Introduction to Biochemistry, Cell and Molecular Biology I

Losiana Nayak

Indian Statistical Institute

http://www.isical.ac.in/~losiana_t/
Biochemistry:

Chemistry that deals with the chemical compounds and processes occurring in organisms. It deals with

“Molecular Basis of life”

Ref: http://www.britannica.com/
Points to Study...

- Carbohydrates
- Proteins
- Lipids
- Nucleic acids
Carbohydrates:

Functional unit- Monosaccharides

Chemically they are aldehydes or ketones having two or more hydroxyl groups; hence divided into two categories:

- Aldoses
- Ketoses
The Aldoses

D-Glyceraldehyde

D-Erythrose

D-Threose

D-Ribose

D-Arabinose

D-Xylose

D-Lyxose

D-Allose

D-Altrose

D-Glucose

D-Mannose

D-Gulose

D-Idose

D-Galactose

D-Talose
The Ketoses

[Diagram showing the structure of different ketoses, including Dihydroxyacetone and its derivatives to D-Ribulose, D-Erythulose, D-Psicose, D-Fructose, D-Sorbose, and D-Tagatose.]
Disaccharides

Contain two molecules of monosaccharide

Example:
- Sucrose [glucose + fructose]
- Lactose [galactose + glucose]
- Maltose [glucose + glucose]
Polysaccharides

Made up of multiple units of monosaccharide

Example:

Glycogen
Starch
Dextran
Cellulose
Role of Carbohydrates in cellular environment

- Serve as energy stores (Glycogen, Starch)
- Act as fuel (ATP is a phosphorylated sugar derivative)
- Metabolic intermediate
- Structural element in cell wall
- Play key roles in cell-cell recognition process
  
  [Fertilization begins with binding of sperm to a specific oligosaccharide on the surface of an egg]
Special note:

Carbohydrates can exist in a complex form with proteins and lipids, i.e., glycoproteins and glycolipids respectively.
Lets go to Proteins...
Origin of the word protein:

Derived from greek word *proteios*, which means “of the first rank”. Due to major role of this class of biomolecules in every aspect of life such a name was given to them. Jons J. Berzelius (1838) coined the term.
Proteins:

Structural unit - amino acid

20 different type of amino acids make all the proteins!
Aliphatic amino acids

Hydrophobic in nature.
Glycine (R=H) - Simplest aa
Alanine (R=CH₃)
Valine
Leucine
Isoleucine
Proline (Contains hetero atom N, hence less hydrophobic in nature)
Hydroxyl aliphatic amino acids

Hydrophilic in nature

Serine

Threonine
Aromatic amino acids

Hydrophobic in nature
- Phenylalanine
- Tryptophan
- Tyrosine

Presence of benzene ring is the characteristic feature
Polar and highly hydrophilic
Lysine, Arginine, Histidine
Acidic Amino acids

Aspartic acid
Glutamic acid
Amides

Amino derivatives of aspartate and glutamate

Asparagine
Glutamine
Amino acids containing sulphur

Cysteine

Methionine

N.B. \[ \text{Cystine} = \text{Cysteine} + \text{Cysteine} \]
<table>
<thead>
<tr>
<th>Name</th>
<th>Single letter abbreviation</th>
<th>Three letter abbreviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Alanine</td>
<td>A</td>
<td>Ala</td>
</tr>
<tr>
<td>2. Cysteine</td>
<td>C</td>
<td>Cys</td>
</tr>
<tr>
<td>3. Aspartate</td>
<td>D</td>
<td>Asp</td>
</tr>
<tr>
<td>4. Glutamate</td>
<td>E</td>
<td>Glu</td>
</tr>
<tr>
<td>5. Phenylalanine</td>
<td>F</td>
<td>Phe</td>
</tr>
<tr>
<td>6. Glycine</td>
<td>G</td>
<td>Gly</td>
</tr>
<tr>
<td>7. Histidine</td>
<td>H</td>
<td>His</td>
</tr>
<tr>
<td>8. Isoleucine</td>
<td>I</td>
<td>Ile</td>
</tr>
<tr>
<td>9. Lysine</td>
<td>K</td>
<td>Lys</td>
</tr>
<tr>
<td>10. Leucine</td>
<td>L</td>
<td>Leu</td>
</tr>
<tr>
<td>11. Methionine</td>
<td>M</td>
<td>Met</td>
</tr>
<tr>
<td>12. Asparagine</td>
<td>N</td>
<td>Asn</td>
</tr>
<tr>
<td>13. Proline</td>
<td>P</td>
<td>Pro</td>
</tr>
<tr>
<td>14. Glutamine</td>
<td>Q</td>
<td>Gln</td>
</tr>
<tr>
<td>15. Arginine</td>
<td>R</td>
<td>Arg</td>
</tr>
<tr>
<td>16. Serine</td>
<td>S</td>
<td>Ser</td>
</tr>
<tr>
<td>17. Threonine</td>
<td>T</td>
<td>Thr</td>
</tr>
<tr>
<td>18. Valine</td>
<td>V</td>
<td>Val</td>
</tr>
<tr>
<td>19. Tryptophan</td>
<td>W</td>
<td>Trp</td>
</tr>
<tr>
<td>20. Tyrosine</td>
<td>Y</td>
<td>Tyr</td>
</tr>
</tbody>
</table>
1° structure - amino acid sequence
2° structure - alpha helices, beta sheets and random coils
3° structure - represent the folded protein
4° structure - More than one polypeptide chain exist. Individual unit is known as motif or domain.
How amino acids exist in a chain?

The answer is: Peptide linkage
α₁-carboxyl group

α₂-amino group

amino terminal

carboxy terminal

Peptide bond
Polypeptide chain is...

A number of amino acids attached to each other by peptide linkage.

ATGHyKILQPRSwRHiSAEdNSwQ

This form represents primary structure of a protein.
Secondary structure of proteins

Does a polypeptide chain attain some periodic structures?

YES

Experimentally confirmed by scientists Pauling and Corey in 1951. Otherwise they are known as protein secondary structures.
Types of 2\(^0\) structures: \(\alpha\)-helix

- Hydrogen bond exists between carboxy group of \(n^{th}\) aa and amino group of \((n+4)^{th}\) aa.
- Each turn contains 3.6 aas
- Gap between two aas is 1.5 Å
- 75% of Myoglobin and Hemoglobin are \(\alpha\)-helix.
Individual unit: β strand. Number of β strands are arranged like sheets of paper in a β-pleated sheet. Whole Structure is stabilized by hydrogen bonds between different strands.

The strands can run in same or opposite direction. According the structure is named parallel or antiparallel β sheet. They are fully extended structures. Distance between two successive aa is 3.5 Å.

Example: Silk fibroin

Types of $2^0$ structures: β-pleated sheets
Types of $2^0$ structures: Random coils

They constitute intermediary stretches between $\alpha$ helices and $\beta$ sheets.
Tertiary Structure

- exhibit one or more different type of secondary structure
- disulphide bonds and vanderwaal’s (weak) interactions come into picture.
- They enable protein folding
- The difference between secondary and tertiary structure is a very fine line and depend on matter of taste
Quaternary structure

Represent association of polypeptide subunits in a defined geometric configuration

\[ \alpha_1 \quad \alpha_2 \]
\[ \beta_1 \quad \beta_2 \]

\( \alpha = \text{same structure} \)

\( \alpha \neq \beta \)
Biological functions of Proteins

- **Enzyme catalysis** (nearly all enzymes are proteins)
- **Transport and storage** (ex: Hemoglobin and Myoglobin)
- **Motion** (muscle movement: actin/myosin; chromosome movement in mitosis; sperm movement etc.)
- **Mechanical support** (ex: skin, bone)
- **Immune protection** (antibodies)
- **Signal transfer** (transmission of nerve impulses)
- **Growth and differentiation in a controlled way** (ex: growth factor proteins)
Special note:

4° structure not required for all proteins to function- many proteins may have only 2° or 3° structure.

Proteins can exist in a complex form with carbohydrates. (Proteoglycans)
Welcome to the Lipid Arena
Characteristics of lipids

- Insoluble in water and soluble in organic solvents
- Contain long aliphatic hydrocarbon chains or benzene rings as side chains
- Overall divided into triglycerides and compound lipids
Triglycerides

- Triesters of fatty acids
- Neutral fats, i.e., glycerol triesters (found in adipose tissue) and waxes, i.e., alcohol triesters (ex: beeswax) belong to this category
Compound lipids

- Phospholipids,
- Sphingolipids
- Amphipathic in nature

Phospholipid structure:

- Hydrophilic head
- Hydrophobic tail
- Fatty acids
- Alcohol
- Hydrophilic head

[Diagram of phospholipid structure with labels]
serve as structural components of biological membranes
provide energy reserves (9 kcal/mol), predominantly in the form of triacylglycerols
serve as vitamins and hormones
The nucleic acids
They form the genetic material.

- DNA (deoxy ribo nucleic acid)
- RNA (ribo nucleic acid)

**Difference between DNA and RNA?**
A Nucleotide
Adenosine Mono Phosphate (AMP)

Nucleotide

Sugar

Base

Nucleoside
Two Families of Bases

Purines
- Adenine
- Guanine

Pyrimidines
- Thymine (DNA)
- Uracil (RNA)
- Cytosine
Scientists James Watson and Francis Crick first proposed the double helical structure of DNA in 1953.

Awarded Nobel Prize in 1962 for medicine and physiology.
Types of RNA

- m- RNA (messenger RNA)
- t- RNA (transfer RNA)
- r- RNA (ribosomal RNA)
The concept of mRNA was formulated by scientists Francois Jacob and Jacques Monod in 1961.

Eukaryotic mRNA

5' Cap

5' G

Protein Coding Region

AAAAA 3'

3' Poly A Tail
Transfer RNA

Base sequence of yeast alanine tRNA was first determined by scientist Robert Holley (1965).

Most of the tRNAs are 73-93 nucleotides long and have complex folded structures.
Transfer RNA (tRNA)

Acceptor Arm - A specific amino acid is attached to the 3’ end.

D Arm - Contains dihydrouridin!

TψC arm - ψ stands for pseudouridin!

Extra Arm - May vary in size.

Anticodon
Ribosomal RNA

- Present in ribosome
- Critical for ribosomal architecture and function
- Have role in protein synthesis
- They are of three types, i.e., 5S, 16S and 23S.
Reference

1. **Biochemistry** by Lubert Stryer
2. **Cell and Molecular Biology** by De Roberties and De Roberties

Some Slides are taken from

Timothy G. Standish, Ph. D.