Unit 3 – Heredity and Continuity of Life

// Biology ATAR - Mark Weldon //

DNA STRUCTURE AND REPLICATION

genetics: the study of the mechanisms and patterns of inheritance through transmission of coded chemical instructions from one generation to the next.

DNA: common genetic material, carries information coded in genes.

→ differences in connections/sequence determines different species

NUCLEIC ACIDS

RNA	DNA
One long strand of nucleotides.	Two long strands of nucleotides wound to form a double helix.
Functions in protein synthesis.	Encodes heritable information.
Ribose as sugar.	Deoxyribose as sugar.
Nitrogenous bases: adenine (A), uracil (U), guanine (G) and cytosine (C).	Nitrogenous bases: adenine (A), thymine (T), guanine (G) and cytosine (C).

Nucleic acids are composed of nucleotides:
- *5 carbon sugar;*
- *a negatively charged phosphate group;*
- *a nitrogenous base.*

NUCLEOTIDE STRAND

▪ sugar binds to phosphate

→ one phosphate is bound to a sugar 5th carbon; the next phosphate binds to its 3rd carbon.

→ strand runs from 5’ to 3’ (prime).

→ opposite occurs on the complimentary strand.

▪ hydrogen bonds hold strands together:

→ A bonds with T/U have 2 hydrogen bonds.

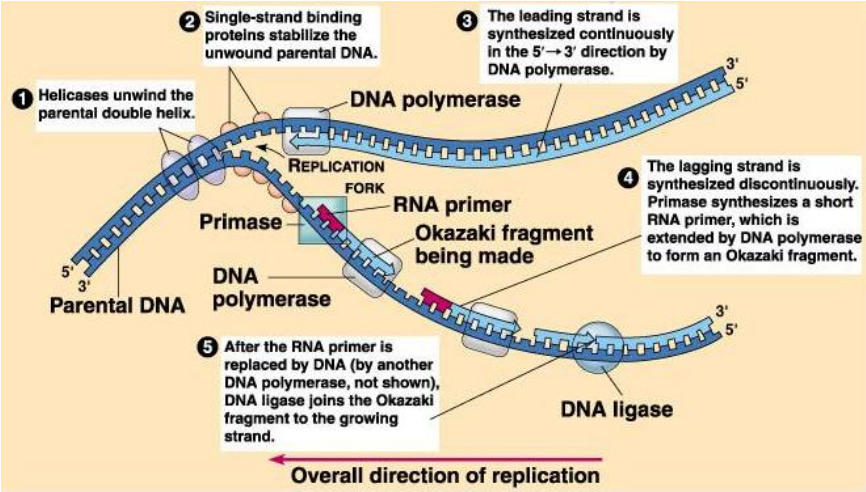
→ G bonds with C have 3 hydrogen bonds.

STAGES OF DNA REPLICATION

▪ DNA helicase ‘unzips’ the double helix by breaking hydrogen bonds.

▪ In the nucleus, free nucleotides attach to exposed bases, with help from DNA polymerase.

▪ DNA ligase seals new stretches into continuous strand that rewinds.



CELLULAR REPRODUCTION

▪ All cells originate from pre-existing cells.

▪ In **asexual reproduction**, offspring closely resemble and originate from one parent.

▪ In **sexual reproduction**, offspring originate from two parents (DNA from two sources), thus the difference from parents is greater.

CHROMOSOMES IN EUKARYOTIC CELLS

▪ DNA is found in the nucleus, *chloroplasts and mitochondria**.
▪ DNA is visible during replication and when stained (coiled around histone proteins).
▪ In the nucleus, all DNA and associated proteins are known as chromatin.
▪ One DNA molecule is known as a chromosome.

**DNA in mitochondria and chloroplasts are similar to plasmids in prokaryotes.*
plasmids: a linear or circular double-stranded DNA that is capable of replicating independently of the chromosomal DNA

KARYOTYPES

▪ chromosomes occur in pairs (one from each parents).
▪ karyotypes show pairs by ordering them by size and banding (ie. location of genes).

HUMAN CHROMOSOMES

▪ Species are characterised by number of chromosomes in each cell.
▪ Humans have 46 chromosomes, in 23 pairs.
→ 22 pairs are homologous autosomes (matching, regular cells).
→ 1 pair are sex chromosomes (XX – female, XY – male).
▪ Chromosomes in somatic cells are diploid (2n) and haploid in germ-line cells.

GENES IN EUKARYOTES

locus: the location of a gene along DNA; genes are found at the same loci in homologous chromosomes
allele: alternative forms of a gene
▪ diploid organisms have two alleles for each gene

CHROMOSOMES IN PROKARYOTIC CELLS

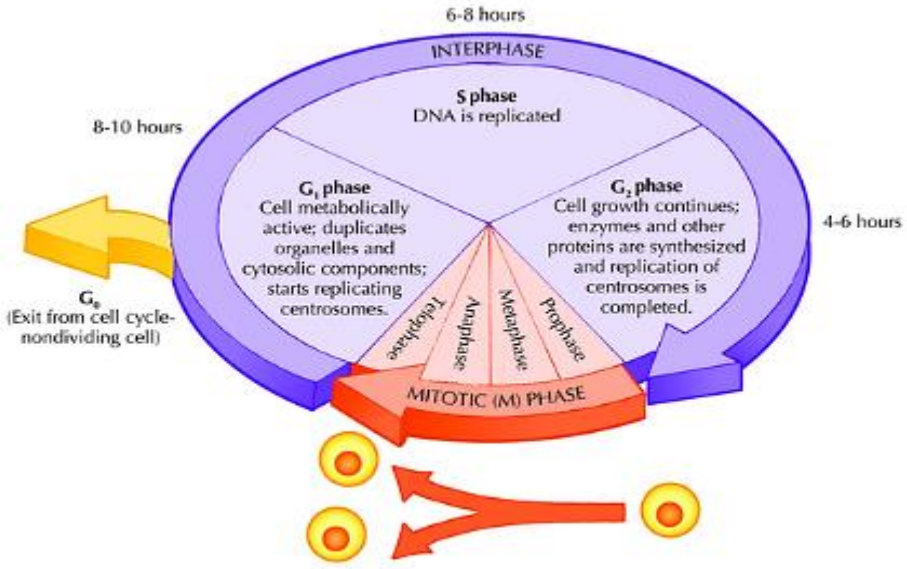
▪ DNA exists in a single, circular chromosome (region is referred to as a nucleoid).
→ No membrane bound organelles in prokaryotic cells.
▪ Chromosomes are in direct contact with cytoplasm and are connected to the cell membrane.
▪ Smaller rings of DNA (plasmids) are found around cytoplasm.
→ Code for non-essential genes.
→ Replicate independently of nucleoid.
→ Easily transferred between species.
▪ Generally, DNA supercoils in prokaryotic cells to fit.
▪ Prokaryotic cells are usually haploid, have little repetitive or non-coding DNA and do not have histones.

CELL DIVISION

▪ Eukaryotic cells pass on instructions via:
→ nuclear division in somatic cells (mitosis);
→ cytoplasmic division (cytokinesis).
▪ Results in two diploid identical daughter cells.

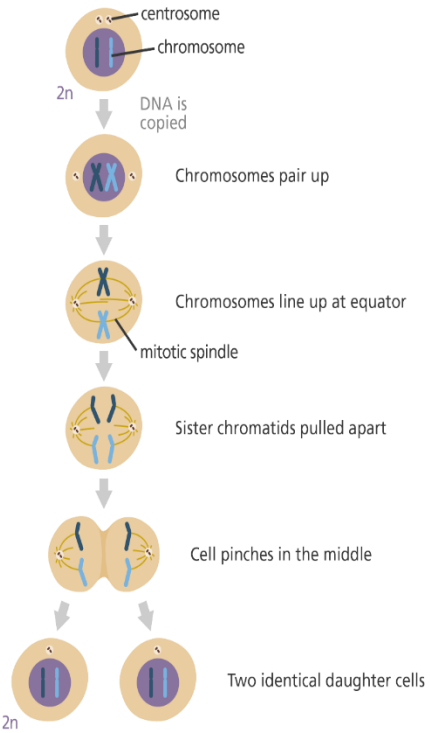
CELL CYCLE

cell cycle: the sequence of events from one division to the next
▪ The cell cycle varies in length according to the type of cell.
▪ Short cell cycles are common in areas with “wear and tear”.
▪ Cell cycle phases are identified by measuring the changes in cell volume/the amount of DNA.



STAGES OF MITOSIS

Interphase	▪ Chromosomes not visible. ▪ Right before mitosis, centrioles visible. → Chromatin threads become thicker and shorter.
Prophase	▪ Chromatin condense and become visible double strands (2 chromatids and 1 centromere). ▪ Spindle forms from centrioles. ▪ Nucleolus disappears. ▪ Nuclear membrane breaks down.
Metaphase	▪ Chromosomes line up at equator.
Anaphase	▪ Spindle fibres attach to centromere. ▪ They contract and pull chromatids apart. ▪ Chromatids move to opposite poles. → Now known as chromosomes again.
Telophase	▪ Chromosomes de-condense (less visible). ▪ New nuclear membrane forms. ▪ Nucleoli forms. ▪ Spindle fibres disassembles. ▪ Cytoplasm pinches in.
Cytokinesis	▪ Cell splits and results in 2 daughter cells.



CYTOKINESIS [PLANT CELLS]

▪ Cytoplasm divides by the formation of a cell plate in the middle of the cell.
→ Made by parts of cell wall fusing with parts of spindle.
→ Cellulose is then deposited forming a wall, which divides the parents cell into 2 daughter cells.

CYTOKINESIS [ANIMAL CELLS]

▪ Cytoplasm divides via cleavage.
▪ Plasma membrane around the middle of the cell draws together to form cleavage furrow.
→ continues to develop until it meets;
→ two daughter cells.
▪ Asymmetrical division sometimes occurs (unequal distribution of proteins).

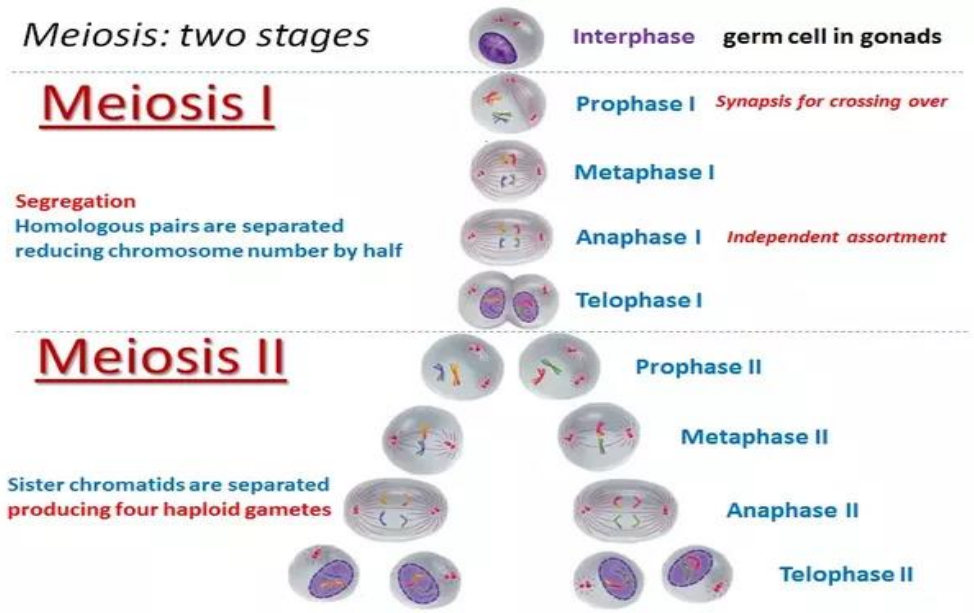
BINARY FISSION

▪ How prokaryotes reproduce, involves: DNA replication, chromosome segregation and cytokinesis.
▪ Results in two daughter cells with the same chromosomes:
→ DNA copies attach to two different parts of the membrane.

→ As the cell pull apart it splits the original chromosome.
→ A wall forms across the cell.
▪ This process occurs in mitochondria and chloroplast which divide independently of nuclear DNA.

MEIOSIS AND FERTILISATION
▪ Occurs in special organs resulting in the production of gametes.
▪ Prevents doubling up of DNA in the final product (zygote).
→ From one diploid (46) cell to four haploid (23) cells.
→ Named 'reduction division' as chromosomes numbers are reduced by half.

First Stage of Meiosis (Occurs in Parent Cell)	
Interphase I	▪ DNA replicates and is visible.
Metaphase I	▪ Chromosomes condense. ▪ Nucleolus disappears. ▪ Centrioles move to poles. ▪ Spindle forms.
Metaphase I	▪ Chromosomes move and line up along equator. ▪ Homologous chromosomes (maternal and paternal) form tetrads. ▪ Spindles form each pole attach to one homologous chromosome each. ▪ Crossing over may occur, leading to increased variation between offspring.
Anaphase I	▪ Homologous chromosomes split and are pulled to poles (disjunction). ▪ Each homologous pair divides independently of others.
Telophase I and Cytokinesis I	▪ Spindle breaks down. ▪ Cell starts to separate. ▪ Nuclear membrane reforms. ▪ Cells separate completely.
Second Stage of Meiosis (Occurs in 2 Separate Cells)	
Interphase II	▪ Break between meiosis I + II but no replication occurs.
Prophase II	▪ Nuclear membrane breaks down again. ▪ New spindles form.
Metaphase II	▪ Chromosomes move to equator (all in one line this time). ▪ Spindles attach to centromeres.
Anaphase II	▪ Chromatids split and move to poles. ▪ Now referred to as chromosomes again.
Telophase II an Cytokinesis II	▪ Cytoplasm begins to divide in both cells, spindles break down, nuclear membrane reforms and separate completely again.



Mitosis vs. Meiosis	
For growth, repair and replacement.	For production of gametes.
Occurs in somatic cells.	Occurs in germline cells (reproductive organs).
Results in 2 cells.	Results in 4 cells.
One cell division.	Two cell divisions.
Daughter cells contain diploid (2n) number of chromosomes.	Daughter cells contain haploid (n) number of chromosomes.
Process of reproduction for asexual organisms (binary fission).	For sexual reproduction.
No variation between daughter cells.	Variation between daughter cells.

CELL DEATH

apoptosis: programmed cell death, all cells have this programme and can activate it

▪ Cells do not divide forever.

▪ Failed apoptosis can lead to cancer.

PROTEINS AND ENZYMES

▪ Proteins are essential to cell structure and functioning.

▪ The structure and function of cells depend on the protein produced by it.

→ Specialised functions, highly suited to task.

▪ Enzymes are **biological catalysts** that speed up reactions without undergoing change themselves.

▪ Enzymes enable cellular metabolism (reactions) to occur at a rate that sustains life.

▪ Proteins are made up of amino acids (about 20 different amino acids).

▪ The order of amino acid determines proteins made.

TRANSCRIPTION

▪ RNA polymerase helps DNA unwind.

→ 2 strands of DNA are exposed, the template and non-template strands.

▪ RNA polymerase attached to a promoter region (TATA box) at the start of a gene and adds complimentary RNA nucleotides to template strand.

▪ Moves along strand until stop signal reached.

▪ mRNA (messenger RNA) released as a single strand.

▪ DNA zips up and rewinds.

mRNA EDITING

▪ pre-mRNA modified before it leaves nucleus.

→ methylated cap added to the 5’ end.

→ poly-A tail (lots of adenines!) added to the 3’ end.

▪ helps in stability, export and translation.

SPLICING

introns: regions of bases that do not code for essential amino acids.

exons: regions of bases that do code for essential amino acids.

▪ introns are removed via splicing.

→ spliceosomes ‘cut’ mRNA at ‘spurs’.

▪ exons remain and leave nucleus as mature mRNA.

ALTERNATIVE SPLICING

▪ Same mRNA strand can have different exons spliced together.

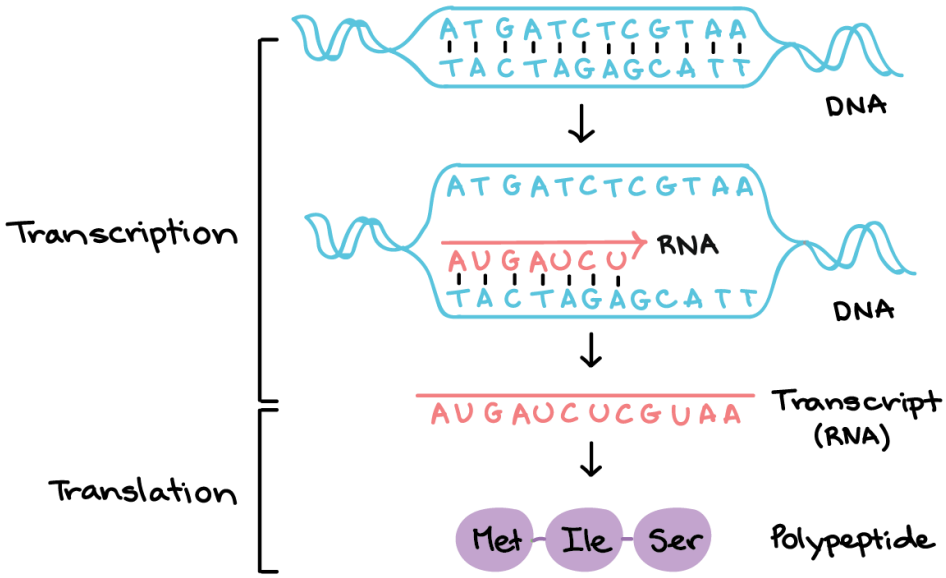
▪ Leads to different proteins.

Replication vs. Transcription	
Whole DNA molecule a template.	Small part of DNA used as a template.
Nucleotides added by DNA polymerase.	Nucleotides added by RNA polymerase.
Double-stranded DNA is product.	Single-stranded RNA is product.
Product found only in nucleus.	Product found in nucleus and cytoplasm.

TRANSLATION

translation: the process by which ribosomes synthesise polypeptides from mRNA made in transcription

▪ Once spliced, mRNA moves through the cytoplasm and attaches to ribosome at 5' methylated cap.
▪ Ribosomes are attached to the rough endoplasmic reticulum and are free in the cytoplasm.
▪ Ribosomes may occur in chains, allowing for large numbers of polypeptides to be produced.
▪ Ribosomes 'scan' mRNA for a start codon (AUG)
→ a **codon** is a triplet base pair.
▪ When a start codon is detected, transfer RNA (tRNA) attaches to mRNA
▪ tRNA has an anti-codon on one end and amino acids on the other.
▪ tRNA matches every consecutive codon with an anti-codon.
▪ Each time this occurs; a new amino acid is added to growing polypeptide strand via peptide bonds.
▪ This process continues until a stop codon is reached, tRNA then peels off.
▪ The amino acid strand releases as well as the tRNA strand and mRNA is broken down and releases free nucleotides into the cytoplasm.
▪ The majority of ATP produced by cells goes into this process.



GENE EXPRESSION

gene expression: gene is transcribed and translated into proteins

gene regulation: process in cells that enables genes to be expressed in specific cells at specific times

▪ All cells have the same DNA, but are different.
→ Cells don't all express of the genome at the same time.
→ Unneeded genes inactivate so energy isn't wasted when making unneeded proteins.
▪ DNA > RNA > Proteins, however, isn't always the case.
→ HIV produces DNA from RNA.
▪ Exons make 1% of the entire genome, yet 80% gets transcribed at one point.
→ Unknown what non-coding areas do.

nucleosomes: DNA double helix wound around histone proteins (chromatin).

▪ When wound tight, RNA polymerase cannot access genes (ie. the gene is 'turned off').

▪ When DNA is in open configuration (relaxed) RNA polymerase can access genes (ie. the gene is 'turned on').

DNA IN EUKARYOTES
▪ Most genes are switched off.
→ Only housekeeping genes are switch on.
→ Housekeeping genes make proteins for basic cellular function.

DNA METHYLATION AND GENE EXPRESSION
DNA methylation: when cytosine in DNA have methyl groups attached to them.
▪ Methyl groups stick out and block RNA polymerase.
▪ This attracts phosphates of DNA causing more condensing.
▪ Genes are then said to be "switched off".
▪ Genes are active if there is no methylation (or by the addition of acetyl).
▪ X in-activation occurs when methylation inactivates an X-chromosome in female mammals (e.g. tortoise shell cats).
▪ Imprinting occurs when methylation silences one of 2 alleles (e.g. Beckwith-Widemann syndrome)

PRODUCTS OF GENES AND GENE EXPRESSION
▪ Regulatory proteins can regulate gene expression.
▪ Transcription facts (TFs) are proteins that bind to DNA:
→ activators help DNA unwind (gene on);
→ repressors prevent RNA polymerase from binding (gene off);
→ are specific;
→ activators can also be repressors.

REGULATION OF TRANSLATION
▪ mRNA binding proteins attach (before AUG) and prevents translation.
▪ miRNA complement mRNA
→ Creates 2 stranded RNA which can't be translated.

ENVIRONMENTAL INFLUENCES
▪ Environment affects gene expression based on what is needed (e.g. Himalayan rabbits).
▪ Diets affect expression; some foods can cause DNA methylation (e.g. agouti mouse).

GENE EXPRESSION IN PROKARYOTES
▪ Most genes are turn on.
→ Repressed when transcription products not needed (e.g. e. coli and lactose/glucose)

ENVIRONMENTAL INFLUENCES ON BACTERIA
▪ Environment also affected prokaryotes (e.g. tryptophan and e. coli)
▪ When low, genes are activated and e. coli can produce its own tryptophan.
▪ When high, tryptophan binds to repressor, activates it and gene is turned off.
▪ This conserves energy.

VARIATION
▪ Differences exist between members of the same species (ie. intraspecific variation).
▪ Types of phenotypic variation includes: morphological, biochemical, physiology and behavioural.
▪ Each copy of a gene isn't always identical.
▪ The phenotype (physical expression) of a gene is affected by the genotype and the environment.

ALLELIC VARIATIONS

crossing over: the swapping over of sections of chromatid during metaphase I.
random assortment: random chance of which egg meets which sperm
non-disjunction: failure of chromosomes to separate properly during division.
▪ Mutations are the largest cause of variation in genes.

VARIATIONS IN CHROMOSOMES

▪ Alteration can occur in large sections of chromosomes. This can be seen in the karyotype.
▪ **Monoploidy** refers to a species having 1n instead of 2n chromosomes.
→ This is observed in many ants, wasps and bees.
→ Male have 1n and make sperm through mitosis; females, rather, have 2n.
→ Half of a male's genetic information lies dormant until fertilisation (female) or pathogenesis (male).
→ Monoploidy is more conservative but diploid organisms are more common because defective alleles can be masked be their second allele.
▪ **Polyploidy** refers to **triploids** (3n) and **tetraploids** (4n), which occurs when cell divisions fail to produce haploid gametes.
→ Common in plants and algae.
→ Polyploid organisms are associated with larger size and power but have reduced fertility.
→ This condition is lethal in humans.
▪ **Aneuploidy** refers to the loss of one or more chromosomes from the cell.
→ **Trisomy** (2n+1) refers to an extra chromosome whilst **monosomy** (2n-1) refers to the loss of a chromosome.
→ Miscarriages are common.
→ Aneuploidy occurs via non-disjunction.

TYPES OF ANEUPLOIDY DISORDERS

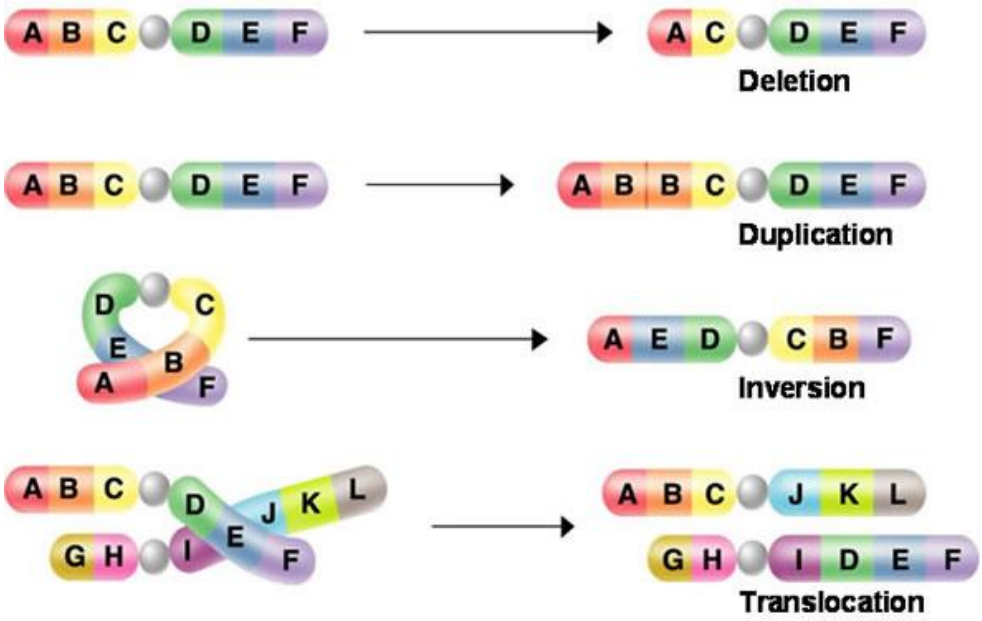
Name	Type	Chromosomes Involved	Symptoms
Down Syndrome	Autosomal trisomy	Chromosome 21	Distinct facial features Intellectual disability
Klinefelter Syndrome	Sex-linked trisomy	XXY	More feminine features Infertility
Wolf-Hirschhorn syndrome	Autosomal monosomy	Partial loss of Chromosome 4.	Distinct facial features Intellectual disability
Turner Syndrome	Sex-linked monosomy	XO	Short stature Infertility

TYPES OF MUTATIONS

mutations: an alteration to a DNA sequence involving single bases, parts of a chromosome or a whole chromosome.
▪ Point mutations are the simplest form of mutation.
→ A single nucleotide is affected (thus, is it also called **single nucleotide polymorphism**);
▪ Substitution occurs when one nucleotide is replaced by another.
→ A **silent/synonymous mutation** occurs when substitution results in a codon that codes for the same amino acid.
→ A **missense mutation** occurs when substitution results in a change in amino acid.
→ A **nonsense mutation** occurs when substitution creates a stop codon (ie. early termination).
▪ Insertions and deletions cause the addition or removal of a nucleotide.
→ Usually results in a **frame-shift mutation**, which affects all codons 'downstream'.

MUTATIONS IN CHROMOSOMES

deletions: the removal of a section of DNA
inversion: when a section of DNA is flipped/reversed
translocation: when a section of a chromosome swaps with a section of a non-homologous chromosome
duplication: when a copy is made of a section



EFFECTS OF MUTATIONS ON SURVIVAL

▪ In terms of the danger of mutations, from lowest to highest: altered base → altered codon → altered amino acid → altered protein.
▪ Mutations may impact survival of the organism positively (uncommon) or negatively (common).
▪ **Neutral mutations** occur when the survival of an organism is not affected.
→ Occurs with silent mutations.
→ It can sometimes occur with missense mutations if the new amino acid has similar properties to the original.
▪ **Deleterious mutations** disrupt the function of encoded proteins and impacts ability to survive.
→ This usually occurs with nonsense mutations with (usually) serious effects.
→ An organism can survive if they have a copy of the normal allele.
▪ **Transposable elements** cause death if occurring in the exon.
→ These are less harmful in introns and can be passed on if in gametes.
▪ **Beneficial mutations** aid the survival of an organism.
→ Missense mutations can change the function of the original protein for the better.
EX: Having one allele of the sickle cell mutation prevents the catching of malaria.
→ Nonsense mutations may eliminate harmful proteins.
EX: Some people have nonsense mutations eliminate surface proteins needed by HIV to enter cells.

CAUSES OF MUTATIONS

▪ Mutations can be **spontaneous** due to errors in cell division.
▪ Mutations can also be **induced** by either chemical or physical mutagens.
▪ According to mutation research:
→ mutations arise spontaneously;
→ environmental influences effect mutations rate;
→ mutations are persistent;
→ mutations usually mean a disadvantage (premature death means alleles spread in population).
▪ Mutations can be invisible, subtle or severe – rarely beneficial.

▪ The effect depends on whether the mutations are in somatic or germ-line cells (gametes).
▪ **Somatic cell mutations** occur only in affected body cells and any daughter cells produced by mitosis.
→ All other cells lack mutation.
→ Mutations usually build up, accelerate ell division and terminates apoptosis.
→ These mutations cannot be inherited.
▪ **Germ-line mutations** affect gametes so it can be inherited.
→ If so, present in every cell of the offspring.
→ This often leads to developmental abnormalities that cause spontaneous abortion.
→ If birth occurs, offspring may be born with severe disorders.
→ If consistently passed on, a new allele has entered the population.
▪ Mutations can occur due to errors in cell division.
→ Mutations usually occur in S phases (DNA is exposed and vulnerable).
→ Chemical alterations of bases may cause incorrect pair binding.
→ DNA structures may be damages (ROS).
→ Errors are often fixed in G2 phase but checkpoints can still fail.

MUTAGENS
▪ A mutagen is anything that can cause mutations and is classified into three types: **chemical**, **physical** (radiation) and **biological**.
▪ Chemical mutagens usually work by substituting a base in for another.
→ As an exception, others can change the structure of bases or simple "slip in" by resembling a base.
▪ Physical mutagens refer to the various types of radiation that cause damage to DNA.
→ UV light causes structural distortion, cross-linking neighbouring nucleotides.
→ X-rays cause gene and chromosomal aberrations.
→ Nuclear radiation leads to breaks in DNA strands.
▪ Mutations causes by invasive pathogens are called biological agents (mutagens).
→ The pathogen's DNA becomes permanently integrated with host.