Mitosis and Meiosis

Chromosome Structure

- **Homologous pair of chromosomes
    - Have the same size, shape, centromere position and staining pattern
    - Carry same genes at corresponding loci on both members of a homologous pair
    - 1 homologue from mother, 1 homologue from father ⇒ Genetically different ⇒ May have different alleles at the same locus

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    - Pair up to form bivalents via synapsis during prophase 1 during meiosis
- When not dividing, chromosomes exist in uncondensed form as long, thin, thread-like fibres called chromatin
- Chromatin = DNA + histone proteins
    - Nucleosomes = DNA + 8 histone proteins
- Chromosome
    - When dividing → Condensed form: Condensed, tightly coiled and folded chromatin that appears as short, thick structures
    - When not dividing → Uncondensed form: Mass of long, thin thread like fibres of chromatin
- Chromatids = 1 DNA molecule
    - 2 chromatids held together at centromere
- Sister chromatids = Genetically-identical DNA molecules (result of semi-conservative replication)
- Alleles = Alternative forms of a gene occupying the same locus on homologues

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Mitosis

X = amount of DNA per cell (diploid number)
Y = no. of chromosomes per cell

Interphase

1. Gap phase 1
    - Organelle synthesis
    - RNA synthesis
    - Protein synthesis
    - ATP synthesis
2. Synthesis phase
    - DNA strands replicate via semi-conservative replication
        - DNA content doubles
3. Gap phase 2
    - Organelle synthesis

        - Centrosome replicates to form 2 centrosomes each containing a pair of centrioles
    - Synthesis of spindle protein
    - ATP synthesis
    - Microtubules begin to form
    - Chromosomes begin to condense

- Summary:
    1. Organelle synthesis during G1 and G2 phases
    2. DNA replication during S phase

Prophase (**P**rominent) [2X/2Y]

1. Chromatin threads condense into chromosomes
2. Centrioles migrate to opposite poles (in animal cells)
3. Spindle fibres extend from each centriole to kinetochores and metaphase plate
4. Nuclear envelope disintegrates
5. Nucleolus disappears

Metaphase (**M**eet at equator) [2X/2Y]

1. Kinetochore microtubules align chromosomes at equator in one row
    - Kinetochore microtubules shorten while centromeres do not divide, causing the poles to get pulled in
2. Kinetochore microtubules from both poles are attached to centromere of chromosome with 2 sister chromatids

Anaphase (Move **A**part) [2X/4Y]

1. **Centromeres** of each chromosome divide and **sister chromatids** separate
2. **Kinetochore microtubules** shorten and pull sister chromatids, now called daughter chromosomes, to opposite poles led by their centromeres
3. Non-kinetochore microtubules elongate and slide pass each other causing the 2 poles to move further apart

Telophase (**T**he end) [2X/4Y]

1. Chromosomes uncoil into chromatin threads
2. Spindle fibres disintegrate
3. Daughter nuclei have diploid set of chromosomes
4. Nuclear envelope reforms around chromosomes at each pole and nucleoli reappear

Cytokinesis [X/2Y]

- Animals
    1. Cell membrane <u>invaginates</u> towards the middle, forming a **cleavage furrow** until the cell membrane fuses and separate the 2 daughter cells
- Plants
    1. Golgi apparatus produces a number of Golgi vesicles which move to equator and coalesce to form cell plate
    2. Contents of vesicles converted to pectin and cellulose, which contribute to middle lamella and cell wall matrix respectively, of the daughter cells while the membranes of the vesicles form the cell surface membrane of the daughter cells
    3. Cell plate fuses with parent cell wall and cell membrane, separating the 2 daughter cells

Significance of Mitosis

1. Maintain genetic stability
    - During <u>S phase of interphase</u>, **semi-conservative replication** of DNA occurs → Both strands of parental DNA act as **templates** for the synthesis of the complementary strand through <u>complementary base pairing</u> ⇒ Produces 2 genetically identical DNA molecules
    - During <u>metaphase</u>, genetically identical sister chromatids are attached to microtubules from either pole and chromosomes align singly at equator
    - During <u>anaphase</u>, centromere divides and microtubules shorten ⇒ Genetically identical sister chromatids are separated and move to opposite poles ⇒ Ensures even distribution of DNA in the daughter cells ⇒ Daughter cells contain the <u>same number and type of chromosomes</u> with the same alleles as parental cells ⇒ Daughter cells are <u>genetically identical to the parents</u> with no genetic variation
2. Growth
    - Allows for an increase in number of genetically identical cells in a multicellular organism ⇒ Increase in size and mass leading to growth of the organism
3. Regeneration and cell replacement
    - <u>Replace damaged cells</u> with genetically identical cells and hence <u>repair tissue</u>
    - Replace lost parts of an organism (e.g. lizard's tail)
4. Asexual reproduction
    - Allows single parent to produce offspring genetically identical daughter cells which are <u>clones</u> of itself
    - Advantageous in stable environments so that offspring are already adapted to the same environment that their parent has thrived in
    - Can reproduce very rapidly ⇒ Colonisation of the habitat

Meiosis
<u>Interphase</u>

- Organelle synthesis during G1 and G2 phases

- DNA replication during S phase

Prophase 1 [2X/2Y]

1. Chromatin threads coil into condense chromosomes
2. **Homologous chromosomes pair up via **synapsis** to form bivalents
3. ****Crossing over** occurs between non-sister chromatids of homologous chromosomes at chiasmata
4. **Corresponding segments exchange genetic material to form non-identical sister chromatids
5. Centrioles migrate to opposite poles
6. Spindle fibres extend from each pole to kinetochores and metaphase plate
7. Nuclear envelope disintegrates
8. Nucleolus disappears

Metaphase 1 [2X/2Y]

1. **Kinetochore microtubules align homologous chromosomes at equator in **two** rows
2. Centromere of each chromosome attached to kinetochore microtubule from only one pole
3. ****Independent assortment of homologous chromosomes** at equator where the orientation of chromosomes of each bivalent is completely independent of the orientation of the other bivalents

Anaphase 1 (Move **A**part) [2X/2Y]

1. **Kinetochore microtubules shorten and pull **homologues** to opposite poles led by their centromeres
    - Centromeres do NOT divide
2. Non-kinetochore microtubules elongate causing the 2 poles to move further apart

Telophase 1 (**T**he end) [2X/2Y]

1. Chromosomes uncoil into chromatin threads
2. Spindle fibres disintegrate
3. Each pole has haploid set of chromosomes
4. Nuclear envelope reforms and nucleoli reappear

Cytokinesis [X/Y]

- Same as mitosis
- In some cells, cytokinesis and telophase 1 are skipped, entering prophase 2 directly from anaphase 1

Prophase 2 [X/Y]

- Chromatin threads coil into condensed chromosomes
- Centrioles migrate to opposite poles (in animal cells)
- Spindle fibres extend from each pole to kinetochores and metaphase plate
- Nuclear envelope disintegrates
- Nucleolus disappears

Metaphase 2 [X/Y]

- Kinetochore microtubules align chromosomes at equator in one row
- **Random orientation of non-identical sister chromatids** of each chromosome at equator due to crossing over during prophase 1

Anaphase 2 (Move **A**part) [X/2Y]

- **Centromeres** of each chromosome divide and **sister chromatids** separate
- **Kinetochore microtubules** shorten and pull sister chromatids, now called daughter chromosomes, to opposite poles led by their centromeres
- Non-kinetochore microtubules elongate and slide pass each other causing the 2 poles to move further apart

Telophase 2 (**T**he end) [X/2Y]

- Chromosomes uncoil into chromatin threads
- Spindle fibres disintegrate
- Daughter nuclei have diploid set of chromosomes
- Nuclear envelope reforms around chromosomes at each pole and nucleoli reappear

Cytokinesis [½X/Y]

- Same as Mitosis
- Gives total of 4 haploid daughter cells

Significance of Meiosis/Reduction division

- Genetic Variation
    1. **Crossing over** between non-sister chromatids of homologous chromosomes during prophase 1
        - Homologous chromosomes pair up via synapsis to form bivalents
        - Corresponding segments exchange genetic material to form non-identical sister chromatids

    - Results in new combinations of alleles on chromosomes of gametes
2. <u>**Independent assortment of homologous chromosomes**</u> during metaphase 1 and their subsequent separation during anaphase 1
    - Orientation of chromosomes of each bivalent completely independent of the orientation of the other bivalents
    - Results in 2^n <u>different combinations of maternal and paternal chromosomes</u> in daughter cells where n is the number of chromosome pairs
3. <u>**Random orientation of non-genetically identical sister chromatids**</u> during metaphase 2 and subsequent separation during anaphase 2
    - Contributes to new combinations of alleles in gametes
4. During fertilisation, <u>**random fusion**</u> of large number of genetically different gametes produced during meiosis
    - Results in greater number of genotypic combinations of a zygote

- Maintenance of chromosome number in offspring in every generation
    - During meiosis (reduction division), 4 haploid gametes are formed from 1 diploid cell
    - During fertilisation, 2 haploid gametes, a sperm and an egg, fuse to produce a diploid zygote resulting in restoration of chromosome number
    - Chromosome number in a species is kept constant after every generation
    - Gives rise to variation in offspring
        - In achieving haploid number, independent assortment and crossing over occur (add details)
        - Allows for random fusion of gametes during sexual reproduction, giving rise to variation in the offspring

	Mitosis	Meiosis
Change in no. of chromosomes	Start: 2n <u>**x2**</u> at start of <u>**anaphase**</u> <u>**÷2**</u> after <u>**cytokinesis**</u> End: 2n	Start: 2n <u>**÷2**</u> after <u>**cytokinesis**</u> of meiosis 1 <u>**x2**</u> at start of <u>**anaphase 1**</u> End: 2n <u>**÷2**</u> after <u>**cytokinesis**</u> of meiosis 2 End: n
Change in amount of DNA	Start: x <u>**x2**</u> during <u>**S phase**</u> of interphase <u>**÷2**</u> after <u>**cytokinesis**</u> End: x	Start: x <u>**x2**</u> during <u>**S phase**</u> of interphase 1 <u>**÷2**</u> after <u>**cytokinesis**</u> of meiosis 1 End: x <u>**÷2**</u> after <u>**cytokinesis**</u> of meiosis 2 End: ½x

	Mitosis	Meiosis
Location and cell type	Somatic cells in all parts	Precursor sex cells in reproductive organs that give rise to gametes
No. of nuclear divisions	1	2
Prophase	No synapsis No chiasma formation No crossing over of non-sister chromatids of homologous chromosomes	For Prophase I: Synapsis occurs where homologous chromosomes pair up to form bivalents Crossing over of non-sister chromatids of homologous chromosomes
Metaphase	Chromosomes align in a single row on equator Each centromere attaches to spindle fibres from both poles	For Metaphase I: Homologous chromosomes align in pairs at equator Centromeres of each chromosome attaches to spindle fibre from only one pole
Anaphase	Separation of centromere Separation of identical sister chromatids	For Anaphase I: No separation of centromere Separation of homologous chromosomes For Anaphase II: Separation of non-identical sister chromatids
Telophase	2 daughter nuclei which are genetically identical and have diploid set of chromosomes	Telophase I: 2 daughter nuclei which are genetically different and have haploid set of chromosomes Telophase II: 4 daughter nuclei which are genetically different and have haploid set of chromosomes

Result of nuclear division	2 genetically identical daughter cells formed No variation occurs Daughter cells have same number of chromosomes as parental cells ⇒ Replicative division	4 genetically different daughter cells formed Genetic variation occurred Daughter cells have half the number of chromosomes as parental cells ⇒ Reductive division