# CHEMISTRY

# Allotropes of Carbon

## Allotropes of Carbon

Allotrope forms or allotropes are the different forms of the same elements with different physical properties but similar chemical properties.

Carbon exhibits both crystalline and amorphous forms.

- **Crystalline form**: Diamond and graphite are two crystalline forms of carbon with a well-defined structure.
- **Amorphous form**: Coal, wood charcoal, animal charcoal, lamp black and coke are many amorphous forms of carbon.

### Structure of different allotropes of carbon

#### Diamond

- Diamond has a network structure consisting of a very large number of carbon atoms bonded to each other.
- Each carbon atom is $sp^3$ hybridised and is bonded to four other carbon atoms by single covalent bonds.
- There is a three-dimensional network of strong covalent bonds in diamond which is very difficult to break.
- This makes diamond an extremely hard crystal with very high melting point (about 3843 K).


Structure of diamond

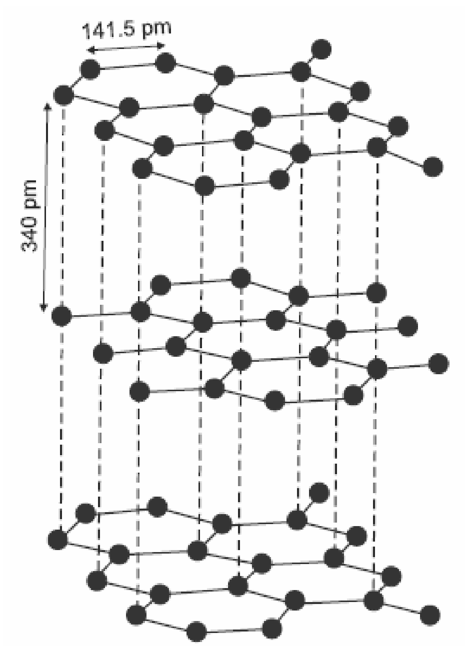
- All the valence electrons of carbon are strongly held in carbon–carbon bonds. This makes diamond a poor conductor of electricity.

**Uses**

- As an abrasive for sharpening hard tools
- In the manufacture of dyes and tungsten filaments for electric light bulbs

## Graphite

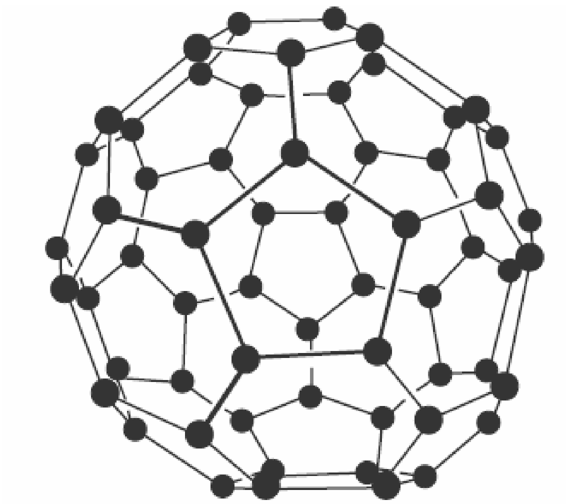
- In graphite, each carbon atom undergoes $sp^2$ hybridisation and is covalently bonded to three other carbon atoms by single bonds.
- The fourth electron on each carbon atom forms $\pi$ bonds.
- In this way, graphite consists of hexagonal rings in two dimensions.
- The C–C covalent distance in rings is 141.5 pm, indicating strong bonding.
- These arrays of rings form layers. The layers are separated by a distance of 340 pm.
- The large distance between these layers indicates that only weak van der Waals forces hold these layers together.
- The weak van der Waals forces which hold these layers together are responsible for the soft nature of graphite. Because of these weak van der Waals forces between layers, one layer can move over the other layer, producing the characteristic slippery nature. Therefore, graphite is used as a lubricant.
- The electrons forming $\pi$ bonds in the rings of graphite are delocalised and are relatively free to move under the influence of an electric field. Therefore, graphite is a good conductor of electricity.




- Graphite is thermodynamically the most stable allotrope of carbon, and hence, $\Delta_f H^{-}$ of graphite is taken as zero. $\Delta_f H^{-}$ of diamond is 1.90 kJ $mol^{-1}$ and that of fullerene ($C_{60}$) is 38.1 kJ $mol^{-1}$.

### Fullerene

- It is an allotrope of carbon containing clusters of 60 carbon atoms joined to form a spherical molecule.
- The $C_{60}$ molecule has a shape like a soccer ball and is called Buckminsterfullerene.
- It contains 20 six-membered rings and 12 five-membered rings.
- All the carbon atoms are equal, and they undergo $sp^2$ hybridisation.
- Each carbon atom forms three sigma bonds with three other carbon atoms.
- The remaining electron at each carbon is delocalised in molecular orbitals, which in turn give an aromatic character to the molecule.
- This ball-shaped molecule has 60 vertices, and each is occupied by one carbon atom, and it also contains both single and double bonds with C–C distances of 143.5 pm and 138.3 pm, respectively.
- Spherical fullerene is also called Bucky ball.



## Uses of Carbon

- Graphite fibres embedded in plastic material form high strength, lightweight composites which are used in the manufacture of products such as tennis racquets, fishing rods, aircraft and canoes.
- Graphite being a good conductor is used for electrodes in batteries and in industrial electrolysis.
- Crucibles prepared from graphite are inert to dilute acids and alkalies.
- Activated charcoal being highly porous is used in adsorbing poisonous gases and in water filters to remove organic contaminators.
- Carbon black is used as a black pigment in black ink and as a filler in automobile tyres.
- Coke is used as a fuel and largely as a reducing agent in metallurgy.
- Diamond is a precious stone and is used in jewellery.

# Some Important Compounds of Carbon

## Carbon Monoxide (CO)

### a) Preparation of carbon monoxide (CO)

- Direct oxidation of carbon in limited supply of air or oxygen gives carbon monoxide.

$$2C_{(s)} + O_{2(g)} \xrightarrow{\Delta} 2CO_{(g)}$$

- CO is also prepared by dehydration of formic acid with conc. $H_2SO_4$ at 373 K on a small scale.

$$HCOOH \xrightarrow[\text{Conc.}H_2SO_4]{373K} 2CO_{(g)}$$

- It is prepared on a commercial scale by the passage of steam over hot coke. The mixture of CO and $H_2$ thus produced is known as water gas.

$$C_{(s)} + H_2O_{(g)} \xrightarrow{473\text{–}1273K} CO_{(g)} + H_{2(g)}$$

- When air is passed instead of steam, a mixture of CO and $N_2$ is produced which is called producer gas.

$$2C_{(s)} + O_{(g)} + 4N_{2(g)} \xrightarrow{1273K} \underbrace{2CO_{(g)} + 4N_{2(g)}}_{\text{Producer gas}}$$

### b) Properties of carbon monoxide (CO)

- It is a colourless, odourless and almost water-insoluble gas.

- It is a powerful reducing agent and reduces almost all metal oxides other than those of the alkali and alkaline earth metals, aluminium and a few transition metals.

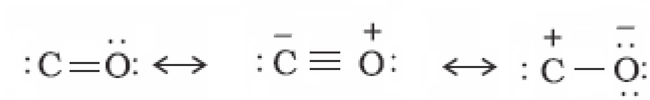
$$Fe_2O_{3(s)} + 3CO_{(g)} \xrightarrow{\Delta} 2Fe_{(s)} + 3CO_{2(g)}$$

$$ZnO_{(s)} + CO_{(g)} \xrightarrow{\Delta} Zn_{(s)} + CO_{2(g)}$$

- CO is highly poisonous because it can form a complex with haemoglobin, which is about 300 times more stable than the oxygen–haemoglobin complex. This prevents haemoglobin in the red blood cells from carrying oxygen around the body and ultimately resulting in death.

### c) Structure of carbon monoxide (CO)

- In the CO molecule, there is one $\sigma$ and two $\pi$ bonds between carbon and oxygen $:C \equiv O:$.
- Because of the presence of a lone pair on carbon, the CO molecule acts as a donor and reacts with certain metals on heating to form metal carbonyls.
- Carbon monoxide is regarded as the resonance hybrid of the following structures:



## Carbon dioxide ($CO_2$)

### a) Preparation of carbon dioxide ($CO_2$)

It is prepared by the complete combustion of carbon and carbon-containing fuels in excess of air.

$$C_{(s)} + O_{2(g)} \xrightarrow{\Delta} CO_{2(g)}$$

$$CH_{4(g)} + 2O_{2(g)} \xrightarrow{\Delta} CO_{2(g)} + 2H_2O_{(g)}$$

It is prepared in the laboratory by the action of dilute HCl on calcium carbonate.

$$CaCO_{3(s)} + 2HCl_{(aq)} \longrightarrow CaCl_{2(aq)} + CO_{2(g)} + H_2O_{(l)}$$

**b) Properties of carbon dioxide ($CO_2$)**

- It is a colourless and odourless gas.
- With water, it forms carbonic acid $H_2CO_3$, which is a weak dibasic acid and dissociates in two steps:

$$H_2CO_{3(aq)} + H_2O_{(l)} \leftrightharpoons HCO_3^-{}_{(aq)} + H_3O^+{}_{(aq)}$$

$$H_2CO_{3(aq)} + H_2O_{(l)} \leftrightharpoons CO_3^{2-}{}_{(aq)} + H_3O^+{}_{(aq)}$$

- $H_2CO_3/HCO_3^-$ buffer system helps maintain the pH of blood between 7.26 and 7.42.
- Carbon dioxide as a solid in the form of dry ice is used as a refrigerant for ice cream and frozen food.
- Gaseous $CO_2$ is used in aerated soft drinks.
- The increase in the combustion of fossil fuels and decomposition of limestone in the cement industry has resulted in an increase in the $CO_2$ content of the atmosphere. This may lead to increase in the greenhouse effect which eventually will raise the temperature of the atmosphere and may have serious consequences.
- Being heavy and a non-supporter of combustion, carbon dioxide is used as a fire extinguisher.

**c) Structures of carbon dioxide**

- In a $CO_2$ molecule, the carbon atom undergoes sp hybridisation.
- Two sp hybridised orbitals of carbon atom overlap with two p-orbitals of oxygen atoms to make two sigma bonds, while the other two electrons of the carbon atom are involved in $p\pi - p\pi$ bonding with the oxygen atom.
- This results in its linear shape with both C–O bonds of equal length (115 pm) with no dipole moment.
- The resonance structures are shown below: