Chemistry of Life

Course: BIO 101: Introduction to Biology

Chapter: 2

BRAC UNIVERSITY

Inspiring Excellence

Matter:

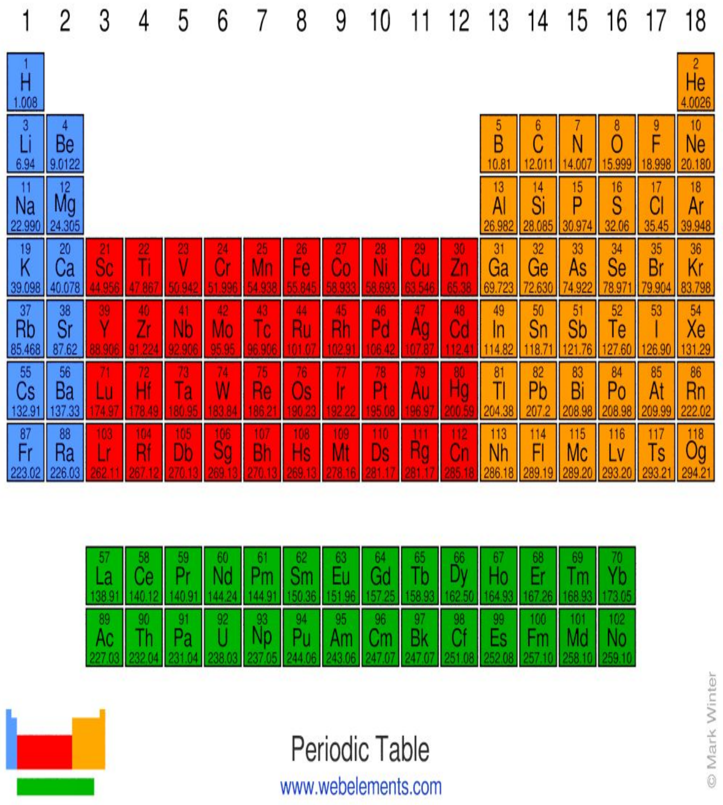
Anything physical that takes up space is matter. The amount of matter is its mass. Matter is composed of elements and compounds.

Elements

- An element is a substance that **cannot** be broken down into any other substance. Every element is made up of its **own type of atom**. This is why the chemical elements are all very different from each other.

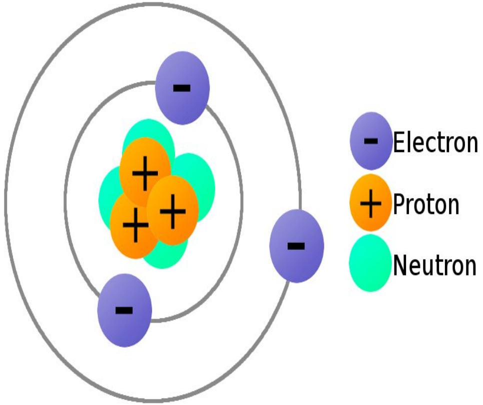
- Fundamental forms of matter.
- The periodic table lists all the known elements, grouping together those with similar properties.

- Most elements are **metals**, which are **shiny and conduct electricity well**. Metals include gold, aluminium and iron which are all solid at room temperature. Mercury is the only metal that is liquid at room temperature.
- Some elements are **non-metals**. Most nonmetals are **gases** at room temperature and **do not conduct electricity.** Non-metal elements with these properties include oxygen, hydrogen and chlorine. A few non-metals, such as carbon and sulphur, are in a **solid state** at room temperature.

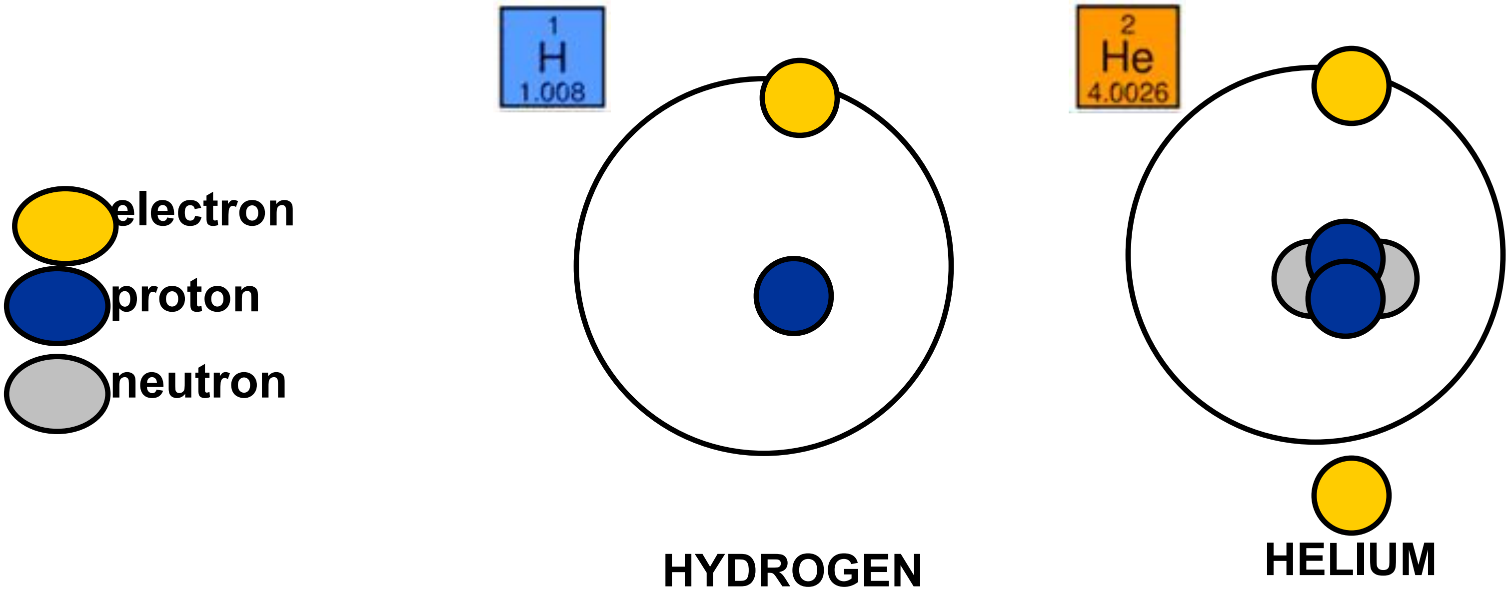


What Are Atoms?

- Smallest particles that retain properties of an element
- Made up of subatomic particles:
  - Protons (+)
  - Electrons (-)
  - Neutrons (no charge)



Hydrogen and Helium Atoms

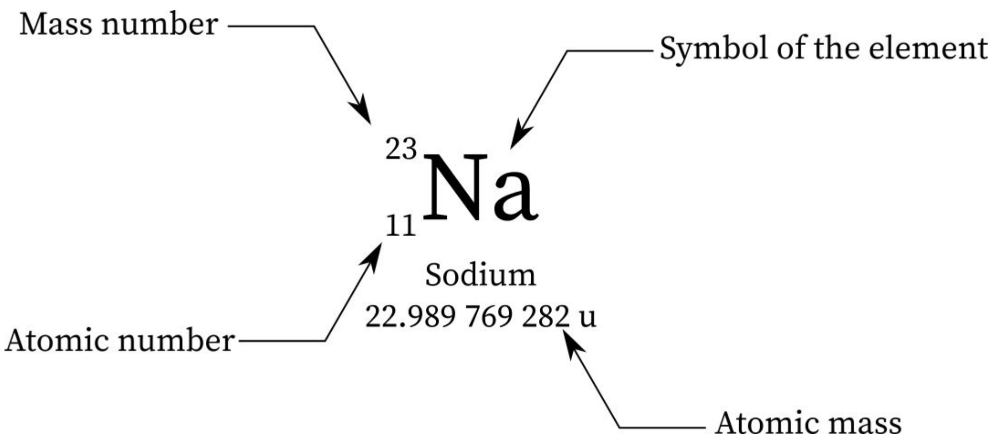


Atomic Number

- Number of protons
- All atoms of an element have the same atomic number
- Atomic number of hydrogen = 1
- Atomic number of carbon = 6
- Atomic number of sodium= 11

Mass Number

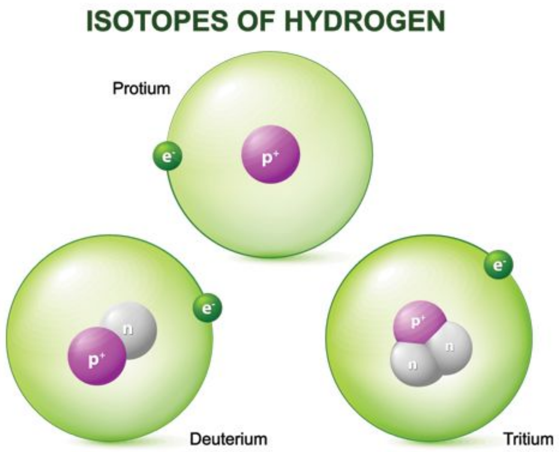
Number of protons
+
Number of neutrons



Isotopes vary in mass number

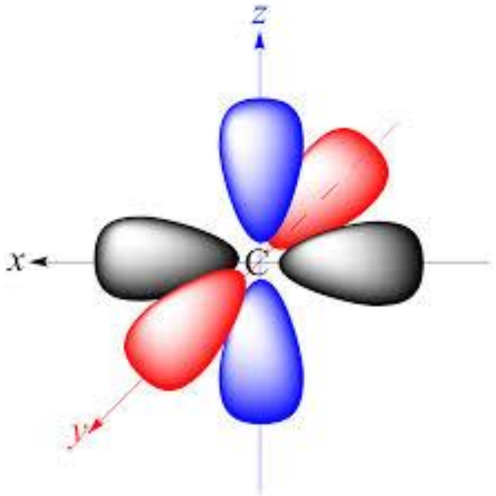
Isotopes

- Atoms of an element with different numbers of neutrons (different mass numbers)
- Hydrogen 1 or Protium has 1 proton, 0 neutron
- Hydrogen 2 or Deuterium has 1 proton, 1 neutron
- Hydrogen 3 or Tritium has 1 proton, 2 neutrons



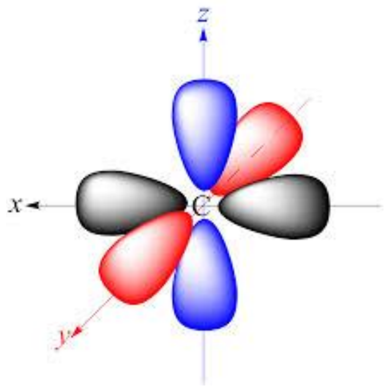
Electrons

- Carry a negative charge (-)
- Repel one another
- Are attracted to protons in the nucleus
- Move in orbitals



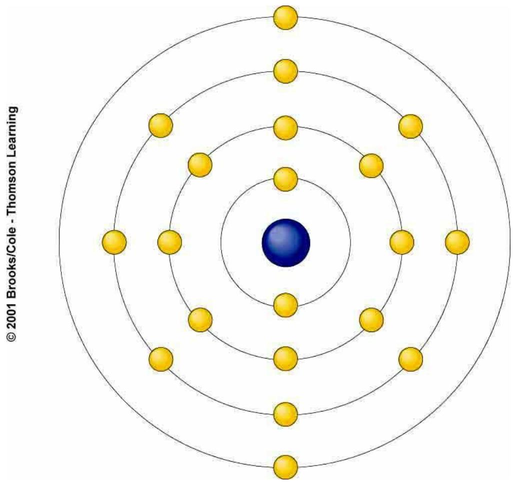
Electron Orbitals

- Orbitals are volumes of space that surround the nucleus
- Orbitals can hold up to two electrons
- Atoms differ in the number of occupied orbitals
- Orbitals closest to nucleus are lower energy and are filled first



Shell Model

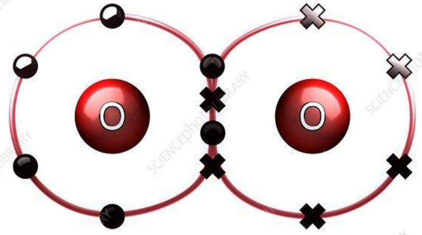
- Shell is something that is made up of orbitals
- First shell
  - Lowest energy
  - Holds 1 orbital with up to 2 electrons
- Second shell
  - 4 orbitals hold up to 8 electrons

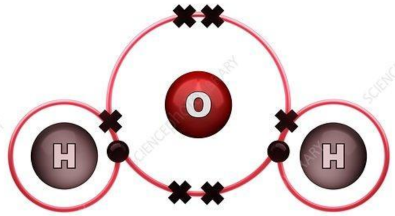


CALCIUM
$20p^+$, $20e^-$

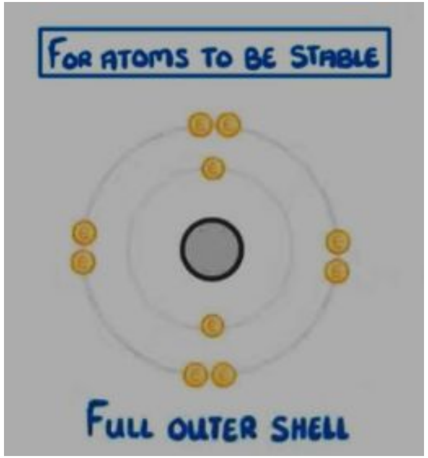
Chemical Bonds

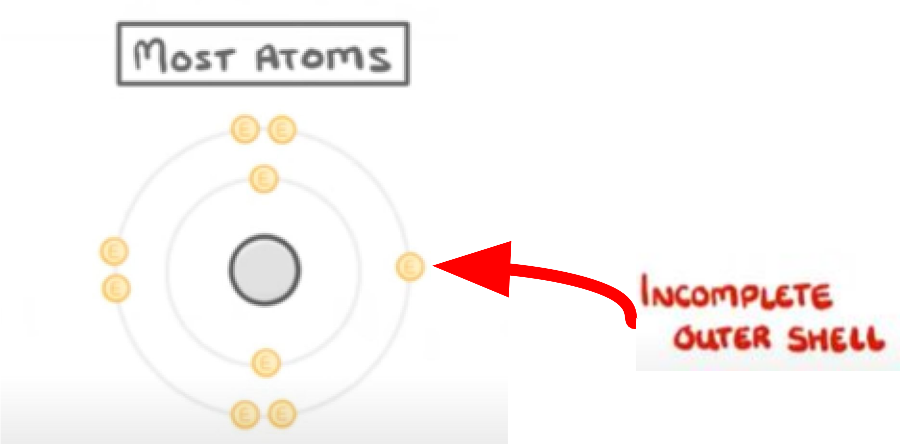
- Bond is union between electron structures of atoms
- Atoms bond to form molecules
- Molecules may contain atoms of only one element - O_2
- Molecules of compounds contain more than one element - H_2O





Chemical Bonds





Important Bonds in Biological Molecules

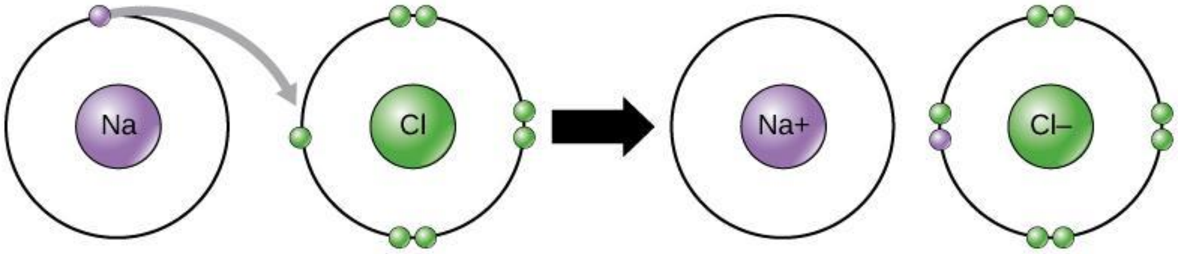
Ionic Bonds

Covalent Bonds

Hydrogen Bonds

1. Ionic Bonding

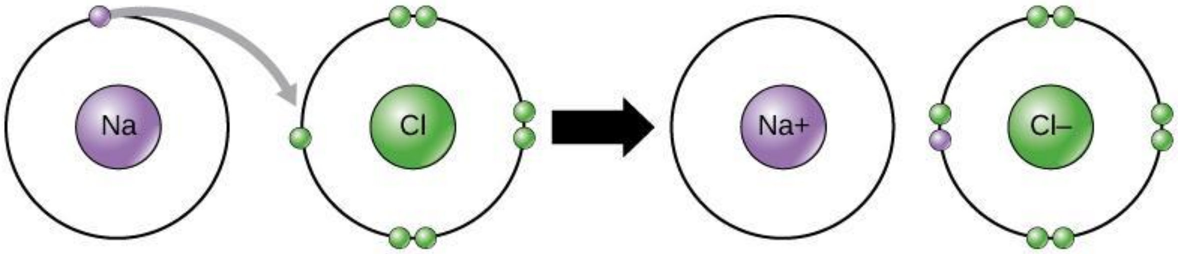
- In ionic bond one atom loses electrons, becomes positively charged ion and another atom gains these electrons, becomes negatively charged ion
- Charge difference attracts the two ions to each other



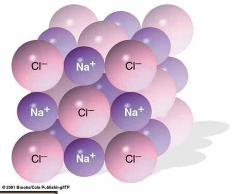
Ion Formation

- Atom has equal number of electrons and protons - no net charge

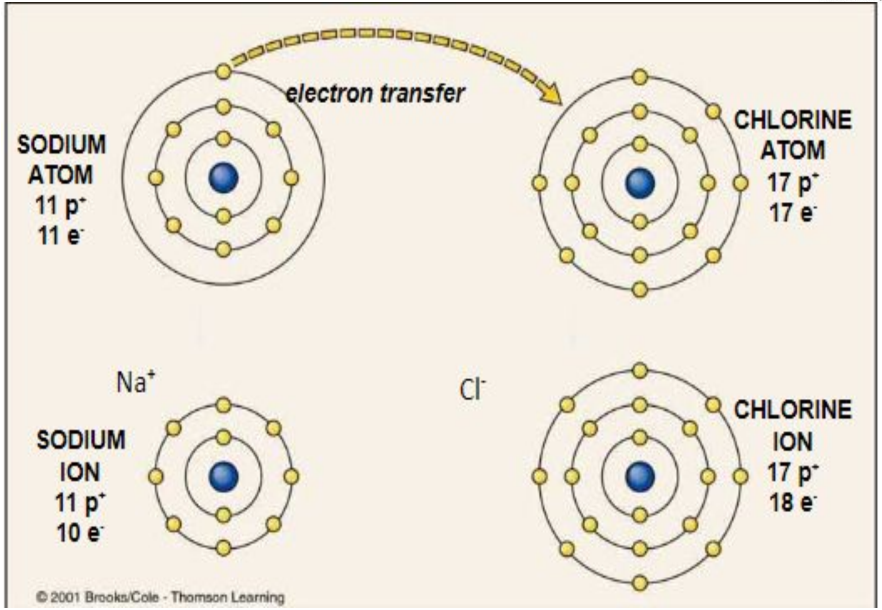
- Atom loses electron(s), becomes positively charged ion
- Atom gains electron(s), becomes negatively charged ion

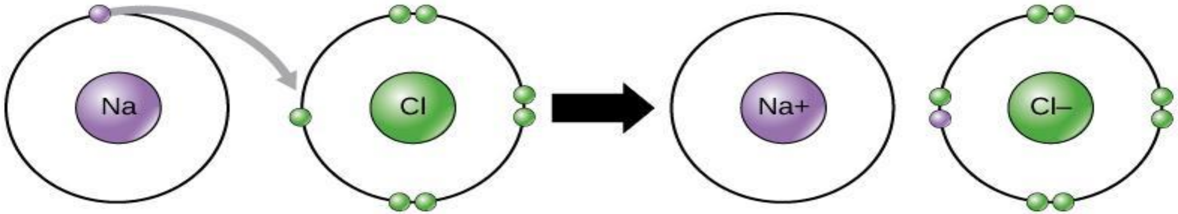


Formation of NaCl: example of ionic bond formation



- Sodium atom (Na)
  - Outer shell has one electron
- Chlorine atom (Cl)
  - Outer shell has seven electrons
- Na transfers electron to Cl forming Na^+ and Cl^-
- Ions remain together as NaCl

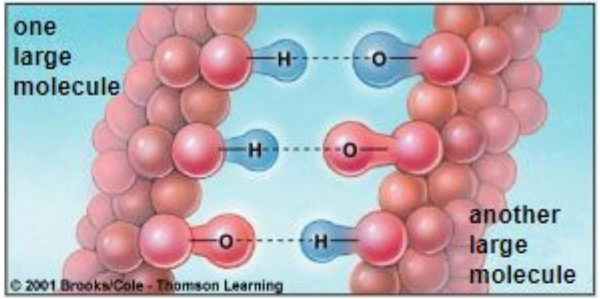


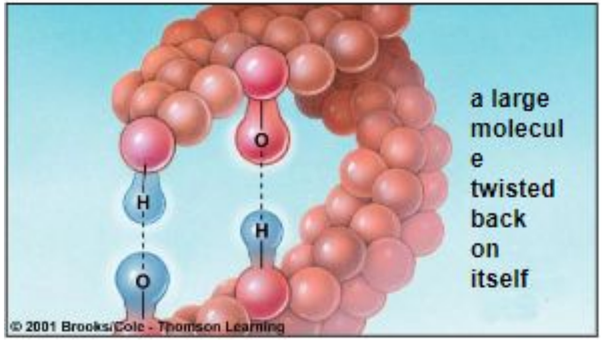


2. Hydrogen Bonding

Hydrogen bonds are bonds created between hydrogen and highly electronegative molecules.

- Molecules held together by polar covalent bonds has no NET charge
- However, atoms of the molecule carry different charges
- Atom in one polar covalent molecule can be attracted to oppositely charged atom in another such molecule



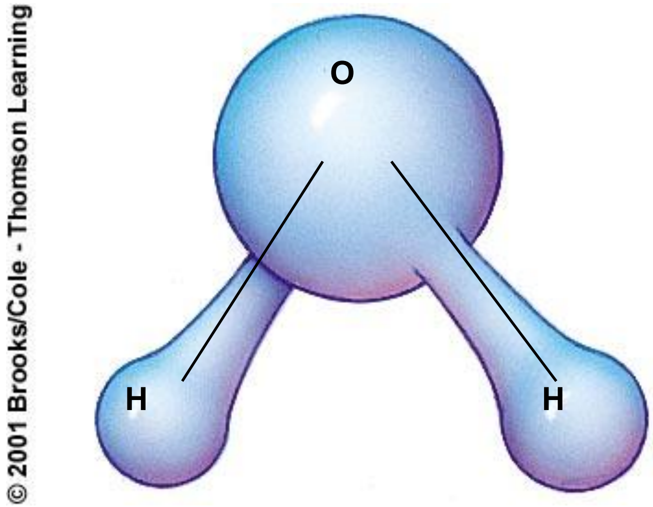


Water containing Hydrogen bond is a Polar Molecule

- Molecule has no net charge

- Oxygen end has a slight negative charge

- Hydrogen end has a slight positive charge



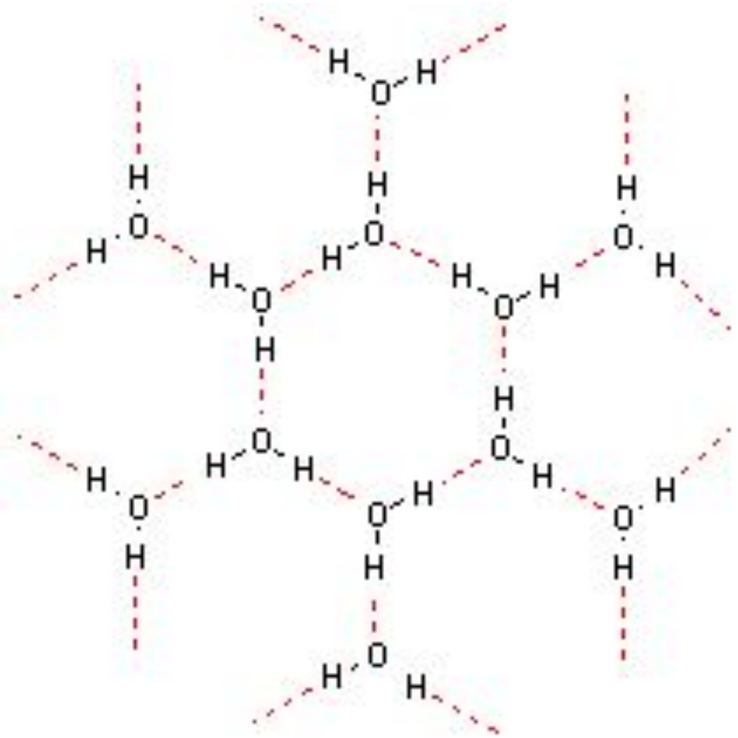
Hydrophilic & Hydrophobic Substances

- Hydrophilic substances
  - Polar
  - Hydrogen bond with water
  - Example: sugar

- Hydrophobic substances
  - Nonpolar
  - Repelled by water
  - Example: oil

Why Ice Floats

- In ice, hydrogen bonds lock molecules in a lattice
- Water molecules in lattice are spaced farther apart than those in liquid water
- Ice is less dense than water

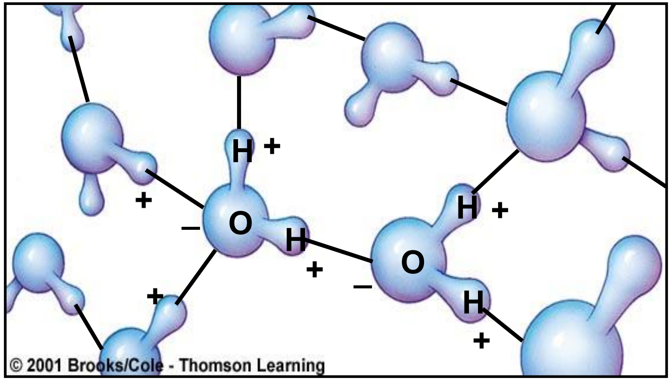


Liquid Water

Water is both weak base and weak acid

The acidity/Basicity of a solution is measured by pH.

A figure expressing the acidity or alkalinity of a solution on a logarithmic scale on which 7 is neutral, lower values are more acidic and higher values more alkaline. The values span from 0 to 14. The pH is equal to $-\log_{10}c$, where c is the hydrogen ion concentration in moles per litre.



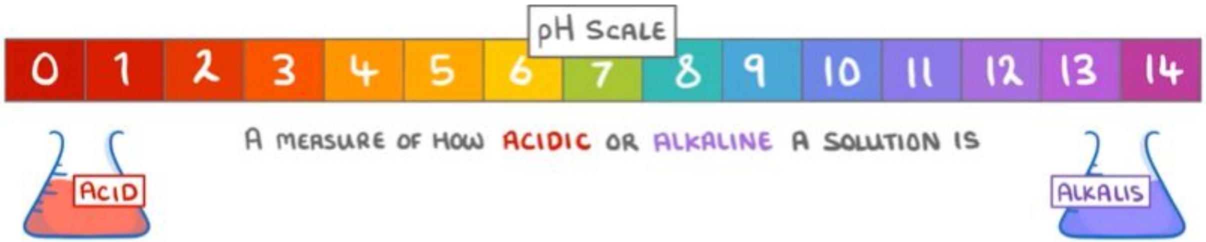
The pH Scale

- Measures H^+ concentration of fluid
- Change of 1 on scale means 10X change in H^+ concentration

Highest H^+ Lowest H^+

0--------------------7------------------14

Acidic Neutral Basic

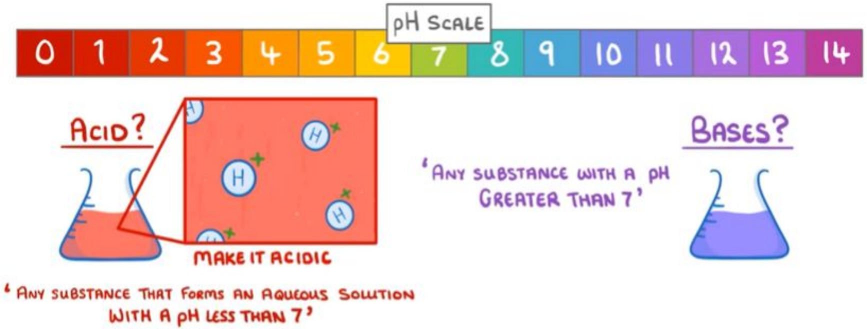


Examples of pH

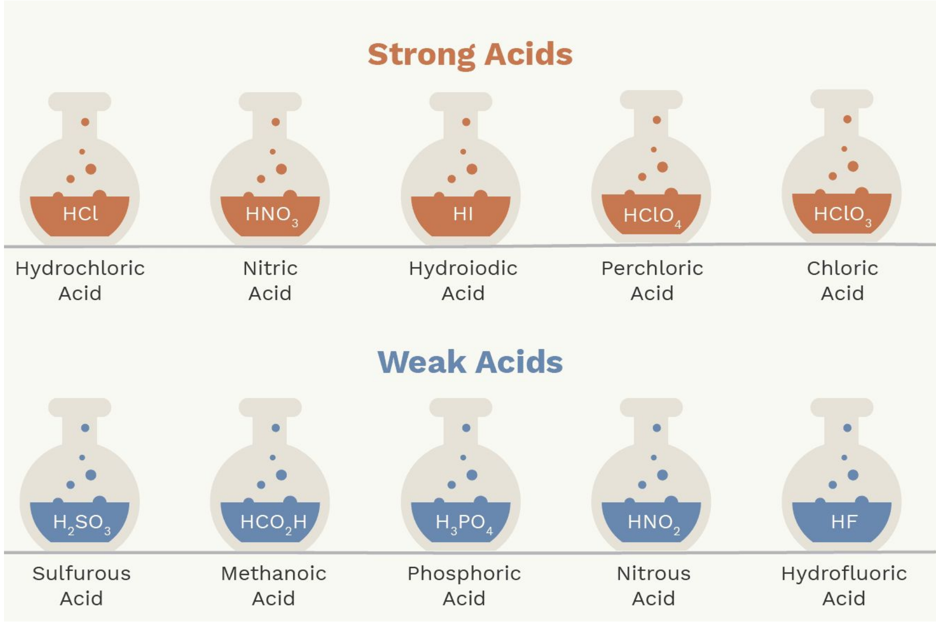
- Pure water is neutral with pH of 7.0
- Acidic
  - Stomach acid: pH 1.0 - 3.0
  - Lemon juice: pH 2.3
- Basic
  - Seawater: pH 7.8 - 8.3
  - Baking soda: pH 9.0

Acids & Bases

- Acids
  - Donate H^+ when dissolved in water
  - Acidic solutions have pH < 7
  - Example: HCl
- Bases
  - Accept H^+ when dissolved in water
  - Basic solutions have pH > 7
  - Example: NH_3



Weak and Strong Acids



- Weak acids
  - Reluctant H^+ donors
  - Can also accept H after giving it up
  - Carbonic acid (H_2CO_3) is example
- Strong acids
  - Completely give up H^+ when dissolved
  - Hydrochloric acid (HCl) is example

Buffer System or Buffer Solution

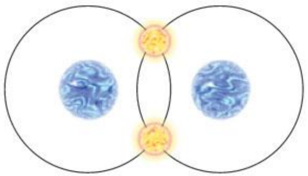
- A buffer solution is an aqueous solution of a weak acid and its conjugate base, or a weak base and its conjugate acid. Its pH changes very little when a small amount of strong acid or base is added to it.
- Buffer solutions are used as a means of keeping pH at a nearly constant value in a wide variety of chemical applications.
- Many life forms thrive only in a relatively small pH range, so they utilize a buffer solution to maintain a constant pH.
- One example of a buffer solution found in nature is blood. The body's acid–base balance is normally tightly regulated, keeping the arterial blood pH between 7.38 and 7.42.

Types of Buffer Solutions

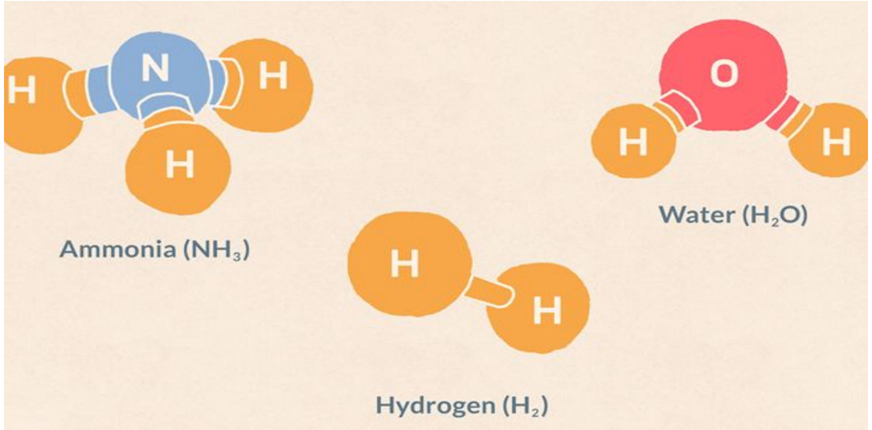
- Buffers are broadly divided into two types: acidic and alkaline buffer solutions.
- **Acidic buffers** are solutions that have a pH below 7 and contain a weak acid and one of its salts. For example, a mixture of acetic acid and sodium acetate acts as a buffer solution with a pH of about 4.75.
- **Alkaline buffers**, on the other hand, have a pH above 7 and contain a weak base and one of its salts. For example, a mixture of ammonium chloride and ammonium hydroxide acts as a buffer solution with a pH of about 9.25.

3. Covalent Bonding

Atoms share a pair or pairs of electrons to fill outermost shell



- Single covalent bond, H_2
- Double covalent bond, H_2O
- Triple covalent bond, NH_3



Covalent Bonding

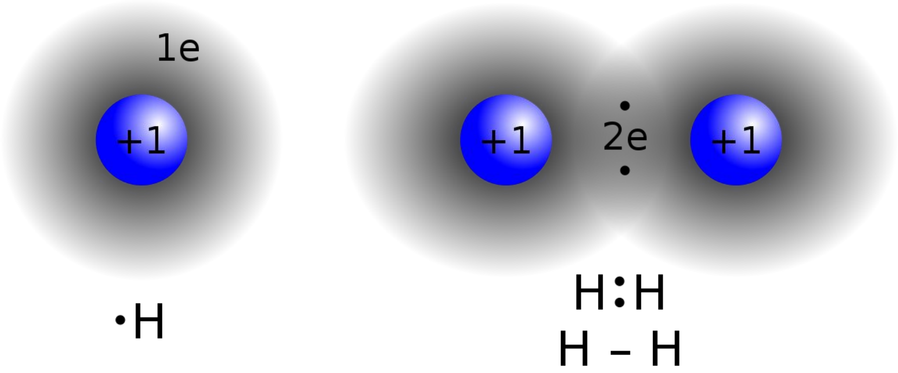
Depending on the polarity that is creation of positive and negative poles, covalent bonds can be of two types.

1. Non-polar covalent bond

2. Polar covalent bond

Nonpolar Covalent Bonds

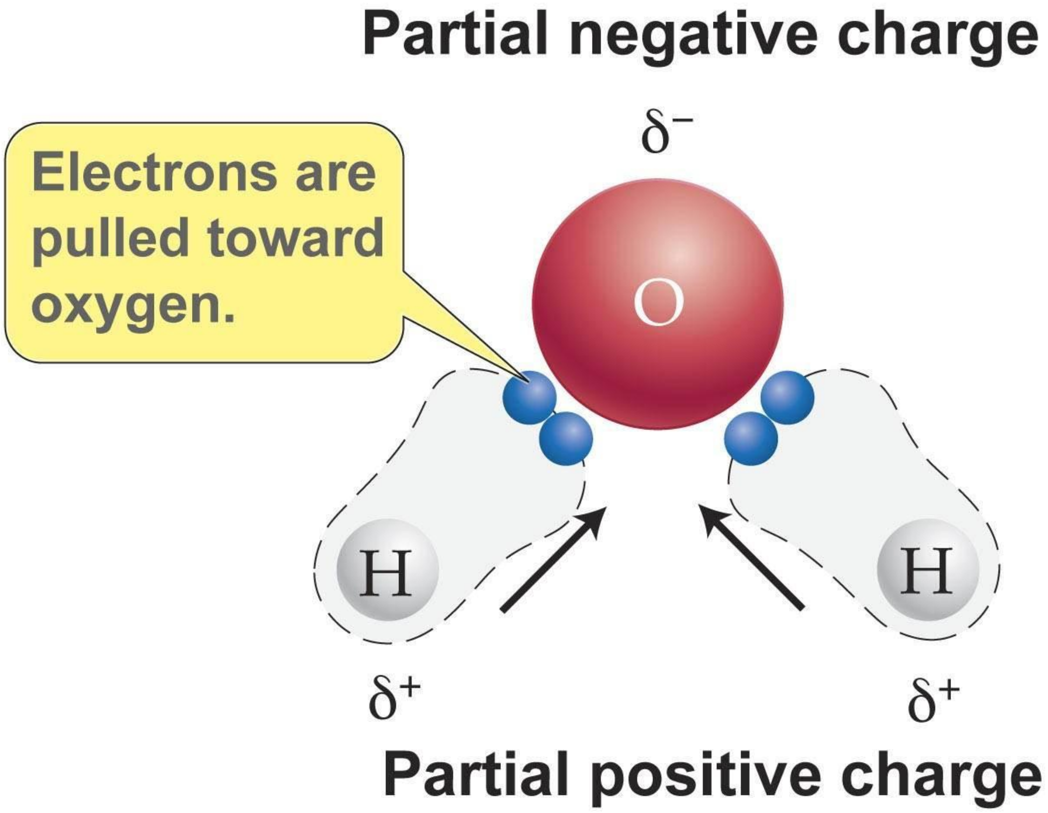
- Atoms share electrons equally
- Nuclei of atoms have same number of protons
- Example: Hydrogen gas (H-H)



Polar Covalent Bonds

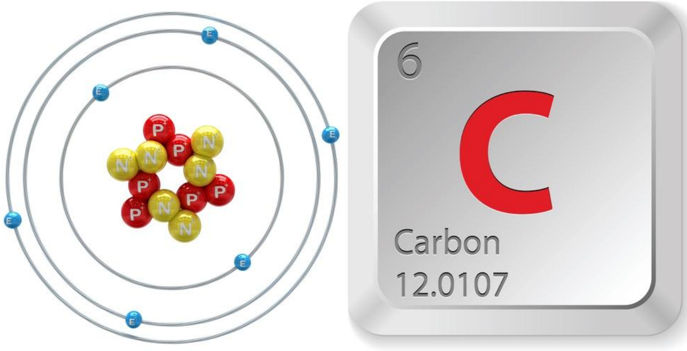
- Number of protons in nuclei of participating atoms is NOT equal
- Electrons spend more time near nucleus with most protons
- Water - Electrons more attracted to O nucleus than to H nuclei

Polar Covalent Bonds



Carbon Bonding Behavior

- The carbon atom is unique among elements in its tendency to form extensive networks of **covalent bonds** not only with other elements but also with itself.
- Carbon has four valence electrons, so it can achieve a full outer energy level by forming four covalent bonds.
- Carbon can form single, double, or triple covalent bonds with other carbon atoms.



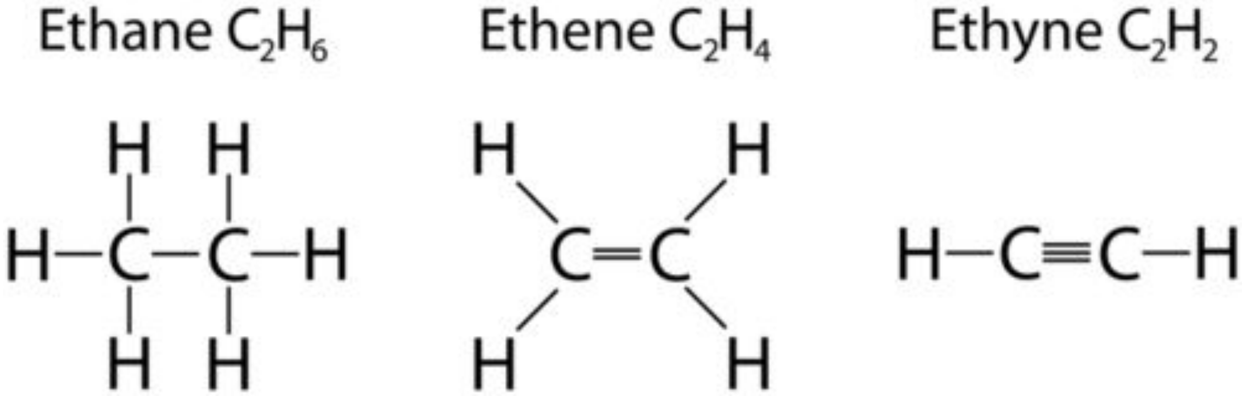
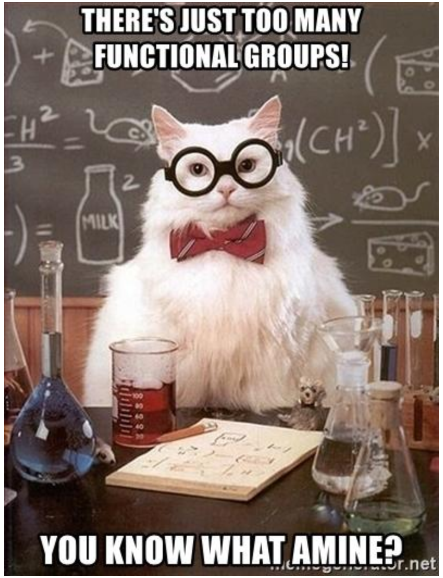
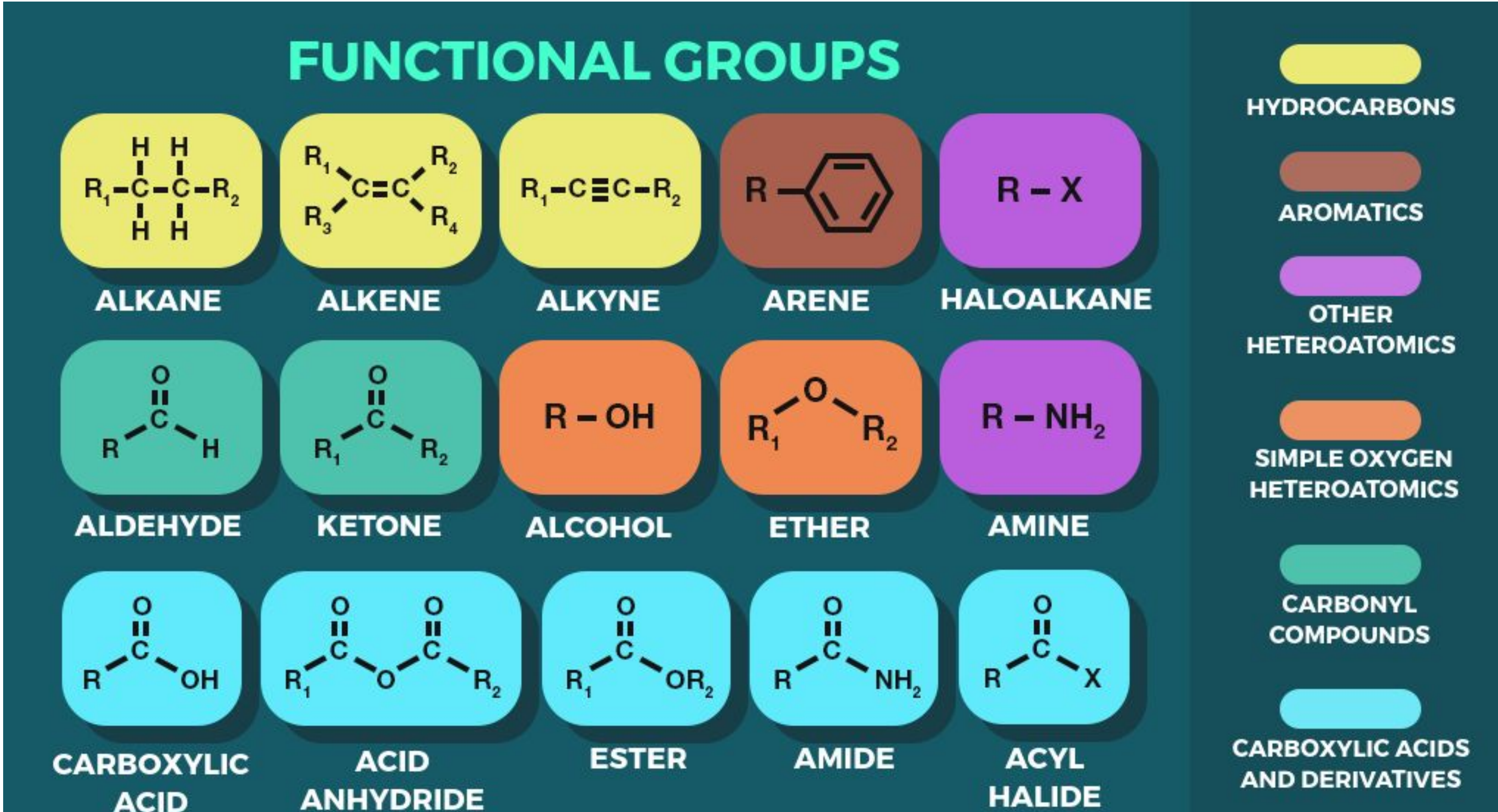


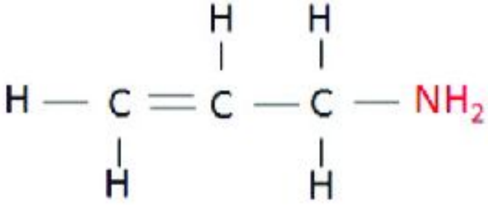
Fig- Carbon bonds on different compounds

Functional Groups

- A functional group is defined as an atom or group of atoms within a molecule that has similar chemical properties whenever it appears in various compounds.
- They give organic compounds their different properties.
- Example- **carboxyl (-COOH)** present in carboxylic acids

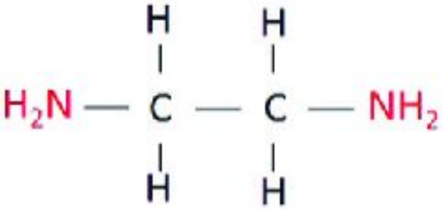



FUNCTIONAL GROUPS
ALKANE
ALKENE
ALKYNE
ARENE
R – X
HALOALKANE
ALDEHYDE
KETONE
R – OH
ALCOHOL
ETHER
R – NH2
AMINE
CARBOXYLIC ACID
ACID ANHYDRIDE
ESTER
AMIDE
ACYL HALIDE
HYDROCARBONS
AROMATICS
OTHER HETEROATOMICS
SIMPLE OXYGEN HETEROATOMICS
CARBONYL COMPOUNDS
CARBOXYLIC ACIDS AND DERIVATIVES



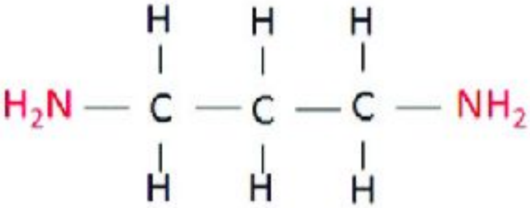
AA

Structure 1- Allylamine



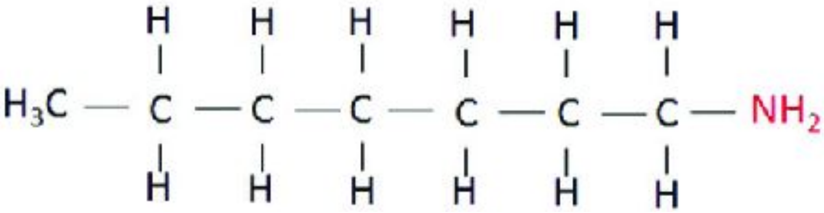
EDA

Structure 2- Ethane-1,2-diamine



DAP

Structure 3-
Propane-1,3-diamine



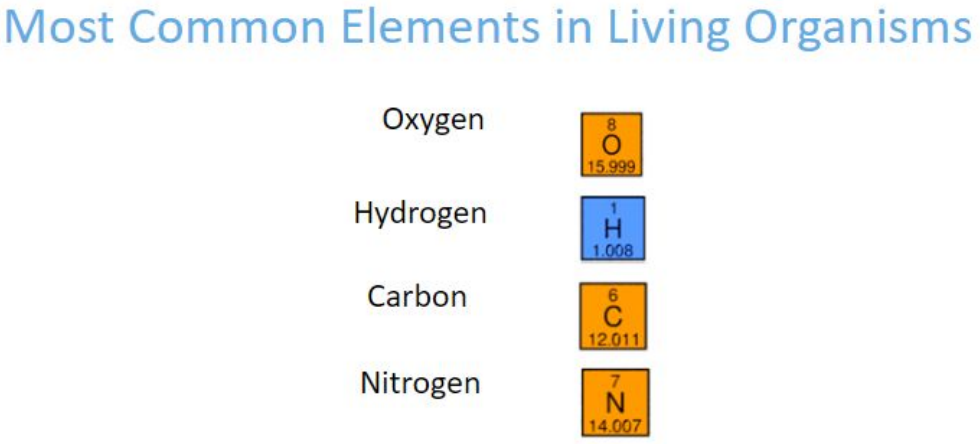
HA

Structure 4-
1-Heptanamine

Polyatomic Compounds

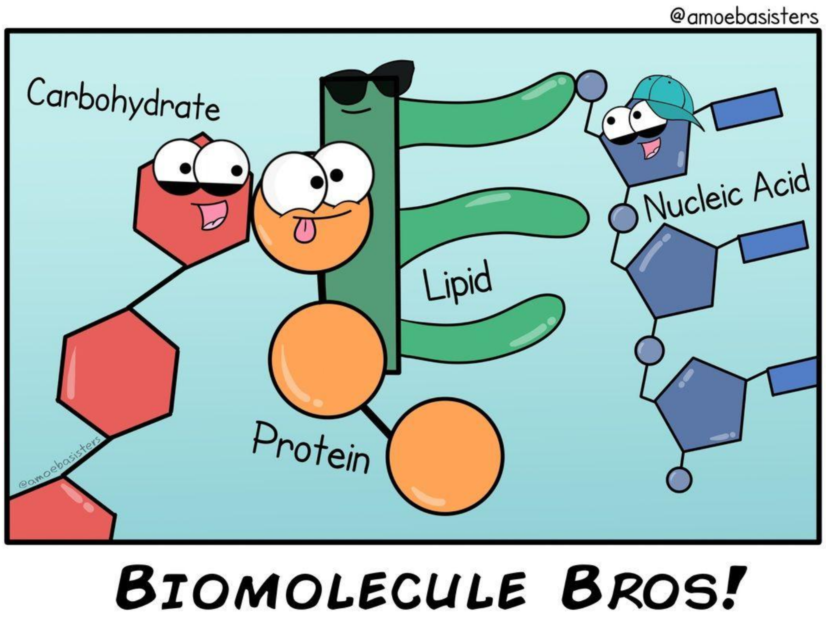
There are two types of compounds:

1. Inorganic Compounds: matter which is not derived from living organisms and contains no organically produced carbon.
2. Organic Compounds: large source of carbon-based compounds found within natural and engineered, terrestrial, and aquatic environments.



What are Biomolecules?

- Biomolecule are molecules and ions present in organisms that are essential to one or more biological processes.
- Most biomolecules are **organic compounds** containing four major elements e.g. carbon, hydrogen, oxygen, and nitrogen.



Carbohydrates

- A carbohydrate is a biomolecule consisting of carbon (C), hydrogen (H) and oxygen (O) atoms.
- Carbohydrates perform numerous roles in living organisms.
- They can storage energy(e.g. starch and glycogen), act as structural components (e.g. cellulose in plants) and even form the backbone of the genetic molecule known as RNA.

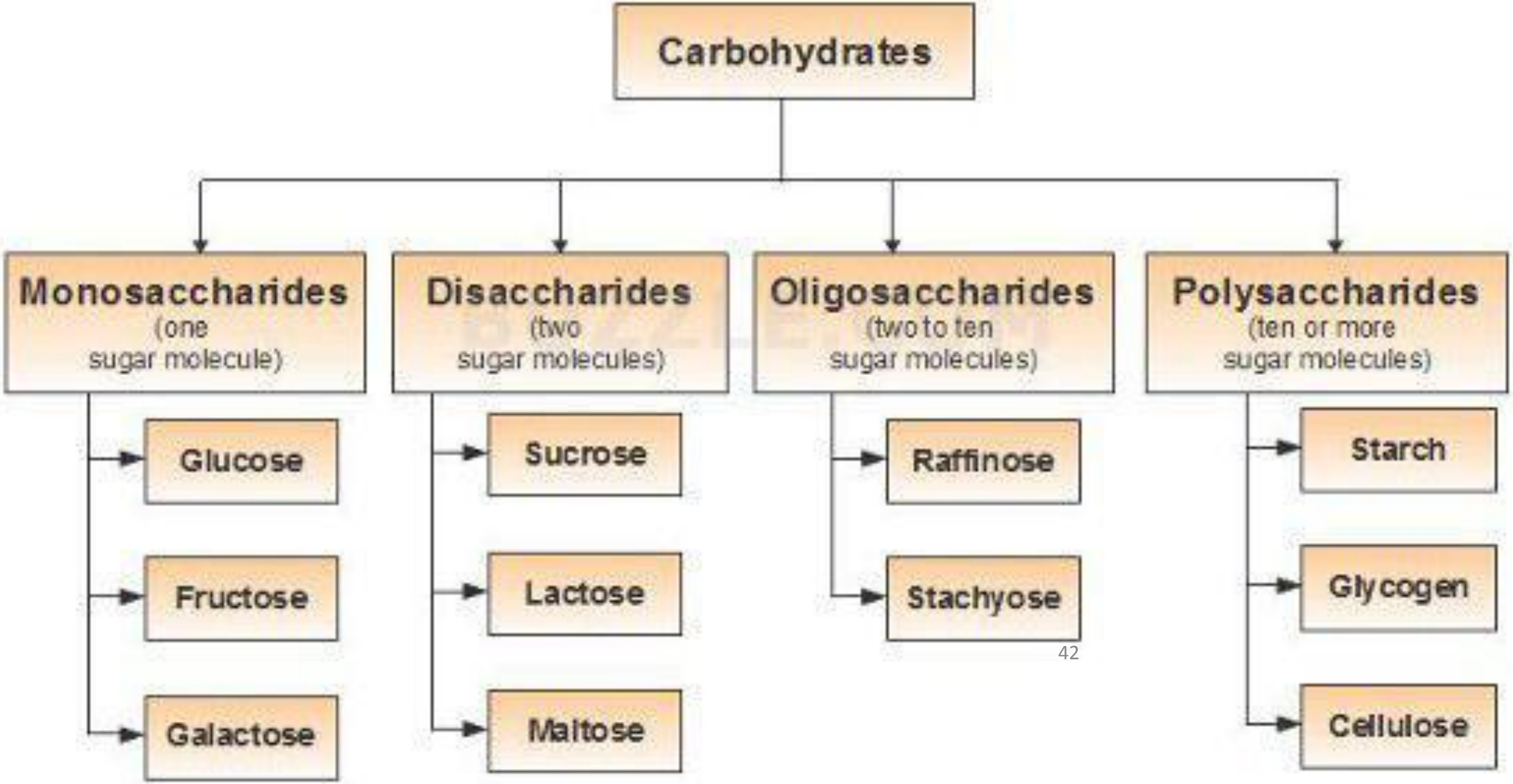


Fig- Classification of carbohydrates

Glycosidic Bond

- A glycosidic bond is a covalent bond formed between a carbohydrate molecule and another molecule.

- In this reaction, the hydroxyl group (OH) of the carbohydrate combines with the hydrogen of another organic molecule, releasing a molecule of water and forming a covalent bond.

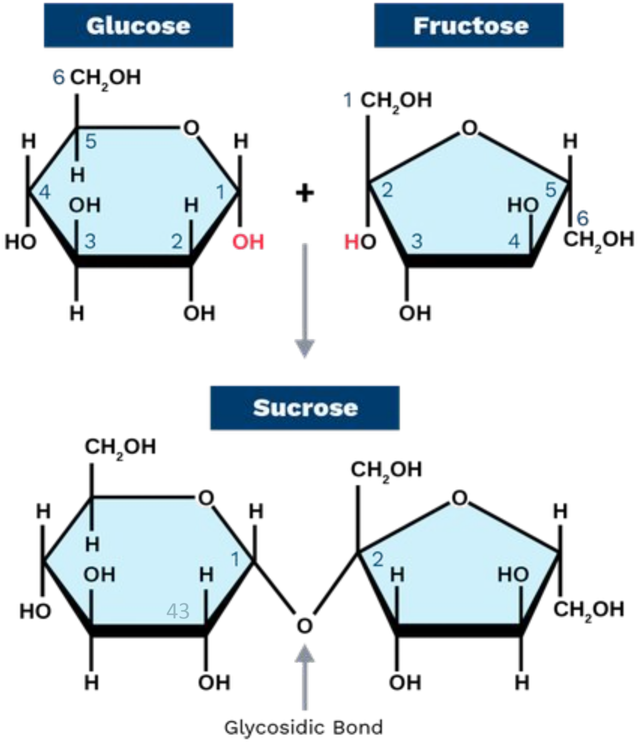


Fig: Sucrose is formed when a monomer of glucose and a monomer of fructose are joined in a dehydration reaction

Lipids

- Lipids are molecules that contain hydrocarbons and make up the basic building blocks of biological membranes. They have various function in living cells.
- Lipids are not soluble in water as they are non-polar, but are soluble in non-polar solvents such as chloroform.
- Examples of lipids include fats, oils, waxes, certain vitamins (such as A, D, E and K), hormones etc.
- The functions of lipids include storing energy, signaling, and acting as structural components of cell membranes.

Ester Bond

- Glycerol is a small organic molecule with three hydroxyl (OH) groups, while a fatty acid consists of a long hydrocarbon chain attached to a carboxyl group.

- The basic unit of lipids are triglycerides . A triglyceride is formed when 1 glycerol molecule links with 3 fatty acid molecules by means of ester bond (covalent bond).

Ester Bonds

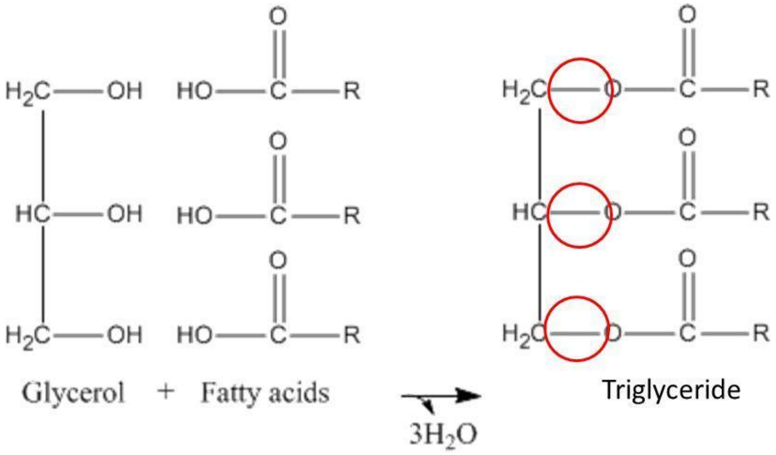


Fig: The glycerol molecule (having three OH− groups) links with three fatty acids via an ester bond

3 Major Types of Lipids

- **Glycolipids** are a class of lipids containing carbohydrate residues. Their role is to maintain the stability of the cell membrane and to facilitate cellular recognition.
- A **phospholipid** is a type of lipid molecule that is the main component of the cell membrane.
- **Sterols** are unique among lipids in that they have a multiple-ring structure. They contain a planar (flat) steroid ring, for example- cholesterol.

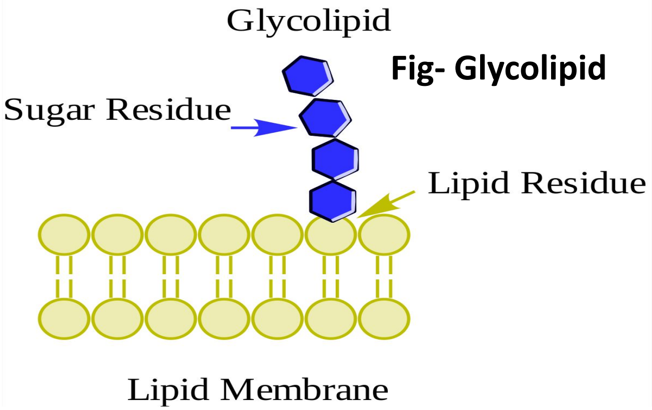


Fig- Glycolipid

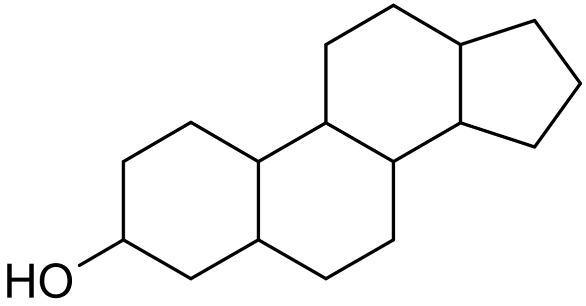
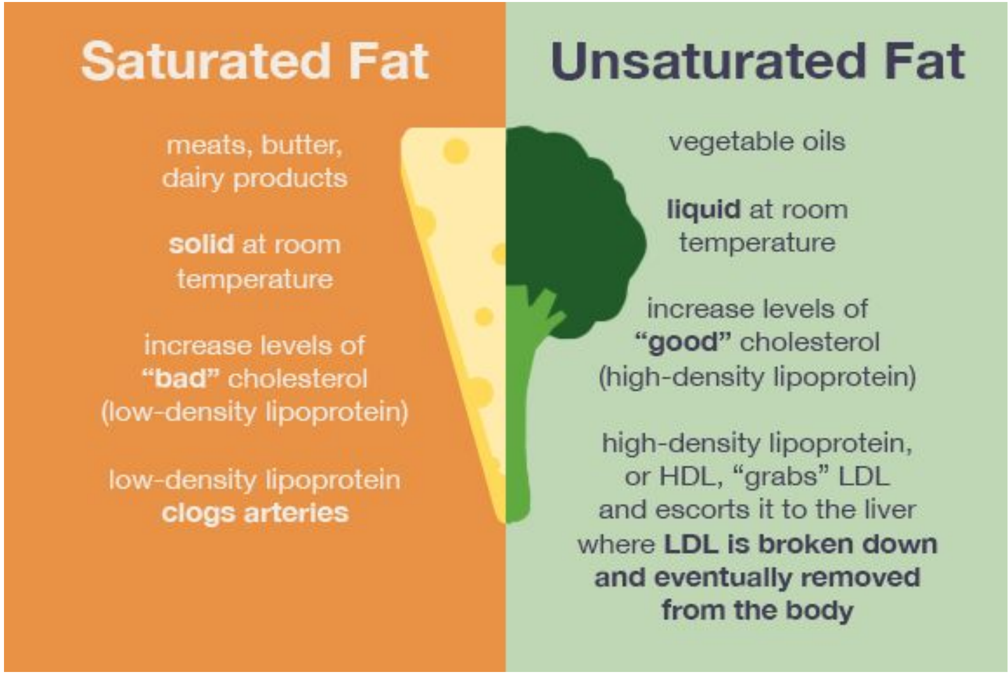


Fig- Sterol

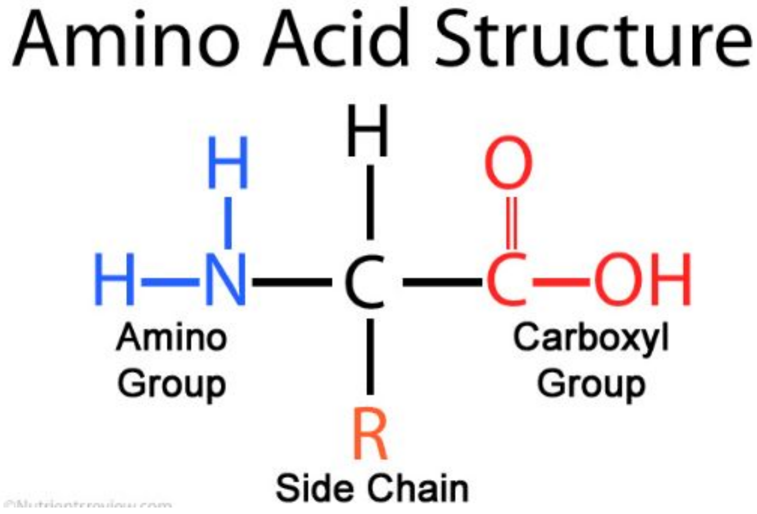
Saturated and Unsaturated Fats



Saturated	Unsaturated
H H | | -C-C- | | H H	H H | | -C=C-
Carbon-Carbon Single Bond	Carbon-Carbon Double Bond

Proteins

- Proteins are large biomolecules and macromolecules that comprise one or more long chains of **amino acid residues**.
- Proteins within a cell have many functions, including building cellular structures and serving as enzyme catalysts for cellular chemical reactions that give cells their specific characteristics.
- They help in metabolism by providing structural support and by acting as enzymes, carriers and hormones.



Peptide Bond

Within a protein, multiple amino acids are linked together by peptide bonds, thereby forming a long chain.

A peptide bond is a chemical bond formed between two molecules when the carboxyl group of one molecule reacts with the amino group of the other molecule, releasing a molecule of water (H2O).

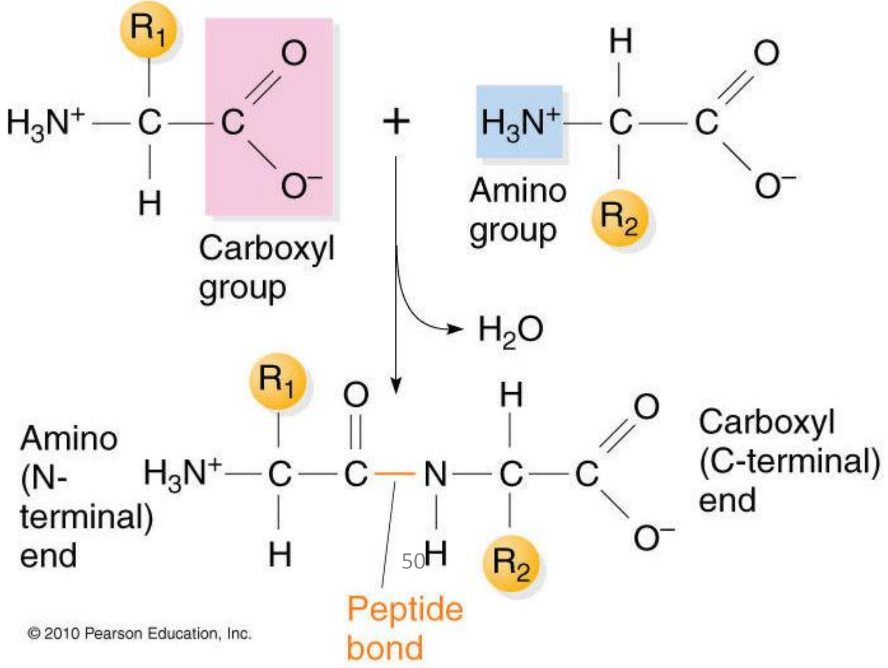


Fig- Formation of a peptide bond

PRIMARY VS SECONDARY VS TERTIARY STRUCTURE OF PROTEIN

PRIMARY STRUCTURE	SECONDARY STRUCTURE	TERTIARY STRUCTURE
Linear sequence of amino acids	Folding of the peptide chain into an α-helix or β-sheet	Three-dimensional structure of a protein
Linear	Either an α-helix or β-sheet	Globular
Composed of peptide bonds formed between amino acids	Encompasses hydrogen bonds	Encompasses disulfide bridges, salt bridges, and hydrogen bonds
Formed during translation	Forms collagen, elastin, actin, myosin, and keratin-like fibers	Includes enzymes, hormones, albumin, globulin, and hemoglobin
Involved in post-translational modifications	Involved in forming structures such as cartilages, ligaments, skin, etc.	Involved in the metabolic functions of the body

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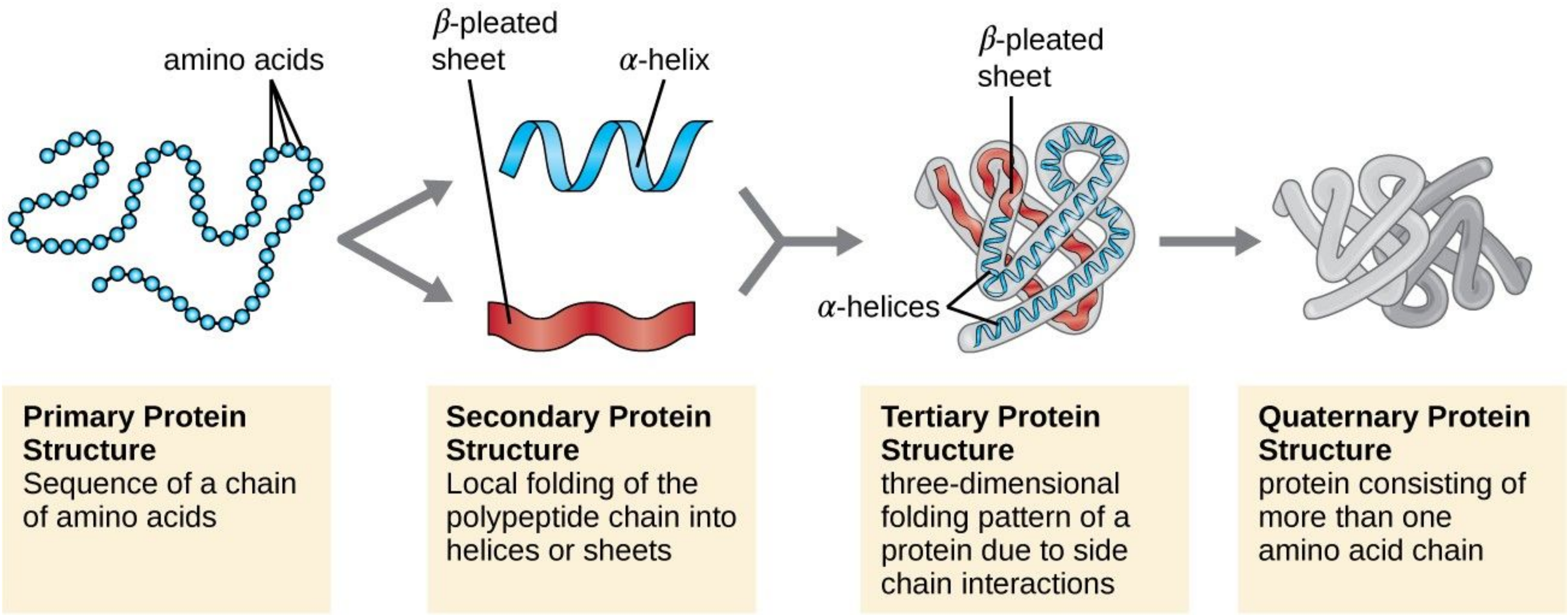
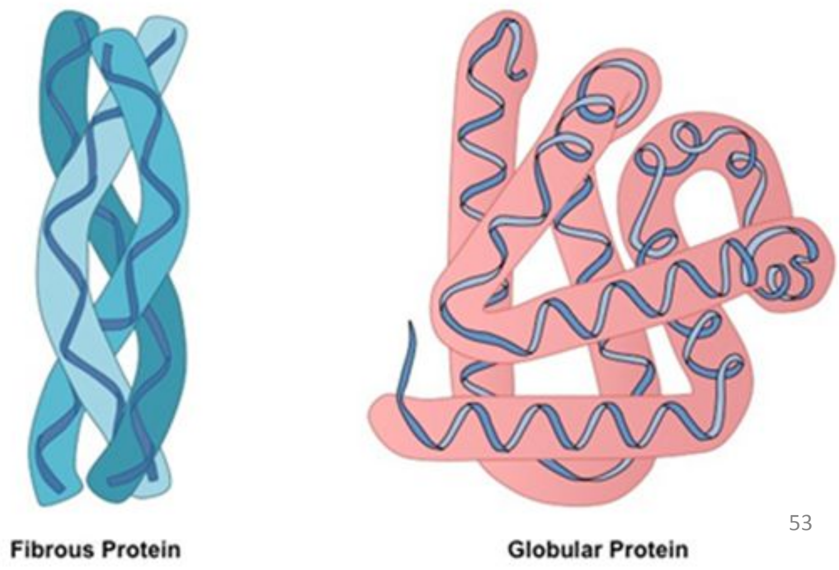


Figure 7: Protein structure has four levels of organization

Protein Shapes

Fibrous proteins are typically elongated and insoluble. Examples - collagen, found in the bones, muscles, skin



Globular proteins are generally compact, soluble, and spherical in shape. Examples - Myoglobin, which is found in muscle tissues.

Fig: Fibrous and globular proteins

Nucleic Acids

- Nucleic acids are essential for all forms of life, and it is found in all cells.
- The functions of nucleic acids have to do with the storage and expression of genetic information.
- The building blocks of nucleic acids are nucleotides.

Deoxyribonucleotides

- Nucleotides that compose of DNA are called deoxyribonucleotides. The three components of a deoxyribonucleotide are a five-carbon sugar called **deoxyribose, a phosphate group and a nitrogenous base**.
- DNA stores the information needed to build and control the cell.

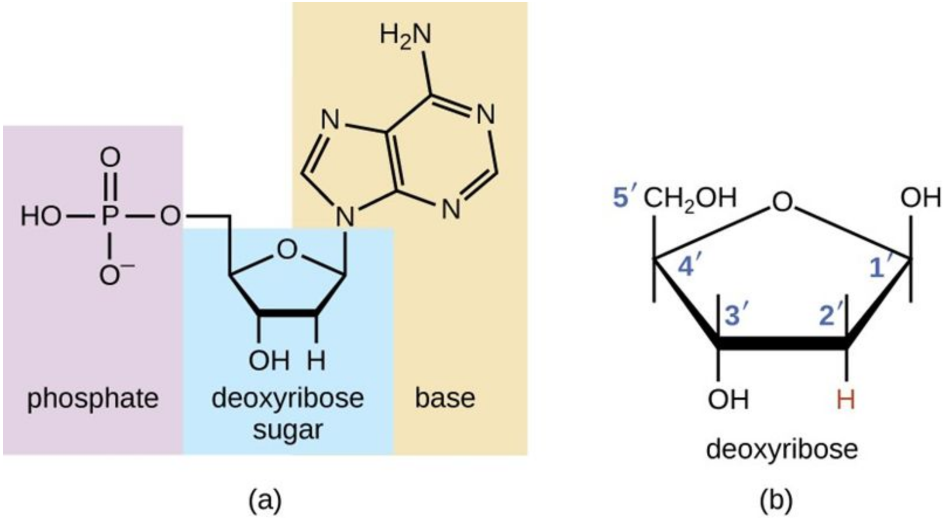


Fig: (a) deoxyribonucleotide. (b) The five carbons within deoxyribose

Nitrogenous Bases

The nitrogenous bases adenine (A) and guanine (G) are the **purines**; they have a double-ring structure with a six-carbon ring fused to a five-carbon ring.

The **pyrimidines**, cytosine (C) and thymine (T), are smaller nitrogenous bases that have only a six-carbon ring structure. Thymine is unique to DNA

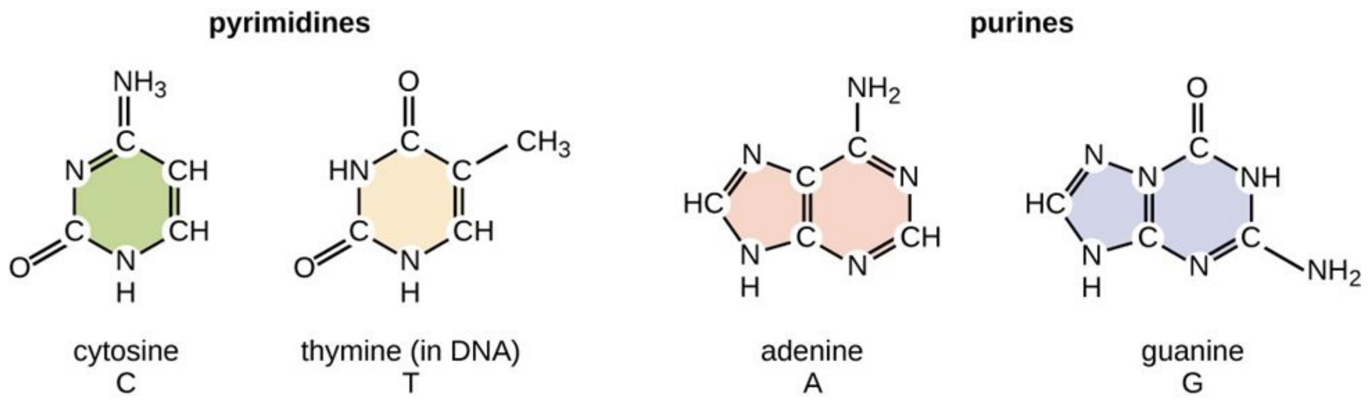
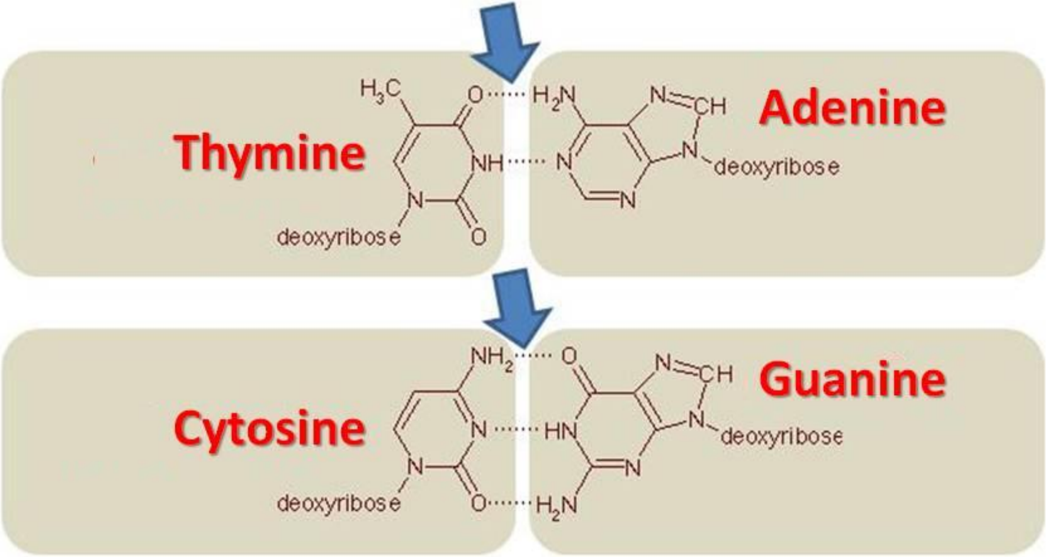


Fig- Structure of purines and pyrimidines

Complementary Base Pairs

In DNA, adenine (A) and thymine (T) are **complementary base pairs**, and cytosine (C) and guanine (G) are also complementary base pairs.

The base pairs are stabilized by **hydrogen bonds**; adenine and thymine form two hydrogen bonds between them, whereas cytosine and guanine form three hydrogen bonds between them.



Ribonucleotides

- Nucleotides that compose of RNA are called ribonucleotides. The three components of a ribonucleotide are a **pentose sugar called ribose**, a phosphate group and a nitrogenous bases (Adenine, **Uracil,** Guanine and Cytosine).
- The RNA-specific pyrimidine **uracil** forms a complementary base pair with adenine and is used **instead of the thymine** used in DNA**.**
- The primary role of RNA is to convert the information stored in DNA into proteins.

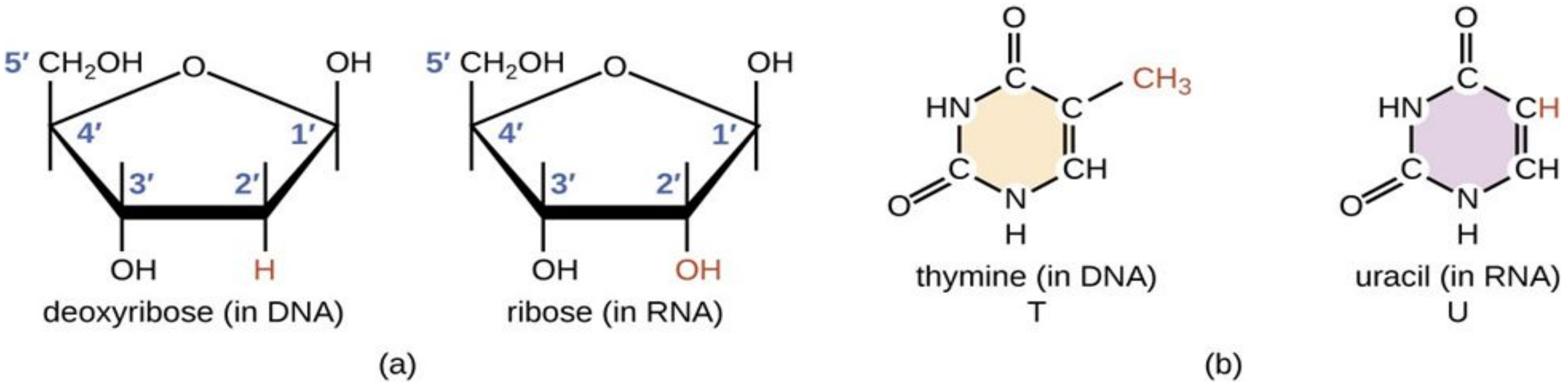


Fig -(a) Ribonucleotides contain the pentose sugar ribose instead of the deoxyribose found in deoxyribonucleotides. (b) RNA contains the pyrimidine uracil in place of thymine found in DNA.

Comparison between DNA and RNA

DNA	RNA
1. It contains a 5C deoxyribose.	1. It contains five carbon sugar ribose
2. It contains adenine, guanine, cytosine and thymine	2. It contains adenine, guanine, cytosine and uracil.
3. It mostly occurs as a double-stranded helix.	3. It often occurs as a single stranded.
4. It is often much longer.	4. It is shorter.
5. It is more stable.	5. It is less stable.