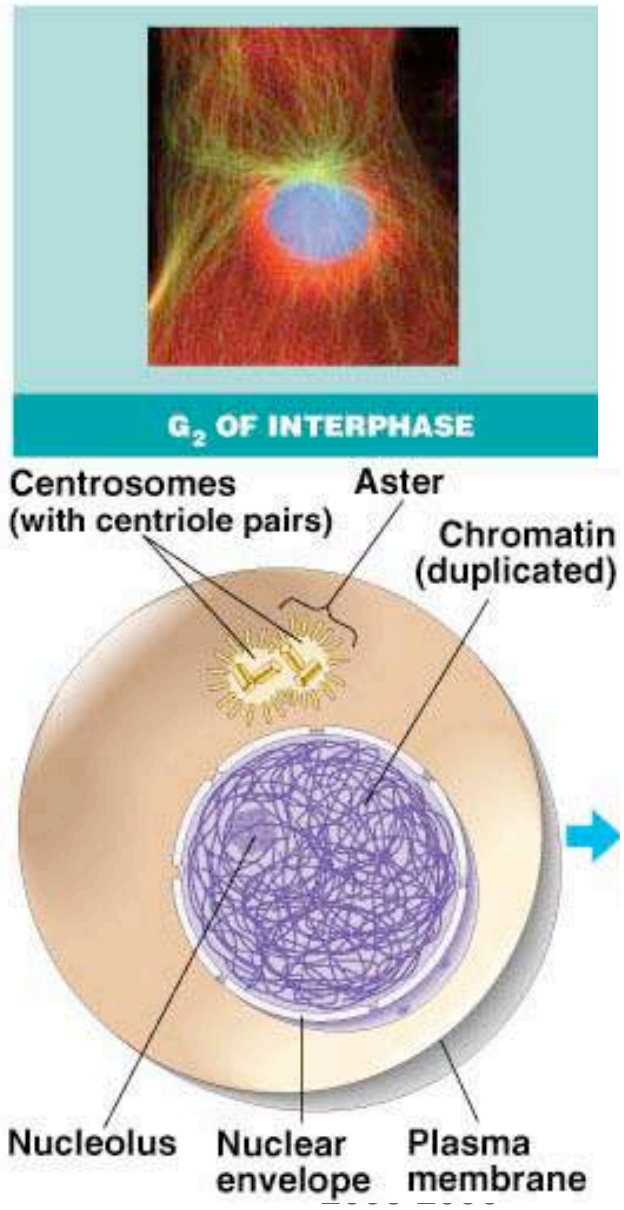
Interphase

- Divided into 3 phases:
  - G_1 = 1st Gap
    - cell doing its "everyday job"
    - cell grows
  - S = DNA Synthesis
    - copies chromosomes
  - G_2 = 2nd Gap
    - prepares for division
    - cell grows
    - produces organelles, proteins, membranes



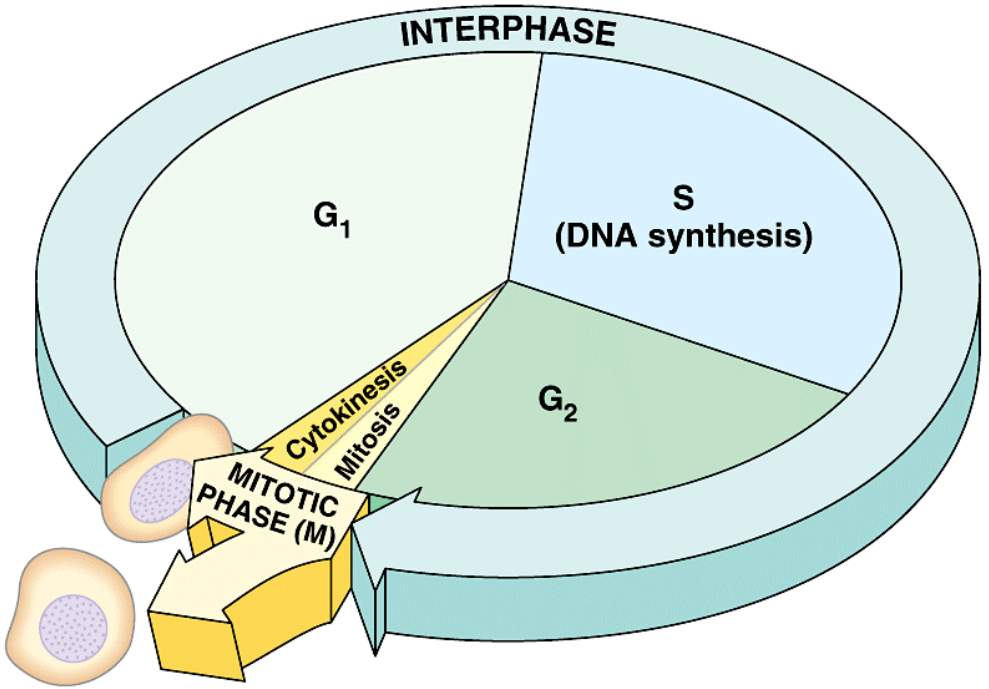
Interphase G2

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

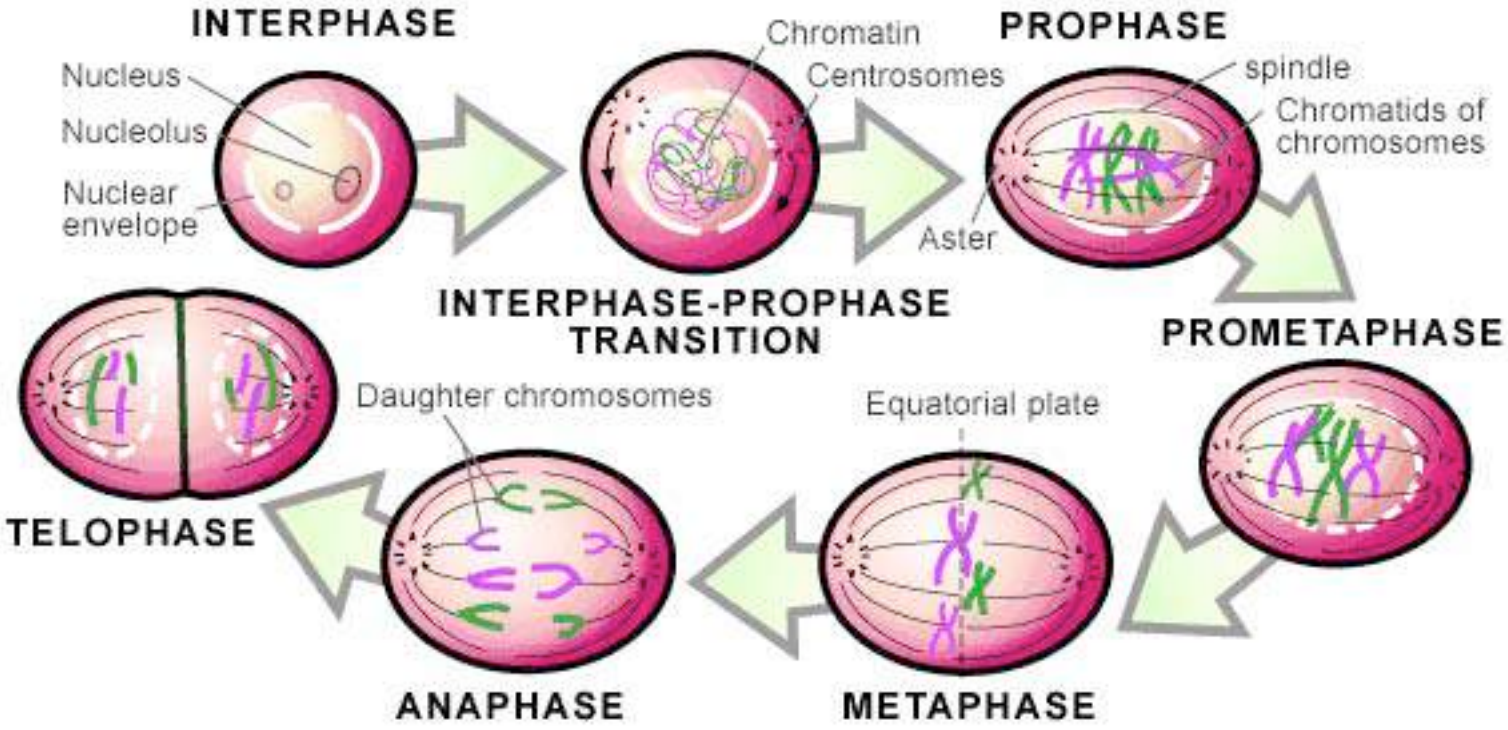


Mitosis

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

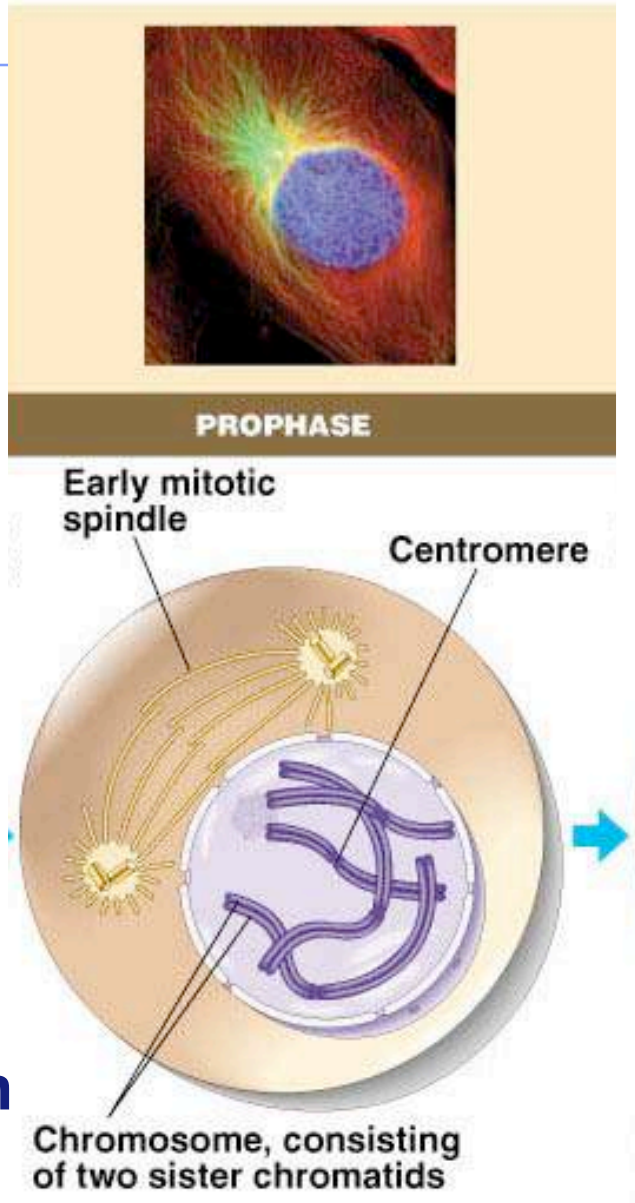


Overview


INTERPHASE
Nucleus
Nucleolus
Nuclear envelope
Chromatin
Centrosomes
PROPHASE
spindle
Chromatids of chromosomes
Aster
INTERPHASE-PROPHASE TRANSITION
PROMETAPHASE
Equatorial plate
METAPHASE
Daughter chromosomes
ANAPHASE
TELOPHASE

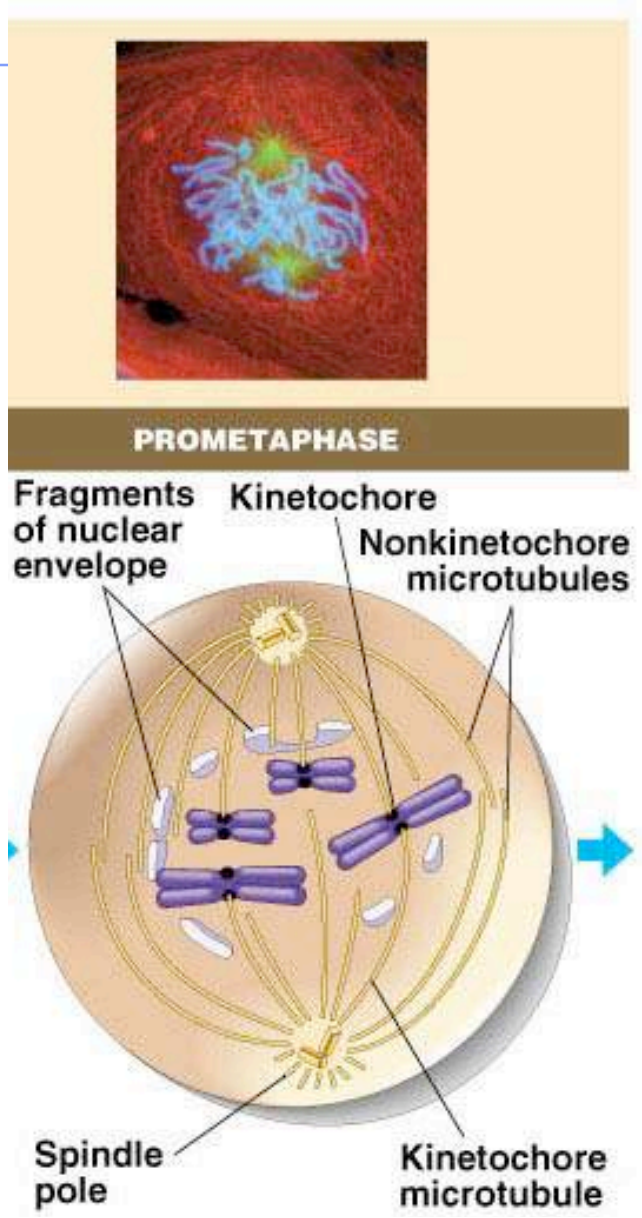
Prophase

- 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



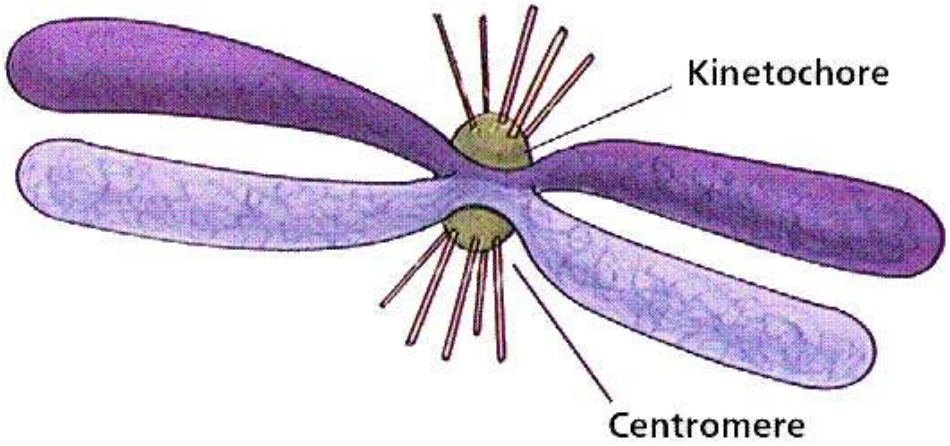
Prometaphase

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



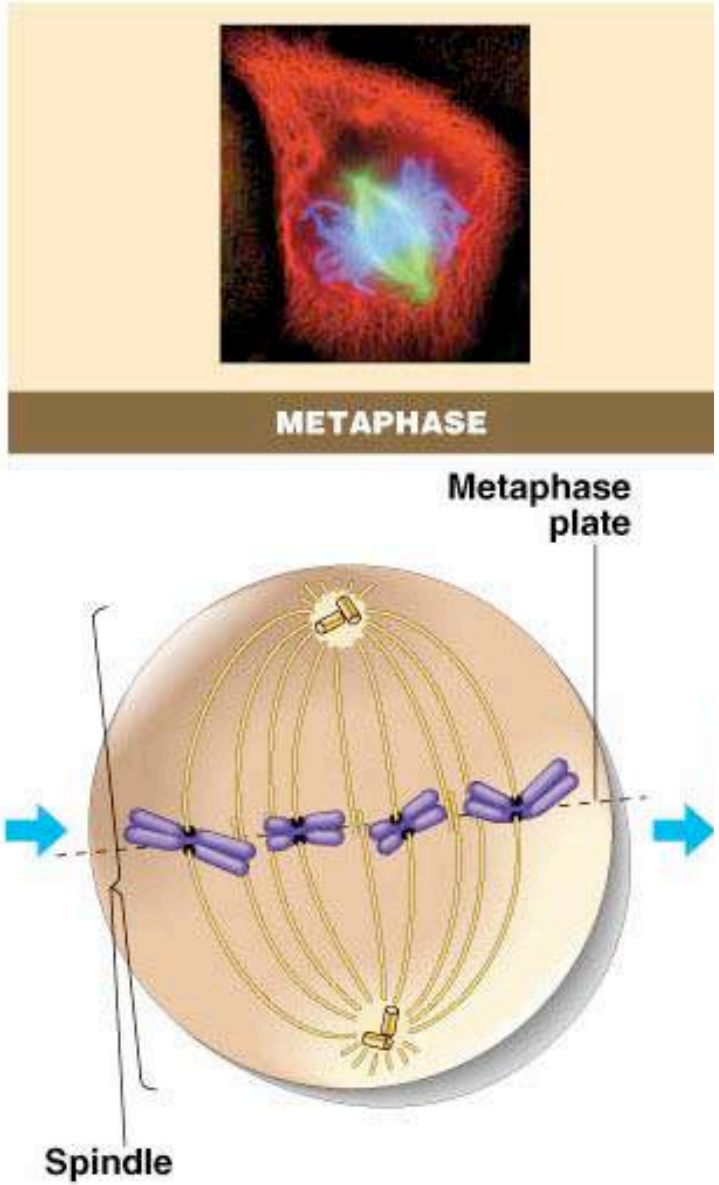
Kinetochore

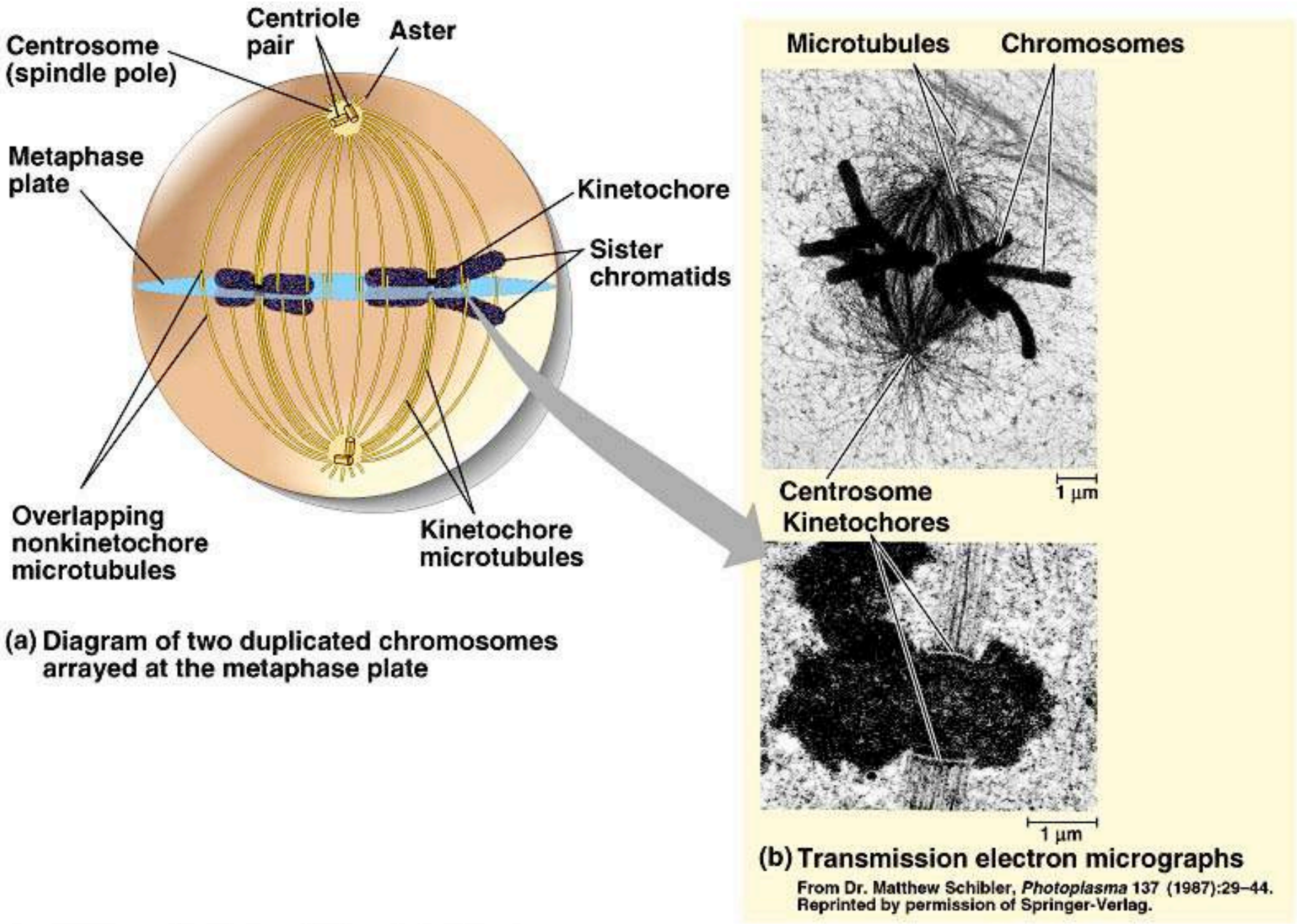
- Each chromatid has own kinetochore proteins
  - microtubules attach to kinetochore proteins



Metaphase

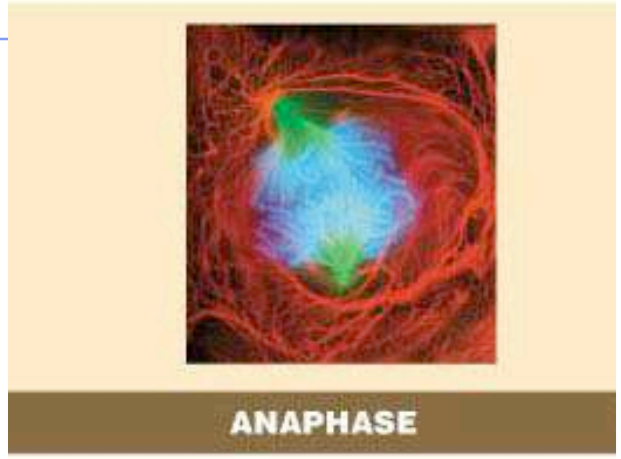
- Spindle fibers align chromosomes along the middle of cell
  - meta = middle
  - metaphase plate
  - helps to ensure chromosomes separate properly
    - so each new nucleus receives only 1 copy of each chromosome

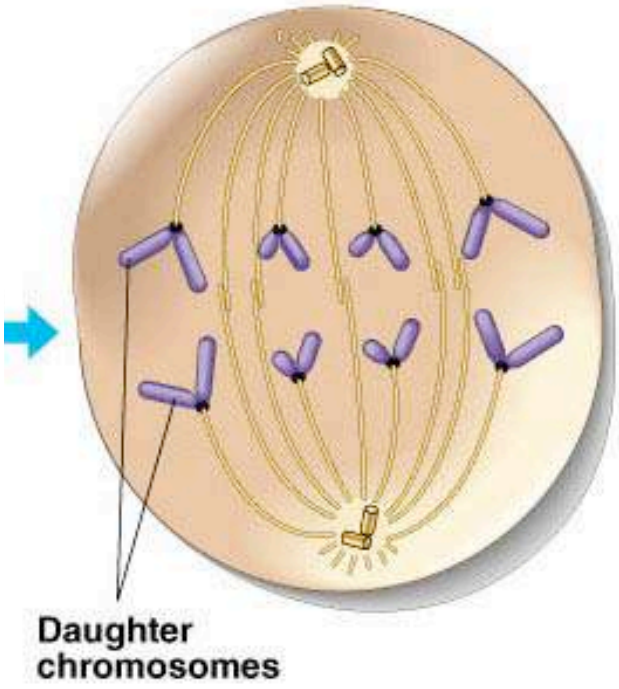



Centrosome (spindle pole)
Centriole pair
Aster
Metaphase plate
Kinetochore
Sister chromatids
Overlapping nonkinetochore microtubules
Kinetochore microtubules
(a) Diagram of two duplicated chromosomes arrayed at the metaphase plate
Microtubules
Chromosomes
Centrosome
Kinetochores
1 µm
1 µm
(b) Transmission electron micrographs
From Dr. Matthew Schibler, Photoplasma 137 (1987):29–44.
Reprinted by permission of Springer-Verlag.

Anaphase

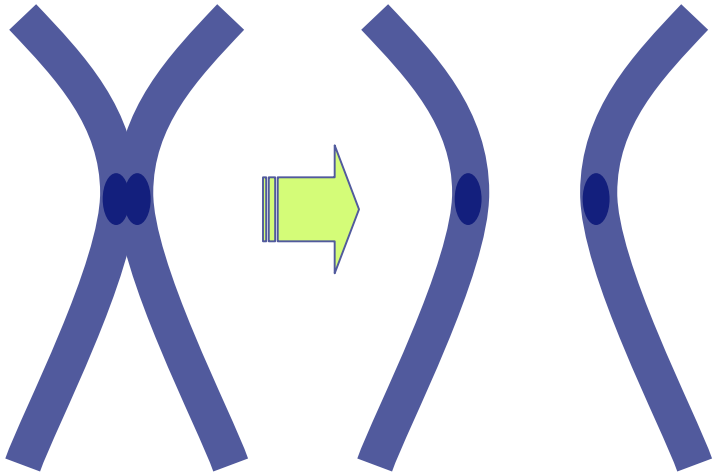
- Sister chromatids separate at kinetochores
  - move to opposite poles
  - pulled at centromeres
  - pulled by motor proteins "walking"along microtubules
    - increased production of ATP by mitochondria
- Poles move farther apart
  - polar microtubules lengthen





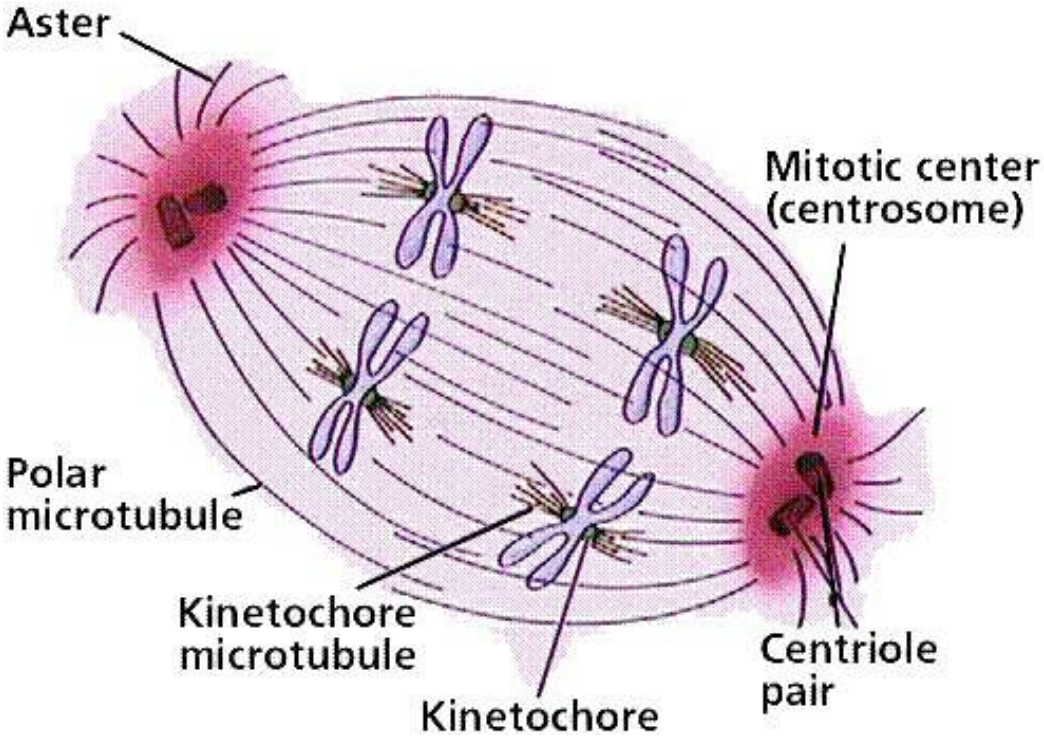
Separation of chromatids

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



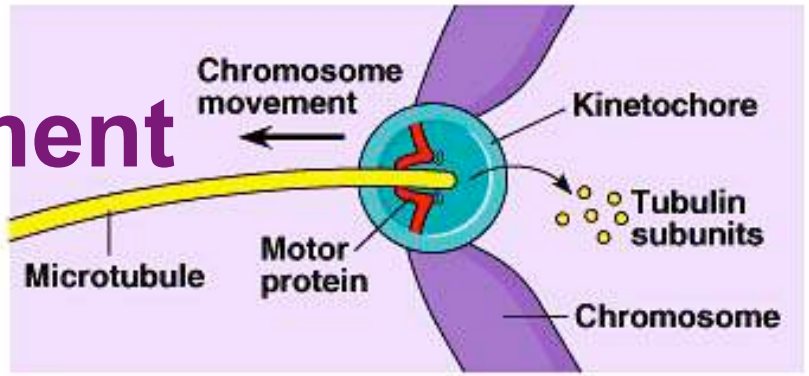
1 chromosome
2 chromatids

2 chromosomes

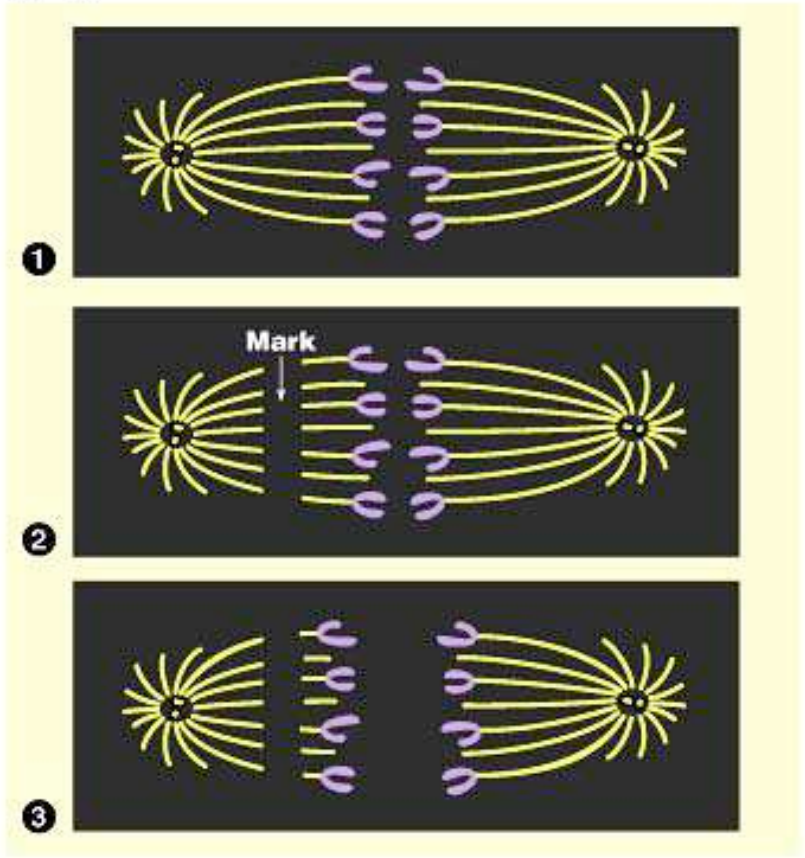


Chromosome movement

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



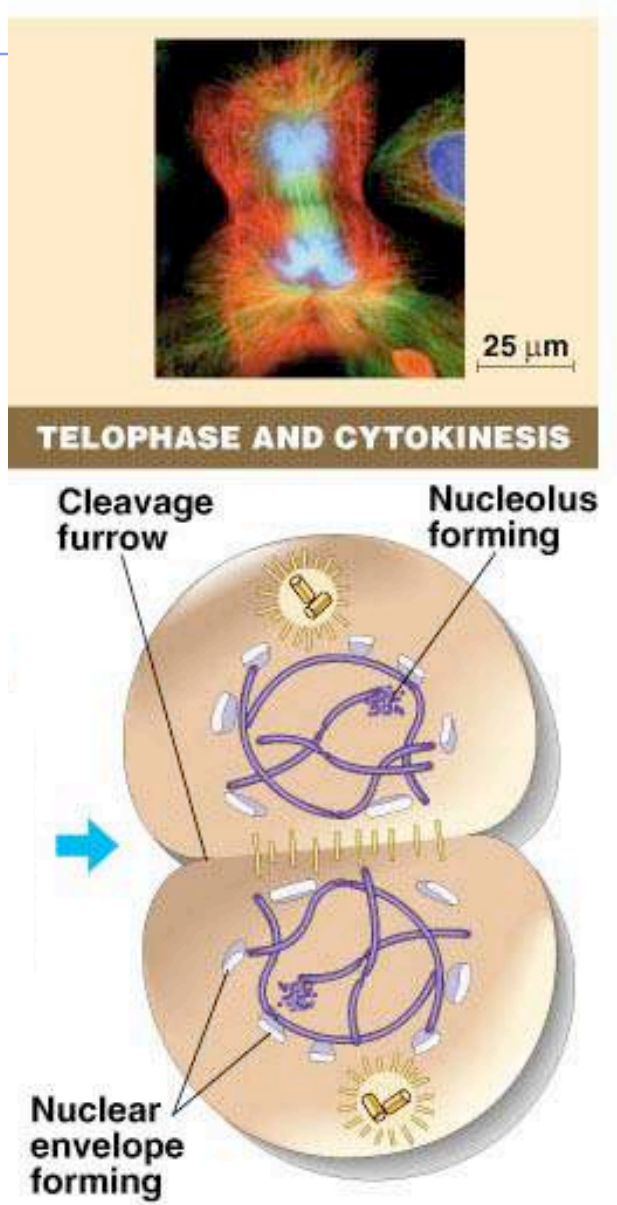
(a) Hypothesis



(b) Experiment

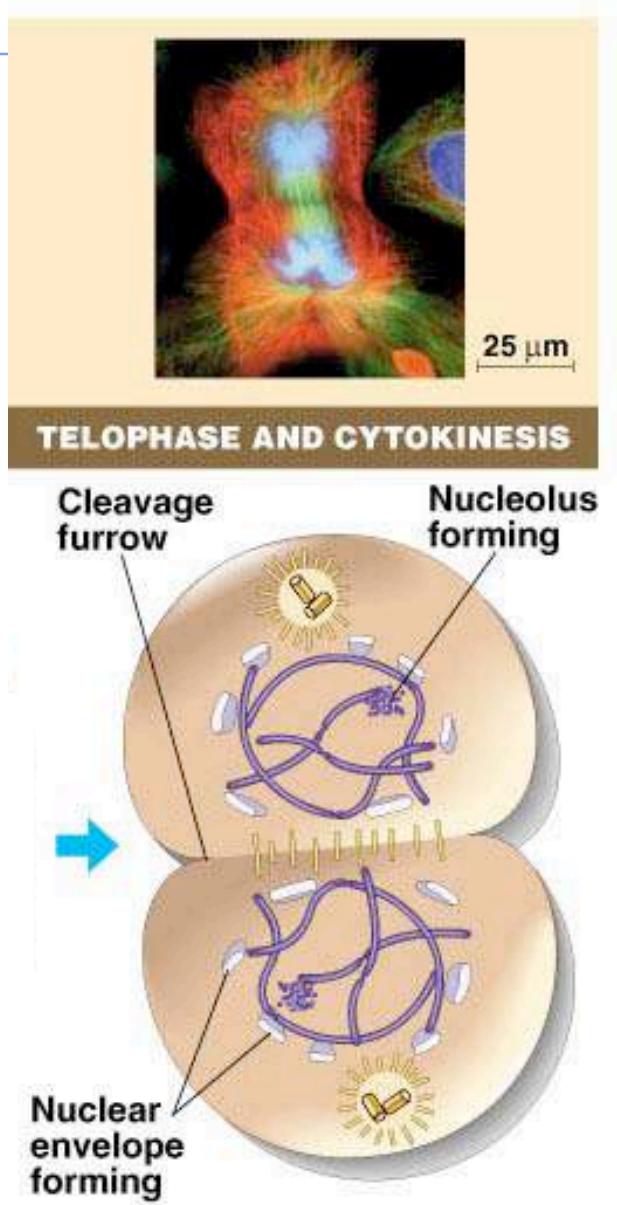
Telophase

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

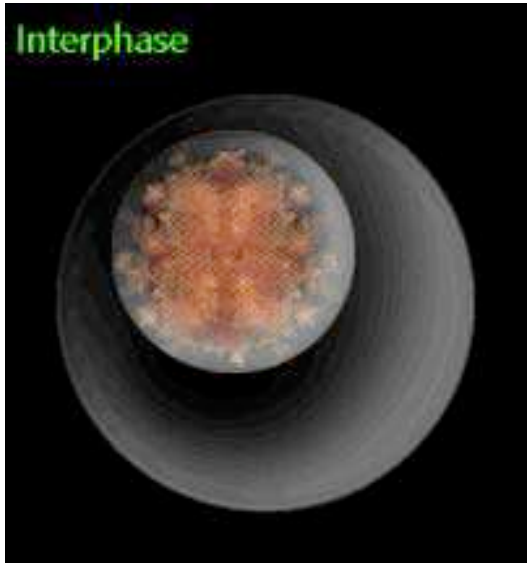


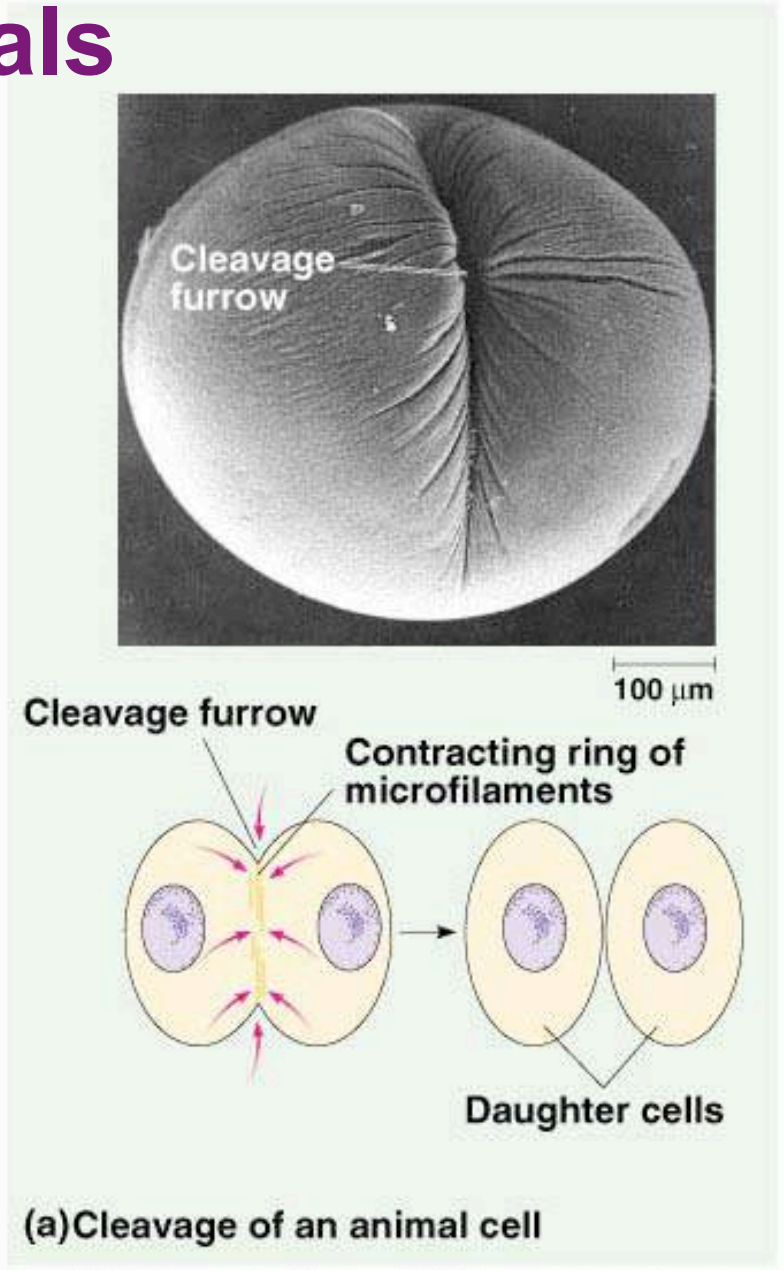
Cytokinesis

- 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



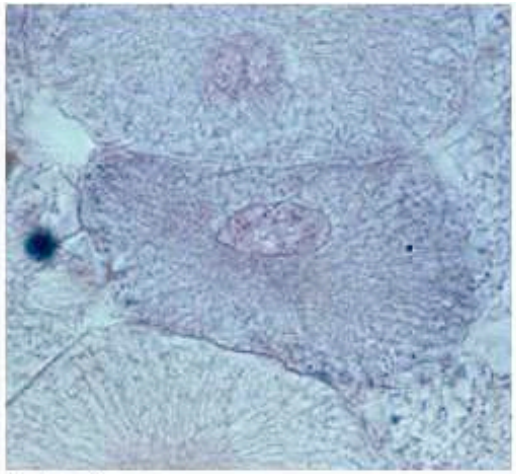
Cytokinesis in Animals

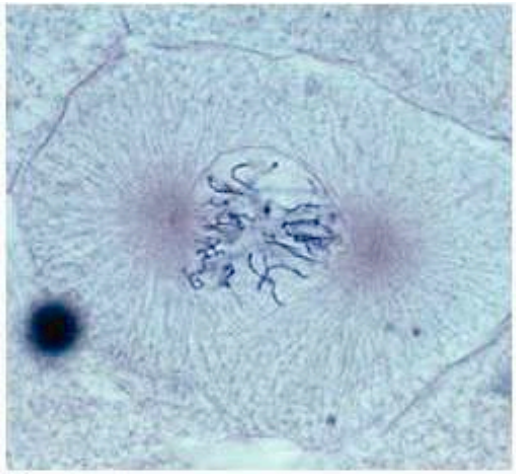


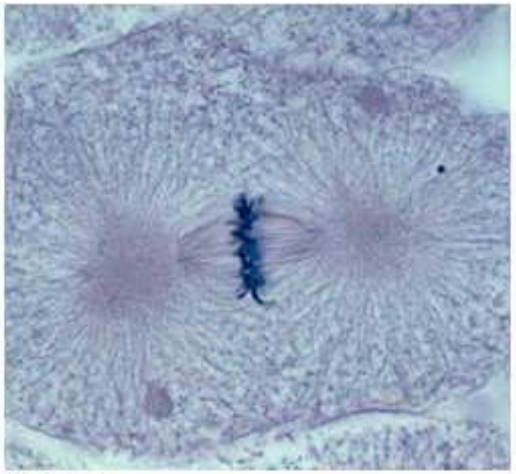


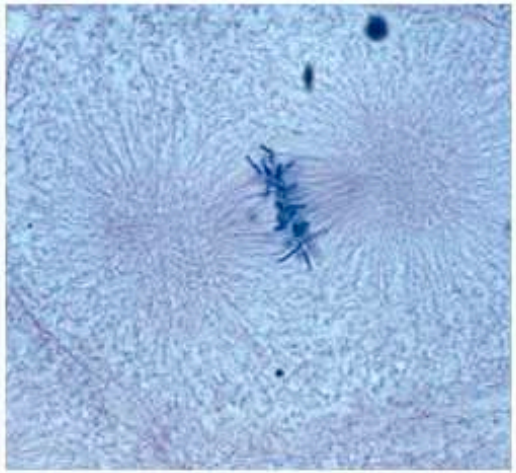
(play Cells Alive movie here)

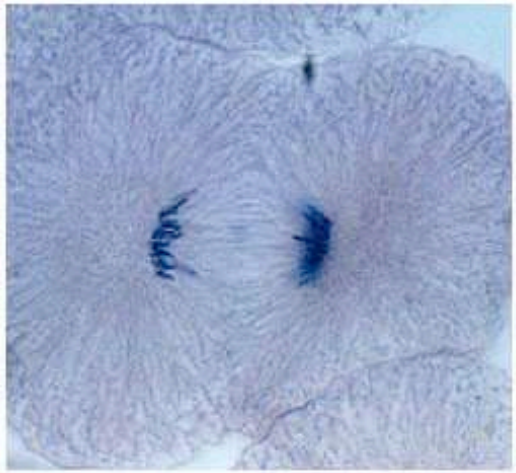
Mitosis in whitefish blastula

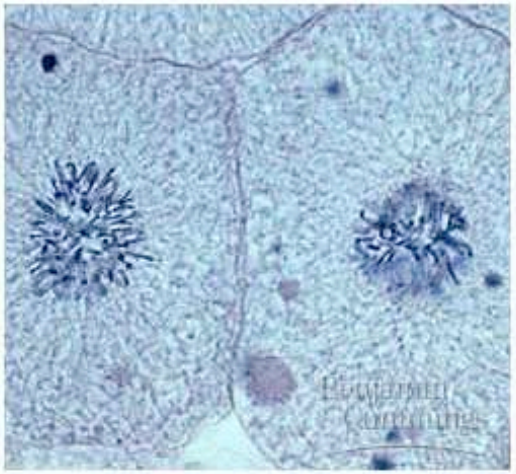

Interphase


Prophase

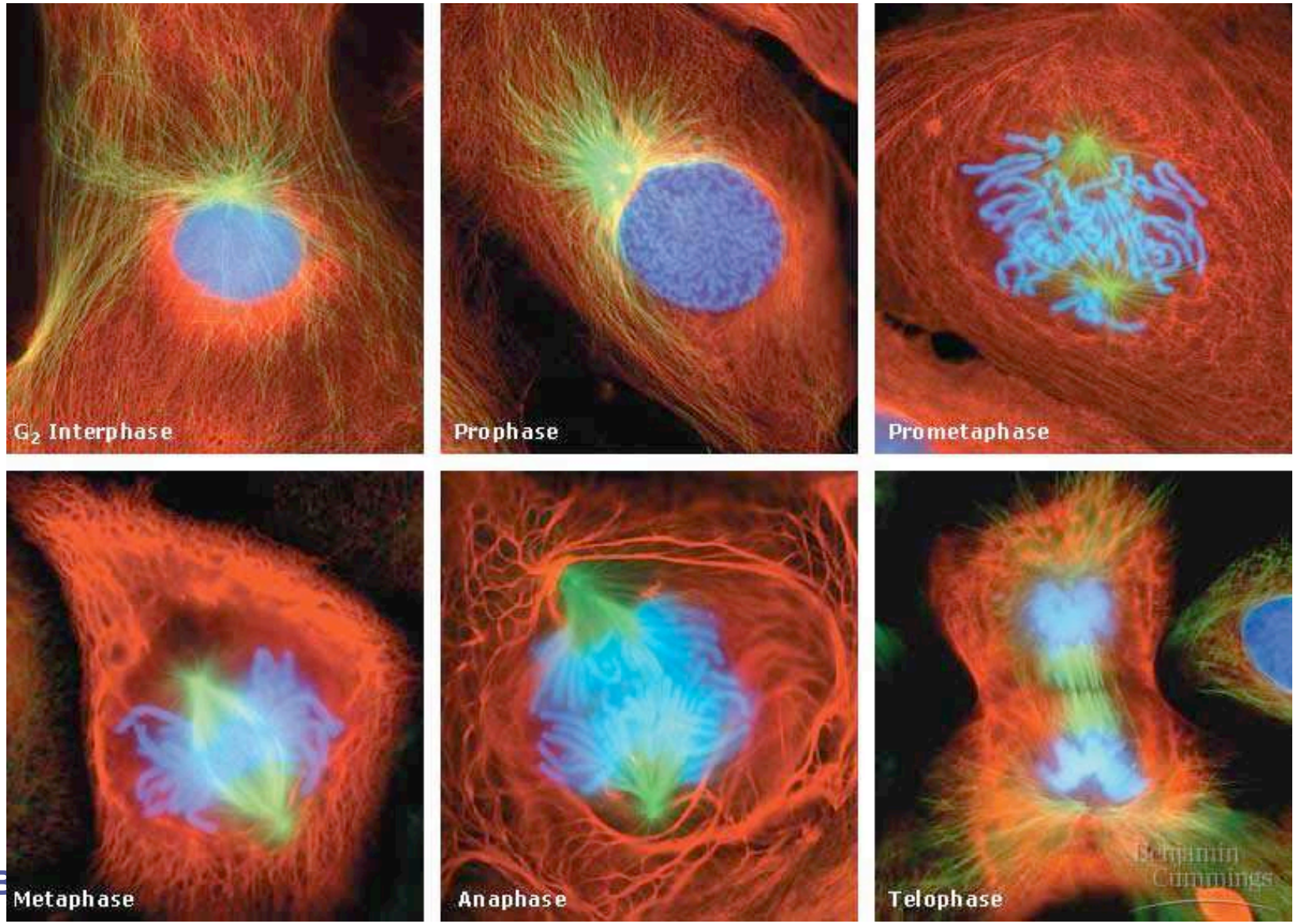

Metaphase


Anaphase


Early Telophase

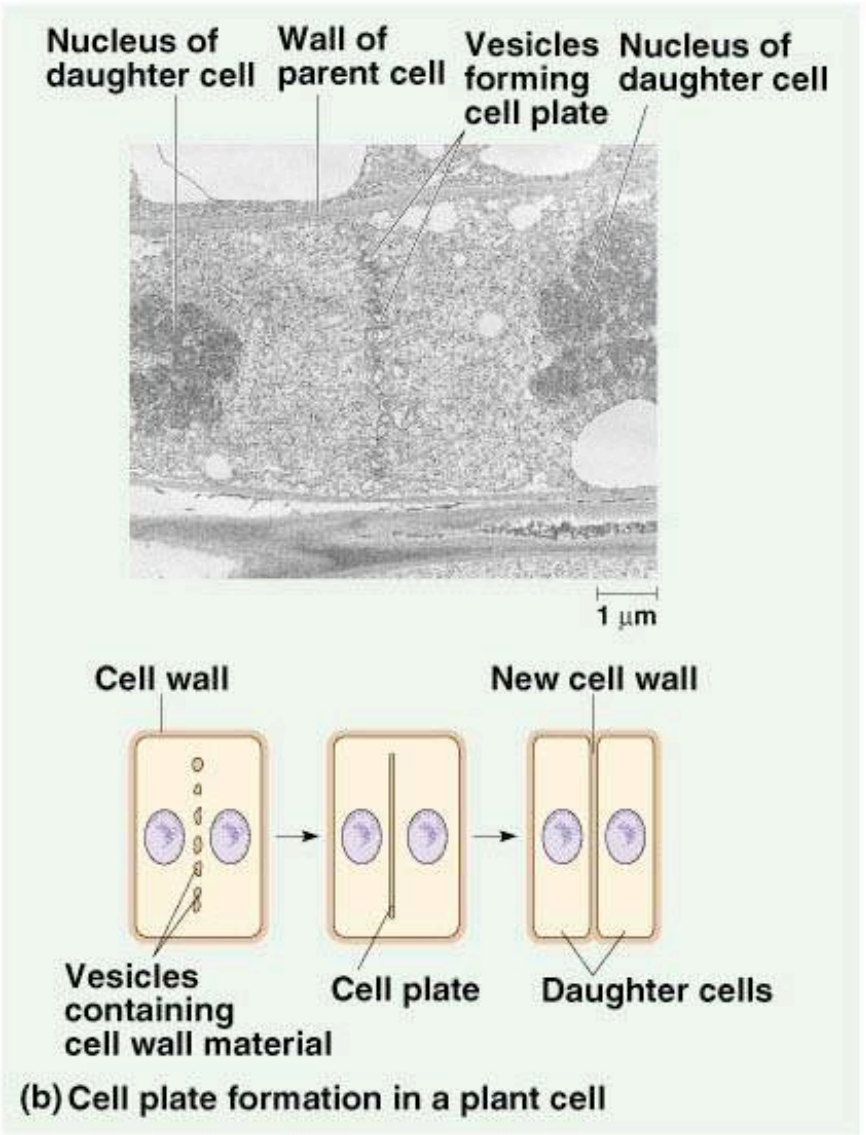

Late Telophase

Mitosis in animal cells



Cytokinesis in Plants

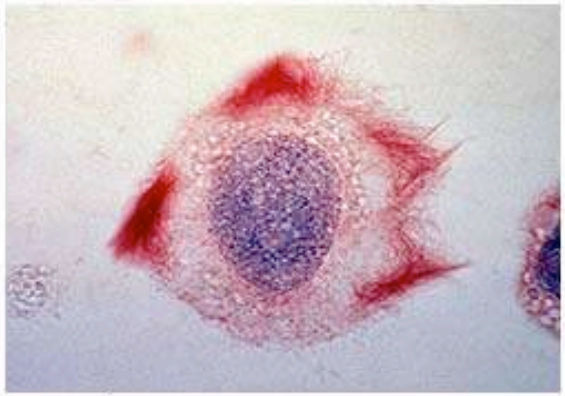
- **Plants**
  - vesicles move to equator line up & fuse to form 2 membranes = <u>cell plate</u>
    - derived from Golgi
  - new cell wall is laid down between membranes
    - new cell wall fuses with existing cell wall



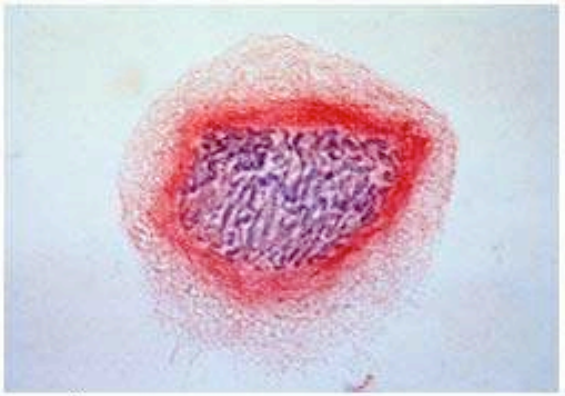
(b) Cell plate formation in a plant cell

Cytokinesis in plant cell

Mitosis in plant cell



Interphase



Prophase

Prometaphase

Metaphase

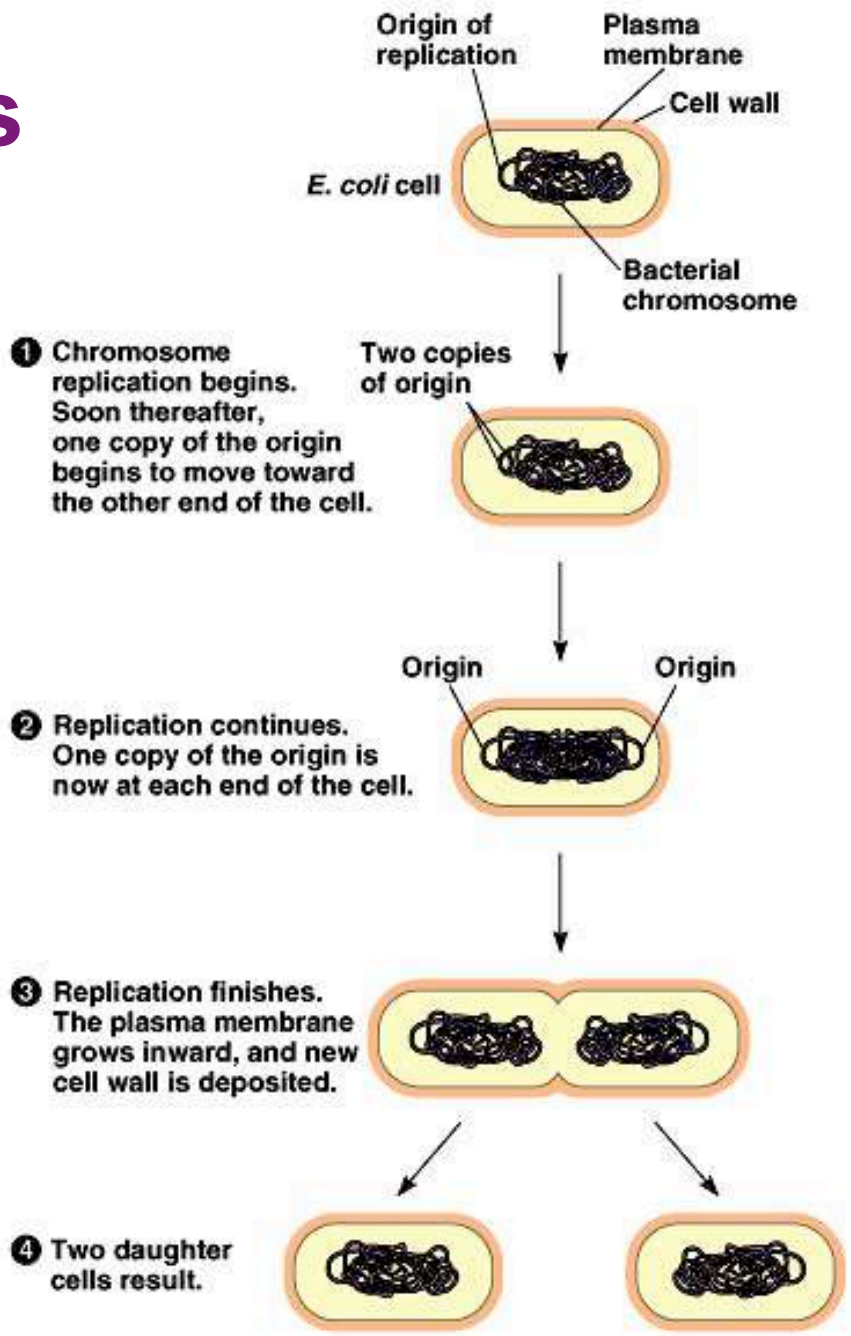
Anaphase

Telophase


onion root tip
Benjamin
Cummings

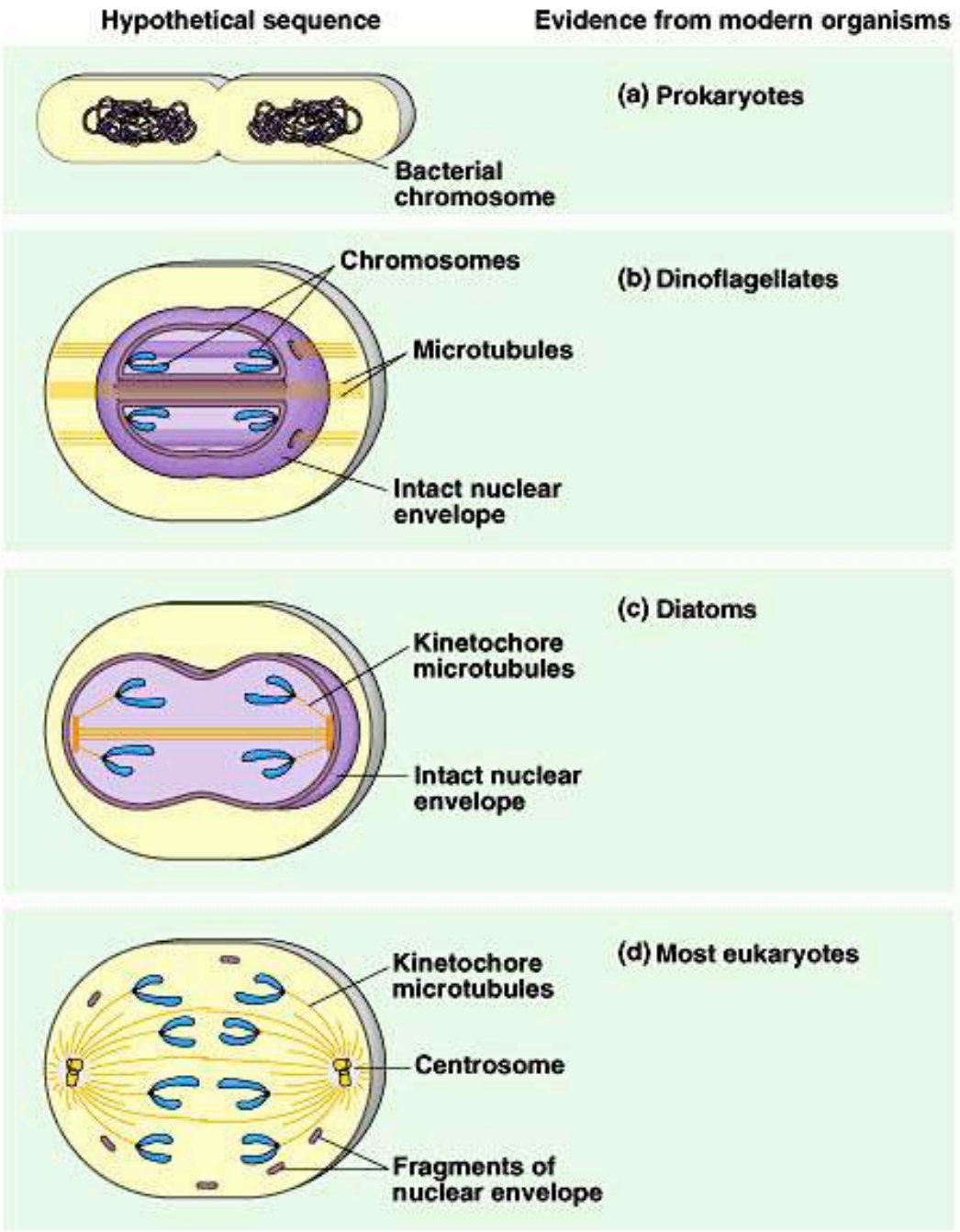
Evolution of mitosis

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



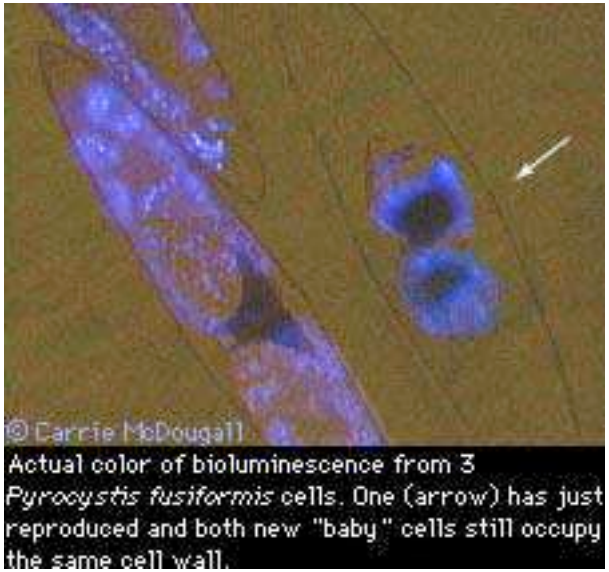
Evolution of mitosis

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



Dinoflagellates

- algae
  - “red tide”
  - bioluminescence

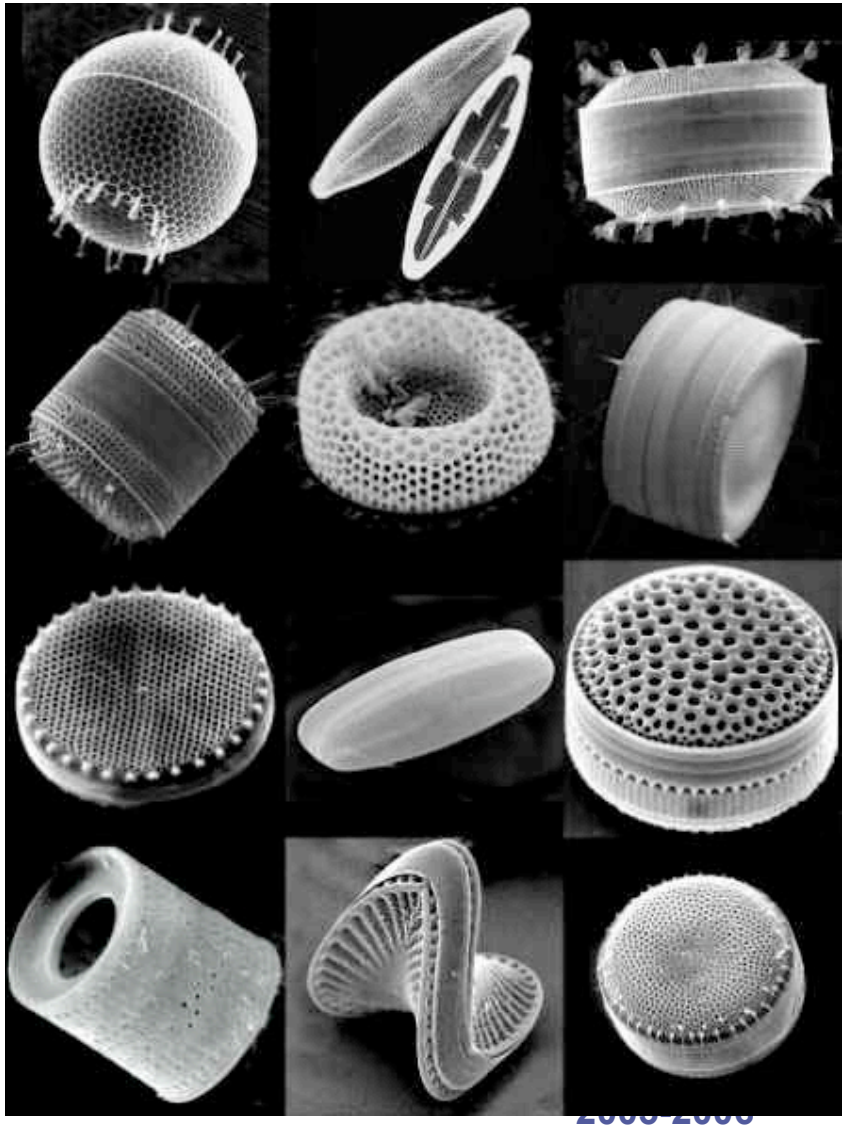


Actual color of bioluminescence from 3 *Pyrocystis fusiformis* cells. One (arrow) has just reproduced and both new "baby" cells still occupy the same cell wall.

Diatoms

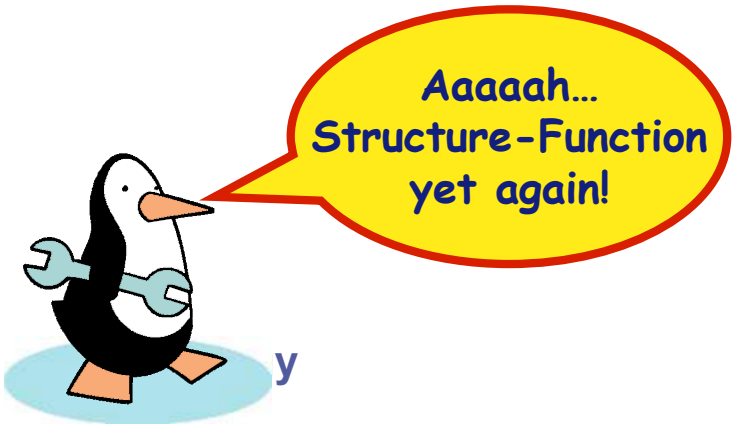
- microscopic algae
  - marine
  - freshwater

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



Any Questions??

Any Questions??


Aaaaah…
Structure-Function
yet again!