3.13 Amino Acids, Proteins and DNA

**General structure of an α amino acid**

\[
\text{NH}_2 - \text{CH} - \text{CO}_2 \text{H}
\]

The R group can be a variety of different things depending on what amino acid it is. The alpha in ‘α’ amino acid means both NH\(_2\) and COOH groups are joined to the same C.

The simplest amino acid is glycine, where the R is an H:

\[
\text{NH}_2 - \text{CH} - \text{CO}_2 \text{H}
\]

**Optical Activity**

All amino acids, except glycine, are chiral because there are four different groups around the C. They rotate plane polarised light.

**Amino Acids**

- **NH\(_2\)CH\(_2\)CO\(_2\)H**
  - (2-)aminoethanoic acid
- **NH\(_2\)CH\(_2\)CO\(_2\)H**
  - 2-aminobutanedioic acid
- **NH\(_2\)CH\(_2\)CO\(_2\)H**
  - 2-amino-3-hydroxypropanoic acid
- **NH\(_2\)CH\(_2\)CO\(_2\)H**
  - 2,6-diaminohexanoic acid
- **NH\(_2\)CH\(_2\)CO\(_2\)H**
  - Lycine (basic)
- **NH\(_2\)CH\(_2\)CO\(_2\)H**
  - Aspartic acid

**Naming amino acids**

You do not need to know any common names for the 20 essential amino acids. You should, however, be able to name given amino acids using IUPAC organic naming.

**Zwitterions**

The no charge form of an amino acid never occurs. The amino acid exists as a dipolar zwitterion. Amino acids are often solids. The ionic interaction between zwitterions explains the relatively high melting points of amino acids as opposed to the weaker hydrogen bonding that would occur in the no charge form.

**Acidity and Basicity**

The amine group is basic and the carboxylic acid group is acidic.

Species in alkaline solution

\[
\text{H}_2\text{N} - \text{C} - \text{CO}_2\text{H} \quad \text{High pH}
\]

Species in neutral solution

\[
\text{H}_3\text{N}^+ - \text{C} - \text{CO}_2\text{H} \quad \text{Low pH}
\]

Species in acidic solution

\[
\text{H}_3\text{N}^+ - \text{C} - \text{CO}_2\text{H} \quad \text{Low pH}
\]

Amino acids act as weak buffers and will only gradually change pH if small amounts of acid or alkali are added to the amino acids.

\[
\text{NH}_3\text{CH}_2\text{CO}_2\text{H} + \text{HCl} \rightarrow \text{Cl}^- \text{NH}_3^+\text{CH}_2\text{CO}_2\text{H}
\]

\[
\text{NH}_3\text{CH}_2\text{CO}_2\text{H} + \text{NaOH} \rightarrow \text{NH}_2\text{CH}_2\text{CO}_2\text{Na}^+ + \text{H}_2\text{O}
\]

The extra carboxylic acid or amine groups on the R group will also react and change form in alkaline and acid conditions.

**Zwitterion**

\[
\text{NH}_2\text{CH}_2\text{CO}_2\text{H} \quad \text{H}^+
\]

Aspartic acid in high pH

**Skeletal formula of lycine in low pH**

\[
\text{NH}_3^+\text{CH}_2\text{CO}_2\text{H}
\]

\[
\text{NH}_3\text{CH}_2\text{CO}_2\text{H}
\]

\[
\text{NH}_3\text{CH}_2\text{CO}_2\text{H}
\]

\[
\text{NH}_3\text{CH}_2\text{CO}_2\text{H}
\]

\[
\text{NH}_3\text{CH}_2\text{CO}_2\text{H}
\]
Dipeptides are simple combination molecules of two amino acids with one amide (peptide) link.

For any two different amino acids there are two possible combinations of the amino acids in the dipeptide.

Other reactions of amino acids

The carboxylic acid group and amine group in amino acids can undergo the usual reactions of these functional groups met in earlier topics. Sometimes questions refer to these.

e.g. Esterification reaction

\[
\text{H}_2\text{N}-\text{C}-\text{CO}_2\text{H} + \text{CH}_3\text{OH} \overset{\text{Strong acid catalyst}}{\longrightarrow} \text{H}_3\text{N}^+ - \text{C}-\text{O-CH}_3 + \text{H}_2\text{O}
\]

If the R group contains an amine or carboxylic acid then these will do the same reactions as the α amine and carboxylic groups.

Hydrolysis of di-peptides/proteins

If proteins are heated with concentrated hydrochloric acid or concentrated strong alkalis they can be hydrolysed and split back into their constituent amino acids.

The composition of the protein molecule may then be deduced by using TLC chromatography.
Chromatography of Amino Acids

A protein can be split into amino acids by reacting with concentrated hydrochloric acid.

The mixture of amino acids can be separated by chromatography and identified from the amount they have moved.

Method: Thin-layer chromatography

a) Wearing gloves, draw a pencil line 1 cm above the bottom of a TLC plate and mark spots for each sample, equally spaced along line.
b) Use a capillary tube to add a tiny drop of each solution to a different spot and allow the plate to air dry.
c) Add solvent to a chamber or large beaker with a lid so that is no more than 1cm in depth.
d) Place the TLC plate into the chamber, making sure that the level of the solvent is below the pencil line. Replace the lid to get a tight seal.
e) When the level of the solvent reaches about 1 cm from the top of the plate, remove the plate and mark the solvent level with a pencil. Allow the plate to dry in the fume cupboard.
f) Spray paper with ninhydrin and put in oven. Draw around them lightly in pencil.
g) Calculate the Rf values of the observed spots.

\[ R_f = \frac{\text{distance moved by amino acid}}{\text{distance moved by the solvent}} \]

Measure how far each spot travels relative to the solvent front and calculate the \( R_f \) value. Each amino acid has its own \( R_f \) value. Compare \( R_f \) values to those for known substances.

Some substances won’t separate because similar compounds have similar \( R_f \) values. So some spots may contain more than one compound.

See chapter 3.16 chromatography for two directional TLC chromatography.

Wear plastic gloves to prevent contamination from the hands to the plate.

pencil line – will not dissolve in the solvent.
tiny drop – too big a drop will cause different spots to merge.

Depth of solvent– if the solvent is too deep it will dissolve the sample spots from the plate.
lid– to prevent evaporation of toxic solvent.

Will get more accurate results if the solvent is allowed to rise to near the top of the plate but the \( R_f \) value can be calculated if the solvent front does not reach the top of the plate.

Dry in a fume cupboard as the solvent is toxic.

If ninhydrin is sprayed on an amino acid and then heated for 10 minutes then red to blue spots appear. This is done because amino acids are transparent and cannot be seen. Can also shine UV light to see the position of spots.
Proteins
Primary Structure of Proteins

Proteins are polymers made from combinations of amino acids. The amino acids are linked by peptide links, which are the amide functional group.

The primary structure of proteins is the sequence of the 20 different naturally occurring amino acids joined together by condensation reactions with peptide links.

Secondary Structure of a Protein.

Secondary Structure: α-helix

The 3D arrangement of amino acids with the polypeptide chain in a corkscrew shape is held in place by Hydrogen bonds between the H of –Nδ-Hδ+ group and the –O of Cδ+=Oδ- of the fourth amino acid along the chain.

The R-groups on the amino acids are all pointed to the outside of the helix.

Secondary Structure: β-Pleated Sheet Structure of Proteins

The secondary structure can also take the form of a β-pleated sheets.

The protein chain folds into parallel strands side by side.

The protein chain is held into a the pleated shape by Hydrogen bonds between the H of –N-H group and the –O of C=O of the amino acid much further along the chain in the parallel region.
Tertiary Structures of Proteins

The tertiary structure is the folding of the secondary structure into more complex shapes. It is held in place by interactions between the R-side groups in more distant amino acids. These can be a variety of interactions including hydrogen bonding, sulfur-sulfur bonds and ionic interactions.

Hydrogen bonds

![Hydrogen bonds](image)

Hydrogen bonds could form between two serine side chains in different parts of the folded chain. (Other amino acids chains can also hydrogen bond)

Ionic interactions

![Ionic interactions](image)

Ionic interactions could form between acidic amino acids such as aspartic acid and basic amino acids such as lysine. There is a transfer of a hydrogen ion from the -COOH to the -NH$_2$ group to form zwitterions just as in simple amino acids.

Sulfur bridges

![Sulfur bridges](image)

If two cysteine side chains end up near each other due to folding in the protein chain, they can react to form a sulfur bridge, which is a covalent bond.

You don’t need to learn the details of these interactions on this page but understand the principles of how the tertiary structure is held in place.
Enzymes

Enzymes are proteins.

The active site of an enzyme is usually a hollow in the globular protein structure into which a substrate molecule can bond to the amino acid side chains through a variety of interactions including:

- Hydrogen bonding
- Van der waals forces
- Permanent dipole forces
- Ionic interactions

The interactions need to be strong enough to hold the substrate for long enough for the enzyme catalysed reaction to occur, but weak enough for the product to be released.

Only substrate molecules with the right shape and correct positions of functional groups will fit and bind to the active site- called the **lock and key hypothesis**

### Stereospecific active site

If the substrate is chiral then its likely that only one enantiomer will fit in the enzyme and so only one isomer will be catalysed.

### Drugs as Enzyme Inhibitors

Many drugs act as an enzyme inhibitor by blocking the active site. The inhibitor will often bind to the active site strongly so stopping the substrate attaching to the enzyme.

(Some Inhibitors can also attach elsewhere on the enzyme but in doing so can change the shape of the active site which also stops its effectiveness)

Computers can be used to help design such drugs.
DNA

**Key molecules in DNA**

- **Phosphate ion**
  
  \[
  \text{HO-PO4-PO4-O} \\
  \]

- **2-deoxyribose (a pentose sugar)**
  
  \[
  \text{HO-CH2-OH} \quad \text{HO-CH2-OH} \quad \text{HO-CH2-OH} \\
  \]

The 4 bases

- **Adenine (A)**
  
  \[
  \text{NH2} \\
  \]

- **Guanine (G)**
  
  \[
  \text{NH2} \quad \text{NH} \quad \text{NH} \quad \text{NH} \\
  \]

- **Thymine (T)**
  
  \[
  \text{H3C} \quad \text{O} \quad \text{N} \quad \text{N} \quad \text{N} \quad \text{N} \quad \text{N} \\
  \]

- **Cytosine (C)**
  
  \[
  \text{NH2} \quad \text{NH} \quad \text{NH} \quad \text{NH} \\
  \]

The structures of these substances are given in the Chemistry Data Booklet.

**Nucleotides**

A nucleotide is made up from a phosphate ion bonded to 2-deoxyribose which is in turn bonded to one of the four bases adenine, cytosine, guanine and thymine.

Although the structures will be given in the data sheet you need to learn which atoms on the base joins on to the sugar and how the sugar attaches to the phosphate ions.
A single strand of DNA (deoxyribonucleic acid) is a polymer of nucleotides linked by covalent bonds between the phosphate group of one nucleotide and the 2-deoxyribose of another nucleotide.

This results in a sugar-phosphate-sugar-phosphate polymer chain with bases attached to the sugars in the chain.

Carefully learn how these join together.

DNA exists as two complementary strands of the sugar phosphate polymer chain arranged in the form of a double helix.

**Complementary** means the two strands must have base sequences that match all A to T and C to G.

Hydrogen bonding between base pairs leads to the two complementary strands of DNA.

- Guanine pairs with cytosine by 3 hydrogen bonds.
- Adenine pairs with thymine by 2 hydrogen bonds.
**Cisplatin**

The Pt(II) complex cisplatin is used as an anticancer drug.

The cisplatin version only works as two chloride ions are displaced and the molecule joins on to the DNA. In doing this it stops the replication of cancerous cells.

Cisplatin prevents DNA replication in cancer cells by a ligand replacement reaction with DNA in which a dative covalent bond is formed between platinum and a nitrogen atom on guanine.

The N and O atoms marked in red can’t bond to cis-platin as they are involved in the bonding within the DNA molecule.

Cisplatin can also prevent the replication of healthy cells by bonding on to healthy DNA which may lead to unwanted side effects like hair loss. Unwanted side effects can be minimised by giving cis-platin in small doses. Society needs to assess the balance between the benefits and the adverse effects of drugs, such as the anticancer drug cisplatin.