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REVIEW ON CARBON DOT A NOVEL NANO MEDICINAL APPROACH: STRUCTURE, PROPERTIES & SYNTHESIS

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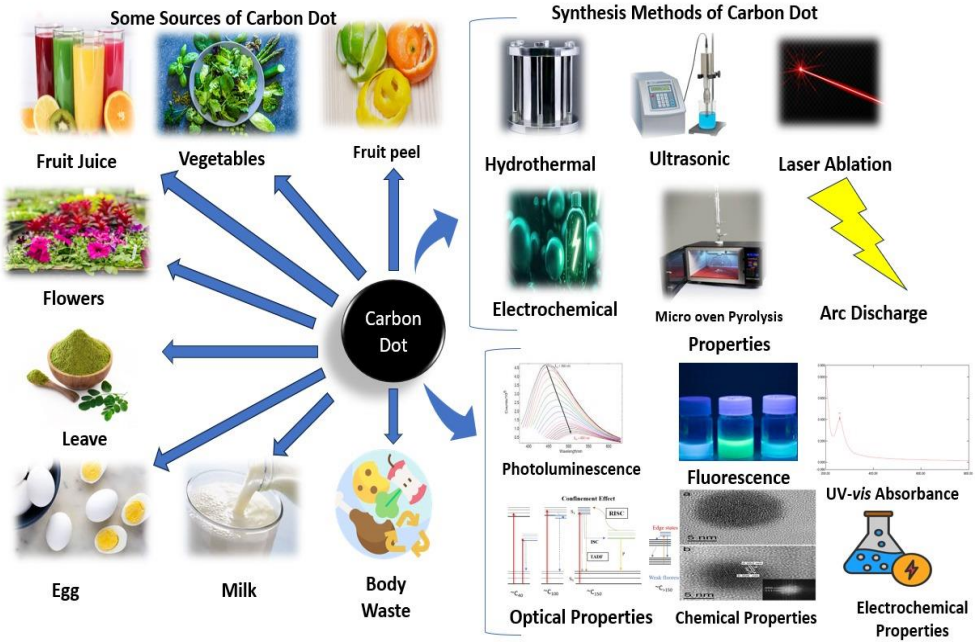
Abstract
The synthesis techniques for C-dots are covered in the review including the template method, which entails calcining the necessary C-dots in an appropriate template before etching to eliminate supports. The sector's difficulties are mentioned, such as the absence of a scalable and systematic synthesis approach for producing high-quality C-dots with desired topologies. It is necessary to systematically investigate how precursors and reaction conditions affect the performance of C-dots because their precise formation process, nucleation process, and response mechanism are not entirely understood. The remarkable potential of C-dots for a diversity of applications is emphasized within this review. In conclusion, it also highlights the carbon dots' extraordinary optical characteristics, exceptional biocompatibility, affordability, and simplicity of customization and functionalization. The potential of C-dots-based material, also emphasizes the need for additional research to address the issues and establish regulated synthetic methods, large-volume manufacturing, and enhanced comprehension of the structure-performance connection.
Keywords: Carbon dot, Nano Technology, Fluorescence, Synthesis, Quantum yield



1. Introduction:

Newly included in the group of fluorescent carbon materials, carbon dots (Carbon dots) have a diameter of not more than 10 nm. They are positioned as viable substitutes for metal-based quantum dots due to their distinct makeup and biocompatibility [1]. C-Dots have attracted interest for applications such as biosensors [2], gene transduction [3], drug carriers [4-8], and bioimaging probes [9,10] because of their exceptional fluorescence qualities, high biocompatibility, and low toxicity. C-Dots remarkable fluorescence properties are very promising for analytical chemistry, particularly for biological and environmental sensing and imaging [2,10-16]. The term "carbon dots" (CDs) refers to quasi-0D carbon-based materials that are smaller than 20 nm in size. Their intrinsic fluorescence is what makes them unique. Fluorescent carbon nanoparticles were first reported in 2004 after they were unintentionally produced while purifying single-walled carbon nanotubes. Upon producing carbon particles through laser ablation of a carbon target, Sun *et al.,* (2006) first categorized them as CDs; nevertheless, the quantum yield (QY) was Approximately 10% of these CDs were surface-passivated. [17,18]. The difficult preparation procedures and low QY of CDs hindered their advancement. The development of carbon dots (CDs) has been hindered by their low quantum yield (QY) and difficult preparation methods. Before 2013, Yang's group produced CDs which are like polymers with an amazing Quantum Yield of as much as 80% by using ethylenediamine and citric acid (CA) as precursors in a single hydrothermal step [19]. The QY with the greatest value among carbon-driven fluorescent compounds is this one. These CDs are adaptable; they can be used in printing inks or as operational nanocomposites. The user-friendly nature, high Quantum Yield, low level of toxicity, and strong protection against photobleaching displayed by Carbon Dots contributed to the spike in research interest.Currently, CDs are categorized into various groups according to their specific characteristics, micro- and nanostructures, and production procedures. As seen in Figure 1, the three main categories are carbonized polymer dots (CPDs), graphene quantum dots (GQDs), and carbon quantum dots (CQDs). By varying the graphene layer and degree of carbonization, connections between these categories can be formed, resulting in a range of linkages [20].

Carbonized polymer dots (CPDs) are a new class of fluorescent nanomaterials that combine organic polymer chains with a carbon core. Conversion of polymer monomers by techniques such as condensation, cross-linking, or mild carbonization is usually required for the synthesis of CPDs [21,22]. Condensation and cross-linking are crucial for the synthesis of CPDs because, in contrast to conventional carbon dots, they show little to no carbonization [23-28]. CPDs have unique qualities due to their unique chemical structure, such as strong emission, high yield, and enhanced oxygen levels, which lead to exceptional water solubility.

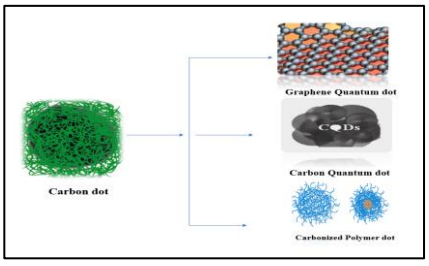


Fig 1: Types of Carbon Dot

Graphene quantum dots (GQDs) are relatively newest member of the graphene nanomaterial family. They have amazing optical and electrical capabilities and are composed of one or more graphene sheets that are nanometers in size. [29]. To create these 0D nanomaterials, graphene sheets were hydrothermally combined in 2010 [30]. GQDs and graphene are comparable in that they have C, O, and H crystal structures in addition to hydroxyl, carboxyl, carbonyl, and epoxy surface groups [31]. Crystalline GQDs are primarily composed of sp^2 hybridized carbon. Surface imperfections, zigzag or armchair edges, and quantum confinement provide GQDs with unique fluorescence properties that add to their luminosity [32-34]. Although GQDs typically have a size range of 3–20 nm, the highest size yet recorded is 60 nm [35]. Because of its exceptional qualities—which include minimal cytotoxicity, exceptional H_2O solubility, strong electrical conductivity, chemical steadiness, photoluminescence, low photobleaching, environmental benevolence, and optoelectronic characteristics—graphene quantum dots, or GQDs, have attracted a lot of interest from researchers [36]. Chemical stability and strong biocompatibility are also included in this list of qualities. Theranostics, photodynamic healing, photocatalysis, anticancer representatives, batteries made of lithium-ion, optoelectric detectors, flash memory apparatuses, solar panels, electronic screens, wrapping, LEDs, antibacterial properties, drug delivery, tissue engineering, hybrid capacitors, and batteries are just a few of the many applications where GQDs show enormous promise [37,38]. Target-specific and biocompatible, biologically derived GQDs are essential for the efficient management and treatment of several serious illnesses. Carbon quantum dots (CQDs) have attracted attention as fluorophores from all over the globe due to their simple synthesis, small size, exceptional photostability, great biocompatibility, up-conversion, tunable photoluminescence (PL), and chemical stability [39,40]. The nanoparticles known as carbon-based quantum dots (CQDs) exhibit a variety of surface passivation as a consequence of functionalization or modification [41]. CQDs can exist in both crystalline and amorphous forms. While sp^3 hybridization has also been reported, sp^2 carbon hybridization is the most common kind in CQDs. CQDs are classified as 0D nanostructures, and most of them are smaller than 10 nm in size. CQDs show about 0.34 nm in terms of crystal lattice characteristics, which is consistent with the (002) graphite interlayer spacing [42]. Functionalization of CQDs can be achieved by using different surface groups. The water solubility of CQDs is attributed to the predominance of oxygen-containing functional groups, such as hydroxyl and carboxyl, on their surface [42]. Furthermore, these functional groups provide an advantage over graphene quantum dots (GQDs), which show poor solubility in common solvents, by facilitating the creation of stable colloids in polar organic solvents or aqueous solutions [43]. Surface groups of CQDs affect their fluorescence characteristics [42]. Many different types of carbon nanostructures exhibit fluorescence: graphene oxide (GO) [44-46], carbon nanotube quantum dots (CNT QDs) [47,48], nanodiamonds (NDs) [49,50], graphene oxide (GO) [51], and GQDs and CQDs. Carbon sources are plentiful and synthesis methods are numerous, which contribute to the diversity of carbon dots (CDs). Detailed insights into CD production, photoluminescence processes, and applications have been provided by several review papers [51-60]. This Outlook will, from a unique vantage point, emphasize the remarkable visual qualities of CDs and highlight recent noteworthy developments

in several areas, such as energy (catalysis, photovoltaics, energy-efficient LEDs, rechargeable batteries), optical (sensors, information encryption), and potential uses in medicine (nanotechnology in medicine, phototherapy, drug/gene delivery process, biological imaging). To wrap off our talk, let's take a quick look at the planning, photoluminescence techniques, and carbon dot applications that are currently facing this field. In the future, this Outlook will offer significant revelations. and comparative viewpoints that will stimulate more fascinating research on carbon dots and promote advances in energy, medical, and environmental applications.

2. Structure of Carbon Dot:

The carbon skeleton makes up the majority of C-Dots, and two necessary elements hydrogen and oxygen are present in different proportions [61,62]. They are mostly amorphous spherical structures made of hybridized carbon particles, with sizes of not more than 10 nm [63]. It is important to differentiate them from Graphene Quantum Dots (GQDs) that are made entirely of sp^2 hybridized carbon stacked in a two-dimensional honeycomb pattern [64]. Various kinds of materials made up of carbon that rely upon distinct precursors and synthesis techniques are used in the production of C-Dots [65]. Rich surface alterations on C-Dots with polar groups, such as carbonyl and carboxyl groups, are made possible by this method.

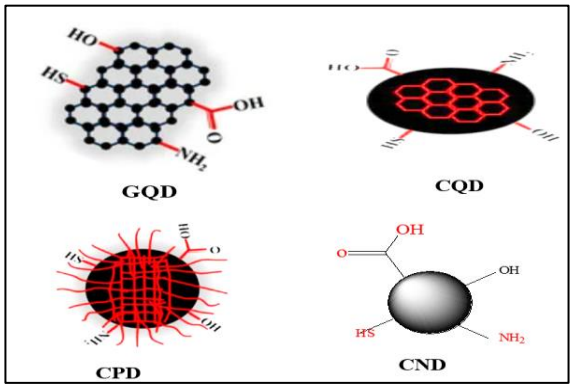


Fig 2. Structure of different CD's [64]

3. Green Sources of Carbon Dot:

When carbon dots (CDs) are obtained from "green sources," or renewable natural resources that act as precursors to carbon, they can be simply categorized as carbon quantum dots (CQDs). Only carbonaceous precursors are used in the synthesis of CDs, which frequently produces CDs with comparatively poorer quantum yield and solubility. To solve this, a variety of green carbon sources have been investigated in an attempt to create simple, affordable, green CDs with distinctive optical and electrical characteristics. These approaches have their roots in various synthetic techniques, and several papers indicate that green CDs can be successfully made from natural materials, as shown in (Fig 3). Generally speaking, the final carbon dots' (CDs') chemical composition is greatly influenced by the raw material choice. Furthermore, a number of these eco-friendly methods have shown improvements in the Quantum Yield (QY) that is attained, providing strong evidence for QY improvement through changed precursors.

Enhancing the QY and solubility of synthesized CDs is largely dependent on surface passivation. In this context, green sources have been defined as plants, fruits, vegetables, juices, baked goods, and byproducts of human metabolism. Depending on whatever carbon precursor was selected, these CDs have been divided into separate sessions [66].

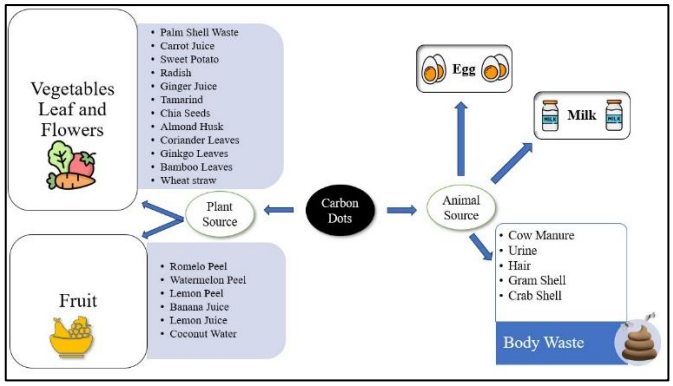


Fig 3: Some Sources of CD's

4. Properties of Carbon Dots:

4.1 Physicochemical Properties:

The electrical characteristics and photoluminescence of carbon dots (CDs) are strongly influenced by fluorophores, element doping, and surface states. These effects rely on electrical transitions taking place across the sp^2 domain band gap. One important feature of CDs is the Quantum Confinement Effect (QCE), which is particularly significant for crystalline lattice-containing graphene quantum dots (GQDs) and carbon quantum dots (CQDs). When the diameter of Carbon Dots is not more

than Bohr's radius, this importance is more noticeable [67]. Quantum confinement gets more and more prominent when the radius of the exciton decreases when the system's dimensions are smaller than its Bohr radius. Size-dependent properties like the band gap and relaxation dynamics are the consequence of this process, which alters the electron distribution [68]. The Quantum Confinement Effect (QCE) in carbon dots (CDs) is primarily caused by the transition between discrete and continuous energy levels in the valence and conduction bands, which limits electron mobility in both directions. An increase in band gap affects the photoelectron properties of CDs as they get smaller (see Fig. 4). In CDs with larger conjugated sp^2 domains and fewer surface states, QCE is usually more apparent. The electron transfer from the conductance band in order to the valence band-aids to the formation of a band gap, and the conjugated sp^2 domains efficiently divide the valence and conduction bands. Higher energy excitation drives the confinement of excitons in a compact area because the average energy between the lowest conduction (EC) and highest valence (EV) bands increases with decreasing size [69]. Excitons produced by photon absorption determine the efficiency of solar systems. One electron-hole pair is typically produced by a single photon, and any extra photon energy is dissipated as heat. On the other hand, it has been shown that in reaction to a single photon absorption event, quantum dots (QDs), such as carbon dots, can produce numerous excitons through multiple exciton generation [70,71]. Robust interactions between carriers in CDs are responsible for the production of numerous excitons, which is a critical element for improving solar efficiency [72].

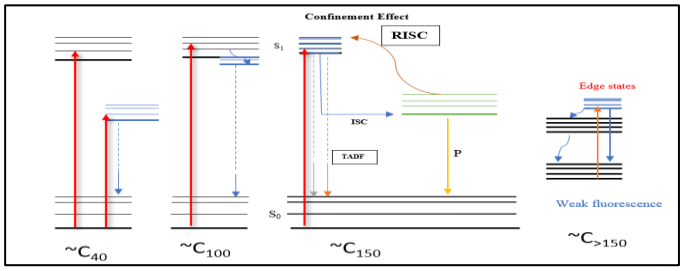


Fig 4: The CDs' π-conjugated domains' dimensions affect electronic band structure and QCE [72]

4.2 Electrochemical properties:

The size, functions, and heteroatom doping of carbon dots (CDs) control their electrochemical characteristics [73]. The effect of graphene quantum dot (GQD) size on electrochemical properties was investigated by Liu *et al.,* [74]. Their study proved that the particular electrolytic capacitor rose as the size of GQDs shrank. When scanning at 5000 Vs^{-1}, then the smallest size demonstrated the best power output. These findings highlight the potential uses of graphene quantum dots (GQDs) in high-power response microelectronics. GQDs were added to husk-derived activated carbon by Li *et al.,* to employ it in lithium-ion batteries. The electrode's electrochemical properties improved with the addition of GQDs, resulting in higher electrical conductivity, improved cycle stability, and a decrease in charge move impedance from 577.7 Ω to 123.9 Ω [75]. Carbon dots (CDs) are often created via oxidative cleavage of carbon precursors. Although edge oxygen-containing capabilities might improve catalytic activity, electron transport is limited by the defects these functionalities create in the sp^2 hybridized carbon network [76]. To investigate the impact of reduction on electrochemical characteristics, carbon nanodots (CNDs) produced by electrochemical oxidation were reduced [77]. The improved sp^2 conjugation led to a remarkable 30% improvement in the electron absorption of carbon nanodots (CNDs) during chemical reduction, even beyond the shift in decrease potentials to negative standard. Because of their advantageous electrochemical characteristics, CDs are frequently utilized in tasks involving supercapacitors. CDs were added to the Carbon Felt working electrode in an attempt to improve the electrode's electrochemical characteristics. A significantly higher capacitance electrode was created by including N_2 and O_2 mixed into CDs with minuscule diameters and N_2 and O_2 -containing functions than the previous "lignite" modified electrode. The enhanced supercapacitance over the precursor is caused by the functions, heteroatom doping, and bigger surfaces [78]. Although dopants have been used to alter the optical and electrochemical characteristics of carbon dots (CDs), little research has been done on how dopant concentration affects these characteristics. By enhancing the amount of urea content in thermal hydrolysis reaction, Christopher *et al.,* investigated the influence of dopant concentration on the electrochemical characteristics of CDs. Not only did the emissive capabilities improve with an increase in nitrogen concentration, but it also improved the electrochemical characteristics, leading the oxidation potential to shift by up to 150 mV to negative values.

4.3 Chemical Properties:

The name "CD" refers to the large class of carbon-based nanoparticles having a diameter of not more than 10 nm and inherent characteristics of fluorescence, as explained in the previous part. On the other hand, different synthesis methods can be used to produce different kinds of CDs, each with its own set of chemical properties [79]. Graphene quantum dots (GQDs)are isotropic, edge-functioning particles composed of one or more graphene-laminated layers. Conversely, two other classes of carbon nanodots (CNDs) are (i) carbon nanoparticles (CNPs) and (ii) carbon quantum dots (CQDs). CNPs adopt an amorphous, spherical form, whereas CQDs have a crystal lattice structure [80,81]. Despite these differences, chemical families that incorporate nitrogen and oxygen constitute an essential surface functionality shared by all forms of CDs. Numerous characterization techniques, such as the analysis of crystallinity, morphology, size distribution, and chemical functionality, can be used to ascertain the structure of CDs. A useful method for figuring out a particle's form, size distribution, and average size is Transmission Electron Microscopy (TEM). Furthermore, lattice spacing, or crystallinity, can be assessed by comparing it to graphitic carbon as a reference material utilizing High-

resolution Transmission Electron Microscopy (HRTEM). Lattice spacing and Using TEM and HRTEM, the morphology of single-layer graphene quantum dots (GQDs) was examined [82]. The experiment's findings demonstrated a 2.2 ± 0.2 nm size variation with a 0.21 nm spacing between lattices at the graphene plane.When used to measure a particle's thickness or topographic profile, atomic force microscopy (AFM) can provide important details about the form, shape, and structure of the particle. AFM is especially helpful in the case of graphene quantum dots (GQDs) to gather data regarding the diameter and texture of the particles in addition to specifics like the aspect ratio and the number of graphene layers. Raman spectroscopy is a practical method for assessing the level of organization or clarity in carbon dots (CDs). Often, CDs' Raman spectra display two distinct bands: D and G. These bands correspond to the oscillations of flaws in the graphitic sp^2 hybridized carbon and the graphitic structure (sp^3 carbon) inside the nanomaterial. Furthermore, the degree of crystallization can be inferred from the proportion of intensity (ID/IG) of the disorderly D band and the crystal-like G band [83]. For instance, two peaks at 1337 and 1583 cm^{-1} are visible in the graphene quantum dots (GQDs) Raman spectrum. These harmonics coincide with the G band, which is associated with the oscillations of sp^2 hybridized carbon atoms, and the D band, which is associated with the oscillations of carbon with lattice flaws. [84]. With an ID/IG ratio of roughly 0.83, a graphite-like structure was suggested. A suitable A band that matched pentagon and heptagon carbon rings was found by Xu *et al.,* [85, 86]. Pentagon and heptagon rings are thought to be responsible for the increased A band to G band intensity proportion, which indicates exacerbated structural flaws in the carbon structure.

4.4 Optical Properties:

4.4.1 UV-vis absorbance of CD's:

Variations in absorption behaviors are always the result of using different carbon sources or synthetic procedures to create carbon dots (CDs). Usually, the π–π* shift of the C=C bond or the n–π* shift of the C=O/C=N bond is responsible for these absorption features. Nonetheless, CDs frequently show notable absorption in the 200–400 nm ultraviolet region, along with a tail that extends across the discernible spectrum [87, 88-92]. π-conjugated electrons are commonly found in the sp^2domains, linked surface groups, or polymer chains of CDs that emit red or near-infrared light. The longer wavelengths of light, usually between 500 and 800 nm, can be absorbed by the CDs thanks to this arrangement [93,94]. Therefore, the main factors influencing the absorption properties of CDs are the types and concentrations of the outermost groups, the size of π-conjugated areas, and variations in the carbon cores' oxygen/nitrogen composition.

4.4.2 Photoluminescence of CD's:

Outstanding CDs with photoluminescence (PL) properties have many uses because, according to their composition, synthesis methods, and morphology, they show a range of color emissions and other optical characteristics. Nevertheless, difficulties in comprehending the PL mechanism and a lack of control over synthesis methods have limited the use of CDs [95]. Although the exact process underlying the photoluminescence (PL) of carbon dots (CDs), in particular Graphene Quantum Dots (GQDs) and Carbon Quantum Dots (CQDs), is still unknown, it is frequently impacted by surface states, heteroatom doping, features, defects, and edge arrangements, as well as the quantum confinement effect (QCE) [95,96]. Due to their size and compositional heterogeneity, the majority of CDs that have been observed to date show excitation-dependent emission characteristics in addition to both green and blue emissions [97-99].

5. Synthesis Strategies of CD's:

Several essential parameters, such as the surface state, quantum confinement effects, and molecular state, affect the production of carbon dots (CDs). By changing the CDs' synthesis methods, these variables are easily controllable [100-103]. A wide variety of functional groups, including the hydroxyl group, carboxyl group, amines, epoxy-based materials, ether, etc., can be introduced throughout the CD manufacturing procedure [104,105]. Furthermore, the outermost layer of CDs can be efficiently customized by supplementing them with heteroatoms such as nitrogen, phosphorus, sulfur, Boron, and so forth employing a range of biological, polymeric, and organic materials [106,107]. Then, using different precursors or different synthesis techniques, it is possible to the amount and range of functional groups on the surface to regulate the characteristics of CDs [108]. To achieve significant surface properties for solvency and their advantageous applications, CDs must be modified [109,110].To improve the bio-applications of carbon dots (CDs), a great deal of study has been devoted to increasing their quantum yield (QY) either during or even after preparation [111-113]. It is difficult to get high QY and biocompatibility in CDs, nevertheless, because maximizing one frequently means sacrificing the other. Separately controlling each parameter can also be difficult. To get increased biocompatibility, CDs with enhanced surface passivation may have reduced light emission intensity, and vice versa. Notwithstanding these issues, it's still unclear how Carbon Dots function as more effective fluorophores that serve a variety of medical applications [114,115]. To generate carbon dots (CDs) with different quantum yields (QYs), a variety of food-derived carbon sources have been used, such as yogurt, honey, bananas, pomegranates, leaves, sugar beetroot molasses, eggs, rice bran, garlic, coffee beans, soybeans, coconut shells, tea leaves, grass, etc. [117-125]. Additionally, several eco-friendly techniques have been established for the one-step synthesis of fluorescent CDs using harmless precursors, either organic or synthetic, for particular biosensing applications. For example, CDs have been synthesized from wool to measure glyphosate [126], and CDs have been prepared from chitosan functionalized with sodium fluoride to measure the amount of retinoic acid [127]. It is possible to synthesize CDs using any of the two approaches—that is, top-down or bottom-up methods [128]. Whereas the latter method either carbonizes small organic molecules or sequentially integrates tiny aromatic molecules, the former method requires breaking down carbon-based substances into smaller nano-sized fragments by electrochemical, chemical, or physical means [129,130]. These two techniques of CD synthesis, as shown in Figure 3, are further divided into different categories [131,132].

5.1 Top-down Approach:

Nowadays, carbon dots (CDs) are made from macroscopic carbonaceous compounds such as activated carbon, carbon nanotubes (CNTs), and graphite using top-down processes like arc discharge, laser ablation, ultrasonic treatment, and electrochemical approaches [133-135]. Nevertheless, high-energy, high-potential, and extremely acidic conditions are typically where these techniques work. These top-down tactics

demand harsh operating conditions, which makes them somewhat more arduous than bottom-up processes [136,137].

5.1.1 Arc Discharge Method:

Even though arc discharge therapy may result in CDs with poor quantum yields (QYs), arc discharge treatment is nevertheless a feasible way to generate CDs from unprocessed carbon nanotubes (CNTs) [138]. The arc discharge process and single-walled carbon nanotubes (CNTs) through a process of oxidation were used as carbon sources in the groundbreaking work of Xu *et al.,* and Bottani *et al.,* in 2004 [139,140]. Furthermore, Arora and Sharma showed that the arc discharge method can be used to reorient the carbon atoms produced by disintegration. This is especially true when using bulky carbon precursors during the CD synthesis to produce extremely energetic plasma inside the reaction assembly [141]. It is important to remember, nonetheless, that the arc discharge method frequently produces a high number of composite categories, which presents difficulties for purification [142].

5.1.2 Laser Ablation Method:

As part of the laser ablation process, the heavy carbon-based substance is exposed to a thermodynamic atmosphere that produces extremely high temperatures and pressures using a highly energetic laser beam. As a result, there is an increase in heat and the dehydration of plasma. Later, a crystallization procedure turns the produced vapour into CDs [143]. Using argon as a carbon target and water vapour carrier gas via laser ablation, Sun *et al.,* demonstrated the production of luminous carbon dots (CDs) [144]. In another work, 3 nm-sized fluorescent CDs were created by suspending carbon-like glass particles in polyethylene glycol and then exposing them to laser light [145]. As fluorescent markers for in vivo bioimaging of human epithelial cells, including both malignant and healthy types, these as-synthesized CDs may find use [145]. Nitrogen-doped carbon dots (CDs) can be created from the powdered form of graphite by laser ablation using organic solvents like amino toluene [146]. Ratiometric pH can be measured since this method makes it easier to produce CDs with wavelengths that are not dependent on stimulation because of the amount of amine and oxygen molecules on their outermost part [146]. The carbon dots (CDs) produced by double-beamed laser ablation may exhibit superior properties to those produced through single-pulsed laser beam ablation, including greater quantum yield, miniature diameter (~1 nm), higher surface-to-volume proportion, improved steadiness, and greater uniformity [147,148]. Therefore, to improve the catalytic and sensing properties of CDs, double-pulsed laser ablation is the recommended method [148].

5.1.3 Ultrasonic Method:

Through the use of ultrasonic waves that operate at both high and low pressures, this approach creates tiny vacuum bubbles that are then uniformly distributed throughout the solution [142]. Through the production of a strong hydrodynamic shear force and quick liquid jet violation, this dispersion process aids in the prevention of aggregation [142,149]. Large-sized carbon-based nanomaterials including graphite, which is activated carbon, and carbon nanotubes (CNTs) can be converted into nanosized carbon dots (CDs) by using the energy produced by the ultrasonic technique [149,150]. Because the synthesis of amine-functionalized carbon dots (NH_2-CDs) involves a hydrothermal procedure involving severe reactions of chemicals, several phases, and high temperatures, the technique is usually costly and time-consuming [151]. Wu *et al.,* recognized this and created a way to employ the ultrasonic process to create amine-functionalized CDs, which provides a more straightforward and effective method for sensing nucleic acids and metal ions like cobalt (II) ions for cell imaging [151].
In a different study, Huang *et al.,* demonstrated how PEG-decorated carbon dots with a high quantum yield (QY) for cell-based imaging could be created utilizing a single-stage ultrasonic technique utilizing cigarette trash as well as thiol group-containing polyethylene glycol (SH-PEG). [152].

5.1.4 Electrochemical/Chemical Oxidation Method:

The most used method for preparing CDs is electrochemical/chemical oxidation due to its advantages. The size of CDs can be easily adjusted and very pure CDs that have high QY can be obtained for mass manufacture using this fast, easy, and repetitive process [144,153]. generally, oxidation-reduction procedures employing chemical or electrochemical techniques are used to synthesize carbon dots (CDs) at room temperature and pressure [154]. In these procedures, strong oxidizing agents including hydrogen peroxide (H_2O_2), sulfuric acid (H_2SO_4), and nitric acid (HNO_3) are frequently used [154]. Hydrophilic functional groups, including -NH_2, -COOH, -OH, and others, may be properly customized onto the surface of CDs by managing the redox processes and the electrolyte compositions [154,155]. The formation of carbon dots (CDs) with distinctive properties including fluorescence emission, cytotoxicity, and surface states can be influenced by the selection of electrolytes and electrode materials [156–159]. Regarding this, Liu *et al.,* proposed a straightforward method for producing CDs suitable for bioimaging applications including identifying the presence of ferric ions (Fe^{3+}) in water samples, using graphite as the electrode material [157]. Graphite is oxidized in alkaline alcohols during the electrochemical synthesis process to produce carbon dots (CDs), which have a diameter of about 4 nm and good crystallinity [144]. Via regulated chemical oxidation, powerful oxidants like nitric acid (HNO_3) and perchloric acid ($HClO_4$) can add carbon atoms to small organic molecules, converting them into carbon-containing materials and allowing them to be inserted into smaller sheets [160]. Tan *et al.,* developed a method for producing a range of CD microstructures appropriate for bioimaging applications after realizing that the microstructure of CDs is influenced by their optical properties. To create CDs with adjustable fluorescence, required carefully oxidizing graphitized activated carbon using oxidizing chemicals such as HNO_3 and ClO_4 [161].

5.2. Bottom-Up Approach:

Due to its many benefits, which include the possibility of practical application, the use of non-toxic precursor compounds, cost-effectiveness, simplicity and convenience of methodology, ease of instrumentation, and accurate measurement, methods that work from the bottom up are currently popular [160].

5.2.1. Thermal Method:

Thermal breakdown, which entails pyrolyzing or carbonizing big carbonaceous precursors at high temperatures, is one of the most efficient methods for creating carbon dots (CDs) [160-162]. Large-scale CD production, affordability, shortened reaction times, improved precursor tolerance, free-of-solvent methods, and ease of synthesis are only a few benefits of this approach [160-163]. By modifying factors like reaction temperatures, reflux duration, and reaction-mix pH, the thermal

method also enables the optimization of CDs' luminous characteristics [160-164]. To produce carbon dots (CDs), Shang *et al.,* employed the thermal method to pyrolyze citric acid as a precursor molecule, varying the degree of carbonization [165]. Ma *et al.,* presented a method in a different study for producing nitrogen-doped CDs on a large scale using one-step pyrolysis, to produce final CDs with a high conversion rate (>80%) and a high fluorescence quantum yield (~88%) [166]. Additionally, Wang *et al.,* used the oxygen-free property to their advantage to synthesize CDs with a high quantum yield (~87%) by directly carbonizing carbon microcrystal precursors and regulating their size [167].

5.2.2. Microwave-assisted Method:

Microwaves offer more energy for the breaking down of chemical bonds in precursor molecules due to their broad spectrum of electromagnetic waves, which spans from 1 mm to 1 m [160-168]. By producing homogeneous heat, the microwave-assisted method guarantees the uniform distribution of carbon dots (CDs) and is relatively easy, fast, cheap, and requires shorter reaction times [169]. Yu *et al.,* synthesized CDs by using two primary compounds —triethylenediamine hexahydrate and phthalic acid—using a one-step microwave-assisted synthesis method. According to reports, this method can be used to create CDs with a greater emitting wavelength, superior biological compatibility, and intense green luminescence in about one minute [170]. Using 2,2-dimethyl-1,3-propanediamine as the carbon source and citric acid monohydrate as the nitrogen source, Ghanem *et al.,* published a microwave-aided production method for N-plated CDs. Using this technique, the right away N-doped CDs may show impressive fluorescence features with elevated QY [170]. Another work used microwave irradiation to create fluorescent carbon dots (CDs) by applying glucosamine to a Co-polymer layer composed of PEG and chitosan. The resultant CDs could have excitation-dependent fluorescence, robust fluorescence intensity in biological matrices, and improved chemical stability [170].

5.2.3. Hydrothermal Method:

The production of carbon dots (CDs) via the Hydrothermal Carbonization (HTC) process is inexpensive, non-toxic, and environmentally benign. It involves the reaction of organic precursors that are heated to high pressures inside a sealed hydrothermal reactor. Because of its versatility, the HTC technique can be used to make CDs from a wide range of raw materials, including proteins, chitosan, citric acid, glucose, and others. Recently, Hasan *et al.,* showed how to use the hydrothermal carbonization (HTC) process to create several types of carbon dots (CDs). As precursors, they used furfural, hydroxy-methyl furfural, and microcrystalline cellulose. Under short-wavelength UV light, these CDs may display a variety of absorption and emission properties as well as green illumination, based on the particular precursor used [167]. In a different work, Luo *et al.,* used the hydrothermal method to create CDs, starting with precursor molecules such as cysteine, ethylenediamine, and trisodium citrate dihydrate. The resultant CDs showed strong blue radiation, excellent biological compatibility, and great luminescence persistence. Sun *et al.,* provided a method for creating nitrogen and sulfur combined carbon dots (N/S-CDs) hydrothermally, utilizing gardenia fruit as the raw material . The resulting N/S-CDs were discovered to be round and around 2nm in size when exposed to UV light. Additionally, over a wide pH value and at greater salt denseness, they demonstrated good luminescence stability. In a different work, methyl blue, citric acid, and ethylenediamine were applied as precursor origin for the hydrothermal generation of N/S-CDs. The resulting N/S-CDs showed the emission of blue fluorescence that was independent of stimulation.

5.2.4. Template Method:

The formation of CDs using the template approach consists of two steps: (i) calcining the required CDs in mesoporous silicon spheres or an appropriate template; and (ii) a cleaning process to eliminate supports [160]. Nevertheless, the synthesis of CDs has not made greater use of this technology. Kurdyukov *et al.,* synthesized homogenous orbicular CDs with a graphite-like structure and a size of around 3.3 nm using the template approach. The plan was to introduce silane functionalized compound as an antecedent into the pores of perforated silica granules, decompose it thermally while CDs were synthesized, and then remove the template . Additionally, a soft-hard template technique was reported by Yang *et al.,* to create CDs with customizable crystallographic degrees, sizes, compositions, and photoluminescence properties. This technique made use of ordered perforated silica (OMS) SBA-15 as the hard template and conjugated polymer Pluronic P123 as the soft template. Four different chemical compounds were used as the carbon sources at the same time: pyrene (PY), 1,3,5-trimethylbenzene (TMB), diamine-benzene (DAB), and phenanthroline (PHA) [167].

6. Conclusion, Challenges and Future Aspects:

In this article, we have mentioned the categories of CDs, their optical, electrical characteristics, and their production techniques. Because of their exceptional electrical, optical, and biological properties— The carbon-based CDs nanomaterials have attracted a lot of attention and interest in the fields of nanotechnology and biomedical science due to their many advantages including enhanced electron adaptability, effects on light bleaching and photo-blinking, high photoluminescent quantum yield, luminescence property, durability against photo-decomposition, raised electrocatalytic action, excellent solubility in water, outstanding biological compatibility, long-term resistance to chemicals, cost-effectiveness, minor toxic exposure, and a significant efficient surface area to volume proportion. Compared to other carbon-based substances and QDs, the study on CDs remains in its early stages. One of the most fundamental challenges today is the absence of a rational and accessible production process to produce excellent CDs with desired architectures (e.g. size, shape, crystalline structure, quantities of functional groups, type, and positioning of flaws). Their specific reaction procedure, nucleation procedure, and generation procedure are known due to uneven synthetic routes and impurities. Therefore, for the effective massive-scale synthesis of CDs with high performance, the impacts of predecessors and reaction parameters (e.g., temperature, time, pH) on the efficiency of CDs must be thoroughly examined. Furthermore, a dimension- or orientation-dependent purification approach must be developed. Notably, developing *in situ* methodologies is required to characterize the mechanism of CD production, which is important for controlling the synthesis of CDs with certain nanostructures.

7. References:

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