UTILIZATION OF DYES AS PHOTOREDOX CATALYST FOR C-C BOND FORMATION REACTION AND SYNTHESIS OF CATALYST

"XANTHYLIDENE-ANTHRONS".

By

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CERTIFICATE

This is to certify that the dissertation entitled, Utilization of dye as photoredox catalyst for C-C bond formation reaction and synthesis of Catalyst "Xanthylidene -Anthrone" is bonafide work carried out by ‘Sweta D. Singh ’ under my supervision in partial fulfilment of the requirements for the award of the degree of Master of Science in Chemistry at the School of Chemical Sciences , Goa University .

Dr. Sandesh Bugde

Guiding Teacher

School of Chemical Sciences.

STATEMENT

I hereby declare that the matter presented in this dissertation entitled, Utilization of " Dyes as Photoredox Catalyst for C-C bond formation reaction and synthesis of Catalyst "Xanthylidene - Anthrones" is based on the result of investigation carried out by me in the department of chemistry, School of Chemical Sciences, Goa University under the surpervision of Dr. Sandesh Bugde and the same has not been submitted elsewhere for the award of Degree .

ACKNOWLEDGEMENT

It gives us an immense pleasure to present this project report entitled, Utilization of dye as photoredox catalyst for C-C bond formation reaction and synthesis of Catalyst "Xanthylidene - Anthrones".

The success and final outcome of this project required a lot of guidance and assistance from many and I am extremely privileged to have got this all along the completion of my project. All that I have done is only due to such supervision and assistance and I would not forget to thank them.

I take this opportunity to express my deep gratitude and indebtness to my project guide Dr. Sandesh Bugde, Assistant Professor, School of Chemical Sciences, Goa University for his valuable guidance, encouragement and thoughtful discussion during the course of work. I am very grateful to him to give us the opportunity and appreciating ideas and allowing us the freedom to take the tasks independently, helping us to explore the things and enriching us with the knowledge.

My sincere thanks to Prof. V.S. Nadkarni – Head of the School of Chemical Science , Goa University for permitting me to carry out this project work in our laboratory by providing all the necessary facilities during the project work.

I gratefully acknowledge Prof. S.G. Tilve for his valuable assistance and also the help rendered by other teaching and non – teaching staff of the Department of Chemistry, Goa University.

I am grateful towards Research students, for helping us record IR spectra of my compounds.

I am also grateful to Mr. Shashank and Mr. Ketan Mandrekar for recording the NMR spectras of the compounds.

My deep sense of gratitude goes to all my friends and classmates for helping me and sharing ideas throughout my dissertation.

General abbreviations

Measurements

min - Minutes

r.t - Room Temperature

^{0}c - Degree Celsius

mmols - Milimol

g - Grams

hr - Hour

mL - Mili litre

Equiv - Equivalent

m.p - Melting point

Techniques

TLC - Thin Layer Chromatography

IR - Infrared Spectroscopy

PMR (^{1}H- NMR) - Proton Magnet Resonance

Solvents

Pet ether - Petroleum ether

DCM - Dichloromethane

EtOH - Ethanol

CH_3CN - Acetonitrile

General remarks

1. IR spectra were recorded on Shimadzu FT – IR spectrophotometer (solid KBr pellet/liquid-neat)
2. melting point were measured by Thiel's tube method .
3. Distilled solvents are used in all cases.
4. Commercial reagents were used without any futher purification.
5. All solvents and reagents were purified and dried by standard techniques.
6. All the reactions were monitored by thin layer chromatography (TLC) on silica gel.
7. The Purification of product was carried out by column chromatography.

8. Room Temperature 25-27°C.

SECTION	TITLE	PAGE NO
01	Introduction	
02	Literature review	
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05	Results and Discussion	
06	Conclusion	
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INTRODUCTION

Photochemistry is the branch of chemistry concerned with the chemical effects of light. This term is use to describe a chemical reaction caused by absorption of UV -Visible radiation. Photochemistry is of immense importance as it is the basis of photosynthesis, vision and formation of vitamin D with sunlight.

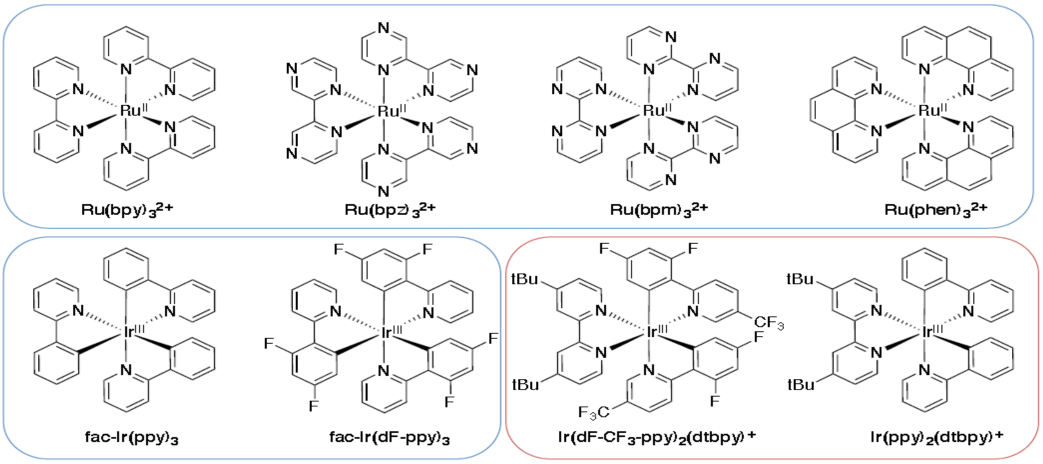
WHAT IS PHOTOREDOX CATALYSIS

Photoredox catalysis is the branch of catalysis that harnesses the energy of light to accelerate a Chemical reaction via single - electron transfer events .This area is named as a combination of " photo" referring to light and " redox" refers to the condense expression for the chemical processes of oxidation and reduction . In particular photoredox catalysis employs small quantities of a light -sensitive compounds that , when excited by light, can mediate the transfer of electrons between chemical compounds that would usually not react at all.

photoredox catalysis has emerged as a powerful tool for the utilization of visible light to drive the chemical reactions between organic molecules that exhibits two rather ubiquitous properties: colorlessness and redox activity .The photocatalyst requires significant absorption in visible spectrum and reversible redox activity [1] .

Organic chromophores have long been acknowledged for their ability to participate in photoinduced electron transfer (PET) processes. The potent reactivity afforded by many organic catalysts allows access to unique chemistries and abroad range of substrates that are unreactive in most synthetic contexts.

TM Photoredox catalysis: metals and ligands

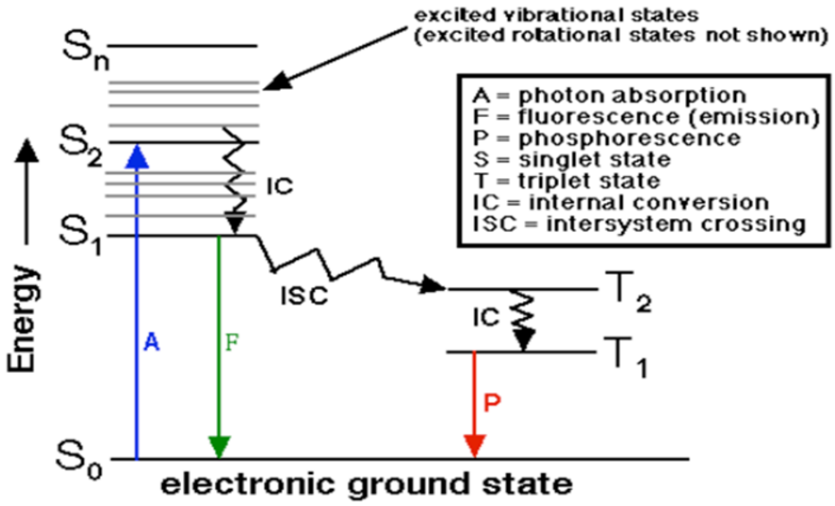


Ru complexes: homoleptic

Ir complexes: homoleptic
and heteroleptic

But Organic catalyst are prefer over Transistion metal as Organic catalysts are cheap, easily avaliable and comparatively easy to handle and less toxic, eosin Y has been widely used as an organo-photocatalyst in synthetic transformations[2].

PHOTOPHYSICAL PROPERTIES OF ORGANIC PHOTOREOX CATALYST.



The photophysical properties of an electronically excited molecule ultimately govern its photochemical reactivity. The properties of a photoredox catalyst in both the excited and ground states is crucial in effecting a desired reactivity.

- λmax abs : Local Absorbance Maximum for Lowest Energy Absorption :

Application of this value is in determining a source of irradiation for a given photoredox catalyst. The λmax abs value gives some information about how much energy an excited state can contribute to a photoinduced electron transfer. The longer the wavelength of absorption, the less energy singlet and triplet excited states will posses.

- Life time of Fluorescence

These values are helpful in gauging whether the first singlet excited state S1 can effectively participate in a PET reaction by providing an approximate assessment of the lifetime of S1 and its propensity towards nonradiative deactivation pathways, namely, IC and ISC. Higher the fluorescence quantum yield, the greater the likelihood of PET in the singlet excited state.

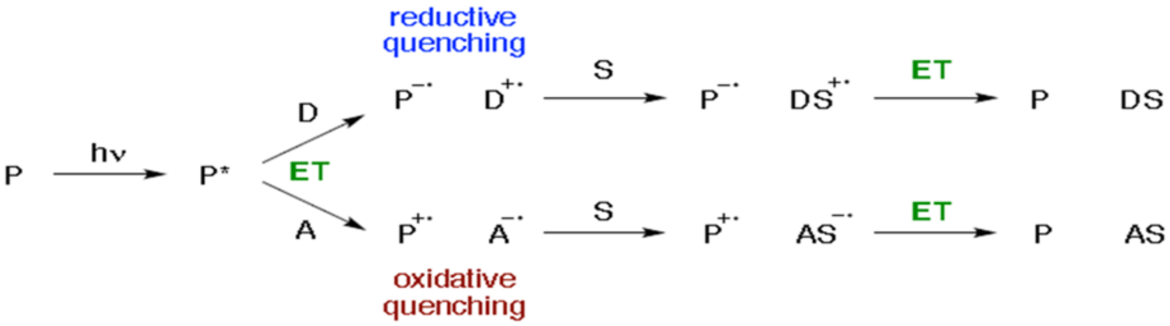
- φISC: Quantum Yield of Intersystem Crossing

When kISC is fast enough to compete with kf (and kIC),theT1 state can be populated and φISC can help to predict whether T1 will be an active excited state in a PET process.

- Excited State Energy of the First Singlet Excited State S1.

The excited state energy refers to the transition between the lowest energy vibrational state (v = 0) of S 1 to v = 0 of S0, which can be estimated at the intersection between normalized symmetrical absorbance and emission spectra after converting the wavelength axis to an energy scale or by finding the midpoint between absorption and emission maxima

General Process



P = photocatalyst, photoredox catalyst

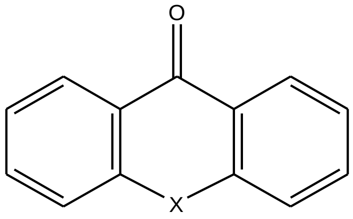
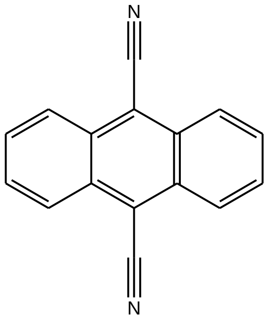
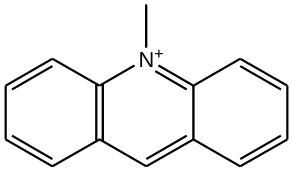
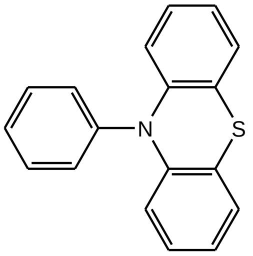
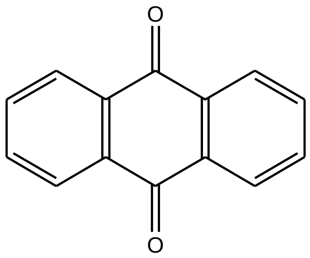
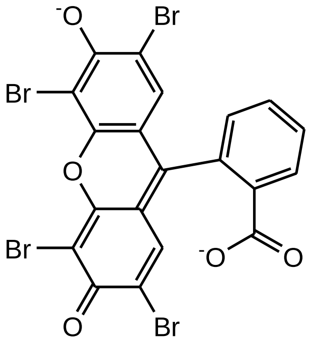
D = electron donor species (amine, alcohol, thiol)

A = electron acceptor species (carbonyl, halide)

S = Redox neutral substra

Photoredox catalyst can enter the oxidative quenching cycle in the presence of good acceptor species having electron withdrawing group like carbonyl group or halide and same photoredox catalyst can also enter the reductive quenching cycle In presence of electron donar species like amine, Alcohol, thiol etc.

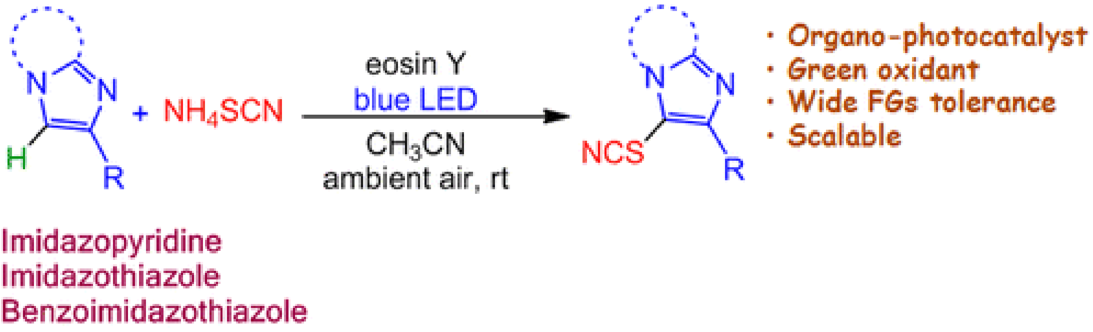
Important Classes Of Organic Photoredox Catalysts and their Examples

BENZOPHENONES	CYANOARENES	ACRIDINIUMS
 Xanthone (X= O) Thioxanthone (X=S)	 9,10-dicyanoanthracene	 10-methylacridinium
THIAZINES	QUINONES	XANTHENES
 10-Phenylphenothaizine	 anthraquinone	 Eosin Y

LITERATURE REVIEW

1. A visible light mediated, metal-free process for the thiocyanation of imidazoheterocycles was been developed using eosin Y as a photoredox catalyst under ambient air at room temperature. A library of 3-(thiocyanato)imidazo[1,2-a]pyridines with broad functionalities was been synthesized in high yields[3].

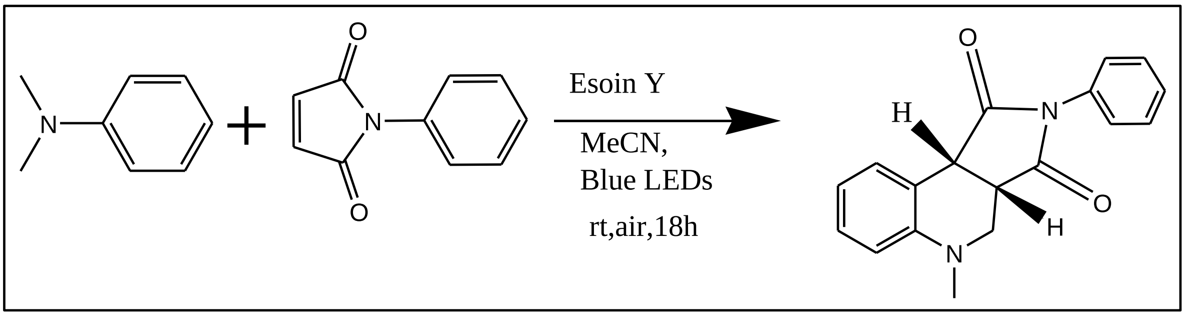
SCHEME 1



A visible light driven eosin Y catalyzed protocol for the C-3 thiocyanation of imidazoheterocycles at room temperature was developed by Shubhanjan Mitra and group. This method showed broad substrates scope applicability and a wide range of functional groups tolerance. this method was scalable and air was used as the sole green oxidant. this protocol have gain much importance in organic synthesis, medicinal chemistry, and material science as a powerful and economical route for the thiocyanation of imidazoheterocycles.

2. The efficient synthesis of the corresponding tetrahydroquinolines from N,N-dimethylanilines and maleimides using visible light in an air atmosphere in the presence of Eosin Y as a photocatalyst was been developed. The metal-free protocol involves aerobic oxidative cyclization via sp3 C–H bond functionalization process to afford good yields in a one-pot procedure under mild conditions[4].

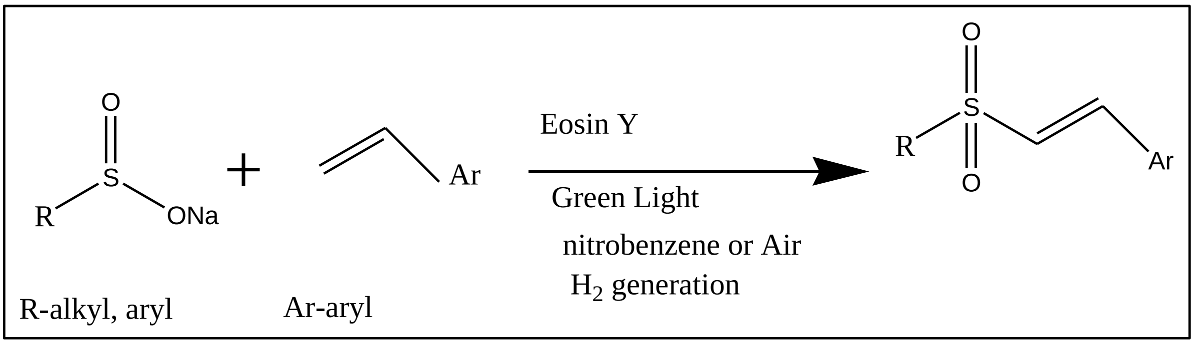
SCHEME 2



The protocol was significantly green because it utilizes visible light and atmospheric oxygen as the greenest reagents, and metal-free cheap Eosin Y with a relatively low loading as the photocatalyst to deliver the product at room temperature in a simple one-pot procedure. This methodology expands the range of substrates in the area of visible light photoredox reactions.

3. Alkyl- and aryl vinyl sulfones were obtained by eosin Y (EY)-mediated visible-light photo oxidation of sulfinate salts and the reaction of the resulting S-centered radicals with alkenes by Meyer and Coworkers in 2016. The reaction mechanism, proceeds through the EY radical cation as key intermediate oxidizing the sulfinate. A visible-light-mediated, metal-free synthesis of alkyl and heteroaryl vinyl sulfones from alkyl or heteroaryl sulfinates and alkenes using green light, the organic dye eosin Y(EY) as photocatalyst and nitrobenzene or air as the terminal oxidant[5].

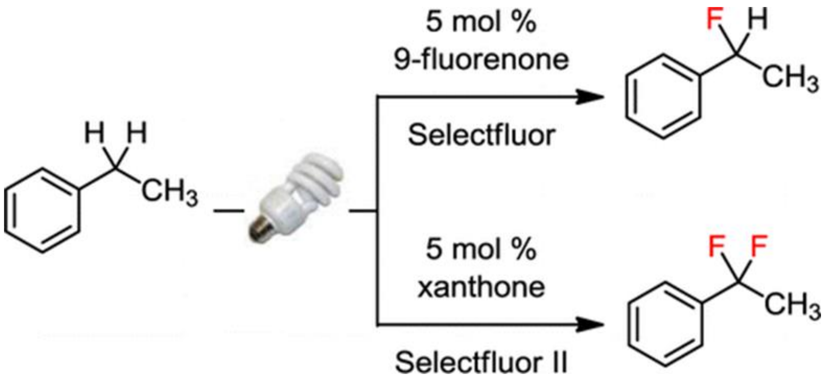
SCHEME 3



The low reactivity of the sulfinate radical makes the reaction selective for activated alkenes, such as styrenes, dihydronaphthalenes, and dihydroquinolines. Complex cyclic sulfones were also obtained in a sequence of two photocatalytic steps, first producing alkenyl vinyl sulfones that undergo sensitized [2+2] intramolecular photocylization.EY can catalyze both oxidations and reductions, and has ambivalent reactivity in the excited state. short singlet lifetime, the triplet state of EY is usually the photocatalytically active state undergoing photoinduced electron transfer. Transient spectroscopy revealed that the triplet state of EY exclusively reacts with the terminal oxidant nitrobenzene giving the EY radical cation. This key intermediate oxidizes the sulfinate salt giving the corresponding radical and the regenerated photocatalyst.

4. The direct conversion of benzylic C–H groups to C–F by visible light was carried out by Chen and co-workers. Adding a fluorine radical donor yields the benzylic fluoride and regenerates the catalyst. The selective formation of mono- and difluorination products can be achieved by catalyst control. 9-Fluorenone catalyzes benzylic C–H monofluorination, while xanthone catalyzes benzylic C–H difluorination[6].

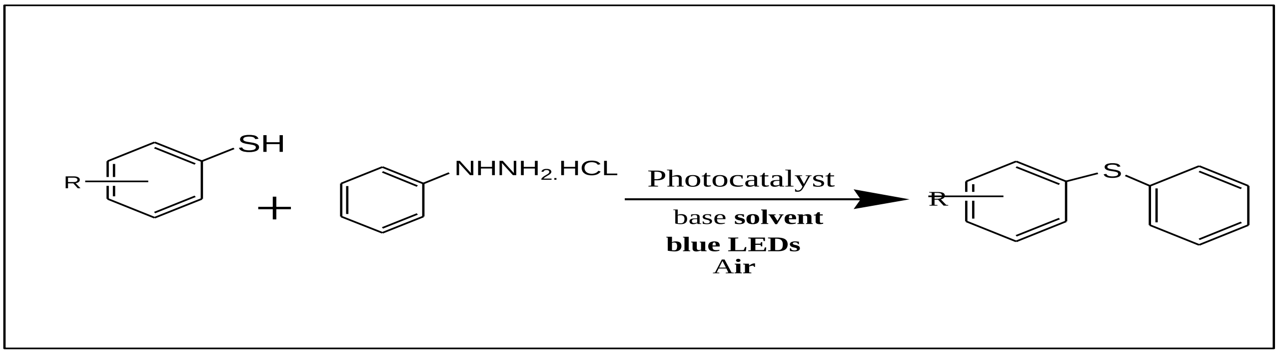
SCHEME 4



Cheap and readily available photolytic method for direct benzylic fluorination was developed. Cheap and readily available diarylketones were used as the catalysts. 9-Fluorenone catalyzed selective benzylic C–H monofluorination and xanthone gem-difluorination by using visible light to drive this C–H fluorination reaction. Only a low loading of the diarylketone catalysts was needed because of efficient catalyst turnover and a wide range of functional groups on the aromatic ring and side-chain was been tolerated.

5. A metal-free visible-light-promoted oxidative coupling between thiols and arylhydrazines was been developed by Golam Kibriya and group in 2018 to afford diaryl sulfides using a catalytic amount of rose bengal as photocatalyst under aerobic conditions. A library of unsymmetrical diaryl sulfides with broad functionalities was synthesized in good yields at room temperature[7].

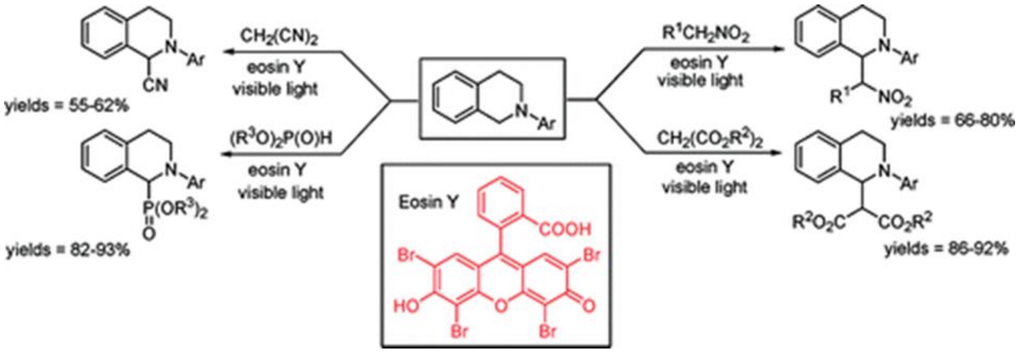
SCHEME 5



A visible-light-promoted oxidative C–S cross-coupling reaction between arylhydrazine and thiol to synthesize unsymmetrical diaryl sulfides under organophotoredox catalysis was developed. A library of diaryl sulfides with broad functionalities was synthesized at ambient temperature under aerobic conditions. Scalability, metal-free conditions,use of water as a green solvent, and ambient air as the oxidant made this method more practicable in organic synthesis.

6.Eosin Y catalyzed visible light mediated oxidative coupling of sp3 C–H bonds adjacent to the nitrogen atom in tetrahydroisoquinoline derivatives in the absence of an external oxidant was carried out . Nitroalkanes, dialkyl malonates, malononitrile, and dialkyl phophonates were used as pronucleophiles in this metal-free, visible light oxidative coupling reaction.

SCHEME 6



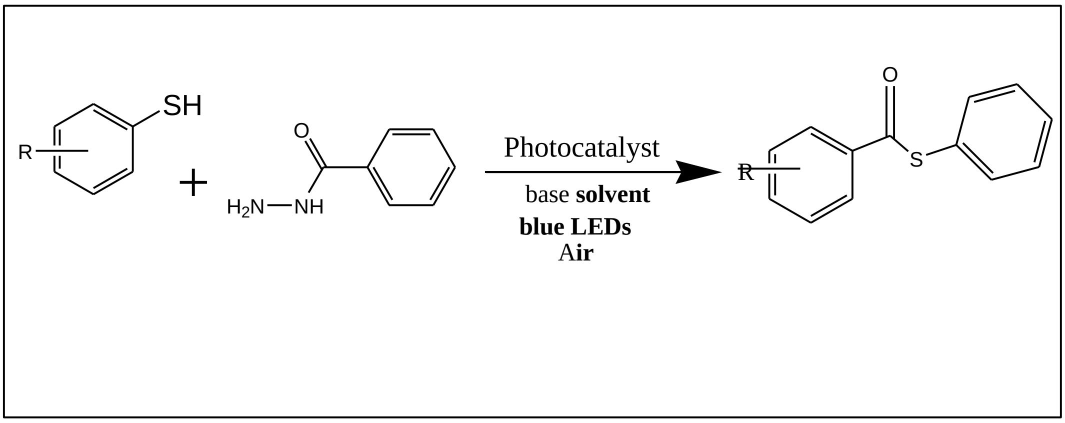
EXPERIMENTAL WORK

1. REACTION METHODOLOGIES INVOLVING DYES AS A PHOTOREDOX CATALYST.

2. SYNTHESIS OF PHOTOREDOX CATALYST

1. REACTION METHODOLOGIES INVOLVING DYES AS PHOTOREDOX CATALYST

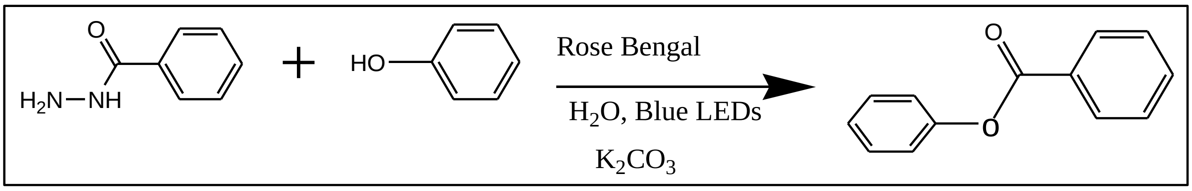
SCHEME 1



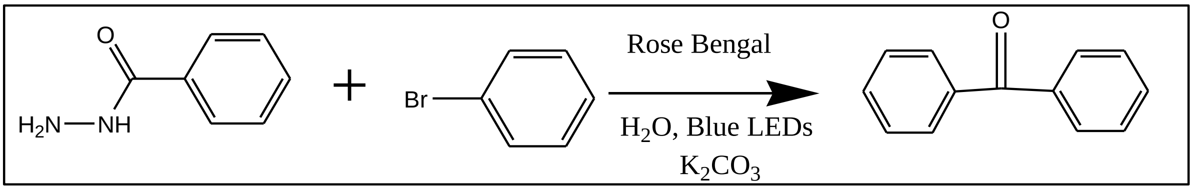
PROCEDURE

5 mmol of Benzoyl hydrazine was taken to that 2.5 mmol of Reactant was added .To the same solvent (5ml) and (2 mol%) K_2CO_3 as a base was added followed by the addition of a organic bye Rose Bengal (5 mol%) as a photocatalyst.The reaction mixture was stirred for 8 hr in presence of 34 w blue LEDs. The progress of the reaction was monitor using TLCs and after the completion of the reaction the product was extract using ethyl acetate.

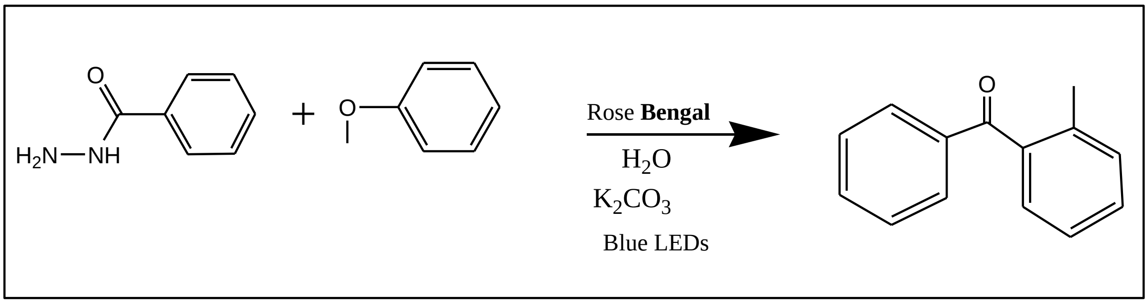
REACTION 1



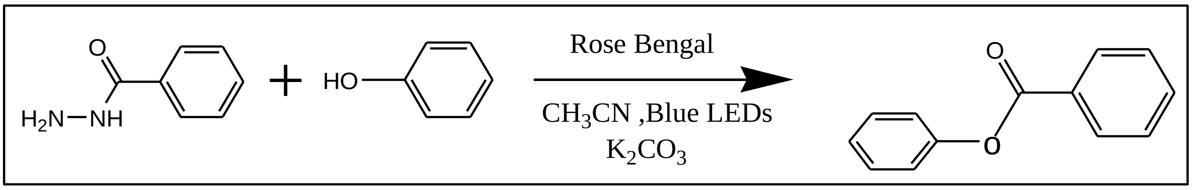
REACTION 2



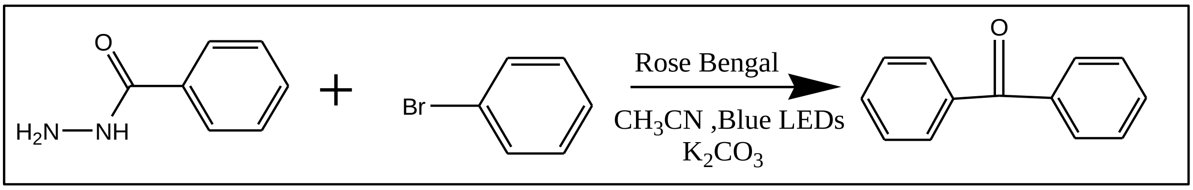
REACTION 3



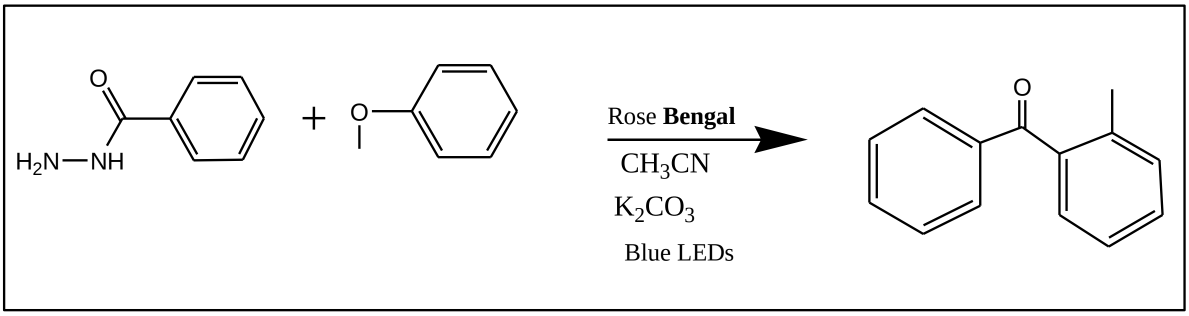
REACTION 4



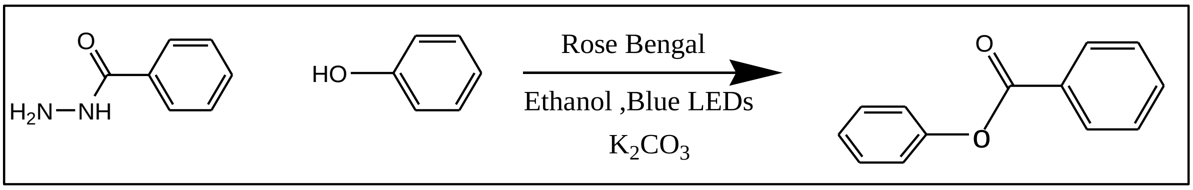
REACTION 5



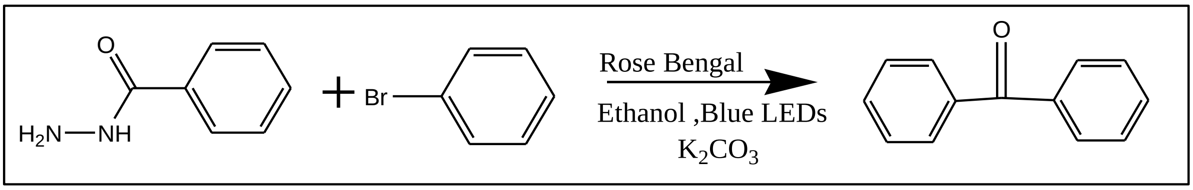
REACTION 6



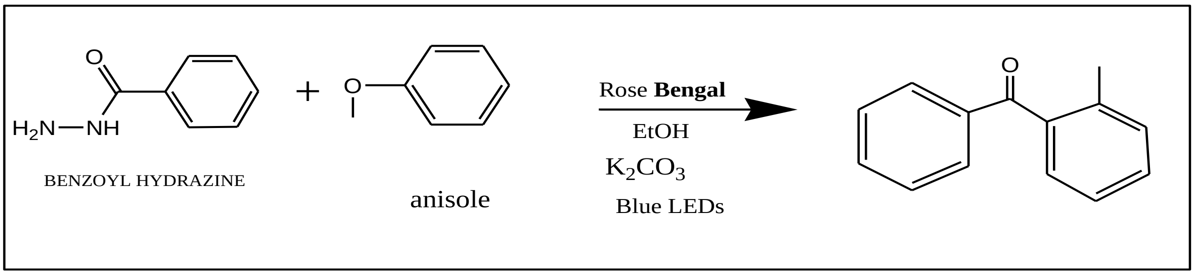
REACTION 7



REACTION 8

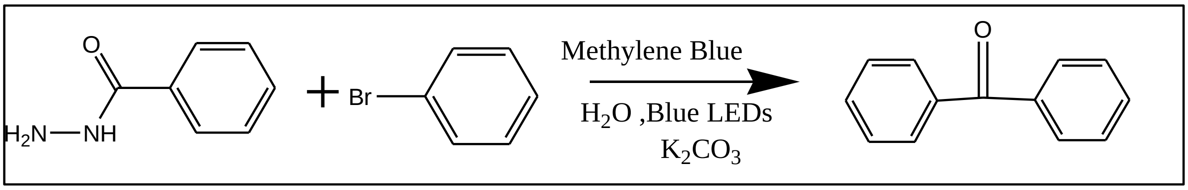


REACTION 9

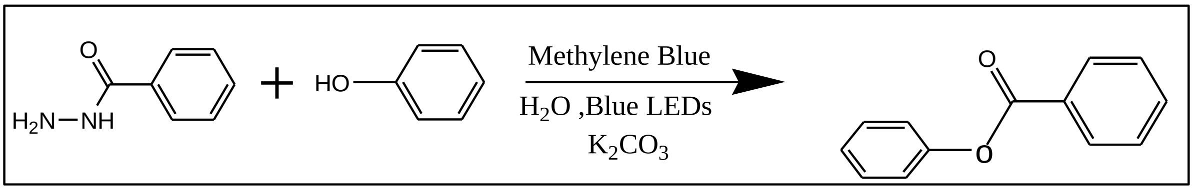


USING METHYLENE BLUE AS A PHOTOCATALYST

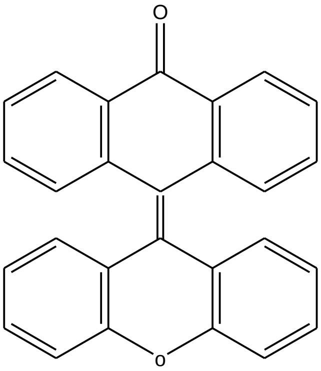
REACTION 1



REACTION 2



2. SYNTHESIS OF PHOTOREDOX CATALYST.



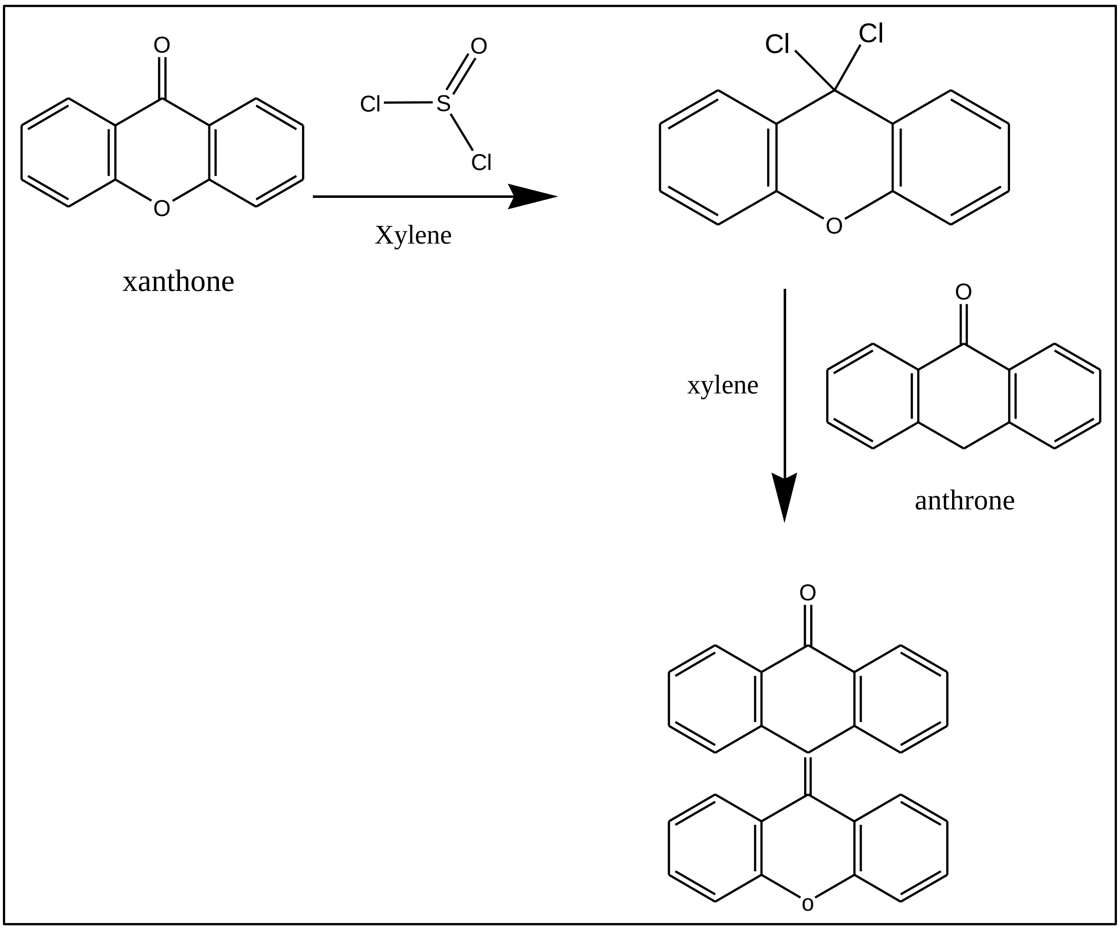
Xanthylidene –Anthrones.

The heteromerous bistricylic aromatic ene was synthesised by the consdensation of dichloroxanthene with Anthrone.

Procedure:

Xanthone (2.5 g, 0.03 mol) was refluxed for 16 h in 100 mL Thionyl chloride. Xylene (25 mL) was added and the solvents were evaporated under reduced pressure with protection from humidity.Xylene (5 mL) was added to the residue and the solvent was evaporated once again.Then (15 mL) of xylene was added and set to reflux. To this Boiling mixture , Anthrone (2.5 g ,0.025 mol), dissolved in (25 mL) of xylene, was carefully added dropwise. The reaction mixture became deep green.The reflux was continued for 20 h.After cooling, the xylene was evaporated and the solid was refluxed with acetic acid (25 mL) for 30 min and filter off.The product was further purified by column chromatography and was recrystallised from toluene.

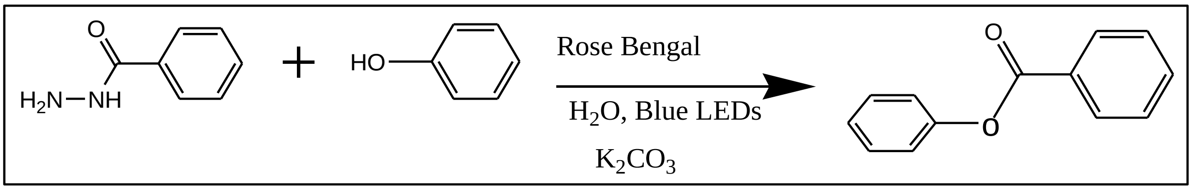
REACTION

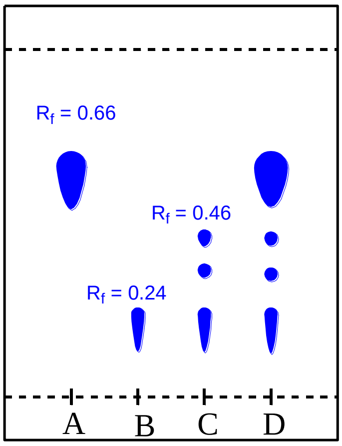


RESULT AND DISCUSSION

As we wanted to utilise dyes for new organic methodologies, we chose to study the reaction between benzoyl hydrazine and different substrate such as phenol, anisole etc. The first reaction we studied is between benzoyl hydrazine and phenol (reaction 1).

Reaction 1

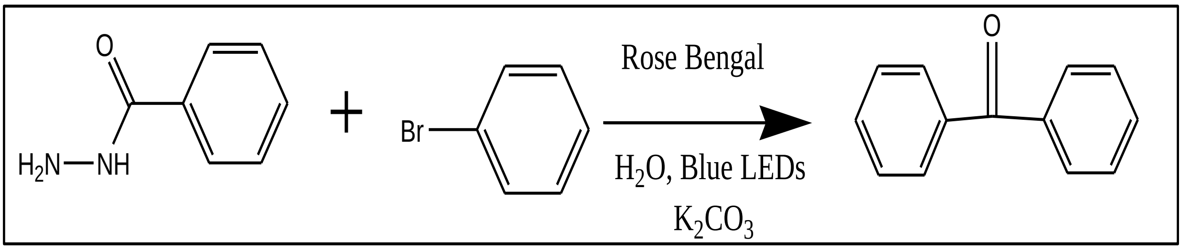


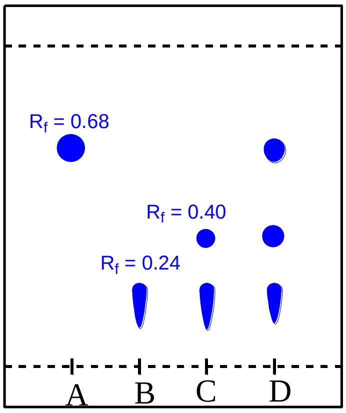


A-Phenol
B-Benzoylhydrazine
C-Reaction mixture
D-CO

The reaction was monitored by thin layer chromatography (TLC), from the TLC developed in 50% of pet ether and ethyl acetate it was observed that two new spot were formed in the reaction mixture. Since the fewly formed spots were in small amount and close by we were unsucesssful in separating and purifying them by column chromatography .

Reaction 2

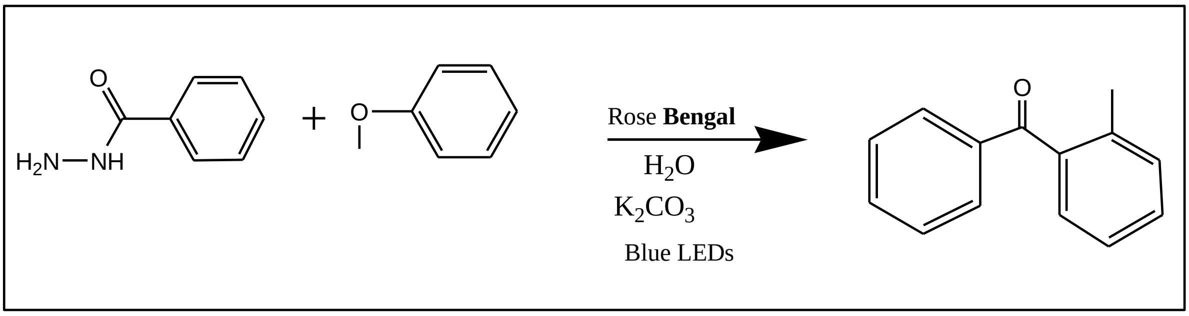


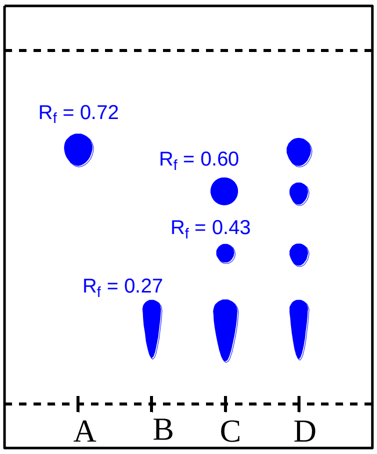


A- bromobenzene
B- Benzoylhydrazine
C-Reaction mixture
D-CO

From the TLC developed in 50% of pet ether and ethyl acetate it was observed that only one new spot was formed in the reaction mixture at the Rf value of 0.40. The formed new spot was separated and purified by column chromatography. The weight of the formed product was 0.018g which was further characterised by NMR Spectroscopy.

Reaction 3





A- anisole

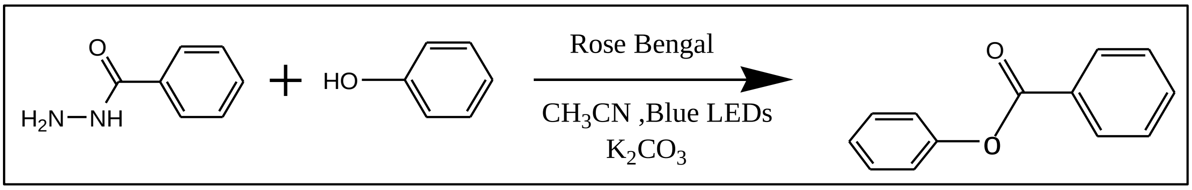
B- Benzoylhydrazine

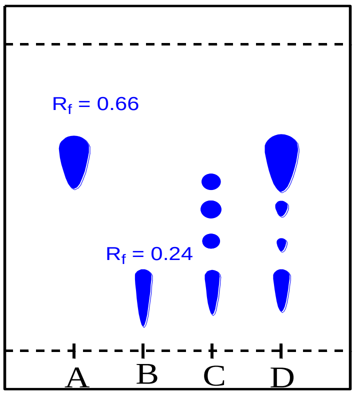
C-Reaction mixture

D-CO

From the TLC developed in 50% of pet ether and ethyl acetate it was observed that two new spots were formed in the reaction mixture at the Rf value of 0.43 and 0.60. The newly formed down spot was separated and purified by column chromatography. The weight of the formed product was 0.1056 g but further characterisation by NMR Spectroscopy is yet to be done.

Reaction 4





A-Phenol

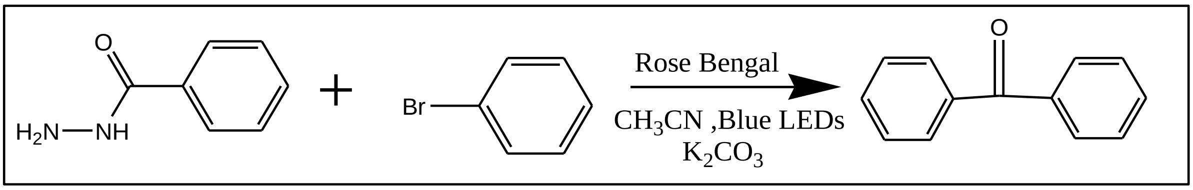
B-Benzoylhydrazine

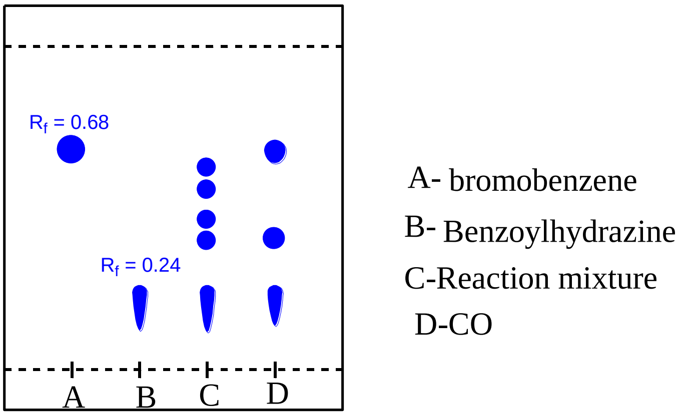
C-Reaction mixture

D-CO

From the TLC developed in 50% of pet ether and ethyl acetate it was observed that three new spots were formed in the reaction mixture .Since the few formed product were in small amount we were unsucesssful in separating and purifying by column chromatography.

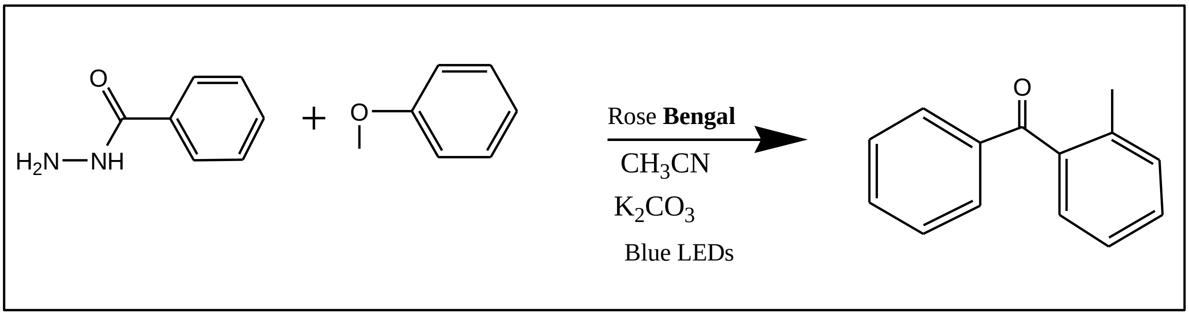
Reaction 5

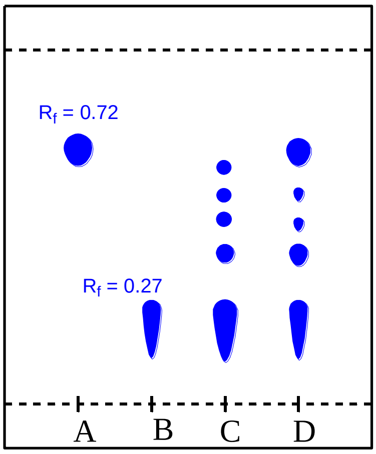




From the TLC developed in 50% of pet ether and ethyl acetate it was observed that number of new spots were formed in the reaction mixture .Since the fewly formed spots were in small amount and close by we were unsucesssful in separating and purifying them by column chromatography.

Reaction 6





A- anisole

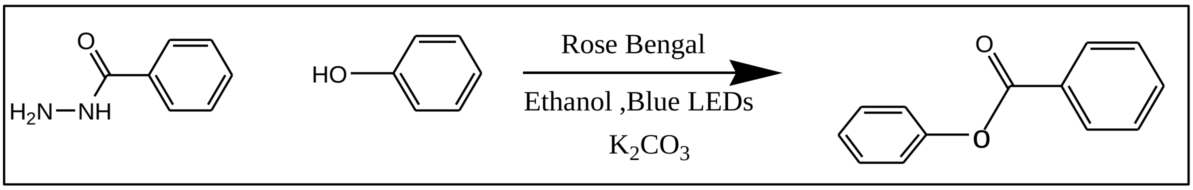
B- Benzoylhydrazine

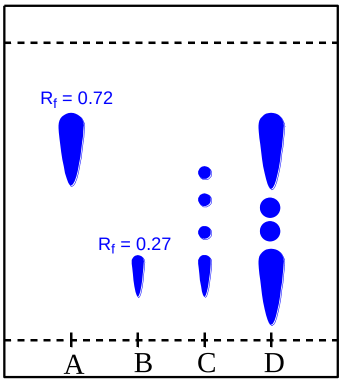
C-Reaction mixture

D-CO

From the TLC developed in 50% of pet ether and ethyl acetate it was observed that number of new spots were formed in the reaction mixture .Since the fewly formed spots were in small amount and close by we were unsucesssful in separating and purifying them by column chromatography .

Reaction 7





A- phenol

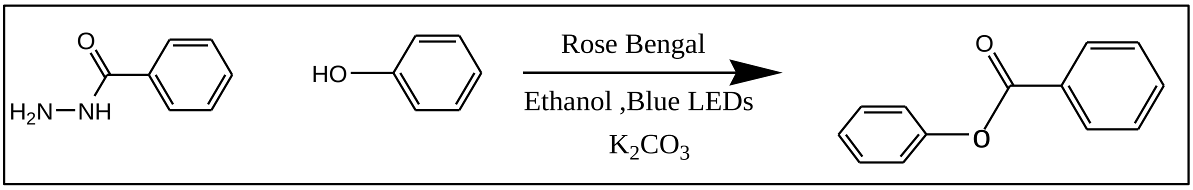
B- Benzoylhydrazine

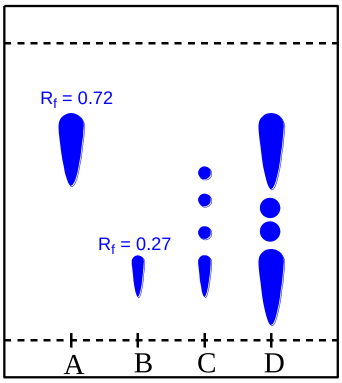
C-Reaction mixture

D-CO

From the TLC developed in 50% of pet ether and ethyl acetate it was observed that number of new spots were formed in the reaction mixture. Since the fewly formed spots were in small amount and close by we were unsucesssful in separating and purifying them by column chromatography .

Reaction 8





A- phenol

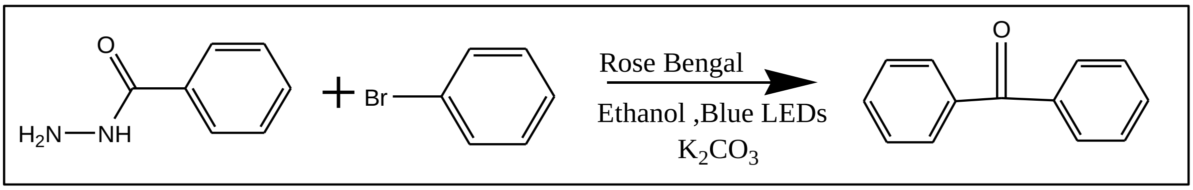
B- Benzoylhydrazine

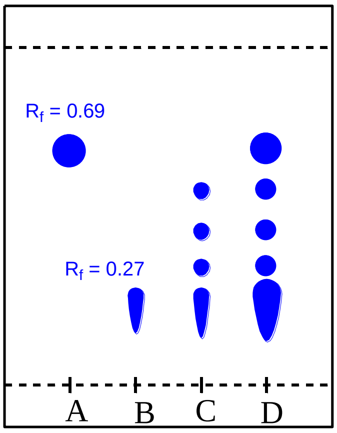
C-Reaction mixture

D-CO

From the TLC developed in 50% of pet ether and ethyl acetate it was observed that number of new spots were formed in the reaction mixture. Since the fewly formed spots were in small amount and close by we were unsucesssful in separating and purifying them by column chromatography .

Reaction 9



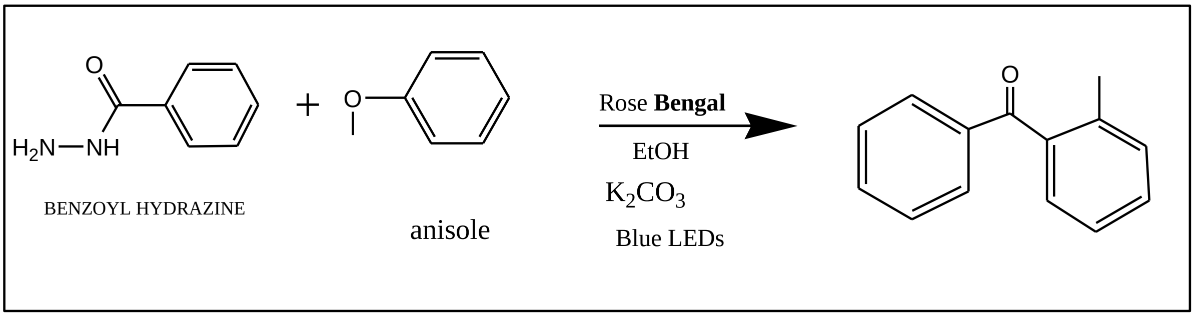


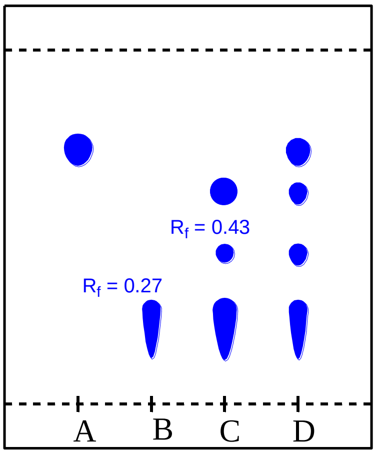
A-Bromobenzene
B-Benzoylhydrazine
C-Reaction mixture

D-CO

From the TLC developed in 50% of pet ether and ethyl acetate it was observed that number of new spots were formed in the reaction mixture .Since the fewly formed spots was in small amount and close by we were unsucesssful in separating and purifying them by column chromatography.

Reaction 10





A- anisole

B- Benzoylhydrazine

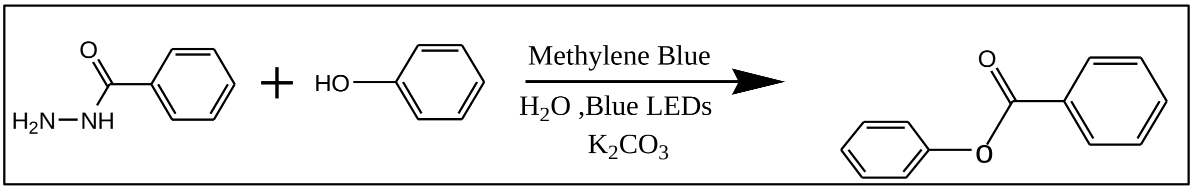
C-Reaction mixture

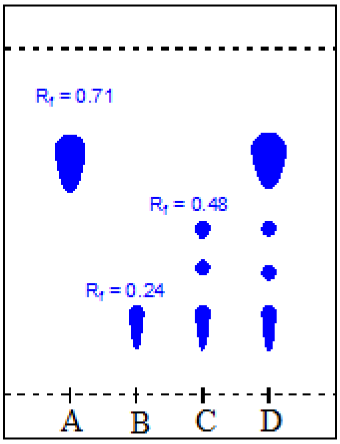
D-CO

From the TLC developed in 50% of pet ether and ethyl acetate it was observed that number of new spots were formed in the reaction mixture .Since the fewly formed spots were in small amount and close by we were unsucesssful in separating and purifying them by column chromatography.

Reaction carried out using Methylene Blue dye as a photoredox catalyst

Reaction 1

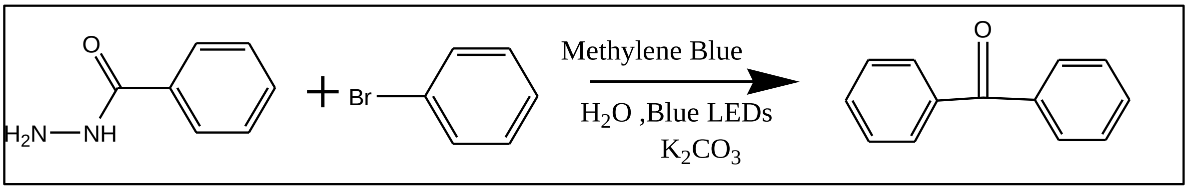


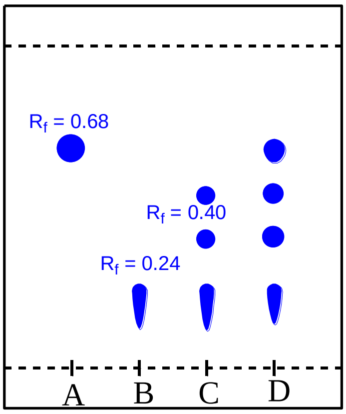


A-Phenol
B-Benzoylhydrazine
C-Reaction mixture
D-CO

From the TLC developed in 50% of pet ether and ethyl acetate it was observed that number of new spots were formed in the reaction mixture .Since the fewly formed spots were in small amount and close by we were unsucesssful in separating and purifying them by column chromatography.

REACTION 2





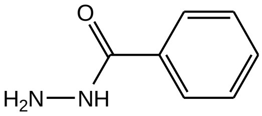
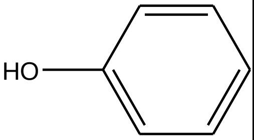
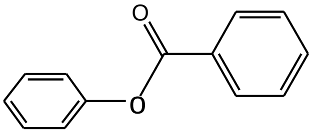
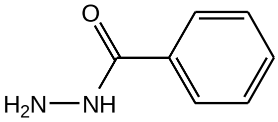
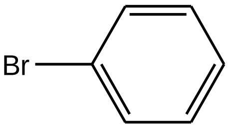
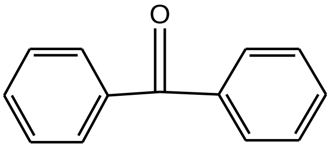
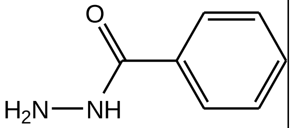
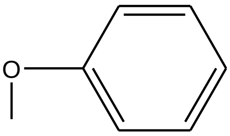
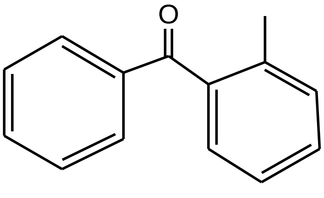
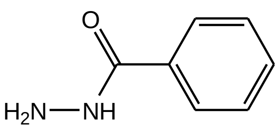
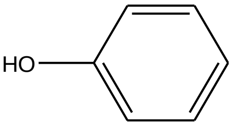
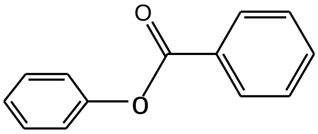
A- bromobenzene

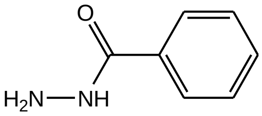
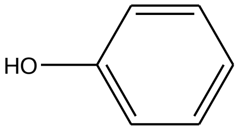
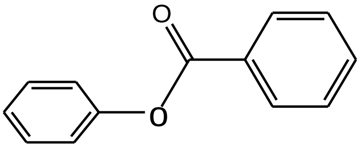
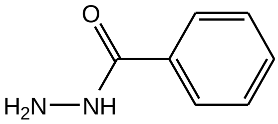
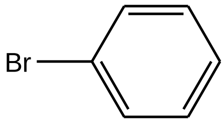
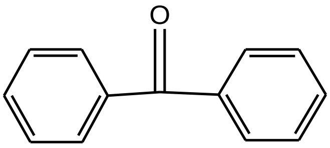
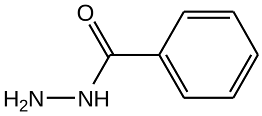
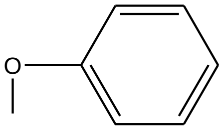
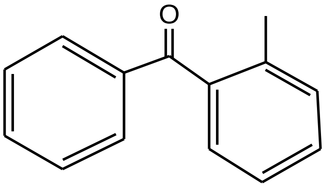
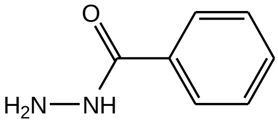
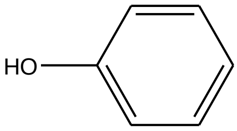
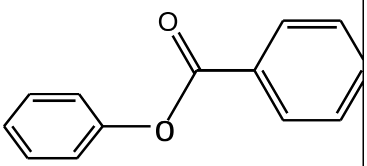
B- Benzoylhydrazine

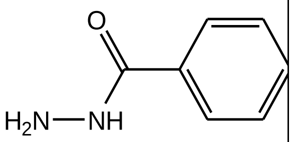
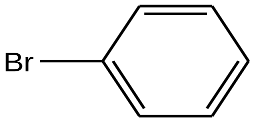
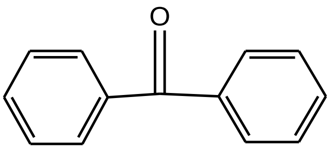
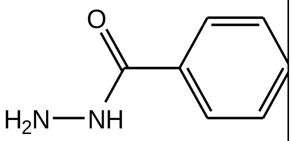
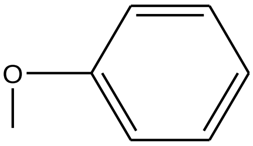
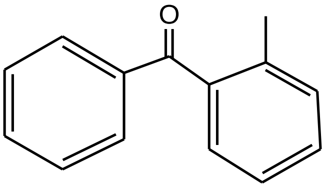
C-Reaction mixture

D-CO

From the TLC developed in 50% of pet ether and ethyl acetate it was observed that number of new spots were formed in the reaction mixture .Since the fewly formed spots were in small amount and close by we were unsucesssful in separating and purifying them by column chromatography.

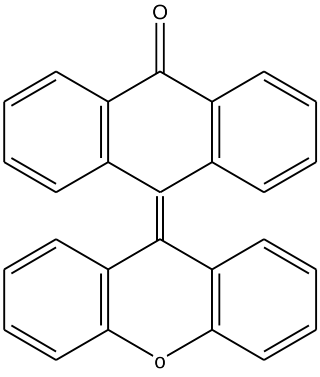
Reactant 1	Reactant 2	Reagent	Excepted product	Result
		Rose Bengal H_2O, Blue LEDs K_2CO_3		Product was not isolated
		Rose Bengal H_2O, Blue LEDs K_2CO_3		
		Rose Bengal H_2O, Blue LEDs K_2CO_3		Characterisation is yet to be done
		Rose **Bengal** MeCN K_2CO_3 Blue LEDs		Product was not isolated

		Rose **Bengal** $\longrightarrow$ EtOH K_2CO_3 Blue LEDs		Product was not isolated
		Rose **Bengal** $\longrightarrow$ EtOH K_2CO_3 Blue LEDs		Product was not isolated
		Rose **Bengal** $\longrightarrow$ EtOH K_2CO_3 Blue LEDs		Product was not isolated
		Methylene Blue $\longrightarrow$ H_2O ,Blue LEDs K_2CO_3		Product was not isolated

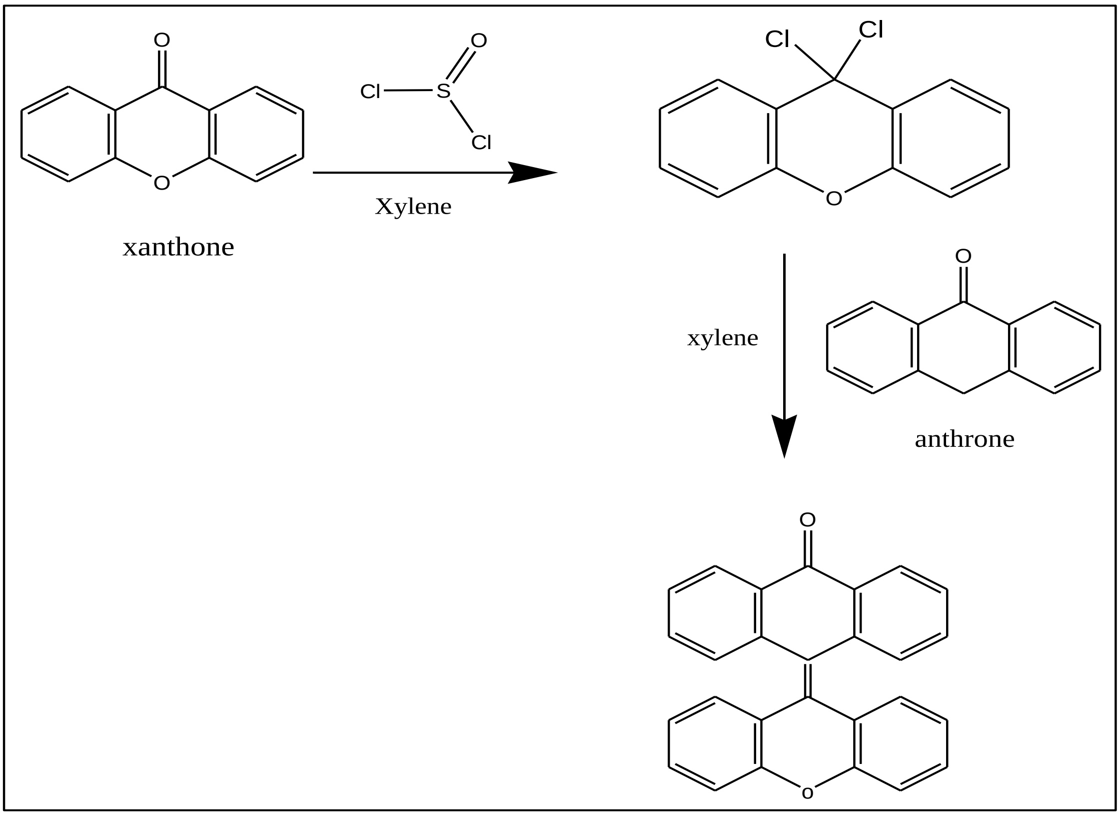
		$\xrightarrow[H_2O\text{ ,Blue LEDs} K_2CO_3]{\text{Methylene Blue}}$	 Excepted product	Product was not isolated
		$\xrightarrow[H_2O\text{ ,Blue LEDs} K_2CO_3]{\text{Methylene Blue}}$		Product was not isolated

Synthesis of Catalyst Xanthylidene Anthrone

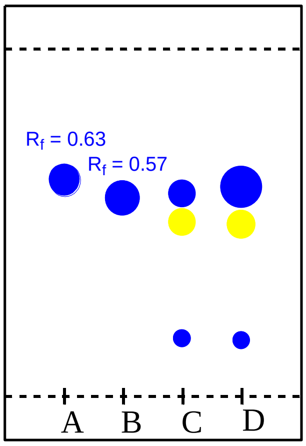
Anthrone derivatives have been utilised as photoredox catalysts, but xanthylidene anthrones were not explored for its photoredox catalysis behaviour. So we wanted to synthesise xanthylidene anthrones derivatives and utilise them as photoredox catalysts. Synthesis of xanthylidene anthrone **(1)** was carried out by reaction between anthrone and xanthone using thionyl chloride under reflux condition (Scheme 1)



(1)



TLC in 10% solvent



A-Xanthone
B-Anthrone
C-Reaction Mixture
D-CO

From the TLC developed in 10% of pet ether and ethyl acetate it was observed that only one new spot was formed in the reaction mixture. The formed new spot was separated and purified by column chromatography. The weight of the formed product was 0.500g which was further characterised by IR and NMR Spectroscopy.

Conclusion

We tried to synthesised C-C Coupling products of benzoyl hydrazine and various reactants like Phenol, Anisole and Bromobenzene using two different photoredox catalyst Rose Bengal and Methylene Blue with different solvent, but we were unsuccessful in isolating and purifying them all as the reaction proceed through radical mechanism, the number of products were formed in small amount hence it became difficult for us to isolate and purify them.

However we were successful in isolating and purifying and coupling product of Benzoyl hydrazine with Bromobenzene using Rose Bengal as a photocatalyst which was further characterised by ^{1}H-NMR Spectroscopy.

We were also successful in isolating and purifying the coupling product of Benzoyl hydrazine with Anisole using Rose Bengal as a photocatalyst but further characterised by ^{1}H-NMR Spectroscopy is yet to be done.

We also tried to synthesised Xanthylidene Anthrone which we were suppose to use as a Photoredox catalyst to carry out various C-C Coupling reactions.

REFERENCE

1) Prier, C. K.; Rankic, D. A.; MacMillan, D. W. C. Visible Light Photoredox Catalysis with Transition Metal Complexes:Applications in Organic Synthesis. *Chem. Rev*. **2013**, 113, 5322−5363.
2) Nathan A. Romero and David A. Nicewicz* Organic Photoredox Catalysis *Chem. Rev*. **2016**, 116, 10075−10166
3) Shubhanjan Mitra, Monoranjan Ghosh, Subhajit Mishra, and Alakananda Hajra Metal-Free Thiocyanation of Imidazoheterocycles through Visible Light Photoredox Catalysis, *J. Org. Chem.* **2015**, 80, 8275−8281
4) Zhongwei Liang, Song Xu, Wenyan Tian and Ronghua Zhang*, Eosin Y-catalyzed visible-light-mediated aerobic oxidative cyclization of N,N-dimethylanilines with maleimides ,*Belistein J. Org. Chem.* **2015**, 11,425-430.
5) Andreas Uwe Meyer, Karolna Strakov, Tomasˇ Slanina, and Burkhard Konig* Eosin Y Photoredox-catalyzed Sulfonylation of alkene: scope and mechanism *Chem. Eur. J.* **2016**, 22,8694–8699
6) Xia, J.-B.; Zhu, C.; Chen, C. Visible Light-Promoted Metal-Free C−H Activation:Diarylketone-Catalyzed Selective Benzylic Mono-and Difluorination. *J. Am. Chem. Soc.* **2013**, 135, 17494−17500.
7) Golam Kibriya, Susmita Mondal, and Alakananda Hajra*Visible-Light-Mediated Synthesis of Unsymmetrical Diaryl Sulfides via Oxidative Coupling of Arylhydrazine with Thiol *Org. Lett.* **2018**, 20, 7740−7743
8) Vila,C.;Lau,J.;Rueping,M. Visible-Light Photoredox Catalyzed Synthesis of Pyrroloisoquinolines via Organocatalytic oxidation/[3+2] Cycloaddition/oxidative Aromatization Reaction Cascade with Rose Bengal. *Beilstein J. Org. Chem.* **2014**, 10, 1233−1238.