CARBON AND ITS ALLOTROPES

Carbon is a non-metal known to people for a long time under the names charcoal, soot and diamond. It occurs naturally as diamond and graphite. Carbon also occurs in an impure form as coal and in combine state as petroleum, wood and natural gases. These carbon compounds form an important source of fuels. They are burnt to release heat and light, which may be converted to other forms of energy.

Other sources that contain carbon are mineral deposits of metallic trioxocarbonate (IV), $CaCO_3$ (limestone), and magnesium trioxocarbonate (IV), $MgCO_3$ (dolomite), and the carbon (IV) oxide, CO_2 in the air and water around us. Carbon is also an essential constituent of all living things.

The chemistry of carbon compounds is known as organic chemistry. However, the study of some of its compounds such as the oxides, sulphides, metallic

carbides, trioxocarbonates (IV) and hydrogentrioxo-carbonates (IV), is usually included in inorganic chemistry.

Allotropes or Physical Forms of Carbon

The ability of carbon to exist in various forms in the same physical state is known as allotropy. Diamond and graphite are two allotropic forms of crystalline carbon.

The others like coal, coke, charcoal, lamp-black, sugar charcoal, and animal charcoal are amorphous or non-crystalline forms of carbon.

Diamond

Diamonds are the purest form of naturally occuring carbon. They are found as colourless, lustreless solids which can be transformed into brilliant gems. They are found naturally in Africa, Brazil, India, Siberia, Venezuela, and the Republic of Guyana.

Diamond is the hardest substance known. As a result, only a diamond can cut a diamond. It has a high melting point and is very dense and resistant to high temperatures and chemical attack. It is a non-conductor of electricity because there are no free valence electrons in the diamond crystal, as all of them are used in bond formation.

Graphite

Graphite occurs naturally as plumbago, an opaque black solid. It is mined mainly in Austria, China, West Germany, Republic of Korea, Madagascar, Mexico, Siberia, and Sri Lanka. Like diamond, it is probably formed by the action of volcanic heat on coal deposits.

The carbon atoms in graphite form flat layers. These layers are arranged in parallel, one above the other, to form a crystal lattice. Graphite is soft and flakes easily because of its layered crystalline structure. It has a high melting point but is less

dense than diamond, 2.3gcm^{-3}. It is relatively inert chemically but can be oxidized to six carbon atom organic compounds under suitable conditions. Unlike diamond, graphite is a good conductor of electricity because of the presence of mobile electrons in the crystal lattice. Mobile electrons exist since only three of the four valence electrons of each carbon atom in the graphite crystal are involved in bond formation.

Coal

Coal was formed from the vegetation of the Carboniferous Era which was protected from complete decay by overlying water-washed earth deposits. Decomposition occurred gradually under pressure and in the absence of air. Carbon (IV) oxide, methane and water were liberated; leaving behind a material that contained a very high percentage of carbon. During this process of carbonization, the vegetable material was converted in stages into peat, lignite (or brown coal), bituminous (or soft) coal, and

finally anthracite (or hard coal) which is about 95% pure carbon. Impurities present may include nitrogen, sulphur, and phosphorus.

Coal is used mainly as a fuel to generate power for steam engines, factories and electric plants. It is also used for making various chemicals. Coal can be naturally found in Nigeria: Enugu, Onitsha, and Asaba.

Coke

Coke is obtained by heating bituminous coal to very high temperatures (about 1300^{o}C) in the absence of air to drive away all the volatile constituents. This process is known as the destructive distillation of coal. Coke is used mainly as a fuel. It burns with practically no smoke and leaves very little residue. It is a very important industrial reducing agent, and is used in the extraction of metals, especially iron, from their ores. It is also used in the production of

gaseous fuels, like water gas, and producer gas, for the manufacture of graphite, calcium carbide, silicon, carbide and carbon (IV) sulphide.

Carbon black (Soot)

Carbon black or soot or finely divided carbon particles produced by burning carbonaceous materials in a limited supply of air. Lamp-black is obtained from vegetable or lamp oil, while carbon black is obtained from coal gas, natural gas or fuel oils. Carbon black is used in manufacturing rubber tyres, black shoe polish, printer's ink, typewriting ribbons, and carbon paper.

Charcoal

Charcoal can be made by heating wood, nutshells, bones, sugar and even blood. Wood charcoal is the most common. It is prepared by heating wood in a

limited supply of air. It contains impurities such as sulphur. Sugar charcoal is formed when sugar is dehydrated either by burning the sugar in a limited supply of air or by the action of concentrated tetraoxosulphate (VI) acid. It is the purest form of amorphous carbon. Animal charcoal is produced when bones and animal refuse are heated in a limited supply of air. It contains high percentage of calcium tetraoxophosphate (V) as impurity.

Charcoal has a very porous structure. It allows small molecules of gases and dyes to absorb or adhere to its internal surfaces. Thus, it is a good absorbent particularly when activated by heating in steam. Wood charcoal is used as domestic fuel in Nigeria.

General Properties of Carbon

Physical Properties

1. All the carbon allotropes, except diamond, are black or greyish black solids.
2. They are odourless and tasteless.
3. Their meling points are very high, 3500^{o}C
4. They are insoluble in common solvents like water, alkalis, acids, petrol and carbon (IV) sulphide. That is why carbon deposits inside motor engines have to be removed mechanically. This is known as decarbonization of motor engines.

Chemical Properties

Carbon is not a very reactive element and most carbon compounds are stable. This is because carbon atom has a valency of four and forms compounds with four covalent bonds. In these compounds, it does not have any lone pair of electrons and so is unreactive since it cannot

function as an electron donor. Also, the stability of carbon compound is due to strong carbon-carbon bonds. This bond could form very long chains of carbon-carbon bond. This is known as catenation.

Combustion. All forms of carbon burn in excess oxygen to produce carbon (IV) oxide only although the temperatures required differ.

$$C_s + O_{2\,g} \rightarrow CO_{2\,g}$$

When the supply of air is limited combustion may not be complete. Carbon (II) oxide is formed instead of carbon (IV) oxide.

$$2\,C_s + O_{2\,g} \rightarrow 2CO_g$$

Combination Reactions. Carbon combines directly with certain elements such as sulphur, hydrogen, calcium, and aluminium at very high temperatures.

$$C_s + 2S_s \rightarrow CS_2\,(l)$$

carbon (IV) sulphide

$$C\ (s) + \ 2H_2\ (g) \rightarrow \ CH_4\ (g)$$

methane

$$2C\ (s) + \ Ca\ (s) \rightarrow \ CaC_2\ (s)$$

calcium carbide

$$3C\ (s) + \ 4Al\ (s) \ \rightarrow \ Al_4\ C_3\ (s)$$

aluminium carbide

As a Reducing Agent. Carbon is a strong reducing agent. It reduces the oxides of less active metals to the metals, although very high temperatures may be required in some cases. Carbon itself is oxidized to either carbon (IV) oxide or carbon (II) oxide, depending on the conditions of the reaction. At high temperatures, carbon also reduces steam to hydrogen, and carbon (IV) oxide to carbon (II) oxide.

$$\mathrm{Fe_2\ O_3\ (s) + \ 3C\ (s) \rightarrow \ 2Fe\ (s) \ + \ 3CO\ (g)}$$

$$\mathrm{2CuO(s) + C\ (s) \rightarrow \ 2Cu\ (s) + CO_2\ (g)}$$

$$\mathrm{H_2\ O\ (g) + \ C\ (s) \rightarrow CO\ (g) \ + \ H_2\ (g)}$$

$$\mathrm{CO_2\ (g) \ + \ C\ (s) \rightarrow \ 2CO\ (g)}$$

Reaction with Strong Oxidizing Agents. When carbon is heated with concentrated trioxonitrate (V) acid or concentrated tetraoxosulphate (VI) acids, it is oxidized to carbon (Iv) oxide.

$$C\ (s) + 4HNO_3\ (aq) \rightarrow 2H_2\ O\ (l) + 4NO_2\ (g) + CO_2\ (g)$$

$$C_{(s)} + 2H_2SO_{4(aq)} \rightarrow 2H_2O_{(l)} + 2SO_{2(g)} + CO_{2(g)}$$

Destructive distillation of Coal and Wood. Coal is a complex mixture of compounds composed mainly of carbon, hydrogen and oxygen, with small amounts of nitrogen, sulphur, phosphorus as impurities. A wide variety of substances can be obtained from it by a process known as the destructive distillation of coal.

$$coal \rightarrow coke + ammoniacal\ liquor + coal\ tar + coal\ gas$$

During this process, coal is heated to a very high temperature in the absence of air so that all the volatile components distil over. The coal is destroyed by this distillation process.

Wood is a complex substance like coal except that the percentage composition of the elements present in it is different. For example, wood has a higher percentage of hydrogen and oxygen but a lower percentage of carbon than coal. Destructive distillation of wood yields these four fractions:

$$wood \rightarrow \ wood\ charcoal\ +\ pyroligneous\ acid + \ wood\ tar\ +\ wood\ gas$$

Pyroligneous acid, which is the liquid fraction, contains mainly ethanoic acid, propanone, methanol and some other compounds.

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