TOPIC: GENETICS

Key Knowledge:

- the distinction between genes, alleles and a genome
- proportionate influences of genetic material, and environmental and epigenetic factors, on phenotypes
- the nature of a pair of homologous chromosomes carrying the same gene loci and the distinction between autosomes and sex chromosomes
- variability of chromosomes in terms of size and number in different organisms
- karyotypes as a visual representation that can be used to identify chromosome abnormalities

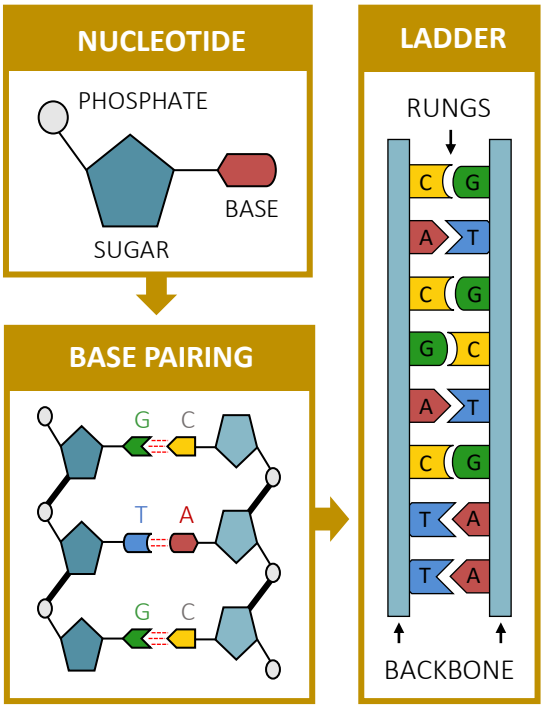
DNA

DNA (deoxyribonucleic acid) functions as the genetic material of the cell and is composed of recurring monomeric subunits called **nucleotides**. Each nucleotide is comprised of three key components: sugar, phosphate group and a nitrogenous base.

Nucleotides are joined by **covalent bonds** between the sugar and phosphate group to form long chains. Two chains of DNA are then linked by **hydrogen bonds** between complementary bases. DNA has four different bases that will pair as follows:

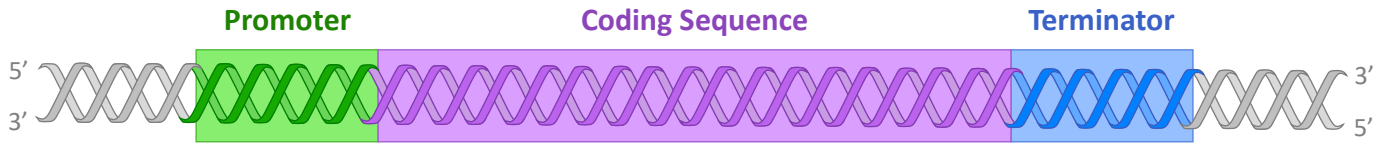
- Adenine (**A**) pairs with thymine (**T**) via two H bonds
- Cytosine (**C**) pairs with guanine (**G**) via three H bonds

In order for the complementary bases to pair, the two DNA strands must be running in opposite directions, and hence the two strands are **antiparallel**. Double-stranded DNA will arrange into the most stable configuration: a **double helix**.



GENES

Genes are sequences of DNA that encode a specific characteristic (via the production of a specific protein). They function as the basic units of inheritance. The order of the nitrogenous bases in a gene sequence will determine the nature of the encoded characteristic. If the base sequence is changed (via mutation), then the expressed characteristic may also potentially change. A gene is composed of three key sections. The **promoter** is the site responsible for switching a gene on (starting point). The **coding sequence** contains the genetic instruction (codes for a trait), while a **terminator** sequence denotes the end of a gene (stop point).



Only a small proportion of an organism's total DNA sequence consists of genes (in humans, genes comprise less than 2% of the genome). The majority of the DNA sequence is non-coding and includes satellite DNA, tandem repeats, introns, transposons and pseudogenes.

GENE EXPRESSION

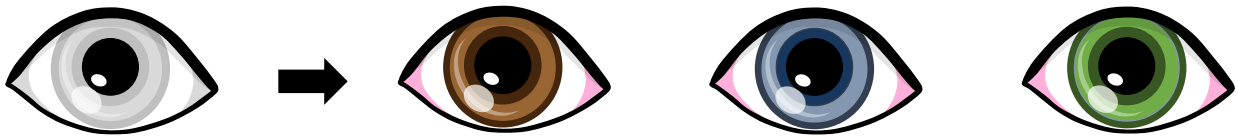
Genes can be switched on or off in response to cellular (internal) or environmental (external) signals. An active gene encodes temporary instructions (RNA molecules) that are decoded by the **ribosomes** to produce specific proteins. The RNA copy is produced via a process called *transcription*, while synthesis of a protein by ribosomes occurs via a process called *translation*. The **genetic code** is the rule set that identifies how a protein is assembled from its subunits (amino acids). Amino acids are encoded by a triplet of bases called a **codon**. Changing a codon sequence could change the protein being synthesised. The genetic code possesses two key characteristics:

- **Universality:** All living organisms use the same code
- **Degeneracy:** Some codons can share an amino acid

UUU	Phe	UCU	Ser	UAU	Tyr	UGU	Cys
UUC		UCC		UAC		UGC	
UUA	Leu	UCA		UAA	STOP	UGA	STOP
UUG		UCG		UAG		UGG	Trp
CUU	Leu	CCU	Pro	CAU	His	CGU	Arg
CUC		CCC		CAC		CGC	
CUA		CCA		CAA	Gln	CGA	
CUG		CCG		CAG		CGG	
AUU	Ile	ACU	Thr	AAU	Asn	AGU	Ser
AUC		ACC		AAC		AGC	
AUA		ACA		AAA	Lys	AGA	Arg
AUG	Met	ACG		AAG		AGG	
GUU	Val	GCU	Ala	GAU	Asp	GGU	Gly
GUC		GCC		GAC		GGC	
GUA		GCA		GAA	Glu	GGA	
GUG		GCG		GAG		GGG	

GENOTYPE

All members of a single species will share identical genes, but individuals may possess different versions of a specific genetic characteristic. These alternate forms of a gene are called **alleles**. Alleles typically differ by only one or a few bases and new alleles can be made via **gene mutations**. The complete set of alleles that a given organism possesses is called the genotype – it reflects the genetic identity of a particular individual.

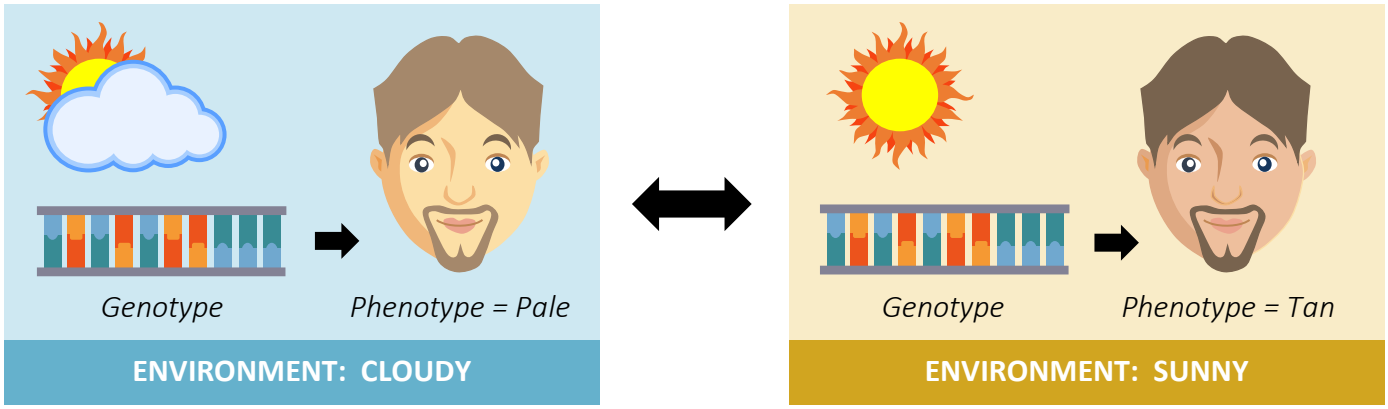


Gene: Eye colour

Alleles: Different shades (brown, blue, green, etc.)

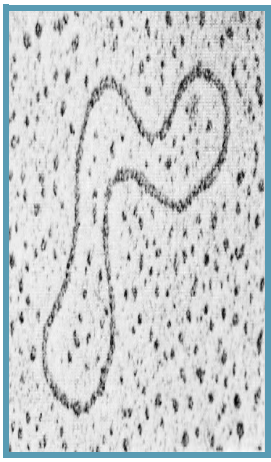
PHENOTYPE

Phenotype describes all of the observable characteristics of a given organism, and will be influenced by both the genotype and the environment. Unlike the genotype, which represents the gene sequences, the phenotype is a reflection of the proteins that are produced. The type of proteins produced by a cell will be determined by the genotype, but the activity or expression of the proteins can be impacted by a variety of environmental factors. For example, production of skin pigment (melanin) is influenced by sun exposure.



CHROMOSOMES

DNA is packaged within cells as discrete chromosomes that carry many different genes. The position of a gene on a chromosome is called the **locus**. Prokaryotic and eukaryotic chromosomes differ in key aspects:

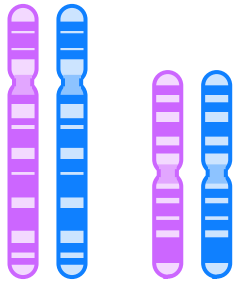


PROKARYOTE
DNA is naked
Chromosome is circular
Sequence is more compact (there are usually no introns)
One chromosome (haploid) plus additional plasmids
DNA is located in cytosol

EUKARYOTE
DNA is bound to histones
Chromosome is linear
Sequence is less compact (genes may contain introns)
Chromosomes are usually present in pairs (diploid)
DNA is stored in a nucleus

AUTOSOMES

In all sexually reproducing organisms, chromosomes will exist as homologous pairs (i.e. a maternal copy and a paternal copy). The homologous pairs will have identical structures (same size, same centromere position, same banding patterns) and will also carry the same sequence of genes at the same loci positions. However, as the paired chromosomes came from different origins (maternal versus paternal copy), the two alleles at each gene locus may be different. Any chromosome that *always* exists as a matched pair is called an **autosome** (i.e. **not** the sex chromosomes).



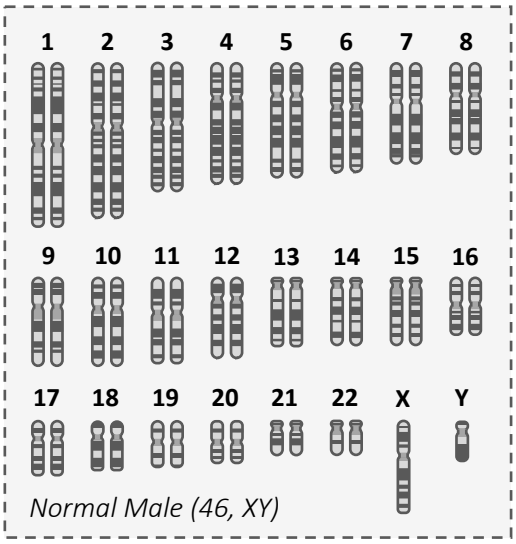
SEX CHROMOSOMES

In diploid organisms, sex is determined by a pair of chromosomes called sex chromosomes (**heterosomes**). Unlike autosomes, the sex chromosomes are **not** homologous and possess different genes. Human sex is determined by the **XY system**. Males possess an X chromosome and a much shorter Y chromosome (XY), while females possess two copies of the larger X chromosome (XX). The Y chromosome contains the genes responsible for developing the male sex characteristics. In its absence, female sex characteristics develop.

KARYOGRAMS

The chromosomal profile of an individual can be represented by a picture called a karyogram. In a karyogram, the chromosomes are organised in homologous pairs according to descending size (with the sex chromosomes shown last). Humans normally have 46 chromosomes (22 autosome pairs and the sex chromosomes). Karyograms are prepared by a process called **karyotyping**, which involves inducing cell division with drugs (chromosomes become visible during prophase). Karyotyping typically occurs pre-natally using cells derived from the placenta (chorionic villi) or amniotic fluid. Karyotyping is typically employed for two main purposes:

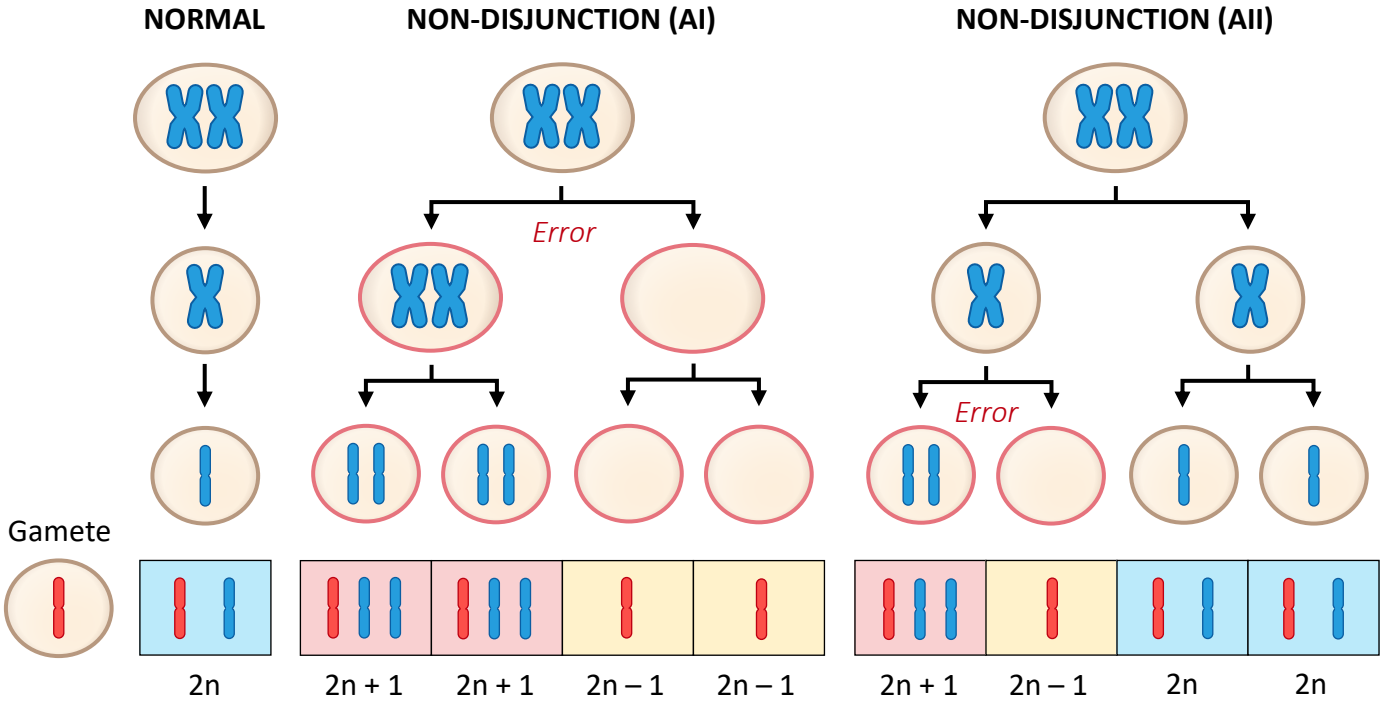
- Determining sex of an unborn child (female = XX, male = XY)
- Identifying any chromosomal abnormalities (**aneuploidies**)



Normal Male (46, XY)

ANEUPLOIDY

Aneuploidy occurs when a single chromosome pair fails to separate, resulting in gametes that are not haploid for that particular chromosome. This failure to separate is called **non-disjunction** and occurs during anaphase (I or II) of meiosis. When the defective gamete is fertilised with a normal gamete, the resulting offspring will have either one missing chromosome (monosomy) or one additional chromosome (trisomy). Examples of aneuploidies in humans include Down's syndrome (trisomy 21), Klinefelter's syndrome (XXY) and Turner's syndrome (fragile X syndrome).



GENOMES

The **genome** is the sum total of an organism's DNA measured in the number of base pairs contained in a haploid set of chromosomes. The genome includes all genes and non-coding sequences. Every cell in a multicellular organism contains an identical genome. Different genes may be activated in certain tissues, leading to the production of different proteins. The totality of proteins expressed within a cell or organism at a particular time is called the **proteome**.

HUMAN GENOME PROJECT

The Human Genome Project was an international cooperative venture established to sequence the entire human genome. The completion of the Human Genome Project in 2003 lead to many beneficial outcomes:

- **Mapping:** The number, location, size and sequence of human genes is now established
- **Screening:** Specific gene probes can now be produced to detect predispositions to genetic diseases
- **Medicine:** The determination of genetic profiles have led to improved treatments (pharmacogenetics)
- **Ancestry:** Comparisons with other genomes have provided insight into the evolutionary origins of man

Scientists are now attempting to sequence the genomes of a variety of different organisms in an effort to identify novel genes and proteins. Because the genetic code is (almost) universal, it is possible to introduce genes from other species into a host organism in order to confer new functionality to the host. Organisms that have incorporated genes from other species are called **transgenic** organisms. Transgenic crops have been used in agriculture to increase the productivity or nutritional content of the crop (e.g. Golden rice).