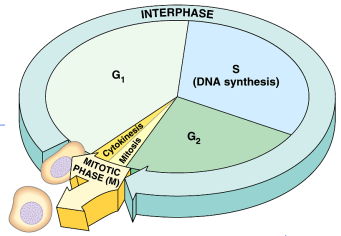
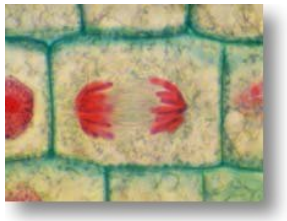
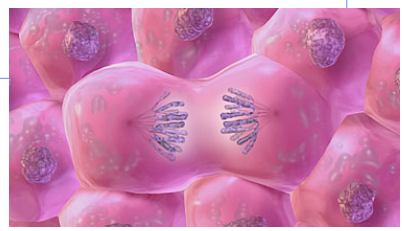
The Cell Cycle:

Cell Growth, Cell Division





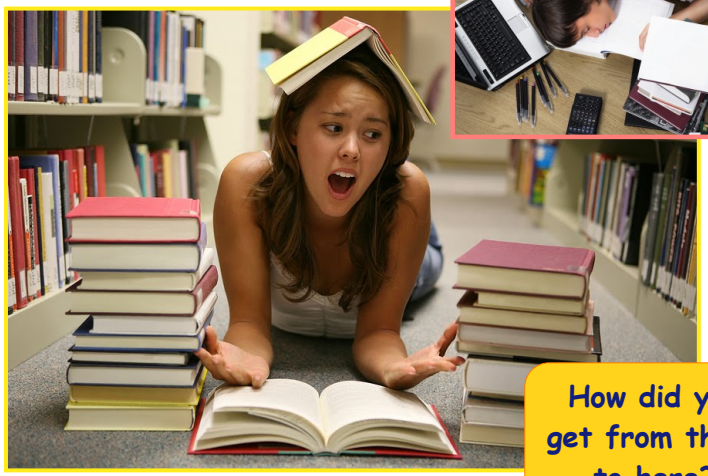


Where it all began…

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

.

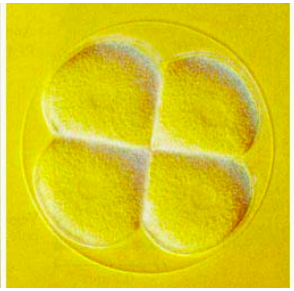
And now look at you…

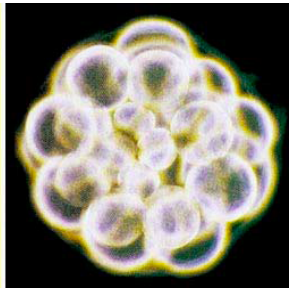


How did you get from there to here?

How did you become you?

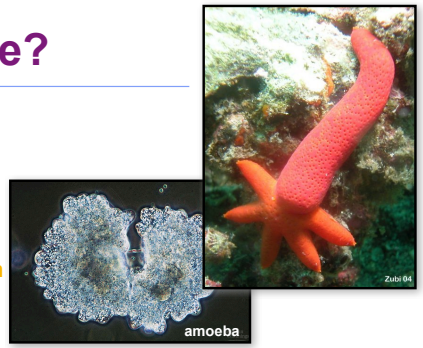
- Going from egg to baby….
  - the original fertilized egg has to divide…
    - and divide…
      - and divide…
        - and divide…
- "Cell Division" = reproduction of cells





Why do cells divide?

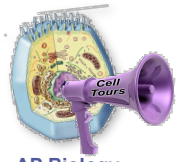
- For reproduction
  - Ex: In asexual reproduction
    - one-celled organisms divide to make two single-celled organisms
      - For these organisms... cell division = reproduction
- For growth & Development
  - Ex: from fertilized egg to multi-celled organism
- For repair & renewal
  - Ex: replace cells that die from normal wear & tear or from injury



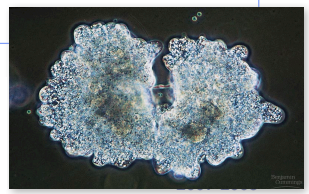
Cell Division is called mitosis

First, lets look at how cells make identical copies of themselves…
MITOSIS

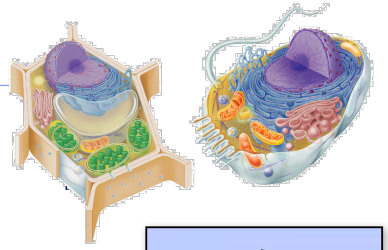
Biology is the only subject in which multiplication is the same thing as division...



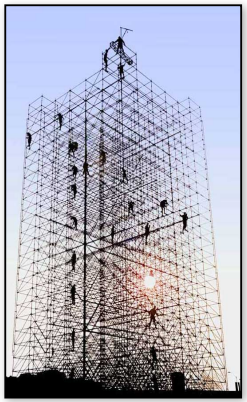
Let's start a quick refresher tour.



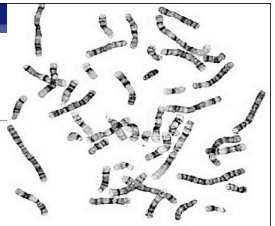
Making new cells



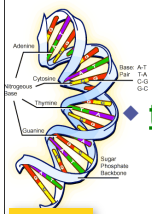
- Involves:
  - Events in the Nucleus
    - Holds chromosomes which be copied and divided up
      - Contain the DNA
  - Events in the Cytoplasm
    - Cells must grow large enough
    - Additional organelles may need to be produced for daughter cells
  - Events involving the Cytoskeleton
    - Centrosomes with centrioles build microtubules
      - (centrioles absent in plant centrosomes)
    - Microtubules make up the spindle fibers that move chromosomes
    - Microfilaments help in dividing the cytoplasm (in animal cells)



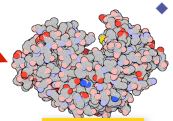
Nucleic Acid Function



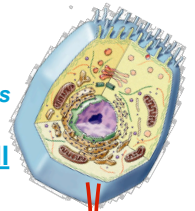
- DNA is the cell's genetic material
  - stores information
    - Genes = key sections of DNA
      - Contain the instructions for building proteins & various RNA molecules
  - transfers information
    - Flow of information in the cell is called the Central Dogma: *DNA → RNA → proteins*
      - Nucleic Acid passes down the information needed from parent cell to daughter cell
      - Nucleic Acid passes down the information needed from one generation to the next generation

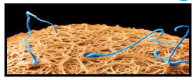


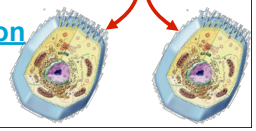
DNA



proteins

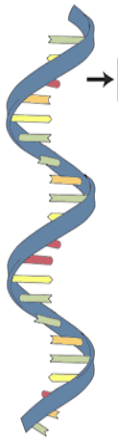






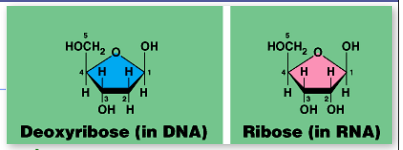
Nucleic Acids

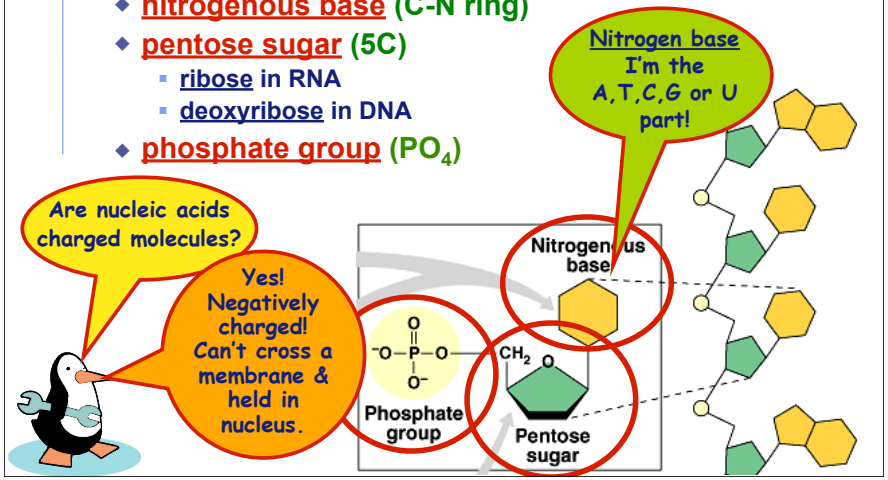
- **Structure:**
  - Nucleic Acids are **POLYMERS**
    - monomers = nucleotides
  - **RNA** (ribonucleic acid)
    - single helix *(which does in some cases fold on itself due to complimentary base paring of distant nucleotides within the same polynucleotide)*
  - **DNA** (deoxyribonucleic acid)
    - double helix *(made up of 2 polynucleotide molecules hydrogen bonded together down the center)*



Nucleotides

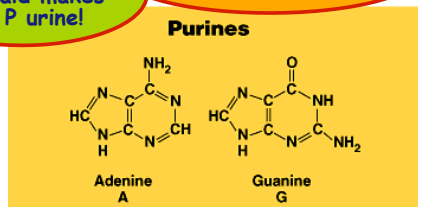
- Made of three parts:
  - nitrogenous base (C-N ring)
  - pentose sugar (5C)
    - ribose in RNA
    - deoxyribose in DNA
  - phosphate group (PO_4)

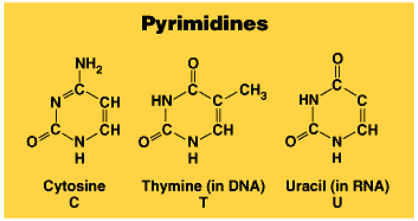




Types of nitrogenous bases

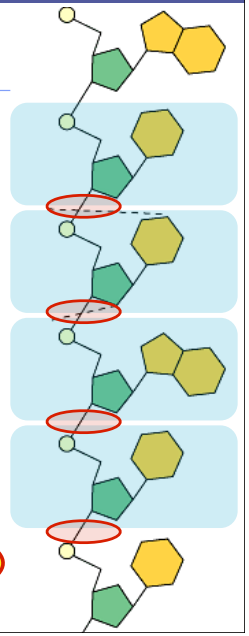
- Different nitrogen bases
  - purines
    - double ring
    - Nitrogenous base
      - adenine (A)
      - guanine (G)
  - pyrimidines
    - single 6-member ring
    - Nitrogenous base
      - cytosine (C)
      - thymine (T)
        - DNA ONLY
      - uracil (U)
        - RNA ONLY





Nucleic acid polymer
(polynucleotides)

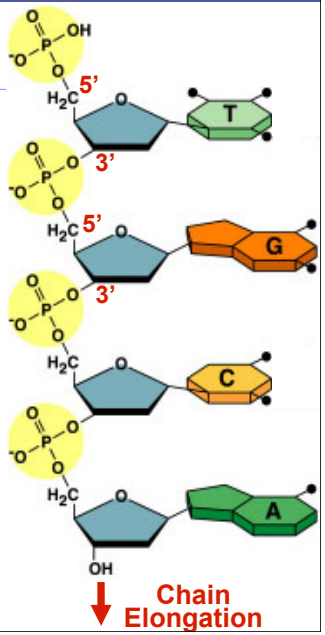
- Contain a sugar-phosphate backbone
  - Monomers joined by dehydration synthesis reactions that form a covalent bond
    - The 3' OH of the sugar of one nucleotide is covalently bonds to the PO_4 of the next nucleotide
      - Nucleotide joined through phosphodiester bond
  - Nitrogenous bases hang off the sugar-phosphate backbone



The Sugar Phosphate Backbone

- Sugar phosphate backbone
  - Phosphate of nucleotide is covalently bonded to the sugar's 5'C (the 5' carbon)
  - Phosphodiester bond exists between 3'C of one nucleotide and the phosphate of the next nucleotide
  - Polynucleotides grows in one direction
    - From the 3'C -OH (hydroxyl) end of the molecule.

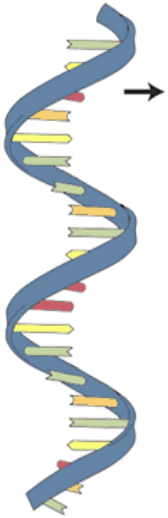
5' → 3' direction



Nucleotides of Nucleic Acids

- Both RNA and DNA polymers are made of the monomers Guanine (G), Adenine (A), and Cytosine (C).
  - However, RNA and DNA do not both use Uracil (U) and Thymine (T):
    - RNA
      - Single strand
      - Substitutes U for T
    - DNA
      - Double stranded
      - T instead of U

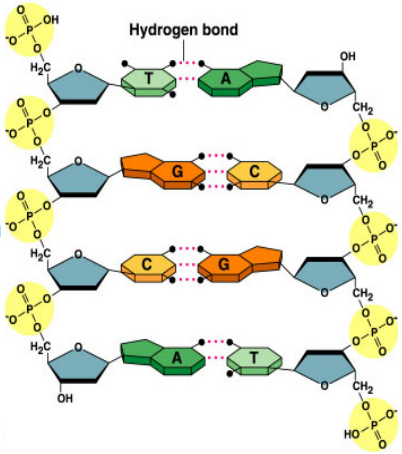
DNA



RNA

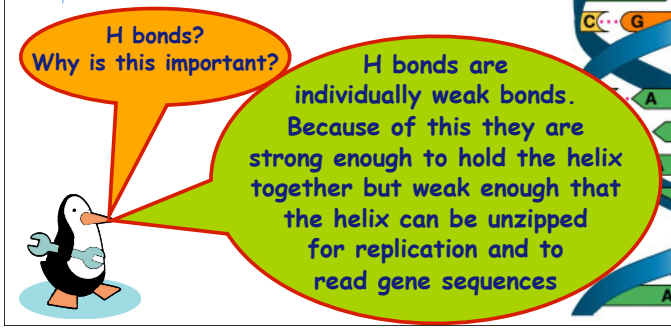
Pairing of nucleotides in DNA

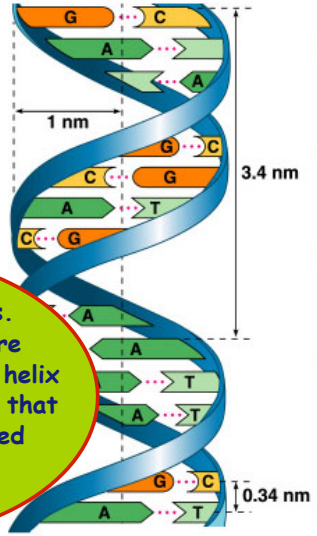
- Nucleotides of two strands of DNA attract through HYDROGEN BONDS between DNA strands
  - Hydrogen bonds are weak bonds unlike covalent (and full ionic) bonds
  - Every complimentary base paring involves one purine in one DNA strand hydrogen bonded to one pyrimidine in the other DNA strand
    - A :: T
      - 2 H bonds
    - G :: C
      - 3 H bonds



DNA molecule made of 2 polynucleotides spiraling around imaginary axis

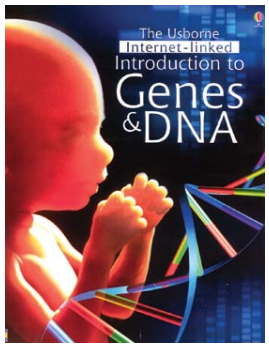
- Double helix
  - Hydrogen bonds between bases join the 2 strands
    - A :: T
    - C ::: G





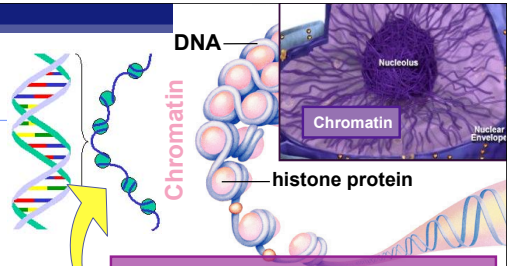
DNA/RNA = Information-carrying polymers

- Function
  - sequence of bases encodes information
    - like the letters of a book
  - stored information is passed from parent to offspring
    - need to copy accurately
  - Sections of DNA = store information = genes
    - Each contain different genetic information on how to make different polypeptides & RNAs

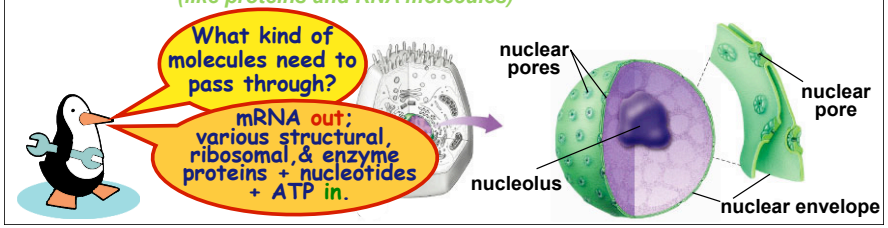


Nucleus

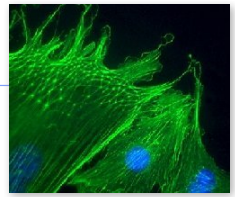
- Function
  - protects DNA
- Structure
  - nuclear envelope
    - double membrane
    - membrane fused in spots via proteins to create protein-based pores
      - pores allow large macromolecules to pass through *(like proteins and RNA molecules)*



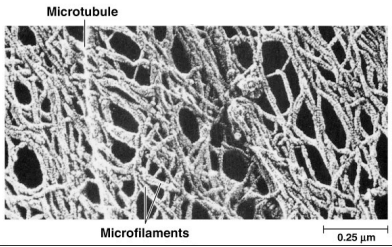
DNA in eukaryotes is wrapped around proteins. The DNA and associated proteins is called chromatin.



Cytoskeleton

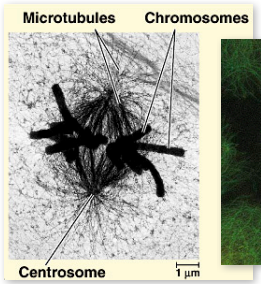


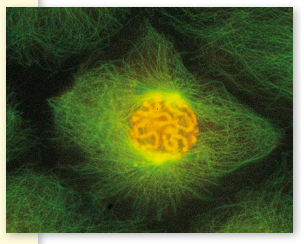
- Function
  - structural support
    - Maintains shape of cell
    - Provides anchorage for organelles
      - made up of protein fibers
        - microfilaments, intermediate filaments, microtubules
  - motility
    - Vesicle movement inside cell
    - Cell locomotion
      - via cilia, flagella, etc.
  - regulation
    - Organizes structures & activities of cell
    - Relays external signals to the cell's interior

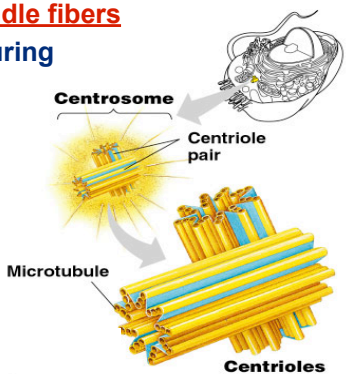


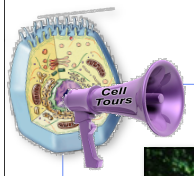
Centrosomes

- Play role in Cell division
  - In animal cells, pair of centrioles in the centrosome region (the "microtubule organizing center") organize and build microtubules
    - Microtubules form the spindle fibers
      - guide chromosomes during mitosis (& meiosis)









End of the Tour

Getting the right stuff - MITOSIS

- **What is passed on to daughter cells?**
  1. **An exact copy of genetic material = DNA**
     - **How? Via Mitosis**
       - The division of nucleus
       - Daughter cells made are genetically **IDENTICAL** *(each have the exactly same DNA sequences to each other)*
         - **Meiosis** is a special kind of cell division resulting in daughter cells that are **NOT** genetically identical
  2. **Organelles, cytoplasm, cell membrane, enzymes, cytosol solutes etc…**
     - **How? Via Cytokinesis**
       - Division of cytoplasm and components

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

Types of cells

SOMATIC CELLS: All the cells of a eukaryotic organism except for reproductive ones

- Every eukaryotic species have a characteristic number of chromosomes in each cell nucleus.
  - Humans = 46 chromosomes per cell
    - Two sets of 23
      - One set from each parent

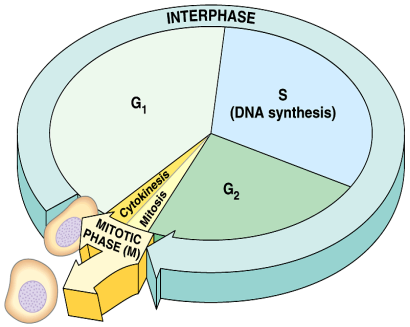
GAMETES: Reproductive cells

- Half as many chromosomes as somatic cells
  - Ex: Sperm and Egg in humans (23 chromosomes)

The Cell Cycle

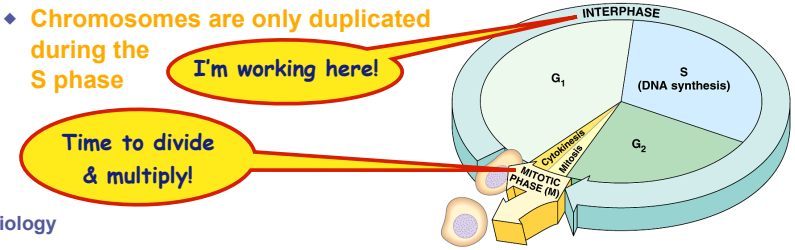
- **Cell Cycle** = The life of a cell form the time it is first formed from a dividing parent cell until its own division into two cells.

  - **Two main phases**
    - **Interphase:**
      - Composed of G_1, S, G_2 sub-phases (G_0 for some cells too)
    - **Mitotic (M):**
      - Composed of Mitosis and Cytokinesis



Interphase

- 90% of cell life cycle.
- Composed of three sub-phases
  - 1. First Gap "G_1" 2. Synthesis "S" 3. Second Gap "G_2"
- Cell doing its "everyday job" & working
  - produce RNA, synthesize specific proteins/enzymes
- During this phase (G_1, S, G_2) the cell grows
- During this phase the cell may prepare for duplication if triggered to do so
  - Chromosomes are only duplicated during the S phase

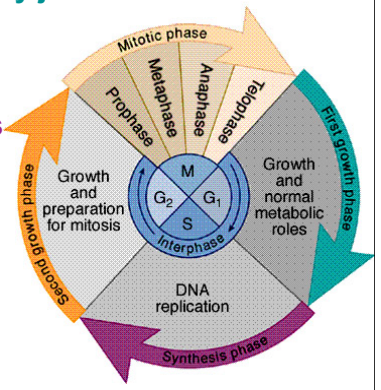


The 3 phases of Interphase

- G_1 = 1st Gap (Growth)
  - cell doing its "everyday job"
  - cell grows
- S = DNA Synthesis
  - copies chromosomes
- G_2 = 2nd Gap (Growth)
  - prepares for division
  - cell grows (more)
  - produces organelles, proteins, membranes

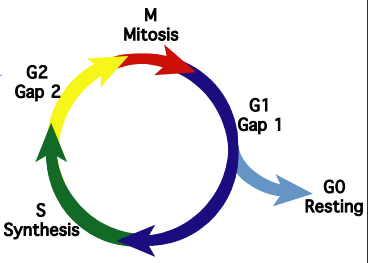
G_0

if gets signal to divide



A "resting state" exists in some cells = G_0 (an extended G1 state)

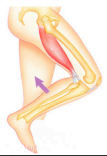
- Cell has a "life cycle"



cell is formed from a mitotic division

- cell grows & matures to divide again
  - G_1, S, G_2, M
  - epithelial cells, blood cells, stem cells
- cell grows & matures to never divide again
  - $G_1 \rightarrow G_0$
  - brain / nerve / muscle cells (permanently in G_0)

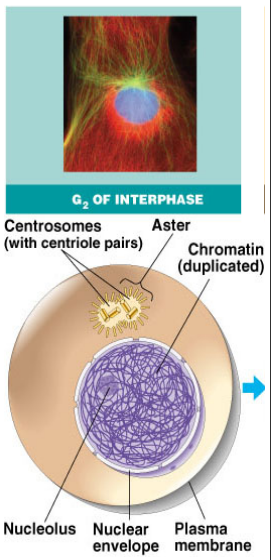
liver cells (cells that can get out of G_0) $G_0 \rightarrow G_1$



During Interphase...

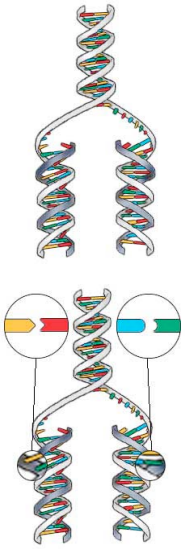
green = key features

- Nucleus is well-defined - DNA loosely packed in long chromatin fibers
  - Chromatin = A complex of DNA & histone proteins
    - Part of the chromatin that is being expressed in order to make RNA and proteins (where genes are 'ON') = euchromatin
    - Part of the chromatin that is not being expressed (where genes are 'OFF')= heterochromatin
  - Histone Protein Function
    - Involved in condensation and compaction of chromatin into chromosomes
    - Maintaining the shape of chromosomes
    - Controlling the activity of genes (on or off)
- If cell given the message, it prepares for mitosis during interphase too.
  - During S phase, the cell replicates "chromatin"
  - During G2 phase, the cell produces proteins & organelles needed during and right after M phase *(when the cell will physically divide)*



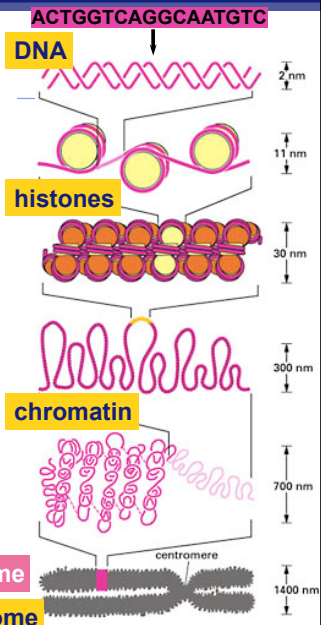
S phase: Copying / Replicating DNA

- "Synthesis" phase of Interphase
  - dividing cell replicates DNA
  - after DNA is replicated, the cell must separate the DNA copies correctly into two daughter cells
    - human cell duplicates ~3 meters DNA
    - each daughter cell gets complete identical copy of all DNA *(each daughter cell in humans gets 46 chromosomes)*
    - eukaryotic cell error rate = ~1 per 100 million bases
      - 3 billion base pairs in mammalian genome
      - ~30 errors per cell cycle (in somatic "body" cells)
        - These errors are referred to as mutations = Changes in DNA nucleotide sequences



Organizing DNA

- During interphase, DNA is found as 'chromatin' (mesh work of diffuse double helical DNA molecules and proteins called histones)
  - When the cell is not dividing, each chromosome is in the form of a long , thin chromatin fiber.
    - wrapped around histone proteins like thread on spools
- During S phase, each DNA molecule is duplicated
- During the end of Interphase & early M phase, chromatin becomes even more densely coiled and folded, making a structure called a chromosome which is much thicker and shorter (and visible under a light microscope)

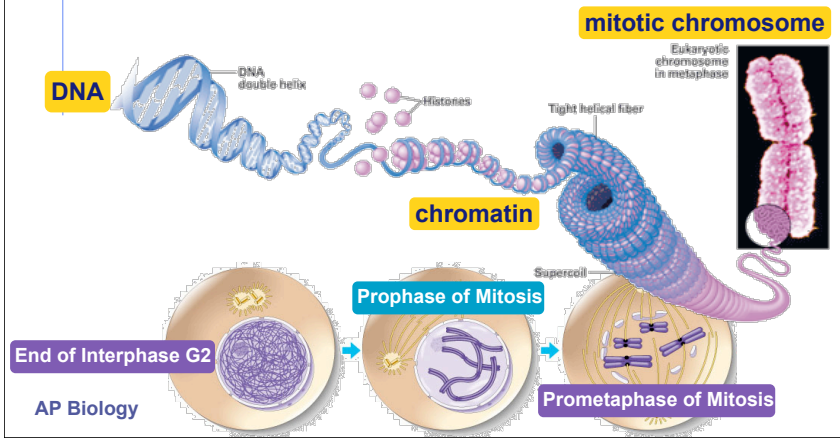


double stranded chromosome

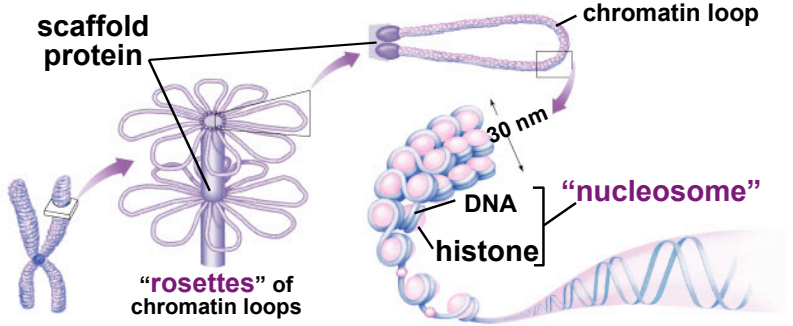
= duplicated mitotic chromosome

Copying DNA & packaging it for division

- After DNA duplication, during late G_2 phase, chromatin starts to condense
  - coiling & folding to make a smaller easy-to-move package
- Chromosomes condense the most during mitosis (prophase specifically).



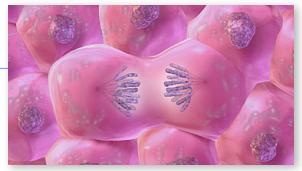
Chromosome formation



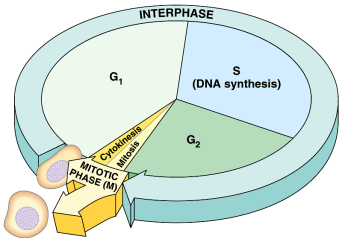
Rosettes loop (process called supercoiling) further making the final chromosome structure

double-stranded mitotic human chromosomes

Mitotic (M) phase



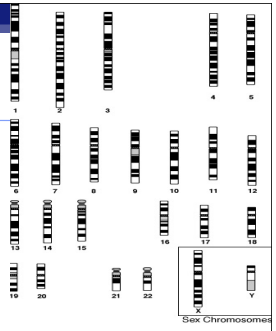
- Shortest phase of the cell cycle.
  - Cell not performing normal working activities during this phase
  - Genes are off
  - Cell is busy actively dividing its contents into two daughter cells
- M (Mitotic) Phase Divided into two phases:
  - I. Mitosis: division of the nucleus
    Divided into sub-phases:
    1. prophase
    2. metaphase
    3. anaphase
    4. telophase
  - II. Cytokinesis: division of the cytoplasm

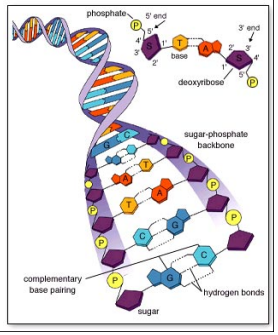


Chromosome Terminology

Sexually reproducing organisms inherit one copy of each type of chromosome from each of two parent.

- Humans have two sets of 23 of UNDUPLICATED chromosomes *(in cells in G1 of interphase).*
  - Each chromosome, each "one" molecule of DNA, is made up of a double helix of two DNA polymer strands
    - In double-stranded DNA, the two strands of DNA are hydrogen bonded together through the nitrogenous bases, making one unduplicated DNA molecule or "chromosome"
- One set of chromosomes is inherited from each parent, making 46 total separate chromosome per cell

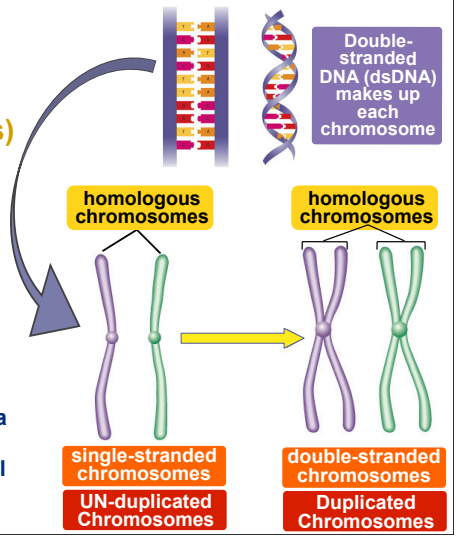




Chromosome Terminology

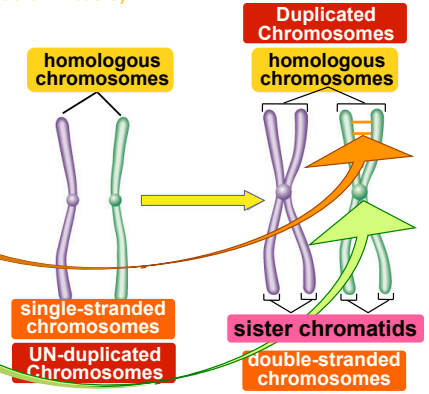
homologous = "same information"

- The matching pairs (one from each parent) are called homologous chromosomes (homologs)
  - Homologs have the same length, same centromere position, and genes for the same inherited characteristics
    - Each homologous chromosome duplicates separately during the S phase of interphase
    - Each homolog becomes a duplicated chromosome made up of TWO identical copies of dsDNA.



Chromosome Terminology

- Chromatid: one of the two DNA copies of a duplicated chromosome
- Sister Chromatids: the two chromatids that make up one chromosome (They become individual chromosomes only when they separate from each other during anaphase of mitosis)
  - Each contains identical copies of the original DNA molecule or double helix
  - Sister chromatids are attached along their lengths by proteins called cohesins
- Centromere: the region where the two chromatids are most closely attached.
  - An Arm of a chromatid = The region on either side of the centromere



Mitotic Chromosome

- Duplicated chromosome:
  - Consists of 2 sister chromatids
  - Still considered 1 chromosome
    - Contains 2 DNA molecules in total
    - Each chromatid contains 1 DNA molecule