Study of Photocatalytic Organic Functional Group Transformation by Metal-CdS Composite Particles

A
Thesis Submitted
in partial fulfillments of requirements for the
Degree of
Master of Science in Chemistry

Submitted By
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June 2009

Acknowledgements

I take this opportunity to thank my guide Dr. Bonamali Pal for his guidance and support in doing this project. He has instilled in me the knowledge and motivation to learn more about the subject.

I am grateful to Prof. Susheel Mittal for approving this project to me.

I am thankful to all the Ph.D. scholars for their timely help and support.

The laboratory staff was very forthcoming and helpful in every possible way and I am highly obliged to them.

I thank all my friends who constantly motivated me and supported me throughout the project.

Ketki

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Candidate's Declaration

I hereby declare that the work being presented in the dissertation entitled **"Study of Photocatalytic Organic Functional Group Transformation by Metal-CdS Composite Particles",** in partial fulfillment of the requirements for the award of the degree of Masters in Chemistry, School of Chemistry and Biochemistry (SCB), Thapar University, Patiala, is my own work during the period of Jan 2009 to May 2009, under the supervision of Dr. Bonamali Pal, Assistant Professor, School of Chemistry and Biochemistry, Thapar University, Patiala. I have not submitted the matter embodied in this dissertation for the award of any other degree.

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Patiala
Date: 28 MAY, 2009

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This is to certify that the above statement made by the candidate is correct and true to the best of our knowledge.

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Certificate

This is to certify that the project entitled **"Study of Photocatalytic Organic Functional Group Transformation by Metal-CdS Composite Particles"**, being submitted by Ms. Ketki Shrivastava in partial fulfillment of the requirement for the award of degree of Master of Science in the School of Chemistry and Biochemistry, Thapar University, Patiala, is a bonifide work carried out under the supervision of Dr. Bonamali Pal and that no part of this project has been submitted for the award of any other degree.

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Introduction

Semiconductors are three-dimensional networks of ordered atoms. They have properties that are intermediate[1] between conductors and insulators. Their conducting power can be increased by a number of factors like increasing temperature, metal doping etc. At 0 K the lower energy levels, or ***valence band,*** are filled with electrons, while the ***conduction band*** consisting of the higher energy levels is unoccupied. Semiconductors typically exhibit band gaps in the range 0.3−3.8 eV. Irradiation of semiconductor with a light of wavelength greater than or equal to the band gap produces charged (electron and holes) carriers. The photoexcited electron in the conduction band together with the resulting hole in the valence band forms an ***“electron−hole”*** pair which is responsible for interesting semiconducting properties in various applications.

The main difference between a semiconductor and metal and insulator is the ***band gap***. In ***Insulators*** the electrons in the valence band are separated by a large gap from the conduction band, in ***Conductors*** like metals the valence band overlaps the conduction band, and in ***Semiconductors***[2] there is a small enough gap between the valence and conduction bands that thermal or other excitations can bridge the gap.

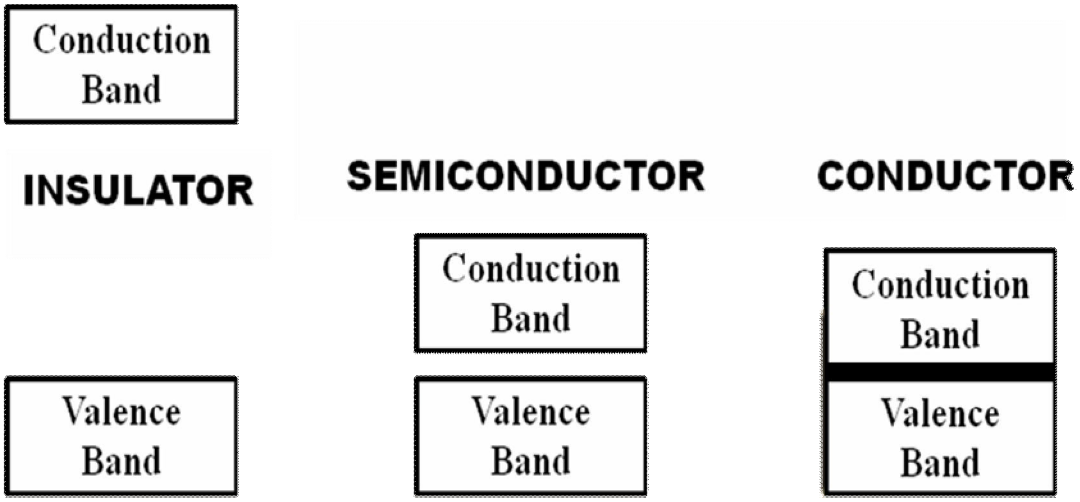


Fig. 1 Comparison of bandgap of conductor, insulator and semiconductor

A semiconductor material can be used effectively as a photocatalyst depending on the absorption capacity of light**.** Photocatalysis is a reaction which uses light to activate a semiconductor material, that produces photogenerated charged species responsible for photocatalytic action. Photocatalysis using semiconductors under irradiation[3] has been extensively studied for about three decades. In 1972, Fujishimna and Honda discovered the photocatalytic splitting of water on TiO_2 electrodes. This event marked the beginning of a new era in *heterogeneous photocatalysis*[4]. The main focus of previous studies have been to investigate the principal application of photocatalysis systems for treatment of water polluted with toxic substances. In the past, a lot of work has been done using CdS photocatalysis. For e.g., a hybrid photocatalytic system based on a mixed-phase cadmium sulfide matrix composed of nanoparticulate cubic-phase CdS with average particle diameters of 13 nm and a bandgap energy of 2.6 eV, is coupled with bulk-phase hexagonal CdS that has a bandgap energy of 2.3 eV and is interlinked with platinum deposits. The resulting hybrid nanocomposite catalysts are photocatalytically[5] efficient in hydrogen gas production from water with visible light irradiation at $\lambda > 420$ nm. The study of photocatalysis is mainly done on sulphides and oxides of metals like PbS, Fe_2O_3, CdS, TiO_2, ZnS etc but here we are going to concentrate on CdS photocatalyst. Most of the work is done using bulk semiconductors but here we will be working with nanocatalysts which have a variety of advantages and applications.

Why is photocatalysis a ***preferred*** and more ***advanced technique*** than conventional organic synthesis? The main reasons[6] for this are:

(i) Since both ***oxidation and reduction occur*** simultaneously on the photo irradiated semiconductor particles, reactions like electrolytic organic synthesis are expected to ***proceed efficiently*** on each particle.

(ii) Redox reactions by e^- and h^+ leave ***no by-product***, unlike conventional organic synthesis using usual redox agents like Lithium Aluminium Hydride and Potassium Permanganate.

(iii) Organic synthesis due to photocatalysis is much more ***simpler and efficient;*** the photocatalytic products can be isolated simply by centrifugation or filtering and there is less requirement of chromatography.

(iv) It is ***superior to general synthetic processes*** since they proceed smoothly even in aqueous solutions and sometimes in organic solvents at ambient temperature and pressure as compared to restricted conditions of conventional synthesis.

(v) Photocatalysis well satisfies the ***requirement of ‘‘green chemistry’’*** since the technique does not leave any dangerous by products and does not use any toxic solvent.

There are many advantages of using photocatalysis and a large number of them have been used for a variety of reactions, but unfortunately, in the field of organic synthesis, ***no photocatalytic reactions have been industrialized***[7] so far.

❖ Function of Metal Loading

Metal loading is mainly done in order to ***improve the photocatalytic activity*** of nanoparticles like CdS. The photocatalytic activity of CdS is observed to be very poor in the absence of a metal. Generally a noble metal like Au, Ag or Pt is added to the nanoparticle in order to ***avoid the recombination*** of electron and hole. Only when this recombination is prevented will the photocatalytic activity be enhanced and redox reactions can be easily carried out.

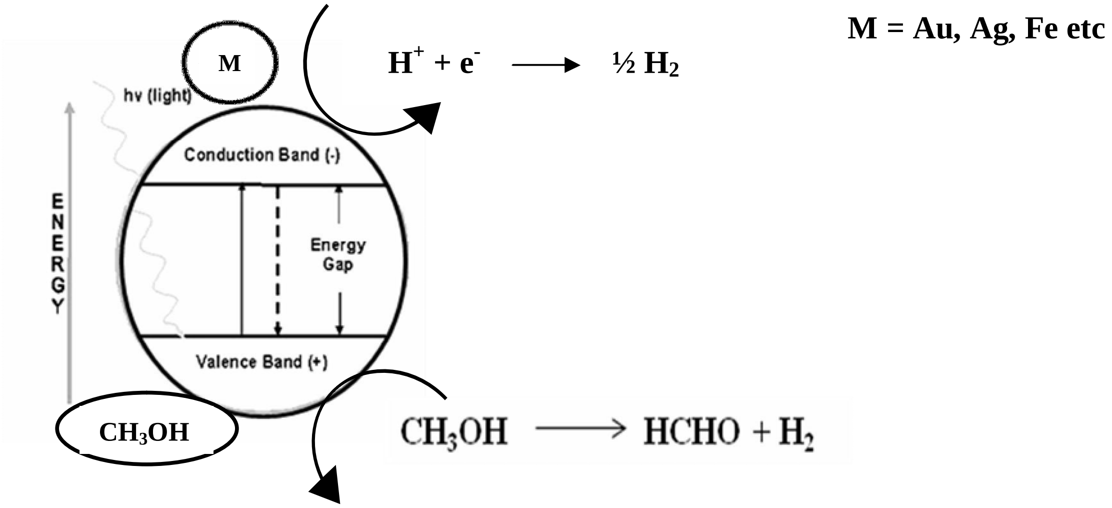


Fig. 2 Loading of metal (electron acceptor) and CH_3OH (electron donor) on CdS nanoparticles

When a metal like Ag/Fe/Au get attached at the surface of the nanoparticle, it ***picks up the electron*** that is transferred from conduction band[8] to valence band before the hole in the valence band can accept it thus preventing recombination. The metal is present on the surface and thus has an ***electron rich region*** which can be attacked by a suitable electrophile. The molecule is susceptible to ***attack by oxidizing agents*** as well that will accept electrons from the surface and bring about oxidation. On the other hand, if an electron rich species like methanol is loaded in the CdS nanoparticle, electron and hole recombination is still prevented as the hole accepts electrons from the electron rich species and the surface of the molecule is ***deficient in electrons.*** Thus, electron rich[9] species will attack the surface. The molecule will get reduced as it is susceptible to attack by reducing agents.

The aim of metal loading is to prevent the recombination of electron and hole produced so that the activity of the photocatalyst can be regulated[10] as per our requirements. By regulating the above we can change the selectivity and yield of the product. It has been reported that there is a direct correlation between the rates of hydrogen evolution and properties of the transition metal cocatalysts. Without cocatalysts[11], photocatalysts show very ***poor performance*** and many of them do not function at all.

Literature Survey

❖ CdS Nanoparticles

CdS nanoparticle has given an idea of the purpose of using a photocatalyst to carry out various organic reactions as well as the advantages and disadvantages of using CdS photocatalyst. In this section, I have mentioned some of the research work, out of the many hundreds, on the photocatalytic activity of CdS[11] along with a few methods of synthesis of CdS nanoparticles.

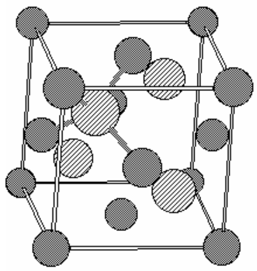


Fig.3 Zinc Blende structure

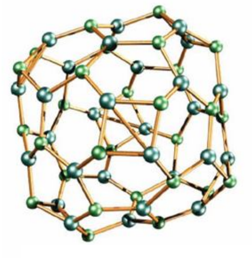


Fig.4 Wurtzite structure

Cadmium Sulphide is a chemical compound with the formula CdS. Cadmium sulfide is yellow in colour and is a semiconductor. It exists in nature as two different minerals[12], ***greenockite*** and ***hawleyite.*** Cadmium sulfide is a ***direct band gap semiconductor*** (2.42 eV). CdS has two crystal forms; the more stable hexagonal ***wurtzite*** structure (found in the mineral Greenockite) and the cubic ***zinc blende***[13] structure (found in the mineral Hawleyite). In both of these forms the Cadmium and sulfur atoms are four coordinate.

There are many synthesis processes that have been reported earlier for the synthesis of CdS nanoparticles and CdS-TiO_2 nanocomposites, a few of which have been described here. A two-step sol–gel process[14] was used to prepare the gel glass. Tetraethyl orthosilicate (TEOS) was in an acidic solution of ethanol and cadmium acetate in ethoxyethanol was added into the solution. Ammonia was added and the gel was dried for 10 days. Finally CdS/ silica nanocomposite was obtained by passing H_2S gas. Zeolite Na-Y was slurried in distilled water and cadmium nitrate was added with continuous stirring. The sample was exposed to flowing hydrogen sulfide and after sometime the white zeolite becomes pale yellow-cream, and this color change is reversible. This indicates formation of CdS nanoparticles by further characterization. There are many intrinsic properties[16] of CdS nanoparticles that are responsible for its photocatalytic activity.

CdS-TiO_2 Nanocomposites

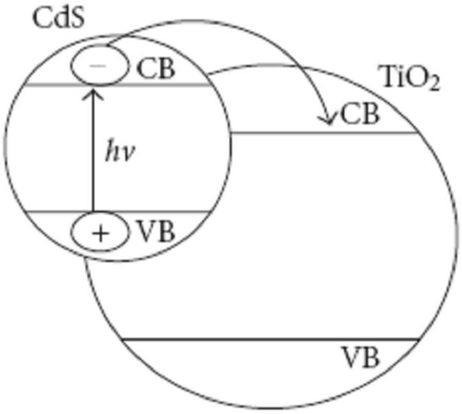


Fig.7 CdS TiO_2 nanocomposite

In order to increase the activity of CdS nanoparticles as efficient photocatalysts, they are generally impregnated in TiO_2 and the combination is called *CdS-TiO_2 nanocomposites*[15]. CdS alone, however, shows negligible photocatalytic activity because of its instability and rapid electron-hole pair (EHP) recombination rates. Studies have proven that with the appropriate particle interaction, CdS-TiO_2 nanocomposites can efficiently decompose organics such as phenol under visible light irradiation less than 495nm. The reaction occurs when a CdS particle is excited by a photon with a wavelength less than 495 nm. Subsequently the photogenerated electron is quickly transferred to the conduction band of a coupled TiO_2 particle that has a conduction band more positive than the CdS particle (□ 0.5 eV). This electron has no holes to recombine with and therefore participate in reduction reactions according to the conduction band energy level of TiO_2.

Organic Synthesis and Group Transfer Reactions

Though CdS has not been explored much in the field of organic synthesis, there are few examples[16] of it where it shows its oxidizing and reducing ability particularly incase of nitroaromatics.

Photoirradiation 2-propanol aqueous solution containing nitrobenzene and rhodium-loaded silica-coated cadmium sulfide nanoparticles produced azoxybenzene with relatively high selectivity (68%), the photocatalytic[17] activity being enhanced with a decrease in the size of the semiconductor particle core.

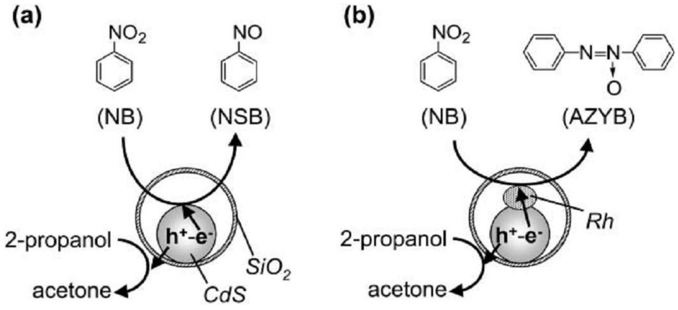


Fig.5 Photocatalytic reduction of NB by SiO_2/CdS without Rh (a) and with Rh loading (b)

Another example is the geometric and valence isomerizations of unsaturated organic molecules on illuminated[18] CdS surface. The cis-trans isomerization of several simple alkenes proceeds with a light conversion efficiency greater than unity on suspended particles of CdS usually in polar inert solvents**.**

The light-conversion efficiency of the valence isomerization of quadricyclene to its ringopened isomer norbornadiene[19] is influenced by the identity of the photocatalyst (TiO_2, CdS, or ZnO) and the solvent (CH_2C1_2, CH_3CN, or THF) with the chemical yield of ring-closed product decreasing in the following order CdS > TiO_2 ≥ ZnO and CH_2C1_2 > CH_3CN > THF.

Fig. 6 Photocatalysis by CdS in excited state in the presence of methyl viologen

Objective

The reason behind the catalytic activity of CdS is *photoetching.* Photoetching is the technique where the size of the CdS particle is reduced selectively in order to suit the experimental needs. When a semiconductor is illuminated[20] with light that has an energy which exceeds that of the band gap, absorption can take place, and electron-hole pairs are created. The electron can subsequently recombine with the hole, either ***radiatively*** or ***non-radiatively.*** When the recombination[21] of electron-hole pairs can be prohibited by removing the electron (by an interfacial process), the hole can be used to dissolve the semiconductor. This well-known process of ***Electroless Photo Etching,*** in combination with the shift of the absorption onset to higher energies upon a decrease of the particle size, provides the basis for the technique of ***Size-Selective Photoetching.*** Removal of the electron from a semiconductor particle can be achieved by using ***electron scavengers*** such as oxygen molecules or ***methylviologen*** ions (MV^{2+}) that are adsorbed on the surface of the particle. The principle of the size-selective photo etching relies on both facts that metal semiconductor particles are ***photo corroded***[22] in aqueous solution under irradiation and that the energy gap of semiconductor nanoparticles increases with a decrease in the particle size. If the irradiation is performed with use of light of selected wavelength, these particles are selectively ***photo etched*** to smaller ones until the irradiated photons are not absorbed anymore in the nanoparticles.

Size-selective photoetching as a means to adjust the size of nanocrystalline semiconductor particles with a high degree of control. The particle size after photoetching[23] is determined by the energy of the light that is used for photoetching. The technique ***works very well for nanocrystalline CdS*** particles and enables one to prepare a series of samples with different well-defined particle radii, covering a wide range from ***35 to 7.5 Å.*** The decrease in mean particle size is accompanied by a narrowing of the particle size distribution from some 40% to 10−15%.

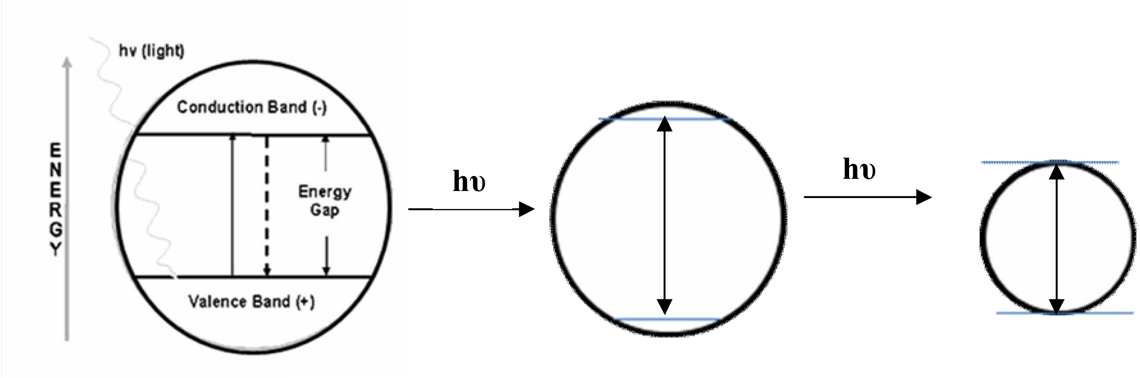


Fig. 8 Size selective photoetching of CdS nanoparticles

As the ***size decreases the band gap increases.*** This is a characteristic phenomena[24] that occurs in a semiconductor nanoparticle when it is being photoetched. The decrease in size brings about changes in physical and chemical properties that is responsible for the photocatalytic action.

Experimental Work

The work done with CdS nanocatalysts was carried out using a photocatalytic reactor, where the photocatalytic reactions were carried out.

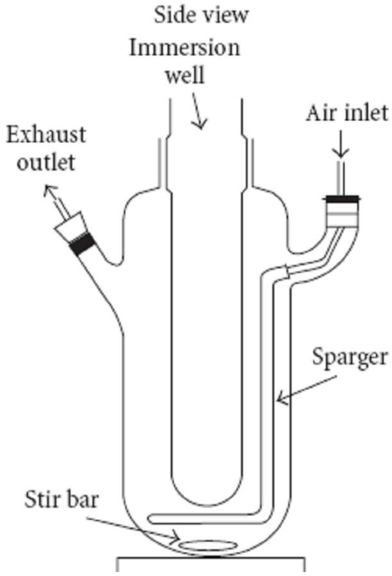


Fig. 9 Photocatalytic Reactor

The reactor[25] has two glass tubes arranged concentrically, one having a larger diameter than the other. The inner channel contains an elongated light source, such as a bulb or a fiber optic bundle radiating light outwardly. There are two openings at the top, one for water inlet and the other water outlet. On the sides, there is an air inlet and an exhaust outlet. A long thin capillary on the air inlet side is a sparger that helps in homogenizing air with the reaction mixture. At the bottom is a stir bar that is magnetic in nature such that the entire set up can be placed over a magnetic stirrer.

In the present case, the outer glass jacket was removed and the reaction mixture was put in 25 ml test tubes in order to test a variety of samples and also to conduct time course reactions. The test tubes were kept as close as possible to the elongated light source, which hung in the inner glass tube, so that they were exposed to UV radiation and the reaction was carried out. The whole set up was placed in a wooden box to prevent the radiations from escaping as well as a safety measure. The lamp used had a power of 125 W and the intensity measured was 10.4 mW/cm^2.

Using the properties of CdS as mentioned, I have divided my experimental work in three sections that are discussed in detail as below:

1. Synthesis of Nanocatalysts.

2. Metal impregnation of catalyst.

3. Testing the catalysts – Experiment with KI and Functional group transformation (Reduction of Nitroaromatics)

- **Synthesis of Nanocatalyst:** CdS from different sources was used in the preparation of nanoparticles. The methods that were carried out are explained in this section.

  50 mg bulk CdS sample was taken in a test tube and 10 ml distilled water was added to it. 50 μM solution of methyl viologen (MV^+) was prepared and 5 drops were added to the CdS solution. O_2 was purged in it for a period of 10 min and it was placed in photochemical reactor for different time intervals of two hours till eight hours. UV Spectra was recorded.

  0.1 mol/dm^3 solutions of $CdCl_2$ and Na_2S were prepared. In a 250 ml beaker, 25 ml solution of 0.1 mol/dm^3 $CdCl_2$ was taken and while stirring using a magnetic stirrer, an equivalent amount of 0.1 mol/dm^3 Na_2S was added from a 25 ml burette. The resulting solution lead to the formation of laboratory synthesized CdS. The solution was allowed to stir for 1 h. After stirring, the solution was placed in the photoreactor and allowed to undergo photoetching with stirring on a magnetic stirrer for 2.5 h. UV Spectra was recorded. The resulting solution was filtered and dried in a muffle furnace at a temperature of 500^o C for a period of 5 h.

  1 g P-25 TiO_2 was taken in a beaker and 50 ml of distilled water was added to it. Different weight percentages of CdS were impregnated in TiO_2 by addition of equimolar amounts of $CdCl_2$ and Na_2S in the solution with stirring on magnetic stirrer for 1 h. The resulting solutions contained a mixture of CdS and TiO_2 in different weight percentages. The solutions were filtered and dried. After drying, 10%, 20% and 50% weight percentages prepared are divided in 3 parts each and each part was subjected to sintering at three different temperatures i.e. 300^o C, 500^o C and 700^o C in the muffle furnace for a period of 5 h each whereas, 1%, 3%, and 5% weight percentages prepared are dried at 100^o C in electric oven for 5 h and were not subjected to a high temperature sintering.

- **Metal Impregnation on CdS:** Different metals were loaded on commercial CdS. The procedure that was followed is explained in this section. 2g CdS was weighed and 50 ml distilled water was added to it in a 250 ml beaker. The metals chosen for impregnation were: **Fe, Au, Ag** and **Ni**. Different weight percentages of these metals (from a solution of their respective metal salts) were impregnated on CdS. Metal was impregnated in the reduced form (M^0) as well as in the oxidized form (M^{n+}). In order to impregnate metal in reduced state, 0.1 mol/dm^3 solution of $NaBH_4$ was added to the solution above in equimolar amount as the solution of metal salt. The catalysts thus prepared are filtered and dried at a temperature of 500^o C in a muffle furnace for a period of 5 h.

- **Photocatalytic Test Reaction with KI:** The catalytic efficiency was tested with 200 mmol/dm^3 aqueous solution of KI. The photocatalytic activity[27] was evaluated through the formation of I_3^- due to oxidation of I^- to I_2 as a model reaction. The absorbance peak of I_3^- appeared at 288 nm. Photocatalytic reaction is based on the following reaction:

$$2I^- \rightarrow I_2 + 2e^-$$

$$I_2 + I^- \rightarrow I_3^-$$

The catalysts prepared above were tested with KI.

50 mg of commercial CdS, photoetched commercial CdS, laboratory synthesized photoetched CdS and metal impregnated CdS were added to 3 ml solution of KI in different test tubes and O_2 was purged in the solutions for a period of 10 min each. The test tubes were kept in photoreactor under UV light for 2.5 h with stirring using a magnetic stirrer. The resulting solutions were analyzed by taking their UV spectra.

Incase of CdS-TiO_2 nanocomposite, the reaction were divided in two categories. Firstly, 50 mg of 1%, 3% and 5% catalysts were taken in three different test tubes and 3 ml KI was added to each of them. O_2 was purged in all the test tubes for a period of 10 min each and they were subjected to UV radiation for different time periods viz. 1 h, 2h and 3h along with continuous stirring on a magnetic stirrer. After the end of each time interval UV spectra of the respective solutions were taken. Secondly, 10%, 20% and 50% prepared at different temperatures were tested in the same manner as above. The test tubes containing the reaction mixture were subjected to UV radiation for a period of 2.5 h. At the end of 2.5 h, the resulting solutions were analyzed by titrating them against 0.1 mmol/dm^3 solution of $Na_2S_2O_3$.

- **Reaction with Nitrobenzene:** The nitroaromatic compound chosen for reaction was **nitrobenzene**, the reason being the ease with which aniline[28] formed under the given experimental conditions can be detected.

  The catalysts used for this reaction were 10%, 20% and 50% by weight of CdS-TiO_2 prepared at three different temperatures. 50 mg of each of the catalysts were taken in different test tubes and 3 ml of nitrobenzene with 5 ml of distilled water was added to each one of them. Since the reaction to be carried out is **reduction**, O_2 had to be removed from the system for which N_2 was purged in the test tubes for a period of 15 min each. The test tubes were tightly capped by rubber caps and sealed using parafilm. They were then subjected to UV radiation for a period of 4 h. At the end of 4 h, the solutions were filtered using a cellulose filter until a clear solution was obtained, which was then analyzed by taking their UV spectra.

Results and Discussion

By the above experimentation, CdS is first characterized using UV visible spectrophotometry and then the data pertaining to reaction with nitrobenzene and KI is presented.

- **Characterization of CdS:** The UV spectras of standard known samples of commercial CdS and laboratory synthesized CdS were taken. From this curve, various comparisons were made regarding the photoetching of different samples of CdS.

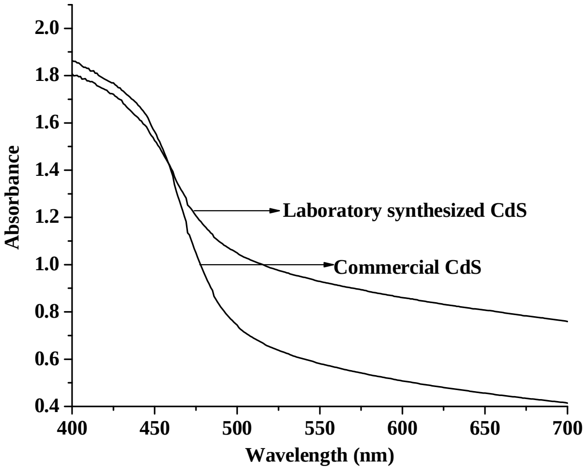


Fig. 10 Absorption maxima values of authentic samples of commercial CdS & laboratory synthesized CdS using MV$^+$

- **Photoetching Data:** Commercial CdS when photoetched for a period of 8 h and laboratory synthesized CdS when photoetched for different intervals of time, **did not show** any significant change in size as observed in its UV spectra.

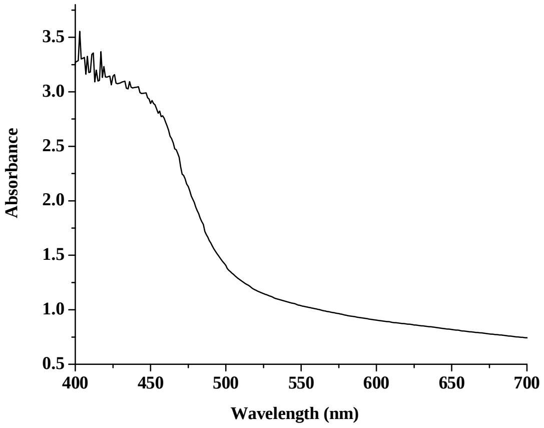


Fig. 11 Photoetching of commercial CdS using MV$^+$ at t=8 hrs

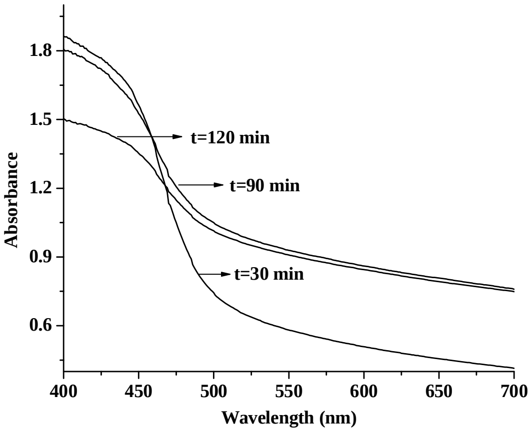


Fig. 12 Comparison of photoetching of laboratory synthesized CdS using MV$^+$

- **Photocatalytic Test Reaction with KI:** Commercial CdS, metal impregnated commercial CdS, photoetched commercial CdS and laboratory synthesized photoetched CdS **did not show** catalytic activity with KI. The possible reason for failure of activity is inadequate reduction in particle size that did not lead to reaction of KI or reduction of nitrobenzene. In case the laboratory synthesized CdS was exposed to UV radiation for over a period of 2.5 h the solution became clear. Thus it was not exposed for more than that period of time. 1%, 3% and 5% by weight of CdS on TiO_2 **did not show** any catalytic activity with KI after being subjected to UV radiation for a variable time periods of 1 h, 2h and 3 h as seen in the UV spectra of the respective solutions.

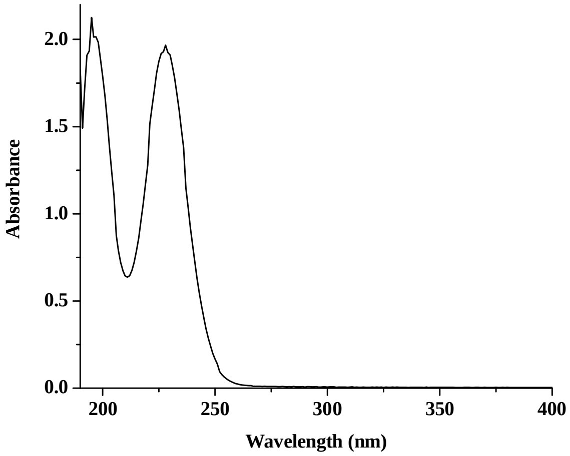


Fig.13 Standard graph of KI (10 µM)

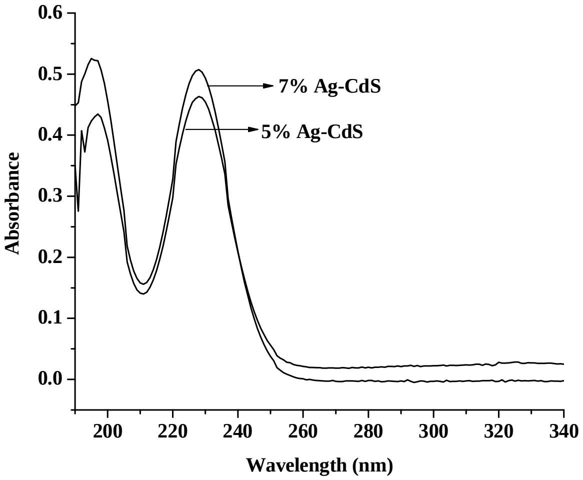


Fig. 14 Comparison of 5% Ag-CdS and 7% Ag-CdS in reaction with KI

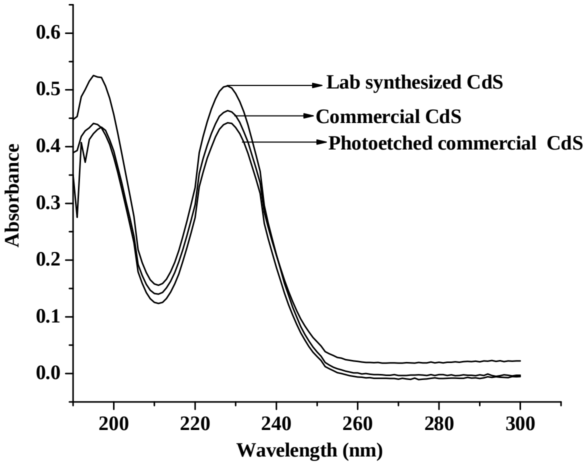


Fig. 15 Comparison of laboratory synthesized CdS, commercial CdS and photoetched commercial CdS

In case of CdS-TiO_2 composite catalyst, for CdS-TiO_2 catalyst sintered at 300°C at the end of 2.5 h, it was seen that there was **no evolution of I_2** as observed by the titration with 0.1 mmol/dm^3 $Na_2S_2O_3$ as well as by data obtained from the UV spectra of the resulting solution. For CdS-TiO_2 catalyst sintered at 500°C and 700°C, it was seen that there was **evolution of I_2** as observed by the titration of the resulting solution against $Na_2S_2O_3$.

Titration Reading of CdS TiO_2 catalysts and concentration of I_3^- evolved

Temperature of sintering	Weight % of CdS-TiO_2 catalyst	Amount of 0.1 mmol/dm^3 $Na_2S_2O_3$ consumed	Concentration of I_2 evolved
500°C	10	21.0	700 µM
	20	10.0	340 µM
	50	-	-
700°C	10	28.0	940 µM
	20	20.0	670 µM
	50	6.0	200 µM

- **Reduction of Nitrobenzene:** In the reduction of nitrobenzene, 10%, 20% and 50% by weight of CdS on TiO_2 sintered at temperatures of 300°C and 700°C **showed catalytic activity** in the formation of product at an absorption maximum of 232 nm, which pertains to aniline i.e. the expected product. No major peaks were observed other than that of aniline.

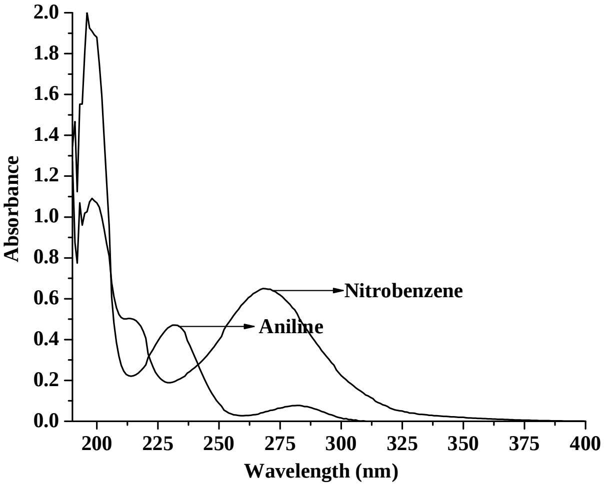
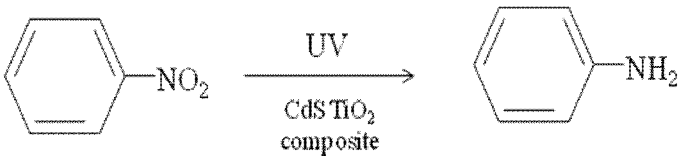


Fig. 16 10 µmol/dm^3 solution of Nitrobenzene and Aniline

In case of CdS-TiO_2 catalysts sintered at 500°C, **no formation of aniline** was seen. The standard graphs of nitrobenzene and aniline are shown. The reaction that is being carried out is reduction of nitrobenzene as under:



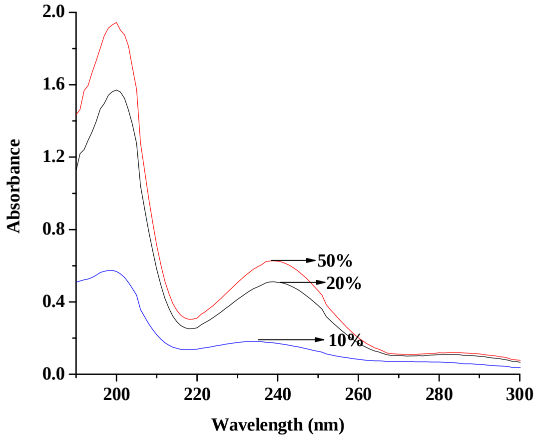


Fig.17 50 mg CdS-TiO_2 sintered at 300° (10%, 20%, 50%) + 2ml Nitrobenzene + 2ml Distilled water at t=4 h

This is a graph of formation of aniline from nitrobenzene using CdS TiO_2 catalyst sintered at 300°C. As per data, 50% CdS TiO_2 seems to be more active amongst all. Possible reason could be combined catalytic activity of CdS and TiO_2 in the composite phase at 300°C.

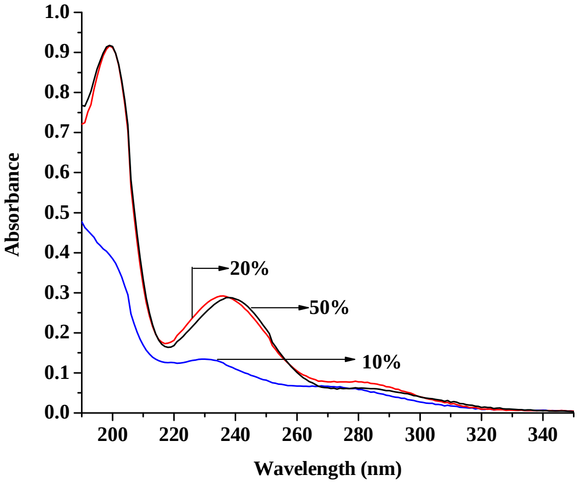


Fig. 18 50 mg CdS-TiO_2 sintered at 700° (10%, 20%, 50%) + 2ml Nitrobenzene + 2ml Distilled water t=4 h

This is a graph of formation of aniline from nitrobenzene using CdS TiO_2 catalyst sintered at 700°C. The activity of 20% and 50% seems to be higher than 10%. The possible reason might be due to increase in crystallinity at higher temperature along with combined activity of CdS and TiO_2.

The activity of CdS-TiO_2 was seen to be higher than bare TiO_2 or CdS as can be seen from I_2 formation reactions and also in the reduction of nitrobenzene. There is greater activity at higher temperature and a possible reason maybe due to crystalline nature or morphology of the composites. The catalytic reaction occurs on the surface thus factors like surface area maybe altering the activity. Incase of CdS TiO_2 sintered at 500°C, discrepancy in results were obtained, that is in contradiction with the expected result. Thus, further experimentation and research needs to be done in this direction.

The amount of aniline obtained in the above can be quantified by comparing the results obtained with wavelength vs. absorbance curve of a sample of aniline having known concentration of 10^{-5} mol/dm^3 with an absorbance value of 0.5. The following observations from the known sample can be made:

Concentration of Aniline obtained by reduction of Nitrobenzene

Temperature of sintering	**Weight % of CdS-TiO_2 catalyst**	**Concentration of Aniline formed (µmol/dm^3)**
300°C	**10**	**4**
	20	**10**
	50	**12**
500°C	**10**	**34**
	20	**4**
	50	**16**
700°C	**10**	**3**
	20	**6**
	50	**3**

Conclusion

From the above experimentation using various techniques, it can be concluded that under the given laboratory conditions, CdS alone failed to show any catalytic activity even after photoetching, but the combined effect of CdS impregnated in TiO_2 showed good catalytic activity in the evolution of I_2 as well as in the reduction of nitrobenzene. Metal loading enhances the catalyst activity tremendously, but under the given experimental conditions, it could not be proved.

Aniline is an industrially important chemical. If its production can be done using alternative methods using sunlight, it will be highly economical and a green process. If we are able to carry out any organic functional group transformation in a single step reaction, it will be highly beneficial and the various post synthesis processes like filtration, chromatographic analysis etc. can be minimized. But in this line, not much research is being carried out at present because the conditions still need to be optimized. If research is advanced in this direction it will be highly revolutionizing. Thus, I have chosen this technique as a subject of my research work but due to shortage of time I have carried out only a single organic transformation.

The future prospects[26] of nanocatalysts are very bright, considering the many applications that they are currently being put into. One such application is using gold[27] nanoparticles and infrared light, researchers have developed a drug-delivery system that allows multiple drugs to be released in a controlled fashion. Such a system could one day be used to provide more control when battling diseases[28] commonly treated with more than one drug. In the field of energy resources[29], recently experiments on cerium oxide nanoparticles may lead to catalytic converters that are better at cleaning up auto exhaust, and is a promising zero-emission fuel for the future.

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