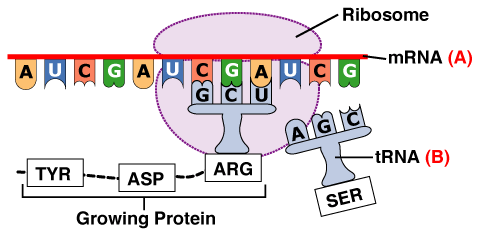
**The Importance of Proteins**

**A picture containing schematic

Description automatically generated**

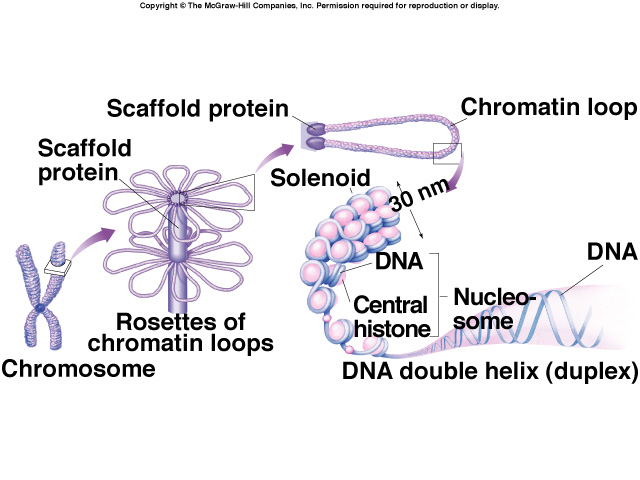
* Proteins have a specific 3D shape – if there is a job to be done in the molecular world of our cells, usually that job is done by a protein
* Proteins can either be fibrous or globular
* Examples of proteins include hormones acting as messengers; enzymes speeding up reactions; antibodies fighting invaders, etc.
* Fibrous proteins include things like collagen, keratin and fibroin – these all have fibres
* Collagen is the most abundant protein in vertebrates – collagen fibres are a major portion of tendons, bone and skin – alpha helices of collagen make up a triple helix structure giving it tough and flexible properties
* Fibroin fibres make the silk spun by spiders and silkworms’ stronger weight for weight than steel – the soft flexible properties come from the beta structure
* Keratin is a tough insoluble protein that makes up the quills of echidna, your hair and nails and the rattle of a rattle snake – the structure comes from alpha helices that are cross-linked by disulphide bonds
* Globular proteins have a number of roles
  + Cell motility – proteins link together to form filaments which make movement possible
  + Organic catalysts in biochemical reactions – enzymes
  + Regulatory proteins – hormones, transcription factors
  + Membrane proteins – MHC markers, protein channels, gap junctions
  + Defense against pathogens – poison/toxins, antibodies, complement
  + Transport and storage – haemoglobin and myosin
* Proteins are bult from subunits called amino acids – amino acids have a particular structure
* The code for making a protein is found in your genes (on your DNA)
* This genetic code is copied onto a messenger which join amino acids together
* The mRNA code is read in multiples of 3 (a codon) by ribosomes which join amino acids to form a polypeptide
* This is known as gene expression
* The amino acids for making new proteins come from the proteins that you eat and digest – every time you eat food, you break the proteins down into single amino acids ready for use in building new proteins
* There are only 20 different amino acids, but they can be joined together in many different combinations to form the diverse range of proteins that exist on this planet

**Chromosome Structure and Karyotype**

***Karyotype***

* An ordered, visual representation of the chromosomes in a cell
* Chromosomes are photographed when they are highly condensed, then photos of the individual chromosomes are arranged in order of decreasing size
* In humans each somatic cell has 46 chromosomes, made up of two sets, one set of chromosomes comes from each parent

***Chromosomes***

* In a diploid cell, the chromosome occurs in pairs – the 2 members of each autosome (non-sex chromosome) pair are called homologous chromosomes or homologues
* Females have 23 homologue pairs (XX in sex chromosomes)
* Non-homologous chromosomes (males XY)
  + Control different traits or different genes
  + Are represented as X and Y
  + XX being female, XY being male
* Most eukaryotes have between 10 and 50 chromosomes in their body cells
* All human body (somatic) cells have 46 chromosomes – Diploid, 2n = 46
* Sex cells (sperm and ova) have 23 chromosomes – Haploid, 1n = 23

***Structure of Chromosomes***

* Chromosomes are composed of a complex of DNA and protein called chromatin that condenses during cell division
* DNA exists as a single, long double-stranded fibre extending chromosome’s entire length
* Each unduplicated chromosome contains one DNA molecule – duplicated chromosome = 2 chromatids
* Every 200 nucleotide pairs, the DNA wraps twice around a group of 8 histone proteins to form a nucleosome
* Higher order coiling and supercoiling also help condense and package the chromosome inside the nucleus

**The Cell Cycle**

**Diagram

Description automatically generated**

* Between cell division, the cell cycle takes place (also known as interphase)
* The cell cycle is the ordered sequence of events in the life of a cell – begins when the cell is formed from its parent cell and is completed with its own division
* The cycle is usually a continuous process rather than being in ‘phases’
* The cell division stage is only a small part of the process – this is known as the M phase, and contains the process of cytokinesis within it (also known as mitotic phase)
* The cell cycle is made up of a period of metabolic activity and growth (G1 phase or first gap phase), duplication of the chromosomes (DNA replication) and of the centrosomes (S phase, or synthesis phase), and further growth and reproduction of organelles as the cell prepares to divide (G2 phase)
* A further phase, G0, includes cells that are in a non-proliferating state – they are undergoing an extended G1 phase but aren’t preparing to replicate their DNA and divide
* Cells in G0 have withdrawn from the active cell cycle and can only re-enter the cell cycle under certain circumstances
* Length of the cell cycle varies from cell to cell, and not all cells divide – e.g., nerve cells and retinal cells in adult humans do not divide

**DNA (Deoxyribonucleic Acid)**

Diagram

Description automatically generated

* DNA is a double-stranded helical molecule, and it stands for deoxyribonucleic acid – it is the code for life
* In eukaryotic cells, DNA is found in a linear form bound to proteins in the nucleus, and in unbound circular form in chloroplasts and mitochondria
* The nucleus is enclosed in a nuclear membrane to protect its interior
* In prokaryotic cells, DNA is found in an unbound circular form in the nucleoid region of the cytosol – the nucleoid region is not bound by a nuclear membrane, and therefore DNA is not contained like it is in a eukaryotic cell
* There are four types of nitrogenous bases found in DNA – Adenine (A) which pairs with Thymine (T), and Cytosine (C) which pairs with Guanine (G)
* The pairs of nitrogenous bases are known as complementary base pairs – complementary pairing is the phenomenon whereby guanine always hydrogen bonds with cytosine, and adenine always hydrogen bonds with thymine
* Guanine and cytosine share 3 hydrogen bonds whilst adenine thymine share 2 hydrogen bonds

**Structural Properties of the DNA Molecule**

***Nucleotides – the building blocks of DNA***

* Diagram

  Description automatically generatedDNA is a nucleic acid made up of nucleotides
* Each nucleotide consists of three parts – a five-carbon (pentose) sugar known as deoxyribose sugar, a phosphate group and a nitrogenous base
* A nucleotide is the basic structural unit of DNA
* Each phosphate group is attached to 2 sugar molecules by ‘ester’ bonds and is then called a phosphodiester bond
* The five carbon atoms in each sugar molecule form a ring which are numbered 1’ to 5’
* One of the ester bonds is formed with the 3’ carbon of one sugar ring and the other is formed with the 5’ carbon of the next sugar ring
* The chain of alternating sugar molecules and phosphate groups is called the sugar-phosphate backbone
* A strand of nucleotides has directionality using the phrase 5’ to 3’ – the 5’ end starts with a phosphate and the 3’ end finishes with a sugar
* DNA and RNA synthesis occurs in the 5’ to 3’ direction

***The structure of the DNA molecule and its function***

* The shape of a DNA molecule is a double helix – the two strands are joined by the weak hydrogen bonds between complementary pairs of nitrogenous bases
* The term ‘helix’ describes the helical/spiral molecular shape
* The two linear strands run in opposite directions to each other, meaning they are anti-parallel, and are twisted into a helix
* DNA carries information in the segments of its molecule known as genes – DNA thus enables certain traits to be passed on to the next generation – a trait is an inheritable characteristic
* DNA can be manipulated (genes) to achieve desired characteristics
* DNA stores the code for making proteins, and the inheritance of particular gene variants causes an individual to have a specific combination of proteins in its makeup – a section of DNA that codes for a specific protein (or polypeptide) is called a gene
* Genes may code for more than one kind of polypeptide, and genes interact with one another, causing changes in their expression – DNA therefore controls the growth and development of an organism
* The structural properties of the DNA molecule (its nucleotide composition, pairing and hydrogen bonding are what allow DNA replication to occur – this is because the DNA strands can function as template strands

**DNA Replication**

* The product of DNA replication is two identical, double-helix DNA molecules, each consisting of one parental strand and one new strand
* DNA replication is referred to as semi-conservative replication as one of the two strands is conserved, or retained, from one generation to the next, while the other strand is new
* DNA replication occurs during the S phase of interphase (cell cycle)
* The purpose of DNA replication to is duplicate the code it carries – the code can then be passed on to daughter cells
* In eukaryotic cells, the chromosomes gain a sister chromatid and become double stranded
* DNA replication occurs in preparation for mitosis and meiosis
* Diagram

  Description automatically generatedDNA replication begins with an enzyme called DNA helicase ‘unzipping’ the long molecule of double stranded DNA by breaking the weak hydrogen bonds between the nucleotides and thus exposing the nucleotide bases
* This separation of the parental DNA strands happens along a small section at a time
* The hydrogen bonds that hold the two strands of the DNA molecule are weak, and the enzyme is easily able to separate them
* The junction between the unwound single strands of DNA and the intact double helix is called the replication fork – the replication fork moves along the parental DNA strand so that there is a continuous unwinding of the parental strands
* Within the nucleus, stockpiles of free nucleotides attach to the exposed bases, according to the base-pairing rule with the assistance of the enzyme DNA polymerase
* DNA ligase seals the new short stretches of nucleotides into a continuous double strand that rewinds
* Ligase catalyses the formation of phosphodiester bonds
* The nucleotides link together in a 5’ to 3’ direction, forming long molecules
* As DNA strands are antiparallel, DNA polymerase moves in opposite directions on the two strands during synthesis
* On the leading strand, DNA polymerase is moving away from the replication fork and synthesis in pieces called Okazaki fragments
* Synthesis is continuous along the leading strand, with additional nucleotides being added one after the other
* It is discontinuous along the lagging strand as it is a 3’ to 5’ strand and DNA can only synthesise new DNA in a 5’ to 3’ direction
* Primers are attached at short intervals, starting from the replication fork
* DNA polymerase synthesises short strands of new DNA starting at each primer, in a 5’ to 3’ direction – these short strands are called Okazaki fragments
* DNA polymerase moves in opposite directions on the two anti-parallel parent strands, and removes the RNA primers and replaces them with DNA nucleotides
* DNA ligase joins the Okazaki fragments together to create a continuous strand, and ligase catalyses the formation of a phosphodiester bond

Diagram

Description automatically generated***Steps of DNA replication summarised***

1. DNA helicase unwinds and separates the double strand by breaking the weak hydrogen bonds between complementary base pairs – each half of the parent molecule is used as a template
2. The enzyme RNA primase attaches a short sequence of RNA, known as a primer, to show DNA polymerase where to start adding nucleotides
3. Free nucleotides are added by DNA polymerase according to complementary base pairing rules – synthesis of the new daughter strand is in a 5’ to 3’ direction
4. DNA ligase removes and replaces the primers – the result is two identical DNA molecules that are each made of one original parent strand and one new daughter strand – DNA replication is described as semi-conservative
5. In eukaryotic organisms, two identical sister chromatids are now ready for cell division – in prokaryotes, two identical circular chromosomes are now ready for binary fission

**Fertilisation**

Diagram

Description automatically generated

* Meiosis initiates process of transferring genetic information to the next generation by replicating DNA and producing male and female gametes
* Fertilisation is the joining of two gametes to form a zygote
* The zygote receives one of each of its pairs of chromosomes from each parent
* Fertilisation completes the transfer of genetic information to the next generation
* In the process of fertilisation, male and female haploid (*1n* or *n*)sex cells (egg and sperm) fuse to produce a diploid (*2n*) zygote
* Two gametes from different individuals, usually male and female, of the same species need to combine to produce a new individual of that species – this is called sexual reproduction
* Organisms produced by sexual reproduction have a different combination of DNA from that of either parent
* The zygote formed is a cell with approximately twice the amount of DNA that each gamete has – meiosis halves the DNA amount, but fertilisation restores the amount to the required amount for a particular species
* In humans, gametes produced by meiosis contain 23 chromosomes (22 autosomes and 1 sex chromosome) and fertilisation restores the number of chromosomes to 46
* Fertilisation leads to increased variation in offspring

***The role of the sex chromosome***

* In humans, normally all female gametes contain 22 autosomes and an X chromosome – 50% of all male gametes contain 22 autosomes and a Y chromosome and the other 50% contain an X instead of a Y
* This means that in fertilisation, there is a 50% chance of a sperm cell bearing a Y chromosome will fuse with an egg cell resulting in a male zygote (XY) and a 50% chance that a sperm cell bearing an X chromosome will fuse with an egg cell resulting in a female zygote (XX)

***Not all life continues***

* Cells are pre-programmed to age and die after a given life span
* E.g., some skin cells known as keratinocytes live for about 3 weeks – the dead cells form a surface layer that is continually shed – keratinocytes self-destruct in an orderly and programmed manner called apoptosis
* Cell death by apoptosis is a vital and formative process that is essential for development and the shaping of organs and tissues
* E.g., cell death allows a human embryo to lose the webbing between its fingers and toes

**Coding and Non-Coding DNA**

Diagram

Description automatically generated

* The entire order of the nucleotides in a human cell’s DNA have been sequenced – the sequence of consecutive DNA nucleotide bases spanning all the chromosomes of a cell from start to finish is known as the genome sequence
* Some sections of the sequence code for proteins are called coding DNA
* The coding DNA sections are also called genes – the coding DNA specifies sequences of amino acids, which are the building blocks of proteins
* Proteins are responsible for nearly all cell functions – humans have around 20,000 protein-coding genes – approximately 1-2% of the DNA in a human is comprised of coding DNA
* Genes contain information for the production of proteins – proteins are the link between the stored genetic code, the genotype and observable traits, called the phenotype
* The majority of the human genome is comprised of non-coding DNA
* A genome is ‘all the DNA in a cell’, and this includes the genes and also DNA that is not part of any gene
* The sections of DNA that do not code for a protein are classified as non-coding DNA – some non-coding DNA is transcribed into functional non-coding RNA molecules, such as transfer RNAs and regulatory RNAs
* Historically, non-coding DNA was referred to as ‘junk DNA’ but scientists have found that some non-coding DNA is important and is not actually ‘junk’

***The genetic code***

* The genetic code is the term used for the way that the four nitrogenous bases of DNA, being adenine, thymine, guanine and cytosine, are ordered
* The base order is ‘read’ by cellular machinery and turned into a protein via a process called protein synthesis – cellular machinery consists of ‘biological machines’ that work to manufacture a biological molecule
* The transcription machinery includes RNA polymerase and binding factors/proteins
* The translation machine is the ribosome
* In the genetic code, each set of three DNA nucleotides in a row counts as a triplet and codes for an mRNA (messenger RNA) triplet called a codon
* The mRNA codon (three nucleotides) is again read by cellular machinery and is translated into a single amino acid – each sequence of three nucleotides codes for an amino acid
* Given that some proteins are made up of hundreds of amino acids, the code that would make one protein could hundreds, sometimes even thousands, of triplets contained in it

**Protein Synthesis**

* Proteins are essential to the structure and function of cells, thus also to the structure and function of organisms
* Protein synthesis is the process of making new proteins from the genetic information encoded in DNA
* There are two main processes that facilitate the flow of information from gene to protein – transcription and translation
* Transcription is the synthesis of mRNA using the stored DNA code – the synthesised mRNA is a chain of RNA nucleotides complementary to the DNA strand except uracil is the base pair to adenine in RNA rather than thymine
* Translation is the synthesis of a polypeptide using the information in the mRNA – the RNA nucleotide code is translated into an amino acid sequence
* Genes are found in chromosomes in cells – they are sequences of DNA that code for a protein – it is only during cell division that DNA can leave the nucleus of a eukaryotic cell – otherwise, it remains there, ready for future cell division (mitosis or meiosis)
* The DNA code must be transcribed into mRNA while still inside the nucleus – the mRNA can fit through the nuclear pores as it is a short, single-stranded molecule
* Therefore, mRNA can carry the code of instructions to the ribosome, where translation can take place – the ribosome binds to the mRNA, and each codon attracts the corresponding anticodon that forms part of a tRNA (transfer RNA) molecule
* The tRNA molecule carries the amino acid that is specific to the codon – as one codon at a time moves into and is read by the ribosome, successive tRNAs transport amino acids to it, translating the code by dropping off amino acids in a sequence that matches the sequence of codons
* Gradually, a polypeptide is produced – the polypeptide can detach and fold to form a protein by itself, or attach to other polypeptides and then fold to form a protein

***Essential materials needed for protein synthesis***

* Enzymes help break or form new bonds, e.g., RNA polymerase
* Codons are a series of three nucleotides found in mRNA, and they act as a code for an amino acid – e.g., UAU codes for the amino acid tyrosine
* A start codon (AUG) initiates translation, and a stop codon (UAG) brings the process to an end
* Nucleic acids – DNA stores the code, mRNA transports the code from the nucleus into the cytoplasm and to the ribosome, and tRNA is found in the cytoplasm – for each codon, a tRNA carries a specific amino acid to the ribosome for incorporation into the growing polypeptide
* Amino acids – twenty amino acids are the building blocks of the polypeptides and proteins – the sequence of amino acids in a protein is a type of code that specifies the structure and function of the protein, making it different from other proteins

***Transcription and translation in prokaryotes***

* In prokaryotic cells, the chromosome is generally in the form of a closed circle that is not wrapped around histone proteins – it is found in the region of the cell known as the nucleoid
* In addition to the single chromosome, bacteria may contain plasmids, which are small rings of DNA
* Plasmids code for traits but are not essential to the survival of the cell (though they may aid in its survival)
* Transcription begins when a section of the double-stranded chromosome is separates and enzymes synthesise an mRNA product complementary to the template strand
* In prokaryotes, transcription and translation are simultaneous – that is, translation begins while the mRNA is still being synthesised, during transcription
* Numerous ribosomes concurrently translate the mRNA transcripts into polypeptides – in contrast, a eukaryotic cell performs transcription in the nucleus and translation in the cytoplasm

***Transcription in eukaryotes***

* Transcription occurs in the nucleus in eukaryotes, and it produces mRNA from DNA
* During transcription, one section of DNA, called a gene, is unwound and separated ready for copying
* RNA polymerase moves step by step along the DNA molecule, separating the two stranded – only the template strand is copied
* The template strand is also known as the antisense or non-coding strand – the other strand is known as the non-template, sense or coding strand
* The coding strand has the same code as the mRNA, except in RNA uracil replaces thymine
* The sequences of the DNA nucleotides determine the sequence of the RNA nucleotides, as RNA polymerase attaches the RNA nucleotide that is complementary to each DNA base
* A promoter attaches to help the DNA template strand to locally separate from the non-template strand, initiating transcription
* RNA polymerase binds to the DNA to get ready to start synthesis, and it synthesises the mRNA in a 5’ to 3’ direction, anti-parallel to the template strand
* The mRNA nucleotide triplets are called codons – the codons are complementary to the template strand, but almost identical to the non-template/coding strand, except for uracil replacing thymine
* After the RNA polymerase enables elongation of the strand, the mRNA molecule detaches as pre-mRNA
* Pre-mRNA requires processing before it exits the nucleus via the nuclear pore
* Stretches of non-coding DNA (known as introns) are removed/spliced out and the remaining stretches of DNA (known as exons) join to form mature mRNA

***mRNA modification – introns and exons***

* As part of the normal process of generating proteins from genes stored in DNA, the code for constructing a particular protein is passed from stored DNA to a form that is transportable known as mRNA
* The strip of mRNA that is first formed when the DNA code is copied has excess baggage
* In most eukaryotes, the mRNA initially carries the instructions for making a protein, but also carries extra nucleotides that are not needed
* The unrefined mRNA is called pre-mRNA
* Before the mRNA can leave the cell nucleus, non-coding regions called introns are spliced out in a process called (pre-)mRNA splicing
* The remaining exons join together as the final set of refined instructions, ready to move out of the nucleus via a nuclear por
* The refined mRNA is called mature mRNA, and it performs the function of carrying the code to the translation site, where proteins are built one amino acid at a time according to the code

***Summary of transcription***

1. Only one of the two strands of DNA is used for transcription – the template strand (also known as the non-coding strand or the antisense strand)
2. RNA polymerase binds to a promoter region – it breaks the weak hydrogen bonds joining the complementary nucleotides and unzips (unwinds) a portion of the double helix
3. Moving along the template DNA strand in a 3’ to 5’ direction, the RNA polymerase adds free-floating nucleotides to the growing mRNA sequence according to the complementary base-pair rules, but in RNA uracil pairs with adenine – the new mRNA strand is synthesis in a 5’ to 3’ direction
4. The DNA bases are in triplets, and the complementary mRNA triplets produced are called codons – the process continues until there is a termination signal and the pre-mRNA is released
5. Only the coding region (gene) of DNA is transcribed – pre-mRNA consists of introns and exons – the introns are spliced out and the exons are joined to create mature mRNA – mature mRNA then exits the nucleus via a nuclear pore

***Translation in eukaryotes***

* Translation is the RNA-directed synthesis of a polypeptide
* Ribosomes facilitate the interaction of mRNA and tRNA to position and connect a specific sequence of amino acids – ribosomes are mostly composed of ribosomal RNA (rRNA), which is non-coding
* After mRNA moves out from the nucleus through a nuclear pore, it enters the cytoplasm and travels to a ribosome, where it will be read and translated – the translation process can be divided into initiation, elongation and termination

***Initiation***

* A ribosome binds to a molecule of mRNA – it ‘reads’ the mRNA nucleotides in codons
* The codon AUG is the start codon, and codes for the amino acid methionine – it signals the start of translation and the beginning of a polypeptide chain
* The tRNA molecule that contains the anticodon UAC is attracted to the start codon and pairs with it – this tRNA molecule brings with it the amino acid methionine
* At initiation, two codons enter and are bound to the ribosome, but after that only one codon enters and is translated at a time

***Elongation***

* A tRNA molecule, which includes in its sequence an anticodon, is attracted to the corresponding codon on the mRNA due to complementary base pairing
* Each tRNA molecule carries an amino acid specified by the codon that it pairs with
* As one codon is read and exits the ribosome, another one slides in to be read
* tRNA molecules transfer the amino acids to the mRNA-ribosomal complex in the order specified by the codons of the mRNA – the ribosomes catalyse the formation of covalent peptide bonds between adjacent amino acids and the mRNA is moved through the ribosome in only one direction
* Once a tRNA molecule has dropped off its amino acid, it will return to the cytoplasm to reload with the same type of amino acid
* The tRNA is not used up during translation, and some amino acids are coded for by more than one codon

***Termination***

* Elongation continues until a stop codon in the mRNA enters the ribosome – the nucleotide base triplets UAG, UAA and UGA do not code for an amino acid, but instead, any one of them acts as a signal to stop translation
* The polypeptide is released, and the mRNA leaves the ribosome
* Once removed, the polypeptide may fold (or join with another polypeptide to fold) to become a structural or functional protein
* The protein will either be used in the cell it was formed in or be transported out of the cell elsewhere

**Proteins**

* Proteins are built from a selection of 20 different amino acids – the amino acids are linked together by peptide bonds to form polypeptide chains, which fold and/or are modified to form the protein
* The sequence of amino acids in a polypeptide is determined by the sequence of mRNA codons in a strand of mRNA
* If the sequence of codons is known, the sequence of amino acids can be determined from an amino acid table
* There are 64 possible base triplets, 1 being the start codon and 3 being the stop codons – the three nitrogenous bases in a codon code for an amino acid, e.g., CUA codes for Leu (leucine)