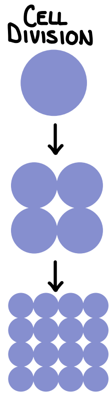
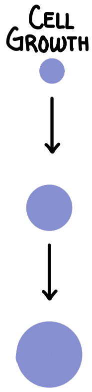
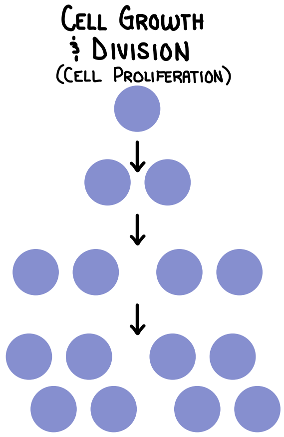
# Chapter 3 ~ The Cell Cycle & Mitosis

## Introduction:




Cell division is a process by which a parent cell divids into TWO OR MORE daughter cells
- Usually occurs as part of the Cell Cycle

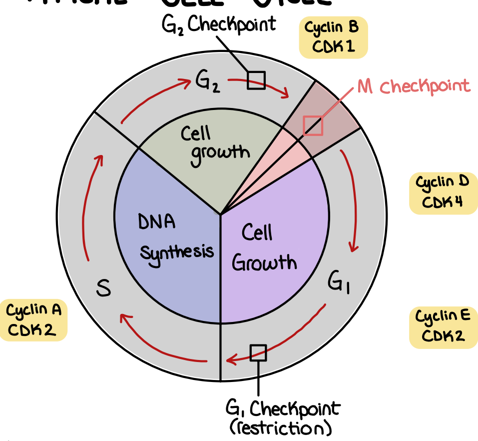



In Eukaryotes
- There are Two distinct types of cell division
  1. Cell Division
     - A vegetative division whereby each daughter cell is genetically IDENTICAL (mitosis) to the parent
  2. Reproductive Cell Division
     - The number of chromosomes in the daughter cells is reduced by half to produce haploid gametes (meiosis)

*Cell division and division is ESSENTIAL to asexual reproduction & the development of multicellular organisms & the transmission of genetic information is accomplished in the cellular process of mitosis
- This process ensures that a cell division occurs, with each daughter cell inheriting identical genetic material

## Typical Cell Cycle

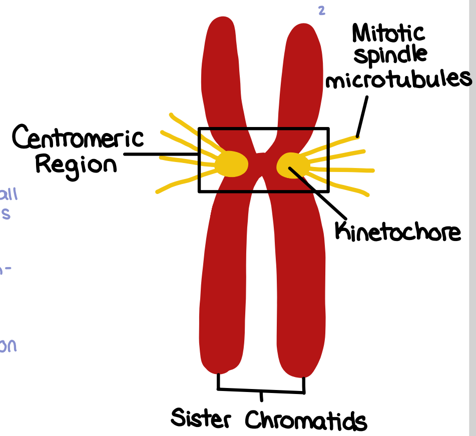



The cell cycle is the repeating pattern of cell growth (increase in size), followed by nuclear and THEN cytoplasmic division (splitting of one cell to produce IDENTICAL daughter cells in mitosis, or to produce UNIQUE gametes in meiosis)

*Many varient of the generalized cell cycle also exists
- Cells undergoing meiosis do NOT usually have a G phase

ex: Hematopoietic stem cells, found in bone marrow & produce all the other blood cells, will consistently go through these phases as they are constantly replicating. Other cells, as in the nervous system, will no longer divide. These cells NEVER leave $G_1$ phase and are said to enter a PERMENANT, non-dividing stage ($G_0$)

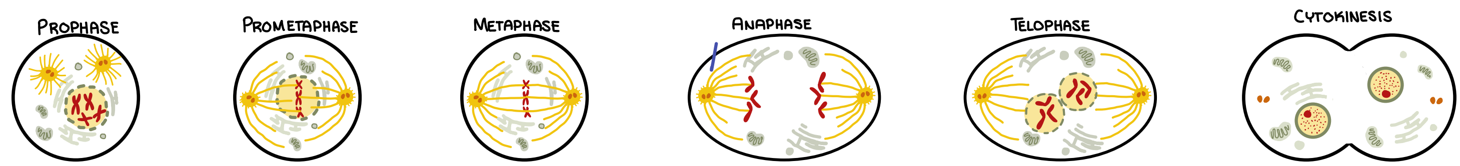
ex: cells in larval tissue in Drosophila, undergo MANY rounds of DNA synthesis (S) without ANY mitosis / cell division leading to endoreduplication




### 4 Stages of the Cell Cycle:

1. Gap ($G_1$)
   - First part of interphase
   - This is where the cell does its NORMAL cellular functions & grows in size - particularly AFTER meiosis when the daughters are HALF the size of the mother cell
2. Synthesis (S)
   - Each chromosome is replicated
   - Though chromosomes are NOT condensed yet, becaus S phase is still part of interphase, they are replicated as TWO sister chromatids attached at the centromere
3. Gap 2 ($G_2$)
   - Second lag phase
   - Cell continues to grow & acquire the proteins necessary for cell division
   - Various checkpoint are called cyclins
     - Family of proteins that control the progression of a cell through the cell cycle by activating cyclin-dependent kinease enzymes / group of enzymes, required for synthesis
4. Mitosis or Meiosis
   - When the cell undergoes cell division

## Steps of Mitosis




**Prophase**
- Chromosomes condense & become visible
- Spindle fibers emerge from the centrosomes
- Nuclear envelope breaks down
- Centrosomes move towards opposite poles

**Prometaphase**
- Chromosomes continue to condense
- Kinetochores appear at centromeres
- Mitotic spindle microtubules attach to kinetochores

**Metaphase**
- Chromosomes are lined up at the metaphase plate
- Each sister chromatid is attached to a spindle fiber originating from opposite poles

**Anaphase**
- Centromeres split in 2
- Sister chromatids (now called chromosomes) are pulled toward opposite poles
- Certain spindle fibers begin to elongate the cell

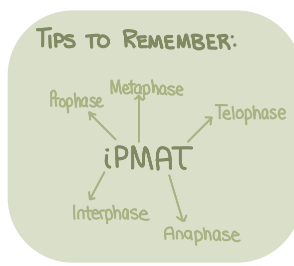
**Telophase**
- Chromosomes arrive at opposite poles and begin to decondense
- Nuclear envelope material surrounds each set of chromosomes
- Mitotic spindle breaks down
- Spindle fibers continue to push poles apart

**Cytokinesis**
- Animal cells
  - A cleavage furrow seperates the daughter cells
- Plant cells
  - A cell plate, the precursor to a new cell wall, seperates the daughter cells

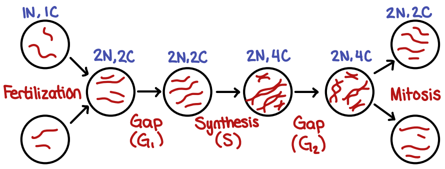
### S phase of Interphase
- Chromosomes replicate
  - Has 2 sister chromatids attached at the centromere

### Importance & Significance of Mitosis
- Keep chromosome number constant
- Maintains genetic stability in daughter cells
- Helps in growth & development of the zygote
- Helps in repair & regeneration
- Restores nucleo-plasmic ratio
- Checks cell size & maintains a favourable surface area/volume ratio

### How Mitosis Helps Maintain Genetic Stability
- Mitosis results in the splitting of replicated chromosomes during cell division & facilitates the generation of two new identical daughter cells.
- Given that chromosomes form from parent chromosomes by making exact copies of their DNA, mitosis helps in preserving and maintaining the genetic stability of a particular population



# Amount of DNA & Number of Chromosomes




Amount of DNA within a cell changes during the above events

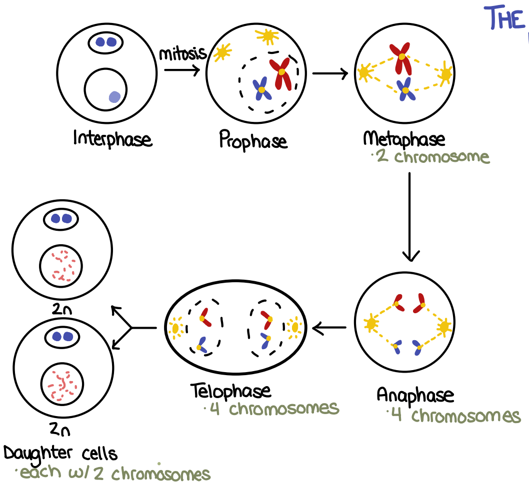
- "C" represents the DNA content in a cell
- "N" represents the number of COMPLETE sets of chromosome

**Haploid Gamete (Sperm/Egg)**
- Amount of DNA = 1c
- # of chromosomes = 1n

**Upon Fertilization**
- Amount of DNA = 2c
- # of chromosomes = 2n

**DNA Replication**
- Amount of DNA = 4c
- # chromosomes = 2n

**Mitosis**
- Amount of DNA = 2c
- # of chromosomes = 2n




## The C-Value of the Nuclear Genome

- The complete set of DNA w/in the nucleus of any organism is called it's nuclear genome and is measured as the C-value in units of either the number of basepairs or picograms of DNA
- There is a general correlation b/w the nuclear DNA content of a genome AND physical size / complexity of an organism

### Exceptions

- Human genome contains only $3.2 \times 10^9$ DNA bases while wheat genome contains $17 \times 10^9$ DNA bases

Thats NEARLY SIX times as much

## C-Value Paradox

- Can be explained by the fact that not all nuclear DNA encods genes — much of the DNA in larger genomes is non-gene coding
- Many organism's genes are seperated from each other by long stretches of DNA that do NOT code for genes or any other genetic info
- Much of this "non-gene" DNA consists of transposable elements of various types, which are an interesting class of self-replicating DNA elements
- Other non-gene DNA includes short, highly repetitive sequences of various types. Together, this non-functional DNA is often referred to as "Junk DNA"

| Organism | DNA content (Mb, 1c) | Estimated Gene # | Average Gene density | Chromosome # (1N) |
|---|---|---|---|---|
| Homo sapiens | 3,200 | 25,000 | 100,000 | 23 |
| Mus musculus | 2,600 | 25,000 | 100,000 | 20 |
| Drosophila melanogaster | 140 | 13,000 | 9,000 | 4 |
| Arabidopsis thalian | 130 | 25,000 | 4,000 | 5 |
| Caenorhabditis elegans | 100 | 19,000 | 5,000 | 6 |
| Saccharomyces cerevisiae | 12 | 6,000 | 2,000 | 16 |
| Escherichia coli | 5 | 3,200 | 1,400 | 1 |

## Number of Chromosome (n-Value)

- Sperm → 1n = 23
- Egg → 1n = 23
- Sperm + Egg = Zygote
- Zygote → 2n = 46

| Human Cell | Chromosome # |
|---|---|
| Gamete | 1n = 23 |
| R.C before S | 2n = 46 |
| R.C after S | 2n = 46 |

*R.C = regular cell

** # of chromosomes DOES NOT change w/ DNA replication
- Replicated chromosome is still one chromosome
- Zygote stays 2n = 46 after S phase
  - When it divids both resulting cells = 46 chromosomes and are still 2n = 46

## The Onion Test:

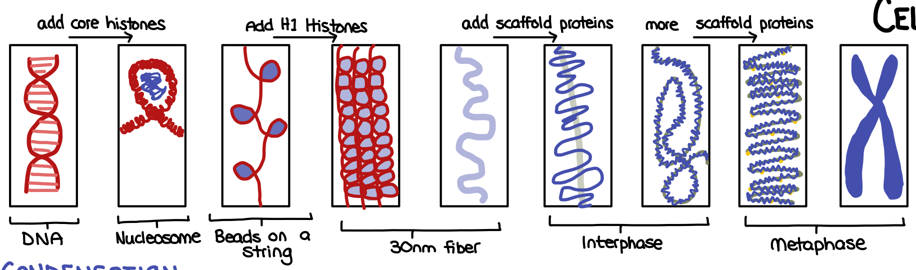
- Deals with any proposed explanation for the function(s) of non-coding (Junk) DNA
- For any proposed function for the excess of DNA in eukaryote genomes (c-value paradox), can it explain why an onion needs about five times more non-coding DNA for this function than a human?
  - The onion has a haploid genome size of ~17pg, while humans have only ~3.5pg
  - Why?
    - ↳ Onion species range from 7 to 31.5pg, so why is there this range of genome size in organisms of similar complexity?

To calculate...
- Human genome = 3000 million base pairs
  - ↳ Shorten to 1c = 3000 Mb
- Egg + Sperm = Zygote
  - ↳ 2n = 6000 Mb
  - ↳ Can divid into 2 cells but MUST have gone through DNA replication
    - Doubles DNA content so... 4c = 12 000 Mb

When zygote DOES ÷ ...
- Each daughter cell inherits ½ the DNA meaning it goes to 2c = 6000 Mb
- Cells then go through replication they become 4c = 12000 Mb

| Human Cell | DNA content |
|---|---|
| Gamete (egg or sperm) | 1c = 3000 Mb |
| Regular cell before S phase | 2c = 6000 Mb |
| Regular cell after S phase | 4c = 12 000 Mb |

# Appearance of a Typical Nuclear Chromosome During the Cell Cycle

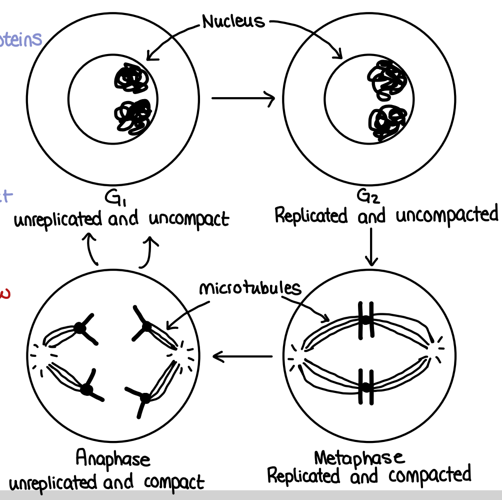



## Condensation

- Eukaryotic DNA is always wrapped around some proteins
- During interphase, a chromosome exists mostly as a 30nm fibre
  - Allows it to fit inside the nucleus and still have the DNA accessible for enzymes performing RNA synthesis, DNA replication, and DNA repair
- At the start of mitosis these processes halt & the chromosome further condense
  - Necessary so that the chromosomes are compact enough to move to opposite ends of the cell
- When mitosis is complete the chromosomes returns to its 30nm fibre structure

Typical chromosome in a human cell alternates b/w
- unreplicated & replicated states
- uncondensed & condensed states

If a cell has made the comitment to divide, if first needs to replicate it's DNA
- Occurs in S phase
- Before S phase chromosome consist of a single piece of double stranded DNA & after they consist of 2 identical double stranded DNA molecules




# Compare & Contrast

| Cell process | Mitosis | Meiosis |
|---|---|---|
| Creates | All the cells in your body except sex cells | Sex cells ONLY; ♀ egg cells & ♂ sperm cells |
| Definition | Process of cell division that forms two new cells (daughter cells) each of which has the same # of chromosomes | Process in cell division during which 4 new cells are created each w/ ½ the original # of chromosomes which results in the production of sex cells |
| End products | 2 daughter cells | 4 daughter cells |
| Steps | Interphase, prophase, Metaphase, Anaphase, Telophase | Interphase, prophase I, Metaphase I, Anaphase I, Telophase I, prophase II, Metaphase II, Anaphase II, Telophase II |
| Type of Reproduction | Asexual | Sexual |
| Identical to parent cell | Yes, they are identical | No, they are different since they have ½ the #'s of chromosomes as the original |
| When does cytokinesis occur? | In Telophase | In Telophase I & II |
| # of divisions for parent | 1 | 2 |
| # chromosomes compared to parent & in pairs or individual | Identical to parent; individual chromosome | ½ as parent; individual chromosome |
| Importance | Needed to repair damaged body, create new body cells, for growth & to replace cells that have died | Need to create sex cells required for sexual reproduction to create a new organism & for variation within a population |
| # of Chromosomes | 46 | 23 |