Optical and Structural Properties of Green Synthesized Graphene Quantum Dots

A DISSERTATION

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I, Ram Krishan Saini, Roll No. 2K21/MSCPHY/39 and Rishikesh Raj, Roll No. 2K21/MSCPHY/40, student of M.Sc. Physics, hereby declare that the project Dissertation titled “**Optical and Structural Properties of Green Synthesized Graphene Quantum Dots**”, which is submitted by me to the Department of Applied Physics, Delhi Technological University, Delhi in partial fulfilment of the requirement for the award of the degree of Master of Science, is original and not copied from any source without proper citation. This work has not previously formed the basis for the award of any Degree, Diploma, Associate ship, Fellowship or other similar title or recognition.

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SUPERVISOR CERTIFICATE

I, hereby certify that the Project Dissertation titled "**Optical and Structural Properties of Green Synthesized Graphene Quantum Dots**" which is submitted by Ram Krishan Saini, Roll No. 2K21/MSCPHY/39 and Rishikesh Raj, Roll No. 2K21/MSCPHY/40 to the Department of Applied Physics, Delhi Technological University, Delhi in partial fulfilment of the requirement for the award of the degree of Master of Science, is a record of the project work carried out by the student under my supervision. To the best of my knowledge, this work has not been submitted in part or full for any Degree or Diploma to this University or elsewhere.

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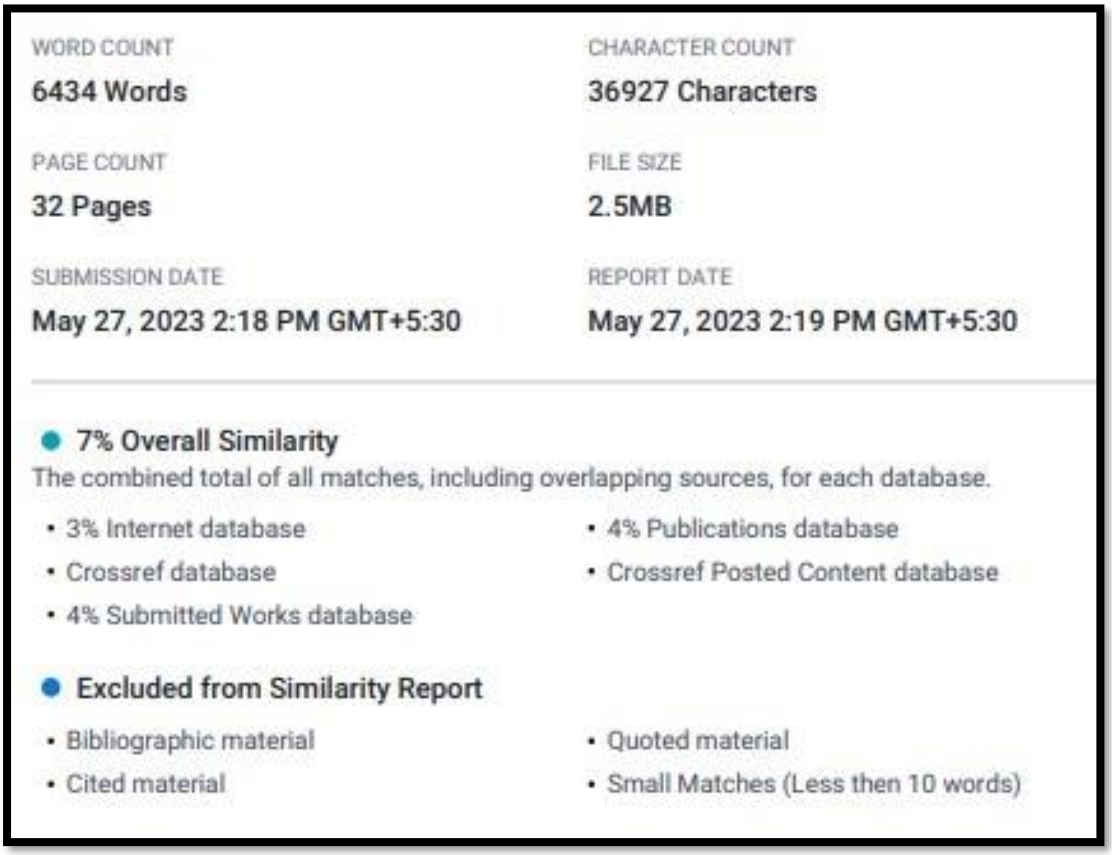

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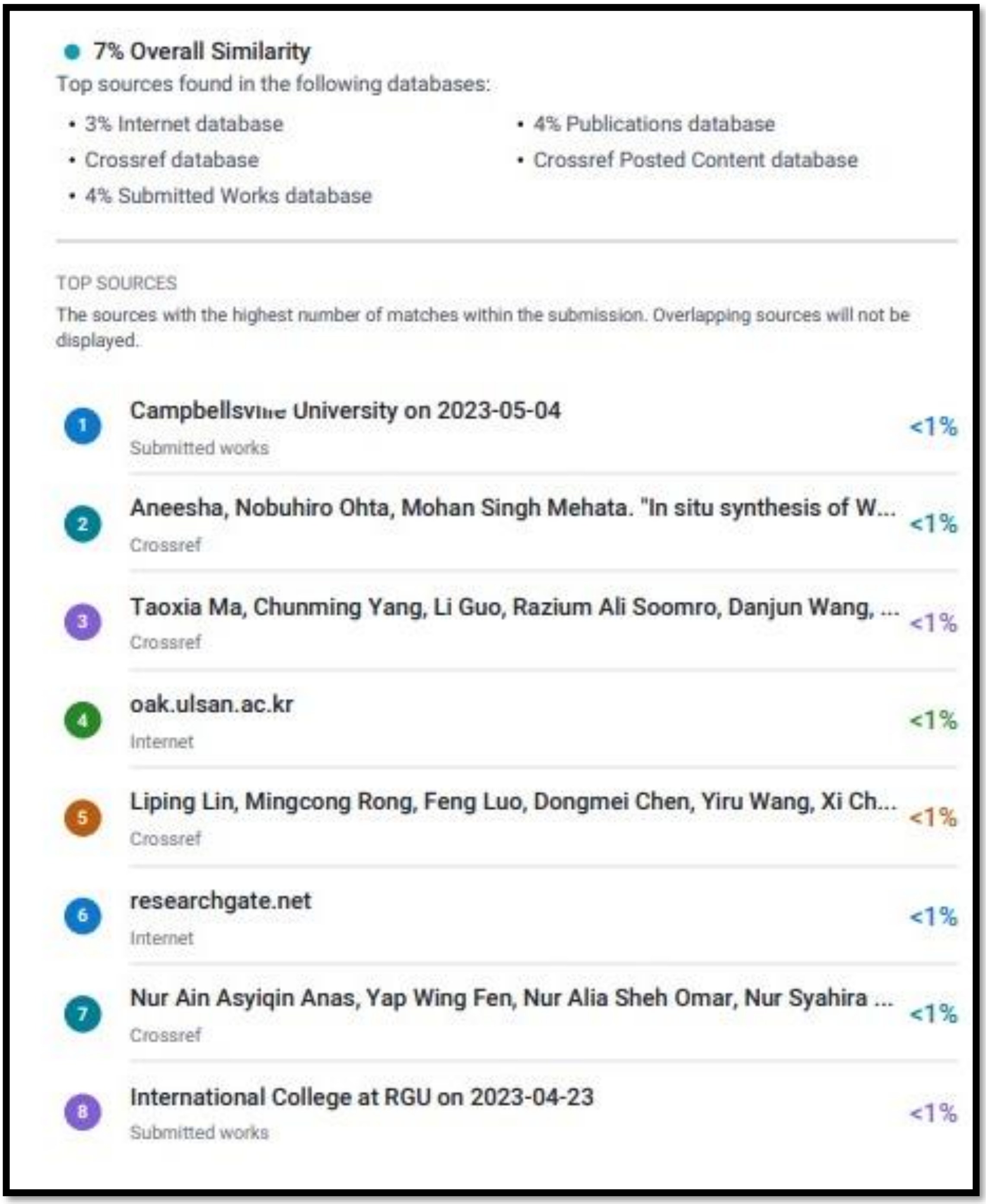

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ABSTRACT

Hydrothermal synthesis of Graphene quantum dots (GQDs) was done using corn powder as a carbon source and water as a solvent. A high-resolution transmission electron microscope shows uniform size distribution with an average diameter of 42 nm. Fourier transform infrared analysis of synthesized GQDs indicates the presence of C=C bond, O-H groups, and aromatic rings. The absorption spectrum of GQDs shows a sharp band at around 227 nm, corresponding to the π-π* transition, and a shoulder peak at 283 nm assigned to the n-π* transition. The band gap of produced GQDs corresponding to 283 nm is 4.07 eV. When the GQDs are excited at 350 nm, the photoluminescence (PL) spectrum with a peak maximum of 450 nm was observed. The band maximum shifted blue of about 100 nm when excited with the band edge of absorption. Hence the PL is excitation dependent. The GQDs could be used as a potential candidate for hazardous metal ions detection in drinking water, and as a catalyst in degrading hazardous dye in wastewater treatment.

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LIST OF SYMBOLS AND ABBREVIATIONS

Symbol/Index	**Meaning/Abbreviation**
GQDs	Graphene Quantum Dots
HR-TEM	High Resolution Transmission Electron Microscope
PL	Photoluminescence
0D	Zero-dimensional
2D	Two-dimensional
π^*	Anti-bonding π-orbitals
CDs	Carbon dots
QY	Quantum Yield
GO	Graphene Oxide
FTIR	Fourier Transform Infrared Analysis
UV	Ultraviolet
h	Planck’s constant
υ	Frequency

CHAPTER 1

INTRODUCTION

1.1. Nanotechnology:

Nanotechnology is a rapidly growing field dealing with the study and modification of matter at the nanoscale, which is approximately 1 to 100 nanometres. At this scale, the physical, biological and chemical properties of substances change dramatically, resulting in unique properties and potential applications [1]. Nanotechnology has the potential to transform from electronics and energy to medicine and environmental science [2].

One of the significant applications of nanotechnology is in electronics. Nanoscale materials, such as graphene and carbon nanotubes, are being used to create faster, smaller, and more energy-efficient electronic devices [3]. The electric properties of these materials are unique which makes them ideal for use in electronic components, such as transistors, sensors, and memory devices. Nanotechnology is being used to create new materials with unique properties that can be used in various applications. For example, the creation of quantum dots, which are nanoscale semiconductor particles, has opened up new possibilities in areas such as electronics, optics, and quantum computing [4-5].

In the field of medicine, nanotechnology has the potential to revolutionize the diagnosis and treatment of diseases. Nanoparticles can be designed to target specific cells or tissues in the body, allowing for more precise drug delivery and reduced side effects. Nanoparticles can also be used to create new diagnostic tools that are more sensitive and accurate than current technologies. For example, gold nanoparticles can be used to detect cancer cells in the early stages [5-7].

Nanotechnology is also being explored for its potential applications in energy production and storage. Nanoscale materials, such as quantum dots and nanowires, can be used for creating solar cells and batteries with better efficiency. Nanotechnology can also be used for improving the efficiency of existing energy technologies, such as fuel cells and wind turbines [7].

In material science, nanotechnology is being used to create new materials with enhanced properties. For example, carbon nanotubes and graphene are being used to create stronger, lighter, and more conductive materials that can be used in various applications, from electronics to aerospace. Nanoparticles can also be used to create new coatings and films with unique properties, such as self-cleaning or anti-corrosive properties.

In engineering, nanotechnology is being used to create new devices and systems with enhanced performance. For example, nanoscale sensors and actuators can be used to create more precise and efficient control systems for various applications, from manufacturing to robotics. Nanotechnology is also being used to create new energy technologies, such as solar cells and fuel cells, that can be more efficient and cost-effective than current technologies [8-10].

In environmental science, nanotechnology is being used to develop new solutions for water treatment, air purification, and pollution control. Nanoparticles can be used for removing contaminants from water and air, and nanomaterials can be used to create more efficient catalysts for chemical reactions. Nanotechnology is also being used to develop new sensors and monitoring systems that can detect and track environmental pollutants at the nanoscale [10-12].

Nanotechnology is being used to develop new diagnostic and therapeutic tools that can target specific cells or tissues in the body. Nanoparticles, such as liposomes and dendrimers, can be used to deliver drugs or genetic material, reducing the side effects of traditional treatments. Nanotechnology is also being used to develop new sensors and imaging techniques that can detect and monitor biological processes at the nanoscale.

Despite its many potential applications, nanotechnology also raises concerns about its potential impact on the environment and human health. As such, it is essential to regulate and oversee the development and use of nanotechnology to ensure that its use is safe and responsible [13-14].

Overall, nanotechnology has the potential to revolutionize various fields and create new possibilities for science, technology, and society. However, it is essential to balance the potential benefits with the potential risks and ensure that the development and use of nanotechnology are safe and responsible.

1.2. Graphene Quantum dots (GQDs)

GQDs, being to a novel category of low-dimensional materials that exhibit distinctive physical and chemical properties. This makes them particularly appealing for diversified applications, such as electronics, biology, energy, and environmental science. A relatively recent addition to the family of carbon-based materials is GQDs. They are minute pieces of graphene with dimensions under 100 nm. They possess features that are a result of both GQDs and carbon dots [1-2]. GQDs are essentially a sort of zero-dimensional (0D) material that can be thought of as incredibly tiny graphene fragments [3-5]. They stand out from their close relatives, carbon dots, by containing a graphene structure inside each dot, excluding its size. As a result, GQDs exhibit certain exceptional behavior of graphene, making them an object of significant research interest [6-7].

In recent years, scientists have successfully developed GQDs using the same principles as two-dimensional (2D) graphene. GQDs that show quantum confinement and edge effects are typically made up of one or more layers. These substances have a variety of appealing characteristics like biocompatibility, high surface area, good stability and adjustable cytotoxicity, tunable PL, small molecular size, chemical inertness and ease of surface grafting and functionalization [1,3,8–14].

Fluorescent nanomaterials known as GQDs have recently been discovered. They have unique optical features and great potential for use in bioimaging-based disease detection and treatment. This is brought about by their 0D structure, which also contributes to solubility, biocompatibility, and chemical stability. They are especially appealing for biomedical applications because of these characteristics [15], [16].

In electronics, GQDs have been studied as potential components in solar cells [17–19], photodetectors [20-21], and field-effect transistors [22-26], due to their photo response and high charge carrier mobility. They have been utilized in biomedicine as biosensors and for targeted medication delivery because of their biocompatibility and substantial surface area for chemical functionalization [27–36]. In energy, they have been studied as catalysts for fuel cells and hydrogen evolution reactions, and in environmental science, they have served as adsorbents for organic pollutants [37–45].

The π-π* transition of C=C makes carbon dots (CDs) as well as GQDs an efficient photon absorber within a small-wavelength range. Normally, they typically exhibit significant optical absorption between 260 and 320 nm, with considerable absorption reaching the visible spectrum. In general, CDs are more effective than GQDs at absorbing long wavelengths. Many GQDs show a peak within 270–390 nm, in contrast to CDs, which may be brought on by the C=O's transition (n-π*). Functional groups and surface passivation cause changes in both materials' absorption properties [46–52]. The tunable photoluminescence (PL) features deriving from quantum confinement phenomena are the most intriguing aspect of both carbon nanodots [9]. The PL intensity fluctuates together with the excitation wavelength, and the redshifts nearly span the visible spectrum as a result. The most thorough and convincing model to describe it is the quantum confinement effect. Surface emissive traps cause bare CDs' poor PL quantum yield (QY). For boosting their brightness, a surface passivation layer is therefore needed. Hence, a surface passivation layer is needed to boost their brightness. Because of their multilayer structure and increased crystallinity, GQDs often provide higher QY than bare CDs. The high QY PL of GQDs is a result of their crystallinity and layer structure. Electrical conductivity is significantly affected by quantum confinement and an edge effect in GQDs thanks to the possibility of high-speed electron mobility. GQDs have high electron mobility and a fast reaction rate, which make them excellent choices for sensing applications [6], [12].

1.3. Synthesis method of GQDs

Bottom-up and top-down are two categories of GQD synthesis methods differing in their reaction mechanisms. In first strategy, large amounts of graphene are exfoliated into smaller particles using physical or chemical techniques like mechanical milling, oxidative cleavage [53,54], nanolithography [55–57], hydrothermal or solvothermal [58–61], microwave irradiation [62-64], laser ablation [65], sonication assisted [66], electrochemical [67,68], or chemical exfoliation [69,70]. This method can result in GQDs with a wide size distribution and a lot of functionalization, but it might also cause oxidation and structural damage.

In the second strategy, organic molecules are controlled pyrolyzed or carbonized, or controlled sp^2 carbon structures are synthesized from organic polymers. This process entails the growth of GQDs from precursors like carbon, metal, or organic precursors.

Chemical vapour deposition can be used for developing graphene on metal substrates and then transferring it for exfoliation. This method can result in GQDs with controlled sizes and compositions, but it might also introduce undesirable impurities and defects. This method produces quantum-sized dots by first carbonizing tiny molecules that have undergone dehydration. There are many different techniques to carry out this synthetic process, including hydrothermal [71], plasma hydrothermal [72], microwave [73], combustion [74], pyrolysis in acid [75], microwave-assisted hydrothermal [76], microreactor-based synthesis [77], etc.

1.4. Eco-Friendly Synthesis of Graphene Quantum Dots: Green Approaches and Raw Materials

The conventional methods for the synthesis of GQDs often involves toxic chemicals, which can pose risks to human health and the environment. Therefore, researchers have been exploring alternative methods for synthesizing GQDs using eco-friendly raw materials and green approaches [2].

Eco-friendly raw materials are those that are natural, renewable, and sustainable, and can be obtained without damaging the environment. These include plant-based materials, such as fruits, vegetables, and biomass waste, which can be converted into graphene oxide (GO) through a simple oxidation process. The GO can then be reduced to GQDs using eco-friendly reducing agents, such as ascorbic acid, sodium borohydride, or green tea extract. Green solvents, such as water or ethanol, can be used to dissolve the precursors and facilitate the synthesis process [78-79].

Green approaches to GQD synthesis involve the use of non-toxic and environmentally friendly materials and methods that minimize the use of hazardous chemicals and reduce waste generation. These include hydrothermal, microwave-assisted, electrochemical, and photochemical methods, as mentioned earlier. These methods have several advantages over conventional methods, including reduced toxicity, lower cost, and higher sustainability. Furthermore, the resulting GQDs can have improved biocompatibility and can be used in bioimaging, drug delivery, and biosensing [16].

The development of eco-friendly raw materials and green approaches for GQD synthesis is an important step towards sustainable and responsible nanotechnology. By reducing the use of toxic chemicals and waste generation, these approaches can help to minimize the environmental impact of nanotechnology while also improving the safety and efficacy of GQDs in various applications. Moreover, these approaches can promote the use of renewable and sustainable resources, which is crucial for addressing global challenges such as climate change and resource depletion [2-16].

Green synthetic routes are being used as a recently growing research area in the field of nanotechnology. In the preparation of GQDs, strong acids or organic solvents are required and green production involves non-toxic reagents but it still has to confront some challenges; that’s why, synthetic routes which are not harmful to the environment and do not involve complicated processes should discover and developed.

CHAPTER 2

SYNTHESIS & CHARACTERIZATION TECHNIQUES

2.1. SYNTHESIS OF GQDS

An innovative and non-toxic precursor (corn powder) was used in the hydrothermal process to create GQDs. Initially, 50 ml DI water and 0.5 g corn powder were mixed and stirred, afterward, it was subsequently placed into an autoclave made of stainless steel and heated for eight hours at 180°C It was subsequently placed into an autoclave made of stainless steel and heated for eight hours at 180°C. The brown solution was obtained, which was further filtered or GQDs were separated from the solution by rapid centrifuge at 7500 rpm for 15 minutes [78,79].

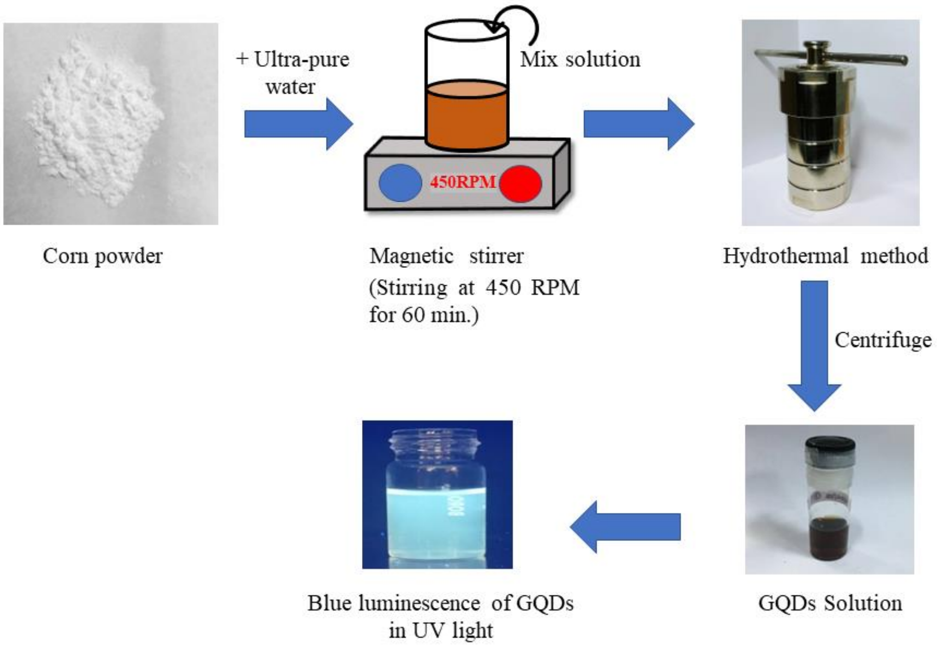

Figure 2.1. Schematic diagram of the synthesis route of GQDs using eco-friendly and cost-effective route

2.2. CHARACTERIZATION TECHNIQUES

TALOS (Accelerating voltage 200 kV) (Fig. 2.1), was used for TEM images, while FTIR spectroscopy within the range of 400 - 4000 cm^{-1} was conducted with Perkin Elmer Two-Spectrum FTIR spectrometers (Fig.2.2) of the obtained GQDs. The UV-Vis spectroscopic data were recorded by a Perkin-Elmer Lambda-750 dual-beam spectrometer (Fig. 2.3). Steady-state PL and PL-excitation measurements were done using Fluorolog-3 spectrofluorometer from Horiba Jobin Yvon (Fig. 2.4), having equipment (photomultiplier tubes and xenon lamp). The measurements were done with a cuvette made of quartz having 10 mm of the optical path.

Figure 2.2. Photograph of TALOS thermo-scientific instrument (Acc. Vol. 200 kV)

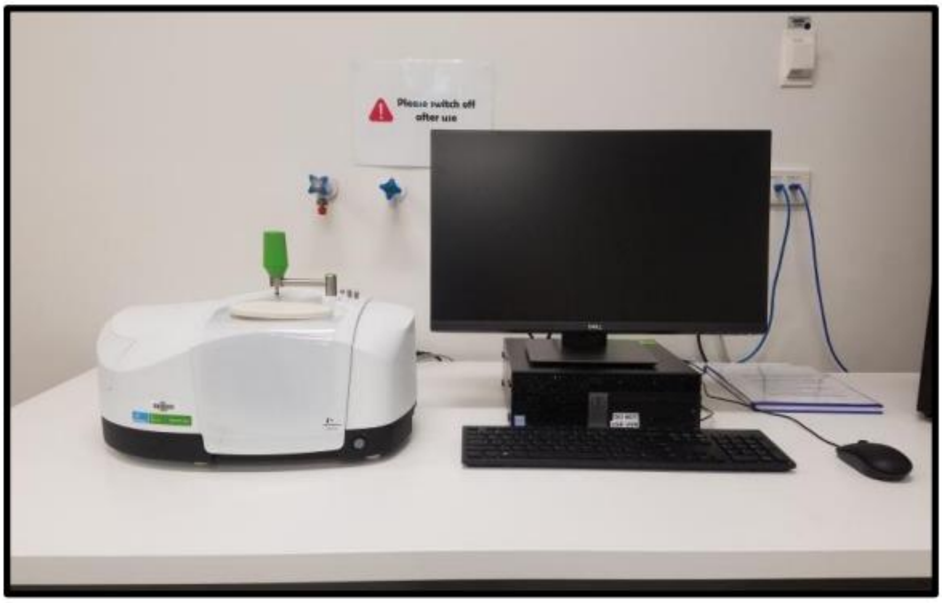

Figure 2.3. Photograph of Perkin Elmer Two–Spectrum FTIR spectrometers

Figure 2.4. Photograph of Perkin Elmer Lambda 750 UV/Vis/NIR spectrophotometer

Figure 2.5. Photograph of Horiba Jobin Yvon Fluorolog-3 spectrofluorometer

CHAPTER 3

RESULTS AND DISCUSSION

3.1. TEM Analysis

The GQDs were subjected to TEM analysis to investigate their size, shape, and uniformity. The GQDs were then drop-cast onto a carbon-coated grid after that it was left for drying before TEM imaging. Fig. 3.1 displays TEM images of the GQDs having a spherical shape and the diameter is within 20 -50 nm. (Fig. 2 c) confirms an average size of 42 nm, having 5 nm of standard deviation [80–82]. ImageJ software was used further for analyzing GQDs' size distribution. It revealed that the size of GQDs is consistent and there is a small range of variation in their sizes. The observed size range is as per previous reports on GQDs, and its shape as observed from TEM images is consistent with spherical morphology, as previously reported for GQDs [83]. The uniformity of GQDs as observed from the TEM images is following the uniformity observed in its size distribution analysis. These results are consistent with previous reports on GQDs which highlight their potential for use in numerous applications, including bioimaging, energy storage, and catalysis. However, it should be noted that there are potential limitations to TEM analysis, including sample preparation and imaging artifacts, which should be taken care of while interpreting the results [84].

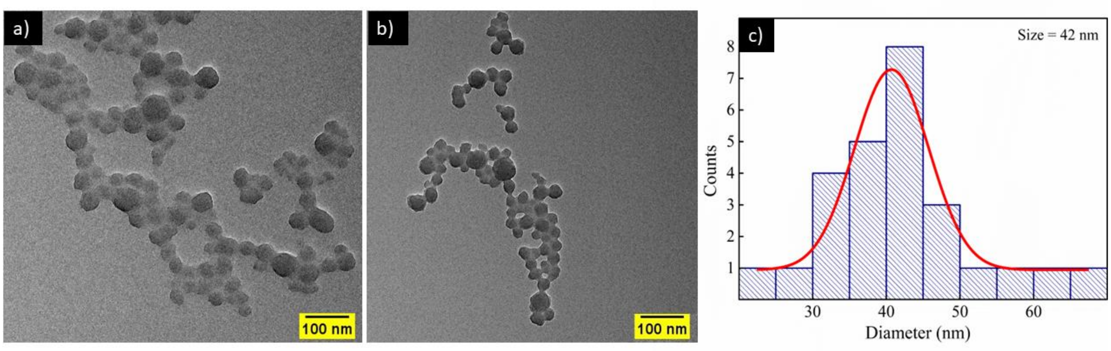

Figure 3.1. TEM images of GQDs at the magnification of 100 nm (a &b) along with particle size distribution (c).

3.2. FT-IR Analysis

The synthesized GQDs were investigated using FTIR, especially to find out functional groups, bonds and chemical composition, and the observed FTIR spectrum is shown in Fig. 3.2. The broad band with a peak at 3297 cm^{-1}, may be attributed to O-H stretching vibration of hydroxyl groups. A weak band at 2103 cm^{-1} is also observed, which may be attributed to the aromatic compounds. A band at 1639 cm^{-1} may be attributed to the C=C stretching vibration of carbonyl groups [85]. The FTIR spectrum of the GQDs indicates various group’s presence on their surface and this could be the reason behind the distinctive characteristics and potential applications of GQDs. The hydroxyl group’s presence suggests that the GQDs may have good water solubility and biocompatibility. Overall, this analysis validates the functional group’s presence on GQDs’ surface and also offers an understanding of their chemical makeup. These results can inform further investigations into the properties and potential applications of GQDs [86–89].

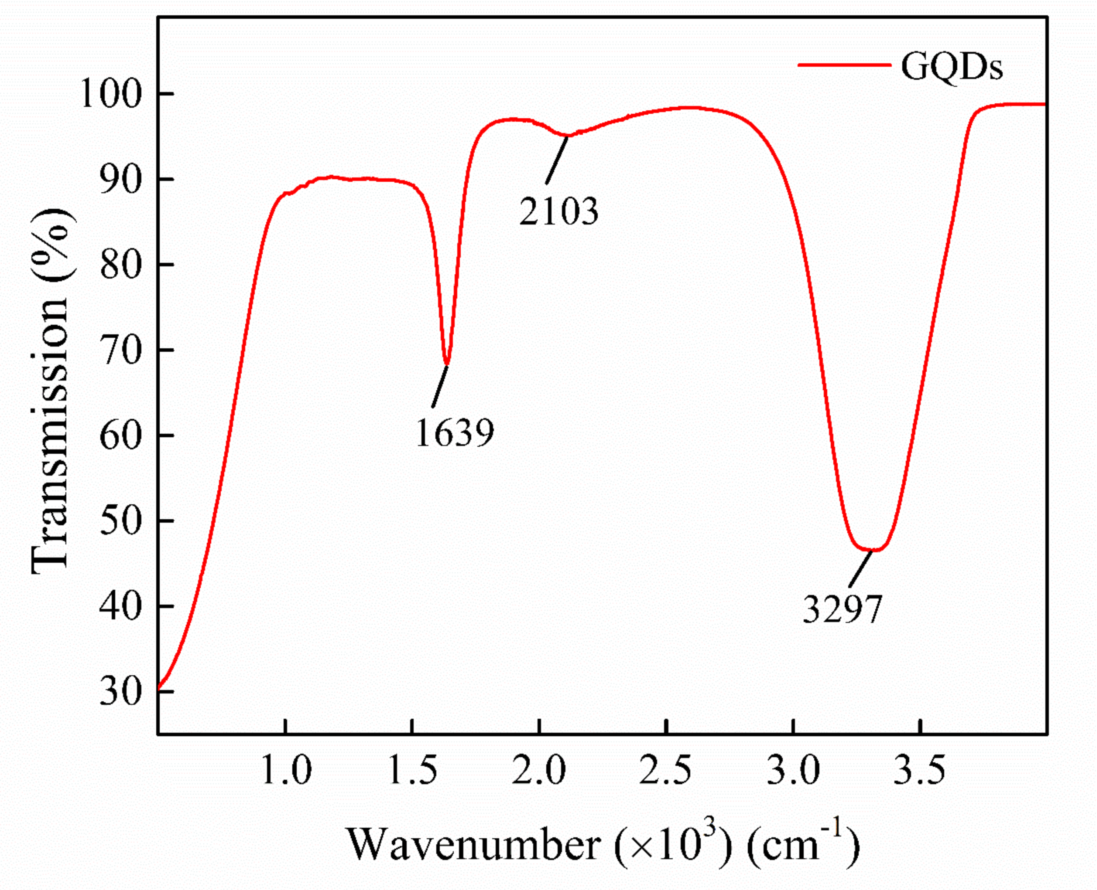

Figure 3.2. FTIR spectrum of green synthesized GQDs

3.3. Absorption Spectrum

The absorption spectrum of GQDs typically shows strong absorbance in the UV-Vis region because of sp^2 hybridization of carbon bonds in the graphene layer. The exact shape and position of the absorption vary depending on their structure and functionalization as well as the solvent used for dispersing the GQDs. In general, smaller GQDs exhibit stronger and narrow peaks compared to larger GQDs. Additionally, the functionalization of the GQDs with various chemical groups can also affect their absorption properties [91,92].

The GQDs absorption spectrum (Fig. 3.3) exhibits two distinct excitonic absorption peaks at approximately 227 and 283 nm as a result of the π-π^* and n-π^* transitions of C=C and C=O groups, respectively [48,90–94]. The longer wavelength band which arises as 283 nm appeared prominently. Tauc's plot was used for calculating the optical band gap and it is described as a plot of the converted absorption coefficient $(\alpha h\upsilon)^r$ versus the photon energy ($h\upsilon$). Here, h is Planck's constant, α is absorption coefficient and υ is light frequency. The appropriate optical band gap can be estimated after determining the value of R, which is 1/2 for materials with an indirect band gap and 2 for those with a direct band gap. (Fig. 3.3) When r = 2, displays a good linear fit, supporting that the synthesized GQDs are direct band gap materials (r = 1/2 does not provide a good linear fit). From Fig. 3.3, we observed the band gap energy (E_g) to be 4.07 eV, and this was accomplished by determining the point at which a line, extrapolated from the range of the curve, intersects the x-axis [95,96].

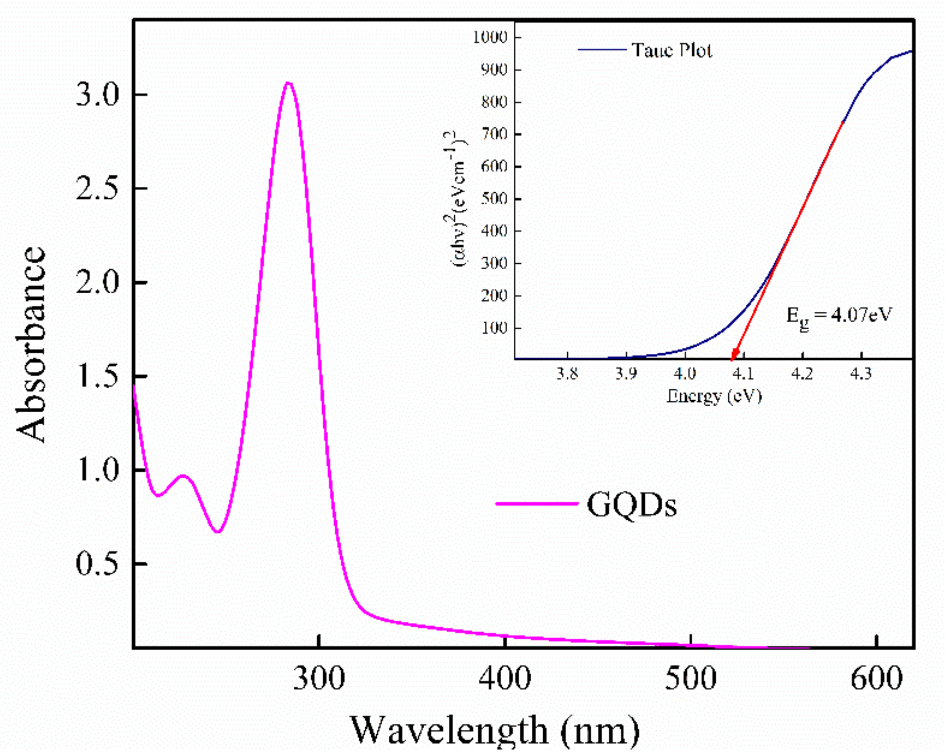

Figure 3.3. UV-Vis absorption spectrum and Tauc plot of $(\alpha h\upsilon)^2$ vs $h\upsilon$ (inset) of synthesized GQDs

3.4. Photoluminescence Spectra

Figure 3.4(a) displays the PL spectra of GQDs within the 330–470 nm wavelength region. The PL of the GQDs is another appealing quality although the mechanism behind the PL phenomenon is still not completely understood, it is thought to involve free zig-zag sites with a triplet state resembling a carbene and surface flaws in the functional groups of the GQDs, quantum effects, edge structure, doping and electron-hole recombination [97,98]. Fig. 3.4(b) shows a broad emission at 450 nm with the excitation wavelength at 350 nm. As the excitation wavelength was increased, there was a rise in the PL intensity before it began to decrease [50]. Notably, the intensity of the PL was the weakest when 330 nm wavelength was used for excitation, and it was the highest when 450 nm wavelength light was used. GQDs emitted an intense blue light when exposed with a wavelength of 365 nm and the band maximum shifted by about 100 nm when excited with the band edge of absorption, indicating that the PL is excitation-dependent, which might be due to size distribution and different emitting centers [99–102].

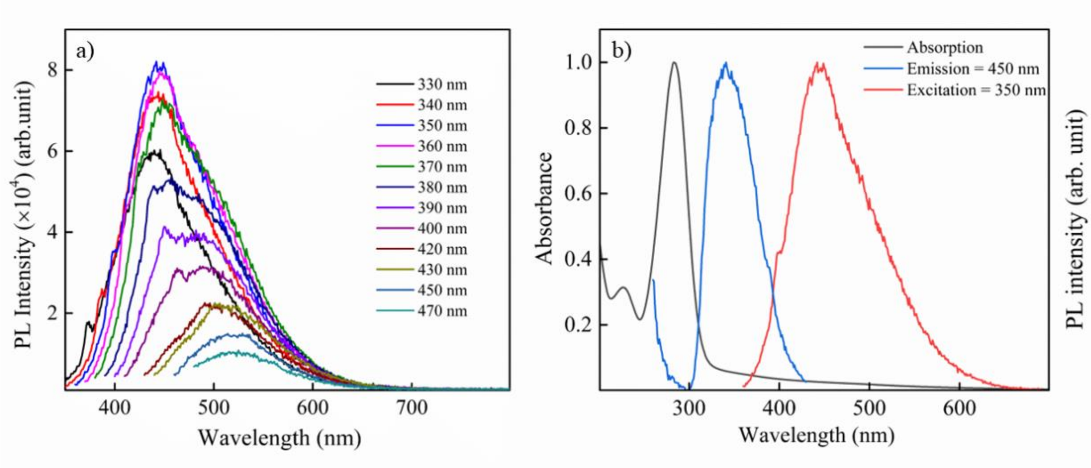

Figure 3.4. PL spectra with varying excitation wavelengths from 330 to 470 nm (a) and a combination of absorption spectrum (black line), PL-excitation spectrum (blue line) with 450 nm PL, and PL spectra with 350 nm excitation (red line) of the GQDs (b).

CHAPTER 4

CONCLUSION

A green method has been used to successfully create GQDs, utilizing corn powder as a precursor. The GQDs exhibited a spherical shape with an average size of 42 nm. The presence of hydroxyl and carbonyl groups, as well as aromatic compounds, was confirmed using FTIR. The GQDs showed promising optical properties with two distinct excitonic absorption bands and intense blue PL. Extensive research is needed to fine-tune the characteristics of GQDs to maximize their potential for different uses, such as bioimaging, sensing, and optoelectronics.

REFERENCES

[1] H. Sun, L. Wu, W. Wei, and X. Qu, “Recent advances in graphene quantum dots for sensing,” *Materials Today,* vol. 16, no.11, pp. 433–442,2013,doi: 10.1016/j.mattod.2013.10.020.

[2] V. Bressi, A. Ferlazzo, D. Iannazzo, and C. Espro, “Graphene quantum dots by eco-friendly green synthesis for electrochemical sensing: Recent advances and future perspectives,” *Nanomaterials*, vol. 11, no.5, 2021, doi:10.3390/nano11051120.

[3] J. Shen, Y. Zhu, X. Yang, and C. Li, “Graphene quantum dots: Emergent nanolights for bioimaging, sensors, catalysis and photovoltaic devices,” *Chemical Communications*, vol. 48, no. 31, pp. 3686–3699, 2012, doi: 10.1039/c2cc00110a.

[4] S. Zhu, S. Tang, J. Zhang, and B. Yang, “Control the size and surface chemistry of graphene for the rising fluorescent materials,” *Chemical Communications*, vol. 48, no. 38, pp. 4527–4539, 2012, doi: 10.1039/c2cc31201h.

[5] Z. Zhang, J. Zhang, N. Chen, and L. Qu, “Graphene quantum dots: An emerging material for energy-related applications and beyond,” *Energy Environ Sci*, vol. 5, no. 10, pp. 8869–8890, 2012, doi: 10.1039/c2ee22982j.

[6] L. Li, G. Wu, G. Yang, J. Peng, J. Zhao, and J.-J. Zhu, “Focusing on luminescent graphene quantum dots: current status and future perspectives ,” vol. 2, no. 1, pp. 1–156, 2010, doi: 10.1039/c0xx00000x.

[7] S. Zhu *et al.*, “Surface chemistry routes to modulate the photoluminescence of graphene quantum dots: From fluorescence mechanism to up-conversion bioimaging applications,” *Adv Funct Mater*, vol. 22, no. 22, pp. 4732–4740, 2012, doi: 10.1002/adfm.201201499.

[8] S. Kim *et al.*, “Anomalous behaviours of visible luminescence from graphene quantum dots: Interplay between size and shape,” *ACS Nano*, vol. 6, no. 9, pp. 8203–8208, 2012, doi: 10.1021/nn302878r.

[9] M. A. Sk, A. Ananthanarayanan, L. Huang, K. H. Lim, and P. Chen, “Revealing the tunable photoluminescence properties of graphene quantum dots,” *J Mater Chem C Mater*, vol. 2, no. 34, pp. 6954–6960, 2014, doi: 10.1039/c4tc01191k.

[10] M. Bacon, S. J. Bradley, and T. Nann, “Graphene quantum dots,” *Particle and Particle Systems Characterization*, vol. 31, no. 4, pp. 415–428, 2014, doi: 10.1002/ppsc.201300252.

[11] D. Wang, J. F. Chen, and L. Dai, “Recent advances in graphene quantum dots for fluorescence bioimaging from cells through tissues to animals,” *Particle and Particle Systems Characterization*, vol. 32, no. 5, pp. 515–523, 2015, doi: 10.1002/ppsc.201400219.

[12] X. T. Zheng, A. Ananthanarayanan, K. Q. Luo, and P. Chen, “Glowing graphene quantum dots and carbon dots: Properties, syntheses, and biological applications,” *Small*, vol. 11, no. 14, pp. 1620–1636, 2015, doi: 10.1002/smll.201402648.

[13] N. Li *et al.*, “Ultrasensitive Profiling of Metabolites Using Tyramine-Functionalized Graphene Quantum Dots,” *ACS Nano*, vol. 10, no. 3, pp. 3622–3629, 2016, doi: 10.1021/acsnano.5b08103.

[14] R. Vithalani, D. Patel, C. K. Modi, and D. H. Suthar, “Glowing photoluminescene in carbon-based nanodots: current state and future perspectives,” *Journal of Materials Science*, vol. 55, no. 21, pp. 8769–8792, 2020, doi: 10.1007/s10853-020-04671-x.

[15] H. Lu, W. Li, H. Dong, and M. Wei, “Graphene Quantum Dots for Optical Bioimaging,” *Small*, vol. 15, no. 36, 2019, doi: 10.1002/smll.201902136.

[16] Y. R. Kumar, K. Deshmukh, K. K. Sadasivuni, and S. K. K. Pasha, “Graphene quantum dot based materials for sensing, bio-imaging and energy storage applications: a review,” *RSC Advances*, vol. 10, no. 40. Royal Society of Chemistry, pp. 23861–23898, 2020, doi: 10.1039/d0ra03938a.

[17] W. Wu, H. Wu, M. Zhong, and S. Guo, “Dual Role of Graphene Quantum Dots in Active Layer of Inverted Bulk Heterojunction Organic Photovoltaic Devices,” *ACS Omega*, vol. 4, no. 14, pp. 16159–16165, 2019, doi: 10.1021/acsomega.9b02348.

[18] M. Li *et al.*, “Graphene quantum dots as the hole transport layer material for high-performance organic solar cells,” *Physical Chemistry Chemical Physics*, vol. 15, no. 43, pp. 18973–18978, 2013, doi: 10.1039/c3cp53283f.

[19] V. Gupta, N. Chaudhary, R. Srivastava, G. D. Sharma, R. Bhardwaj, and S. Chand, “Luminscent graphene quantum dots for organic photovoltaic devices,” *J Am Chem Soc*, vol. 133, no. 26, pp. 9960–9963, 2011, doi: 10.1021/ja2036749.

[20] A. Subramanian *et al.*, “High-performance photodetector based on a graphene quantum dot/CH3NH3PbI3 perovskite hybrid,” *ACS Appl Electron Mater*, vol. 2, no. 1, pp. 230–237, 2020, doi: 10.1021/acsaelm.9b00705.

[21] W. Zhu *et al.*, “Graphene Quantum Dot-Decorated Vertically Oriented Graphene/Germanium Heterojunctions for Near-Infrared Photodetectors,” *ACS Appl Nano Mater*, vol. 3, no. 7, pp. 6915–6924, 2020, doi: 10.1021/acsanm.0c01258.

[22] F. Hetsch, N. Zhao, S. V. Kershaw, and A. L. Rogach, “Quantum dot field effect transistors,” *Materials Today,* vol. 16, no. 9. pp. 312–325, 2013, doi: 10.1016/j.mattod.2013.08.011.

[23] Y. Kim *et al.*, “Graphene quantum dot (GQD)-induced photovoltaic and photoelectric memory elements in a pentacene/GQD field effect transistor as a probe of functional interface,” *J Phys D Appl Phys,* vol. 50, no. 36, 2017, doi: 10.1088/1361-6463/aa7e3f.

[24] O. Salihoglu, N. Kakenov, O. Balci, S. Balci, and C. Kocabas, “Graphene-Quantum Dot Hybrid Optoelectronics at Visible Wavelengths,” *ACS Photonics,* vol. 5, no. 6, pp. 2384–2390, 2018, doi: 10.1021/acsphotonics.8b00163.

[25] V. Laxmi *et al.*, “Protecting black phosphorus with selectively adsorbed graphene quantum dot layers,” *Appl Surf Sci*, vol. 538, 2021, doi: 10.1016/j.apsusc.2020.148089.

[26] Z. Jin, P. Owour, S. Lei, and L. Ge, “Graphene, graphene quantum dots and their applications in optoelectronics,” *Current Opinion in Colloid and Interface Science,* vol. 20, no. 5–6. Elsevier Ltd, pp. 439–453, 2015, doi: 10.1016/j.cocis.2015.11.007.

[27] M. C. Biswas, M. T. Islam, P. K. Nandy, and M. M. Hossain, “Graphene Quantum Dots (GQDs) for Bioimaging and Drug Delivery Applications: A Review,” *ACS Materials Letters*, vol. 3, no. 6, pp. 889–911, 2021, doi: 10.1021/acsmaterialslett.0c00550.

[28] J. Dong *et al.*, “Application of graphene quantum dots for simultaneous fluorescence imaging and tumor-targeted drug delivery,” *Sens Actuators B Chem,* vol. 256, pp. 616–623, 2018, doi: 10.1016/j.snb.2017.09.200.

[29] T. K. Henna and K. Pramod, “Graphene quantum dots redefine nanobiomedicine,” *Materials Science and Engineering C*, vol. 110, 2020, doi 10.1016/j.msec.2020.110651.

[30] J. Qiu *et al.*, “Fluorescent graphene quantum dots as traceable, pH-sensitive drug delivery systems,” *Int J Nanomedicine*, vol. 10, pp. 6709–6724, 2015, doi: 10.2147/IJN.S91864.

[31] R. Xie *et al.*, “Graphene quantum dots as smart probes for biosensing,” *Analytical Methods*, vol. 8, no. 20. Royal Society of Chemistry, pp. 4001–4006, 2016, doi: 10.1039/c6ay00289g.

[32] F. Chen *et al.*, “Graphene quantum dots in biomedical applications: Recent advances and future challenges,” *Frontiers in Laboratory Medicine*, vol. 1, no. 4, pp. 192–199, 2017, doi: 10.1016/j.flm.2017.12.006.

[33] K. Li *et al.*, “Technical synthesis and biomedical applications of graphene quantum dots,” *Journal of Materials Chemistry B*, vol. 5, no. 25, pp. 4811–4826, 2017, doi: 10.1039/c7tb01073g.

[34] B. D. Mansuriya and Z. Altintas, “Applications of graphene quantum dots in biomedical sensors,” *Sensors (Switzerland)*, vol. 20, no. 4, 2020, doi: 10.3390/s20041072.

[35] R. Ding *et al.*, “Recent advances in quantum dots-based biosensors for antibiotics detection,” *Journal of Pharmaceutical Analysis*, vol. 12, no. 3, pp. 355–364, 2022, doi: 10.1016/j.jpha.2021.08.002.

[36] F. Faridbod and A. L. Sanati, “Graphene Quantum Dots in Electrochemical Sensors/Biosensors,” *Curr Anal Chem*, vol. 15, no. 2, pp. 103–123, 2018, doi: 10.2174/1573411014666180319145506.

[37] Z. Du, S. L. Shen, Z. H. Tang, and J. H. Yang, “Graphene quantum dots-based heterogeneous catalysts,” *Xinxing Tan Cailiao/New Carbon Materials*, vol. 36, no. 3, pp. 449–467, 2021, doi: 10.1016/S1872-5805(21)60036-7.

[38] G. Xu *et al.*, “Graphene quantum dot reinforced hyperbranched polyamide proton exchange membrane for direct methanol fuel cell,” *Int J Hydrogen Energy*, vol. 46, no. 15, pp. 9782–9789, 2021, doi: 10.1016/j.ijhydene.2020.06.303.

[39] N. Shaari, S. K. Kamarudin, and R. Bahru, “Carbon and graphene quantum dots in fuel cell application: An overview,” *International Journal of Energy Research*, vol. 45, no. 2, pp. 1396–1424, 2021, doi: 10.1002/er.5889.

[40] Q. Liu *et al.*, “Graphene quantum dots for energy storage and conversion: From fabrication to applications,” *Materials Chemistry Frontiers*, vol. 4, no. 2, pp. 421–436, 2020, doi: 10.1039/c9qm00553f.

[41] Y. Yan *et al.*, “B-doped graphene quantum dots implanted into bimetallic organic framework as a highly active and robust cathodic catalyst in the microbial fuel cell,” *Chemosphere*, vol. 286, 2022, doi: 10.1016/j.chemosphere.2021.131908.

[42] I. Shtepliuk, N. M. Caffrey, T. Iakimov, V. Khranovskyy, I. A. Abrikosov, and R. Yakimova, “On the interaction of toxic Heavy Metals (Cd, Hg, Pb) with graphene quantum dots and infinite grapheme,” *Sci Rep*, vol. 7, no. 1,2017, doi: 10.1038/s41598-017-04339-8.

[43] N. A. A. Anas, Y. W. Fen, N. A. S. Omar, W. M. E. M. M. Daniyal, N. S. M. Ramdzan, and S. Saleviter, “Development of graphene quantum dots-based optical sensor for toxic metal ion detection,” *Sensors (Switzerland)*, vol. 19, no. 18, 2019, doi: 10.3390/s19183850.

[44] M. K. Chini, V. Kumar, A. Javed, and S. Satapathi, “Graphene quantum dots and carbon nano dots for the FRET based detection of heavy metal ions,” *Nano-Structures and Nano-Objects*, vol. 19, 2019, doi: 10.1016/j.nanoso.2019,100347.

[45] T. Anusuya, V. Kumar, and V. Kumar, “Hydrophilic graphene quantum dots as turn-off fluorescent nanoprobes for toxic heavy metal ions detection in aqueous media,” *Chemosphere*, vol. 282, 2021, doi: 10.1016/j.chemosphere.2021,131019.

[46] D. Ghosh, S. Kapri, and S. Bhattacharyya, “Phenomenal Ultraviolet Photoresponsivity and Detectivity of Graphene Dots Immobilized on Zinc Oxide Nanorods,” *ACS Appl Mater Interfaces*, vol. 8, no. 51, pp. 35496–35504, 2016, doi: 10.1021/acsami.6b13037.

[47] L. Li, G. Wu, G. Yang, J. Peng, J. Zhao, and J. J. Zhu, “Focusing on luminescent graphene quantum dots: Current status and future perspectives,” *Nanoscale*, vol. 5, no. 10. Royal Society of Chemistry, pp. 4015–4039, 2013, doi: 10.1039/c3nr33849e.

[48] S. N. Baker and G. A. Baker, “Luminescent carbon nanodots: Emergent nanolights,” *Angewandte Chemie - International Edition*, vol. 49, no. 38. pp. 6726–6744, 2010, doi: 10.1002/anie.200906623.

[49] G. Eda *et al.*, “Blue photoluminescence from chemically derived graphene oxide,” *Advanced Materials*, vol. 22, no. 4, pp. 505–509, 2010, doi: 10.1002/adma.200901996.

[50] V. A. Chhabra, R. Kaur, N. Kumar, A. Deep, C. Rajesh, and K. H. Kim, “Synthesis and spectroscopic studies of functionalized graphene quantum dots with diverse fluorescence characteristics,” *RSC Adv*, vol. 8, no. 21, pp. 11446–11453, 2018, doi: 10.1039/c8ra01148f.

[51] D. Pan, J. Zhang, Z. Li, and M. Wu, “Hydrothermal route for cutting graphene sheets into blue-luminescent graphene quantum dots,” *Advanced Materials*, vol. 22, no. 6, pp. 734–738, 2010, doi: 10.1002/adma.200902825.

[52] D. Li, M. B. Müller, S. Gilje, R. B. Kaner, and G. G. Wallace, "Processable aqueous dispersions of graphene nanosheets," *Nat Nanotechnol*, vol. 3, no. 2, pp. 101–105, 2008, doi: 10.1038/nnano.2007.451.

[53] N. R. Nirala, G. Khandelwal, B. Kumar, Vinita, R. Prakash, and V. Kumar, "One step electro-oxidative preparation of graphene quantum dots from wood charcoal as a peroxidase mimetic," *Talanta*, vol. 173, pp. 36–43, 2017, doi: 10.1016/j.talanta.2017.05.061.

[54] Q. Liu *et al.*, "Green preparation of high yield fluorescent graphene quantum dots from coal-tar-pitch by mild oxidation," *Nanomaterials*, vol. 8, no. 10, 2018, doi: 10.3390/nano8100844.

[55] L. A. Ponomarenko *et al.*, "Chaotic dirac billiard in graphene quantum dots," *Science (1979)*, vol. 320, no. 5874, pp. 356–358, 2008, doi: 10.1126/science.1154663.

[56] L. J. Wang *et al.*, "A graphene quantum dot with a single electron transistor as an integrated charge sensor," *Appl Phys Lett*, vol. 97, no. 26, 2010, doi: 10.1063/1.3533021.

[57] S. Fringes *et al.*, "Charge detection in a bilayer graphene quantum dot," *Phys Status Solidi B Basic Res*, vol. 248, no. 11, pp. 2684–2687, 2011, doi: 10.1002/pssb.201100189.

[58] D. Pan *et al.*, "Cutting sp^2 clusters in graphene sheets into colloidal graphene quantum dots with strong green fluorescence," *J Mater Chem*, vol. 22, no. 8, pp. 3314–3318, 2012, doi: 10.1039/c2jm16005f.

[59] H. Tetsuka *et al.*, "Optically tunable amino-functionalized graphene quantum dots," *Advanced Materials*, vol. 24, no. 39, pp. 5333–5338, 2012, doi: 10.1002/adma.201201930.

[60] D. Pan, J. Zhang, Z. Li, and M. Wu, “Hydrothermal route for cutting graphene sheets into blue-luminescent graphene quantum dots,” *Advanced Materials*, vol. 22, no. 6, pp. 734–738, 2010, doi: 10.1002/adma.200902825.

[61] Q. Liu, B. Guo, Z. Rao, B. Zhang, and J. R. Gong, “Strong two-photon-induced fluorescence from photostable, biocompatible nitrogen-doped graphene quantum dots for cellular and deep-tissue imaging,” *Nano Lett*, vol. 13, no. 6, pp. 2436–2441, 2013, doi: 10.1021/nl400368v.

[62] L. L. Li *et al.*, “A facile microwave avenue to electrochemiluminescent two-color graphene quantum dots,” *Adv Funct Mater*, vol. 22, no. 14, pp. 2971–2979, 2012, doi: 10.1002/adfm.201200166.

[63] R. K. Singh, R. Kumar, D. P. Singh, R. Savu, and S. A. Moshkalev, “Progress in microwave-assisted synthesis of quantum dots (graphene/carbon/semiconducting) for bioapplications: a review,” *Materials Today Chemistry*, vol. 12, pp. 282–314, 2019, doi: 10.1016/j.mtchem.2019.03.001.

[64] M. K. Kumawat, R. Srivastava, M. Thakur, and R. B. Gurung, “Graphene quantum dots from mangifera indica: Application in near-infrared bioimaging and intracellular nanothermometry,” *ACS Sustain Chem Eng*, vol. 5, no. 2, pp. 1382–1391, 2017, doi: 10.1021/acssuschemeng.6b01893.

[65] A. K. Narasimhan, S. B. Lakshmi, T. S. Santra, M. S. R. Rao, and G. Krishnamurthi, “Oxygenated graphene quantum dots (GQDs) synthesized using laser ablation for long-term real-time tracking and imaging,” *RSC Adv*, vol. 7, no. 85, pp. 53822–53829, 2017, doi: 10.1039/c7ra10702a.

[66] S. Zhuo, M. Shao, and S. T. Lee, “Upconversion and downconversion fluorescent graphene quantum dots: Ultrasonic preparation and photocatalysis,” *ACS Nano*, vol. 6, no. 2, pp. 1059–1064, 2012, doi: 10.1021/nn2040395.

[67] M. Zhang *et al.*, “Facile synthesis of water-soluble, highly fluorescent graphene quantum dots as a robust biological label for stem cells,” *J Mater Chem*, vol. 22, no. 15, pp. 7461–7467, 2012, doi: 10.1039/c2jm16835a.

[68] D. B. Shinde and V. K. Pillai, “Electrochemical preparation of luminescent graphene quantum dots from multiwalled carbon nanotubes,” *Chemistry - A European Journal*, vol. 18, no. 39, pp. 12522–12528, 2012, doi: 10.1002/chem.201201043.

[69] F. Liu, M. H. Jang, H. D. Ha, J. H. Kim, Y. H. Cho, and T. S. Seo, “Facile synthetic method for pristine graphene quantum dots and graphene oxide quantum dots: Origin of blue and green luminescence,” *Advanced Materials*, vol. 25, no. 27, pp. 3657–3662, 2013, doi: 10.1002/adma.201300233.

[70] L. Lin and S. Zhang, “Creating high yield water soluble luminescent graphene quantum dots via exfoliating and disintegrating carbon nanotubes and graphite flakes,” *Chemical Communications*, vol. 48, no. 82, pp. 10177–10179, 2012, doi: 10.1039/c2cc35559k.

[71] Y. Yang *et al.*, “One-step synthesis of amino-functionalized fluorescent carbon nanoparticles by hydrothermal carbonization of chitosan,” *Chemical Communications*, vol. 48, no. 3, pp. 380–382, 2012, doi: 10.1039/c1cc15678k.

[72] J. Wang, C. F. Wang, and S. Chen, “Amphiphilic egg-derived carbon dots: Rapid plasma fabrication, pyrolysis process, and multicolor printing patterns,” *Angewandte Chemie - International Edition*, vol. 51, no. 37, pp. 9297–9301, 2012, doi: 10.1002/anie.201204381.

[73] H. Zhu, X. Wang, Y. Li, Z. Wang, F. Yang, and X. Yang, “Microwave synthesis of fluorescent carbon nanoparticles with electrochemiluminescence properties,” *Chemical Communications*, no. 34, pp. 5118–5120, 2009, doi: 10.1039/b907612c.

[74] A. B. Bourlinos, A. Stassinopoulos, D. Anglos, R. Zboril, M. Karakassides, and E. P. Giannelis, “Surface functionalized carbogenic quantum dots,” *Small*, vol. 4, no. 4, pp. 455–458, 2008, doi: 10.1002/smll.200700578.

[75] H. Peng and J. Travas-Sejdic, “Simple aqueous solution route to luminescent carbogenic dots from carbohydrates,” *Chemistry of Materials*, vol. 21, no. 23, pp. 5563–5565, 2009, doi: 10.1021/cm901593y.

[76] L. Tang *et al.*, “Deep ultraviolet photoluminescence of water-soluble self-passivated graphene quantum dots,” *ACS Nano*, vol. 6, no. 6, pp. 5102–5110, 2012, doi: 10.1021/nn300760g.

[77] J. Zong, Y. Zhu, X. Yang, J. Shen, and C. Li, “Synthesis of photoluminescent carbogenic dots using mesoporous silica spheres as nanoreactors,” *Chemical Communications*, vol. 47, no. 2, pp. 764–766, 2011, doi: 10.1039/c0cc03092a.

[78] H. Teymourinia, M. Salavati-Niasari, O. Amiri, and H. Safardoust-Hojaghan, “Synthesis of graphene quantum dots from corn powder and their application in reduce charge recombination and increase free charge carriers,” *J Mol Liq*, vol. 242, pp. 447–455, 2017, doi: 10.1016/j.molliq.2017.07.052.

[79] D. S. Ahmed, M. K. A. Mohammed, and S. M. Majeed, “Green synthesis of eco-friendly graphene quantum dots for highly efficient perovskite solar cells,” *ACS Appl Energy Mater*, vol. 3, no. 11, pp. 10863–10871, 2020, doi: 10.1021/acsaem.0c01896.

[80] S. Kumar, A. K. Ojha, B. Ahmed, A. Kumar, J. Das, and A. Materny, “Tunable (violet to green) emission by high-yield graphene quantum dots and exploiting its unique properties towards sun-light-driven photocatalysis and supercapacitor electrode materials,” *Mater Today Commun*, vol. 11, pp. 76–86, 2017, doi: 10.1016/j.mtcomm.2017.02.009.

[81] L. Nilewski *et al.*, “Highly Oxidized Graphene Quantum Dots from Coal as Efficient Antioxidants,” *ACS Appl Mater Interfaces*, vol. 11, no. 18, pp. 16815–16821, 2019, doi: 10.1021/acsami.9b01082.

[82] M. S. Mehata and S. Biswas, “Synthesis of fluorescent graphene quantum dots from graphene oxide and their application in fabrication of GQDs@AgNPs nanohybrids and sensing of H2O2,” *Ceram Int*, vol. 47, no. 13, pp. 19063–19072, 2021, doi: 10.1016/j.ceramint.2021.03.252.

[83] J. Wu, P. Wang, F. Wang, and Y. Fang, “Investigation of the microstructures of graphene quantum dots (GQDs) by surface-enhanced raman spectroscopy,” *Nanomaterials*, vol. 8, no. 10,2018, doi: 10.3390/nano8100864.

[84] S. H. Kang *et al.*, “Ultrafast Method for Selective Design of Graphene Quantum Dots with Highly Efficient Blue Emission,” *Sci Rep*, vol. 6, 2016, doi: 10.1038/srep38423.

[85] P. R. Kharangarh, S. Umapathy, and G. Singh, “Synthesis and luminescence of ceria decorated graphene quantum dots (GQDs): Evolution of band gap,” *Integrated Ferroelectrics*, vol. 184, no. 1, pp. 114–123, 2017, doi: 10.1080/10584587.2017.1368801.

[86] F. P. Du *et al.*, “PEDOT:PSS/graphene quantum dots films with enhanced thermoelectric properties via strong interfacial interaction and phase separation,” *Sci Rep*, vol. 8, no. 1, 2018, doi: 10.1038/s41598-018-24632-4.

[87] T. A. Tabish *et al.*, “Investigating the bioavailability of graphene quantum dots in lung tissues via fourier transform infrared spectroscopy,” *Interface Focus*, vol. 8, no. 3, 2018, doi: 10.1098/rsfs.2017.0054.

[88] N. Far’aina, M. M. Salleh, M. Ashraf, M. Y. A. Rahman, and A. A. Umar, “Synthesis of blue-luminescence graphene quantum dots using hydrothermal method,” in *Solid State Phenomena*, pp. 259–263, 2017, doi: 10.4028/www.scientific.net/SSP.268.259.

[89] S. Sarabiyan Nejad, A. Babaie, M. Bagheri, M. Rezaei, F. Abbasi, and A. Shomali, “Effects of graphene quantum dot (GQD) on photoluminescence, mechanical, thermal and shape memory properties of thermoplastic polyurethane nanocomposites,” *Polym Adv Technol*, vol. 31, no. 10, pp. 2279–2289, 2020, doi: 10.1002/pat.4948.

[90] B. De and N. Karak, “A green and facile approach for the synthesis of water soluble fluorescent carbon dots from banana juice,” *RSC Adv*, vol. 3, no. 22, pp. 8286–8290, 2013, doi: 10.1039/c3ra00088e.

[91] Z. Fan *et al.*, “Surrounding media sensitive photoluminescence of boron-doped graphene quantum dots for highly fluorescent dyed crystals, chemical sensing and bioimaging,” *Carbon N Y*, vol. 70, pp. 149–156, 2014, doi: 10.1016/j.carbon.2013.12.085.

[92] A. Abbas, T. A. Tabish, S. J. Bull, T. M. Lim, and A. N. Phan, “High yield synthesis of graphene quantum dots from biomass waste as a highly selective probe for Fe3+ sensing,” *Sci Rep*, vol. 10, no. 1, 2020, doi: 10.1038/s41598-020-78070-2.

[93] S. Premkumar, D. Nataraj, G. Bharathi, S. Ramya, and T. D. Thangadurai, “Highly Responsive Ultraviolet Sensor Based on ZnS Quantum Dot Solid with Enhanced Photocurrent,” *Sci Rep*, vol. 9, no. 1, 2019, doi: 10.1038/s41598-019-55097-8.

[94] F. Jiang *et al.*, “Eco-friendly synthesis of size-controllable amine-functionalized graphene quantum dots with antimycoplasma properties,” *Nanoscale*, vol. 5, no. 3, pp. 1137–1142, 2013, doi: 10.1039/c2nr33191h.

[95] Q. Dong *et al.*, “Electron-hole diffusion lengths > 175 μm in solution-grown CH3NH3PbI3 single crystals,” *Science (1979)*, vol. 347, no. 6225, pp. 967–970,2015, doi: 10.1126/science.aaa5760.

[96] C. Zhu *et al.*, “Negative induction effect of graphite N on graphene quantum dots: Tunable band gap photoluminescence,” *J Mater Chem C Mater*, vol. 3, no. 34, pp. 8810–8816, 2015, doi: 10.1039/c5tc01933h.

[97] S. Kundu and V. K. Pillai, “Synthesis and characterization of graphene quantum dots,” *Physical Sciences Reviews*, vol. 5, no. 4. De Gruyter, 2020, doi: 10.1515/psr-2019-0013.

[98] Z. Wang, H. Zeng, and L. Sun, “Graphene quantum dots: Versatile photoluminescence for energy, biomedical, and environmental applications,” *Journal of Materials Chemistry C*, vol. 3, no. 6. Royal Society of Chemistry, pp. 1157–1165, 2015, doi: 10.1039/c4tc02536a.

[99] Y. Li *et al.*, “Nitrogen-doped graphene quantum dots with oxygen-rich functional groups,” *J Am Chem Soc*, vol. 134, no. 1, pp. 15–18, 2012, doi: 10.1021/ja206030c.

[100] E. Colusso, L. Cicerchia, M. Rigon, V. Gomes, and A. Martucci, “Photoluminescence properties of silk–carbon quantum dots composites,” *J Solgel Sci Technol*, 2022, doi: 10.1007/s10971-022-05742-y.

[101] W. U. Khan *et al.*, “High quantum yield green-emitting carbon dots for Fe(III) detection, biocompatible fluorescent ink and cellular imaging,” *Sci Rep*, vol. 7, no. 1, 2017, doi: 10.1038/s41598-017-15054-9.

[102] F. Zhang *et al.*, “Graphene quantum dots doped PVDF(TBT)/PVP(TBT) fiber film with enhanced photocatalytic performance,” *Applied Sciences (Switzerland)*, vol. 10, no. 2, 2020, doi: 10.3390/app10020596.

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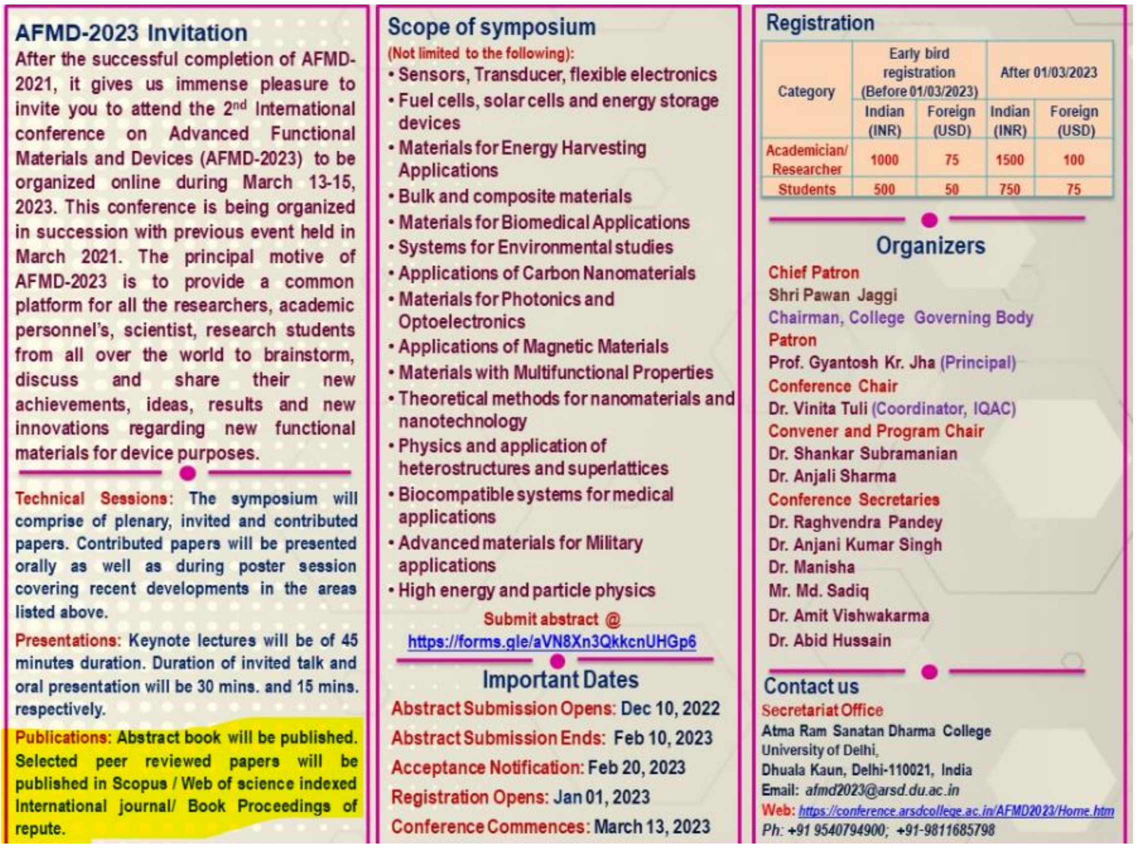

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Abstract Submission Ends: Feb 10, 2023
Acceptance Notification: Feb 20, 2023
Registration Opens: Jan 01, 2023
Conference Commences: March 13, 2023

Registration

Category	Early bird registration (Before 01/03/2023)		After 01/03/2023	
	Indian (INR)	Foreign (USD)	Indian (INR)	Foreign (USD)
Academician/ Researcher	1000	75	1500	100
Students	500	50	750	75

Organizers

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Shri Pawan Jaggi
Chairman, College Governing Body
Patron
Prof. Gyantosh Kr. Jha (Principal)
Conference Chair
Dr. Vinita Tuli (Coordinator, IQAC)
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Conference Secretaries
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Mr. Md. Sadiq
Dr. Amit Vishwakarma
Dr. Abid Hussain

Contact us

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