THE ERA OF CARBON AND ITS VERSATILE PHYSICAL AND CHEMICAL PROPERTIES

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ABSTRACT: In this article, we have attempted to summarize the carbon and carbon materials. Carbon in its single entity and various forms has been used in technology and human life for many centuries. Since prehistoric times, carbon-based materials such as graphite, charcoal and carbon black have been used as writing and drawing materials. In the past two and a half decades or so, conjugated carbon nanomaterials, especially carbon nanotubes, fullerenes, activated carbon and graphite have been used as energy materials due to their exclusive properties. Due to their outstanding chemical, mechanical, electrical and thermal properties, carbon nanostructures have recently found application in many diverse areas; including drug delivery, electronics, composite materials, sensors, field emission devices, energy storage and conversion, etc. Following the global energy outlook, it is forecasted that the world energy demand will double by 2050. This calls for a new and efficient means to double the energy supply in order to meet the challenges that forge ahead. Carbon nanomaterials are believed to be appropriate and promising (when used as energy materials) to cushion the threat.

Keywords:: **Carbon, Semiconductor nature, Properties , Unique diversity, Applications, etc.**

I. INTRODUCTION

Carbon (from Latin: *carbo* "coal") is a chemical element with symbol C and atomic number 6. It is non-metallic and tetravalent making four electrons available to form covalent chemical bonds. It belongs to group 14 of the periodic table. Three isotopes occur naturally, ^{12}C and ^{13}C being stable, while ^{14}C is a radio nuclide, decaying with a half-life of about 5,730 years. Carbon is one of the few elements known since antiquity. Carbon is the 15th most abundant element in the Earth's crust and the fourth most abundant element in the universe by mass after hydrogen, helium, and oxygen. Carbon's abundance, its unique diversity of organic compounds, and its unusual ability to form polymers at the temperatures commonly encountered on Earth enables this element to serve as a common element of all known life. It is the second most abundant element in the human body by mass (about 18.5%) after oxygen. The atoms of carbon can bond together in different ways, termed allotropes of carbon. The best known are graphite, diamond, and amorphous carbon. The physical properties of carbon vary widely with the allotropic form. For example, graphite is opaque and black while diamond is highly transparent. Graphite is soft enough to form a streak on paper (hence its name, from the Greek verb "γράφειν" which means "to write"), while diamond is the hardest naturally occurring material known. Graphite is a good electrical conductor while diamond has a low electrical conductivity. Under normal conditions, diamond, carbon nanotubes, and graphene have the highest thermal conductivities of all known materials. All carbon allotropes are solids under normal conditions, with graphite being the most thermodynamically stable form at standard temperature and pressure. They are chemically resistant and require high temperature to react even with oxygen. The most common oxidation state of carbon in inorganic compounds is +4, while +2 is found in carbon monoxide and transition metal carbonyl complexes. The largest sources of inorganic carbon are lime stones, dolomites and carbon dioxide, but significant quantities occur in organic deposits of coal, peat, oil, and methane clathrates. Carbon forms a vast number of compounds, more than any other element, with almost ten million compounds described to date, and yet that number is but a fraction of the number of theoretically possible compounds under standard conditions. For this reason, carbon has often been referred to as the **"king of the elements".**

Carbon-based resources (coal, natural gas and oil) give us most of the world energy today, but the energy economy of the future must necessarily be far more diverse. Energy generation through solar, wind and geothermal means is developing now, but not fast enough to meet our expanding global energy needs. We advocate that 'green carbon', which enables us to use carbon-based sources with high efficiency and in an environmentally friendly manner, will provide our society time to develop alternative energy technologies and markets without sacrificing environmental or economic quality. Green carbon will help to reduce the loss of our precious carbon resources, which are better reserved for high-value chemicals, and it will ensure that those hydrocarbons used for fuels will minimize carbon emissions. Through intensive research and development in green carbon, our society can guarantee an energy future that uses carbon strategically, without smokestacks, greenhouse gases and extensive environmental damage. Carbon is an element which plays a very important role in our lives. The atomic element carbon has very diverse physical and chemical properties due to the nature of its bonding and atomic arrangement.

II. HISTORY AND ETYMOLOGY OF CARBON

The English name *carbon* comes from the Latin *carbo* for coal and charcoal, whence also comes the French *charbon*, meaning charcoal. In German, Dutch and Danish, the names for carbon are *Kohlenstoff*, *koolstof* and *kulstof* respectively, all literally meaning coal-substance. Carbon was discovered in prehistory and was known in the forms of soot and charcoal to the earliest human civilizations. Diamonds were known probably as early as 2500 BCE in China, while carbon in the form of charcoal was made around Roman times by the same chemistry as it is today, by heating wood in a pyramid covered with clay to exclude air. In 1722, René Antoine Ferchault de Réaumur demonstrated that iron was transformed into steel through the absorption of some substance, now known to be carbon. In 1772, Antoine Lavoisier showed that diamonds are a form of carbon; when he burned samples of charcoal and diamond and found that neither produced any water and that both released the same amount of carbon dioxide per gram. In 1779, Carl Wilhelm Scheele showed that graphite, which had been thought of as a form of lead, was instead identical with charcoal but with a small admixture of iron, and that it gave "aerial acid" (his name for carbon dioxide) when oxidized with nitric acid. In 1786, the French scientists Claude Louis Berthollet, Gaspard Monge and C. A. Vandermonde confirmed that graphite was mostly carbon by oxidizing it in oxygen in much the same way Lavoisier had done with diamond. Some iron again was left, which the French scientists thought was necessary to the graphite structure. In their publication they proposed the name *carbone* (Latin *carbonum*) for the element in graphite which was given off as a gas upon burning graphite. Antoine Lavoisier then listed carbon as an element in his 1789 textbook. A new allotrope of carbon, fullerene, which was discovered in 1985 includes nanostructured forms such as bucky balls and nanotubes. Their discoverers – Robert Curl, Harold Kroto and Richard Smalley received the Nobel Prize in Chemistry in 1996. The resulting renewed interest in new forms lead to the discovery of further exotic allotropes, including glassy carbon, and the realization that "amorphous carbon" is not strictly amorphous. For this reason, several other allotropes and forms of carbon were discovered Fig.1, such as graphene buckminsterfullerene carbon nanotubes etc., hence making carbon to have the highest number of identified allotropes when compared to anyother material.

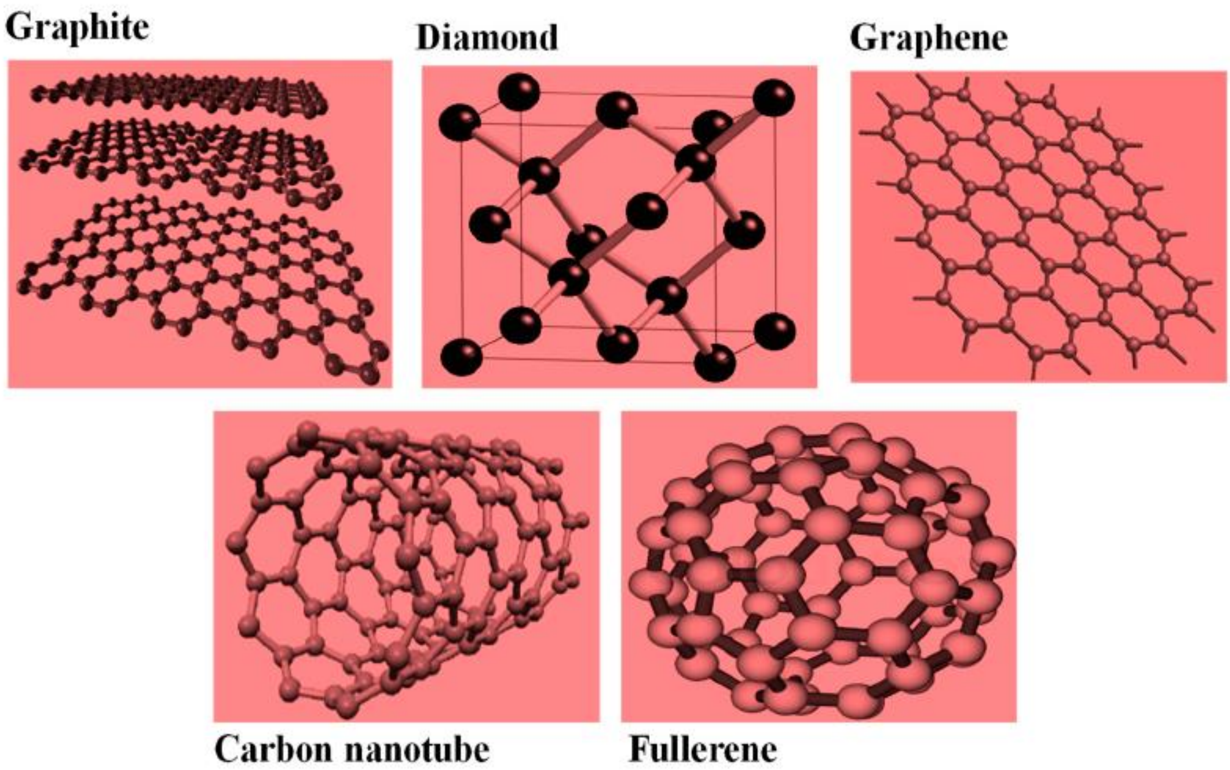

Fig. 1. Structural illustration of some 0-, 1-, 2- and 3-dimensional carbon nanomaterials with sp^2 and sp^3 hybridization allotropes occurring in different crystallographic forms

Table 1. Comparison of some properties of various carbon nanomaterials

Carbon Nanomaterials	Dimensions	Hybridization	Experimental Specific Surface Area ($m^2 g^{-1}$)	Thermal Conductivity ($W m^{-1} K^{-1}$)	Electrical Conductivity ($S cm^{-1}$)	Tenacity	Hardness
Graphite	3	sp^2	~10–20	Anisotropic: 1500–2000, 5–10	Anisotropic: 2–3 x 10^4	Flexible, non-elastic	High
Graphene	2	sp^2	~1500	4840–5300	~2000	Flexible, elastic	Uppermost (for single layer)
Carbon nanotube	1	mostly sp^2	~1300	3500	Structure-dependent	Flexible, elastic	High
Fullerene	0	mostly sp^2	80–90	0.4	10^{-10}	Elastic	High

Table 2. Comparison of some properties of the two renowned allotropes of carbon; graphite and diamond

Properties	Graphite	Diamond
Crystal system and form	Hexagonal; substantial lamellar veins and earthy masses	Isometric; cubes and octahedrons
Specific Gravity	2.2	3.5
Density (g/cm^3)	2.25	3.52
Color/Appearance	Grey black, Black silver, opaque shiny	Variable-pale yellows, browns, grays, and also white, blue, black, reddish, greenish, colorless and sparkling
Hardness (Mohs)/ Field indicator	1–2; Soft, slippery, soapy, greasy luster, density and streak	10; Very Hard (a hardest substance known)
Luster	Metallic to dull	Adamantine to waxy
Cleavage	Perfect in 1 direction	Perfect in 4 directions forming octahedrons
Transparency	Crystals are opaque	Crystals are transparent to translucent in rough crystals
Fracture	Flaky	Conchoidal
Electrical and Heat conductivity (E&H)	Good conductor of both E&H	Poor electrical conductor; good thermal conductor
Burning in the air	At about 700 °C	Most readily at about 900 °C

III. VERSATILE NATURE OF CARBON

The unique nature of carbon atom and the arrangement of the bond carbon forms with other atoms enable the existence of such a large number of organic compounds. Tetravalent Nature-Due to its tetravalent nature carbon always form covalent bonds by sharing electrons with one, two, three or four carbon atoms or atoms of other elements or groups of atoms . The tetra covalence of carbon atom allows it to combine easily with other carbon atoms. This property of carbon to combine with other carbon atoms to form a stable chain like structure is called Catenation.

IV. TETRAVALENCY IN CARBON

1. **A carbon atom has a total of six electrons.**
2. **Electrons occupy the first shells i.e., the K-shell, 4 electrons occupy L-shell.**
3. **Therefore, a carbon atom has four valence electrons.**
4. **It could gain four electrons to form C4- anion or lose four electrons to form C4+ cation.**
5. **But carbon undergoes bonding by sharing its valence electrons.**
6. **This allows it to be covalently bonded to one, two, three or four carbon atoms or atoms of other elements or groups of atoms.**

V. CATENATION PROPERTIES OF CARBON

Carbon readily forms long chains of bonds with itself. This property is called *catenation*, and is fairly unique. The properties of carbon which are responsible for such large number of compounds are:
1. Carbon forms covalent bonds
2. Carbon shows Tetravalency
3. Catenation- Property to bind with other carbon atoms

VI. IMPORTANCE OF CARBON

Important constituent of Carbon

1. Foods (starch, sugar, fats, vitamins, proteins have carbon)
2. Fuels (wood, coal, alcohol, petrol)
3. Household and commercial articles (paper, soap, cosmetics, oils, paints)
4. Textile fabrics (cotton, wool, silk, linen, rayon, nylon)
5. Drugs (penicillin, quinine, aspirin etc)
6. Poisons (opium)
7. Perfumes(vanillin, camphor)
8. Explosives (nitroglycerine, dynamite, TNT)
9. Dyes [indigo, congo red, malachite green)
10. War gases (mustard gas, chloropicrin)

VII. APPLICATIONS OF CARBON

Carbon is essential to all known living systems, and without it life as we know it could not exist (see alternative biochemistry). The major economic use of carbon other than food and wood is in the form of hydrocarbons, most notably the fossil fuel methane gas and crude oil (petroleum). Crude oil is distilled in refineries by the petrochemical industry to produce gasoline, kerosene, and other products. Cellulose is a natural, carbon-containing polymer produced by plants in the form of wood, cotton, linen, and hemp. Cellulose is used primarily for maintaining structure in plants. Commercially valuable carbon polymers of animal origin include wool, cashmere and silk. Plastics are made from synthetic carbon polymers, often with oxygen and nitrogen atoms included at regular intervals in the main polymer chain. The raw materials for many of these synthetic substances come from crude oil.

The uses of carbon and its compounds are extremely varied. It can form alloys with iron, of which the most common is carbon steel. Graphite is combined with clays to form the 'lead' used in pencils used for writing and drawing. It is also used as a lubricant and a pigment, as a molding material in glass manufacture, in electrodes for dry batteries and in electroplating and electroforming, in brushes for electric motors and as a neutron moderator in nuclear reactors. Charcoal is used as a drawing material in artwork, barbecue grilling, iron smelting, and in many other applications. Wood, coal and oil are used as fuel for production of energy and heating. Gem quality diamond is used in jewelry, and industrial diamonds are used in drilling, cutting and polishing tools for machining metals and stone. Plastics are made from fossil hydrocarbons, and carbon fiber, made by pyrolisys of synthetic polyester fibers is used to reinforce plastics to form advanced, lightweight composite materials. Carbon fiber is made by pyrolisys of extruded and stretched filaments of poly acrylonitrile (PAN) and other organic substances. The crystallographic structure and mechanical properties of the fiber depend on the type of starting material, and on the subsequent processing. Carbon fibers made from PAN have structure resembling narrow filaments of graphite, but thermal processing may re-order the structure into a continuous rolled sheet. The result is fibers with higher specific tensile strength than steel. Carbon black is used as the black pigment in printing ink, artist's oil paint and water colors, carbon paper, automotive finishes, India ink and laser printer toner. Carbon black is also used as a filler in rubber products such as tyres and in plastic compounds. Activated charcoal is used as an absorbent and adsorbent in filter material in applications as diverse as gas masks, water purification, and kitchen extractor hoods, and in medicine to absorb toxins, poisons, or gases from the digestive system. Carbon is used in chemical reduction at high temperatures. Coke is used to reduce iron ore into iron (smelting). Case hardening of steel is achieved by heating finished steel components in carbon powder. Carbides of silicon, tungsten, boron and titanium, are among the hardest known materials, and are used as abrasives in cutting and grinding tools. Carbon compounds make up most of the materials used in clothing, such as natural and synthetic textiles and leather, and almost all of the interior surfaces in the built environment other than glass, stone and metal.

IV. CONCLUSIONS

In the last few decades, carbon based materials are became new branch of material science and has played vital role in the development of science and technology including solar cells, solid-state physics, electronics devices, and industries, etc. This paper is based on the incredible future that lies ahead with these smart carbon-based materials. This review is determined to give a synopsis of new advances towards their synthesis, properties, and some applications as reported in the existing literatures. Consequently, the amazing properties of these materials and greatest potentials towards greener and environment friendly synthesis methods and industrial scale production of carbon nanostructured materials is undoubtedly necessary and can therefore be glimpsed as the focal point of many researchers in science and technology in the 21^{st} century. There is no doubt that carbon based materials changed the world beyond anything that could have been imagined before them.

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