



# Dendrimer Enhanced Fingerprint and Explosive Detection: A Critical Review

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## Abstract

Forensic science deals with crime scene investigation and evidence analysis, which provides physical evidence to address legal problems. Fingerprint detection and explosive detection are the key research areas explored using dendrimer-based detection. Dendrimers have a unique structure, size, shape, monodispersed, generation, and surface terminal groups. Dendrimers are biodegradable and low-toxic. Dendrimer applications are well established in the biomedical and pharmaceutical fields. Dendrimer applications have been reported in multidisciplinary fields like sensors, environmental, water purifier, solar cell, cosmetics, catalysis, drug delivery, photo activity, energy harvesting, and forensic science. Dendrimer-nanocomposites are reported for fingerprint detection, explosive detection, photoluminescence-based optical sensing. Still, alcohol and narcotics drugs sensing are significant challenges. Dendrimer-nanocomposites can be a suitable sensor as well as detection techniques.

**Keywords:** Dendrimer; Fingerprint detection; Explosive detection; Forensic science; Nanostructures.

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## 1. Introduction

Before early 1978, polymers were long-chain conjugated monomers with branching or cross-linking. Fibers, flexible films, adhesives, resistant paints, *etc.*, are well-known polymers.<sup>[1-6]</sup> Polymer chemistry is historically targeted at linear and branching polymers.<sup>[7-9]</sup> In 1978, Fritz Vogtle proposed a divergent synthesis approach that resulted in the first "Cascade molecule."<sup>[10]</sup> Dendritic polymers are known as "Dendrimers." Dendrimers have unique physical, chemical properties and structure therefore they provide a wide range of potential applications like adhesives and coatings, chemical sensors, medical diagnostics, drug-delivery systems, high-performance polymers, catalysts, supramolecular assembly, separation agents, and many more.<sup>[10-12]</sup> Donald A. Tomalia discovered the first family of dendrimers in 1985.<sup>[10]</sup> The dendrimer term originates from two Greek words: 'dendron' and 'meros'. 'Dendron' means tree and 'meros' means part. Dendrimers are sometimes referred to as cascade molecule or hyperbranched polymer. In nanotechnology, dendrimer synthesis is executed using a bottom-up synthesis approach. The synthesized dendrons or dendrimers are highly defined

nanoparticles of 1 to 15 nm in size and versatile surface functionalization, as shown in Fig. 1.<sup>[13-16]</sup>

The dendrimer's general structure shows a high degree of molecular uniformity, narrow molecular weight distribution, specific size and shape, and a highly-functionalized terminal surface. Dendrimers are highly branched, tree-shaped molecules with nanometer-scale dimensions, as shown in Fig. 1. Dendrimers are defined by three components: a central core, an interior dendritic structure (the branches), and an exterior surface with functional surface groups. The varied combinations of these components yield different shapes and sizes with shielded interior cores, which are ideal candidates for applications in both biological and materials sciences. While the connected surface groups affect the solubility and chelation ability, the varied cores impart unique properties to the cavity size, absorption capacity, and capture-release characteristics. Its graphical representation is shown in Fig. 2.

Dendrimers are generally prepared using either a divergent method or a convergent method, as shown in Fig. 3. In the divergent method of synthesis, a dendrimer is assembled from a multi-functional core that is extended outward via a series of reactions, usually a Michael reaction. Each step of the reaction must be driven to a full completion to prevent mistakes in the dendrimer, which can cause trailing generations (a few branches are shorter than the others). Such impurities can affect the dendrimer's functionality and symmetry but are

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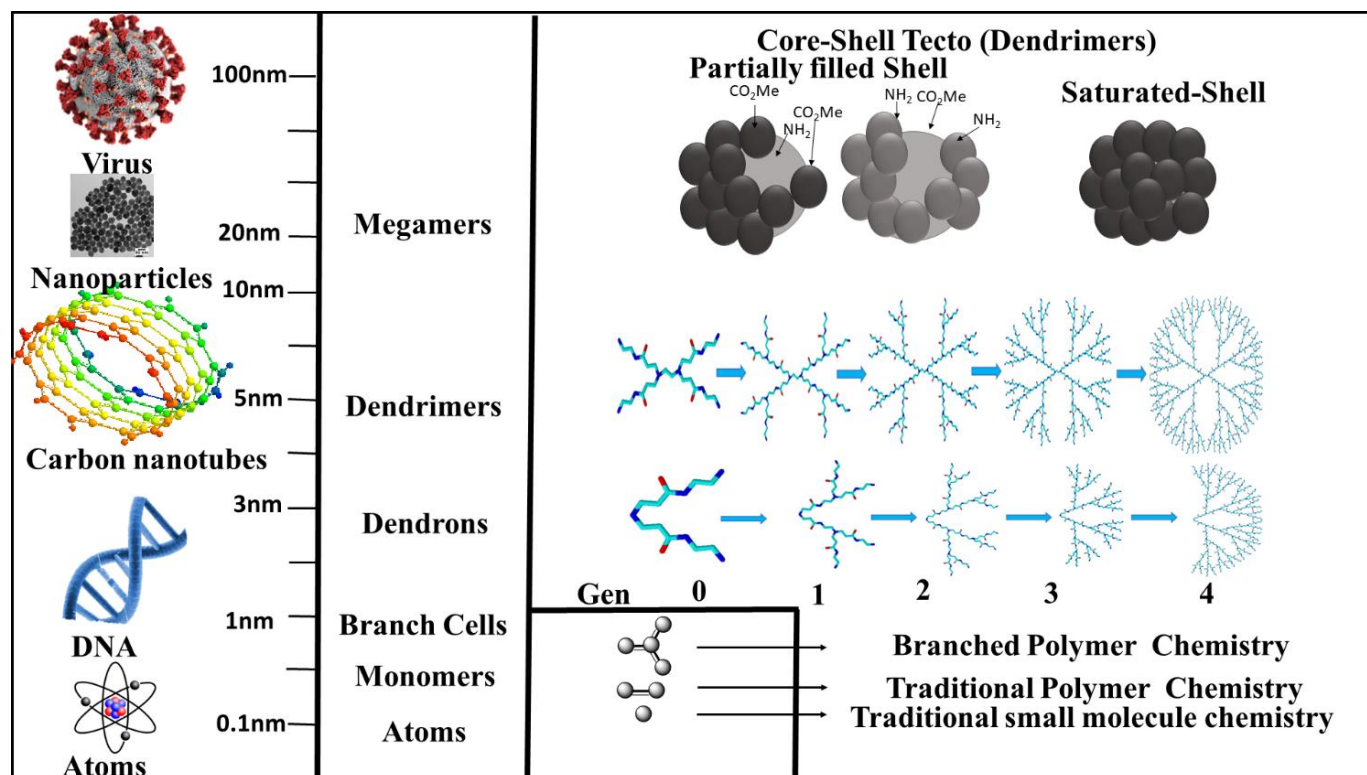


Fig. 1 Molecular complexity as a function of molecular size.

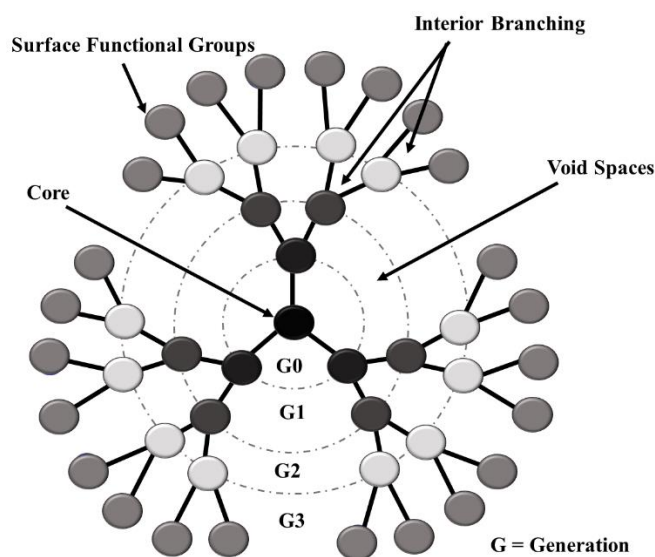


Fig. 2 The general structure of dendrimers.

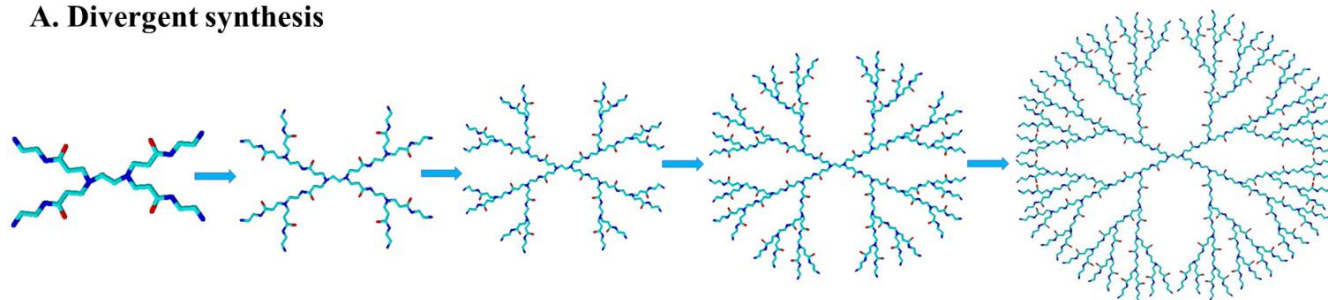
extremely difficult to purify out because the relative size difference between perfect and imperfect dendrimers is very small. In the convergent synthesis method, dendrimers are constructed from small molecules that end up on the sphere's surface, and reactions proceed inward, building inward and subsequently connecting to a core. This method makes it much less complicated to cast off impurities and shorter branches alongside the manner so that the very last dendrimer is more monodisperse. However, dendrimers made in this manner aren't as large as those made means of divergent methods, because steric effects along the core are limiting. The double exponential and mix growth methods are an aggregate of both

divergent and convergent methods. In this method, a single starting material is taken, from which two monomers are prepared using the divergent and convergent methods. Then those two monomers are reacted together to offer an orthogonally protected trimer. This protector trimer can be used to repeat the growth process.<sup>[13,14,16]</sup>

Significant applications of dendrimers are drug delivery and biomedical fields. As mentioned above, areas also have acute problems that may be solved through this dendrimer or dendrimers nanocomposites. But dendrimer can be more applicable and more beneficial for remedying many social troubles, and it's a super polymer that facilitates society, as shown in Fig. 4.

Briefly reported applications of dendrimers are in pharmaceuticals,<sup>[17-24]</sup> forensic science,<sup>[1-9,25]</sup> immunoassay and vaccines,<sup>[21,26]</sup> MRI contrast imaging,<sup>[27-32]</sup> drug delivery,<sup>[33-37]</sup> biochemical assay,<sup>[38-40]</sup> supramolecular chemistry,<sup>[41-44]</sup> electrochemistry,<sup>[45]</sup> catalyst,<sup>[46]</sup> sensors,<sup>[15,47-53]</sup> environmental,<sup>[54-56]</sup> water purifier,<sup>[57-59]</sup> solar cell<sup>[60]</sup> and cosmetics<sup>[61,62]</sup> etc. Forensic chemistry studies chemicals, chemical substrate, gases, or trace elements evidence to identify and analyse using chemical and analytical methods. Forensic chemistry enhances crime scene investigation, which provides physical evidence using chemical and analytical methods to address legal problems. Forensic chemistry deals with fingerprint detection, explosive detection, gunshot residue detection, drug abuse, fibre analysis, paint and coatings examination, glass examinations, fire residues, and fire debris analysis, as shown in Fig. 5.<sup>[63]</sup>

### A. Divergent synthesis



### B. Convergent synthesis

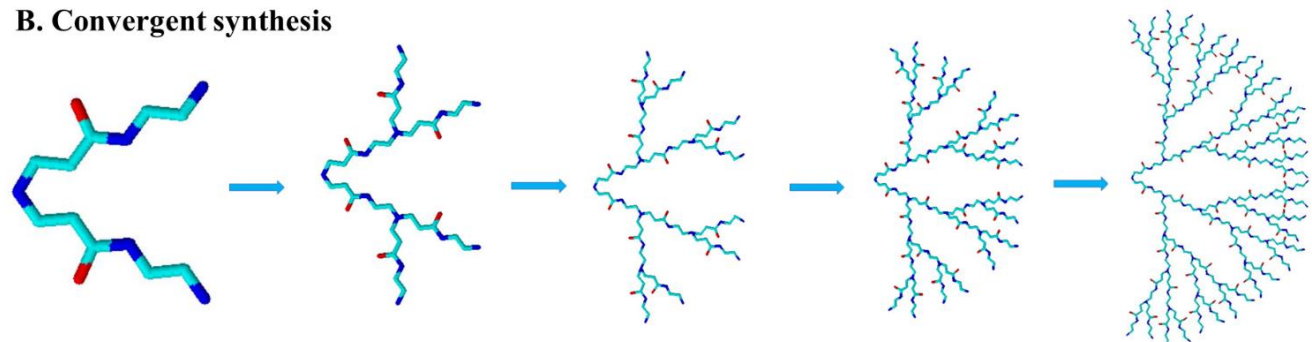


Fig. 3 Major dendritic polymers synthesis routes.

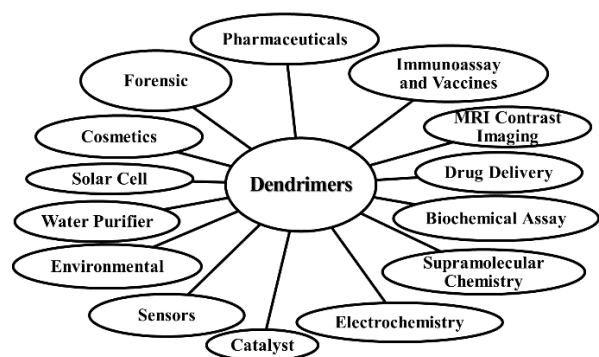


Fig. 4 Applications of dendrimers.

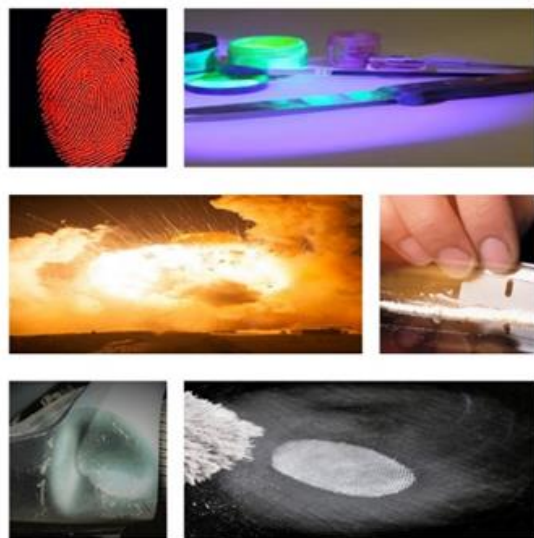


Fig. 5 Various fields of the investigation in forensic chemistry (Various fields of forensic chemistry in criminal investigation).

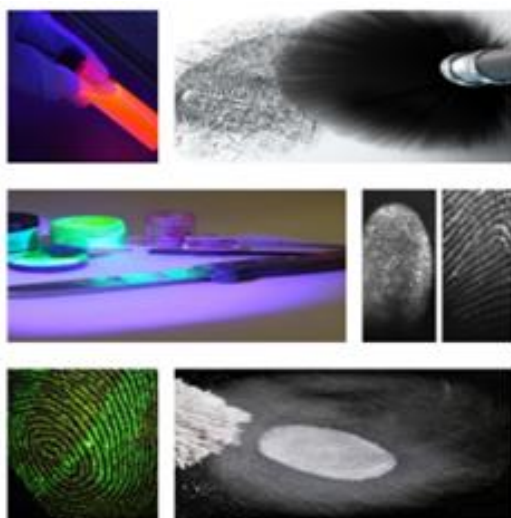
## 2. Fingerprint development

A simple, effective, and sensitive powder for fingerprint detection is a commonly used approach for evidence collecting in criminal instances involving rape. Since the late nineteenth century, the unique patterns of fingerprints have been used to identify individuals biometrically. Development, identification, and presentation of the fingerprint are among the best systems for safety and security of documents, devices (like phone, laptop, etc.), bank locker, entry control of workplaces, and forensic application in crime scene investigation.<sup>[63]</sup>

### 2.1 Traditional methods for fingerprint development

Fingerprints left at crime scenes are one of the tools used to incriminate or eliminate suspects. The fingerprint can be classified into three classes: patent prints, plastic prints, and latent prints. The patent prints are already visible to the naked eye because of blood, or through blood-covered fingers, or in ink or dirt. Plastic prints are visible to the naked eye, which are left on a pliable surface consisting of clay or wax. Both patent and plastic prints can frequently be recorded using photography. Latent prints are invisible to the naked eye and pose more of a problem. Latent prints are left on surfaces due to the natural oils and sweat secreted from the skin. Though those stay at the surface, they are not visible except for many visualization methods, as shown in Fig. 6.

Two methods can perform fingerprint detection, one is the “physical method” (powder dusting method), and another is the “chemical method”. The most frequently used method is the powder dusting method for latent fingerprint development. Traditional fingerprint powder composition is shown in Table 1.



**Fig. 6** Investigation of fingerprint.

**Table 1.** Traditional fingerprint powder composition.<sup>[63]</sup>

Black fingerprint powder formulas:		
Ferric oxide powder	Black ferric oxide	50%
	Rosin	25%
	Lampblack	25%
	Manganese dioxide	45%
Manganese dioxide powder	Black ferric oxide	25%
	Lampblack	25%
	Rosin	5%
	Lampblack	60%
Lampblack powder	Rosin	25%
	Fuller's earth	15%
White fingerprint powder formulas		
Titanium oxide powder	Titanium oxide	60%
	Talc	20%
	Kaolin lenis	20%
Chalk-titanium oxide powder	Chalk	15%
	Kaolin lenis	15%
	Titanium oxide	70%
Gray fingerprint powder formulas		
Chemist gray powder	Chemist gray	80%
	Aluminum powder	20%
	Lead carbonate	80%
Lead carbonate powder	Gum Arabic	15%
	Aluminum powder	3%
	Lampblack	2%

The powder method is the application of a powder using a camel hair brush or a glass-fibre brush which develops immediate apparent prints for detecting latent finger-mark impressions. The ridge pattern is easily defined due to sweat residue. When it is impossible to develop prints by physical method, chemical methods like iodine, ninhydrin, cyanoacrylate (super glue), gentian violet solution - phenol containing formulation, gentian violet solution - non-phenol formulation, coumarin 540 dye, ardrex dye, rare earth

complexes, and many more are used. There are four classes of dusting powders: regular, luminescent, metallic, and thermoplastic.<sup>[63]</sup>

## 2.2 Dendrimers based fingerprint development:

Currently used fluorescent fingerprint powders have less selectivity on different surfaces.<sup>[9]</sup> Quantum dots (QDs) are a powerful and outstanding photoluminescence material for developing latent fingerprints on nonporous substrates. QDs-dendrimer nanocomposite can be utilized in both physical and chemical methods. The results are more elaborate compared to traditional organic dyes, such as rhodamine 6G.<sup>[7,9]</sup> This nanocomposite could be very useful for fingerprint development. The dendrimer can offer stability, enhanced detection, and resolution of the latent fingerprints on several different non-porous surfaces such as tinfoil, aluminium, glass, plastic, *etc.*<sup>[9]</sup> Cadmium sulfide (CdS) QD-dendrimer nanocomposite was synthesized using in-situ reaction with generation 4.0-NH<sub>2</sub> PAMAM dendrimers in methanol.<sup>[9]</sup> In the CdS/PAMAM dendrimer nanocomposites, PAMAM dendrimers act as a host. CdS/PAMAM dendrimer nanocomposites are uniform and well-dispersed with distinctive optical properties, in which luminescence is observed at 365 nm. A CdS/PAMAM dendrimer nanocomposites solution was utilized for detection of latent fingerprints.<sup>[9]</sup> The detection was carried out using cyanoacrylate ester fumed on tinfoil.

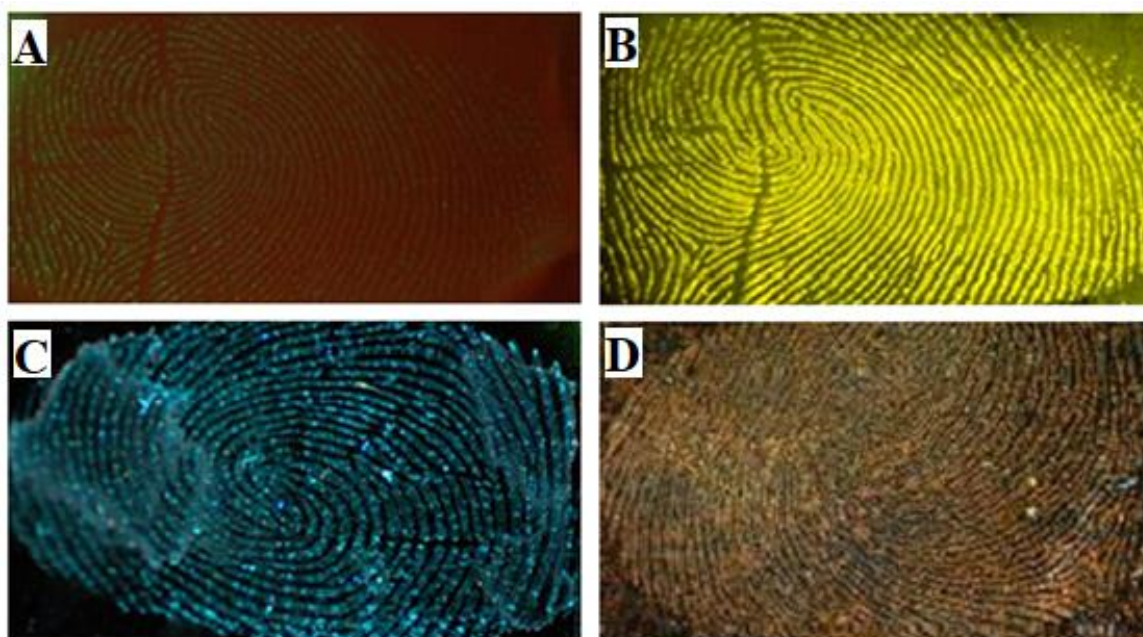
The dendrimer was replaced with the aid of mercaptoethanol according to the conventional approach, and the outcome<sup>[9]</sup> which indicates dendrimer is better than mercaptoethanol for detection of latent fingerprints, as shown in Fig. 7.

A dendrimer was functionalised with a different metal, then nanocomposite was synthesized using an in-situ reaction.<sup>[7]</sup> Cadmium selenide CdSe-dendrimer nanocomposite and functionalised dendrimers had been efficaciously detected with higher resolution, as shown in Fig. 8.

The fingerprint development using CdSe/PAMAM dendrimer nanocomposite on tinfoil was compared with Cd<sup>2+</sup>-CdSe/PAMAM dendrimer nanocomposite and Zn<sup>2+</sup>-CdSe/PAMAM dendrimer nanocomposite. The results of Cd<sup>2+</sup> and Zn<sup>2+</sup> functionalized Nanomaterials shows better fingerprint visualization, which is represented in Fig. 8. Latent fingerprints were developed under UV light irradiation at the wavelength of 365 nm in the dark on the tinfoil surface.<sup>[7]</sup> Metal functionalised dendrimer Cd<sup>2+</sup>-CdSe/PAMAM NCs and Zn<sup>2+</sup>-CdSe/PAMAM NCs showed more enhanced resolving ability than CdSe/PAMAM NCs.<sup>[7]</sup>

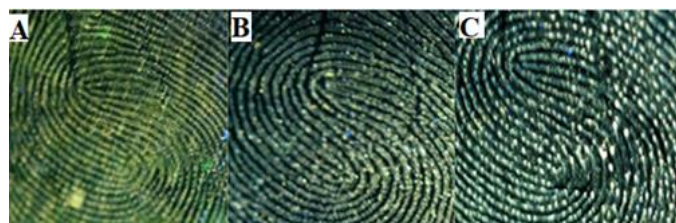
## 3. Explosive detection

Explosives are used for military operations and legitimate mining. Explosive material is highly flammable and is intended to initiate a fire. Explosive material is either a liquid, a powder, or a solid. Explosive materials play a significant role in a bomb blast, explosive/incendiary devices, and improvised



**Fig. 7** CdS nanocomposite developed fingerprint with cyanoacrylate ester-fumed on tinfoil A. without CdS/G4.0 PAMAM nanocomposite (yellow light filter), B. with CdS/G4.0 PAMAM nanocomposite (yellow light filter), C. with CdS/G4.0 PAMAM nanocomposite (blue light filter), D. with CdS/mercaptopoacetic nanocomposite.<sup>[9]</sup>

explosive devices (IED) used by criminals or terrorists, which are dangerous to society. Detection of explosive materials gives essential information for monitoring rail stations, airports, and terrorist attacks. An explosives detection is vital to discover landmines and improvised explosive devices (IEDs) in the military.<sup>[25]</sup>



**Fig. 8** CdSe/PAMAM dendrimer nanocomposite developed Fingerprint on tinfoil developed: (a) CdSe/PAMAM dendrimer nanocomposite (b) Cd<sup>2+</sup>-CdSe/PAMAM dendrimer nanocomposite (c) Zn<sup>2+</sup>-CdSe/PAMAM dendrimer nanocomposite.<sup>[7]</sup>

### 3.1 Traditional methods for explosive detection

The initial requirement of explosive detection is to detect a wide range of explosive materials such as conventional explosive substances, including 2,4,6-trinitrotoluene (TNT) and chemicals used in IEDs, including ammonium nitrate. The improvement of the latest techniques can enhance result quality, and/or reduce time and cost. Currently used analytical approaches of evaluation for explosive examination are listed below: thin-layer chromatography (TLC), liquid chromatography (LC), gas chromatography (GC), ion chromatography (IC), capillary electrophoresis (CE), gas chromatography-mass spectrometry (GC-MS), liquid chromatography-mass spectrometry (LC-MS), inductively

coupled plasma mass spectrometry (ICP-MS), scanning electron microscopy/energy dispersive spectroscopy (SEM/EDX), X-ray fluorescence (XRF), powder X-ray diffraction (XRD), Fourier transform infrared spectroscopy (FTIR), and Raman spectroscopy for identifying intact explosives and their post-blast residues.<sup>[25,38]</sup>

### 3.2. Explosive detection using dendrimers

Dendrimers are highly branched supramolecular nano polymers. A dendrimer is an appropriate nanostructure for sensing applications. Dendrimers have physical properties, including size, shape, monodispersed, generation, and surface terminal groups, enhancing sensing ability of analyte. Chemical explosive detection could be very crucial in public security, military operations, and environmental monitoring. The dendrimers are monodispersed in nature, so a few light-emitting dendrimers can act as nano-optical chemo-sensor.<sup>[15]</sup> The working principle of nano optical chemo-sensor is fluorescence quenching study. Fluorescence quenching is the study of a decrease in fluorescence quantum yield using fluorescence spectroscopy.<sup>[64]</sup> The quantum yield of a dendrimer was calculated using fluorescence lifetimes and different concentrations of a quencher where nitro compounds act as a quencher.

A few dendrimers have excellent fluorescence properties for the detection of explosives using fluorescence quenching study. The nitrated analytes significantly focus on chemical explosives detection, including trinitrotoluene (TNT), 2,4-dinitrotoluene (DNT), and the plastic explosives taggant 2,3-dimethyl-2,3-dinitrobutane (DMNB). The fluorescence quenching is technique to analyse explosives using dendrimer. The photoluminescence quantum yield (PLQY) is reported for

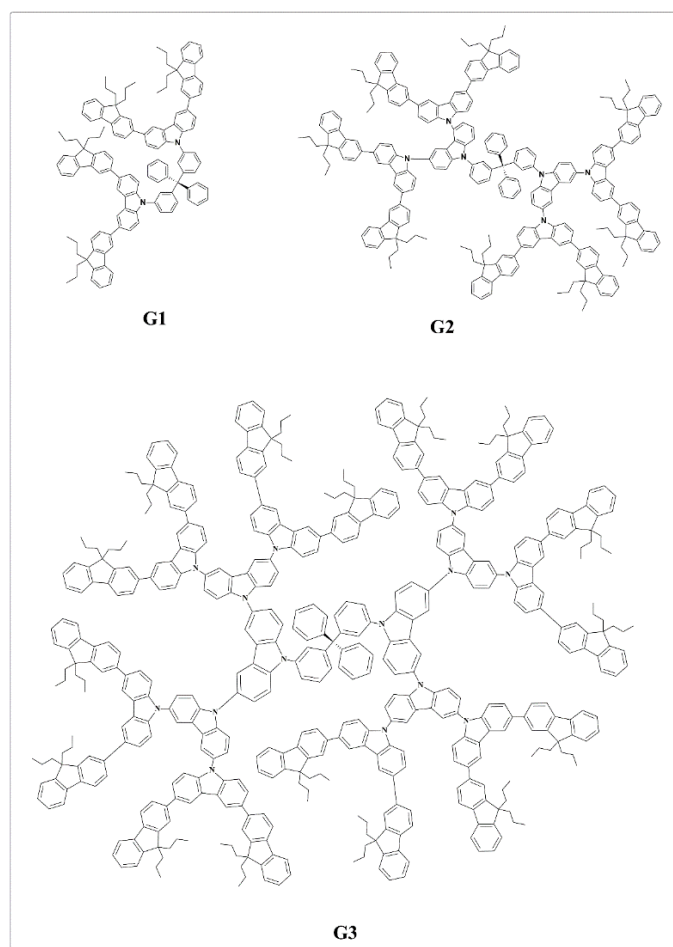
various dendrimer-based nanostructures as listed in Table 2.

**Table 2.** PLQY of various dendrimer-based nanostructures.

Sr. no.	Dendrimer based nanostructures	PLQY
1	Spirobifluorene core carbazole dendrimers G1 solution	$65 \pm 3\%$ <sup>[3]</sup>
2	Spirobifluorene core carbazole dendrimers G2 solution was	$21 \pm 2\%$ <sup>[3]</sup>
3	Spirobifluorene core carbazole dendrimers G3 solution	$18 \pm 2\%$ <sup>[3]</sup>
4	Poly(dendrimer)s M1	$34 \pm 3\%$ <sup>[2]</sup>
5	Poly(dendrimer)s P1	$28 \pm 3\%$ <sup>[2]</sup>
6	Poly(dendrimer)s M2	$79 \pm 8\%$ <sup>[2]</sup>
7	Poly(dendrimer)s P2	$65 \pm 7\%$ <sup>[2]</sup>
8	Poly(dendrimer)s M3	$17 \pm 2\%$ <sup>[2]</sup>
9	Poly(dendrimer)s P3	$17 \pm 2\%$ <sup>[2]</sup>
10	Carbazole-based dendrimers G1	$29 \pm 2\%$ <sup>[5]</sup>
11	Carbazole-based dendrimers G2	$25 \pm 2\%$ <sup>[5]</sup>
12	Carbazole-based dendrimers G3	$13 \pm 1\%$ <sup>[5]</sup>
13	Dendrimer 3	$67 \pm 7\%$ <sup>[8]</sup>
14	Bifluorene-cored dendrimers (R1) (solution)	$0.81 \pm 0.01\%$ <sup>[6]</sup>
15	Bifluorene-cored dendrimers (R1) (film)	$0.83 \pm 0.06\%$ <sup>[6]</sup>
16	Bifluorene-cored dendrimers (R2) (solution)	$0.85 \pm 0.01\%$ <sup>[6]</sup>
17	Bifluorene-cored dendrimers (R2) (film)	$0.71 \pm 0.05\%$ <sup>[6]</sup>
18	carbazole based dendrimer (R1) (solution)	$19 \pm 1\%$ <sup>[6]</sup>
19	carbazole based dendrimer (R1) (film)	$27 \pm 6\%$ <sup>[6]</sup>
20	carbazole based dendrimer (R2) (solution)	$15 \pm 1\%$ <sup>[6]</sup>
21	carbazole based dendrimer (R2) (film)	$25 \pm 6\%$ <sup>[6]</sup>
22	spirobifluorene (SBF) dendrimer G1	$0.65 \pm 0.01\%$ <sup>[4]</sup>
23	spirobifluorene (SBF) dendrimer G2	$0.29 \pm 0.01\%$ <sup>[4]</sup>
24	spirobifluorene (SBF) dendrimer G3	$0.16 \pm 0.01\%$ <sup>[4]</sup>
25	fluorene (FL) dendrimer G1	$0.57 \pm 0.01\%$ <sup>[4]</sup>
26	fluorene (FL) dendrimer G2	$0.20 \pm 0.01\%$ <sup>[4]</sup>
27	fluorene (FL) dendrimer G3	$0.19 \pm 0.01\%$ <sup>[4]</sup>
28	tribiphenylamine	$0.55 \pm 0.03\%$ <sup>[1]</sup>
29	N triarylamine cored thiophene dendrimer G1	$0.60 \pm 0.03\%$ <sup>[1]</sup>
30	N triarylamine cored bithiophene dendrimer G1	$0.10 \pm 0.01\%$ <sup>[1]</sup>

The fluorescent spirobifluorene core carbazole dendrimers are analysed as chemo-sensor for nitroaromatic explosives detection with a series of nitrated analytes, including the 2,4,6-trinitrotoluene (TNT), 2,4-dinitrotoluene (DNT) and the plastic explosives taggant 2,3-dimethyl-2,3-dinitrobutane

(DMNB) using fluorescence quenching. The fluorescent spirobifluorene core carbazole dendrimers structures are represented in Fig. 9.<sup>[3]</sup>



**Fig. 9** Spirobifluorene core carbazole dendrimers.<sup>[64]</sup>

Poly dendrimers are luminescent organic semiconductor materials. The poly dendrimers can provide photophysical properties, high thermal stability, glass transition temperature, and sensing of the desired analytes. The poly dendrimers D1, D2, and D3 structures are represented in Fig. 10.<sup>[2]</sup>

Dendrimer films may detect fast nitrated vapor at 4 ppb concentration, including that of DNT. Fluorescence quenching responses were achieved within 10 s.<sup>[5]</sup> The dendrimers have an excellent capacity to absorb analyte. Different dendrimer generations were showing different sensitivities to the analyte. It can detect sub-saturation levels of DMNB, DNT, and pNT (full name). Carbazole-based dendrimers structures are represented in Fig. 11.<sup>[5]</sup>

Light-emitting dendrimers thin films not having fluorescence quenching property. The detection of explosive vapors and taggants was selectively carried out using a combination of quartz crystal microbalance, neutron reflectometry, and photophysical measurements.<sup>[8]</sup> It was not based on diffusion kinetics. The nitro-group contained explosive vapors can be detected using standoff detection. Dendrimer structures are represented in Fig. 12.<sup>[8]</sup>

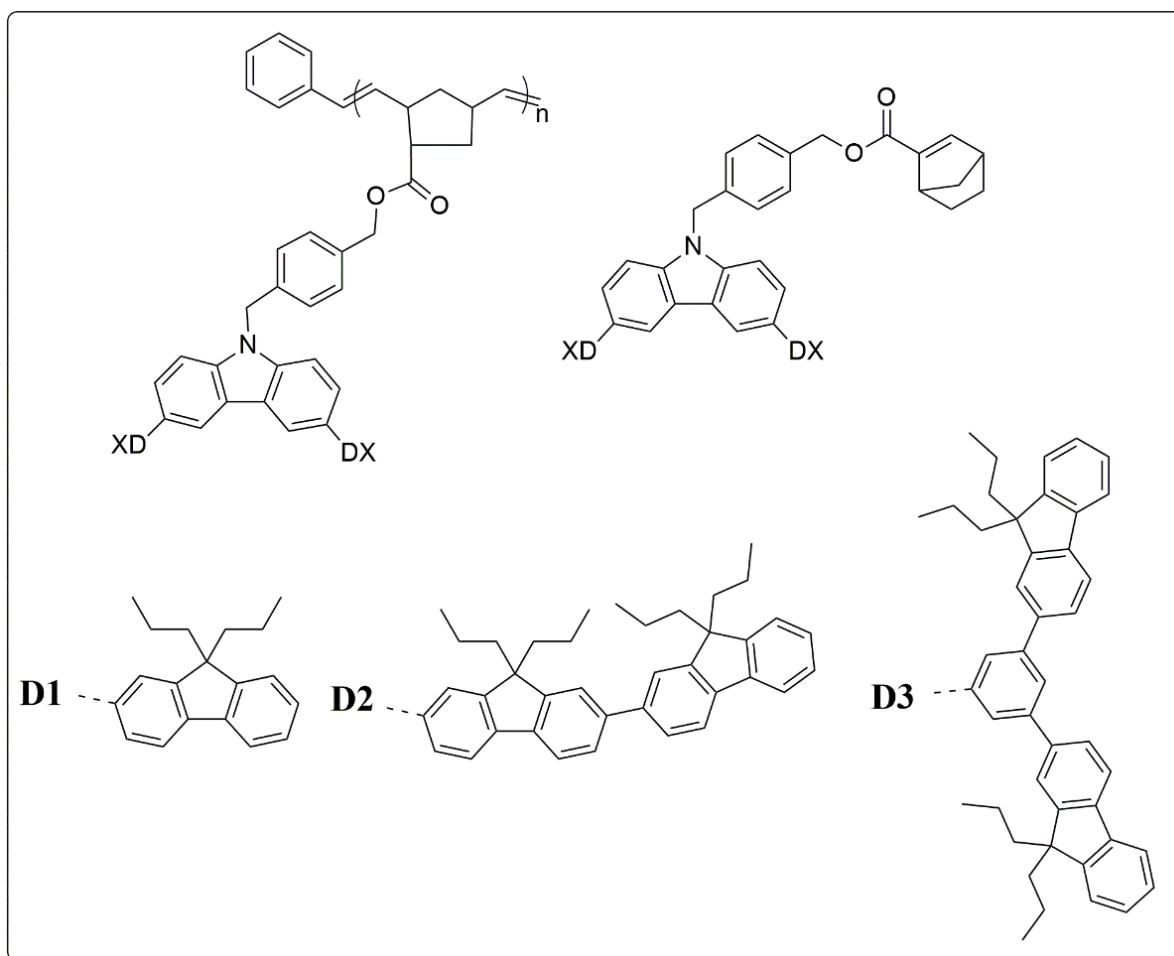


Fig. 10 Poly dendrimers D1, D2 and D3.<sup>[2]</sup>

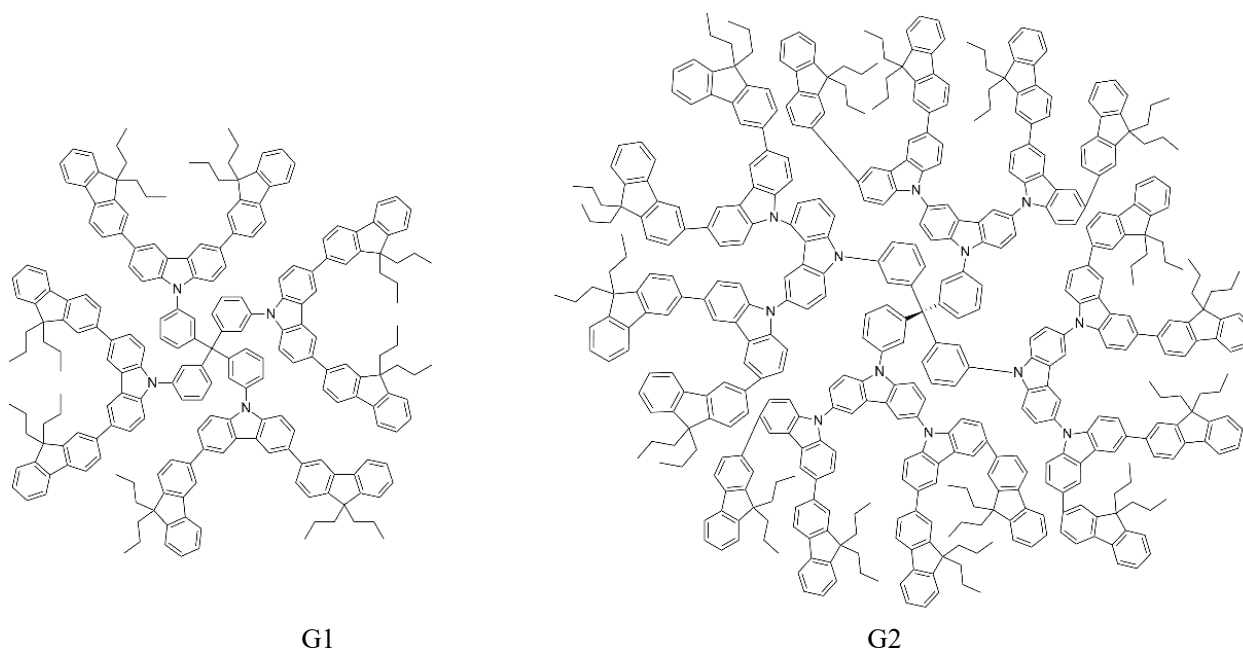


Fig. 11 Carbazole-based dendrimers.<sup>[5]</sup>

The carbazole- and bifluorene-cored dendrimers with first generation biphenyl-based dendrons are used for explosive sensing. Both bifluorene and carbazole dendrimers have shown increased sensitivity towards the nitro-aliphatic tagging agent DMNB. Dendrimers structures are represented in Fig. 13.<sup>[6]</sup>

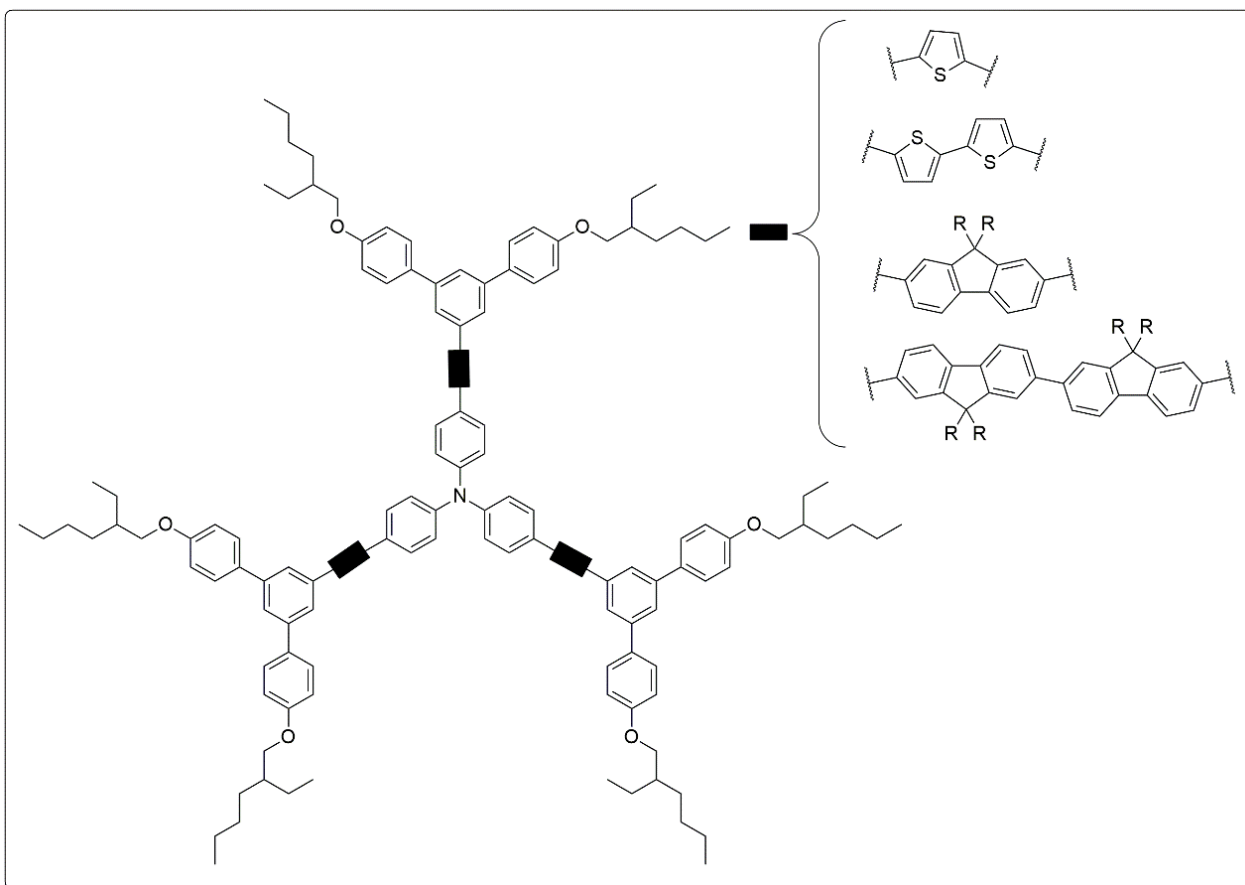


Fig. 12 Dendrimer.<sup>[8]</sup>

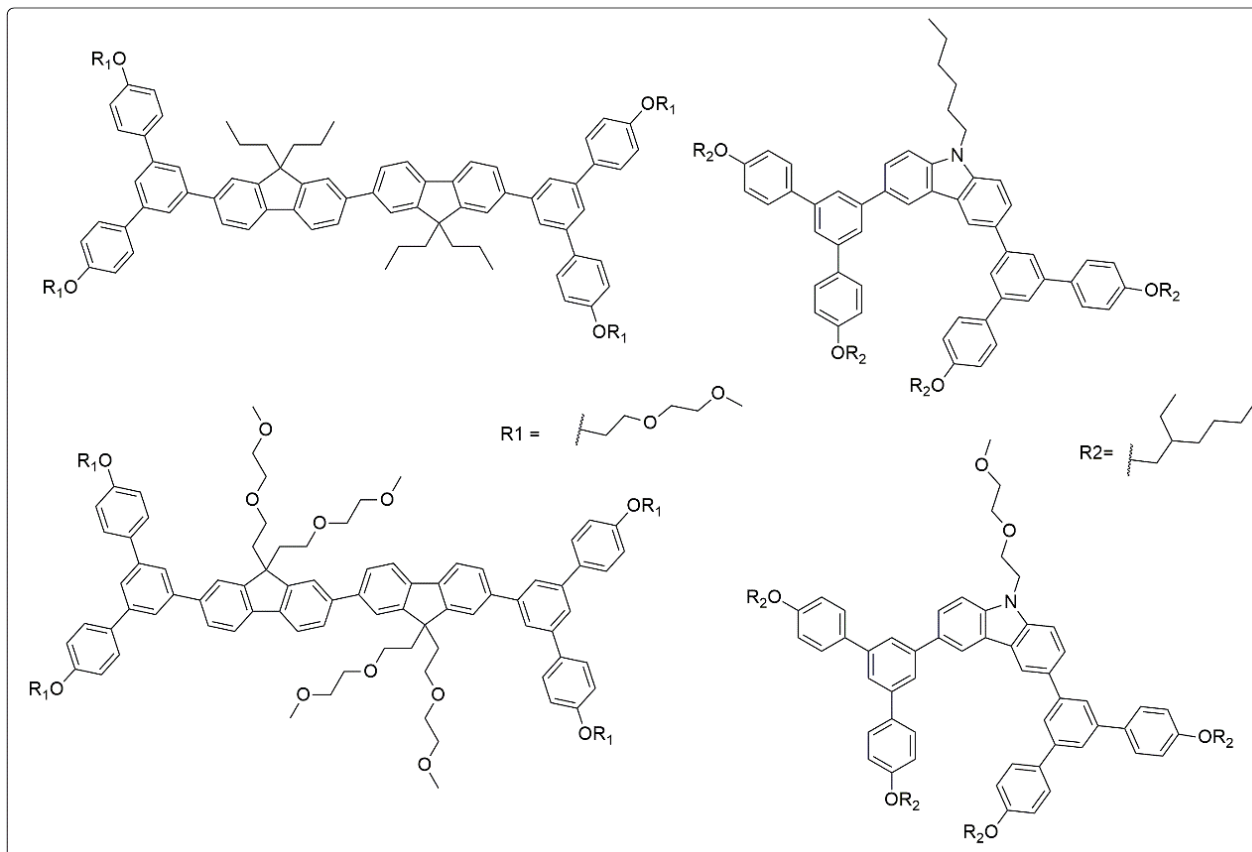


Fig. 13 Bifluorene-cored dendrimers(A), Carbazole cored dendrimer(B).<sup>[6]</sup>



increasing number of generations in synthesized dendrimers can improve the sensor qualities, such as selectivity, affectability, and water solvency. In forensic science, few dendrimer and dendrimer nanocomposites were shown acceptable qualities instead of traditional method. In addition, dendrimers can make simple and less tedious tests.

Fluorescent dendrimers are an emerging class of organic semiconductor polymer that can detect trace nitro-based explosives and taggants. The dendrimers can be a rapid and reliable detection method for nitro-based explosives. These methods are playing an important role in military operations and to provide domestic and international security, such as airport security and checkpoints. The optical properties of dendrimers are better than other types of nanomaterials with respect to forensic chemistry application.

Dendrimers are synthesized using either a divergent method or a convergent method. The organic synthesis can be planned according to a central core moiety, a chain of monomer and surface functional group.<sup>[2]</sup> The dendrimer was purified by size exclusion chromatography (SEC) method. The SEC method was commonly used to purify dendrimer depending on the size and polydispersity of polymers. Dendrimer's characterization has been elaborated with techniques such as FTIR, electrospray ionization mass spectrometry (ESI-MS), MALDI-TOF-MS, NMR, thermogravimetric analysis (TGA) and differential scanning calorimetry (DSC) analysis.<sup>[65]</sup>

#### 4.1 Future scope

Dendrimers have a wide scope in forensic science fields like forensic pathology and histochemistry, chemistry, biochemistry and toxicology, biology, serology, and odontology. Dendrimers are reported for many scientific investigations and analysis like heavy metals sensing<sup>[47,52,66,67]</sup> chemical sensing,<sup>[68]</sup> quenching<sup>[53,66-69]</sup> with nitromethane and C reactive protein in human serum.<sup>[70]</sup> Dendrimer nanocomposites with CdS,<sup>[9,71]</sup> CdSe,<sup>[7]</sup> and ZnX<sup>[63]</sup> are indicating an application in fingerprint detection. CdS/dendrimer can also additionally act as optical sensors, microelectronic devices, and luminescent biological probes to use fabrication.<sup>[9]</sup> Dendrimer-quantum dots nanocomposites are a pioneer of advanced cutting-edge optical sensing.

#### 4.2 Strength

A dendrimer is an easy and handy tool to provide various problem solutions in forensic science, food science, agriculture, and cosmetics, *etc.* Most of the studies of dendrimers are based on biomedical application. Dendrimer can contribute to various scientific field, which is helpful to society.

#### 4.3 Limitation

Nowadays biggest challenge in forensic science is implementing the newer technologies and standards into the laboratory. New technology has been shown to decrease time,

save money and facilitate resolving cases quicker than traditional forensic science practices. However, validation is expensive and time-consuming. This creates a struggle between processing cases in a timely manner and staying up-to-date with current technology.

### 5. Conclusions

This article's objective is to examine the dendrimer application in crime scene investigation and evidence analysis, which can enhance the quality of the forensic investigation. Dendrimer nanocomposites are less toxic, which diminishes the negative impact on the examiner and climate. Dendrimer-based fingerprint detection is an excellent fluorescent nanomaterial for latent fingerprinting. DMNB is difficult to detect using fluorescence quenching due to its low electron affinity and diffusion. Finally, based on the literature review, the light-emitting dendrimer is a breakthrough technology for detecting explosives with very sensitivity to DMNB, a taggant added to commercial plastic explosives. Henceforward alcohol, narcotics, and drugs sensing are significant difficulties. The synthesis of new dendritic molecules at nano-sized offers an extraordinary occasion to build up another application in the forensic field. Additionally, it can broaden its wide range of applications in multidisciplinary.

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### Conflict of Interest

The authors declare no conflict of interest.

### Supporting information

Not applicable.

### References

- [1] G. Vamvounis, P. E. Shaw, P. L. Burn, Design protocols in triarylamine cored dendrimer-based explosive sensors, *Journal of Materials Chemistry C*, 2013, **1**, 1322-1329, doi: 10.1039/c2tc00541g.
- [2] A. S. Loch, D. M. Stoltzfus, P. L. Burn, P. E. Shaw, High-sensitivity poly(dendrimer)-based sensors for the detection of explosives and taggant vapors, *Macromolecules*, 2020, **53**, 1652-1664, doi: 10.1021/acs.macromol.0c00060.
- [3] G. Tang, S. S. Y. Chen, P. E. Shaw, K. Hegedus, X. Wang, P. L. Burn, P. Meredith, Fluorescent carbazole dendrimers for the detection of explosives, *Polymer Chemistry*, 2011, **2**, 2360, doi: 10.1039/c1py00222h.
- [4] P. E. Shaw, S. S. Y. Chen, X. Wang, P. L. Burn, P. Meredith, High-generation dendrimers with excimer-like photoluminescence for the detection of explosives, *The Journal of Physical Chemistry C*, 2013, **117**, 5328-5337, doi: 10.1021/jp4002884.
- [5] S. Shoaee, S. S. Y. Chen, H. Cavaye, A. R. G. Smith, P. L.

- Burn, I. R. Gentle, P. Meredith, P. E. Shaw, Assessing the sensing limits of fluorescent dendrimer thin films for the detection of explosive vapors, *Sensors and Actuators B: Chemical*, 2017, **239**, 727-733, doi: 10.1016/j.snb.2016.08.046.
- [6] A. J. Clulow, H. Cavaye, G. Tang, P. E. Shaw, J. J. Cooper-White, P. L. Burn, P. Meredith, Quantitative real time sensing reveals enhanced sensitivity of polar dendrimer thin films for plastic explosive taggants, *Journal of Materials Chemistry C*, 2015, **3**, 9412-9424, doi: 10.1039/c5tc01967b.
- [7] Y. J. Jin, Y. J. Luo, G. Z. Xu, B. Yang, Effects of metallic ions on photoluminescence properties of CdSe/PAMAM nanocomposites and their application in fingerprint detection, *Advanced Materials Research*, 2011, **295-297**, 900-906, doi: 10.4028/www.scientific.net/amr.295-297.900.
- [8] Y. Geng, M. A. Ali, A. J. Clulow, S. Fan, P. L. Burn, I. R. Gentle, P. Meredith, P. E. Shaw, Unambiguous detection of nitrated explosive vapours by fluorescence quenching of dendrimer films, *Natural Communications*, 2015, **6**, 8240, doi: 10.1038/ncomms9240
- [9] Y.-J. Jin, Y.-J. Luo, G.-P. Li, J. Li, Y.-F. Wang, R.-Q. Yang, W.-T. Lu, Application of photoluminescent CdS/PAMAM nanocomposites in fingerprint detection, *Forensic Science International*, 2008, **179**, 34-38, doi: 10.1016/j.forsciint.2008.04.010.
- [10] E. B. Bahadır, M. K. Sezgintürk, Poly(amidoamine) (PAMAM): an emerging material for electrochemical bio(sensing) applications, *Talanta*, 2016, **148**, 427-438, doi: 10.1016/j.talanta.2015.11.022.
- [11] A. Bahadoran, H. Moeini, M. H. Bejo, M. Z. Hussein, A. R. Omar, Development of tat-conjugated dendrimer for transdermal DNA vaccine delivery, *Journal of Pharmacy & Pharmaceutical Sciences*, 2016, **19**, 325, doi: 10.18433/j3g31q.
- [12] M. Bernechea, E. de Jesús, C. López-Mardomingo, P. Terreros, Dendrimer-encapsulated Pd nanoparticles versus palladium acetate as catalytic precursors in the stille reaction in water, *Inorganic Chemistry*, 2009, **48**, 4491-4496, doi: 10.1021/ic9002753.
- [13] D. A. Tomalia, J. B. Christensen and U. Boas, applications, and the future, *Cambridge University Press*, 2012.
- [14] P. J. Gittins, L. J. Twyman, Dendrimers and supramolecular chemistry, *Supramolecular Chemistry*, 2003, **15**, 5-23, doi: 10.1080/1061027031000073199.
- [15] E. Soršak, J. V. Valh, Š. K. Urek, A. Lobnik, Application of PAMAM dendrimers in optical sensing, *The Analyst*, 2015, **140**, 976-989, doi: 10.1039/c4an00825a.
- [16] F. Vögtle, G. Richardt and N. Werner, *Dendrimer Chemistry: Concepts, Syntheses, Properties, Applications*, 2009, doi: 10.1002/9783527626953.
- [17] L. Balogh, D. R. Swanson, D. A. Tomalia, G. L. Hagnauer, A. T. McManus, Dendrimer-silver complexes and nanocomposites as antimicrobial agents, *Nano Letters*, 2001, **1**, 18-21, doi: 10.1021/nl005502p.
- [18] B. Devarakonda, R. A. Hill, M. M. de Villiers, The effect of PAMAM dendrimer generation size and surface functional group on the aqueous solubility of nifedipine, *International Journal of Pharmaceutics*, 2004, **284**, 133-140, doi: 10.1016/j.ijpharm.2004.07.006.
- [19] J. Li, H. Liang, J. Liu, Z. Wang, Poly (amidoamine) (PAMAM) dendrimer mediated delivery of drug and pDNA/siRNA for cancer therapy, *International Journal of Pharmaceutics*, 2018, **546**, 215-225, doi: 10.1016/j.ijpharm.2018.05.045.
- [20] S. Nummelin, M. Skrifvars, K. Rissanen, Polyester and ester functionalized dendrimers. *Dendrimers II. Berlin, Heidelberg: Springer Berlin Heidelberg*, 2000, 1-67, doi: 10.1007/3-540-46577-4\_1.
- [21] K. B. Riaz Ahmed, A. M. Nagy, R. P. Brown, Q. Zhang, S. G. Malghan, P. L. Goering, Silver nanoparticles: significance of physicochemical properties and assay interference on the interpretation of in vitro cytotoxicity studies, *Toxicology In Vitro*, 2017, **38**, 179-192, doi: 10.1016/j.tiv.2016.10.012.
- [22] R. Pajriyansyah, A. Firmansyah, *Keberlanjutan*, 2017, **2**, 431-459, doi: 10.1128/AAC.03728-14.
- [23] R. Touzani, H. Alper, PAMAM dendrimer-palladium complex catalyzed synthesis of five-, six- or seven membered ring lactones and lactams by cyclocarbonylation methodology, *Journal of Molecular Catalysis A: Chemical*, 2005, **227**, 197-207, doi: 10.1016/j.molcata.2004.10.024.
- [24] C. Yi, Z. Xu, W. T. Ford, Nano-sized dendrimer PAMAM/polystyrene composite polymer emulsion, *Colloid and Polymer Science*, 2004, **282**, 1054-1058, doi: 10.1007/s00396-003-1031-x.
- [25] M. J. Lefferts, M. R. Castell, Vapour sensing of explosive materials, *Analytical Methods*, 2015, **7**, 9005-9017, doi: 10.1039/c5ay02262b.
- [26] A. W. Arstenstein, S. M. Opal, Novel approaches to the treatment of systemic anthrax, *Clinical Infectious Diseases*. 2012, **54**, 1148-1161, doi: 10.1093/cid/cis017.
- [27] S. Zhang, Y. Zheng, D.-Y. Fu, W. Li, Y. Wu, B. Li, L. Wu, Biocompatible supramolecular dendrimers bearing a gadolinium-substituted polyanionic core for MRI contrast agents, *Journal of Materials Chemistry B*, 2017, **5**, 4035-4043, doi: 10.1039/c6tb03263j.
- [28] K. Pavuluri, M. T. McMahon, pH imaging using chemical exchange saturation transfer (CEST) MRI, *Israel Journal of Chemistry*, 2017, **57**, 862-879, doi: 10.1002/ijch.201700075.
- [29] L. Tei, G. Gugliotta, G. Gambino, M. Fekete, M. Botta, Developing high field MRI contrast agents by tuning the rotational dynamics: bisaquea GdAAZTA-based dendrimers, *Israel Journal of Chemistry*, 2017, **57**, 887-895, doi: 10.1002/ijch.201700041.
- [30] S. Langereis, A. Dirksen, T. M. Hackeng, M. H. P. van Genderen, E. W. Meijer, Dendrimers and magnetic resonance imaging, *New Journal of Chemistry*, 2007, **31**, 1152, doi: 10.1039/b616960k.
- [31] W. Zhu, B. Okollie, Z. M. Bhujwalla, D. Artemov, PAMAM dendrimer-based contrast agents for MR imaging of Her-2/neu receptors by a three-step pretargeting approach, *Magnetic Resonance in Medicine*, 2008, **59**, 679-685, doi: 10.1002/mrm.21508.

- [32] L. Ding, Z. Lyu, D. Dhumal, C.-L. Kao, M. Bernard, L. Peng, Dendrimer-based magnetic resonance imaging agents for brain cancer, *Science China Materials*, 2018, **61**, 1420-1443, doi: 10.1007/s40843-018-9323-6.
- [33] A. Zala & H. Patel, Two-dimensional quantitative structure activity relationship study on polyamidoamine dendrimers as a multivalent inhibitor of channel-forming bacterial toxins, *Asian Research Journal of Current Science*, 2022, **4**, 73-82.
- [34] P. Kesharwani, K. Jain, N. Jain, Dendrimer as nanocarrier for drug delivery, *Progress in Polymer Science*, 2014, **39**, 268-307, doi: 10.1016/j.progpolymsci.2013.07.005.
- [35] D. Luong, P. Kesharwani, R. Deshmukh, M. C. I. Mohd Amin, U. Gupta, K. Greish, A. K. Iyer, PEGylated PAMAM dendrimers: enhancing efficacy and mitigating toxicity for effective anticancer drug and gene delivery, *Acta Biomaterialia*, 2016, **43**, 14-29, doi: 10.1016/j.actbio.2016.07.015.
- [36] A. M. Grumezescu, Design and Development of New Nanocarriers, *William Andrew*, 2017.
- [37] P. Gurnev, E. Nestorovich, Channel-forming bacterial toxins in biosensing and macromolecule delivery, *Toxins*, 2014, **6**, 2483-2540, doi: 10.3390/toxins6082483.
- [38] J. A. Siegel, *Forensic Chemistry: Fundamentals and Applications*, 2015, doi: 10.1002/9781118897768.
- [39] N. Suleman, R. S. Kalhapure, C. Mocktar, S. Rambharose, M. Singh, T. Govender, Silver salts of carboxylic acid terminated generation 1 poly (propyl ether imine) (PETIM) dendron and dendrimers as antimicrobial agents against *S. aureus* and MRSA, *RSC Advances*, 2015, **5**, 34967-34978, doi: 10.1039/c5ra03179f.
- [40] A. Guichard, V. Nizet, E. Bier, New insights into the biological effects of anthrax toxins: linking cellular to organismal responses, *Microbes and Infection*, 2012, **14**, 97-118, doi: 10.1016/j.micinf.2011.08.016.
- [41] I. S. Cho, T. Ooya, A supramolecular hydrogel based on polyglycerol dendrimer-specific amino group recognition, *Chemistry Asian Journal*, 2018, **13**, 1688-1691, doi: 10.1002/asia.201800559.
- [42] J. M. Fréchet, *Proceedings of the National Academy of Sciences*, 2002, **99**, 4782-4787, doi: 10.1073/pnas.082013899.
- [43] J. A. Kretzmann, C. W. Evans, M. Norret, K. Swaminathan Iyer, Supramolecular assemblies of dendrimers and dendritic polymers in nanomedicine. *Comprehensive Supramolecular Chemistry II. Amsterdam: Elsevier*, 2017, 237-256, doi: 10.1016/b978-0-12-409547-2.12639-3.
- [44] F. Zeng, S. C. Zimmerman, Dendrimers in supramolecular chemistry: from molecular recognition to self-assembly, *Chemical Reviews*, 1997, **97**, 1681-1712, doi: 10.1021/cr9603892.
- [45] A. Sánchez, A. Villalonga, G. Martínez-García, C. Parrado, R. Villalonga, Dendrimers as soft nanomaterials for electrochemical immunosensors, *Nanomaterials*, 2019, **9**, 1745, doi: 10.3390/nano9121745.
- [46] C. Deraedt, G. Melaet, W. T. Ralston, R. Ye, G. A. Somorjai, Platinum and other transition metal nanoclusters (Pd, Rh) stabilized by PAMAM dendrimer as excellent heterogeneous catalysts: application to the methylcyclopentane (MCP) hydrogenative isomerization, *Nano Letters*, 2017, **17**, 1853-1862, doi: 10.1021/acs.nanolett.6b05156.
- [47] B. B. Campos, M. M. Oliva, R. Contreras-Cáceres, E. Rodríguez-Castellón, J. Jiménez-Jiménez, J. C. G. E. da Silva, M. Algarra, Carbon dots on based folic acid coated with PAMAM dendrimer as platform for Pt(IV) detection, *Journal of Colloid and Interface Science*, 2016, **465**, 165-173, doi: 10.1016/j.jcis.2015.11.059.
- [48] K. Jayakumar, R. Rajesh, V. Dharuman, R. Venkatesan, J. H. Hahn, S. Karutha Pandian, Gold nano particle decorated graphene core first generation PAMAM dendrimer for label free electrochemical DNA hybridization sensing, *Biosensors and Bioelectronics*, 2012, **31**, 406-412, doi: 10.1016/j.bios.2011.11.001.
- [49] G. Li, X. Li, J. Wan, S. Zhang, Dendrimers-based DNA biosensors for highly sensitive electrochemical detection of DNA hybridization using reporter probe DNA modified with Au nanoparticles, *Biosens. Bioelectron*, 2009, **24**, 3281-3287, doi: 10.1016/j.bios.2009.04.022.
- [50] M. Algarra, B. B. Campos, B. Alonso, C. M. Casado, J. C. G. Esteves da Silva, J. Benavente, Inclusion of thiol DAB dendrimer/CdSe quantum dots based in a membrane structure: surface and bulk membrane modification, *Electrochimica Acta*, 2013, **89**, 652-659, doi: 10.1016/j.electacta.2012.10.143.
- [51] T. Goodson, O. Varnavski, Y. Wang, Optical properties and applications of dendrimer-metal nanocomposites, *International Reviews in Physical Chemistry*, 2004, **23**, 109-150, doi: 10.1080/01442350310001628875.
- [52] M. Algarra, B. B. Campos, B. Alonso, M. S. Miranda, Á. M. Martínez, C. M. Casado, J. C. G. Esteves da Silva, Thiolated DAB dendrimers and CdSe quantum dots nanocomposites for Cd(II) or Pb(II) sensing, *Talanta*, 2012, **88**, 403-407, doi: 10.1016/j.talanta.2011.11.007.
- [53] B. B. Campos, M. Algarra, K. Radotić, D. Mutavdžić, E. Rodríguez-Castellón, J. Jiménez-Jiménez, B. Alonso, C. M. Casado, J. C. G. Esteves da Silva, ZnS: Mn nanoparticles functionalized by PAMAM-OH dendrimer based fluorescence ratiometric probe for cadmium, *Talanta*, 2015, **134**, 317-324, doi: 10.1016/j.talanta.2014.10.010.
- [54] B. Maleki, M. Baghayeri, M. Ghanei-Motlagh, F. Mohammadi Zonoz, A. Amiri, F. Hajizadeh, A. Hosseinifar, E. Esmailnezhad, Polyamidoamine dendrimer functionalized iron oxide nanoparticles for simultaneous electrochemical detection of Pb<sup>2+</sup> and Cd<sup>2+</sup> ions in environmental waters, *Measurement*, 2019, **140**, 81-88, doi: 10.1016/j.measurement.2019.03.052.
- [55] M. A. Barakat, M. H. Ramadan, M. A. Alghamdi, S. S. Algarny, H. L. Woodcock, J. N. Kuhn, Remediation of Cu(II), Ni(II), and Cr(III) ions from simulated wastewater by dendrimer/titania composites, *Journal of Environmental Management*, 2013, **117**, 50-57, doi: 10.1016/j.jenvman.2012.12.025.
- [56] B. Liu, M. Li, Y. Zhao, M. Pan, Y. Gu, W. Sheng, G. Fang, S. Wang, A sensitive electrochemical immunosensor based on PAMAM dendrimer-encapsulated Au for detection of norfloxacin in animal-derived foods, *Sensors*, 2018, **18**, 1946, doi: 10.3390/s18061946.

- [57] J. Savage, Sound2Picture: developing compositional pedagogies from the sound designer's world, *Music Education Research*, 2005, **7**, 331-348, doi: 10.1080/14613800500324481.
- [58] J.-Y. Wu, Y. Li, Y. Mao, J. Xu, X. Zhou, Amine-terminated TEG-derived PAMAM dendrimer as template for preparation of gold nanoparticles in water, *Frontiers of Materials Science in China*, 2010, **4**, 95-99, doi: 10.1007/s11706-010-0006-3.
- [59] D. G. Mullen, A. Desai, M. A. van Dongen, M. Barash, J. R. Baker Jr, M. M. Banaszak Holl, Best practices for purification and characterization of PAMAM dendrimer, *Macromolecules*, 2012, **45**, 5316-5320, doi: 10.1021/ma300485p.
- [60] P. Rajakumar, A. Thirunarayanan, S. Raja, S. Ganesan, P. Maruthamuthu, Photophysical properties and dye-sensitized solar cell studies on thiaziazole-triazole-chalcone dendrimers, *Tetrahedron Letters*, 2012, **53**, 1139-1143, doi: 10.1016/j.tetlet.2011.12.098.
- [61] J. Lu, P. F. Xia, P. K. Lo, Y. Tao, M. S. Wong, Synthesis and properties of multi-triarylamine-substituted carbazole-based dendrimers with an oligothiophene core for potential applications in organic solar cells and light-emitting diodes, *Chemistry of Materials*, 2006, **18**, 6194-6203, doi: 10.1021/cm062111o.
- [62] N. Satoh, T. Nakashima, K. Yamamoto, Metal-assembling dendrimers with a triarylamine core and their application to a dye-sensitized solar cell, *Journal of the American Chemical Society*, 2005, **127**, 13030-13038, doi: 10.1021/ja050765c.
- [63] R. Ramotowski, Lee and Gaensslen's advances in fingerprint technology, *CRC press*, 2012.
- [64] P. E. Shaw, P. L. Burn, Real-time fluorescence quenching-based detection of nitro-containing explosive vapours: what are the key processes? *Physical Chemistry Chemical Physics*, 2017, **19**, 29714-29730, doi: 10.1039/c7cp04602b.
- [65] O. Dragostin, L. Profire, Molecular weight of polymers used in biomedical applications. *Characterization of Polymeric Biomaterials. Amsterdam: Elsevier*, 2017: 101-121, doi: 10.1016/b978-0-08-100737-2.00005-4.
- [66] B. B. Campos, M. Algarra, B. Alonso, C. M. Casado, J. Jiménez-Jiménez, E. Rodríguez-Castellón, J. C. G. Esteves da Silva, Fluorescent sensor for Cr(VI) based in functionalized silicon quantum dots with dendrimers, *Talanta*, 2015, **144**, 862-867, doi: 10.1016/j.talanta.2015.07.038.
- [67] B. B. Campos, M. Algarra, B. Alonso, C. M. Casado, J. C. Esteves da Silva, Mercury(II) sensing based on the quenching of fluorescence of CdS-dendrimer nanocomposites, *Analyst*, 2009, **134**, 2447-2452, doi: 10.1039/b914302e.
- [68] M. Algarra, B. B. Campos, M. S. Miranda, J. C. G. E. da Silva, CdSe quantum dots capped PAMAM dendrimer nanocomposites for sensing nitroaromatic compounds, *Talanta*, 2011, **83**, 1335-1340, doi: 10.1016/j.talanta.2010.10.056.
- [69] B. B. Campos, M. Algarra, J. C. G. Esteves da Silva, Fluorescent properties of a hybrid cadmium sulfide-dendrimer nanocomposite and its quenching with nitromethane, *Journal of Fluorescence*, 2010, **20**, 143-151, doi: 10.1007/s10895-009-0532-5.
- [70] M. Algarra, B. B. Campos, D. Gomes, B. Alonso, C. M. Casado, M. M. Arrebola, M. J. Diez de los Rios, M. E. Herrera-Gutiérrez, G. Sella-Pérez, J. C. G. Esteves da Silva, Thiolated DAB dendrimer/ZnSe nanoparticles for C-reactive protein recognition in human serum, *Talanta*, 2012, **99**, 574-579, doi: 10.1016/j.talanta.2012.06.037.
- [71] E. R. Menzel, S. M. Savoy, S. J. Ulvick, K. H. Cheng, R. H. Murdock, M. R. Sudduth, Photoluminescent semiconductor nanocrystals for fingerprint detection, *J. Journal of Forensic Science*, 2000, **45**, 545-551.

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