COMPOUNDS OF CARBON
Important Compounds of Carbon
Carbon Monoxide (CO)

Preparation:

(i) It is generated in conjunction with CO_2 when carbon or carbon-containing substances undergo oxidation in the presence of air or oxygen. Additionally, it is produced when red-hot carbon is used to reduce CO_2, and this reaction holds significance in the field of metal extraction.

$$C(s) + CO_2(g) \longrightarrow 2CO(g)$$

(ii) In the laboratory it can be prepared by dehydrating methanolic acid with concentrated sulphuric acid.

$$HCOOH\ (liq) \xrightarrow[\text{conc.} H_2SO_4]{373K} CO(g) + H_2O$$

(iii) If oxalic acid is dehydrated in the same way, CO_2 is formed as well.

$$H_2C_2O_4 \xrightarrow[-H_2O]{\text{conc. } H_2SO_4,\Delta} CO + CO_2$$

(iv) On commercial scale it is prepared by the passage of steam over hot coke. The mixture of CO and H_2 thus produced is known as water gas or synthesis gas.

$$C\ (s) + H_2O\ (g) \xrightarrow{473-1273K} CO\ (g) + H_2(g)\ \text{(water gas)}.$$

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

$$2C(s) + O_2\ (g) + 4\ N_2\ (g) \xrightarrow{1273K} 2\ CO\ (g) + 4\ N_2\ (g)\ \text{(Producer gas)}.$$

Water gas and producer gas are very important industrial fuels. Carbon monoxide in water gas or producer gas can undergo further combustion forming carbon dioxide with the liberation of heat.

(v) $$CO_2 + H_2 \longrightarrow CO + H_2O$$

(vi) $$K_4Fe\ (CN)_6 + 6H_2SO_4\ \text{(concentrated)} + 6H_2O \xrightarrow{\Delta} 2K_2SO_4 + FeSO_4 + 3(NH_4)_2SO_4 + 6CO$$

(vii) $$HCN + 2H_2O \longrightarrow HCOOH + 2NH_3\ \text{(absorbed by } H_2SO_4)$$

$$HCOOH \xrightarrow{\Delta} H_2O + CO$$

(viii) Also obtained as by-product when carbon is used in reduction processes such as, of phosphite rock to give phosphorus.

Properties

(i) Carbon monoxide, a gas devoid of color and odor, combusts in the presence of air, producing CO_2 with a blue flame. It exhibits limited solubility in water and is considered a neutral oxide. CO is hazardous due to its ability to create a complex with hemoglobin in the bloodstream, which is more stable than oxy-hemoglobin. As a result, this complex obstructs hemoglobin's capacity to transport oxygen throughout the body, resulting in oxygen deficiency, followed by loss of consciousness and eventual fatality.

$$Hb—O_2 + CO \longrightarrow Hb—CO + O_2$$

Regular gas masks do not offer protection from this gas, as it is not easily adsorbed by activated charcoal. In the presence of air, a combination of manganese (IV) oxide and copper (II) oxide catalytically converts it into CO_2. This mixed catalyst is employed in the breathing apparatus utilized by rescue teams during my disasters.

(ii) Carbon monoxide is a potent reducing agent used in industrial processes for extracting iron and nickel.

$$Fe_2O_3(s) + 3CO(g) \longrightarrow 2Fe(s) + 2CO_2(g)\ ;\ NiO(s) + CO(g) \longrightarrow Ni(s) + CO_2(g)$$

(iii) It reacts with many transition metals, forming volatile carbonyls; the formation of nickel carbonyl followed by its decomposition is the basis of the Mond's process for obtaining very pure nickel.

$$Ni(s) + 4CO(g) \xrightarrow{28^{o}C} Ni(CO)_4(liq) \xrightarrow{180^{o}C} Ni(s) + 4CO(g)$$

(iv) Apart from its reaction with oxygen, carbon monoxide also forms carbonyl sulphide when combined with sulfur and carbonyl chloride (phosgene) when exposed to light and chlorine. Phosgene is utilized in the manufacturing of polyurethane foam plastics and is an extremely toxic gas.

$$CO(g) + S(s) \longrightarrow COS(s)\ \text{(carbonyl sulphide)};$$

$$CO(g) + Cl_2(g) \longrightarrow COCl_2(g)\ \text{(carbonyl chloride)}$$

(v) Although carbon monoxide is not a true acid anhydride since it does not react with water to produce an acid, it reacts under pressure with fused sodium hydroxide to give sodium methanolate:

$$NaOH(liq) + CO(g) \longrightarrow HCOONa(s) \xrightarrow{\text{dil.HCl}} HCOOH\ (aq)$$

(vi) While carbon monoxide is not a conventional acid anhydride because it doesn't react with water to produce an acid, it can, under pressure, combine with molten sodium hydroxide to form sodium methanolate.

$$CO(g) + 2H_2(g) \longrightarrow CH_3OH\ (liq)$$

(vii) CO is readily absorbed by an ammoniacal solution of copper (I) chloride to give $CuCl.CO.2H_2O$. It reduces an ammoniacal solution of silver nitrate to silver (black) and, in the absence of other gaseous reducing agents, this serves as a test for the gas. It can be estimated by reaction with iodine pentoxide, the iodine which is produced quantitatively being titrated with standard sodium thiosulphate solution.

$$5CO(g) + I_2O_5(s) \longrightarrow I_2(s) + 5CO_2(g)$$

(viii) It reduces an aqueous $PdCl_2$ solution to metallic Pd.

Carbon Dioxide (CO_2)

Preparation:

(i) In the laboratory it can be conveniently made by the action of dilute hydrochloric acid on marble chips:

$$CO_3^{2-}(aq) + 2H^+(aq) \longrightarrow CO_2(g) + H_2O(\lambda)$$

(ii) Industrially it is produced as a by-product during the manufacture of quicklime and in fermentation processes:

$$CaCO_3(s) \longrightarrow CaO(s) + CO_2(g)\ ;\ C_6H_{12}O_6(aq)\{glucose\} \longrightarrow 2C_2H_5OH(aq) + 2CO_2(g)$$

Properties:

(i) This gas is clear, scentless, and dense. It can dissolve in an equivalent volume of water at standard temperature and pressure. Like most gases, its solubility in water significantly increases when the pressure is elevated. This fundamental principle is harnessed in the production of soda water and carbonated beverages.

(ii) CO_2 readily undergoes liquefaction (with a critical temperature of 31.1ºC), making a pressurized gas cylinder a practical fire extinguisher. When the tightly compressed gas is swiftly released, it transforms into solid carbon dioxide, commonly known as 'dry ice.' Solid carbon dioxide sublimes at -78ºC, and because it transitions directly from a solid to a gas without an intermediate liquid stage, it serves as a convenient method for achieving low temperatures.

(iii) Carbon dioxide is the acid anhydride of carbonic acid, which is a weak dibasic acid and ionise in two steps as follows:

$$H_2CO_3(aq) + H_2O\ (\lambda) \rightleftharpoons HCO_3^-\ (aq) + H_3O^+\ (aq)$$

$$HCO_3^-\ (aq) + H_2O\ (\lambda) \rightleftharpoons CO_3^{2-}\ (aq) + H_3O^+\ (aq)$$

H_2CO_3 / HCO_3^- buffer system helps to maintain pH of blood between 7.26 to 7.42.

A solution of carbonic acid in water will slowly turn blue litmus red and when the solution is boiled, all the CO_2 is evolved.

(iv) Carbon dioxide readily reacts with alkalis forming the carbonate and, if CO_2 is in excess, the hydrogen carbonate. This is the basis of the lime-water test for CO_2 gas.

$Ca(OH)_2(aq) + CO_2(g) \rightarrow CaCO_3(s) + H_2O(liq)$; $CaCO_3(s) + H_2O(liq) + CO_2(g) \rightarrow Ca(HCO_3)_2(aq)$

The above reaction accounts for the formation of temporarily hard water.

(v) Carbon dioxide, typically found at approximately 0.03% by volume in the atmosphere, is extracted through the process called photosynthesis. This is the mechanism through which green plants transform atmospheric CO2 into carbohydrates, such as glucose.

The overall chemical change can be expressed as:

$$6\ CO_2 + 12\ H_2O \xrightarrow[\text{Chlorphyll}]{hv} C_6H_{12}O_6 + 6\ O_2 + 6\ H_2O$$

Through this process, plants produce sustenance not only for their own growth but also for consumption by animals and humans. However, the rising combustion of fossil fuels and the decomposition of limestone for cement production in recent times appear to be elevating the atmospheric CO_2 levels. This could potentially result in an amplified greenhouse effect, leading to higher atmospheric temperatures and potentially significant repercussions.

(vi) Gaseous CO_2 is extensively used to carbonate soft drinks. Being heavy and non–supporter of combustion it is used as fire extinguisher. A substantial amount of CO_2 is used to manufacture urea.

Recovery of CO_2

(a) $Na_2CO_3 + CO_2 + H_2O \underset{\text{Hot}}{\overset{\text{Cool}}{\rightleftharpoons}} 2NsHCO_3$

(b) Gaseous process: $2HOCH_2CH_2NH_2 + CO_2 + H_2O \underset{100-150^\circ C}{\overset{30-60^\circ C}{\rightleftharpoons}} (HOCH_2CH_2NH_3)_2CO_3$

Carbon Halides

(i) Simple halides of carbon encompass CF_4, CCl_4, CBr_4, and Cl_4, all of which are confirmed to exist.

(ii) The stability of these tetrahalides follows a decreasing order as the size of the halogen increases, namely: $CF_4 > CCl_4 > CBr_4 > Cl_4$.

(iii) Mixed halides include compounds like $CFCI_3$, CF_2Cl_2, CCl_3Br, and so forth.

CF_4 (Carbon tetrafluoride)

- It is an extraordinarily stable compound.
- Lab preparation: Sic + F2 $\xrightarrow{\Delta}$ SiF4 + CF4
- No hydrolysis is possible.

CCl_4 (Carbon tetrachloride)

- Common solvent, fairly readily decomposed photo chemically.
- Although it is thermodynamically unstable with respect to hydrolysis, the observe of acceptor orbitals carbon makes the attack very difficult.

CBr_4 (Carbon tetrabromide)

- Pale yellow solid at room temperature.
- Insoluble in water, soluble in non-polar solvent.

CI_4 (Carbon tetraiodide)

- Bright red, crystalline material.
- odor like that of iodine.

Properties:

(i) All tetrahalides are categorized as covalent compounds. They exhibit chemical inertness and are non-flammable substances.

(ii) These compounds resist hydrolysis by water due to the inability of carbon to extend its coordination number beyond four. This limitation arises from the absence of vacant d orbitals in carbon.

Carbon suboxide (C_3O_2)

This is a foul-smelling gas that can be produced by dehydrating propane dioic acid (malonic acid), from which it is derived, using phosphorus pentoxide.

$$3\ CH_2(COOH)_2 + P_4O_{10} \longrightarrow 3C_3O_2 + 4H_3PO_4$$

When heated to about 200^oC, it decomposes into CO_2 and C:

$$C_3O_2(g) \longrightarrow CO_2(g) + 2C(s)$$

The molecule is thought to have a linear structure: $O = C = C = C = O$.

Hydrides of carbon

Carbon forms a vast number of chain and ring compounds including:

- The alkanes (Paraffins) C_nH_{2n+2}
- The alkenes (olefines) C_nH_{2n}
- The alkynes (acetylenes) C_nH_{2n-2}
- Aromatic compounds

Carbides

Based on the nature of the bonding they exhibit; carbides can be categorized into the following types:

(i) Ionic or Salt-like Carbides

Ionic or salt-like carbides are compounds formed by the bonding of carbon with strongly electropositive elements. Examples include CaC_2, Al_4C_3, Be_2C, and similar compounds.

(ii) Covalent Carbides

Covalent carbides form when carbon bonds with elements possessing electronegativity slightly lower than that of carbon. These carbides involve covalent bonds between carbon and other elements. Examples of covalent carbides include SiC, B_4C, and others.

(iii) Interstitial Carbides

These carbides are formed with transition metals and are characterized by compounds such as TiC, WC, ZrC, VC, and others. Interstitial carbides involve the insertion of carbon atoms into the interstitial spaces of the metal lattice, contributing to their distinct properties.