Chapter 4: Carbon And Its Compounds

Covalent Bonding In Carbon Compounds

Covalent bonds are created when two atoms (either the different or same atoms) share an electron pair. Carbon (C) has an atomic number of 6. As a result, its electrical arrangement equals = $\frac{K}{2,} \frac{L}{4}$

Thus, its outermost shell has **four electrons**, and its octet may be completed in one of two ways:

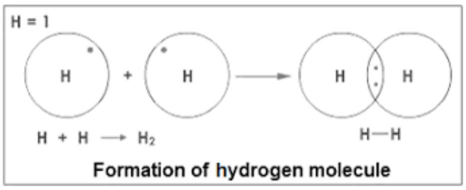
- It is possible for it to acquire **four electrons** and form the **C4- anion**. However, for a nucleus with six protons, it would be quite difficult to retain ten electrons, i.e. **four more electrons**. It may lose **four electrons** and produce the **cation C4**+.
- However, removing **four electrons** would need an enormous amount of energy, leaving behind a carbon cation with **six protons** in its nucleus and just **two electrons**, which is not feasible.
- That is the reason why carbon shares its electron density with other carbon atoms or with atoms of other elements in order to solve this difficulty. These shared electrons are present in both atoms' outermost shells, and as a result, both atoms acquire the closest noble gas configuration. This is known as **covalent bonding**.
- The number of electrons shared by two atoms to complete their octet (except for hydrogen, which exhibits **duplet**) is known as the atom's **covalency**. Thus, hydrogen has a **covalency of 1**, oxygen has a **covalency of 2**, nitrogen has a **covalency of 3**, and carbon has a **covalency of 4**. Additionally, other atoms display a similar form of bonding.

Some Examples Depicting Covalent Bonding

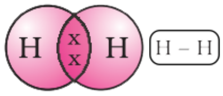
Formation Of Hydrogen Molecule H_2

- H has an atomic number of 1.
- $\frac{K}{1}$ is the electronic configuration.
- It possesses one electron in its K-shell and requires one more electron to entirely fill the K-shell.
- Thus, when two H-atoms share their electrons, they create the molecule H_2. This enables each H-atom to co-achieve the closest configuration of

noble gas, i.e. the helium configuration (having 2 electrons in its K-shell). Crosses are used for representing valence electrons.

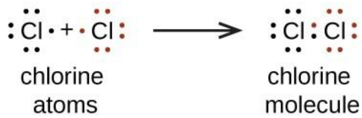


- The common pair of electrons between the two H-atoms forms a single bond, which is depicted by a single line connecting the two atoms.



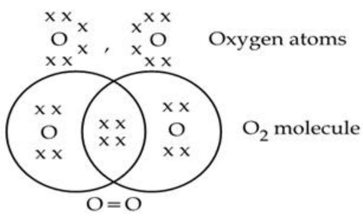
Formation Of Chlorine Molecule Cl_2

- Cl has an atomic number of 17.
- $\frac{K}{2,}, \frac{L}{8,}, \frac{M}{7}$ are the electronic configurations.
- It contains seven electrons in its outermost shell and hence requires an additional electron to complete it. This is accomplished by exchanging one electron with another Cl-atom, resulting in the formation of a chlorine diatomic molecule (Cl_2).



Formation Of Oxygen Molecule O_2

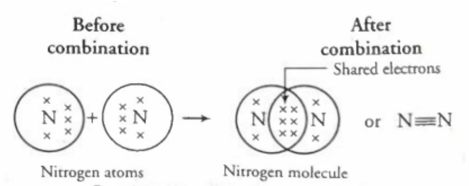
- O possesses an atomic number of 8.
- $\frac{K}{2,}, \frac{L}{6}$ is the electronic configuration.
- It possesses six electrons in its outermost shell, and hence requires two more electrons for completion of its octet to achieve the noble gas configuration. This is accomplished by collaborating with a different oxygen atom to share two electrons.
- Each oxygen atom contributes two electrons, which results in the formation of two shared pairs of electrons.



- A dual bond is formed between two oxygen atoms in this step, which results in the formation of an oxygen molecule. The diagram above illustrates the sharing of four electrons.

Formation Of Nitrogen Molecule N_2

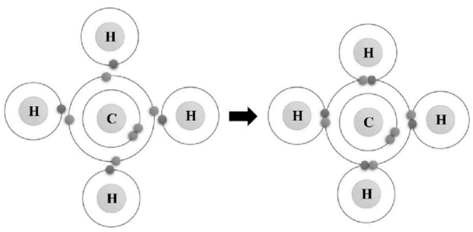
- N has an atomic number of 7.
- Electronic Configuration = $\frac{K \quad L}{2, \quad 5}$
- Nitrogen requires three more electrons for achieving the noble gas configuration. Thus, each nitrogen atom in a nitrogen molecule contributes three electrons to achieve octets, resulting in three shared pairs of electrons.
- Here a triple bond is created between two nitrogen atoms.



Covalent bonding in N_2 molecule

Formation Of Methane CH_4

- One carbon atom shares four electrons with four hydrogen atoms during the formation of a methane molecule (one electron of each hydrogen atom).
- Carbon is tetravalent in nature due to its four valence electrons, while hydrogen is monovalent for its single valence electron.



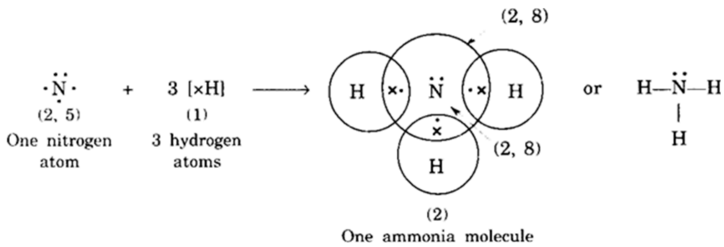
- Methane is just a carbon molecule that is sometimes referred to as marsh gas. It is a type of fuel and a significant component of compressed natural gas (CNG) and biogas. It is one of the simplest carbon compounds.

Formation Of Ammonia NH_3 And Water Molecule H_2O

Ammonia (NH_3)

- N has an atomic number of 7.

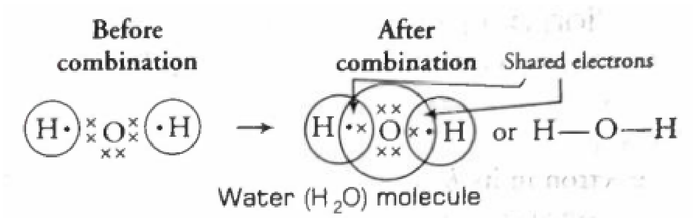
- Electronic configuration = $\frac{K \quad L}{2, \quad 5}$
- H Atomic Number = 1
- Electronic Configuration = $\frac{K}{1}$
- Nitrogen requires three electrons and hydrogen just one electron to achieve the electrical configuration of the closest noble gas.
- When an ammonia molecule is produced, one nitrogen atom shares its three electrons with each three hydrogen atoms.



- NH_3 (Ammonia Gas) may also be used as a refrigerant.

Water (H_2O)

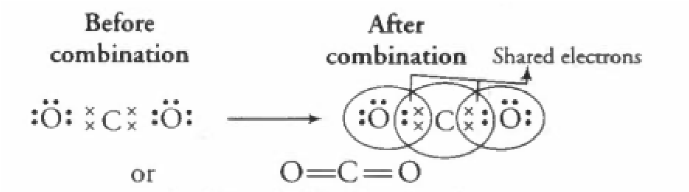
- O has an atomic number of 8.
- Electronic configuration = $\frac{K \quad L}{2, \quad 6}$
- Atomic number of H = 1
- Electronic configuration = $\frac{K}{1}$
- Hydrogen requires one electron and oxygen requires two electrons to achieve the stable electronic configuration of the closest noble gas.
- In the case of water, two hydrogen atoms share an electron pair with an oxygen atom, giving hydrogen a duplet configuration and oxygen an octet configuration, resulting in the formation of two single covalent bonds.



Formation Of Carbon Dioxide CO_2

- C has an atomic number of 6.

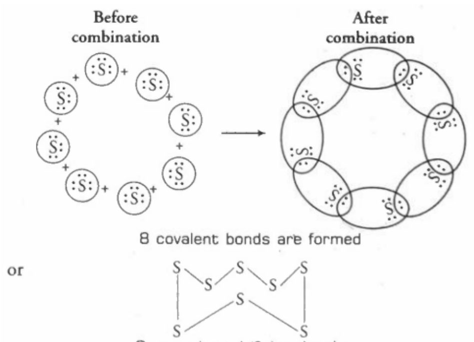
- Electronic configuration = $\frac{K \quad L}{2, \quad 4}$
- Atomic number of O = 8
- Electronic Configuration = $\frac{K \quad L}{2, \quad 6}$
- Carbon requires four electrons to achieve a stable electronic state, while oxygen only requires two electrons. Thus, each oxygen atom in CO_2 shares 2 electrons with carbon. Thus, both oxygen and carbon reach the octet.



Carbon dioxide (CO_2) molecule

Formation Of Sulphur Molecule S_8

- Sulphur (S) has an atomic number of 16
- Electronic configuration = $\frac{K \quad L \quad M}{2, \quad 8, \quad 6}$
- Each sulphur atom requires two electrons to achieve the electrical configuration of the closest noble gas.



Crown shaped (S_8) molecule

Properties Of Covalent Compounds

Covalent chemicals are those that possess **covalent bonding**. It has the following characteristics:

- Because in between the atoms, the intermolecular forces of attraction are modest, **covalent compounds** have **low melting and boiling temperatures**. In general, **covalent compounds** are **poor conductors of electricity**.

- Reason being, electrons are exchanged between atoms in these combinations, and no charged particles are generated. In general, **covalent molecules** are **volatile** in nature.

Allotropes Of Carbon And Their Properties

Allotropy is the feature of an element that allows it to exist in several states with distinct physical qualities but the **same chemical properties**. These many forms are referred to as **allotropes**. **Carbon** occurs in many varieties of **allotropic forms**, including the following:

- **Crystalline state**, for example, **diamond**, **graphite**, or **fullerene**.
- **Amorphous or microcrystalline form**, e.g. **coal**, **lampblack**, and **charcoal**.

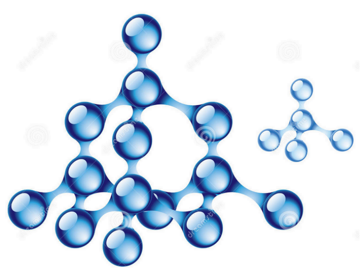
Diamond

General Properties

Because of its high index of refraction, it's a **colorless translucent material** with extraordinary brightness. It is very **thick and extremely hard** (*the world's toughest natural material*). It **does not conduct electricity** (as it faces the scarcity of free electrons), yet it is a good conductor of heat and has a **high melting point**.

Structure

1. It is a **huge carbon molecule** in which each carbon atom is connected to **4 other carbon atoms**, providing a rigid three-dimensional network structure which contributes to the material's hardness.



2. Additionally, a great amount of energy is needed to destroy the **diamond crystal's network of strong covalent connections**. That is the reason why its **melting point is quite high**.

Graphite

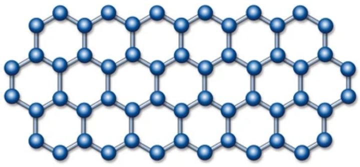
General Properties

Certainly, here's the text with the requested formatting:

It's an **opaque, greyish black material**. It is **less heavy than diamond**, **smoother to the touch**, and **more slippery**. With the existence of **free electrons**, it is an **excellent conductor of electricity** but a **poor conductor of heat**.

Structure

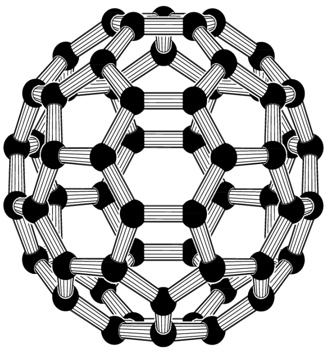
- **A graphite crystal** is composed of carbon atoms arranged in layers or sheets.
- Each carbon atom in a graphite sheet is covalently linked to **three other carbon atoms**, forming flat hexagonal rings.



- However, each carbon atom has a **free fourth electron**, resulting in making it an **excellent conductor of electricity**.
- Carbon atoms in graphite are kept together by **weak van der Waals forces**, allowing them to glide over one another, which is why graphite feels **slippery** to the touch.

Fullerenes

- Fullerenes are newly found allotropic forms of carbon that were synthesised for the first time by Robert Curt and H W Kroto, Smalley, using a laser beam to operate on graphite vapours. C_{60} was the first fullerene discovered.



- It includes 60 carbon atoms (C_{60}) with a lower fraction of (C_{70}) and traces of compounds containing up to 370 carbon atoms.
- Buckminster fullerene (C_{60}) was called for its structural similarities to the geodesic domes planned and erected by American architect Robert Buckminster Fuller.

Versatile Nature Of Carbon

Today, an estimated **three million carbon compounds** are known. However, the issue today is whether features or properties of carbon are responsible for the production of so many carbon compounds. The primary components that contribute to carbon's ability to generate a huge range of compounds are as follows:

Catenation

- It is the process by which elements, mostly **carbon atoms**, self-link through covalent bonds to create long, straight or branching chains and rings of various diameters.
- Carbon exhibits the highest degree of **catenation** in the periodic cable as a result of its tiny size and strong **C - C bond**. Hence, it is stable.

Tetravalency Of Carbon

- Carbon is a member of the periodic table's group 14. It has an **atomic number of six** and an **electrical configuration of two and four**. As a result, the outermost shell contains four electrons.
- As a result, its valency is four, indicating that it may bind or pair with **four additional carbon atoms** or with atoms of other monovalent elements such as **hydrogen, halogen (chlorine, bromine)**, and others.

Tendency While Forming Multiple Bonds

- Carbon, due to its tiny size, has a great inclination to create multiple bonds (double and triple bonds) by exchanging more than one electron pair with its own atoms or with the atoms of other elements such as **oxygen, nitrogen, and sulphur**.
- As a consequence, it may produce a range of very stable compounds.

Organic Compounds

- **Carbon compounds** except oxides, carbonates, and hydrogen carbonate salts fall in the category of **organic compounds**.
- Initially, natural substances were used for extracting these compounds, and it was believed that these carbon compounds could be formed only within a living system.
- As a result, it was hypothesised that a '**vital force**' was required for their creation.
- **Friedrich Wohler**, a German scientist, accidentally created **urea** from ammonium cyanate in 1828 while attempting to make ammonium cyanate by heating ammonium sulphate and potassium cyanate. Thus, **urea synthesis** negated the vital force idea.

Hydrocarbons

- Hydrocarbons are molecules of organic nature which are composed entirely of hydrogen and carbon, such as CH_4, C_2H_4, C_2H_6 and C_2H_2.
- These are the vital fundamental organic molecules and are hence known as parent organic compounds.
- All other compounds are regarded to be formed from them by substituting a group of atoms or other atoms for one or multiple hydrogen atoms. Hydrocarbons are categorised as follows:

Saturated Hydrocarbons

- Saturated hydrocarbons, paraffins or alkanes are hydrocarbons where all carbon atoms are connected by single covalent bonds.
- These compounds have the generic formula C_nH_{2n+2} where *n* is the number of carbon atoms in one molecule of a hydrocarbon.
- For example, if there is one carbon atom, the formula should be $C_1H_{2\times1+2}$= CH_4 (methane).
- Similarly, if a saturated hydrocarbon (alkane) has two carbon atoms, then the formula should be $C_2H_{2\times2+2}$ = C_2H_6(ethane).

Unsaturated Hydrocarbons

- **Unsaturated compounds** are defined as hydrocarbons that have at least one **double or triple bond (or multiple bond)** in addition to single bonds.
- As a result of their incomplete combustion, these chemicals often produce a **sooty or smoky flame**. These are **more reactive** than saturated hydrocarbons and are often the subject of additional reactions.
- Unsaturated compounds may be further classified into two categories.

Alkenes Or Olefins : Alkenes are unsaturated hydrocarbons that include a minimum of one double bond in addition to single bonds. (A double bond occurs when two carbon atoms share two pairs of electrons.) These compounds are classified as C_nH_{2n} by their general formula. For instance, if an alkene has two carbon atoms, its formula is $C_2H_{2x\,2}$ =C_2H_4 (ethene).

Alkynes : Alkynes are unsaturated hydrocarbons that include at least one triple bond in addition to the single bonds. (Three pairs of electrons are shared between two carbon atoms to create a triple bond). These compounds have a general formula of C_nH_{2n-2}, for example, if an alkyne has two carbon atoms, its formula is C_2H_{2x2-2} = C_2H_2 (ethyne). If an alkyne has 3 carbon atoms, it must have the formula C_3H_{2x3-2} = C_3H_4.

How To Draw The Structure Of Saturated And Unsaturated Compounds?

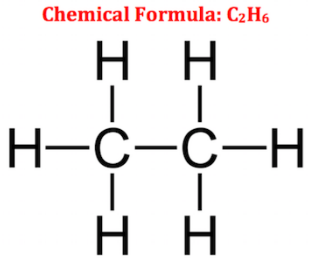
Step 1 - All the carbon atoms must be connected together with a **single bond.**

Step 2 - After this, the hydrogen atoms must be used for satisfying the remaining valencies of carbon because carbon forms **four bonds** as a result of its four valency.

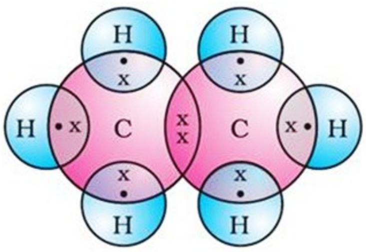
Step 3 - **Triple or double bonds** must be used for satisfying the remaining valencies if the number of H-atoms are less than the required amount.

Structure Of Ethane C_2H_6

- Ethane has 2 carbon atoms. For determining the structure of simple carbon compounds, the very first step is to connect the two carbon atoms by a single bond, i.e. C - C.
- Following this phase, only one valence of carbon is fulfilled, leaving the other three valencies of each carbon atom unsatisfied. H-atoms are used to satisfy each of these unfulfilled valencies.



- Carbon's tetravalency in ethane is now fulfilled. Ethane (C_2H_6) has an electron dot structure.



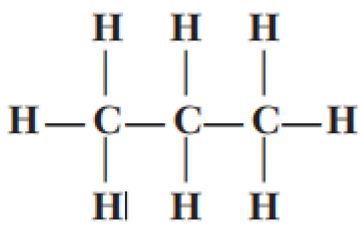
Electronic dot structure of ethane

Structure Of Propane C_2H_8

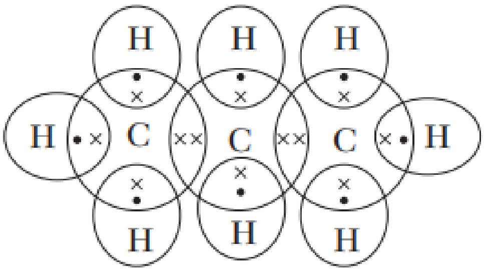
- The same principles apply here as it does with ethane. Here, a single bond connects the - 3 carbon atoms.

C_C_C

- For satisfying the carbon atom's remaining valencies, hydrogen atoms are linked with them.



- Two carbon atoms are covalently bound to three hydrogen atoms, whereas one carbon atom is covalently bonded to two hydrogen atoms. Propane has an electron dot structure (C_3H_8)

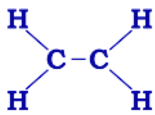


Structure Of Ethene C_2H_4

Step 1 - Linking the two atoms by a single bond.

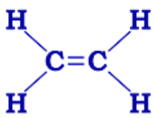
C—C Step 1

Step 2 - Linking the carbon atom with four hydrogen atoms for satisfying the valencies of carbon.



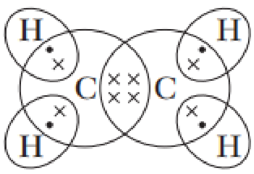
Step 2

Step 3 - However, even after connecting the available hydrogen atoms to carbon atoms, one of the valencies of each carbon remains unfulfilled. A dual bond between the two carbon atoms is utilised to fulfil it.



Step 3

Finally, all the 4 valencies of carbon are now satisfied. The below diagram illustrates the electron dot structure of ethene.

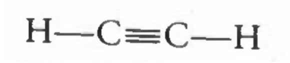


Structure Of Ethyne C_2H_2

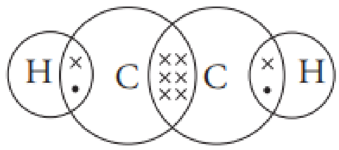
Step 1 - Linking the two atoms by a single bond. **C-C**

Step 2 - Linking the unsatisfied valencies of carbon with the two hydrogen atoms. **H-C-C-H**

Step 3 - However, in this situation, even after connecting the remaining hydrogen atoms to carbon atoms, two of the carbon valencies remain unfulfilled. A **triple bond** between the **two carbon** atoms are utilised to fulfill it.



- The 2 carbon atoms in ethyne share 3 pairs of electrons to create a carbon-carbon triple bond. Each carbon atom shares an electron with one hydrogen atom, resulting in the two carbon-hydrogen single bonds. Ethyne's (C_2H_2) electron dot structure.



How To Draw The Structure Of Cyclic Compounds?

Some of the carbon compounds exist in a ring or cyclic structure. For drawing the structure of ring or cyclic compounds, following steps must be followed:

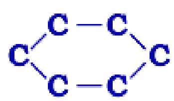
Step 1 - To begin, join the available carbon atoms through a **single cyclic bond.**

Step 2 - Make an attempt to fulfil the **tetravalency of each carbon** with the hydrogen atoms available.

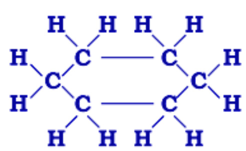
Step 3 - Now each carbon's valence will be determined. If it is discovered to be dissatisfied, it may be fulfilled with a **triple or double bond.**

Example - Cyclohexane (C_6H_{12})

Step 1 - Join the carbon atoms by a single bond.



Step 2 - Joining of H-atoms with the unsatisfied valencies of carbon.



As each C-four atom's valencies are fulfilled, As a result, no double or triple bond is required.

Isomerism

- **Isomers** are organic molecules with a **similar molecular formula** but distinct chemical and physical characteristics. This is referred to as **isomerism**.
- The variation in attributes between these compounds is attributable to their **structural differences**. Although these compounds possess the same chemical formula, their structures are distinct.
- As a result, they are known as **structural isomers**, and the phenomena is called **structural isomerism**.

Functional Groups

- Additionally, carbon may create connections with other elements such as **halogens, nitrogen, oxygen, and sulfur**. These are known as **heteroatoms**. These groups of atoms or atoms operate as a substitute for one or more hydrogen atoms in the hydrocarbon and they are also responsible for the compound's chemical reactivity regardless of its length and form of the carbon chain. Hence, they are called **functional groupings**.
- Thus, **functional groups** may be defined as an '**atom**' or '**group of atoms**' that contribute to the reactivity of a carbon compound (or organic molecule) and determine its characteristics (or functions) independent of the length and type of the carbon chain.

Homologous Series

Homologous series is a collection of similarly constructed compounds in which all members have the same functional group and exhibit comparable chemical characteristics and in which any two subsequent members vary in their molecular formula by a -CH 2- unit. CH_4, C_3H_8, C_2H_6, C_4H_{10} are all alkanes.

Characteristics Of A Homologous Series

- A homologous series's members may all be expressed using the same generic formula.
- Any two adjoining homologues have a chemical formula that differs by one carbon atom and two hydrogen atoms.
- The chemical characteristics of all substances in a homologous sequence are comparable.