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# Plant Mediated Synthesis of CdS Nanoparticles: Their Characterization and Application for Photocatalytic Degradation of Toxic Organic Dye

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ABSTRACT

In this work, an environmentally friendly and cheap method for the synthesis of CdS nanoparticles for the first time using an extract of *Dicliptera Roxburghiana* is presented. The present method is found to be reproducible and rapid. Structural analysis is carried out by UV-visible, FTIR, XRD, EDX, SEM, and TEM. XRD and TEM analysis revealed that the nanoparticles have spherical shape and size in the range of 2.5-8nm. FTIR studies showed the presence of functional groups which belong to the phytochemicals of plant extract that surround the nanoparticle preventing them from agglomeration. Thus the prepared CdS NPs exhibit excellent stability even after 2 months. The optical band gap was calculated using Tauc Plot i.e. 3.31 eV. Their activity as photocatalysts against an aqueous solution of methylene blue degradation under solar irradiation in a comparative manner is also reported and the particle has a % degradation of 87.12% in just 120 minutes under solar light irradiation.

## 1. Introduction

Nanotechnology is the study and application of particles having a size of about 1-100 nm (nanoparticle) and it is one of the emerging fields of material science in recent years and it is being used in almost every aspect of daily life. Nanoparticles are the substance having the size in between 1-100 nm so they are having a very small size also they have a high surface to area ratio [1]. It is, for this reason, they are nowadays the most important materials having distinguished physical and chemical properties. A variety of nanoparticles either have been synthesized and are in use for several purposes but semiconductor nanoparticles are of vital interest [2-6]
In the past few years semiconductors substances in nanocrystalline forms and the methods to synthesize those NPs, have gained the enormous interest of researchers because of their incomparable and distinctive spectroscopic and optical properties [7] and their applications in the remediation of the environment. Semiconductor nanoparticles can be used as sensing and inactivating environmental hazardous gas as well as they can be used for the treatment of polluted water [8-13]. Several semiconductor nanoparticles such as CdS, CdSe, ZnO, ZnSe, and CuO can be prepared by different bottom-up approach fabrication techniques [13-17] but among them, CdS-NPs are most extensively studied due to their distinctive physical and chemical properties. Cadmium Sulfide has a wide bandgap and its bandgap energy is 2.42 eV [18]. CdS nanoparticles are found to have high bandgap energy as compared to bulk due to the high surface area to volume ratio. The groups II-IV (chalcogenides), CdS semiconductor nanoparticles are highly sensitive towards the detection of visible rays since it's the sample photoconductor in most optical-electronic devices [19]. Increasing the efficiency of solar cells and also being used in various biological uses [20]. CdS nanoparticles as electrocatalyst in water splitting for the evaluation of $H_2$ and $O_2$ gases and also have a major part in water purification. They can be used for diagnosing and treating cancer because of their enhanced fluorescence and optical properties. The CdS

nanoparticles are preeminent materials for the investigation of the electronic and optical properties of quantum confined semiconductors [21].

Nanoparticles can be synthesized using many physical and chemical routes i.e. hydrothermal and solvothermal methods [22, 23] but unfortunately, they have certain drawbacks such as the use of toxic chemicals and solvents, and also these methods are expensive. The increasing demand for nanoparticles requires some eco-friendly, cheap, and non-toxic synthesis techniques which can be done by biological or green synthesis where microorganisms and plants are used. A wide number of preparative techniques are already reported for the synthesis of various metallic and non-metallic nanoparticles using microorganisms [24, 25] and different plants [26-31]. Studies showed that nanoparticles of controlled size & shape can be synthesized using various plants and are potential candidates for various useful applications [32, 39].

Cadmium Sulfide nanoparticles have many potential applications especially as photo electronic devices, cell imaging, sensors, solar cells, and photocatalysis [41-42]. Photocatalysis is a charge separation process by absorbing light energy that is equal to or greater than the band gap of the semiconductor substance. This process of charge separation generates electron pairs holes as a result of which free radicals are generated in the structure [43]. This technique is proved to be efficient in the treatment of wastewater that contains organic dyes because the free radicals generated as a result of photocatalysis are excellent oxidizers and can degrade pollutants [44, 45].

Mostly the CdS nanoparticles used for the degradation of dyes are synthesized by chemical methods and they are found to be effective [46] but as discussed earlier the demerits of these methods therefore, we used the extract of un-reported *dicliptera roxburghiana* to investigate its potential for the synthesis of CdS nanoparticles and the prepared nanoparticles are used as photocatalyst for the degradation of methylene blue dye to investigate the efficiency of prepared CdS NPs by this method. The phytochemical studies showed that *dicliptera roxburghiana* is rich in coumarins, alkaloids, tannins, saponins, flavonoids, terpenoids, and phenolics contents [47] which are excellent reducing agents. The extract of *dicliptera roxburghiana* contained these phytochemicals which help in the reduction of cadmium sulfide ions into cadmium sulfide nanoparticles having excellent morphology and stability without any agglomeration even after 2 months. The characterization of synthesized CdS nanoparticles was carried out by UV-Visible, FT-IR, XRD, and TEM. The efficiency of prepared CdS nanoparticles as photocatalyst was investigated against methylene blue dye degradation with the help of a UV-Visible spectrophotometer.

## 2. Results and Discussion

### *UV-Visible spectrometer analysis:*

Ultraviolet-visible (UV-Vis) spectrophotometer was used to study the relation of incubation time with the synthesis of CdS nanoparticles using absorbance spectrum. A spectrum two 108335 UV-Visible spectrophotometers was used for this purpose. The sample was initially analyzed after 12 hours of incubation time while the absorbance spectrum showed that the process of synthesis of CdS-NPs has been started but is very slow as the peak was less intense which indicates it will be not enough to degrade methylene blue sufficiently. The process of nanoparticle synthesis was enhanced by increasing the incubation time as clearly indicated in the absorbance spectrum while after 72 hours of incubation the spectrum showed maximum absorbance at 332nm as shown in fig. 2 and 3a. So the most stable CdS-NPs were attained after the incubation period of 72 hours at 332nm.

The energy bandgap of green synthesized CdS NPs was calculated by Tauc plot of $h\nu\alpha^2$ versus $h\nu$ [33,50] using following equation

$$\alpha h\nu = B(h\nu - Eg)^{1/2}$$

- Where $\alpha$ = absorption coefficient
- $h\nu$ = photon energy
- $Eg$ = band gap energy
- $B$ = a constant.

Absorption coefficient '$\alpha$' *was calculated from* $A = I/I0 = e^{(-\alpha d)}$ or can be calculated from Beer Lambert's Law. The UV-visible absorption spectra of synthesized CdS nanoparticles and Tau plot is shown in Figure 3(a&b). The calculated energy band-gap of synthesized CdS-NP s was 3.31 eV which is higher as compared to bulk CdS (2.42 eV) due to the presence of quantum confinement effects.

From the plot/ absorbance spectrum of UV-Visible analysis, it is proven that growth of CdS-NPs increased with the increase of incubation time and also that the absorption curves were weak after 12 hours and they're increasing with time while after 7 hours of incubation the reaction stops and stable CdS-NPs were prepared without having any agglomeration. The CdS-NPs synthesized using *dicliptera roxburghiana* had excellent stability even after 2 months they were not agglomerated.

### *FT-IR spectrometer analysis:*

PerkinElmer FTIR spectrometer was used for further analysis and to study the role and presence of reducing agents/ capping agents present in the plant extract and also to understand the nature of various phytochemicals

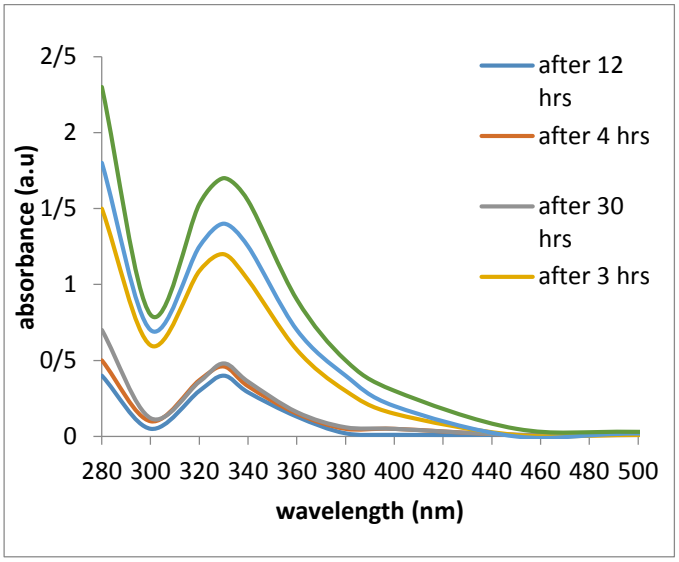


**Figure 2:** UV-Visible absorbance spectrum of CdS nanoparticles after incubation at various intervals of time.

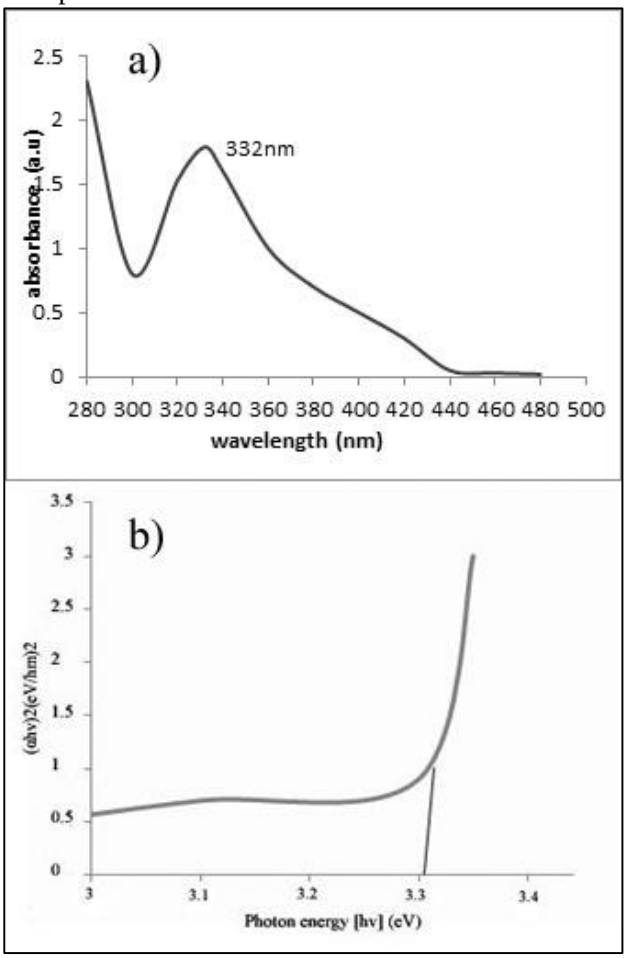


**Figure 3: a)** UV-Visible absorbance spectrum of CdS nanoparticles after 72 hrs of incubation time. **b)** Tauc plot of synthesized CdS nanoparticles.

functional groups responsible for nanoparticle synthesis present in the extract of *dicliptera roxburghiana*.

The FTIR absorbance spectrum is shown in Figure 4, the absorbance was carried out in a spectral range of about 4500 $cm^{-1}$ to 500 $cm^{-1}$. The spectrum of FTIR spectrometer presented peaks at different wavelengths corresponding to the existence of various functional groups like the peak at 3389.46 $cm^{-1}$ was assigned to the -OH group spreading plant material. The absorption peak in 2464.08$cm^{-1}$ is assigned with the C-H group. The deep peak or strong absorption band at 1628.11.72 $cm^{-1}$ could be assigned with the stretch of C = C particles while a weak absorption band was reported at 1108.06 $cm^{-1}$ can be attributed to C = O stretching. The absorption peak reported at 1048.95 $cm^{-1}$ can be assigned to the presence of ester group extract with the absorbance peak at 606.37 $cm^{-1}$ correspondings to the formation of CdS nanoparticles.

From the FTIR analysis, it is found that the extract of *dicliptera roxburghiana* is enriched with phytochemicals which not only help in the reduction of CdS into CdS NPs but also help to prevent agglomeration of nanoparticles. So the stable CdS nanoparticles were synthesized without any agglomeration.

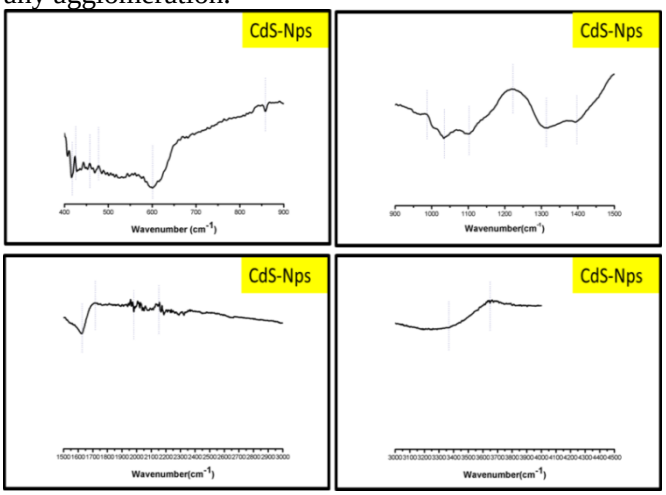


**Figure 4:** FTIR spectrum of CdS NPs synthesized using dicliptera roxburghiana extract.

***X-ray diffraction (XRD) analysis:***

X-ray diffraction analysis was performed on the prepared CdS nanoparticles to study the crystal structure, phase distribution, and size identification. These distinguishing peaks appeared at 8.15, 11.85, 15.55, 26.45, 37.65, 44.01, 51.15, 58.08, and 78.85 as shown in Figure 5. The average crystalline size of CdS nanoparticles was calculated by using the highest peak of 26.45 it was found to be 2.5 nm while using the lowest peak i.e. 78.85 the size of CdS nanoparticles was found to be 3.8nm.

Therefore, the synthesized CdS-NPs prepared using the extract of *dicliptera roxburghiana* ranged in the range of 2.5–8 nm, indicating a higher surface area and surface area to volume ratio of nanoparticles.

***EDX analysis:***

Energy dispersive X-ray (EDX) spectrometer (Sigma) is used for the elemental analysis of prepared CdS nanoparticles. The EDX pattern is shown in Figure 6c as X-ray counts versus energy (keV) which showed strong peaks of Cd and S which are their elemental signals from the emission of energies respectively. The spectra also

contain two peaks which are for Cu used during sample preparation as copper gird.

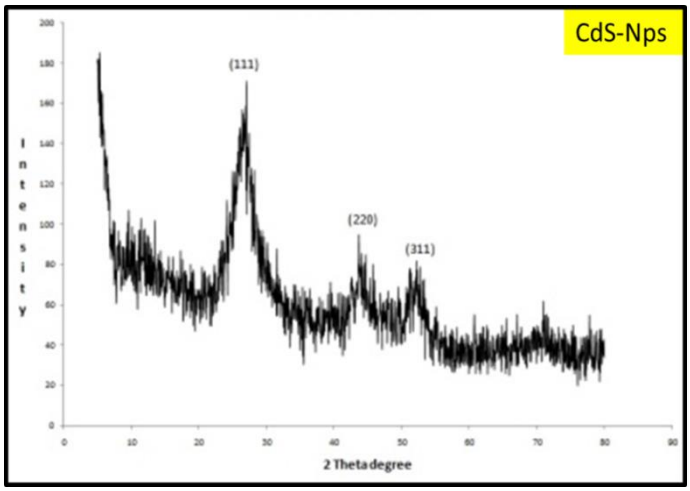


**Figure 5:** XRD pattern of CdS nanoparticles synthesized using *dicliptera roxburghiana* extract.

***Scanning electron microscopy (SEM) analysis:***

JSM5910 Scanning Electron Microscope at Centralized Resource Laboratory, University of Peshawar (CRL-UOP) was used for the morphological studies and the SEM micrograph is shown in Figure 6a which shows that the particles are well distanced from each other and they are not agglomerated due to the presence of phytochemicals in plant extract which prevent the nanoparticles from agglomeration while by other chemical methods especially in solution methods of preparation of CdS nanoparticles the particles are found to be agglomerated in the solvent [23].

***Transmission electron microscopy (TEM) analysis:***

The TEM analysis was carried out by (JEM 2100) transmission electron microscope which reveals details about the size and shape of synthesized cadmium sulfide nanoparticles using the extract of *dicliptera roxburghiana* as a capping and reducing agent. The technique used for the size and morphological studies of synthesized CdS nanoparticles was that a drop-coated film of synthesized CdS-NPs was made over Cu-coated Cu-grid. The transmission electron microscopy analysis was carried out at an accelerating voltage about of 200 kV and with 20000× magnification. The micrograph of transmission electron microscopy shows that the size of CdS-NPs synthesized using the extract of *dicliptera roxburghiana* has an almost uniform size distribution i.e. in the range 2.5-8nm with spherical morphology (Figure 6b). The other thing which is evident from the TEM micrograph is that the nanoparticles are free from agglomeration and well separated from each other.

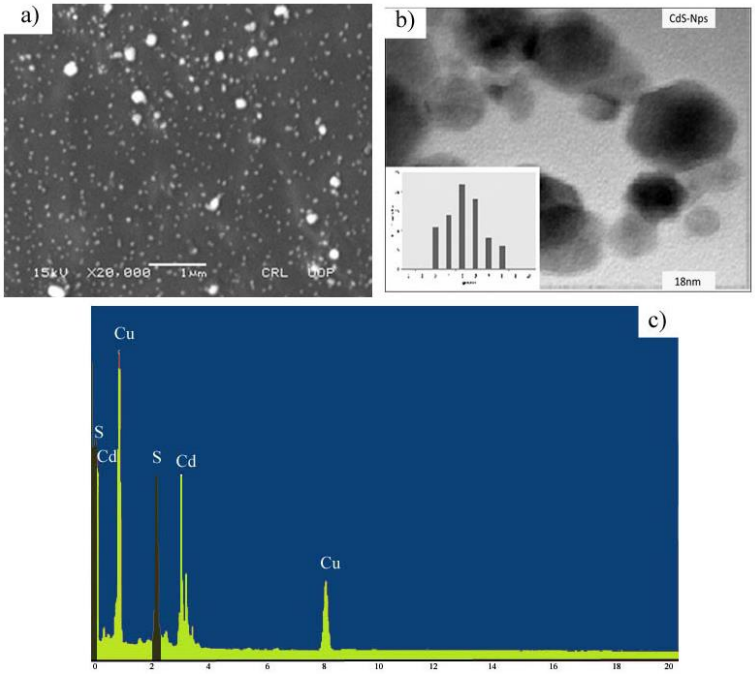


**Figure 6:** a) SEM image of CdS NPs, b)TEM image of CdS NPs using dicliptera roxburghiana extract along with particle size distribution histogram at bottom left corner, c) Energy dispersive X-ray spectra of CdS NPs.

***Photo kinetic study of CdS nanoparticles:***

The prepared CdS nanoparticles were now used as photocatalyst for the degradation of organic dye methylene blue under the action of solar irradiation. Here we developed a comparison of methylene blue degradation by dry CdS NPs and CdS NPs along with the plant extract solution. For this purpose, two sets of the experiment were carried outside by side where one of the 100 ml aqueous solutions of methylene blue contained 5 mg CdS-NPs where the other 100ml of methylene blue was without NPs. Both the solutions were exposed to sunlight and 5ml of the solution was taken out into centrifugation tubes from each of the flasks after every 15 minutes intervals. After centrifugation, the solutions were analyzed through a UV-Vis spectrophotometer and their maximum absorbance was written on the table. The initial maximum absorbance of methylene blue was at 644 nm which gradually decreased with time as a result of degradation whereas in the solution without nanoparticles we haven't observed any such kind of results and degradation, in that case, was almost zero.

***Time versus absorbance graph:***

As discussed earlier that the process of methylene blue organic dye degradation in the presence of CdS-nanoparticles synthesized using an aqueous extract of *dicliptera roxburghiana* increased as time pass and after 2 hours the reaction was completed and no degradation was noted further while the color of methylene blue turned light blue from dark blue whereas the solution without CdS-NPs remained the same with almost zero degradation. The absorbance spectrum became less intense with time because of the degradation of methylene blue and after 120 minutes the least

absorbance spectra were obtained. The relationship of time with absorbance and degradation of organic dye, methylene blue has been illustrated in the following figure 7;

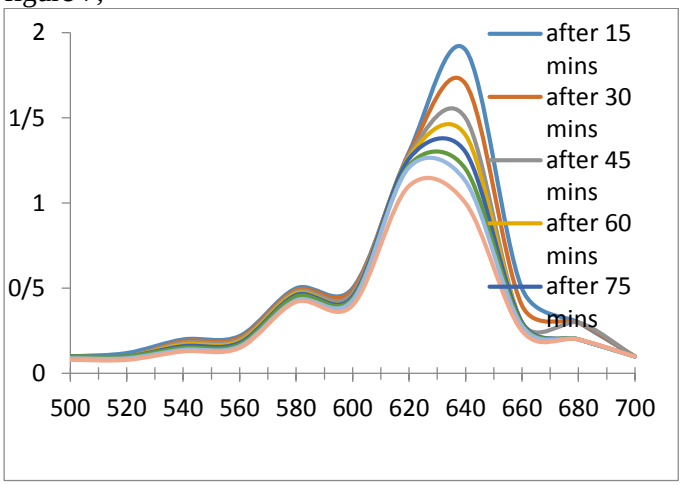


**Figure 7:** Time versus absorbance spectrum of methylene blue degradation by CdS-NPs at various intervals of time

***Time versus % degradation:***

As discussed earlier that with time the process of degradation increase as compared to earlier stages where degradation was too slow but after 30 minutes the reaction rate increases however it was found that the reaction follows first-order kinetics with the overall increase in the rate with time fig.8. The % degradation after various intervals of time from UV-Vis analysis was recorded on the table which is illustrated in the following fig and also the % degradation of 120 minutes was found to be 87.12% from our research which is calculated by equation (ii) following the pseudo-first-order reaction as reported in earlier researches that photodegradation of dye follows pseudo-first-order reaction kinetics [39].

% of degradation = $(A_0\text{-}A)/A_0 \times 100$ (ii)

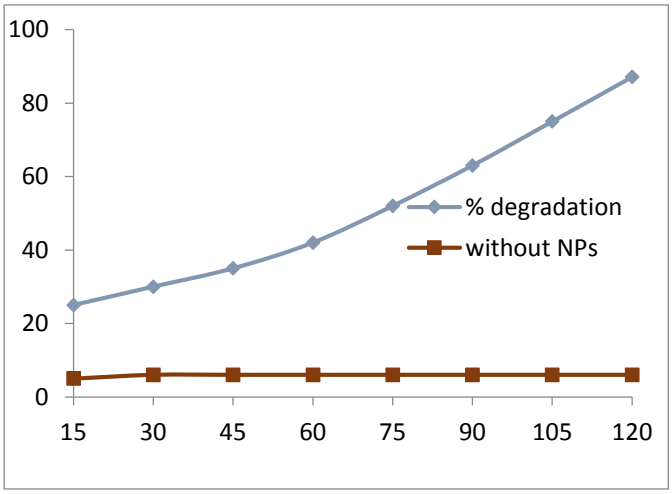


**Figure 8:** showing the degradation of methylene blue by CdS-NPs as a photocatalyst compared to methylene blue without NPs.

***Mechanism of photodegradation:***

The mechanism of photodegradation is explained in the following steps [51] :

1st step involves the generation of electrons and holes which are charge carriers;

$2CdS + h\nu \rightarrow CdS\ (e^-) + CdS\ (h^+)$

2nd step involves trapping of the charge carriers;

$H_2O + CdS\ (h^+) \rightarrow {}^{\bullet}OH + H^+ + CdS$

$O_2 + CdS\ (e^-) \rightarrow {}^{\bullet}O^{2-} + CdS$

3rd step involves the generation of the peroxy radicals;

$^{\bullet}O^{2-} + H^+ \rightarrow {}^{\bullet}OOH$

4th step involves the recombination of free radicals to generate hydroxyl free radicals;

$2\,{}^{\bullet}OOH \rightarrow H_2O_2 + O_2$

$H_2O_2 \rightarrow 2OH^{\bullet}$

5th step involves degradation of the dye (methylene blue) by interfacial transfer of charge;

Methylene blue + $^{\bullet}O^{2-}/OH^{\bullet}$ → oxidized & reduced products ($CO_2 + H_2O + NH_4 + NO_3 + SO2^{4-}$)

## 3. Experimental

***Materials:***

*Dicliptera Roxburghiana*, Analytical grade Cadmium Nitrate [Cd $(NO_3)_2$ $.4H_2O$] (98.5%), Analytical grade, Sodium Sulphide ($Na_2S.xH_2O$), Double distilled water, Methanol, Whatman filter paper No.1, Magnetic Stirrer (XTMD-702), Conical flask, 250ml Beaker.

***Methods:***

For the preparation of cadmium sulfide nanoparticles, the extract was prepared from the whole plant of *dicliptera roxburghiana* which was functioned further as a reducing and capping agent. 0.1M solution of cadmium nitrate and 0.1M solution of sodium sulfide were used for the synthesis of CdS-NPS, prepared in double distilled water, and stored in airtight conical flasks.

***Collection of plant:***

Along with the roots, stem, leaves, and flower fresh plant of *dicliptera roxburghiana* was collected from Government Postgraduate College Kohat, Pakistan, and washed several times with running tap water for removal of impurities and dust particles and then they were enclosed inside a box kept in a room for a week to remove the residual moisture in dark condition. The dried plant was crushed into small pieces and then ground into a fine powder. The finely powdered plant was placed in a tight air bottle for further use.

***Preparation of plant extract:***

The plant *dicliptera roxburghiana* was washed several times with running tape water to remove drains, dust particles, and soil. The plant material was then shade dried after which it was crushed into small pieces, and then grounded into a fine powder. For the preparation of plant extracts 10g of *dicliptera roxburghiana* plant powder was taken out into a 250ml beaker, into which

150ml of double distilled water was added and mixed well. 10 ml of methanol was added to the mixture at last with proper mixing. The mixture was then heated to 100 ° C until the volume was reduced to half of the total volume. The mixture was now filtered through Whatman filter paper No. 1 and was allowed to cool down to room temperature. The plant extract prepared (filtrate) was used in the reduction of CdS into CdS nanoparticles as well it was used also as a capping agent to prevent NPs from agglomerations.

***Phytochemical study of dicliptera roxburghiana extract:***

The plant extract of *dicliptera roxburghiana* prepared for the synthesis of CdS nanoparticles was now subjected to phytochemical analysis to study and detect the phytochemical contents which are responsible for the reduction of CdS ions into CdS-NPs. The analysis was carried out using standard phytochemical techniques [38].

***Test for the detection of flavonoids:***

1ml from 2N sodium hydroxide was added into 2ml of *dicliptera roxburghiana* extract and the solution turned yellow which indicated the presence of flavonoids.

***Test for the detection of Terpenoids***

To 2ml of plant extract 1ml of conc. $H_2SO_4$ and 2ml of chloroform were added. The appearance of reddish-brown color in the solution confirmed the existence of terpenoids.

***Test for the detection of Alkaloids:***

The 2ml extract of *dicliptera roxburghiana* was treated initially with 2ml conc. $H_2SO_4$ and after which 0.5ml Mayer's reagent was added dropwise into solution. The solution turned red and a white precipitate appeared in the solution which is the confirmation sign of the presence of Alkaloids.

***Synthesis of CdS nanoparticles:***

The scheme for the synthesis of CdS nanoparticles was designed after a detailed literature survey where various preparative parameters were compared [46, 47].

A 0.5 mm *dicliptera roxburghiana* extract was taken into 250 ml beaker placed on magnetic stirrer in which 50 ml from 0.1M cadmium nitrate was added and it was mixed thoroughly than 50 ml from 0.1M sodium sulfide was added in dropwise manner while the supernatant was placed on a magnetic stirrer for successful mixing. The mixture was kept on a magnetic stirrer in dark conditions for 12 hours while proper aluminum foil was wrapped in the beaker so that no light could interact with the mixture. A color change from light orange into yellow confirms initially the synthesis of cadmium sulfide nanoparticles and they were later on subjected to structural characterization. A complete stepwise sequence of CdS nanoparticles is illustrated in figure 1.

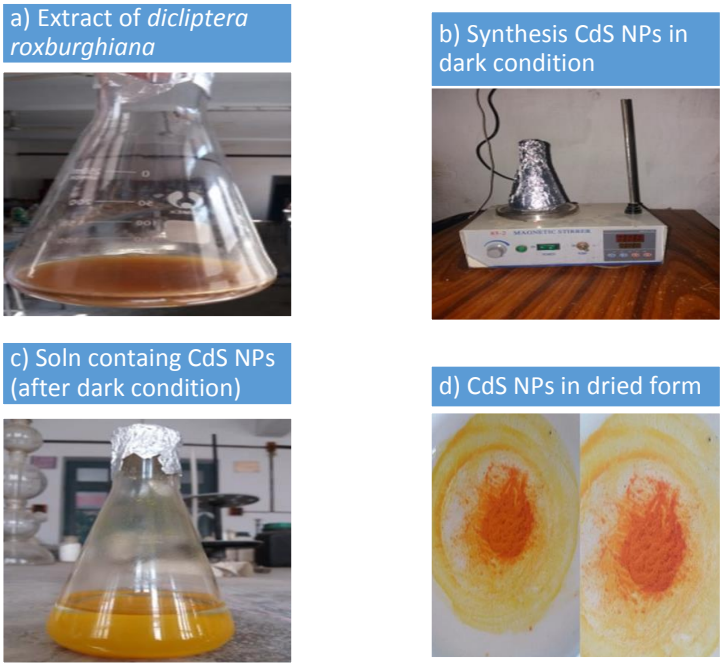


***Figure 1:*** *stepwise (a-c) synthesis of CdS nanoparticles using an extract of dicliptera roxburghiana*

***Characterization techniques and Instrumentations:***

The synthesis of CdS-NPs was confirmed by using the UV-Visible analysis initially. The analysis was performed using a UV-Visible spectrometer (spectrum two 108335) where the blank was prepared by adding 80 ml deionized water into 20 ml of plant extract. FTIR analysis of synthesized CdS nanoparticles was carried out to detect the reducing agents present in the plant extract. The analysis was performed using an FTIR spectrometer (PerkinElmer IR). The CdS nanoparticles were grounded on a KBr pellet which was used further for FTIR analysis. Phase distribution and particle size were determined by XRD analysis using a JDX-3532 XRD spectrometer with a scanning rater of 0.030/s and the Cu-K α radiation at a current of 20 MA and voltage of 30 kV. X' pert high scoring program was used to the determination of various phases present in the prepared sample by the ease of search and match.

Debye Scherrer's equation [48, 49] was used for the determination of particle size of the synthesized CdS nanoparticles as:

$$D = K\lambda/\beta\cos\theta$$

- Where D is the crystal size of CdS nanoparticles
- *K* is the Scherer's constant (shape factor) values range from 0.9 to 1.0
- $\lambda$ *is* the wavelength X-Ray radiation source while 5418 Å / 1.54059 nm is used in the case of XRD
- $\beta$ is the width of the XRD peak at half height
- $\theta$ is the Bragg angle.

An energy-dispersive X-ray spectrometer (sigma) is used to analyze the purity of prepared CdS nanoparticles where the sample was prepared by coating it on a copper

grid. JSM5910 Scanning Electron Microscope and was JEM 2100 transmission electron microscope which reveals details about the size and shape of synthesized cadmium sulfide nanoparticles using the extract of *dicliptera roxburghiana* as capping and reducing agent. The technique used for the size and morphological studies of synthesized CdS nanoparticles was that a drop-coated film of synthesized CdS-NPs was made over Cu-coated Cu-grid. The micrographs were obtained at an accelerating voltage about of 200 kV and with 20000× magnification.

***Photocatalytic activity of CdS-NPs:***

The photocatalytic activity and photokinetic study of synthesized CdS-NPs against the degradation of methylene blue organic dye were studied. The experiment was performed under solar light/ sunlight and for this purpose two separate aqueous solutions of the dye, methylene blue was prepared while the concentration of methylene blue was 10 ppm in each of the solutions. 100 ml of methylene blue solution was taken out into a conical flask. 5mg of CdS-NPs were added in one of the aqueous solutions of methylene blue while the other remained untouched. This was done to compare the effect of CdS nanoparticles in the degradation of methylene blue with a solution without the addition of nanoparticles and both the solutions were exposed to sunlight during a sunny day between 10 am to 12 pm (temperature 36-40 'C). Before exposure to sunlight, the solution containing the CdS-NPs was put on a magnetic stirrer at room temperature to get a uniform/equilibrium state of our working solution. 5ml of solution from each of the conical flask was taken out into centrifugation tubes at every 15 minutes interval and after centrifugation; the filtrate was measured by a UV-Visible spectrophotometer to study its maximum absorption values. The photodegradation of methylene blue was completed in two hours and the blue color of methylene blue disappeared with time, which indicates the degradation of methylene blue where CdS NPs act as photocatalyst. Before subjection to sunlight, the aqueous solution of methylene blue shows a maximum absorption spectrum at 644 nm. The efficiency of the process of degradation was calculated from absorption intensity at 644 nm by the use of the following equation

% degradation of Methylene Blue = $(A_a - A_t)/A_a \times 100$

Here $A_a$ is the initial absorbance of methylene blue soln. and $A_t$ is the final absorbance or absorbance after time 't' exposure to sunlight irradiation. The degradation depends upon several factors such as the nature of nanoparticles used, time period of exposure to radiation, and their surface modification by doping or to use the selected metal in nanocomposites form can also affect the degradation percentage. Table 1 compares the methylene blue degradation by some green synthesized nanoparticles based on exposure time period, degradation percentage, and the nature of nanoparticles in pure form as well in form of nanocomposites.

| Green NPs | Degradation % | Time | Ref |
|---|---|---|---|
| Cu NPs | 72.60% | 90 mins | [52] |
| ZnO NPs | 92% | 300 mins | [53] |
| Mn-ZnO NPs | 99% | 120 mins | [54] |
| $Fe_2O_3$ NPs | 81% | 360 mins | [55] |
| RGO-$Fe_3O_4$ | 89.35% | 60 mins | [56] |
| NiO NPs | 79% | 240 mins | [57] |
| $TiO_2$ NPs | 76% | 120 mins | [58] |
| $ZnTiO_3$ NPs | 80% | 60 mins | [59] |
| $SnO_2$ NPs | 73% | 85 mins | [60] |
| $Cu_2SnSe_3$ | 90% | 120 mins | [61] |
| $Cu_2ZnSnS_4$ | 83% | 100 mins | [62] |
| CS-ZnS-NPs | 96.7% | 100 mins | [63] |

NPs= Nanoparticles, Cu NPs= Copper nanoparticles, ZnO= Zinc oxide nanoparticles, Mn-ZnO NPs= Manganese doped Zinc oxide nanoparticles, $Fe_2O_3$ NPs= Iron oxide nanoparticles, RGO-$Fe_3O_4$= Reduced Graphene oxide nanoparticles, NiO NPs = Nickel oxide nanoparticles, $TiO_2$ NPs: Titanium oxide nanoparticle, $ZnTiO_3$ NPs: Zinc titanate nanoparticles, $SnO_2$ NPs: Tin oxide nanoparticles, $Cu_2ZnSnS_4$= Copper zinc tin sulfide, CS-ZnS= Chitosan - zinc sulfide

## 4. Conclusion

Green synthesis of CdS nanoparticles using the extract of *dicliptera roxburghiana* is reported in this paper. The techniques used for the characterization of synthesized CdS NPs include UV-Vis, FTIR, XRD, EDX, SEM, and TEM. Spherical CdS nanoparticles with a size range 2.5 – 8nm were prepared to have bandgap 3.31 eV furthermore the characterization reveals the presence of stabilizers i.e. phytochemicals in plant extract which not only act as a reducing agent but also prevented nanoparticles from agglomeration. The present method for the synthesis of CdS nanoparticles is cheap, environmentally friendly, and reproducible and the prepared nanoparticles have the potential applications same as those prepared by other chemical methods.

The photocatalytic activity of prepared CdS nanoparticles against methylene blue is reported in a comparative manner i.e. two sets of the experiment are performed in

such a way that one set of the experiment has dry CdS NPs, second has the CdS NPs in solution form with plant extract and. Dry CdS NPs are most efficient among all with a degradation % of 87.12% in just 120 minutes following pseudo-first-order rate. Other applications of CdS NPs prepared by the same method can be performed in the future as they can perform well.

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