

Research Article

Preparation and Characterization of Aloe Vera Extract Capped CdS Nanoparticles and Their Photocatalytic, Luminescence and Optical Studies

Bandaru Srinivasa Goud^{1,*} , Gudikandula Odelu² , Keerthi Rajesh³ 

¹Department of Physics, Vivekananda Government Degree College (Autonomous), Hyderabad, India

²Department of Botany, Government Degree College, Huzurabad, India

³Department of Physics, Sri Raja Rajeshwara Government Arts & Science College (Autonomous), Karimnagar, India

Abstract

Green synthesis method is used to prepare the Cadmium Sulphide Nanoparticles (CdS NPs) using various cadmium salts. CdS NPs are prepared by using the Cadmium Chloride, Cadmium Nitrate along with Cadmium Sulphate additionally Sodium Sulphide as precursors and Aloe vera leaf gel extract is used as stabilizing agent. The materials are characterized by X-ray Diffraction (XRD) technique to know its structure. The XRD trends display broad peaks at 2θ values of around 26.38° , 29.84° , 44.42° , 51.96° and 71.14° which could be indexed to scattering from (111), (200), (220), (311) and (331) planes of cubic phase respectively of Cadmium Sulphide. The Band gap of the sample is found from UV-Visible absorbance spectroscopy and its value determined as 5.04 eV, 5.18 and 5.09 eV for the precursors cadmium chloride, cadmium nitrate and cadmium sulphate respectively apart from this cadmium sulphate precursor shows 3.58 eV that means there are two size distribution of NPs formed for cadmium sulphate precursor. Fourier Transform Infrared (FTIR) spectroscopy, Scanning Electron Microscopy (SEM) as well as Energy Dispersive Spectroscopy (EDS) techniques are employed to know the functional groups, morphology and elemental analysis of the as synthesized material. The average particle size of CdS NPs determined from TEM is around 3 nm for all the precursors and it is further confirmed by Small Angle X-ray Scattering (SAXS).

Keywords

CdS NPs, Aloe Vera, Environmentally Friendly Materials, Cadmium Nitrate, Cadmium Chloride, Cadmium Sulphate, Sodium Sulphide

1. Introduction

Molecular or Atomic aggregates among which one dimension within 1 - 100 nm range are referred to as NPs. Research has demonstrated the significance of NPs for enhancing human health, electrical, magnetic, as well as optoelectronic, biological,

pharmacological, cosmetic, energy, environmental, catalytic, as well as material uses [1]. The material's characteristics of NPs differ dramatically from those at larger scales, at the nano scale, quantum phenomena have an impact on the characteristics and

*Correspondence: Bandaru Srinivasa Goud (srinivasegoudbhu@gmail.com)

Received: 24 December 2025; Accepted: 12 January 2026; Published: 2 February 2026



Copyright: © The Author(s), 2026. Published by Science Publishing Group. This is an **Open Access** article, distributed under the terms of the Creative Commons Attribution 4.0 License (<http://creativecommons.org/licenses/by/4.0/>), which permits unrestricted use, distribution and reproduction in any medium, provided the original work is properly cited.

behaviour of particles. NP interacts with other naturally occurring molecules differently than a molecule composed of the same chemical components at the microscale because it has such a huge surface area per unit mass [2].

The semiconducting material Cadmium Sulfide (CdS) is a belonging to the II – VI group with a direct band gap of 2.42 eV in the bulk state at ambient temperature. It has three distinct crystal structures: cubic zinc blend, hexagonal wurtzite, as well as high pressure rock salt phases. The quantum confinement effect is the cause for nanosize materials to exhibit distinct variations in their optical, electrical attributes, melting point, transition temperature, further crystallinity compared to their bulk counterparts. These variations are primarily influenced by the scale of the crystallites. Because of its excellent absorption coefficient, CdS NPs have promising advantages such as photovoltaic devices, light emitting diodes (LEDs) [3], photo detectors [4], electric driven lasers [5], photocatalysts [6], optoelectronics, heterojunction solar cells [7]. CdS NPs could be altered with B, In, Ga, and Al to achieve n-type conductivity, and CdS material can indeed be modified with Cu, Au, along with Ag to get p-type conductivity [8].

Synthesis approaches of nanomaterials were classified into two categories, one is traditional synthesis and the other is Green Synthesis methods. Traditional synthesis methods comprehend chemical precipitation, chemical reduction, chemical displacement reaction and template based chemical route. The different methods followed by the researchers to synthesize CdS NPs are chemical precipitation approach [9], Solvo thermal procedure [10], Laser ablation process [11], Hydrothermal process [12], Photo chemical method [13], Microwave heating procedure [14], Photo etching [15], and Ultrasonic irradiation method [16]. CdS NPs with improved optical properties are being produced using a chemical precipitation technique, and their photoluminescence (PL) behavior was investigated. The results show that the PL peaks became more intense when the capping reagent concentration is raised and also explained why PL intensity dips as annealing temperature rises [17]. Chemical displacement technique is used to produce CdS NPs, and they discovered that the NPs have a relative dielectric constant that is noticeably greater than that of the bulk CdS powder [18], Green Synthesis of Cadmium Oxide NPs using *syzygiumcumini* [19], Green synthesis of copper oxide NPs using *Ficusracemosa* leaf extract and investigation of its antibacterial properties [20], Facile Green Synthesis of CdS Nanoparticles in a Glycine Medium for Waste Valorization of Ni-Cd Battery [21], Synthesis of Silver and Copper oxide nanoparticles using *Ficusracemosa* leaf extract [22]. Much priority given to CdS NPs due to some encouraging factors like, the availability of discrete energy levels, variable bandgap, dimensional dependent optical properties, good chemical stability, convenient including cost effective preparation techniques.

The literature could not find the preparation of CdS NPs employing Aolevera as a stabilizing or reducing agent. The comparison of three different cadmium precursors such as

cadmium chloride, cadmium nitrate and cadmium sulphate with Aloe vera leaf gel is important, because of the interaction of cadmium precursor with Aloe vera effects differently and lead to changes in optical property such as tunable band gap, physico-chemical properties, size formation, morphology and fluorescence. The motivation for applying green synthesized CdS NPs as photocatalysts in Photocatalytic and PL studies is that these CdS NPs exhibit the structural and optical properties and hence influencing the efficiency of photo catalysts in degrading organic pollutants or dyes.

The photocatalytic activity as well as photo luminescence studies carried out for natural stabilizer Aloe vera leaf gel extract has been applied as catalyst due to the deterioration of two dyes which are Methylene Blue (MB) as well as Rhodamine B (Rh B) to the exposure of visible light and studied their catalytic activity for three hours in which first one hour is in dark observation and continued two hours manifestation under visible light. The luminescence studies of as-prepared CdS NPs stabilized by Aloe vera leaf gel extract are explained in the present work. All the Figures in this chapter designated as (a) indicates the CdS NPs prepared using cadmium chloride, (b) signifies CdS NPs produced from cadmium nitrate and (c) demonstrates the CdS NPs composed out of cadmium sulphate precursors.

CdS NPs prepared using laser liquid ablation (LLA) in a natural Aloe vera medium and found particles size of about 40 nm in the literature [23]. The novelty of using Aloe vera in preparing CdS NPs in the present work is that various cadmium precursors such as cadmium chloride, cadmium nitrate and cadmium sulphate are used as a source of cadmium and obtained NPs size of 3 nm with enhanced optical band gap at room temperature ambience with cost effective method and testing CdS NPs against Methylene Blue (MB) and Rhodamine B (RhB) dyes. Aloe vera assisted CdS NPs could reduce the toxicity of CdS due to the phytochemicals present in Aloe vera, tunable band gap CdS NPs have applications in treating the waste water, luminescence, hetero junction solar cells.

2. Experimental

The sodium sulphide ($\text{Na}_2\text{S}\cdot\text{H}_2\text{O}$) solution of 0.1M was prepared by adding 0.7804 g in aqua solution of 100 ml Millipore water, then the freshly prepared Aloe vera leaf gel extract (30 weight percent of Cd source i.e., 36 ml for $\text{Cd}(\text{NO}_3)_2$, 62 ml for CdSO_4 , and 30 weight percent of Cd source for CdCl_2 i.e., 55 ml) is added to the above solution slowly drop by drop while stirring. The cadmium precursor solution (0.05M of CdCl_2 , 0.05M of $\text{Cd}(\text{NO}_3)_2$, and 0.1M CdSO_4 separately added in 100 ml Millipore water) added to the above mixture, 1M of NaOH was added to the solution obtained above and adjusted the pH appraisal to 11. The above said solution underwent stirring at 900 rpm for 4 hrs continuously. Finally an orange or yellow color solution has formed.

In synthesis process without adding any NaOH solution to the mixed solution of cadmium precursor and aloe vera extract, without adjustment pH value reached 11 for cadmium chloride

precursor, 6 for cadmium sulphate precursor and got good XRD graphs at these values, and after several repetitions optimized pH value as 11 for cadmium nitrate precursor.

The final precipitate was washed several times and dried it to get in powder form. The final product is in yellow color and this material was characterized by utilizing the X-ray Diffraction and discovered to have CdS NPs. UV Visible absorption spectroscopy, Fourier Transform Infrared spectroscopy and Scanning Electron Microscopy and Small Angle X-ray Scattering techniques utilised to determine the band gap along with functional groupings, morphology as well as particle size of as prepared powder.

The XRD spectrums abide inscribed employing the inel equinox 3000 X-ray diffractometer at 40 kV and 25 mA with $\text{CuK}\alpha$ radiation wavelength of 1.540560 Å obsessed among position sensitive detector. The material's optical characteristic was recognized by utilizing the UV-Visible spectris 2092 spectrophotometer. The SHIMADZU FTIR-8400S spectrometer was used to record the FTIR spectrum in the 400–4500 cm^{-1} range. Using a scanning electron microscope (ZEISS Special Edition 18), the morphology of the CdS NPs was determined. A dual energy Mo-Cr-SAXS laboratory system (Model Xeuss from M/s Xenocs, France) was used to perform the SAXS measurements [24]. To extract the size, IRENA macros were utilised to model fit the data and volume distribution of the CdS NPs [25]. The nanoparticles' shape and average particle size were verified by the use of a Transmission Electron Microscope (TEM) type Philips CM 20 that operated at 200kV. JobinYvon Fluorolog-3-11 spectrofluorimeter was employed to get the photoluminescence properties of CdS NPs. The excitation was obtained from a 450W Xenon lamp source (Oriel, model 9119), the photons were counted by a detector PMT as well as the data were analyzed by DATA MAX/GRAMS/31 software.

Under 300 W of tungsten light, two dyes, Methylene Blue (MB) and Rhodamine B (RhB), with starting engrossment of $0.5 \times 10^{-5} \text{ mol/L}$, were decomposed to see how good the CdS NPs worked as photocatalysts. The catalyst concentration used for the dye degradation is 50 mg/100 ml of the dye solution of MB and RhB. Before irradiation, the mixture was stirred for one hr in the dark to reach equilibrium between adsorption and/or desorption. After that, the lamp was turned on, and for every 30 min, a sample of about 3 mL was taken to measure the photocatalytic degradation. Before measurements, the photocatalyst was taken out of the solution by spinning the sample in a centrifuge. All of the photocatalytic tests were done twice to make sure that the results are correct.

3. Results and Discussion

3.1. Characterization of Powder

Figure 1 (a-c) presents XRD spectra of Aloe vera gel extract encapsulated CdS NPs. The XRD peaks located at 2θ posi-

tions of 26.38° , 29.84° , 44.42° , 51.96° and 71.14° are commenced to reflect (111), (200), (220), (311) and (331) planes, accordingly. These peaks matched well with the cubic cadmium sulphide (JCPDS Card No.89-0440). Apart from these planes, there are additional intensity peaks present in Figure 1 (a) at 2θ values of around 45.44° and 75.23° which could be indexed to scattering from (107) including (211) planes of cadmium chloride (JCPDS Card No.89-1568) and this may be owing to presence of small residues of cadmium chloride because of its incomplete dissolve.

The peak at 2θ value of 56.43° endows to reflect from (222) plane of sodium chloride (JCPDS Card No.89-3615) is due to reaction of cadmium chloride along with sodium sulfide which employed during reaction. The average size of the crystallites found as 8 nm for Figure 1(a), 3 nm for 1 (b) and 3 nm for 1 (c). The lattice parameter reckoned from XRD information is 5.7917 Å which is very nearer to that of the reported value 5.8304 Å with a disparity of 0.0387 Å. The broadness of the peaks in the XRD spectra is the witness for the nano size particles among three graphs in XRD spectra.

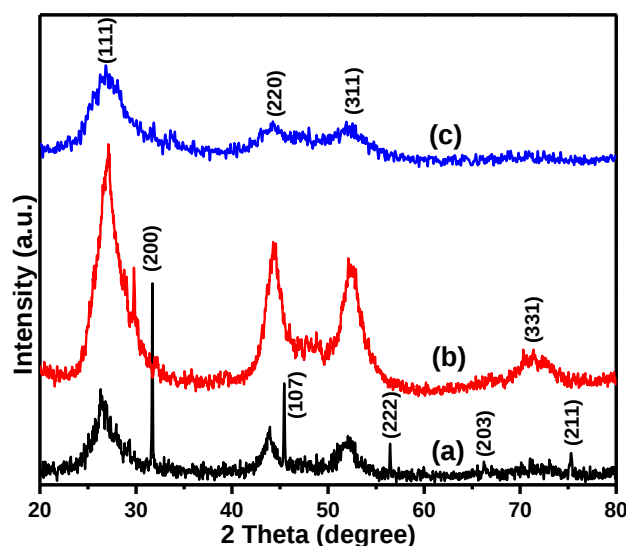


Figure 1. XRD spectrums of Aloe vera extract assisted CdS NPs produced by using: (a) cadmium chloride, (b) cadmium nitrate including (c) cadmium sulphate precursors.

The broadness is larger for the CdS NPs prepared from the cadmium nitrate precursor comparing to other two cadmium sulphate and cadmium chloride salts. The CdS NPs prepared from cadmium chloride precursor exhibiting extra peaks other than the CdS phase is may be due to that the less effect of Aloe vera leaf gel stabilizer on formation of CdS NPs. Figure 1 (a) confirming that there exists two sorts of powders existing one is in nano range along with the secondary peaks consent coarse-grained powder and latency of this is very small in CdS NPs prepared from cadmium nitrate precursor shown in Figure 1 (b).

3.2. Studies of Surface Morphology Along with Elemental Analysis

SEM micrographs of Aloe vera gel stabilized CdS NPs prepared from various cadmium salts are shown in Figure 2 (a-c). Since CdS NPs are seen to be somewhat aggregated in SEM images, it can be the result of a higher pH value during synthesis. Morphology of as prepared CdS NPs is both spherical, facet shaped particles which can be witnessed in Figure 2 (a) and the CdS NPs made up of extremely minute particles and having spherical shape unveil in Figure 2 (b).

Along with spherical morphology some irregular shaped NPs present as flocks depicting dense aggregation of crystallites in remaining cases shown in Figure 2 (c). All samples from Figure 2 (d-f) of EDS spectra reflect the existence of Cd and S elements clearly which confirms that nano particles are made up of Cd and S. The proportions of carbon, calcium, oxygen, sodium, and chlorine in the EDS spectra of CdS NPs validate the presence of phyto-chemicals of Aloe vera leaf gel stabilizer [26, 27]. Analyzing EDS Spectra is also helpful in comprehending the Stoichiometric ratio of the cadmium to sulfur ratio. The CdS NPs derived from cadmium chloride as well as cadmium nitrate have cadmium to sulfur ratio of about 1:1, while the CdS NPs generated from cadmium sulfate have cadmium to sulfur ratio of nearly 1:2.

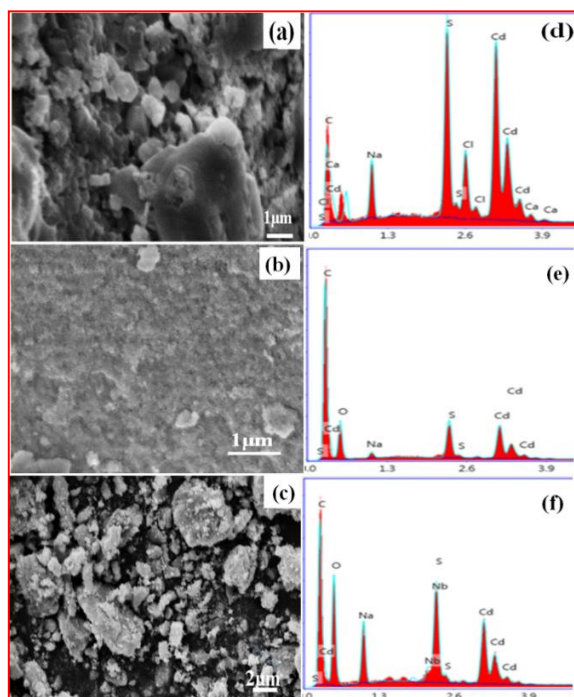


Figure 2. SEM images (a-c) and EDS spectrums (d-f) of Aloe vera leaf gel capped CdS NPs extracted from: (a, d) cadmium chloride, (b, e) cadmium nitrate along with (c, f) cadmium sulphate precursors.

With the help of TEM, the size besides morphology of the NPs is examined. In TEM images of Aloe vera leaves gel stabilized CdS NPs processed from discrepant cadmium precursors, including cadmium chloride, cadmium nitrate, in addition to cadmium

sulphate shown in Figure 3 (a-c), numerous spherical NPs are visible. Using Image J software, more than 250 and up to 5000 particles are measured, with the majority of the observed particles with a maximum dimension of under 10 nm. Employing cadmium chloride, cadmium nitrate, further more cadmium sulphate as starting materials, Aloe vera gel stabilized CdS NPs are found to have average particle sizes of 2.61, 2.51, along with 2.62 nm, respectively. The high sample concentration that is put onto the grid and the length of the probe sonication that is used to dissolve the powdered sample into solution are both potential causes of aggregate formation [28].

The SAED images of Aloe vera leaf gel stabilized CdS NPs are analyzed and clearly demonstrate the CdS cubic structure. The presence of smaller particles is confirmed by the intense rings in an electron diffraction image depicted in Figure 3 (b) in place of the normal dots. The d spacings from the JCPDF data of the CdS cubic crystalline phase are compatible with the d spacings evaluated for all significant rings in these samples and the results are in greater conformity with the obtained from XRD and SAXS analyses.

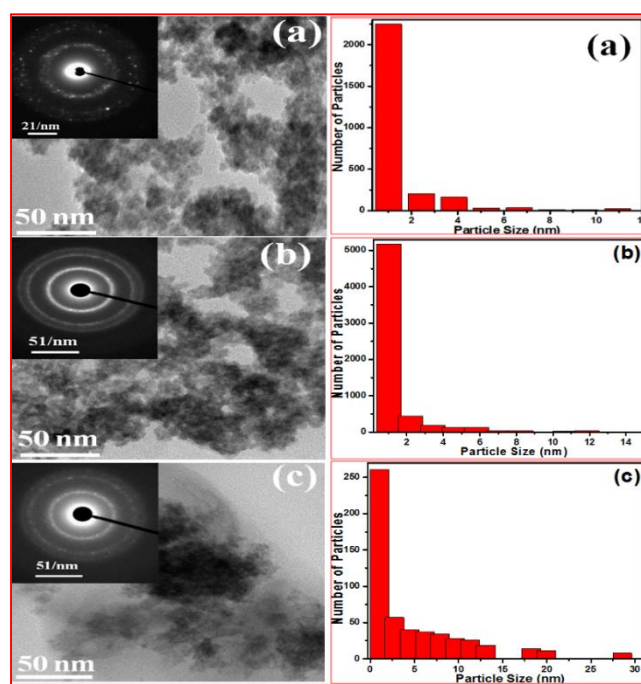


Figure 3. TEM micrographs, size distribution of Aloe vera leaves gel stabilized CdS NPs prepared from: (a) cadmium chloride, (b) cadmium nitrate including (c) cadmium sulphate.

The more broadness of peaks in XRD spectra, spherical morphology of small nano size particles also confirmed from TEM for the Aloe vera gel stabilized CdS NPs prepared from cadmium nitrate precursor.

3.3. Micro Structural Analysis

The quantitative micro-structural analysis is done by SAXS

characterization. Figure 4 shows the SAXS intensity profiles and volume distribution curves of as-synthesized Aloe vera leaf gel extract stabilized by Cadmium precursors which consist of cadmium chloride, cadmium nitrate along with cadmium sulphate, are the sources of CdS NPs. Substantial scattering through chemical heterogeneity, specifically CdS NPs at the midrange q -regions (Guinier Region) between 0.3 to 1 nm^{-1} is seen in SAXS profiles. CdS NPs stabilized with Aloe vera leaf gel extract exhibits bimodal size distribution. The bimodal size distribution indicates the presence of two different

sizes based on the band gap values of NPs present in the prepared powder which reflects two maxima in the volume distribution curves of Figure 4.

The dispersed NPs with an average size of nearly equal volume of fractions 3.8 nm small in number and large number of particles having distribution with in 2 nm range are depicted in the CdS NPs derived from cadmium chloride, while the dispersion of cadmium nitrate is shown with an average size of massive volume fractions of 5.8 nm, along with a minimal volume fraction of closely 12 nm.

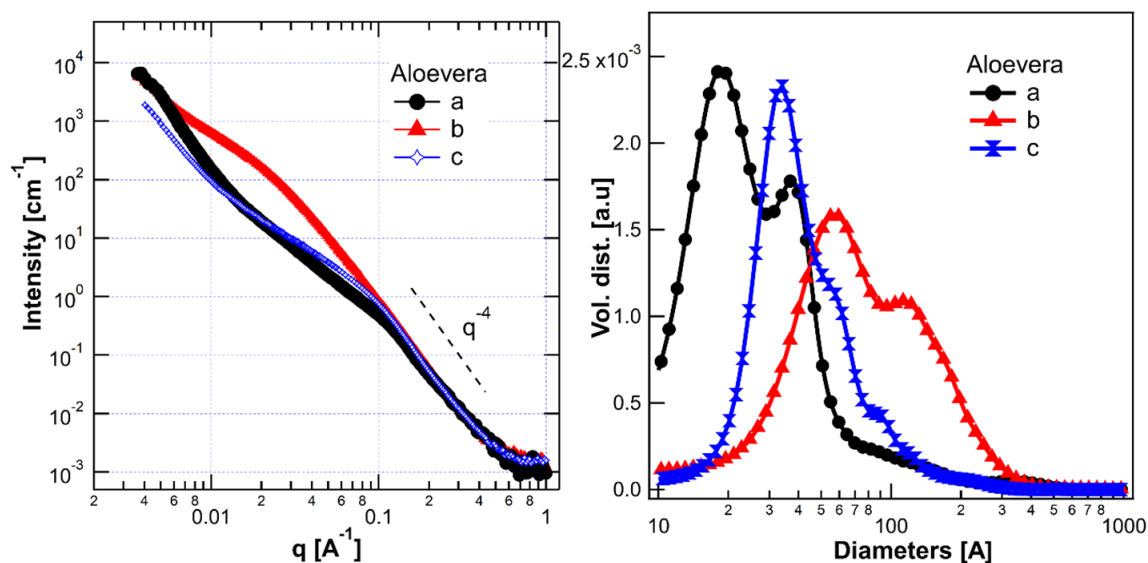


Figure 4. SAXS patterns and volume distribution curves of Aloe vera gel extract stabilized CdS NPs obtained by: (a) cadmium chloride, (b) cadmium nitrate including (c) cadmium sulphate precursors.

The CdS NPs produced out of cadmium sulphate provides the distribution's with average size of small volume fraction of 3.4 nm, large volume fraction of 9.4 nm, along with medium volume fraction of 6 nm. The primary allocation is the predominant one and having this size distribution by large number of particles that is approximately 2, 5 and 3 nm for the CdS NPs produced from cadmium chloride, cadmium nitrate including cadmium sulphate.

3.4. Studies of Functional Groups

The FTIR graphs of as synthesized CdS NPs stabilized by Aloe vera leaf gel extract is shown in Figure 5 (a-c) which are composed with various cadmium sources like cadmium chloride, cadmium nitrate including cadmium sulphate and Figure 5 (d) demonstrates FTIR curve of Aloe vera leaf gel stabilizer.

The broad peak found in the high energy region of FTIR peak at 3451 cm^{-1} gives O-H stretch vibrations of water molecules. The small intense broad peak in the range 2088 cm^{-1} is ascribed to anti-symmetric as well as symmetric vibrations of the $-\text{CH}_2$ groups of the hydrocarbons or bending vibrations of water molecule.

The strong intense narrow sharp peak at 1631 cm^{-1} is assigned to C=C stretching. The vibration of the methanol is noticed at 1383 cm^{-1} because it is employed in the procedure, this peak is very small and can be attributed to CH_3 bending deformation [29, 30] or S=O group [31] and the small sharp peak near to 1110 cm^{-1} is ascribed to C-H bending vibrations. The IR peaks observed in the spectrum ranging at around 570 cm^{-1} is because of Cd-S stretching [32]. Table 1 displays a number of absorption peaks that can be connected to several functional groupings.

Table 1. The appropriate functional categories of CdS NPs capped by an Aloe vera leaves gel stabilizer and their wave numbers.

Sl.No.	Wave Number (cm^{-1})	Bonding of Chemical Compounds
1	3451	-OH stretching of water molecule

Sl.No.	Wave Number (cm^{-1})	Bonding of Chemical Compounds
2	2088	Anti symmetric as well as symmetric vibrations of the $-\text{CH}_2$ groups of hydro carbons
3	1631	Assigned to $\text{C}=\text{C}$ stretching
4	1383	CH_3 bending deformation or sulfate $\text{S}=\text{O}$ group
5	1110	Attributed to $\text{C}-\text{H}$ bending vibrations
6	570	$\text{Cd}-\text{S}$ stretching

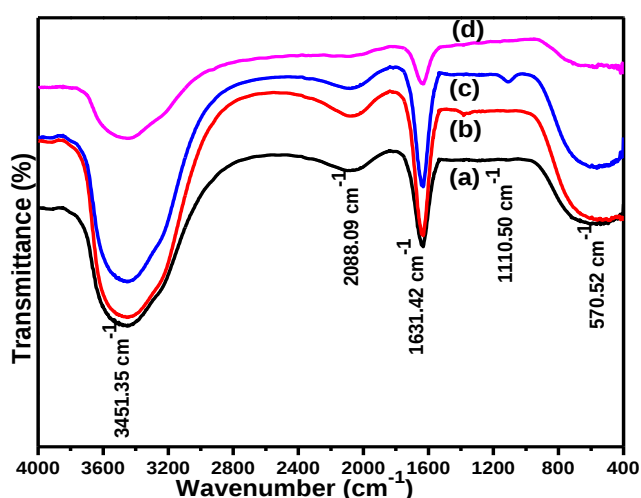


Figure 5. FTIR spectra of Aloe vera leaf gel extract stabilized CdS NPs concocted out of: (a). cadmium chloride, (b) cadmium nitrate, (c) cadmium sulphate including the (d) Infrared spectrum of Aloe vera leaf gel extract.

3.5. Optical Studies

Figure 6 (a-c) depicts the UV-Visible absorbance characteristics of Aloe vera leaf gel extract capped CdS NPs braced out of cadmium chloride, cadmium nitrate together with cadmium sulphate as well as Figure 6 (d-f) manifests the plots of photon energy vs. the square of the product of absorption coefficient, energy. The wavelength of maximum absorption around 215, 224 in addition to 254 nm specify the substance's inherent surfactant content [33].

The CdS NPs prepared out of cadmium nitrate is found to be having large band gap of 5.18 eV furthermore absorbance as compared to that of the CdS NPs prepared by using cadmium chloride is exhibiting band gap of 5.04 eV in addition to cadmium sulphate which is having band gap between 3.58 and 5.09 eV. This finding indicates that the absorption edge's blue shift, that means the absorption wavelength shifted to lower wavelength side causes wider band gap is occurred in all the materials.

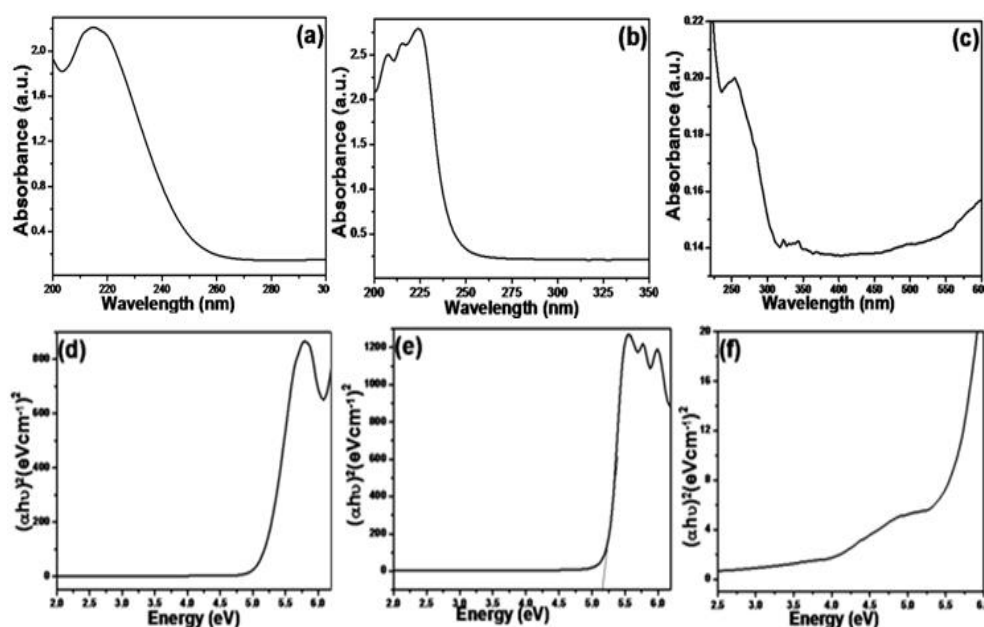


Figure 6. Absorption spectra and band gap energy plots of Aloe vera gel stabilized CdS NPs attained from cadmium chloride (a, d), cadmium nitrate (b, e) including cadmium sulphate (c, f) metal precursors.

The reduction in size of CdS NPs is because of the quantum confinement effect. The property of tunable band gap of CdS NPs poses substantial progress over the visible region which gives hope for the electronic, optoelectronic, semi conductor devices and gas sensors applications [34].

3.6. Catalytic Study of Aloe Vera Leaves Gel Extract Mediated CdS NPs

Exemplary UV-Visible Absorption spectrum changes undergoing the solution of dye in terms of reaction duration is illustrated by Figure 7 (a-c) to explain the changes in molecular properties of MB as a result of photocatalytic degradation. It can be seen from this Figure that, the original MB solution absorption spectrum has two peaks in the visible spectrum, featuring the greatest sensitivity at approximately 664 nm. Disintegration of

bands causes the absorbance values to decrease during photo deterioration. The measured parameter for the process of photocatalytic decomposition has been determined to be the typical absorption of MB at around 664 nm. The relationship between MB concentration as well as absorbance is proportional.

The insignificance of the downstream of MB as well as RhB dyes in the dark and in the existence of CdS may be observed in Figures 7 and 8 [35]. The down fall in maximum absorption and lost its peak wavelength value observed for the Aloe vera included CdS NPs obtained from cadmium chloride, cadmium nitrate along with cadmium sulphate being 12, 12 and 47% of its MB dye, respectively after 180 min. Aloe vera stabilized CdS NPs synthesized from cadmium sulphate is exhibiting the highest activity i.e., 47% which is higher than the reported value of 30.55% photocatalytic efficiency observed for the Hibiscus rosa-sinesis leaves extract capped CdS NPs for degradation of Methylene Blue Dye [36].

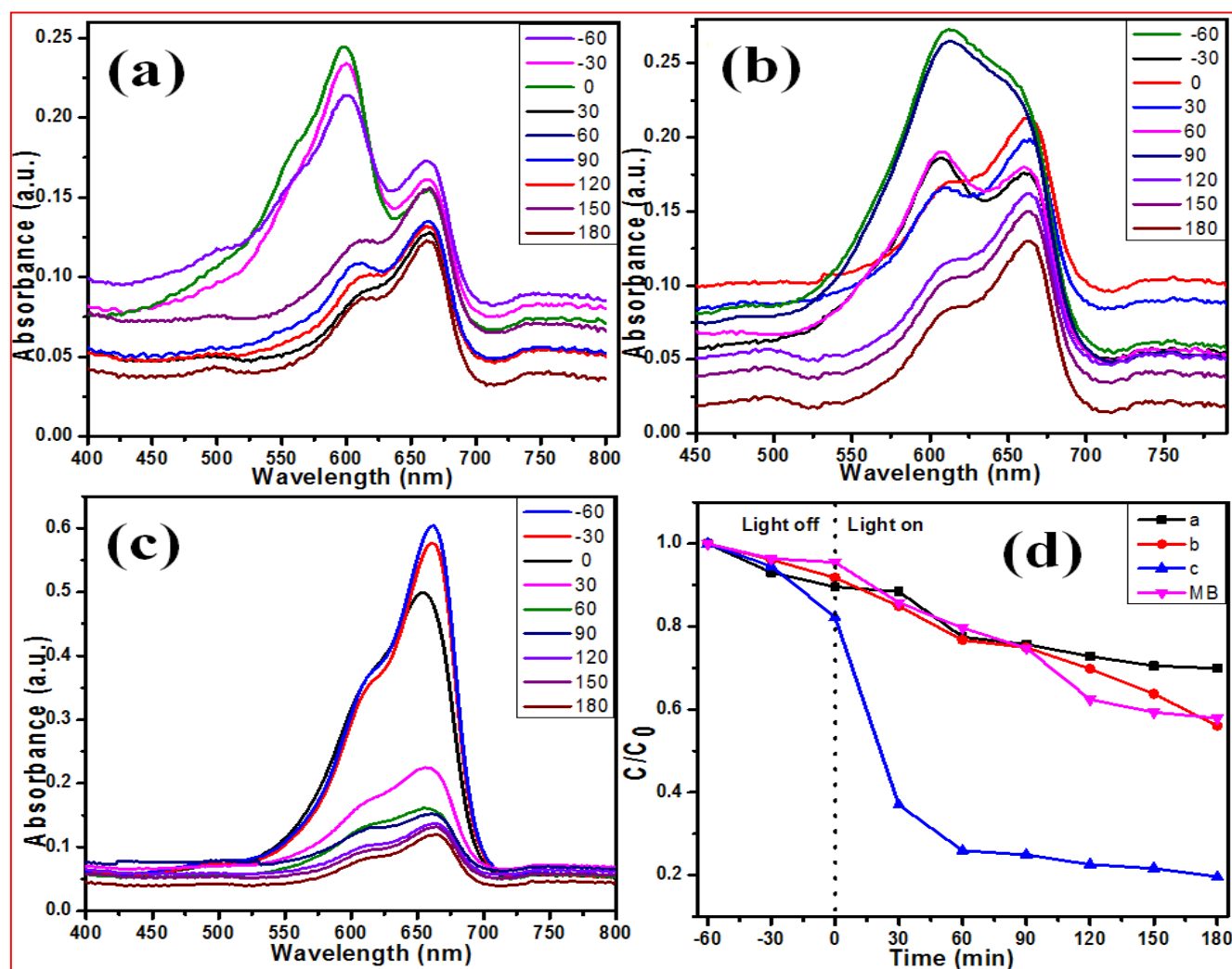


Figure 7. Photocatalytic activity (a-c) and the degradation trend (d) of MB as a function of irradiation time of Aloe vera leaf gel extract capped CdS NPs composed out of: (a) cadmium chloride, (b) cadmium nitrate including (c) cadmium sulphate salts towards the decrease in absorbance.

Figure 7 (d) illustrates the degradation curves of aqueous MB solution exposed to visible radiation in existence of CdS NPs including degradation trend of pure MB dye without any catalyst. Figure 7 makes it abundantly evident that after 180 min of photocatalytic investigation, no new peaks are seen and the parent absorption peaks have significantly decreased, indicating that the photo-degradation of MB has been assessed to be complete. The degradation of strong absorption peak is decreasing gradually in case of Figure 7 (a) and (b), where there is a sudden escalation in the maximum absorption in Figure 7 (c) after 60 min in dark and followed by 30 min exposure to visible light. This indicates that the photocatalytic activity is more prominent in presence of light irradiation.

A sudden escalation in peak intensity or the maximum absorption curve in Figure 7 (c) of a CdS NPs photocatalysts is typically may be due to an increase in the concentration of the catalyst or a change in the physical state of the NPs, such as agglomeration. It could also be due to an adsorption-desorption dynamics because an initial phase of a photo catalysis involves an adsorption process in the dark and an escalation after 60 min in dark and 30 min exposure in light might be observed if a significant amount of dye

was initially adsorbed onto the CdS NP surface, and then some experimental change caused a sudden desorption of these molecules back into the solution, increasing the concentration of free dye in the measured volume.

The photocatalytic activity of Aloe vera leaves surfactant stabilized CdS NPs is assessed by an absorption spectrum of the RhB dye having absorption peak at around 552 nm over a period of 180 min is displayed in Figure 8 (a-c). The paramount absorption peak wavelength shift happened to higher wavelength side after 60 min observation in dark for the Aloe vera leaves gel surfactant capped CdS NPs made from cadmium chloride along with the cadmium sulphate. It can be attributed to cadmium to sulfur precursor ratio employed as 1:2 which indicates more sulfur content and also higher pH value [37]. Whereas for the Aloe vera assisted CdS NPs made out of cadmium nitrate shows the shifting of maximal absorption wavelength from 552 nm to a lower wavelength side be observed and depicted by Figure 8 (b). The Figure 8 (d) exhibits degradation trend of the RhB dye that is variation in concentration of the dye along with time for Aloe vera leaf extract assisted CdS NPs as well as pure RhB dye.

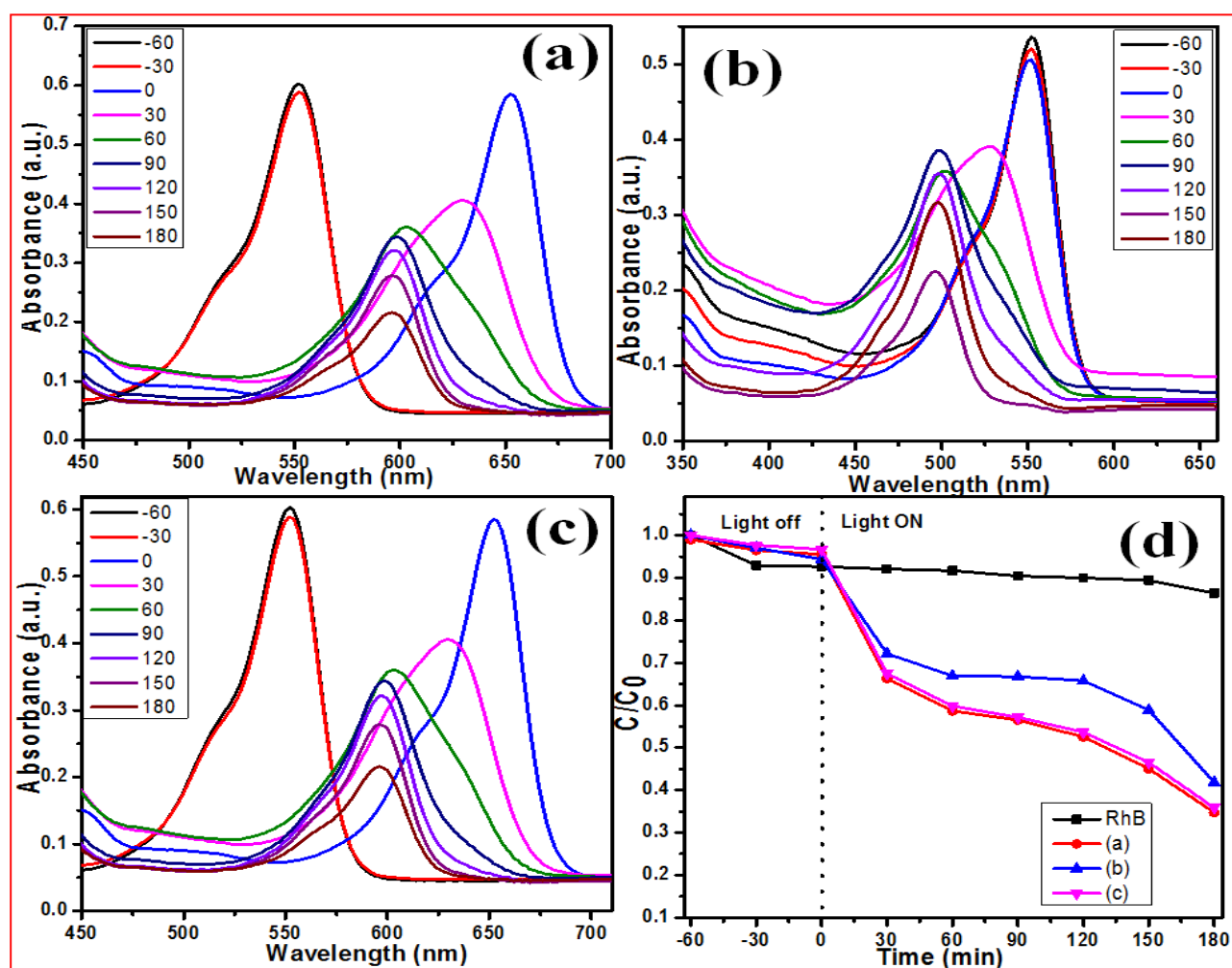


Figure 8. Photocatalytic activity (a-c) including the degradation trend (d) of RhB as a function of irradiation time of Aloe vera leaf gel stabilized CdS NPs prepared from: (a) cadmium chloride, (b) cadmium nitrate, (c) cadmium sulphate towards decrease in absorbance.

The photocatalytic effectiveness of CdS NPs' manufactured by the cadmium precursors like cadmium chloride, cadmium nitrate including cadmium sulphate disclose 39, 31 along with 39% against RhB dye, respectively. The shift of absorption wavelength from 552 nm to a lower wavelength side that is around 494 nm for the CdS NPs armed out of cadmium nitrate of RhB dye degradation depicts by Figure 8(d) gives the clear evidence of the evolution of the complete de-ethylated RhB molecule.

3.7. PL Study of Aloe Vera Leaves Gel Extract Stabilized CdS NPs

The light emission of a material at a specific wavelength

can be identified using photoluminescence which is a measurement of photo absorption in a direct band gap materials. The PL spectra are being carried out to explore the luminescence characteristic of the Aloe vera leaf gel extract assisted CdS NPs produced from cadmium chloride, cadmium nitrate and cadmium sulphate correspond to (a), (b) including (c) are displayed in PL spectra 9 (a-c). The PL spectrum is captured in the region of wavelength 200-800 nm.

PL graphs of Aloe vera stabilized CdS NPs in Figure 9(a)-(c), exhibit a band edge luminescence that can be identified by a narrow strong sharp edge peak at around 492 nm. The PL peak at around 512 nm can be seen in Figure 9(a) with medium intense broad band and that of small intense low broad band at around 512 nm in Figure 9(b) and almost no peak at the same wavelength in Figure 9(c).

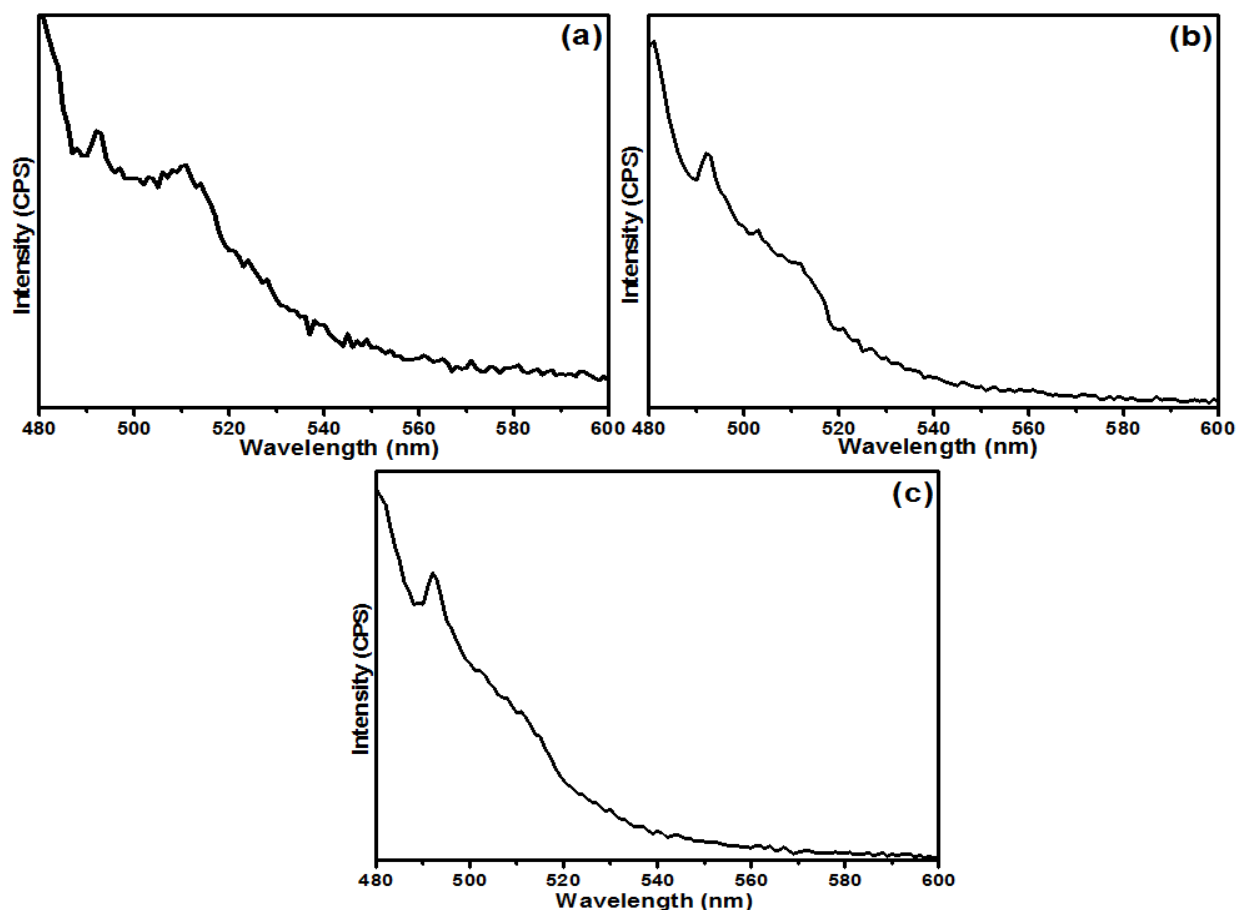


Figure 9. Photoluminescence emission spectra of Aloe vera leaves gel extract encapsulated CdS NPs prepared from: (a) cadmium chloride, (b) cadmium nitrate including, (c) Cadmium sulphate salts.

The low energy of the PL band indicates that the CdS excitonic dispersion is not what causes the PL maximum at about 512 nm. Additionally, with restricted CdS NPs, the PL excitonic peak is typically found at 410 nm [38]. Because the PL band energies being below or closely comparable to that of the band gap energy, the luminescence bands may be

distinguished from transitions comprising donors, acceptors along with surface traps [39]. This band, as compared to that of bulk CdS, is almost certainly the outcome of recombination via deeper imperfection states [40]. Additionally, it implies that this shallow state donor-acceptor interaction in the CdS energy gap can lead to a

small-energy range [41]. As a result, native defects like sulfur or cadmium vacancies are primarily responsible for the defect levels that contribute to low lying energy band edge PL [42]. Various trapping modes on NPs may be accountable for the decline in PL peak intensity [43] which is illustrated in Figure 9 (a) and (b).

3.8. Discussions

The CdS NPs are being synthesized successfully by applying various cadmium salts along with the natural surfactant Aloe vera leaves gel extract. The length of time needed for a reaction using distinct sources of cadmium and sulphur in var-

ious molecular quantities, in addition to different reaction allocations, stirring velocities and variable ratios of natural surfactant, is being estimated with suitable mole fractions of cadmium salts, weight percentages of natural extracts are employed in the synthesis process of CdS NPs. It is found that for 0.1 M or 0.05 M of cadmium salts including sodium sulfide of 0.1 M, 4 hrs reaction time and stirring speed of 900 rpm and temperature at 60 °C giving the better outcome for the surfactant agent Aloe vera leaf gel extract.

Factors for synthesis used in the process of producing CdS NPs steadiness by Aloe vera leaf gel surfactant, cadmium chloride, cadmium nitrate including cadmium sulphate is expressed in Table 2.

Table 2. Specifics of the synthesis parameters used to synthesize CdS NPs.

S.No.	Natural stabilizer	Cd Precursor	Mole fraction of Cd: S	Source of Sulfur	Stirring-Time(hrs)	pH	Extract wt.% inCd source
1	Aloe vera Gel extract	CdCl ₂	1:2	Na ₂ S	4	11	40
		Cd(NO ₃) ₂	1:2	Na ₂ S	4	11	30
		CdSO ₄	1:1	Na ₂ S	4	6	30

Table 3 lists the average particle size of the as-prepared CdS NPs derived from SAXS, SEM, along with TEM investigations as well as the corresponding crystallite sizes from XRD investigations. Presence of additional peaks other than CdS which corresponds to sodium chloride is a limitation for the CdS NPs prepared from cadmium chloride precursor. It has been established that CdS NPs are generated with sizes less than 9 nm and all of these values are nearly identical to one another. Particle size usually decreases with increasing pH. The pH level is changed in the current investigation to produce tiny CdS NPs with a particle size of less than 9 nm.

The crystallite sizes calculated from XRD and average NP size calculated from TEM are in good agreement for the CdS NPs prepared from cadmium nitrate and cadmium sulphate precursors whereas discrepancy in calculated the crystallite

size for CdS NPs obtained from XRD which is 8 nm and that calculated from TEM is 2.6 nm may be attributed to the presence of coarse-grained powder and cluster particles.

The surface of NPs significantly influences their physical also chemical characteristics. The PL phenomenon is notably influenced by the surfactants, necessitating meticulous measures to eliminate probable trap sites and attain elevated fluorescence quantum yields. In case of CdS, it is observed that two distinct forms of emission can occur, namely band edge emission corresponds to wavelength below 500 nm and the surface defect emission, which is attributed to the wavelength more than 500 nm. The active species involved in photocatalytic degradation of dyes are holes as well as super oxide radicals played a significant role [44].

Table 3. Average size of as synthesized CdS NPs determined from SAXS, SEM as well as TEM characterization studies along with their respective average crystallite sizes by XRD analysis.

S.No	Surfactant	Notation	Source of Cd	XRD(nm)	SEM(nm)	SAXS(nm)	TEM(nm)
1	Aloe vera GelExtract	A	CdCl ₂	8	2.10	2-4	2.61
		B	Cd(NO ₃) ₂	3	2.16	5-12	2.51
		C	CdSO ₄	3	1.60	3-9	2.62

Stoichiometric ratio of as prepared CdS NPs according to the natural stabilizers is illustrated in Table 4.

Table 4. The stoichiometric ratio, band gap values and morphology of as prepared CdS NPs capped with Aloe vera leaf gel stabilizer.

S.No.	Natural Stabilizer	Cd Source	Atomic wt.% Cd: S	SCR; Cd: S	Band gap (eV) Max-Min	Morphology of CdS NPs
5	Aloe vera leaf Gel extract	CdCl ₂	7.89:10.34	1:1.31	5.04	Both spherical, facet shape
		Cd(NO ₃) ₂	1.43:1.97	1:1.37	5.18	Both spherical, irregular shape
		CdSO ₄	5.83:10.95	1:1.87	5.09-3.58	Spherical and irregular shape

The emission of blue light is ascribed to electron-hole pair disintegration through radiative action. The PL spectrum of CdS NPs, which are capped with surfactants, exhibited comparable characteristics to those of CdS NPs without any capping agent, however with slightly higher fluorescence intensity and blue shift of high intensity peaks. It can be inferred that the presence of natural surfactants has the potential to enhance the fluorescence of uncapped CdS. The PL emission peaks traced at 491, 492 nm which are being better acceptance to that of reported value and are due to sulphur vacancy to valence band [45]

transition of electron represented by sulphur vacancy $V_S^{2+} \rightarrow V_b$ valence band edge. The luminescent emission peak located at 493 nm almost coincides with the reported value and peak position at 499 nm little deviates with 5 nm to that of the reported value and these peaks are due to an excitonic emission which comes under near band edge emission.

The PL peaks located at 509 deviates 3 nm from reported value, 511 and 512 are because of electron transitions between donor to acceptor level, which can be demonstrated as interstitial cadmium $I_{Cd}^+ \rightarrow V_{Cd}^- \rightarrow V_{Cd}^-$ acceptor levels [46]. Transition due to interstitial sulphur sites gives raise the peak at 514 nm [9] which can be illustrated as interstitial sulphur $I_s^- \rightarrow C_b$ conduction band edge.

4. Conclusions

The Aloe vera leaf gel extract capped CdS NPs are successfully synthesized via Green synthesis method at room temperature ambience with various cadmium precursors such as cadmium chloride, cadmium nitrate and cadmium sulphate. Compared the performance of CdS NPs prepared from different cadmium precursors in various aspects such as band gap values, morphology and catalytic activity. The synthesis parameters such as time to 4 hrs, stirring speed as 900 rpm, 60°C temperature, pH value as per the precursor and precursor weight percentage are optimized in the present investigation. The XRD analysis confirmed the formation of CdS NPs. The remarkable enhancement in band gap of the CdS NPs is found to be of 2.76 eV and most of the CdS NPs are spherical in shape. FTIR analysis confirmed the presence of Aloe vera layer capping on CdS. The lowest average size of the CdS NPs synthesized is 3 nm

confirmed from TEM. The largest photocatalytic activity and also good enhancement in band gap observed for pH value of 6. CdS NPs prepared with cadmium chloride shows some impurities that is presence of cadmium chloride and sodium chloride present in XRD spectra and the formation of different size of NPs found from SAXS, The SEM images show agglomeration upto some extent of CdS NPs could be the limitations. There is a need enhance the catalytic efficiency to apply the Aloe vera capped CdS NPs in practical applications of waste water treatment. However the formation of large band CdS NPS can be applied in hetero junction solar cells.

Abbreviations

CdS NPs	Cadmium Sulfide Nanoparticles
XRD	X-ray Diffraction
FTIR	Fourier Transform Infrared Spectroscopy
UV Vis. Spectrum	Ultraviolet Visible Spectrum
SEM	Scanning Electron Microscopy
EDS	Energy-Dispersive Spectroscopy
SAXS	Small Angle X-ray Spectroscopy
TEM	Transmission Electron Microscopy
MB	Methylene Blue
RhB	Rhodamine B
FWHM	Full Width at Half Maximum
IRENA	A Data Manipulations and Analysis Tool Box for SAXS
SAED	Selected Area Electron Diffraction

Acknowledgments

The authors thank the Head, Department of Physics, Osmania University, Hyderabad, Director, DMRL, Hyderabad and SAIF IIT Chennai for extending co-operation and allowing to use experimental facilities. The authors also thank University Grants Commission, Commissioner of Collegiate Education, Government of Telangana and Principal of the college, for their encouragement and motivation to do research work in the college.

Author Contributions

Bandaru Srinivasa Goud: Conceptualization, Investigation, Supervision, Writing – original draft

Gudikandula Odelu: Data curation, Methodology, Resources, Validation

Keerthi Rajesh: Formal Analysis, Visualization, Writing – review & editing

Conflicts of Interest

The authors declare no conflicts of interest.

References

- [1] Youtie Y, Shapira P, Porter A L: Nanotechnology Publications and Citations by Leading Countries and Blocs, *J. Nanopart. Res.*, 10 (2008) 981-986.
<https://doi.org/10.1007/S11051-008-9360-9>
- [2] Prathna T C, Chandrasekaran N, Raichur A M, Mukherjee A: Kinetic Evolution Studies of Silver Nanoparticles in a Bio based Green Synthesis Process, *Colloids Surf. A*, 377 (2011) 212–216. <https://doi.org/10.1016/j.colsurfa.2010.12.047>
- [3] Murai H, Abe T, Matsuda J, Sato H, Chiba S, Kashiwaba Y: Improvement in the Light Emission Characteristics of CdS: Cu/CdS Diodes, *Appl. Surf. Sci.*, 244 (2005) 351-354.
<https://doi.org/10.1016/j.apsusc.2004.10.125>
- [4] Wang Y, Ramanathan S, Fan Q, Yan F, Morkoe H, Bandyopadhyay R S: Electric Field Modulation of Infrared Absorption at Room Temperature in Electro Chemically Self Assembled Quantum Dots, *J. Nano-sci. Nanotechnol.*, 6 (2006) 2077-2080.<https://doi.org/10.1166/jnn.2006.359>
- [5] Duan X, Huang Y, Agarwal R, Lieber C M: Single-Nanowire Electrically Driven Lasers, *Nature*, 421 (2003) 241-245.
<https://doi.org/10.1038/nature01353>
- [6] Huynh W V, Dittmer J J, Alivisatos A P: Hybrid Nanorod-Polymer Solar Cells, *Science*, 295 (2002) 2425-2427.
<https://doi.org/10.1126/science.1069156>
- [7] Oladeji I O, Chow L, Ferekides C S, Viswanathan V, Zhao Z: Metal/CdTe/Cds/Cd_{1-x}Zn_xS/TCO/Glass: A New CdTe Thin Film Solar Cell Structure, *Sol. Energy Mater. Sol. Cells*, 61 (2000) 203-211. [https://doi.org/10.1016/S0927-0248\(99\)00114-2](https://doi.org/10.1016/S0927-0248(99)00114-2)
- [8] Cha D, Kim S, Huang N K: Study on Electrical Properties of CdS Films Prepared by Chemical Pyrolysis Deposition, *Mater. Sci. Eng. B*, 106 (2004) 63-68.
<https://doi.org/10.1016/j.mseb.2003.09.010>
- [9] Singh V, Chauhan P: Structural and Optical Characterization of CdS Nanoparticles Prepared by Chemical Precipitation Method. *Journal of Physics and Chemistry of Solids*, 70 (2009) 1074–1079. <https://doi.org/10.1016/j.jpcs.2009.05.024>
- [10] Phuruangrat A, Thongtem T, Thongtem S: Characterisation of One-Dimensional CdS Nanorods Synthesised by Solvothermal Method, *J. Exp. Nanosci.*, 4 (2009) 47-54.
<https://doi.org/10.1080/17458080802654486>
- [11] Lalayan A, Avetisyan A, Djotyan A: The Luminescence Properties of the Colloidal GaAs and CdS Semiconductor Quantum Dots, *Laser Phys. Lett.* 2 (2005) 12-15.
<https://doi.org/10.1002/lapl.200410138>
- [12] Jinxin Z, Gaoling Z, Gaorong H: Preparation of CdS Nanoparticles by Hydrothermal Method in Microemulsion, *Front Chem. Chin.*, 2 (2007) 98-101.
<https://doi.org/10.1007/s11458-007-0020-x>
- [13] Marandi M, Teghavinia N, Iraj A, Mahadevi S M: A Photo Chemical Method For Controlling the Size of CdS Nanoparticles, *Nanotechnology*, 16 (2005) 334-338.
<https://doi.org/10.1088/0957-4484/16/2/027>
- [14] Wada Y, Kuramoto H, Anand J, Tikamura T, Sakata T, Mori H, Yangida S: Microwave-Assisted Size Control of CdS Nanocrystallites, *J. Mater. Chem.*, 11 (2001) 1936-1940.
<https://doi.org/10.1039/B101358K>
- [15] Torimoto T, Reyes J P, Iwasaki K, Pal B, Shibayama T, Sugawara K, Takahashi H, Ohtani B: Preparation of Novel Silica-Cadmium Sulfide Composite Nanoparticles Having Adjustable Void Space by Size-Selective Photoetching, *J Am Chem Soc.* 125 (2003) 316-317.
<https://doi.org/10.1021/ja0278133>
- [16] Wang G Z, Chen W, Liang C H, Wang Y W, Meng G W, Zhang L D: Preparation and Characterization of CdS Nanoparticles by Ultrasonic Irradiation, *Inorganic Chemistry Communications*, 4 (2001) 208-210.
[https://doi.org/10.1016/S1387-7003\(01\)00172-1](https://doi.org/10.1016/S1387-7003(01)00172-1)
- [17] Singh V, Sharma P K, Chauhan P: Synthesis of CdS Nanoparticles with Enhanced Optical Properties, *Materials Characterization*, 62 (2011) 43-52.
<https://doi.org/10.1016/j.matchar.2010.10.009>
- [18] Khan Z R, Zulfeqar M, Khan M: Chemical Synthesis of CdS Nanoparticles and Their Optical and Dielectric Studies, *J. Mater. Sci.*, 46 (2011) 5412-5416.
<https://doi.org/10.1007/s10853-011-5481-0>
- [19] Sivakumar Sivalingam, Jyoti Kavirajwar, K. Seethalakshmi, Jayagopi Gayathri and A. Roniboss. Green synthesis of cadmium oxide nanoparticles (CdO-NPS) using *syzygium cumini*: exploring industrial applications of CdO NPs as a corrosion inhibitor of mild steel in the acidic environment. *RSC Adv.*, 2024, 14, 7932-7939. <https://doi.org/10.1039/d4ra00560k>
- [20] Maurya, A. K., Varshney, S., Upadhyay, S., Gupta, A., Jeyakumar, E., Lawrence, R., & Mishra, N. Green synthesis of copper oxide nanoparticles using *Ficus racemosa* leaf extract and investigation of its antibacterial properties. *Advances in Materials and Processing Technologies*, ((2024) 1–21.
<https://doi.org/10.1080/2374068X.2024.2402970>
- [21] Azmand, A., Firoozi, S. & Haghshenas, D. F. Facile Green Synthesis of CdS Nanoparticles in a Glycine Medium for Waste Valorization of Ni-Cd Battery. *Waste Biomass Valor* 16, 5939–5951 2025. <https://doi.org/10.1007/s12649-025-03026-4>

- [22] Akhilesh Kumar Maurya, ShagunVarshney, Vinod Verma, Hifzur R., Siddique, Nidhi Mishra. Synthesis of Silver and Copper oxide nanoparticles using Ficus racemosa leaf extract: characterization, anticancer potential, and dye degradation efficacy. *Journal of Umm Al-Qura University for Applied Sciences*. 2025, 11, 581–594. <https://doi.org/10.1007/s43994-024-00182-6>
- [23] RashaShakir Mahmood, DhiaHadi Hussain, Nibras Abdul Ameer Aboud. Green laser-ablated CdS nanoparticles in aloe vera medium: structural, optical, electrochemical, and synergistic photocatalytic–adsorptive performance for pentachlorophenol degradation. *Journal of Materials Science: Materials in Electronics*. 2025, 36: 2135. <https://doi.org/10.1007/s10854-025-16253-1>
- [24] Suresh K: A Multi-Functional Dual-Energy Laboratory Mo-Cr-SAXS System, *J. applied Crystallography*, 48 (2015) 2040–2043. <https://doi.org/10.1107/S1600576715018804>
- [25] Ilavsky J, Jemian P R: Irena: Tool Suite for Modeling and Analysis of Small-Angle Scattering, *J. Appl. Crystallogr.*, 42 (2009) 347–353. <https://doi.org/10.1107/S0021889809002222>
- [26] Naranthatta S, Janardhanan P, Pilankatta R, Nair S S: Green Synthesis of Engineered CdS Nanoparticles with Reduced Cytotoxicity for Enhanced Bioimaging Application, *ACS Omega*, 6 (2021) 8646–8655. <https://doi.org/10.1021/acsomega.1c00519>
- [27] Josias H. Hamman: Composition and Applications of Aloe vera Leaf Gel. *Molecules*, 13 (2008) 1599–1616. <https://doi.org/10.3390/molecules13081599>
- [28] Rao M D, Pennathura G: Green Synthesis and Characterization of Cadmium Sulphide Nanoparticles from *Chlamydomonas Reinhardtii* and their Application as Photocatalysts. *MRB (Materials Research Bulletin)* 8929 (2016) 1–44.
- [29] Kamble M M, Rondiya S R, Bade B R et al.: Optical, Structural and Morphological Study of CdS Nanoparticles: Role of Sulfur Source, *Nanomaterials and Energy*, 9 (2020) 72–81. <https://doi.org/10.1680/jnaen.19.00041>
- [30] Shruti G, Kumar T K: Catalytic Reduction of Organic Dyes with Green Synthesized Silver Nanoparticles Using Aloe vera Leaf Extract, *Journal of Nanoscience, Nano Engineering and Applications*, 9 (2019) 1–13. <https://doi.org/10.37591/jonsnea.v9i2.661>
- [31] Kulkarni P, Abhijit N, Omkar K, Rahul S, Dhanshri L, Pooja K: Phytochemical and FTIR Analysis of *Tinispora Cordifolia*, *International Journal of Current Research*, 10(2018) 75331–75334. <https://doi.org/10.24941/ijcr.33147.11.2018>
- [32] Alivisatos A P: Semiconductor clusters, Nano Crystals and Quantum Dots, *Science*, 271 (1996) 933–937. <https://doi.org/10.1126/science.271.5251.933>
- [33] Moghaddasi S M, Kumar V S: Aloe vera their Chemicals Composition and Applications: A Review, *Int J Biol Med Res*. 12 (2011) 466–471.
- [34] Dwivedi D, Dayashankar K, Dubey M: Synthesis, Structural and Optical Characterization of CdS Nanoparticles, *Journal of Ovonic Research*, 6 (2010) 57–62.
- [35] Zhang T, Oyama T, Horikoshi S, Hidaka H, Zhao J N: Serpone, Photocatalyzed N-Demethylation and Degradation of Methylene Blue Titania Dispersions Exposed to Concentrated Sun Light. *Sol., Energy Matter. Sol., Cells*. 73 (2002) 287–303. [https://doi.org/10.1016/S0927-0248\(01\)00215-X](https://doi.org/10.1016/S0927-0248(01)00215-X)
- [36] Salian A. R, Henriques S. K, Ardra S. S. Synthesis of Cadmium Sulfide Nanoparticles via Green Route for Photocatalytic Degradation of Methylene Blue Dye. *Orient J Chem* 2025; 41(1). <https://doi.org/10.13005/ojc/410605>
- [37] Hong L, Cheung T L, Rao N, Ouyang Q, Wang Y, Zeng S, Yang C B, Cuong D, Han P, Chong J, Liu L, Law W C and Yong K T: Microfluidic Synthesis of Cadmium Sulfide Nanoparticles and Their Application in Bioimaging, *RSC Adv.*, 7 (2017) 36819–36832. <https://doi.org/10.1039/C7RA05401G>
- [38] Khanna P K, Singh N: Light Emitting CdS Quantum Dots in PMMA: Synthesis and Optical Studies. *Journal of Luminescence*, 127 (2007) 474–482. <https://doi.org/10.1016/j.jlumin.2007.02.037>
- [39] Nanda K K, Sarangi S N, Sahu S N: Visible Light Emission from CdS Nanocrystals, *Journal of Physics D*, 32 (1999) 2306–2310. <https://doi.org/10.1088/0022-3727/32/17/323>
- [40] Nesheva D, Raptis C, Levi Z, Popovic Z, Hinic I: Photoluminescence of CdSe Nanocrystals Embedded in a SiO₂ Thin Film Matrix. *Journal of Luminescence*, 82 (1999) 233–240.
- [41] Chahboun A, Rolo A G, Filonovich S A, Gomes M J M: Factors Influencing the Passivation of CdS Quantum Dots Embedded in Silica Glass. *Solar Energy Materials and Solar cells*, 90 (2006), 1413–1419. <https://doi.org/10.1016/j.solmat.2005.10.006>
- [42] Alipour A, Lakouraj M M, Tashakkorian H: Study of The Effect of Bandgap and Photoluminescence on Biological Properties of Polyaniline/CdS QD Nanocomposites Based on Natural Polymer., *Nature Research - Scientific Reports*, 11 (2021) (1–15). <https://doi.org/10.1038/s41598-020-80038-1>
- [43] Alani R R, Ibrahim O A: Effect of Point Defects on the Structural and Optical Properties of CdS Nanoparticles Synthesized by Chemical Method, *International Journal of Mechanical Engineering*, 7 (2022) 5156–5165.
- [44] Srinivasa Goud B., Suresh Y., Annapurna S., Bhikshamaiah G., Tarun Babu M., A. K. Singh: Photoluminescence and Photocatalytic studies of rice water and papaya fruit extract encapsulated cadmium sulfide nanoparticles, *Journal of the Korean Ceramic Society*, 60 (3) (2022) 1–20. <https://doi.org/10.1007/s43207-022-00253-6>
- [45] Chaure S, Chaure N B, Pandey R K, Ray A K: Stoichiometric Effects on Optical Properties of Cadmium Sulphide Quantum Dots, *IET Circuits Devices Syst.*, 1 (2007) 215–219. <https://doi.org/10.1049/iet-cds:20070048>
- [46] Berry A K, Amirtharaj P M, Jing-Tong Du, Boone J L, Martin D D: Photoluminescence and Raman Studies of CdS Films Grown by Metal-Organic Chemical Vapour Deposition on Si{111} Substrates, *Thin Solid Films*, 219 (1992) 153–156. [https://doi.org/10.1016/0040-6090\(92\)90736-U](https://doi.org/10.1016/0040-6090(92)90736-U)