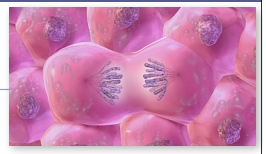
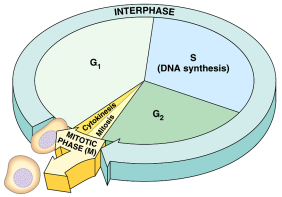
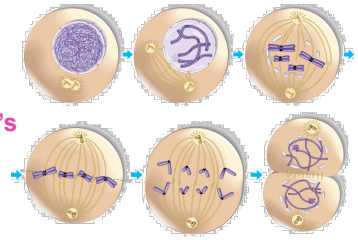
Mitosis & Cytokinesis



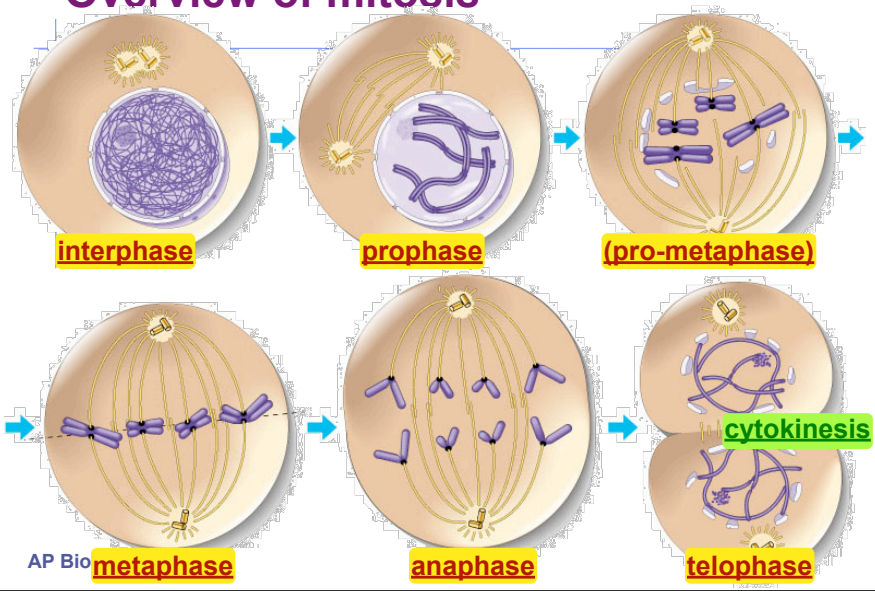
- Mitosis: Dividing cell's DNA between 2 daughter nuclei
- 4 phases:
  - prophase
  - metaphase
  - anaphase
  - Telophase
- Cytokinesis: Dividing cell's cytoplasm





Overview of mitosis

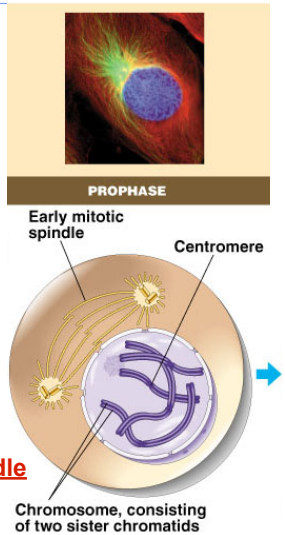
I.P.M.A.T.



End of G_2 & Start of Mitosis

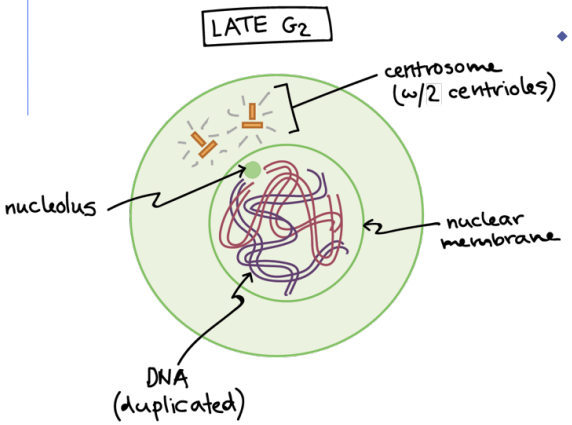
green = key features

- **End G_2**
  - 2 Centrosomes have formed by replication of one centrosome
    - Each has 2 centrioles in animal cells
  - Duplicated chromosomes cannot be seen yet individually under a microscope
- **Prophase *(1st sub-phase of mitosis)***
  - Chromatin condenses
    - Starts turning into visible chromosomes
      - Each made of 2 sister chromatids
  - Nucleolus disappears
  - Centrosomes move to opposite cell poles
    - microtubules between them lengthen
      - Asters visible (radial arrays of short microtubules around centrosome)
  - Microtubules are forming the mitotic spindle
    1. Coordinates movement of chromosomes
    2. Will elongate the cell later in mitosis



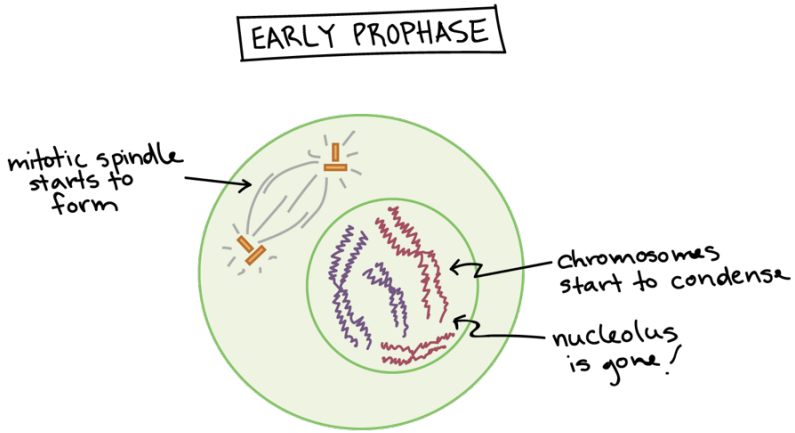
End of G_2 (of Interphase)

- Chromosomes were replicated during S phase of interphase
  - Each 1 chromosome is made up of 2 identical copies of double-helical DNA called sister chromatids



- Remember, earlier in G_2
  - DNA errors made during replication are corrected when possible
  - Organelles are duplicated, if needed
  - Proteins needed during M phase (mitosis & cytokinesis) are synthesized
  - Cell may grow slightly more, if necessary

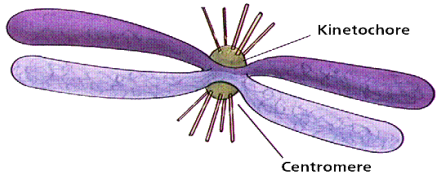
Start of Mitosis (Prophase)

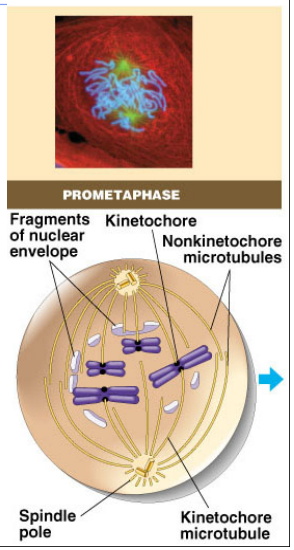


Transitioning to Metaphase

green = key features

- **Prometaphase** *(late prophase)*
  - Nucleus fragments (breaks up)
  - Chromosomes condense still more
  - Two kinetochores appear on the side of each chromatid at the centromere of the duplicated chromosome
    - Chromosomes attach to spindle fibers at kinetochores
      - Structures of proteins located at the centromere of the chromosomes
  - Spindle fibers are attaching to centromeres of chromosomes and become known as "kinetochore microtubules"

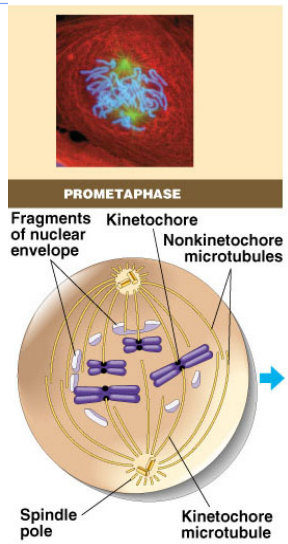




Transitioning to Metaphase

green = key features

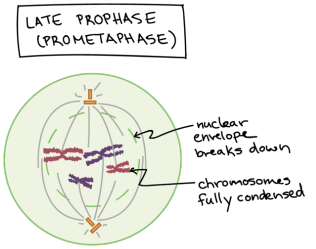
- **Prometaphase continued** *(late prophase)*
  - Chromosomes begin moving toward a region equidistant between the two centrosomes, which are now located on opposite ends of the cell
  - "nonkinetochore microtubules" originating from one pole interact with those originating at the opposite pole of the mitotic spindle
    - Nonkinetochore microtubule interactions begin to cause some lengthening of the cell



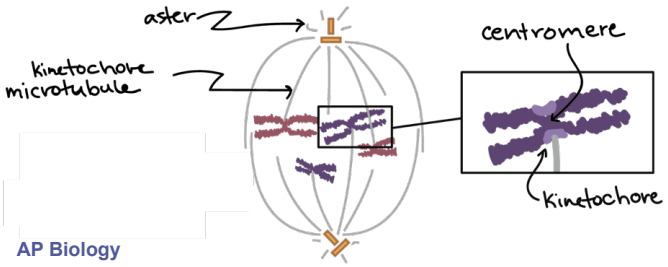
Pro-metaphase (Late Prophase)

Centromeres

- Regions of DNA where the sister chromatids are most tightly connected via proteins
- Region where kinetochore proteins will attach to each sister chromatid



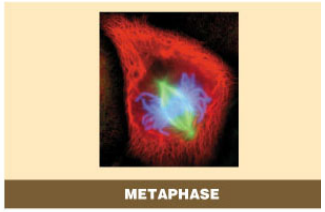
SPINDLE ANATOMY

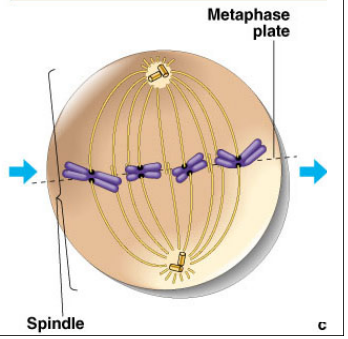


Metaphase (longest phase; 20min.)

green = key features

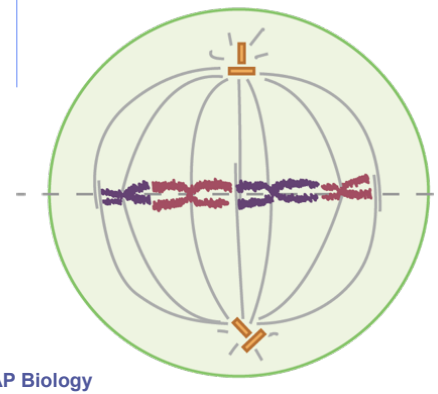
- Chromosomes align along middle of cell
  - On the metaphase plate
    - meta = middle
      - Imaginary line half way between the spindle poles
  - spindle fibers coordinate movement of chromosomes
    - Kinetochore microtubules from opposite poles are attached to the kinetochore of each sister chromatid in a chromosome
  - helps to ensure chromosomes separate properly
    - so each new nucleus receives only 1 copy of each chromosome



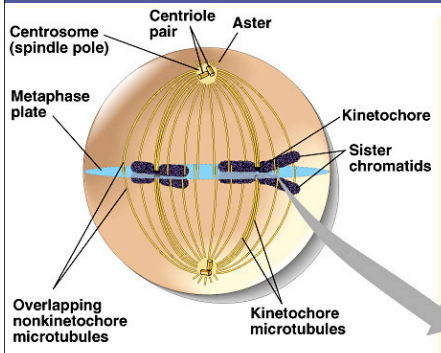


Metaphase (longest phase; 20min.)

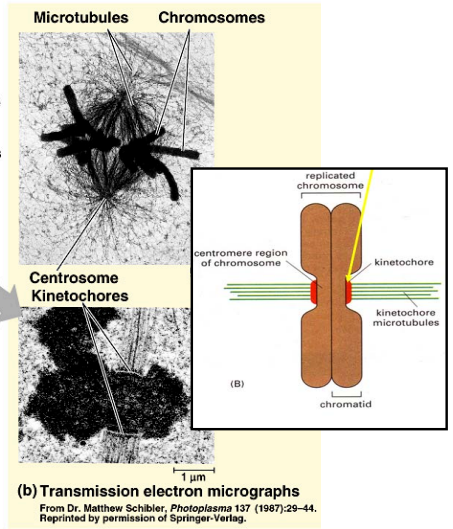
metaphase plate is not a physical structure, just a term for the plane where the chromosomes line up.



chromosomes line up at metaphase plate



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



(b) Transmission electron micrographs

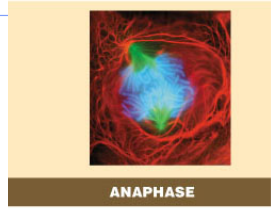
From Dr. Matthew Schibler, *Photoplasma* 137 (1987):29–44. Reprinted by permission of Springer-Verlag.

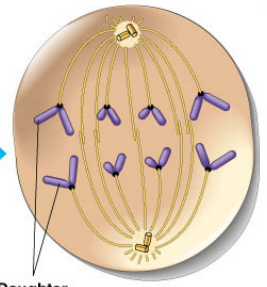
Metaphase:
Sister chromatids face opposite poles.

Anaphase (shortest phase; few min.)

green = key features

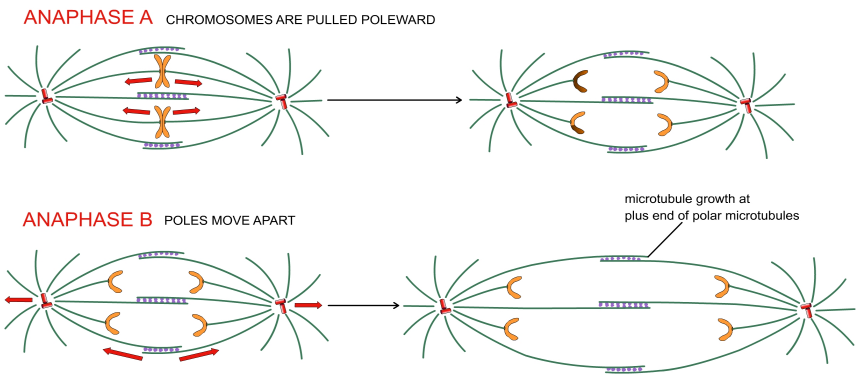
- Sister chromatids separate
  - Cohesin proteins, holding them together, are cleaved
    - Each chromatid now considered an individual chromosome
      - Each chromatid of a chromosome is pulled to opposite poles from the kinetochores at the centromeres
        - Pulled by motor proteins "walking" along microtubules (ATP)
          - Increased production of ATP by mitochondria
        - Kinetochore microtubules shorten
- Poles move farther apart (cell lengthens)
  - "non-kinetochore microtubules" lengthen push apart





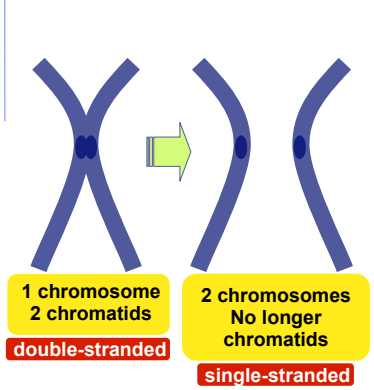
Anaphase

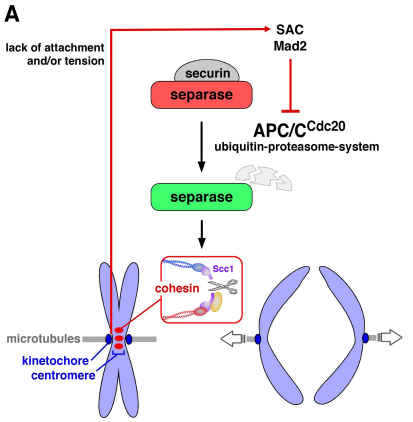
- Sister chromatids separate (becoming independent UNDUPLICATED chromosomes)
  - Kinetochore microtubules pull sister chromatids to opposite poles by shortening
- Poles of the cell are pushed farther apart (cell lengthens)
  - Non-kinetochore microtubules elongate, interact via motor proteins, & push the centrosome/asters further apart, thereby, pushing the whole plasma membrane outward at both poles



Separation of chromatids

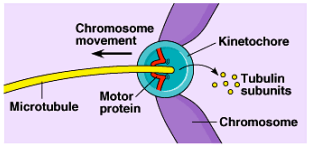
- In anaphase, proteins holding together sister chromatids are inactivated
  - Chromatids separate to become individual chromosomes



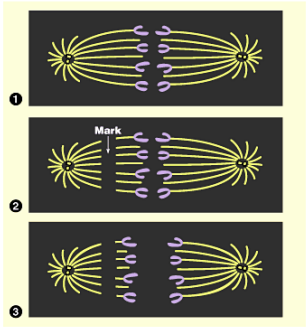


Chromosome movement

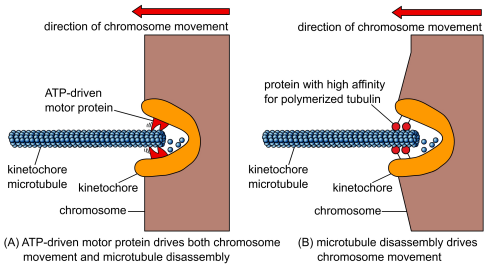
- Kinetochores use motor proteins (dynein) that "walk" chromosome along attached microtubule
  - microtubule shortens by dismantling at kinetochore (chromosome) end



(a) Hypothesis



(b) Experiment



(A) ATP-driven motor protein drives both chromosome movement and microtubule disassembly

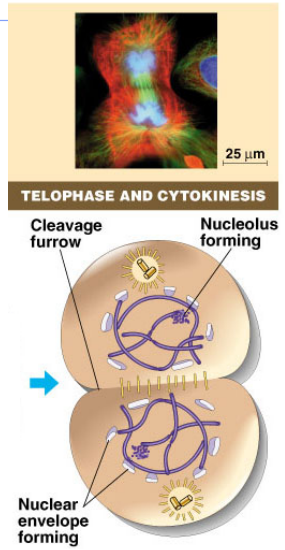
(B) microtubule disassembly drives chromosome movement

Alternative hypotheses for how microtubules shorten

green = key features

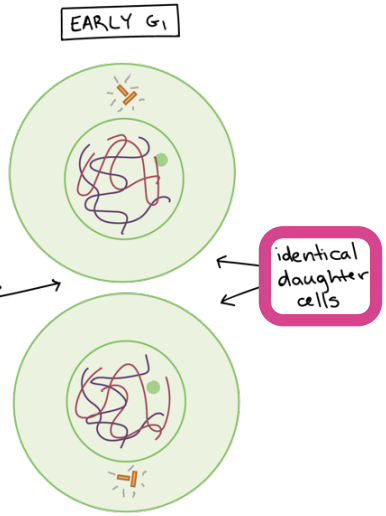
Telophase - the end of mitosis

- Chromosomes arrive at opposite poles
  - 2 daughter nuclei form
    - Nuclei forms
    - Nucleoli form
  - chromosomes disperse (uncoil)
    - no longer visible under light microscope as they turn back into being chromatin
- Spindle fibers break down
- Cytokinesis begins
  - Cytoplasm divides
    - Involves Cleavage Furrow in animal cells & Cell Plate formation in plant cells.



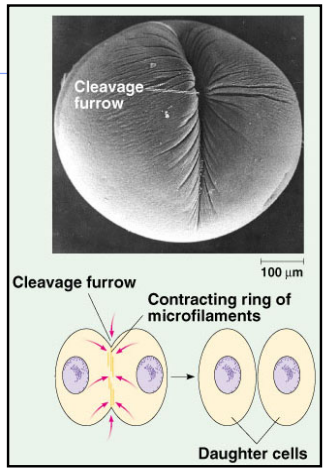
After Mitosis & Cytokinesis

- After mitosis & cytokinesis, the daughter cells are back in G_1 of Interphase
- During G_1...
  - the cells begin performing their normal metabolic functions
  - gene transcription & mRNA translation start up again
  - the cell grows into its "adult" size

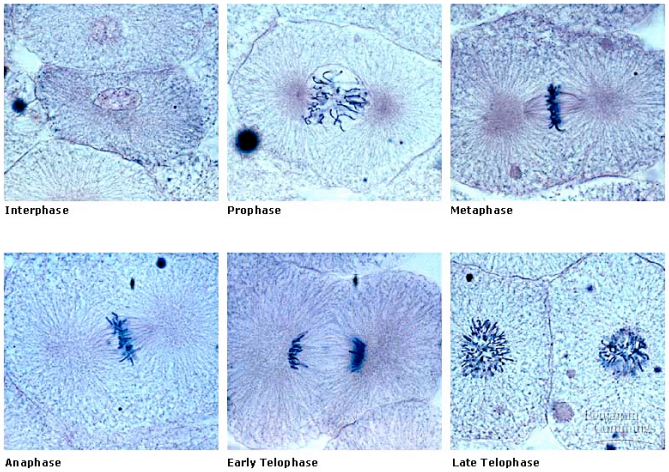


Cytokinesis

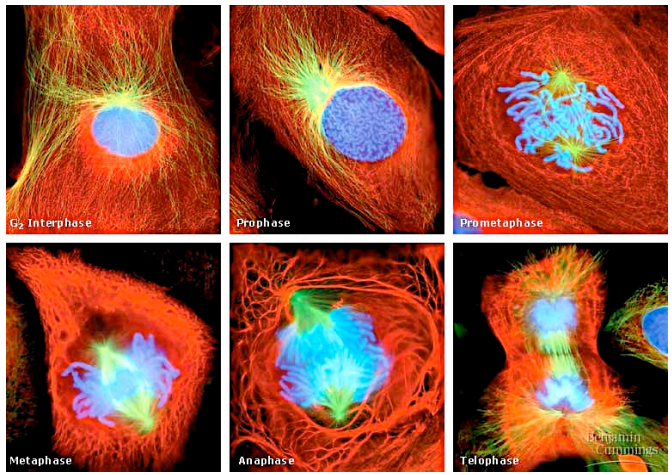
- In Animals:
  - Involves cleavage.
  - Constricting belt of actin microfilaments together with myosin proteins forms around the equator of cell
    - cleavage furrow forms = shallow groove in the cell surface near location of past metaphase plate
      - splits cell in two
        - Looks like the tightening of a draw string
        - Actin filaments interact with plasma membrane proteins pulling the plasma membrane inward.



Mitosis in whitefish blastula

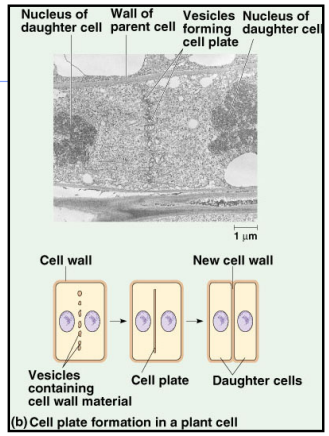


Mitosis in animal cells

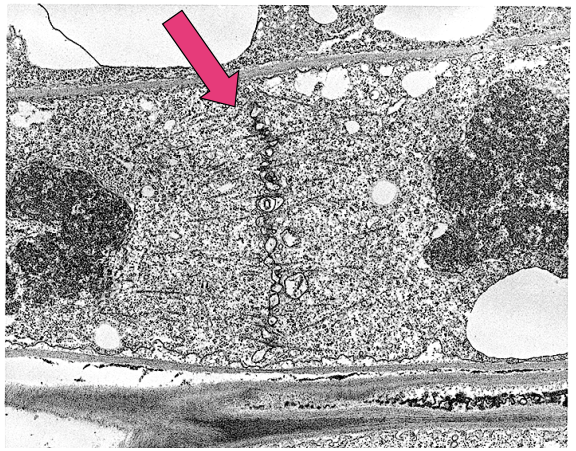


Cytokinesis in Plants

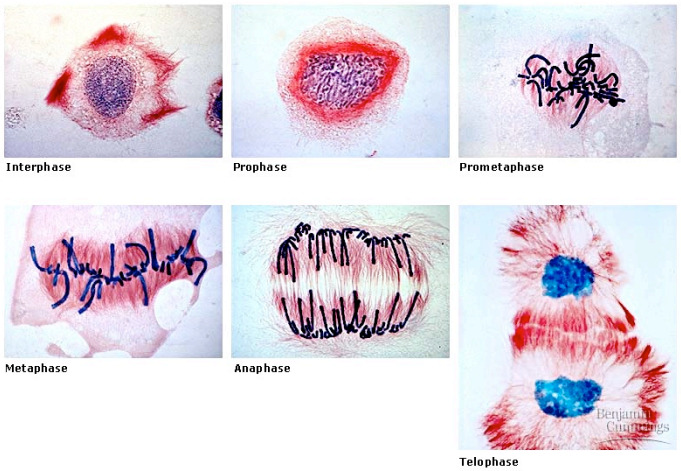
- **Plants**
  - cell plate forms late in telophase
    - vesicles line up at equator (move along microtubules)
      - *derived from Golgi*
    - vesicles fuse together to form the eventual two cell membranes of the daughter cells.
    - This growing line of fused vesicles [cell plate] eventually fuse with the plasma membrane along the perimeter of the dividing parent cell
    - Contents of vesicle make up middle lamella (pectin-rich)
      - This is a carbohydrate "sticky" substance that holds plant cells together.
  - Cellulose [the new primary cell walls] will then be secreted by the two new daughter cells directly from the plasma membrane enzyme *cellulose synthase [not through exocytosis by vesicles from the Golgi]*
    - This new cell wall forms under the middle lamella, between the middle lamella and each plasma membranes
      - new cell wall forming in between the daughter cells fuse with existing cell wall on the other three sides of each daughter cell



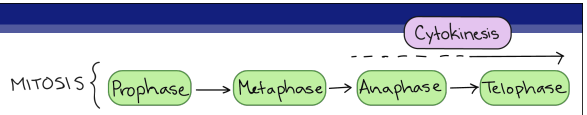
Vesicles with Pectin fusing to form cell plate



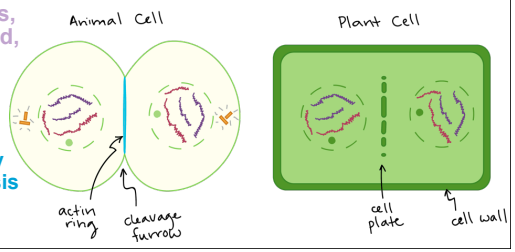
Mitosis in plant cell



Cytokinesis

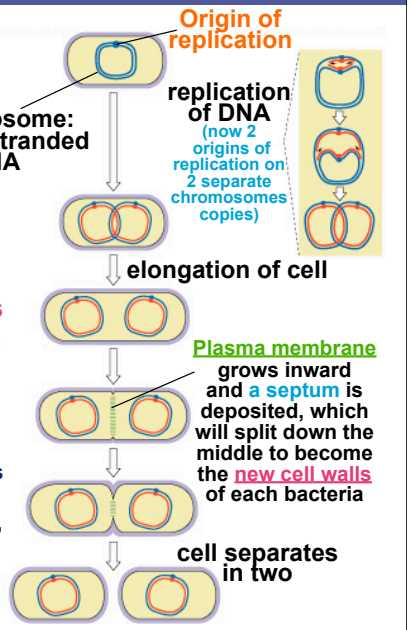


- **Cytokinesis, the division of the cytoplasm, overlaps with the final stages of mitosis.**
  - It may start in either anaphase or telophase, and finishes shortly after telophase.
    - In animal cells, cytokinesis is contractile. The cell is pinched in two with the help of filaments made of actin proteins interacting with plasma membrane proteins.
    - Plant cells have a stiff cell wall that cannot be pinched in two. A cell plate forms from vesicles aligning down the middle of the cell, splitting it into two daughter cells separated by a new wall.
  - When cytokinesis finishes, two new cells have formed, each with a complete set of chromosomes identical to those of the mother cell.
    - The daughter cells may one day undergo mitosis themselves, repeating the cycle.



Binary Fission

- Mitosis in eukaryotes likely evolved from binary fission in bacteria (prokaryotes)
  - Binary fission means 'division in half'
- Prokaryotes do NOT use mitosis
  - In bacteria, most genes are carried on a SINGLE bacterial chromosome consisting of a circular DNA molecule.
    - This single circular chromosome is much shorter than the multiple linear chromosomes of eukaryotes and so is faster to duplicate
    - No membrane-bound organelles exist, including no nucleus that surrounds the bacterial DNA



Evolution of mitosis

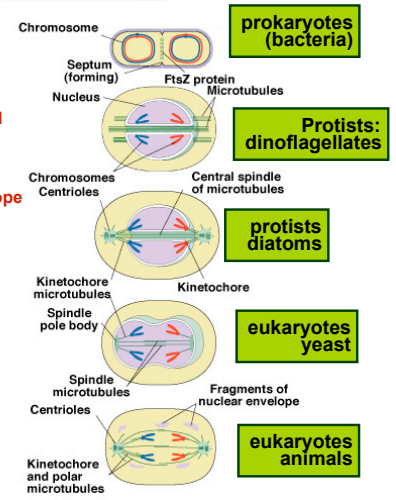
- A possible progression of mechanisms intermediate between binary fission & mitosis seen in modern organisms

Prokaryotes (bacteria)
- ✓ No nucleus
- ✓ Single circular chromosome. After DNA is replicated, it is partitioned in the cell.
- ✓ After cell elongation, proteins assemble into a ring and facilitates separation and cell division.

Single Celled Protists like Dinoflagellates
- ✓ Chromosome attached to nuclear envelope
- ✓ Microtubules pass through nucleus
- ✓ Nucleus divides similar to binary fission

Single Celled Protists, Diatoms, & Yeasts
- ✓ Nuclear envelope remains intact
- ✓ Microtubules in yeast form spindle inside nucleus (in diatoms it forms between two pairs of centrioles and passes through a tunnel)
- ✓ Microtubules separate chromosomes
- ✓ Nucleus splits into daughter nuclei

Most Eukaryotes
- ✓ Spindle forms outside the nucleus
- ✓ Nuclear envelope breaks down during mitosis
- ✓ Microtubules separate the chromosomes
- ✓ Nuclear envelope reforms



Any Questions??