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Proteins

IB Biology - Revision Notes

Exam Papers Practice

Formation of Proteins

Amino Acid Structure

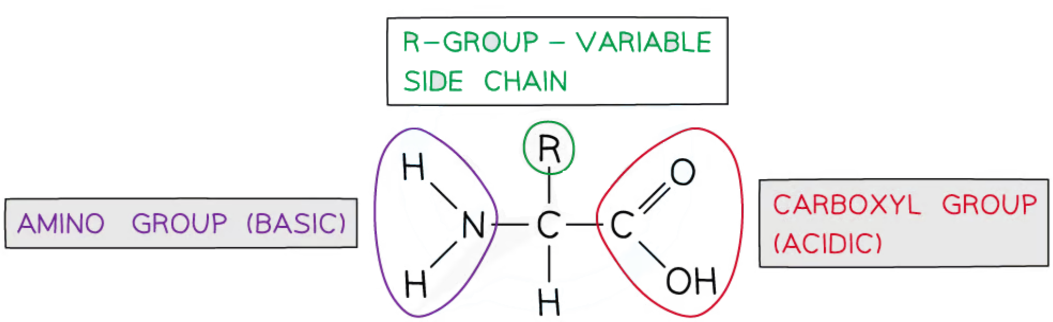
Proteins

- Proteins are polymers (and macromolecules) made of monomers called **amino acids**
- The **sequence, type** and **number** of the amino acids within a protein determines its shape and therefore its function
- Proteins **are extremely important in cells** because they form all of the following:
  - **Enzymes**
  - Cell membrane proteins (e.g. carrier)
  - **Hormones**
  - Immunoproteins (e.g. immunoglobulins)
  - **Transport** proteins (e.g. haemoglobin)
  - **Structural** proteins (e.g. keratin, collagen)
  - **Contractile** proteins (e.g. myosin)
- Because all genes code for proteins, **all of the reactions necessary for life** are dependent on the function of proteins

Amino acids

- Amino acids are the **monomers** of polypeptides
- There are **20 amino acids** found in polypeptides common to all living organisms
- The general structure of all amino acids is a central carbon atom, the alpha carbon, bonded to:
  - An **amine**/amino group -NH_2
  - A carboxylic acid/**carboxyl** group -COOH
  - A **hydrogen** atom
  - An **R** group (which is how each amino acid differs and why amino acid properties differ e.g. whether they are acidic or basic or whether they are polar or non-polar)
    - The **R** group can be as simple as another hydrogen atom (glycine), right through to complex aromatic ring structures (e.g. phenylalanine)

Structure of an amino acid diagram



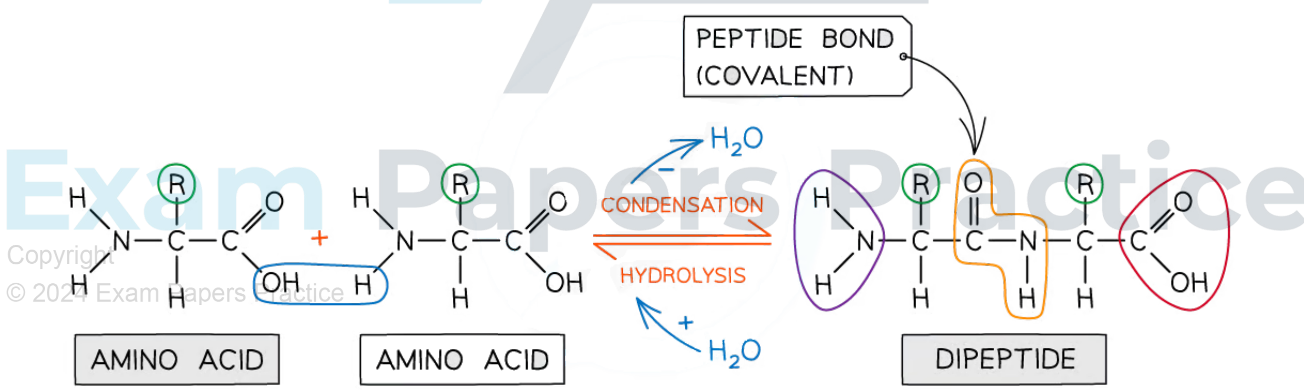
The generalised structure of an amino acid

The Peptide Bond

Peptide bond

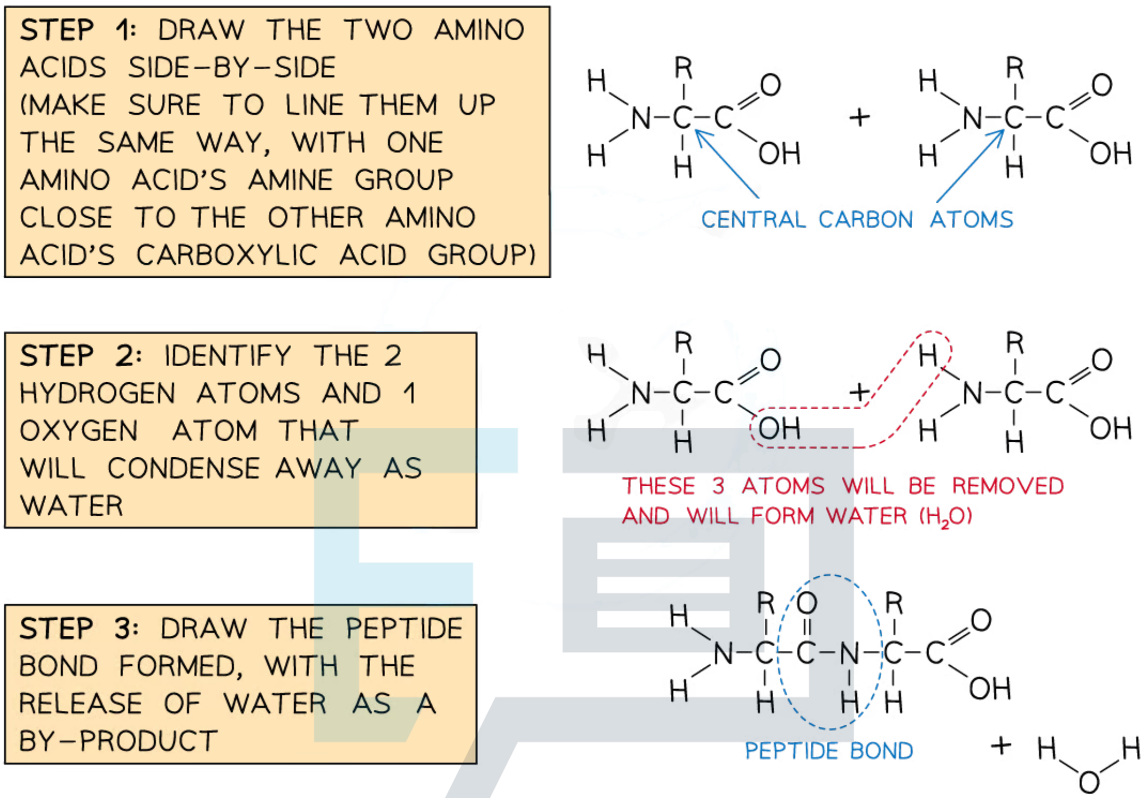
- In order to form a **peptide bond**, a hydroxyl group (-OH) is lost from the carboxylic group (-COOH) of one amino acid and a hydrogen atom is lost from the amine group (-NH2) of another amino acid
- The remaining carbon atom (with the double-bonded oxygen) from the first amino acid bonds to the nitrogen atom of the second amino acid
- This is a **condensation** reaction so water is released
- **Dipeptides** are formed by the condensation of **two** amino acids
  - The word equation for this reaction is **amino acid + amino acid → dipeptide**
- **Polypeptides** are formed by the condensation of **many** (3 or more) amino acids
- A protein may have only one polypeptide chain or it may have multiple chains interacting with each other
- During **hydrolysis** reactions, the addition of water **breaks the peptide bonds** resulting in polypeptides being broken down into amino acids
- **Molecular modelling** kits can be used to build physical models that demonstrate peptide bond formation between different types of amino acids

Peptide bond diagram



Amino acids are bonded together by covalent peptide bonds to form a dipeptide in a condensation reaction

Drawing a peptide bond diagram



These steps can be followed to draw a peptide bond and a generalised dipeptide

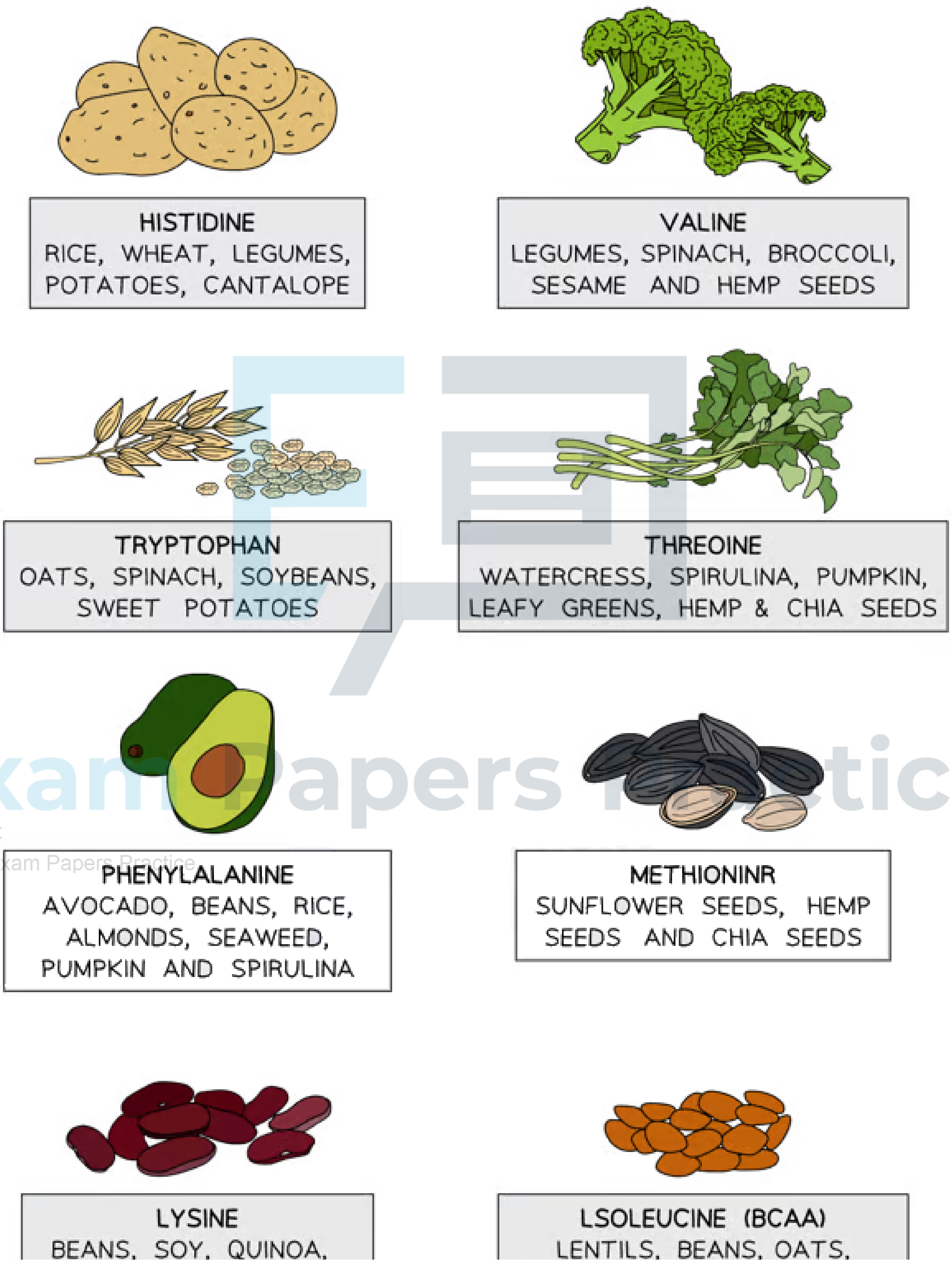
Exam Tip

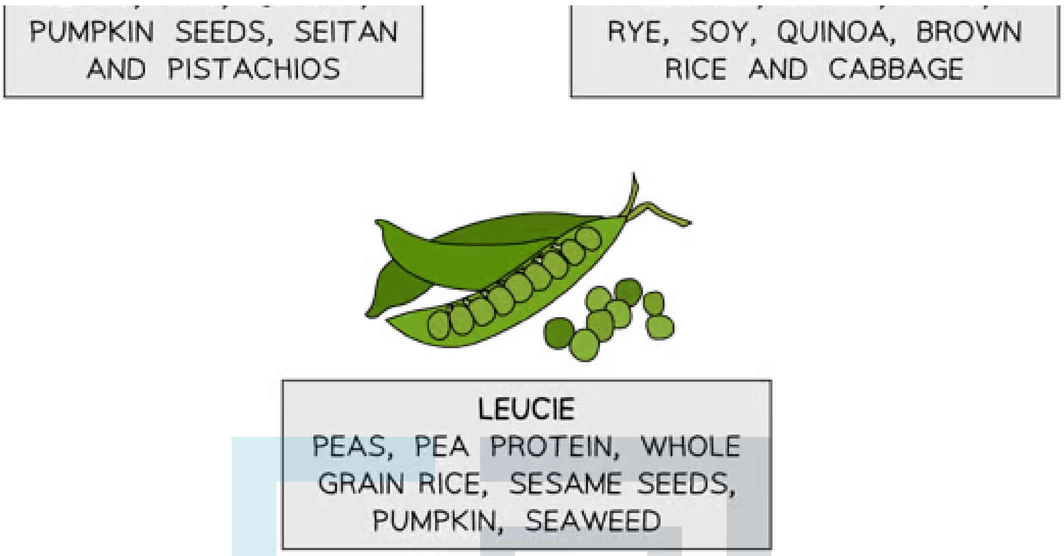
You will be expected to recognise whether an unfamiliar molecule is an amino acid or polypeptide so look for the functional groups (amine and carboxyl). When asked to identify the location of the peptide bond, look for where nitrogen is bonded to a carbon that has a double bond with an oxygen atom, note the R group is not involved in the formation of a peptide bond.

Amino Acids: Dietary Requirements

- There are 20 naturally occurring amino acids
- Our cells can synthesise 11 of these from other amnio acids
  - These are termed **non-essential amino acids**
- The remaining nine we need to consume via our diets
  - These are called **essential amino acids**
- A healthy, varied, well balanced diet will contain all the nine essential amino acids required
- Diets that restrict certain foods may require supplementation
  - Meat contains all nine essential amino acids so a vegetarian or vegan diet needs to be well balanced and varied to ensure all essential amino acids are consumed regularly

Essential amino acid sources diagram


HISTIDINE
RICE, WHEAT, LEGUMES, POTATOES, CANTALOPE
VALINE
LEGUMES, SPINACH, BROCCOLI, SESAME AND HEMP SEEDS
TRYPTOPHAN
OATS, SPINACH, SOYBEANS, SWEET POTATOES
THREOINE
WATERCRESS, SPIRULINA, PUMPKIN, LEAFY GREENS, HEMP & CHIA SEEDS
PHENYLALANINE
AVOCADO, BEANS, RICE, ALMONDS, SEAWEED, PUMPKIN AND SPIRULINA
METHIONINR
SUNFLOWER SEEDS, HEMP SEEDS AND CHIA SEEDS
LYSINE
BEANS, SOY, QUINOA,
LSOLEUCINE (BCAA)
LENTILS, BEANS, OATS,



Plant based (vegan) sources of the nine essential amino acids

Exam Tip

You are not required to remember or give examples of non-essential and essential amino acids.

The Variety of Proteins

Peptide Chain Diversity

- There is a large variety of proteins available to living organisms
- This is because:
  - There are 20 naturally occurring amino acids that form the basic structure of a polypeptide chain
  - Polypeptides can vary in length from a few to thousands
  - The structure and amino acid sequence can also vary
  - The genetic code, meaning DNA base sequence, codes for the number and order of amino acids in a polypeptide, and there is a huge variety of options for DNA base sequence
- 20 amino acids can give an almost infinite number of polypeptides
- Polypeptides are assembled at a ribosome by condensing **individual amino acids** onto a growing chain, **one by one**
- This allows a **choice of 20 amino acids** each time one is added
- The **mRNA codon** determines which amino acid is added
- For a polypeptide chain of 50 amino acids in length (considered a very **short protein**), there would be **20^{50}** possible combinations of amino acids
  - This gives 1.13 x 10^{65} combinations
- Given that the average length of a protein is **300 amino acids**, the number of possible combinations is so large, we can consider it to be **infinite**

Role of proteins

- The range of proteins available means that they are very **versatile** so that they have many different roles in cells, tissues and organs, such as:
  - Speeding up cellular reactions, or **catalysis**, is performed by **enzymes**
  - **Blood clotting**, where blood proteins interact with oxygen to form a gel-like scab across a wound
  - **Strengthening** fibres in skin, hair, tendons, blood vessels e.g. **collagen, keratin**
  - **Transport** of vital metabolites e.g. oxygen which is carried by **haemoglobin**
  - Formation of the **cytoskeleton**, a network of tubules within a cell that cause chromosomes to move during the cell cycle
  - **Cell adhesion**, where cells in the same tissue stick together
  - **Hormones**, chemical messengers that are secreted in one part of the body to have an effect elsewhere
  - **Compaction of DNA** in chromosomes for storage, caused by **histone** proteins
  - The immune response produces **antibodies**, the most diverse group of proteins
  - Membrane transport **channel and carrier proteins** that determine which substances can pass across a membrane

- **Cell receptors**, which are binding sites for hormones, chemical stimuli such as tastes, and for other stimuli such as light and sound

Examples of polypeptides

Rubisco

- **R**ib**u**lose **Bis**phosphate **C**arb**o**xylase
- An enzyme that catalyses the **fixing of CO_2 from the atmosphere** during photosynthesis
- Composed of **16 polypeptide chains** as a **globular** protein
- This is **the source of all organic carbon**, so Rubisco is arguably the most important enzyme in nature!
- The **most abundant enzyme on Earth** as it's present in all leaves
- Rubisco is **a very slow catalyst**, but it's the most effective to have evolved so far to fulfil this vital function

Insulin

- A **hormone** produced and secreted by β-cells in the **pancreas**
- Binds to insulin receptors (on liver, fat and muscle cells) reversibly, causing **absorption of glucose from the blood**
- Composed of **2 polypeptide chains** as a **short, globular protein**

Immunoglobulins

- Also known as **antibodies**
- They have a **generic 'Y' shape**, with specific binding sites at the two tips of the 'Y'
- They bind to specific antigens
- The binding areas of immunoglobulins are **highly variable**, meaning that antibodies can be produced **against millions of different antigens**
- Immunoglobulins (as the name suggests) are **globular** and are the **most diverse range of proteins**

Rhodopsin

- A **pigment in the retina** of the eye
- A **membrane protein** that is expressed in rod cells
- Contains a light-sensitive part, **retinal**, which is derived from **Vitamin A**
- A photon of **light causes a conformational change** in rhodopsin, which sends a nerve impulse along the optic nerve to the **central nervous system**

Collagen

- A **fibrous protein** made of **three separate polypeptide chains**
- The **most abundant protein in the human body** - approximately 25%
- Fibres **form a network** in skin, blood vessel walls and connective tissue that can **resist tearing forces**
- Plays a role in **teeth** and **bones**, helping to **reduce their brittleness**

Spider Silk

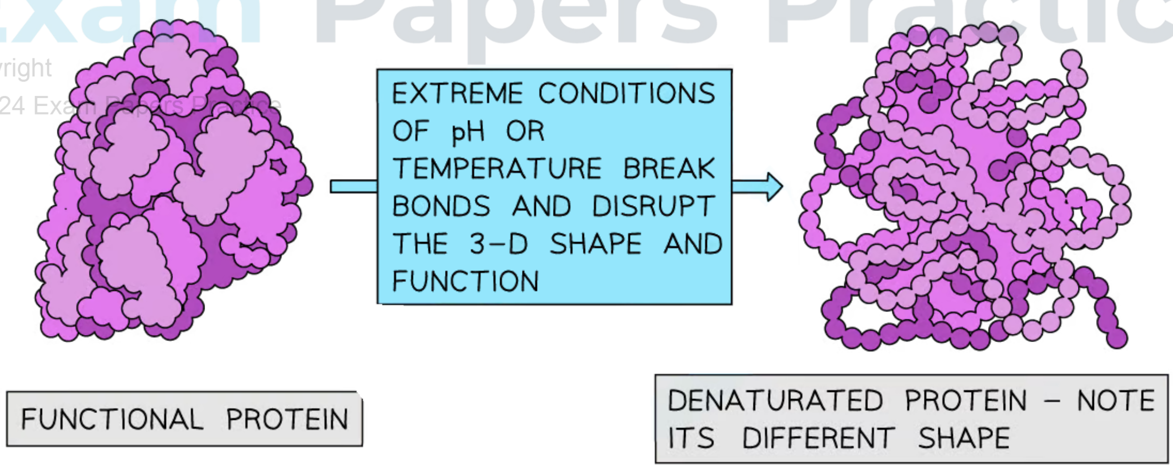
- The silk used by spiders to suspend themselves and create the spokes of their webs is as **strong as steel wire** though considerably lighter
- Contains **rope-like, fibrous parts** but also **coiled parts** that stretch when under tension, helping to **cause extension** and **resist breaking**
- Does not denature easily at extremes of temperature
- Has many attractive aspects for **engineering** and **textile product design** thanks to its **strength** and **low weight**
- Can be **genetically engineered** to be **expressed in goats' milk** as spiders can't be farmed on a large enough scale
- Other kinds of spider silk protein are **tougher** though lack the tensile strength, e.g. the silk they use to encase their prey after capture

Protein Structure: Effect of pH & Temperature

Protein Structure: Effect of pH & Temperature

- Proteins structure is sensitive to changes in the environment, particularly **temperature** and **pH changes**
- The **precise structure** of a protein is dependent on the ionic interactions, hydrogen bonds and other intermolecular forces between polypeptide chains being intact
- **Denaturation** may occur by temperature and pH extremes that interfere with these bonds
  - Denaturation is the irreversible change of protein conformation
- The bonds that form **between different R groups** are **relatively weak** (compared to the peptide bonds that hold the amino acids in sequence)
- These bonds can be **broken easily**, which can cause the **conformation** of the protein to change and denaturation
- The **altered protein shape** may affect its **function**, **physical state** and general usefulness in its original role
- A certain pH is considered as an optimum for a particular protein, because at that pH, the protein's 3D structure is not denatured
- Denaturation is almost always **irreversible**
  - The protein **cannot be re-formed** in its original conformation by reversing the change in conditions
  - However, **small denaturations** and **renaturations** are possible in certain proteins to respond to small fluctuations in pH e.g. haemoglobin

Denaturation of a protein diagram



The effect of heat and pH on the shape and function of a globular protein

Denaturation in action

- Denaturation can be seen most easily by looking at the **changes in an egg white** as the egg is fried or poached
- Egg white is mainly the protein **albumin**
- The **hydrophobic amino acids** in albumin are at the centre of the molecule in its normal state, so albumin is soluble
- Heating causes the hydrophobic amino acids to appear **at the edges**, where they cause the protein to become **insoluble**
- A harder, solid layer forms, which is the **cooked white**
- Similar events occur in the proteins of the **egg yolk** as it cooks
- Denaturation also occurs in the **stomach**, where the low pH (pH2) causes **proteins in the diet to become denatured** on their way to being fully hydrolysed further down the digestive system
- The stomach enzyme **pepsin**, a protein-digesting enzyme has an optimum pH of 2 for this reason
- Certain extremophiles have evolved to have proteins that are stable even at extreme pH or temperature
  - Eg. *Thermus aquaticus*, a **bacteria that lives in hot springs** at 80°C
  - This temperature would denature most other proteins
- **Denaturation of enzymes** can be used as part of experiments to measure enzyme activity
  - For example, **an experiment to establish the optimum pH or temperature** of an enzyme e.g. pepsin or lipase
- Many drugs are proteins that **cannot be taken by mouth**, because the protein will be **denatured by stomach acid**
  - These drugs should be **delivered in another way** e.g. by **direct injection** into the blood

Exam Tip

Remember to avoid confusing the bonds that hold a protein's shape together with the peptide bonds that attach each amino acid in sequence. Picture the peptide bonds holding the amino acids in a straight chain, then the other bonds and forces holding the chain in its folded, 3D structure.