The organic molecules of life are divided into four classes:

<table>
<thead>
<tr>
<th>POLYMERS</th>
<th>MONOMERS</th>
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<tbody>
<tr>
<td>1. Carbohydrates</td>
<td>building blocks are:</td>
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<tr>
<td>2. Lipids</td>
<td>building blocks are:</td>
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<tr>
<td>3. Nucleic Acids</td>
<td>building blocks are:</td>
</tr>
<tr>
<td>4. Proteins</td>
<td>building blocks are:</td>
</tr>
</tbody>
</table>

- **Hydrolysis** → adding water to break down the organic molecules (POLYMERS) into their building blocks (MONOMERS)
  
  e.g. Carbohydrates into glucose molecules

- **Dehydration Synthesis** → removing a water molecule water to join building blocks (MONOMERS) to form organic molecules (POLYMERS)
  
  e.g. glucose molecules into carbohydrates

http://nhscience.lonestar.edu/biol/dehydrat/dehydrat.html

### Carbohydrates

- Are a group of molecules that includes **sugars and starches**

- All carbohydrates contain **carbon (C), hydrogen (H) and oxygen (O)**

- **All carbohydrate molecules are made up of one or more monomers called monosaccharides.**

- Carbohydrates have a variety of important functions in living organisms:
  1) **Energy storage, Fuels**
    - Foods rich in carbohydrates include: breads, pasta, rice, corn, oats, fruit and veggies.
  2) **Structural**
    - Components of nucleotides, animal connective tissue, plant and bacterial cell walls, arthropod exoskeletons
  3) **Cell to cell communication and cell identification**
    - Carbohydrates are located on the outer surface of the cell membrane for the above purpose

**Monosaccharides “Simple Sugars”**

- **Single-chain or single-ring** structures containing 3-7 carbon atoms
  
  E.g. Glucose \((C_6H_{12}O_6)\), a hexose sugar, is blood sugar.
E.g. Ribose ($C_5H_{10}O_5$), a pentose sugar, is found in ribonucleic acid (RNA).

- **Empirical formula** for a monosaccharide:

E.g. **Glucose**, aka blood sugar, is a 6 carbon sugar \( (n=6) \)

- The chemical formula of glucose is: \( C_6H_{12}O_6 \)

![Glucose structure](image)

E.g. **Ribose** is a 5 carbon sugar \( (n=5) \) found in RNA molecules.

- The chemical formula of ribose is: \( C_5H_{10}O_5 \)

![Ribose structure](image)

**Disaccharides “Double Sugars”**

- A disaccharide is formed when **2 monosaccharides are joined by dehydration synthesis**.

- During dehydration synthesis a bond between 2 monosaccharides is created when one monosaccharide loses a hydroxyl group (-OH) and another loses a hydrogen (-H) → forming a water (dehydration)

- **Disaccharides must be digested into monosaccharides before they can be absorbed from the digestive tract and into the blood**

- A **hydrolysis reaction** is used to break a disaccharide apart into 2 monosaccharides.
Polysaccharides “Many Sugars”

- Polysaccharides are long carbohydrate chains made up of individual monosaccharides that have been linked together by dehydration synthesis
- They are fairly insoluble, making them great storage molecules

Starch

- Storage form of glucose inside plant cells
- When we eat starchy foods such as potatoes or grains the starch must be digested so its glucose monomers can be absorbed and used to make energy
- Composed of many glucose monomers in straight chains, with only a few branched chains
Glycogen

- **Storage form of glucose** in animals and humans
- **Stored in muscle and liver cells**
- **Is a highly branched large molecule**
- **When blood sugar levels drop, liver cells break down glycogen and release its glucose monomers into the blood**

**Question to Ponder....**

How does the highly branched structure of glycogen make it both an effective storage molecule and allow us to an almost instant access to glucose fuel?

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**What is the key difference between starch and glycogen??**

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Cellulose

- **Found in plant cell walls** – gives them rigidity.
- **We are unable to digest it, BUT it acts as an important source of fiber that helps move feces through the colon**
- **Is a linear molecule with an alternating ester bond that humans cannot break**
Lipids

- Lipids are **insoluble** (do not dissolve) **in polar solvents like water**
- Like carbohydrates, **all lipids contain carbon (C), oxygen (O) and hydrogen (H)**.
- The most familiar are found in fats (animal source) and oils (plant source)

Main Functions:

1. Used for **long-term energy storage** – they give the most energy per unit gram of food
2. **Insulate against heat loss**
3. Form a **protective cushion around major organs** E.g. Kidneys
4. **Storage of fat soluble vitamins** – E, K, A & D

3 Main Types:

1. **Neutral Fats (Triglycerides)**
2. **Phospholipids**
3. **Steroids**

Neutral Fats (Triglycerides)

- The neutral fats are commonly known as **fats when solid or oils when liquid**
- Deposits of neutral fats are found mainly beneath the skin, where they insulate the deeper body tissues from heat loss and protect them from mechanical trauma
- As neutral fats are digested into their monomers, they release large amounts of energy our body can use
They are produced when 1 glycerol and 3 fatty acid chains are joined by dehydration synthesis.
Because of the 3:1 fatty acid to glycerol ratio, the neutral fats are also called triglycerides.

Saturated Fatty Acids
- Fatty acid chains with single covalent bonds between carbon atoms
- Solid at room temperature.
- Usually from animal sources i.e. Butter, lard

Unsaturated Fatty Acids
- Fatty acid chains with one (monounsaturated) or more (polyunsaturated) double bonds between carbons.
- Liquid or soft at room temperature i.e. oils
- Usually from plant sources
- Hydrogenation (adding hydrogens = trans fat) can convert them to margarine and Crisco.

CBC Radio Interview on Fatty Acids
Phospholipids

- Phospholipids are the **chief component of cell membranes**
- Phospholipids are **modified triglycerides**
- **Phospholipids contain a phosphate group and 2 fatty acid chains**
- The “head” region is **hydrophilic** (attracts water or other charged ions).
- The “tail” region is **hydrophobic** (“phobic” repels water).
- These properties result in a **2 layered membrane** often called a “**phospholipid bilayer**”.
- The membrane which surrounds **ALL** of our cells is a phospholipid bilayer and maintains a barrier between extracellular (“extra” outside) and intracellular (“intra” inside) fluids.
Steroids

- Structurally steroids are very different from fats
- Basic structure is 4 interlocking hydrocarbon rings
- The single most important molecule in our steroid chemistry is cholesterol
- We ingest cholesterol in animal products such as eggs, meat, and cheese, and our liver produces a certain amount
- Main Functions of Cholesterol:
  1. Cholesterol is a key component to plasma membranes in animal cells - plays a role in membrane fluidity (more on that when we learn about cells).
  2. Cholesterol is the precursor to the sex hormones estrogen and testosterone
  3. Raw material for the synthesis of vitamin D and bile salts.

Did You Know?

Cholesterol has earned a bad reputation because of its role in arteriosclerosis – clogging and hardening of the arteries. Although excessive amounts of cholesterol in the diet can lead to this dangerous condition, it is absolutely essential for human life. For example, without sex hormones such as estrogen and testosterone, reproduction would be impossible, and a total lack of corticosteroids produced by the adrenal gland is fatal.
Functions of Proteins

- **Enzymes** - biological catalysts that speed up chemical reactions in our bodies. e.g. synthesis and hydrolysis, DNA replication, digestion, and blood clotting.

- **Structural proteins** - are found throughout the body. e.g. keratin builds hair and nails, collagen gives strength to skin, cartilage, ligaments, tendons, muscle fibers (skeletal, smooth, and cardiac) are composed of actin and myosin proteins.

- **Membrane proteins** - The plasma membrane of cells has numerous embedded proteins that act as channels or pores, carriers, and pumps to move molecules into and out of the cell.

- **Chemical messengers** - peptide hormones control functions such as metabolic rate, growth, stress response, blood glucose levels, immune function, and circadian rhythms.

- **Plasma proteins** - plasma is the liquid portion of blood making up 55% of the volume. Plasma is mainly water and contains 7-8% proteins.
  - Albumin helps maintain blood volume and pressure
  - Globulins help fight infection
  - Fibrinogen forms blood clots

Structure of Proteins

Amino Acids

- **Proteins** are linear polymers made from monomers called amino acids.
- There are 20 **common amino acid**
- The 12 amino acids our body can produce are called **non-essential amino acids**
- The 8 amino acids we must obtain from our food are called **essential amino acids**

Chemical Structure of an Amino Acid

- All amino acids have the same structural components. A central carbon atom is linked to 4 different chemical groups:
  1) **Hydrogen atom**
  2) **Amine group** –NH2
  3) **Carboxylic acid group** –COOH
  4) **R-group** (remainder group)
- **Differences in the "R" group make each amino acid chemically unique**
- We can think of the 20 amino acids as a 20-letter "alphabet" used in specific combinations to form proteins.
- In our bodies there are thousands of proteins and **everyone has a specific and exact combination of amino acids**

**Peptide Bonds**

- Proteins are polymers, i.e. long linear chains (no branches) of amino acids joined together by **dehydration synthesis**
- The bond which is formed between 2 amino acids is called a **peptide bond**
• **Dipeptide** – when 2 amino acids are linked by peptide bonds
• **Polypeptide** – when several or many amino acids are linked by peptide bonds
• Most proteins contain 100 – 10 000 amino acids

For example:
• Oxytocin is a protein hormone that stimulates a woman’s uterus to contract during labour.
• It is a small polypeptide chain made up of 9 amino acids linked together by peptide bonds.

### Levels of Protein Organization

• Proteins have 4 different structures or levels of organization.

**Primary Structure (1°)**

• **Linear sequence of amino acids that form a polypeptide chain**
• Resembles a strand of beads on a chain.
• **Proteins are not functional in this form**

![Primary Structure Image](image)

**Secondary Structure (2°)**

• **Hydrogen bonds form between the NH and CO groups in amino acids in the primary polypeptide chain**
• **These hydrogen bonds cause the chain to form an alpha helix or a beta pleated sheet**
• A single polypeptide chain may have BOTH types of secondary structure at various places along its length.

![Secondary Structure Image](image)
Tertiary Structure (3°)

- Tertiary structure is achieved **when an alpha helix or pleated sheet, folds up to produce a compact ball-like or globular molecule**
- This structure is maintained by both hydrogen and covalent bonds between amino acids.

Quaternary Structure (4°)

- **When 2 or more polypeptide chains join together to form a single complex protein**
- The oxygen-binding protein haemoglobin has this structure
- Most enzymes have this structure
- **The activity of a protein depends on its specific 3-dimensional structure**

Denaturing Proteins

- The ability of a protein to function correctly directly depends on its 3-dimensional shape
- **When the pH drops below a critical level or our body temperature rises above normal, this can cause hydrogen bonds to break - proteins will unfold and lose their 3-D shape**
- When a tertiary or quaternary protein loses its 3-D shape it **becomes non-functional and is said to be denatured**

  *e.g* When you add acid to milk (lower the pH) the milk curdles because casein proteins found in milk have lost their quaternary structure

  If you cook an egg you are adding excessive heat to the albumin proteins found in egg whites

  High body temperatures (fever) have the potential to cause many different enzymes within the body to denature
The nucleic acids are the largest biological molecules in the body. They are often referred to as the "molecules of life" because they carry all of life’s instructions encrypted in chemical code. This code governs how the body grows, develops, functions, and maintains homeostasis – a state of internal balance.

- There are 2 major classes of nucleic acids in our bodies:
  1) Deoxyribonucleic Acid (DNA)
  2) Ribonucleic Acid (RNA)

- Both DNA and RNA molecules are polymers **constructed from monomers called nucleotides**

- Every nucleotide is made from 3 subunits:
  1. **Phosphate** (phosphoric acid)
  2. **Pentose sugar** (5-carbon sugar)
      - Deoxyribose in DNA
      - Ribose in RNA
  3. **Nitrogen-containing base** (base because their presence raises the pH of a solution)
      - Nitrogenous bases in DNA: cytosine (C), guanine (G), adenine (A), thymine (T)
      - Nitrogenous bases in RNA: cytosine (C), guanine (G), adenine (A), uracil (U)

- Examine the chemical structure of a nucleotide below:
Deoxyribonucleic Acid (DNA)

- Chemically, DNA looks a lot like a “twisted ladder” – two long polymers made up of adjoining nucleotides that twist to form a double helix.
- The 2 sides of the ladder are referred to as the “sugar-phosphate backbones”
- The “rungs” of the ladder are formed when 2 complementary nitrogenous bases are joined by weak hydrogen bonds
- Adenine (A) always hydrogen bonds to ___________ (complementary bases)
- Cytosine (C) always hydrogen bonds to ___________ (complementary bases)
- The sugar of one nucleotide and the phosphate of another are held together by strong phosphodiester bonds
A Closer Look at DNA

- DNA’s 4 nitrogenous bases (C, G, A, T) can be separated into 2 categories:
  1) **Purines**
     - Have a 2-ring structure
     - E.g. Guanine (G) and Adenine (A)
  2) **Pyrimidines**
     - Have a single-ring structure
     - Ex. Cytosine (C) and Thymine (T)

- One **purine always hydrogen bonds to a pyrimidine.**
- The complementary base pair A – T forms _____ hydrogen bonds
- The complementary base pair C – G forms _____ hydrogen bonds

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Did You Know?

- Our entire DNA sequence would fill 200 1,000 page New York telephone directories.
- If unwound and tied together, the strands of DNA in one cell, would stretch almost six feet long but would only be 50 trillionths of an inch wide.
- If you uncoil the DNA in all of your cells, you could reach the moon 6000 times!
- There are 3 billion letters in the human genome and it would take a person who could type 60 words per minute, 8 hours a day, around 50 years to type out the human genome.
- In 2003, the human genome was completely sequenced, down to the last nucleotide.

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- DNA has a multi-coiled structure that allows an incredible amount of it to be packed into the tiny space within a cell’s nucleus
- **When cells are not dividing, DNA is called chromatin** – a loosely coiled tangled mess of DNA inside the nucleus
- **When human cells are preparing to divide,** their DNA is tightly coiled into 46 X shaped chromosomes that are arranged in 23 pairs.
• Each chromosome contains sections of DNA called **genes**
• **Each gene contains a set of instructions to make a specific protein**
Ribonucleic Acid (RNA)

- DNA is simply a storage molecule for genetic information – although DNA contains the instructions for how to build proteins, it is NOT capable of building proteins itself.
- RNA is a “molecular slave” - it uses instructions provided by the genes in DNA to build proteins.
- RNA is made within a cell’s nucleus; however it functions mainly outside of the nucleus.
- RNA is a single-stranded polymer of many nucleotides.
- The pentose sugar in the sugar-phosphate backbone (S-P-S-P-S...etc.) of RNA is ribose.
- The 4 nitrogenous bases found in an RNA molecule are: Cytosine (C), Guanine (G), Adenine (A), Uracil (U).
- There are 3 major types of RNA – all play a unique role in protein synthesis.
  1) **Messenger RNA (mRNA)**
  2) **Ribosomal RNA (rRNA)**
  3) **Transfer RNA (tRNA)**
Comparing DNA and RNA

DNA
- Nitrogenous Bases: Cytosine (C), Guanine (G), Adenine (A), Thymine (T)
- Deoxyribonucleic acid
- ATCG's
- Base pair
- Sugar phosphate backbone

RNA
- Nitrogenous Bases: Cytosine (C), Guanine (G), Adenine (A), Uracil (U)
- Ribonucleic acid
- AUGC's
- Base pair
- Sugar phosphate backbone
- Replaces Thymine in RNA

The diagram illustrates the structural differences between DNA and RNA, highlighting their molecular components and bases.
ATP – Adenosine Triphosphate

- As we have learned glucose is the most important fuel for our bodies and our cells, however NONE of the chemical energy stored in its bonds is used directly to power cellular work.
- As glucose is broken down in the mitochondria the energy that is produced is captured and stored as small packets of energy in the bonds of ATP.
- ATP, in turn, acts as a chemical “drive shaft” that provides a useable form of energy immediately available to cells.
- Structurally ATP has a similar structure to a RNA nucleotide in that it contains adenine, ribose and a phosphate group however, it has a total of 3 phosphate groups instead of one.
- The unstable bonds that hold the phosphate molecules together contain large amounts of stored energy.
- When cells require energy, ATP undergoes hydrolysis, and a bond between phosphate molecules is broken to release energy.

E.g.

- ATP is used by virtually all cells in the body to synthesize macromolecules such as carbohydrates and proteins.
- Muscle cells use the energy from the breakdown of ATP to contract.
- Nerve cells use the energy from the breakdown of ATP to conduct nerve impulses.
- Cells use ATP to actively pump various molecules against their concentration gradients either in or out of the cell.

(a) Structure of adenosine triphosphate

(b) Hydrolysis of ATP