Chapter 3A

Studies on acid catalyzed multicomponent synthesis of *anti*-2, 3-dihydro-1, 2, 3-trisubstituted-1*H*-naphth[1, 2-e][1,3]oxazine derivatives as single diastereomer

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3A.1. Introduction

Multicomponent synthesis of fused 1,3-oxazine derivatives has emerged as a challenging structure development in organic chemistry in the context of modern drug discovery [1-2]. Various oxazine derivatives have been shown to exhibit wide spectrum of pharmacological activities which have been discussed elaborately in **Chapter-1**(**Section-1.1c**) [3-4]. Several one-pot synthesis of fused 1,3-oxazines have previously been reported which included pyrrolo/pyrido[2,1-a]benzoxazin-ones and pyrrolo/pyrido[2,1-a] quinazolinones [5], pyrido[2,3-e][1,3]oxazine [6], benzoxazine derivatives [7], substituted imidazo[2,1-b][1,3]oxazines derivatives [8], substituted naphth-[1,2-e][1,3]oxazines [9-10] etc. The synthesis of mono substituted naphth[1,3]oxazine (**1**) was first disclosed by Bruke *et al* [10] in 1954 by stirring a mixture of 2-naphthol, formaldehyde and substituted aniline in hot ethanol for several hour **(Fig.3A.1)**. It has been observed that the preparation of 1,3-disubstituted naphth[1,2-e] [1, 3] oxazine **(2-4)** is only limited to the use of 1-or 2-naphthol with various aryl and heteroaryl aldehydes in dry methanolic ammonia solution at room temperature with longer reaction time (24-48h) and lower yields **(Fig.3A.1)** [11]. Later on, the use of ammonium acetate reduced the reaction time in solvent–free medium using thermal and microwave energies [12]. Substituent effects in the ring-chain tautomerism of 1,3-disubstituted naphtho[1,3]oxazine derivatives **(2-4)** in solution were extensively studied by Fulop and his group **(Fig.3A.1)** [13-14]. The review of reported methods on the synthesis of trisubstituted naphthoxazine derivatives in first chapter **(Chapter-1, Section-1.6)** reveals that there is no report for the multicomponent synthesis of 1,2,3-trisubstituted-naphth[1,3]oxazine **(5)** using acid catalyst in solution as well as solvent–free medium. Ratnam and his group prepared few compounds of these series from the condensation of 1- or 2-naphthol with preformed Schiff bases (benzylideneanilines) in AcOH at room temperature for several hour [15-16]. Li *et al* also described the formation of title compound by stirring the solution of 2-naphthol, butylamine and benzaldehyde in ethanol for 6 days at ambient temperature [17-18]. Cimarelli *et al* isolated two trisubstituted-naphthoxazine as side products during the stereoselective synthesis of aminoalkylnaphthol at 60 °C after 12-24 h reaction period [19]. All these 1,2,3 trisubstituted-naphth[1,2-e][1,3]oxazines were known without studying the orientation of H-2 and H-4 protons in the oxazine ring. Thus, there is a lot of scope for generation of

combinatorial library of 1,2,3-trisubstituted naphth[1,3]oxazines using multi-component approach.

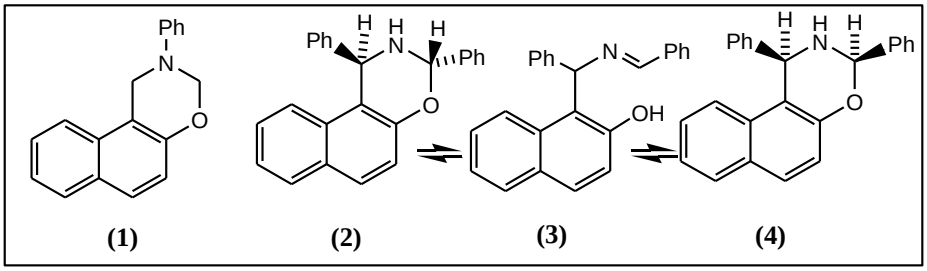
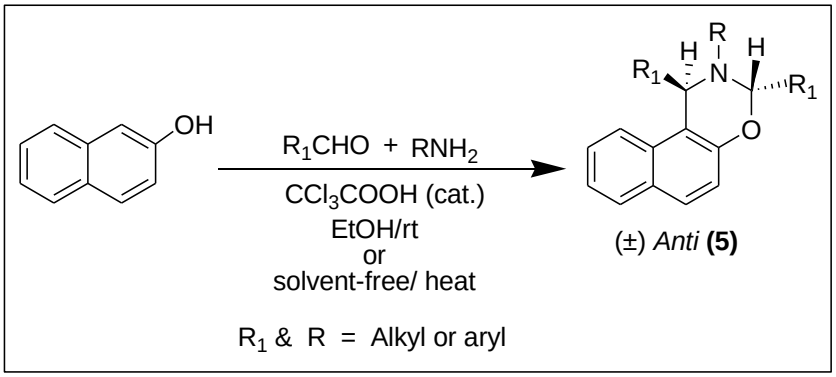


Fig.3A.1: Mono-substituted oxazine (**1)** and tautomerism of 1, 3-disubstituted-naphth[1,3] oxazines (**2-4)**

Herein, we described an efficient trichloroacetic acid catalyzed three component selective synthesis of *anti*-1-2,3-trisubstituted-naphth-[1,3]oxazine diastereomer (**5)** in solution and under solvent-free medium (**Scheme-3A.1**).

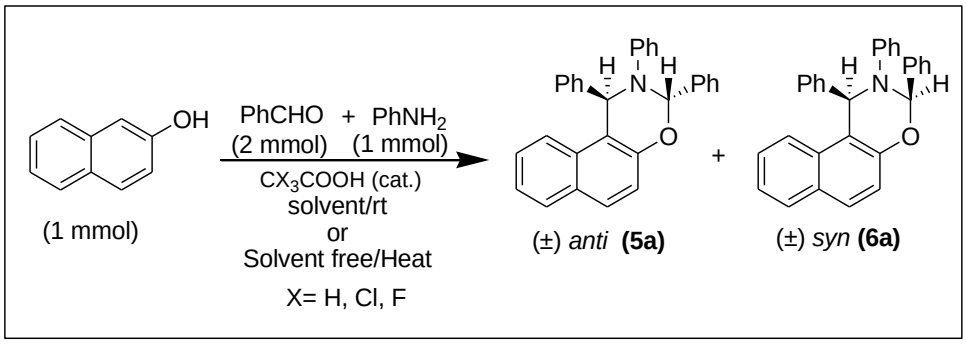


Scheme-3A.1: Multicomponent synthesis of a*nti*-1, 2, 3-trisubstituted-naphth[1,3] oxazine diastereomer

3A.2. Results and Discussion

The preliminary works involved with the optimization of reaction condition for a typical three component model reaction of 2-naphthol (1 mmol), benzaldehyde (2 mmol) and aniline (1 mmol) in presence of three acid catalysts such as acetic acid, trichloroacetic acid and trifluoroacetic acid at 25 °C in $CHCl_3$. The same reaction was also investigated under solvent-free medium to examine the catalytic activity of these acids. **Table-3A.1** distinctly demonstrated the selective formation of *anti*-product **(5a)** with the three catalysts in all conditions out of the two possible diastereomers **(5a)** and **(6a)**. In *anti*-product, the 1,3-oxazine moiety suffers from less steric effect of the three phenyl groups.

Table-3A.1: Optimization of the reaction with acid catalysts



Entry	Catalyst	Catalyst mol%	Time (min)	% of yield [a] **(5a)**
1	CH_3COOH	25	60[b]/40[c]	75/82
2	CCl_3COOH	25	30[b]/20[c]	87/92
3	CF_3COOH	25	30[b]/20[c]	93/30[f]
4	CH_3COOH	10	120[b]	40
5	CCl_3COOH	10	40[b]	75
6	CF_3COOH	10	25[b]	80
7	CCl_3COOH	25	30[d]/30[e]	85/75
8	No catalyst	-	12h[b]/4h[c]	40/50

[a] Isolated yields ; [b] Reaction in $CHCl_3$ at room temperature ; [c] Reaction in solvent-free medium at 100 °C ; [d] Reaction in $CHCl_3$ at 0 °C ; [e] Reaction in solvent-free medium at 80 °C ; [f] Product decomposed

The *syn*-product (**6a)** will be unstable-from the above mentioned steric effects of three phenyl substituents. The optimization results identified 25 mol % of CCl_3COOH as the suitable-catalyst to complete the reaction within short time in solution at 25 °C and 100 °C in absence of solvent (table-3A.1, entries 2). Decreasing reaction temperature had reduced the yield of product under solvent-free condition with the best catalyst as compared to solution at 0 °C (table-3A.1, entry 7). The higher acidity of CF_3COOH destabilized the oxazine ring at high temperature, but it gave excellent result in chloroform under mild condition (table-3A.1, entry 3). The lower acidity of acetic acid increased the reaction time

to give good yield of product (table-3A.1, entry 1). Without catalyst, the reactions remain incomplete for longer reaction time (table-3A.1, entry 8). Again, use of stronger acids like H_2SO_4 and HCl reduced the *anti*-product selectivity and generated various side products in ethanol at ambient temperature.

The effects of solvents were also studied for the same reaction in protic and non-polar solvents under optimized conditions using CCl_3COOH as catalyst (table-3A.2).

Table-3A.2: Optimization of solvent at room temperature

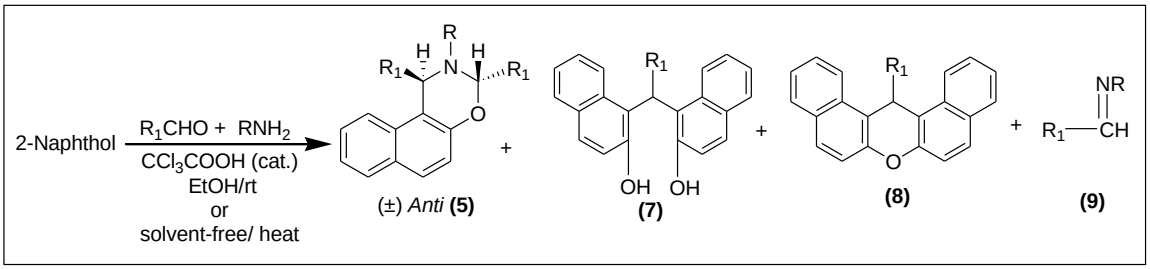
Entry	Solvents	Time(min)	% of yield [a, b] **(5a)**
1	$CHCl_3/CH_2Cl_2$	30/30	87/85
2	MeOH/EtOH/H_2O	30/30/60	90/95/50
3	H_2O + EtOH(1:1)	40	80

[a] Isolated yields; [b] Using1:2:1 ratio of 2-naphthol, benzaldehyde and aniline with 25 mol % of trichloroacetic acid catalyst

The homogeneous phases of all reactants in chloroform, dichloromethane and alcohol provided a suitable-medium to produce excellent yields of oxazine derivatives within half an hour (table-3A.2. entries 1-2). Alcohol may be the appropriate solvent for this reaction to increase the stability of reaction intermediates via H-bonding (table-3A.2, entry 2). The heterogeneous phases of reactant in water had reduced the yield of product to 50 % in 1 h reaction (table-3A.2, entry 2). The use of 50% aqueous ethanol improved the yield of product to 80% during 40 minutes (table-3A.2, entry 3).

After optimization we had extended this study to get structurally diverse novel *anti*-1,2,3-trisubstituted naphth[1,3]oxazine (**5)** as racemic mixture in achiral environment (**Scheme-3A.1**) by changing both aldehyde and amine compounds in solution and solvent-less medium.

Table-3A.3: Substituent effects on the synthesis of *anti*-1,2,3-trisubstituted-naphth[1,3]oxazine derivatives

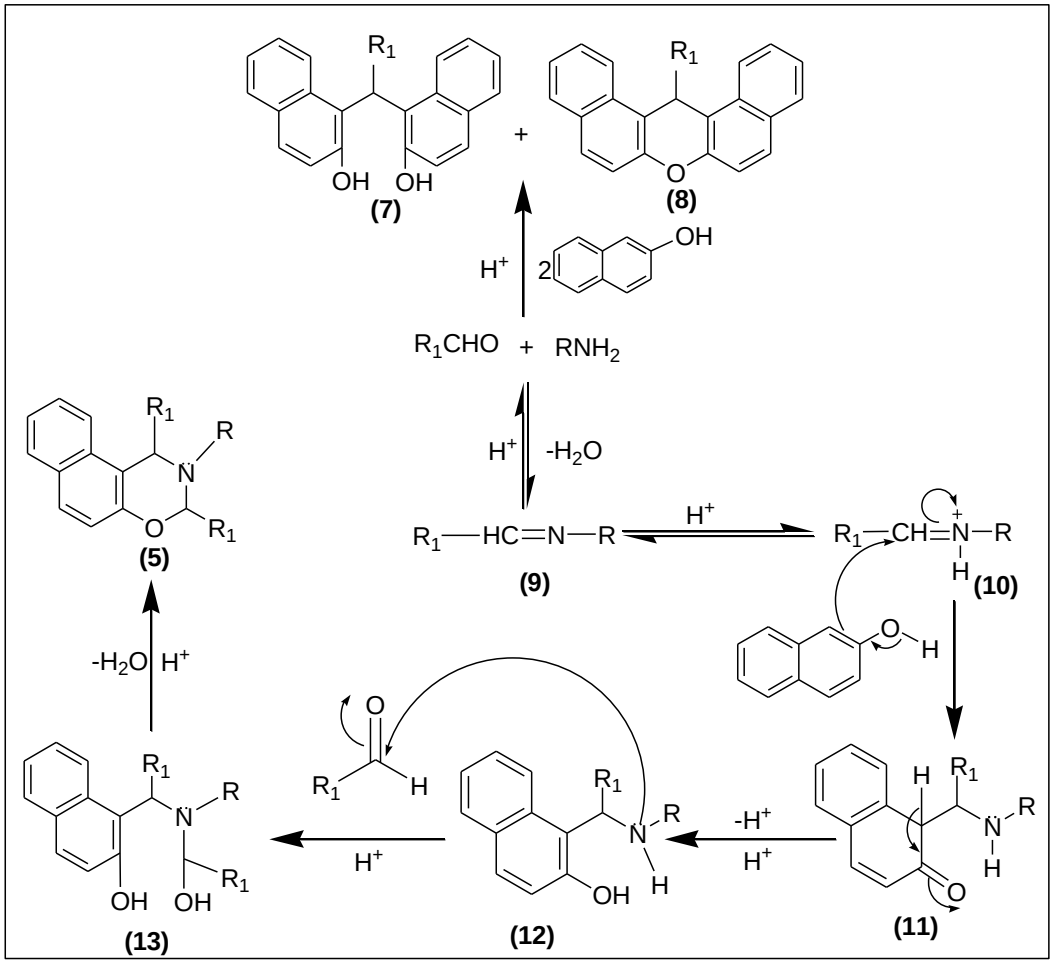


Entry	R_1	R	Time (min) (B/C)[b]	Product(s) Yield (%)[a,c]			
				(9)	**(5)**	**(7)**	**(8)**
1	C_6H_5	C_6H_5	30/20		85/92 **(5a)**		
2	C_6H_5	4-$(Me)_2CHC_6H_4$	30/20		82/96 **(5b)**		
3	C_6H_5	-$CH_2C_6H_5$	40/25		85/92 **(5c)**		
4	C_6H_5	*n*-C_4H_9	30/20		90/94 **(5d)**		
5	C_6H_5	4-NO_2-C_6H_4	2 h/1 h	85/40 **(9a)**		-/25 **(7a)**	-/30 **(8a)**
6	C_6H_5[d]	C_6H_5	1 h/-	86 **(9b)**			
7	C_6H_5[d]	*n*-C_4H_9	1 h/-	88 **(9c)**			
8	4-Cl-C_6H_4	*n*-C_4H_9	30/30		82/92 **(5e)**		
9	4-NO_2-C_6H_4	C_6H_5	40/20	87/18 **(9d)**		-/60 **(7b)**	-/15**(8b)**
10	4-NO_2-C_6H_4	*n*-C_4H_9	30/30		85/92 **(5f)**		
11	4-Me-C_6H_4	C_6H_5	12 h/40	88/20 **(9e)**			-/65**(8c)**
12	4-Me-C_6H_4	*n*-C_4H_9	45/30		80/87 **(5g)**		
13	*n*-C_3H_7	C_6H_5	2 h/1 h	20/15 **(9f)**			-/60**(8d)**
14	*n*-C_3H_7	*n*-C_4H_9	1 h/1 h	25/5 **(9g)**			-/65**(8e)**

[a] isolated yield; [b] Method, B: Reaction in ethanol at room temperature; C: Reaction in solvent-free medium at 100 °C; [c] **(7)** and **(8)** are known compounds [20-21]; [d] using 1- naphthol as starting

In a typical procedure, the mixture of 2-naphthol (1 mmol), aldehyde (2 mmol) and primary amine (1 mmol) was stirred at room temperature in ethanol (or treated under solvent-free medium at 100 °C) using 25 mol % of trichloroacetic acid as catalyst for the specific period of time. After completion of the reaction as monitored by thin layer chromatography the product was isolated as pure solid from the reaction mixture by following a steps of work up procedure. All these results are included in **table-3A.3**.

The one-pot synthesis of *anti*-1,2,3-trisubstituted naphth[1,3]oxazine (**5)** is possible only in situ formation of the reaction intermediates **(9), (10), (11)**, **(12)** and **(13)** and during the course of reactions **(Scheme-3A.2**). Another competitive reaction also observed in these multicomponent reactions which lead to the formation of dibenzoxanthene derivative (**8**) and its precursor (**7**). The success of this method depends on the reversible nature of imine bond formation followed by driving the protonation of imine in one direction under thermodynamic equilibrium to form 1-alkylaminomethyl 2-naphthol intermediate **(12)** [22]. Then nucleophilic attack of this intermediate to the second aldehyde molecule yield the stable-naphthoxazine derivatives **(5)**. The protonation of imine equilibrium can be driven in the favor of desired product by adjusting acidity of catalyst, solvent and temperature, steric and electronic factors of substrates. We observed higher yields (80-94 %) of naphthoxazines from the reaction of aromatic aldehydes and aliphatic primary amines in both conditions (table-3A.3, entries 3, 4, 8, 10, 12) with the formation of electron rich N-alkyl substituted imine. The same type of imines could be obtained from 4-isopropyl aniline and benzaldehyde (table-3A.3, entry 2). Electron deficient imine had no tendency for protonation to give the required product in solution (table-3A.3, entries 5, 9). Furthermore, in solvent-free medium the acid catalyzed activation of carbonyl group observed the preferred path to get dibenzoxanthene instead of electron deficient imine (table-3A.3, entries 5, 9, 11). The rapid reversible equilibrium of aldimine obtained from n-butanal prevents the formation of desired product in solution (table-3A.3, entries 13, 14). Significantly the high temperature reaction directed to the synthesis of dibenzoxanthene **(8)** in dry medium (table-3A.3, entries 13, 14). Formations of imines were the only products from the reactions of 1-naphthol with aromatic aldehydes and electron rich amines in solution (table-3A.3, entries 6, 7). All these products were characterized by ^{1}H NMR, ^{13}C NMR, FT-IR and CHN analytical techniques.



Scheme-3A.2: Plausible mechanism of the multicomponent synthesis of trisubstituted naphthoxazine

The exact orientation of naphth[1,3]oxazine diastereomer was determined from the COSY and NOESY interaction of H-2 and H-4 protons of oxazine ring of the compound **(5a)** (**Fig. 3A.2).** They showed two singlets within the chemical shift values of 5.48-6.08 ppm and 5.79-6.24 ppm without any cross peak in their COSY and NOESY spectra which is possible only by *anti*-orientation of H-2 and H-4 protons in pseudo-axial equatorial conformation of oxazine ring (**Fig. 3A.3).** The HETCOR spectra of (**5a)** assigned the positions of two singlet's by their cross peak with C-2 and C-4 carbons of the oxazine moiety **(Fig. 3A.4).** The three DEPT spectra 135º, 90º, and 45º of **(5a)** are identical **(Fig. 3A.5).** For **(5g)** the DEPT-135 spectrum reveals three negative signals for $–CH_2-$ groups, four positive signals for two –CH- and three $–CH_3$ groups in the aliphatic region and other positive signals for –CH- atoms of aromatic region while no peaks for quaternary carbons.

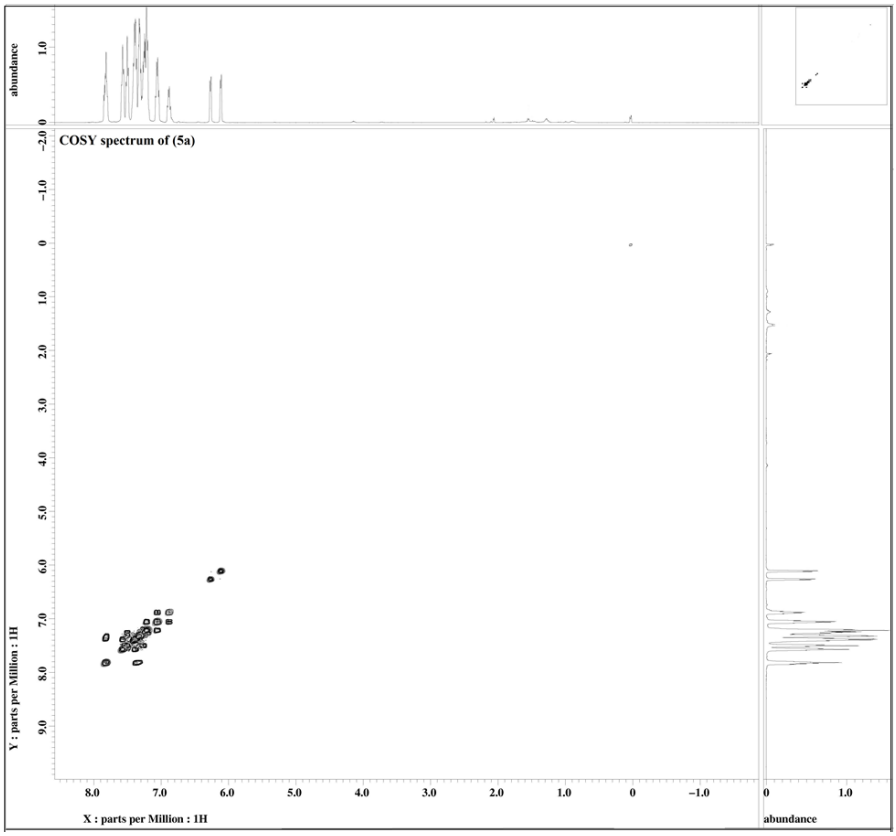


Fig.3A.2a: COSY spectrum of (**5a**)

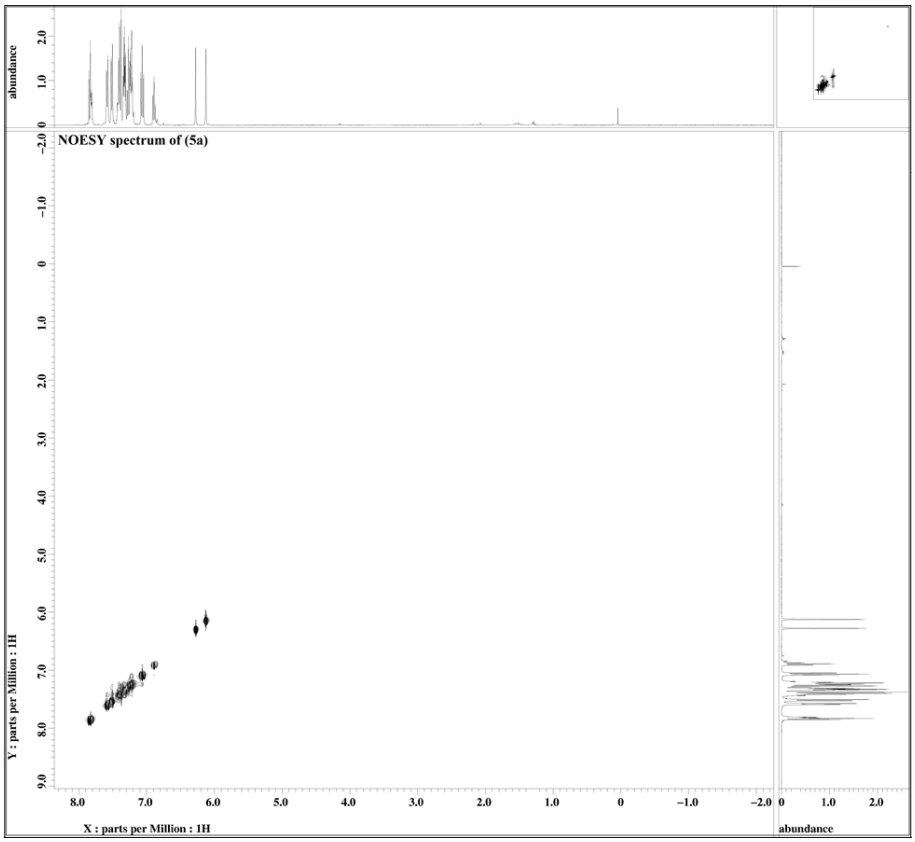


Fig.3A.2b: NOESY spectrum of (**5a**)

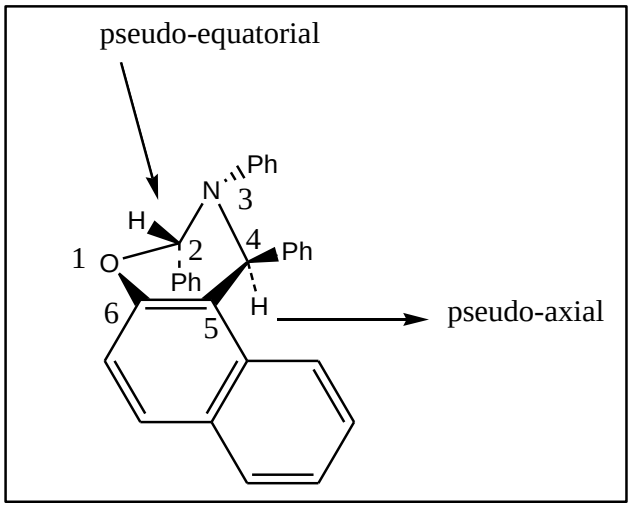


Fig.3A.3: Pseudo-axial-equatorial conformation of oxazine ring

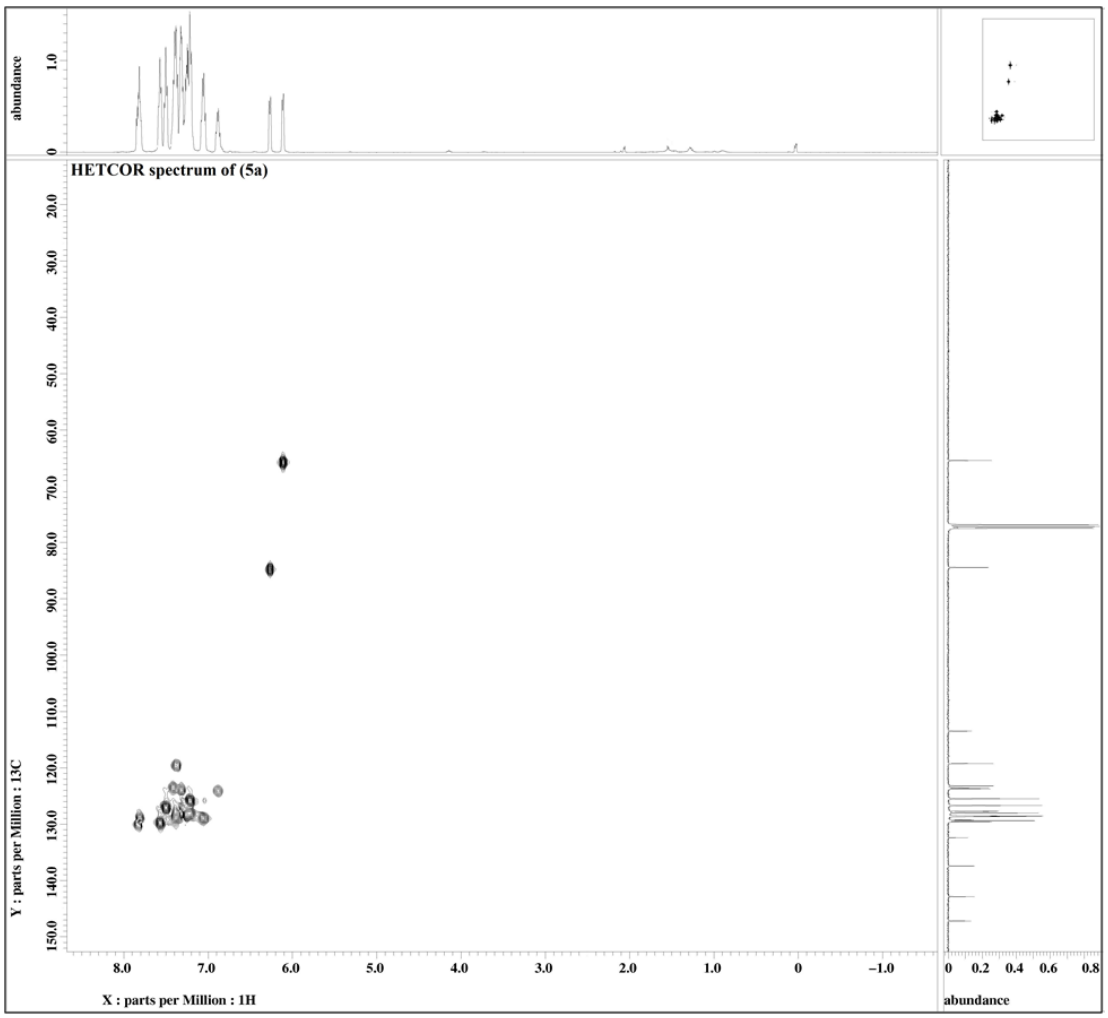


Fig.3A.4: HETCOR spectrum of **(5a)**

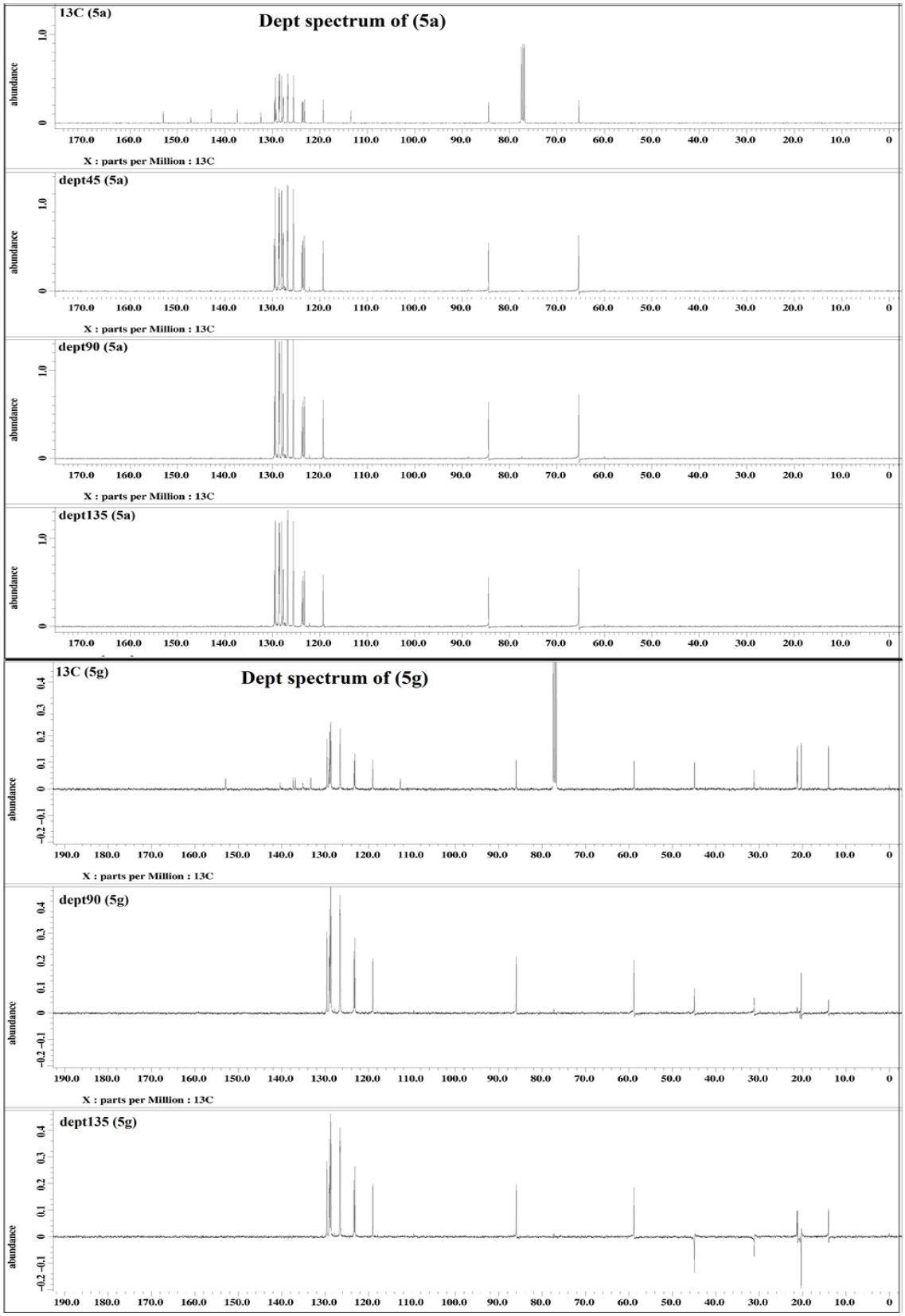


Fig.3A.5: DEPT spectrum of **(5a)** and **(5g)**

Cambridge Structural Database (CSD) [23] shows no structural report for this series of compounds, except **(5c)** and **(5d)** [18-19]. Crystals of **(5d)** have regrown and the structure was evaluated with better data parameter ratio in comparison with reported structure. The C–H···O and π···π interactions are predominant in generating 3D structure of **(5c)** (**Fig.3A.6**). Literature reveals only the emphasis on conformational studies of oxazine family specially naphthoxazine by NMR and semi empirical minimization theory [14, 17]. Difficulties in growing suitable-crystals for this class of compounds ensue single report in CSD. We were able to crystallize out colorless block crystal of compound **(5b)** from 1:1 ethanol-chloroform solvent mixture. Single crystal X-ray data were collected.

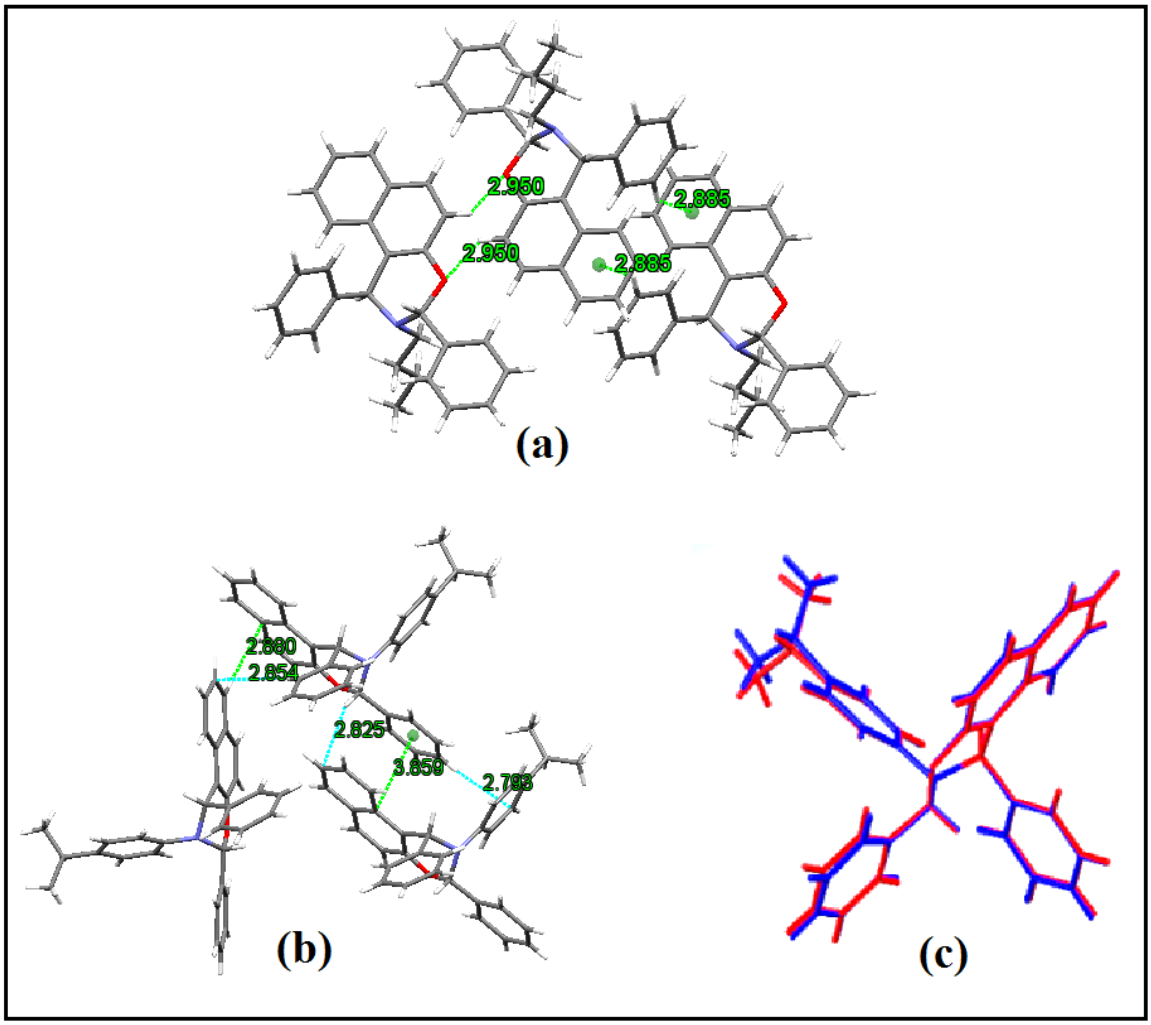


Fig.3A.6: (a) Crystal structure of compound **(5d)**, (b) Molecular packing shows C–H···O and π···π interactions in compound **(5b)**, (c) Overlay of two symmetry independent molecules of structure **(5b)** shows a narrow angle deviation in the isopropyl group.

3A.3. Conclusion

In conclusion, we have reported two efficient multicomponent conditions for the selective synthesis of *anti*-2,3-dihydro-1,2,3-trisubstituted-1*H*-naphth[1,2-e][1,3]oxazine as a single diastereomer for the first time in higher yields utilizing a mixture of 2-naphthol, aryl aldehyde and electron rich primary amines in solution as well as in solvent-free medium using trichloroacetic acid catalyst. The present approach has the ability to synthesize a variety of structurally diverse *anti*-trisubstituted-naphth[1,3]oxazines derivatives within short time. In addition, it has opened up the possibility of asymmetric synthesis of 1, 2, 3-trisubstituted-naphth[1, 3]oxazine products in near future.

3A.4. Experimental section

3A.4.1. General methods: All the chemicals and solvents were obtained from Merck, Alfa-aser, Aldrich and used as received without any further purification. The products were identified by FT-IR, ^{1}H NMR, ^{13}C NMR, CHN analyses and also from their melting point. We had taken COSY, NOESY, HETCOR and DEPT spectra of two compounds **(5a** and **5g**) to identify exact orientation of naphthoxazine diastereomers.

3A.4.2. General procedure for the syntheses of 2, 3-dihydro-1, 2, 3- trisubstituted - 1*H*-naphth[1,2-e][1, 3]oxazine derivatives: A mixture of 2-naphthol (1 mmol), primary amine (1 mmol), and aldehydes (2 mmol) was stirred at room temperature in ethanol(2 mL) or heated in an oil bath for the specified time in absence of any solvent at 100°C using 0.25 mmol of trichloroacetic acid as catalyst. After completion of the reaction as monitored by TLC, the reaction mixture was diluted with 5 mL of dichloromethane and washed with an aqueous solution of sodium hydroxide for removal of unreacted 2-naphthol and acid catalyst.The product mixture was extracted with dichloromethane (3 x 3 mL) and distilled under reduced pressure to get the crude mixture in rotary evaporator. The pure product was precipitated from the saturated solution of crude mixture in ethanol at room temperature.

References:

[1] Ganem, B. *Acc. Chem. Res.* **42,** 463--472, 2009.

[2] Domling, A., & Ugi, I. *Angew. Chem. Int. Ed.* **39,** 3168--3210, 2000.

[3] Mueller, R., et al. *Bioorg. Med. Chem. Lett*. **21,** 3923--3926, 2011.

[4] Kupchan, S.M., et al. *J. Am. Chem. Soc.* **94,** 1354--1356, 1972.

[5] Feng, E., et al. *J. Org. Chem.* **75,** 3274--3282, 2010.

[6] Kurz, T. *Tetrahedron* **61,** 3091--3096, 2005.

[7] Shen, G., et al. *Tetrahedron* **68,** 166--172, 2012.

[8] Adib, M., et al. *Tetrahedron* **62,** 3435--3438, 2006.

[9] Shinde, P.V., et al. *Chin .Chem. Lett.* **22,** 915--918, 2011.

[10] Burke, W.J., et al. *J. Org. Chem.* **29,** 407--410, 1962.

[11] Turgut, Z., et al. *Molecules* **12,** 345--352, 2007.

[12] Sapkal, S.B., et al. *Green Chem. Lett. Rev.* **2,** 57--60, 2007.

[13] Szatmari, I., et al. *Eur. J. Org. Chem.* **10,** 2231--2238, 2004.

[14] Szatmari, I., et al. *Tetrahedron* **59,** 2877--2884, 2003.

[15] Hanumanthu, P., & Ratnam, C.V. *Indian J. Chem.* **15B,** 1019--1021, 1977.

[16] Reddy, V.P., et al. *Indian J. Chem.* **21B,** 148--149, 1982.

[17] Li, Y.H., et al. *Acta Cryst*. **E64,** o1972, 2008.

[18] Zhang, Y., & Li, Y.H. A*cta Cryst.* **E65,** o1796, 2009.

[19] Cimarelli, C., et al. *J. Org. Chem*. **66,** 4759--4765, 2001.

[20] Kumar, A., et al. *J. Comb. Chem.* **12,** 20--24, 2010.

[21] Ohishi, T., et al. *Tetrahedron Lett.* **42,** 2493--2496, 2001.

[22] Belowich, M.E., & Stoddart, J.F. *Chem. Soc. Rev.* **41,** 2003--2024, 2012.

[23] CCDC 968939-968940 (for **5b**, **5c)** contains the supplementary crystallographic data. This data can be obtained free of charge from the Cambridge Crystallographic Data Centre via www.ccdc.ac.uk./data/ request/cifor from the supporting information.

Chapter 3B

Development of environmentally benign Brønsted acidic catalytic system for multicomponent synthesis of *anti*-2,3-dihydro-1,2,3-trisubstituted-1*H*-naphth[1,2-e][1,3]oxazines

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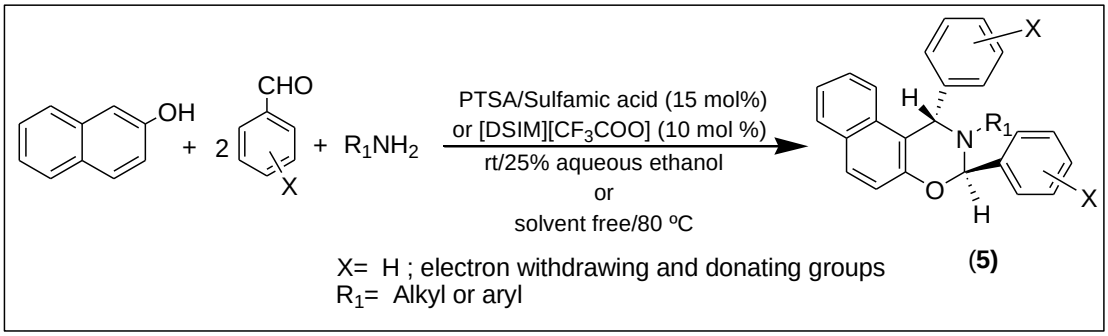
3B.1. Introduction

Substituted 1, 3-oxazine derivatives are ubiquitous as natural products, and many of them have been recognized as pivotal intermediate for the synthesis of molecules with various medicinal properties [1-2]. The great potential of multicomponent reactions (MCRs) to replace multistep organic synthesis, offers a convenient approach toward modern chemical processes to generate complex library of diverse structure in simple method [3-4]. The synthesis of mono- or di-substituted naphthoxazine derivatives was extensively studied by various groups through formation of precursor intermediate aminobenzylnaphthol which was also named as Betti base [5-8]. In the previous **Chapter-3A,** the first acid catalyzed multicomponent synthesis of *anti*-1,2,3- trisubstituted naphthoxazine was isolated as single diastereomer using 25 mol% of CCl_3COOH as non recyclable catalyst in CH_2Cl_2 at atmospheric temperature and solvent-free thermal method [9]. That study also determined the *anti* orientation of trisubstituted naphthoxazine by considering the COSY , NOESY and single crystal XRD analysis**.** But the lack of literature for the preparation of trisubstituted naphthoxazines provides a scope to design environmentally benign methodologies for such compounds within the framework of Green Chemistry principles. The sustainable development process can be made with the help of less energy consumption, one-pot reactions, avoid of toxic solvents, use of recyclable catalysts, decrease of reaction time, mild condition, single product formation and minimization of waste [10]. Therefore, the efficient use of non-toxic and more selective recyclable acid catalysts such as *p*-toluene sulfonic acid, I_2, $ZnCl_2$, sulfamic acid etc. in aqueous medium or solvent-less medium have great demand for the multicomponent reactions of trisubstituted naphthoxazine in the context of cleaner synthesis. The use of water as reaction medium provides several advantages as compared to volatile organic solvents because it is cheap, safe, easy to operate, and environmentally beneficial [11]. Similarly the use of acidic ionic liquids (ILs) instead of conventional Brønsted/Lewis acid in organic synthesis has focussed as dual solvent-catalytic system due to their low viscosity; lower vapour pressure, high thermal and chemical stability [12]. The traditional liquid acid catalysts such as H_2SO_4, HCl, H_3PO_4, HF etc. are often toxic, corrosive, and difficult to separate and recover from products despite their high catalytic activity [13]. The presence of $-SO_3H$ group in imidazolium ILs represents a dual nature of strong task specific Brønsted acidic ionic liquids. These ILs act as recyclable catalyst/medium for organic reactions at mild conditions which is rather difficult to obtain with other conventional acid

catalysts. The higher acidity of 1,3-disulfoimidazolium trifluoroacetate [DSIM][CF_3COO] as mentioned in the **Chapter-2** had attracted our attention to observe its catalytic activity for the synthesis of trisubstituted naphthoxazine derivatives [14]. Thus, from the above facts, we were interested to investigate the catalytic activity of several acidic systems in aqueous or neat condition as reusable catalysts for the synthesis of title compond **(5)** at diferent temperatures (**Scheme-3B.1**).



Scheme-3B.1: Synthesis of *anti*-2,3-dihydro-1,2,3-trisubstituted-1*H*-naphth[1,2-e][1,3] oxazine

3B.2. Results and Discussion

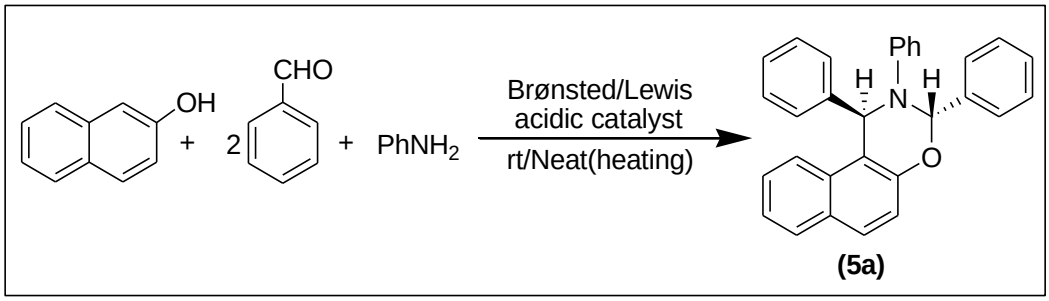
Our initial attempts focussed on the screening of the catalytic activity of non-toxic and cheaper Brønsted/Lewis acids as recyclable catalyst for the multicomponent synthesis of *anti*-diastereomer of 2,3-dihydro-1,2,3-trisubstituted-1*H*-naphth[1,2-e][1,3]oxazines **(5)** in ethanol (or aqueous ethanol or water) at ambient temperature or without solvent at various temperature (Table-3B.1).

For this purpose, we did a comparative study of six acidic catalysts in presence of 25 % of each catalyst in ethanol at room temperature stirring and neat at 90 ºC for the synthesis of **(5a)** (table-3B.1, entries 1-4, 6**,** 8**).** The high catalytic activity was observed for *p*-toluene sulfonic acid (PTSA), sulfamic acid and $FeCl_3$ catalysts (table-3B.1, entries 4, 6 & 8) while the other catalysts, I_2, $BF_3.OEt_2$ and $ZnCl_2$ were found to be less effective under the reaction conditions (table-3B.1, entries 1-3). Decreasing the reaction temperature to 75 ºC for the three reactive catalysts reduced the yields of **(5a)** as compared to 80 ºC under solvent-free method (table-3B.1, entries 5, 7 & 9).

By varying the amount of three catalyst from 15 to 10 mol % in the above optimized temperature in ethanol and neat conditions (table-3B.1, entries 10-13), we observed that 15 mol % of each catalyst would be suitable-to conduct the reactions with varieties of aldehydes and primary amines (table-3B.1, entries 10-12). Solvent study was performed for the model reaction with 15 mol% of PTSA, sulfamic acid and $FeCl_3$ catalysts in 25 %

aqueous ethanol, chloroform and water (table-3B.1, entries 14-16). The above investigation expressed 25% of aqueous ethanol as the safer medium to give excellent yields of product **(5a)** at mild temperature and recycling of PTSA and SA catalysts (table-3B.1, entries 14-15) except $FeCl_3$. The hydration of $FeCl_3$ may reduce the catalytic activity in aqueous ethanol (table-3B.1, entry 16) as compared to ethanol (table-3B.1, entry 12). In absence of catalyst in ethanol, the reaction required 12 h to generate 43% of **(5a)**. Similarly, the catalytic activity of [DSIM][CF_3COO] was also examined by conducting the same reaction in 25 % aqueous ethanol at room temperature in presence of 5 mol%, 10 mol % and 15 mol% of the ionic liquid and at neat at 80 ^oC (table-3B.2, entries 1-3 & 5). From the optimization study of ILs, it was found that 10 mol % of IL produced 94-98 % of **(5a)** in both cases within 10-15 min. The same reaction becomes slower at 70 ^oC and gave only 70 % of **(5a)** during 45 min (table-3B.2, entry 4). The results in **Table-3B.1** and **Table-3B.2** indicated that the homogeneous solution of reaction mixture in aqueous ethanol provides a suitable-medium to increase the stability of reaction intermediates via H-bonding for the acid catalysed reactions at mild condition as compared to solvent-free medium.

Table-3B.1: Optimization of six Brønsted /Lewis acids catalyzed synthesis of **(5a)**

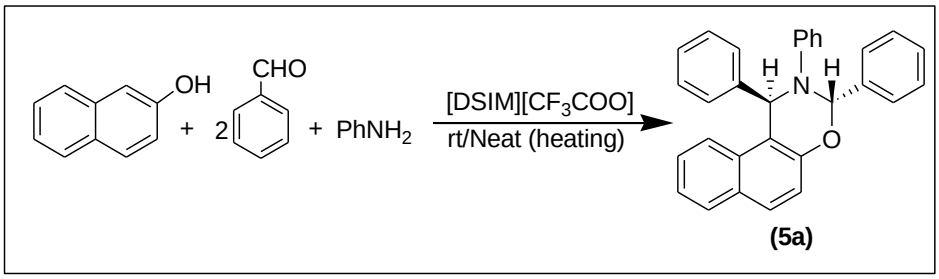


Entry	Catalyst	Cat. (mol%)	Time (min)[a, b]	% of Yields [c] **(5a)**
1	I_2	25	35(A)/25(B)	65(A)/68(B)
2	$BF_3.OEt_2$	25	30(A) /25(B)	73(A)/77(B)
3	$ZnCl_2$	25	35(A)/30(B)	62(A)/75(B)
4	PTSA	25	25(A)/15(B)	86(A)/94(B)
5	PTSA	25	15(C)/20(D)	93(C)/81(D)
6	Sulfamic acid	25	25(A)/15(B)	87(A)/96(B)
7	Sulfamic acid	25	15(C)/20(D)	94(C)/83(D)

8	$FeCl_3$	25	20(A)/25(B)	86(A) /89(B)
9	$FeCl_3$	25	20(C)/30(D)	85(C) /77(D)
10	PTSA	15	25(A)/15(C)	84(A)/92(C)
11	Sulfamic acid	15	25(A)/15(C)	86(A)/94 (C)
12	$FeCl_3$	15	30(A)/20(C)	82(A)/88(C)
13	PTSA/SA	10	35(A)/35(A)/	71(A)//74(A)
14	PTSA	15	25(E)/20(F)/3h(G)	87(E)/86(F)/50(G)
15	Sulfamic acid	15	25(E)/20(F)/ 3h(G)	91(E)/88(F)/55(G)
16	$FeCl_3$	15	1.5 h(E)/35(F)	30(E)/83(F)

[a] Methods: (A) Reaction at room temperature (r.t.) in ethanol; (B) Reaction at 90°C in neat; (C) Reaction at 80°C in neat; (D) Reaction at 75°C in neat; (E) Reaction at r.t. in 25 % aqueous ethanol; (F) Reaction at r.t. in chloroform; (G) Reaction at r.t. in water; [b] The slash mark "/'' is used to differentiate the experimental methods, catalysts and product yields in various conditions. [c] Isolated yield

Table-3B.2: Optimization of (5a) using [DSIM][CF_3COO] ionic liquid as catalyst



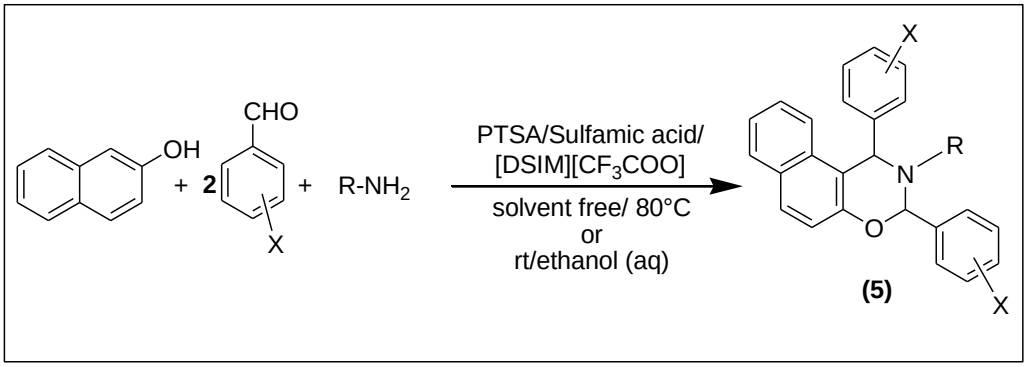
Entry	Cat (mol%)	Temp. (°C)	Time (min)	% of yield[b]
1	5	rt[a]	45	65
2	10	rt[a]	15	94
3	15	rt[a]	15	94
4	10	70	45	70
5	10	80	10	98
6	10	85	10	98

[a] Reaction at room temperature using 25 % aqueous ethanol ; [b] Isolated yield

The above standardized procedures with the three reusable catalytic systems (e.g. PTSA, SA and [DSIM][CF_3COO], **IL-3**) were successfully utilized to generate different *anti*-1,2,3-trisubstituted naphthoxazine derivatives **(5)** from the mixture of 2-naphthol, various aromatic aldehydes and primary amines under environmentally benign routes like 25 % aqueous ethanol with stirring at atmospheric temperature or solvent-free thermal energy

(table-3B.3 and table-3B.4). It was found that this three component protocol proceeds well in presence of primary amines and *p*-substituted aromatic aldehydes containing electron withdrawing or donating group [9].

Table-3B.3: Synthesis of different naphthoxazine derivative using PTSA/sulfamic acid



Entry	X	R	PTSA		Sulfamic acid	
			Time (min) (A/B)[a]	% of Yield [b]	Time (min) (A/B)[a]	% of Yield [b]
1	H	C_6H_5	15/25	92/87 **(5a)**	15/25	94/91 **(5a)**
2	H	*n*-butyl	15/25	95/86 **(5d)**	15/25	97/90 **(5d)**
3	H	4-$CH(Me)_2C_6H_4$	20/30	90/84 **(5b)**	20/30	93/87 **(5b)**
4	H	-CH_2-C_6H_5	20/25	93/83 **(5c)**	20/25	95/86 **(5c)**
5	H	4-CH_3-C_6H_4	15/25	92/85 **(5h)**	15/25	94/88 **(5h)**
6	H	4-OCH_3-C_6H_4	15/20	94/86 **(5i)**	15/20	97/93 **(5i)**
7	H	4-Cl-C_6H_4	20/25	88/83 **(5j)**	20/25	90/85 **(5j)**
8	4-NO_2	*n*-butyl	10/15	95/88 **(5f)**	10/15	97/92 **(5f)**
9	4-CH_3	*n*-butyl	20/30	90/82 **(5g)**	20/30	93/84 **(5g)**
10	4-Cl	*n*-butyl	20/25	93/85 **(5e)**	20/25	95/87 **(5e)**
11	4-Cl	4-CH_3-C_6H_4	20/25	90/83 **(5k)**	20/25	90/85 **(5k)**
12	4-Cl	4-Cl-C_6H_4	20/30	94/86 **(5l)**	20/25	97/88 **(5l)**
13	3-NO_2	*n*-butyl	2 h	NR	2 h	NR
14	2-NO_2	*n*-butyl	2 h	NR	2 h	NR

[a] Methods: (A) Reaction at 80 °C in neat condition; (B) Reaction at room temperature in 25 % aqueous ethanol; [b] Isolated yield

Table-3B.4: Synthesis of different naphthoxazine derivative using [DSIM][CF_3COO]

Entry	X	R	**IL-3**	
			Time (min) (A/B)[a]	% of Yield [b]
1	H	C_6H_5	10/15	98/94 **(5a)**
2	H	*n*-butyl	10/15	97/93 **(5d)**
3	H	4-$CH(Me)_2C_6H_4$	12/20	95/90 **(5b)**
4	H	-CH_2-C_6H_5	15/20	96/90 **(5c)**
5	H	4-CH_3-C_6H_4	10/17	97/92 **(5h)**
6	H	4-OCH_3-C_6H_4	10/15	95/91 **(5i)**
7	H	4-Cl-C_6H_4	15/20	93/89 **(5j)**
8	4-NO_2	*n*-butyl	8/12	98/94 **(5f)**
9	4-CH_3	*n*-butyl	12/20	94/88 **(5g)**
10	4-Cl	*n*-butyl	12/20	96/93 **(5e)**
11	4-Cl	4-CH_3-C_6H_4	10/15	95/87 **(5k)**
12	4-Cl	4-Cl-C_6H_4	15/20	96/92 **(5l)**
13	3-NO_2	*n*-butyl	2 h	NR
14	2-NO_2	*n*-butyl	2 h	NR

[a] Methods: (A) Reaction at 80 °C in neat condition; (B) Reaction at room temperature in 25 % aqueous ethanol; [b] Isolated yield

The nucleophilic primary aromatic amines such as *p*-toluidine, *p*-anisidine, *p*-chloroaniline and 4-isopropylaniline reacted rapidly with the mixture of *p*-substituted aromatic aldehydes and 2-naphthol within 10-30 min using 15 mol% of PTSA and sulfamic acid as catalysts by following the above standard procedures (table-3B.3, entries 3, 5-7, 11-12). Reactions of electron deficient 4-nitrobenzaldehyde with n-butylamine formed 88-98 % yield of product within short period (table-3B.3, entry 8). Likewise electron rich *p*-substituted aldehydes also reacted efficiently with both the primary aliphatic/aromatic amines in these two methods (table-3B.3, entries 9-12). Similarly the same trend of results was also observerd for the reactions catalysed by 10 mol% of **IL-3** [DSIM][CF_3COO]) in **Table-3B.4.** The three catalysts failed to produce the corresponding naphthoxazines from the reactions of 2-nitrobenzaldehyde and 3-nitrobenzaldehydes with n-butylamines (table-3B.3 & table-3B.4, entries-13-14). The steric effects expected from the two aldehydes may

restrict the formation of aminoalkylnaphthol which is the precursor intermediate of naphthoxazine. Furthermore the three acidic systems were recycled for four runs with the model reaction in aqueous ethanol **(Fig.3B.1)**.

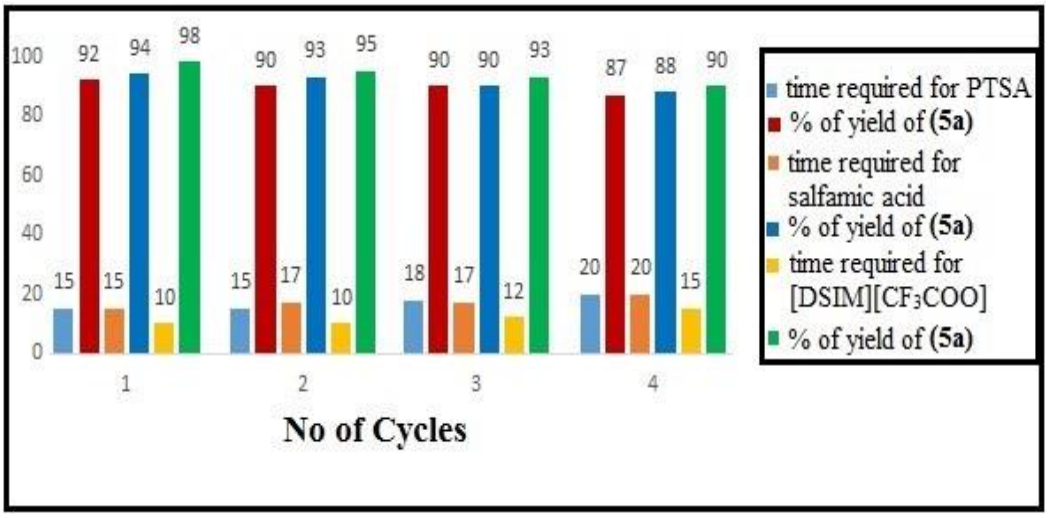


Fig.3B.1: Reusability curve of the three catalysts for the preparation of **(5a)**

3B.3. Conclusion

In summary we have utilized three efficient environmentally safe Brønsted acidic catalysts for the multicomponent one-pot synthesis of 1, 3-naphthoxazine derivatives from 2-naphthol, *p*-substituted aromatic aldehydes and electron rich primary amine in aqueous ethanol at mild condition and in solvent-free medium at 80 °C with excellent results within short time. The advantages of these methods are one-pot reaction, higher yields of product, less time, reusable catalyst and simple work-up procedure. This is the first report of task specific acidic IL catalysed synthesis of trisubstituted naphthoxazine derivatives in greener medium in an efficient manner along with two other safer solid acid catalysts.

3B.4. Experimental section

3B.4.1. General Information

The acidic IL 1,3-disulfoimidazoliumtrifluoroacetate [DSIM][CF_3COO] was prepared according to the known literature [14]. All the products were characterized by using FT-IR, ^{1}H NMR, ^{13}C NMR and CHN analyzer. The known compounds were identified by comparision of their melting point, FT-IR, ^{1}H NMR and ^{13}C NMR with the literature data [9].

3B.4.2. General procedure for the synthesis of 2,3-dihydro-1,2,3-trisubstituted-1H-naphth[1,2-e][1,3]oxazine derivatives (5) using reusable Brønsted acidic catalytic systems

A two necked 50 mL round bottom flask fitted with a water condenser, a mixture of 2-naphthol (1 mmol), primary amine (1 mmol), and aromatic aldehydes (2 mmol) was stirred in 25 % aqueous ethanol (2 mL) at room temperature (or at 80-90 ºC in neat) using 15 mol % of the two Brønsted acids (PTSA/sulfamic acid) and 10 mol % of 1,3-disulfoimidazolium trifluoroacetate [DSIM][CF_3COO] respectively. The completion of the reaction was monitored by thin layer chromatography. The work up procedure involved through addition of 5 mL of water to the reaction mixture after completion with vigorous stirring for p-toluene sulfonic acid (PTSA) or sulfamic acid catalysts. The crude organic product was extracted using dichloromethane (3 x 3 mL) from the aqueous solution containing PTSA or sulfamic acid. The Brønsted acids catalysts were isolated as solid residue from the aqueous phase for reuse by evaporating in rotary vacuum evaporator at 85 °C. For ionic liquid catalyzed reactions in absence of solvent(or elimination of 1 mL of aqueous EtOH in rotary vacuum evaporator), after completion of the reaction as monitored by TLC, the product was extracted from the ionic liquid phases using dry dichloromethane (3 x 3 mL) as solvent**.** The CH_2Cl_2 layer was dried over anhydrous sodium sulfate and evaporated under reduced pressure to get the crude product. The pure product was then isolated as precipitate by adding ethanol at room temperature and further recrystallization from absolute ethanol provides analytically pure product. The ionic liquid catalyst was reused for next cycle of reactions in the same reaction vessel after washing using dichloromethane (1.5 x 2 mL) solvent.

References

[1] Reddy, D.N., & Prabhakaran, E.N. *J. Org. Chem.* **76**, 680--683, 2011.

[2] Turgut, Z., et al. *Molecules* **12**, 345--352, 2007.

[3] Ruijterm, E., et al. *Angew. Chem. Int. Ed.* **50,** 6234--6246, 2011.

[4] Ganem, B. *Acc. Chem. Res.* **42**, 463--472, 2009.

[5] Szatmari, I., & Fulop, F. *Curr. Org. Synth.* **1**, 155--165, 2004.

[6] Cardellicchio, C., et al. *Tetrahedron: Asymmetry* **21**, 507--517, 2010.

[7] Szatmari, I., & Fulop, F. *Tetrahedron* **69,** 1255--1278, 2013.

[8] Shinde, P.V., et al. *Chin. Chem. Lett.* **22**, 915--918, 2011.

[9] Borah, R., et al. *RSC Adv*. **4**, 10912--10917, 2014.

[10] Horva'th, I.T., & Anastas, P.T. *Chem. Rev*. **107,** 2169--2173, 2007.

[11] Dallinger, D., & Kappe, C.O. *Chem. Rev*. **107**, 2563--2591, 2007.

[12] Martins, M.A.P., et al. *Chem. Rev*. **108**, 2015--2050, 2008.

[13] Zhao, G., et al. *Green Chem*. **6**, 75--77, 2004.

[14] Dutta, A.K., et al. *RSC Adv*. **4**, 41287--41291, 2014.

Chapter 3C

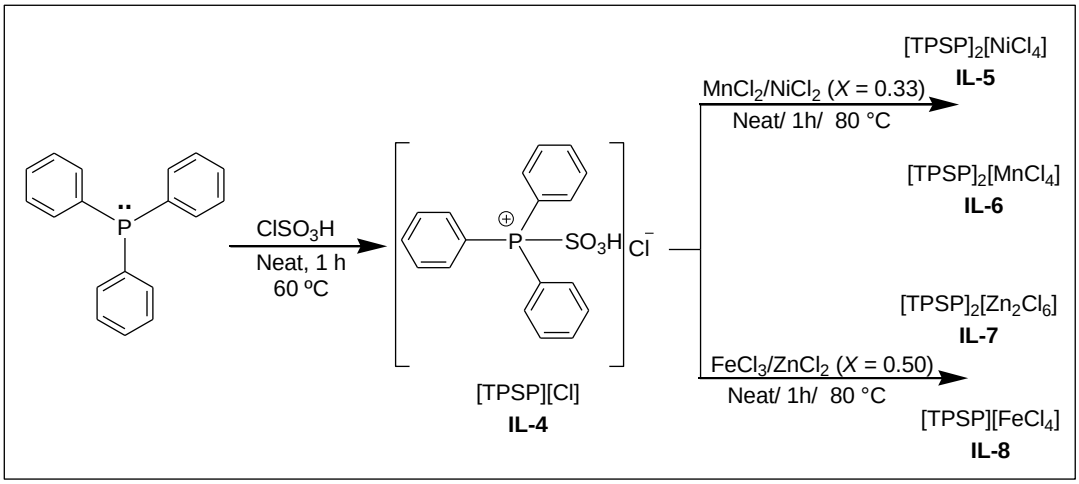
Exploration of triphenylsulfophosphonium chlorometallates as heterogeneous catalyst for the synthesis 1, 2, 3-trisubstituted naphthoxazines

3C.1. Introduction

Most of the recent development on ionic liquids (ILs) covers the utilization of large number of nitrogen based salts such as imidazolium, pyridinium and quaternary ammonium cations as designer solvents and catalysts in organic synthesis which reveals less attention on phosphonium salts [1-5]. The melting points of phosphonium salts are higher than quaternary nitrogen salts and they are thermally more stable-than nitrogen based ILs. Many phosphonium salts are not exist in liquid state at room temperature, but by proper selection of the alkyl substituent of cation and suitable-anion, there are many of them which fall within the broad definition of ionic liquids [6]. Badri *et al* described the first uses of tetrabutylphosphonium halides (TBPHs) as solvent in regioselective *o*-alkylation reaction [7]. Before that, Knifton *et al* employed tetrabutylphosphonium halides as molten solvent for ruthenium-catalyzed hydrogenation of carbon monoxide to ethylene glycol [8] and hydroformylation of olefins [6, 9-10]. Few crystalline alkyltriphenyl phosphoniumtosylates of melting points above 100 °C utilized for catalytic hydroformylation of 1-hexene [11-12] and also Diels-Alder reaction of isoprene with methyl acrylate in molten state [13]. They also acted as good co-catalyst for the Baylis-Hillman reaction [14]. But they can be explored as efficient reusable catalyst or reagents by attaching specific functional groups for definite uses. The preparation and uses of task-specific acidic phosphonium ILs were only observed by Shaterian *et al* and Khazaei *et al* for organic reactions [15-16]. However, the direct -SO_3H functionalized phosphonium chlorometallate salts are not reported in literature till date. Halometallates of phosphonium salts $[PPh_3Me]_x[MX_y]$ without any functional group were prepared by Essawi *et al* as solid material, where M = Cu^{2+}, Co^{2+}, Mn^{2+}, Ni^{2+}, Fe^{3+}, Pb^{2+} and Hg^{2+} ; X= I or Cl [17]. Therefore, in this report we attempted to prepare and characterize four Brønsted-Lewis acidic bi-functionalized sulfophosphonium chlorometallate ionic systems $[TPSP]_n[X]$ (or $[PPh_3SO_3H]_x[X]$), where n = 1 or 2; X = $FeCl_4^-$, $Zn_2Cl_6^{2-}$, $NiCl_4^{2-}$, $MnCl_4^{2-}$ by reacting parent $[PPh_3SO_3H][Cl]$ salt with corresponding transition metal chlorides ($FeCl_3$, $MnCl_2$, $ZnCl_2$ and $NiCl_2$) with different ratios under solvent-free condition at 80 °C for one hour (**Scheme-3C.1**) [18-20].

After characterization by different analytical techniques, they were subjected for thermogravimetric analysis and Hammett acidity studies which reflected their nature for uses as heterogeneous acid catalyst. Thus, the catalytic performances of these salts were examined as heterogeneous acid catalyst for the multicomponent synthesis of *anti*-

diastereomer of 1, 2, 3-trisubstituted naphthoxazines **(5)** in continuation of our earlier reports that have already been discussed in the Chapters **3A** and **3B** [19-20]. In material science, these types of fused naphthoxazine derivatives can be applicable as chemical sensors, fluorescent labeling, dyes, biological detectors, cosmic-ray detection, and most commonly, fluorescent lamps for their fluorescent properties [21].



Scheme-3C.1: Synthesis of phosphonium based $[TPSP]_n[X]$ salts

3C.2. Results and Discussion

3C.2.1. Characterization of chlorometallate ionic liquids

Four chlorometallate ionic liquids ($[TPSP]_n[X]$, where n= 1 or 2; X= $FeCl_4^-$, $Zn_2Cl_6^{-2}$, $NiCl_4^{-2}$, $MnCl_4^{-2}$) were synthesized from the reaction of [TPSP][Cl] with transition metal halides such $FeCl_3$, $ZnCl_2$, $NiCl_2$, $MnCl_2$ as shown in the **Scheme-3C.1.**

3C.2.1.1. Spectral analysis of the chlorometallate ILs

The five mid-infrared spectra of sulfophosphonium salts in **Fig.3C.1** presented the symmetric, antisymmetric stretching and bending vibrations of S-O bond of $–SO_3H$ groups at 1177-1206, 1044-1052 and 586-594 cm^{-1} respectively. The medium strength P-Aryl stretch at 1130-1090 cm^{-1} also matched in the same region of S-O stretching frequencies. The P-C stretching frequency shifted from 754 cm^{-1} to 870-879 cm^{-1} for direct attachment of $–SO_3H$ group to phosphorus [22-23]. A strong peak around 1622-1631 cm^{-1} observed for –C=C- stretching vibration of three phenyl groups of PPh_3. The –OH stretching frequency observed as broad band in the range of 3410-3444 cm^{-1}.

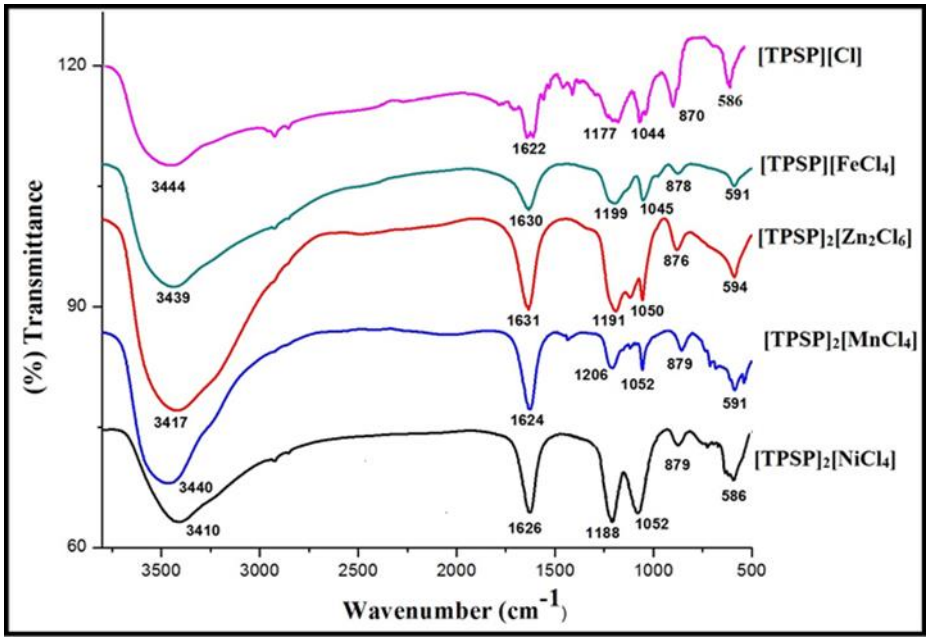


Fig.3C.1: FT-IR spectra of triphenylsulfophosphonium salts

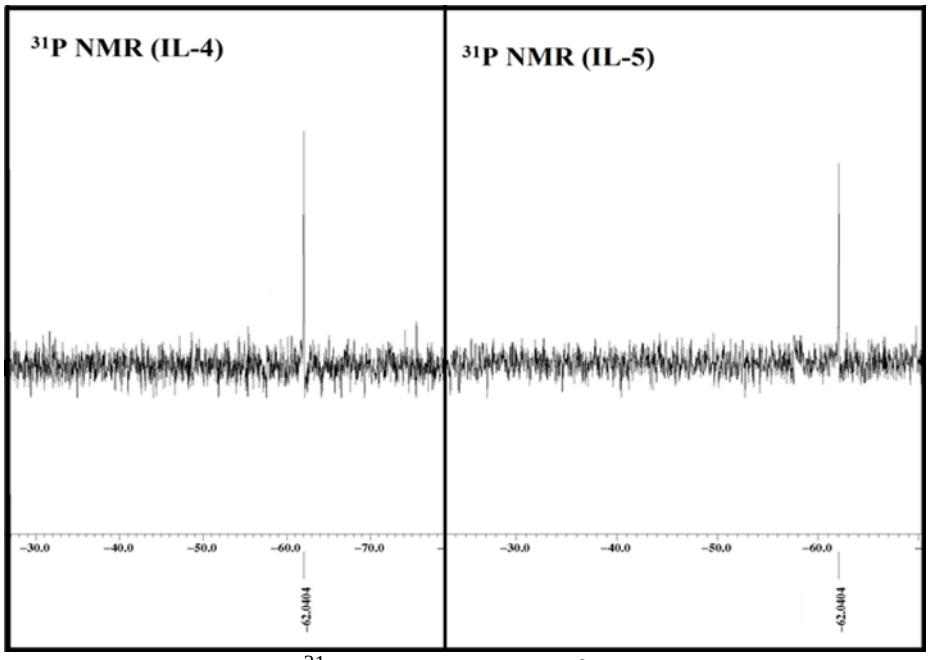


Fig.3C.2a: ^{31}P NMR spectrum of **IL-4** and **IL-5**

The ^{31}P NMR spectra of [TPSP][Cl] (**IL-4**) and $[TPSP]_2[Zn_2Cl_6]$ (**IL-7**) salts were studied using dilute solution of DMSO-d_6 which exhibited one singlet peak at δ= −62.04 ppm in contrast to the single peak of PPh_3 at δ= −5.4 ppm which is shown in **Fig.3C.2a** [24]. The lower solubility of other three chlorometallates restricted to take the ^{1}HNMR, ^{13}C NMR and ^{31}P NMR spectra. The ^{1}H NMR spectrum of basic ionic salt **IL-4** is shown in **Fig.3C.2b,** has one proton singlet at δ= 13.9 ppm for -SO_3H group and a multiplet at δ= 7.49-7.57 ppm for phenyl proton.

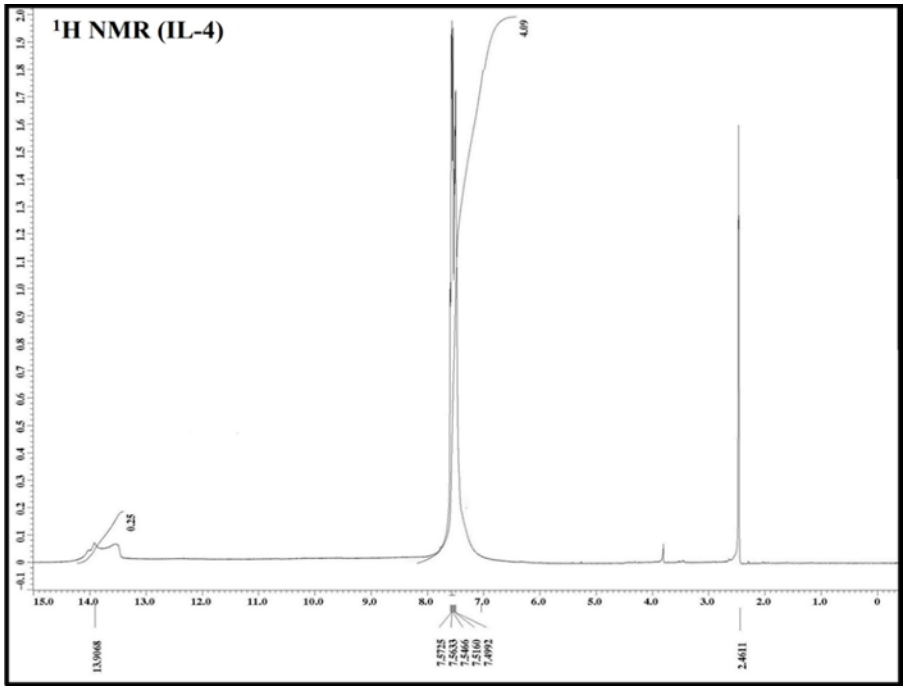


Fig.3C.2b: ^{1}H NMR of **IL-4**

3C.2.1.2. Spectral data for synthesized triphenylsulfo phosphonium IL:

[TPSP][Cl] **(IL-4):** Light reddish semi-solid, 98% yields**;** FT-IR (KBr): 3444, 1622, 1177, 1044, 870, 586 cm^{-1}; ^{1}H NMR (400MHz, DMSO-d_6): δ 7.49-7.7.57 (m, 15H), 13.9 (broad, 1H); CHN analysis of $C_{18}H_{16}O_3PSCl$ (%): Cal. C 57.07, H 4.26; Found C 57.22, H 4.32

$[TPSP]_2[NiCl_4]$ **(IL-5):** Off white solid, 95% yield; M.p. 138°C; FT-IR (KBr): 3407, 1628, 1193, 1054, 1119, 880, 580 cm^{-1}; CHN analysis of $C_{36}H_{32}O_6P_2S_2NiCl_4$ (%): Cal. C 42.52, H 3.17; Found C 42.54, H 3.20

$[TPSP]_2[MnCl_4]$ **(IL-6):** Faint yellow solid; 95% yield; M.p. 115 °C; FT-IR (KBr):3453, 1619, 1210, 1100, 1054, 875, 580 cm^{-1}; CHN analysis of $C_{36}H_{32}O_6P_2S_2MnCl_4$ (%): Cal. C 42.84, H 3.20; Found C 42.87, H 3.25.

$[TPSP]_2[Zn_2Cl_6]$ **(IL-7):** White solid; 96% yield; M.p. 186°C; FT-IR (KBr):3416, 1632, 1197, 1123, 1045, 884, 584 cm^{-1}; CHN analysis of $C_{36}H_{32}O_6P_2S_2Zn_2Cl_6$ (%): Cal. C 41.97, H 3.13; Found C 42.01, H 3.15

$[TPSP][FeCl_4]$ **(IL-8):** Yellow solid; 95% yield; M.p. 117 °C; FT-IR (KBr): 3435, 1632, 1184, 1054, 880, 580 cm^{-1}; CHN analysis of $C_{18}H_{16}O_3PSFeCl_4$ (%): Cal. C 39.96, H 2.98; Found C 39.84, H 3.02

3C.2.1.3. Study of surface morphology

The SEM images expressed different surface morphology for the four chlorometallate ILs in Fig.3C.3 Among the four figures we observed more aggregations of $[TPSP]_2[MnCl_4]$

salt which is less in case of Fe and Ni containing phosphonium solids. The surface of Zn salt is covered with similar size particles having crack and deformative structures. The Fe salt shows non-uniform distribution of rod-like crystallite structures on its surface. There are no definite shapes of particles on the surface of Ni salt. These variations may be considered for different structural changes of chlorometallate anions in these salts.

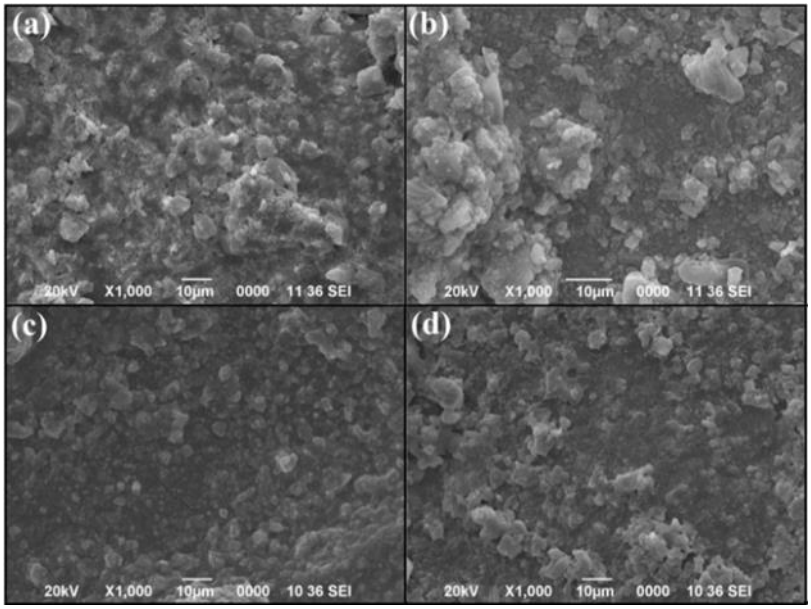


Fig.3C.3: SEM images of (a) $[TPSP][FeCl_4]$; (b)$[TPSP]_2[MnCl_4]$; (c) $[TPSP]_2[Zn_2Cl_6]$; (d) $[TPSP]_2[NiCl_4]$

3C.2.1.4. EDX analysis

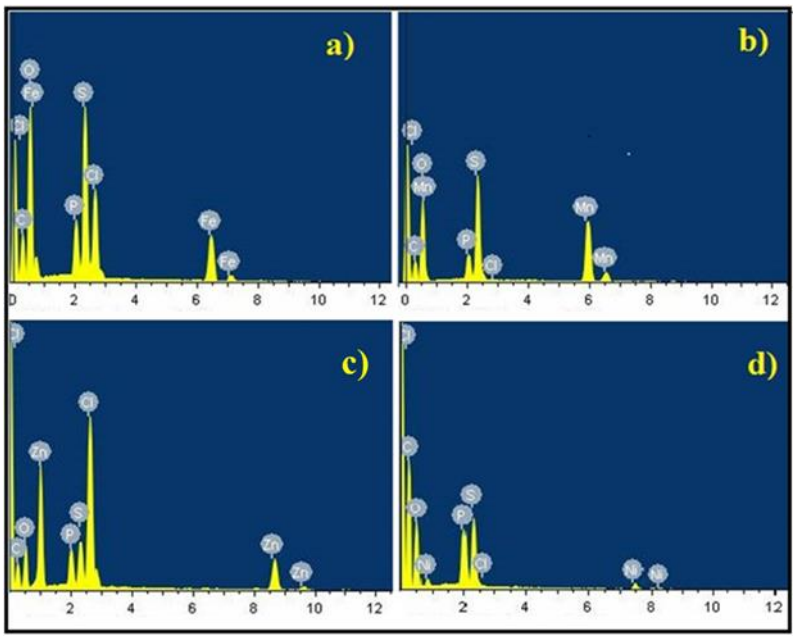


Fig.3C.4: EDX analyses of (a) $[TPSP][FeCl_4]$; (b) $[TPSP]_2[MnCl_4]$; (c) $[TPSP]_2[Zn_2Cl_6]$; (d) $[TPSP]_2[NiCl_4]$

The energy dispersion X-ray (EDX) analysis of four chlorometallate ILs $[TPSP]_n[X]$ indicates the respective transition metal chlorides on their surfaces in addition to other constituent elements phosphorus, sulfur, oxygen and carbon (**Fig.3C.4**).

3C.2.1.5. Powder X-ray diffraction analysis

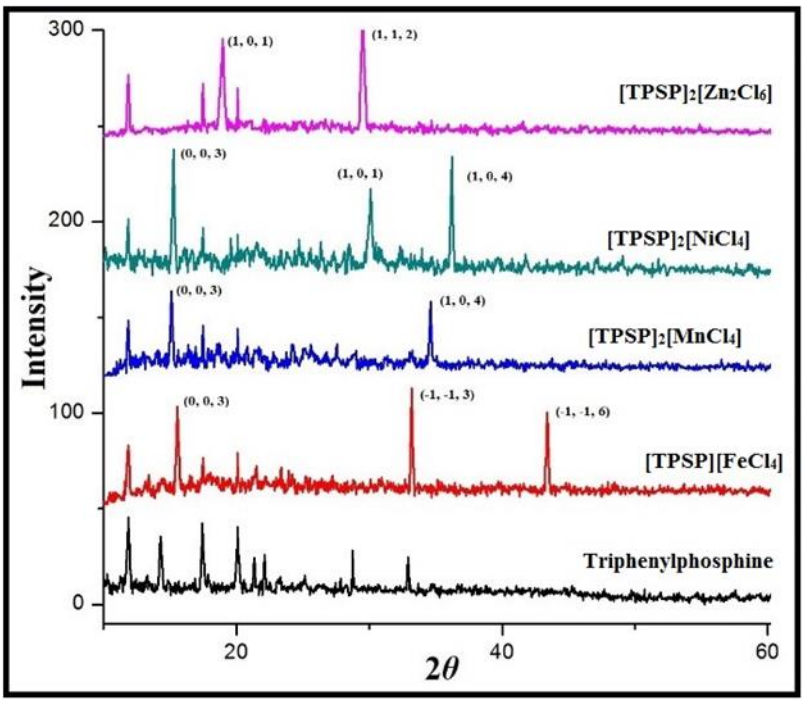


Fig.3C.5: Powder XRD pattern of the four catalysts and PPh_3

Fig.3C.5 demonstrated the higher crystalline powder XRD pattern of chlorometallate ILs and PPh_3. In case of **[**TPSP][$FeCl_4$] salt, the characteristic peaks are displayed at 2θ= 15.7°, 33.3°and 43.45° for the planes (0, 0, 3), (-1, -1, 3), (-1, -1, 6) with JCPDS card no. 77-0998. The XRD data of $[TPSP]_2[Zn_2Cl_6]$ observed at 2θ = 18.9° and 29.6° are matched well with the (1, 0, 1) and (1, 1, 2) reflection planes (JCPDS card no. 72-1285). Similarly the different peaks for $[TPSP]_2[NiCl_4]$ can be assigned to the reflection planes (0, 0, 3), (1, 0, 1), (1, 0, 4) at 2θ = 15.1°, 30.0° and 36.2° according to the data base (JCPDS card no. 71-2032).The other catalyst $[TPSP]_2[MnCl_4]$ also displayed peaks at 2θ = 15.2° and 34.6° for the reflection (0, 0, 3) and (1, 0, 4) against JCPDS no. 22-0720. The powder XRD patterns of all the four catalysts were compared with PPh_3 which indicated the retention of basic three peaks at 2θ = 11.88º, 17.42º and 20.08º in the four solids with different intensity. It was found that the peak at 2θ = 11.88º has the same intensity in all the XRD patterns while other two slightly lost their intensities.

3C.2.1.6. Raman analysis

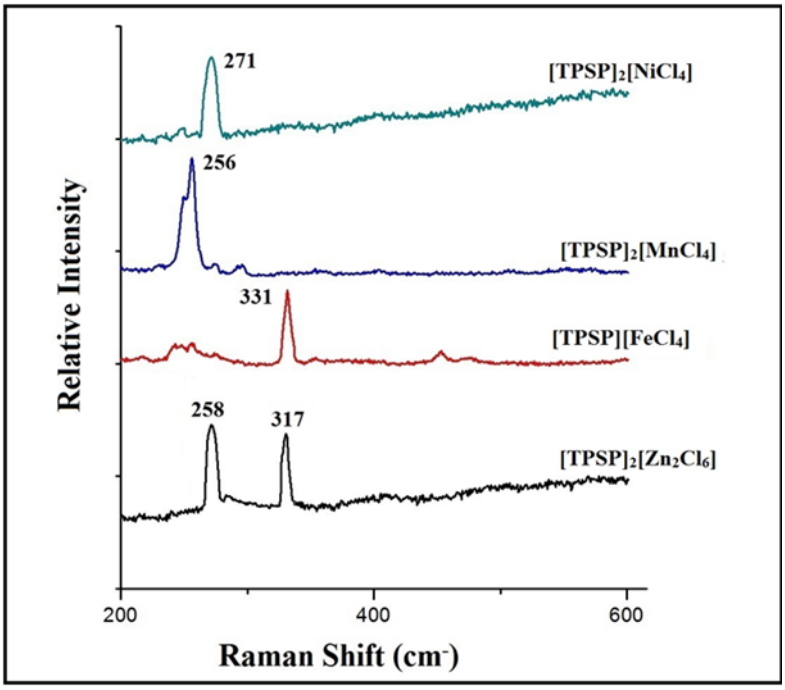


Fig.3C.6: Raman spectra of four sulfophosphonium salts

The Raman spectra in **Fig.3C.6** displayed the characteristic peaks of the anionic components for these chlorometallate salts. The [TPSP][$FeCl_4$] solid gave one strong peak at 331 cm^{-1} for $FeCl_4^-$ anion [25]. In case of [TPSP]$_2$[Zn_2Cl_6], two sharp peaks were observed around 258 cm^{-1} and 317 cm^{-1} which can be attributed for doubly charged $Zn_2Cl_6^{2-}$ of the ionic salt as evidenced from the existing studies [26-27]. Moving towards [TPSP]$_2$[$MnCl_4$] and [TPSP]$_2$[$NiCl_4$] solids, we found one intense peak at 256 cm^{-1} for $MnCl_4^{2-}$ and at 271 cm^{-1} for $NiCl_4^{2-}$ anions in the solid materials according to the reported data [28-29].

3C.2.1.7. Electronic spectra

The electronic spectra of four chlorometallates showed various characteristic absorption peaks of anionic species at different wavelength in **Fig.3C.7**. From the figure, the wide absorption band around 273-382 nm for [TPSP][$FeCl_4$] salt can be obtained from ligand to metal (L→Fe(+3)) charge transfer transition. The weak intensity band may be appeared for d-d transition of $FeCl_4^-$ at 570 nm [30-31]. Similarly the electronic spectra of [TPSP]$_2$[$NiCl_4$] displays one ligand-to-metal-charge transfer transition at 264 nm according to the molecular orbital model accepted for tetrahedral transition metal halide complexes [32].The similar intensity absorption bands at 781 nm and 684 nm for

$^3T_1(F) \rightarrow {}^3T_1(P)$ transition also confirm the structure as regular tetrahedral $NiCl_4^{2-}$ complex. Another smaller absorption peak at 405 nm can be expected from mixing of small amount of octahedral nickel species which are capable of the transition of $^3A_{2g}(F) \rightarrow {}^3A_{1g}(P)$ [33]. Similarly absorption for $[TPSP]_2[Zn_2Cl_6]$ observed at 224 nm and 338 nm can be assigned for inter ligand charge transfer transitions of two $ZnCl_4^{2-}$ tetrahedral unit present as $Zn_2Cl_6^{2-}$ complex anion through sharing an edge [34]. Two distinct absorption bands are observed in the UV/Vis region for $[TPSP]_2[MnCl_4]$ solid. The most intense band corresponds to the $^6A_1 \rightarrow {}^4E(D)$ transition at 358 nm. Other weak band represents the $^6A_1 \rightarrow {}^4A$, ^4E (G) transitions in agreement with the literature [35-36]. Furthermore, this tetrahedral environment of Mn^{2+} is also supported from its faint yellow colour in contrast to characteristic pink colour of octahedral complexes.

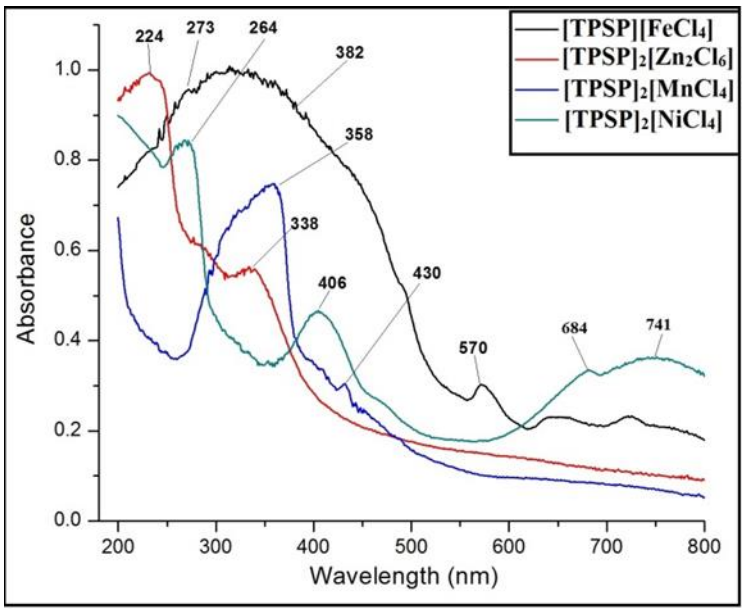


Fig.3C.7: Electronic spectra of sulfophosphonium chlorometallates

3C.2.1.8. Thermogravimetric analysis (TGA)

The four chlorometallates exhibited two step decomposition patterns in the TGA as shown in **Fig.3C.8**. For each of the curve, initial weight loss of approximately 5-11 % below 100 °C can be assigned for the elimination of absorbed moisture from the salts which expressed $[TPSP]_2[MnCl_4]$ as the more hygroscopic salt. The 2nd decomposition started around 250-280 °C for the three acidic salts except $[TPSP][FeCl_4]$. This step was observed at 280°C with an unusual 2 % weight loss for the curve of Fe salt followed by gradual decomposition at 350°C.The parent [TPSP][Cl] ionic compound displayed three step decomposition of total 40 % weight loss up to 350 °C including 15 % physisorbed moisture at 100 °C.

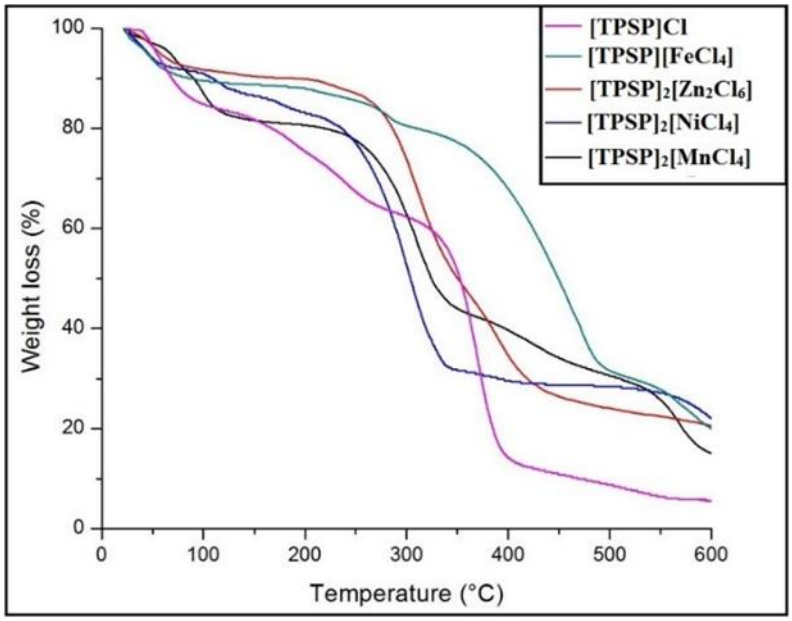


Fig.3C.8: TGA analysis of chlorometallate salts

3C.2.1.9. Leaching test

The leaching study of the four chlorometallate salts was performed with four common solvents such as EtOH, CH_3CN, CH_2Cl_2 and water. For this purpose 50 mg of ionic salt was stirred separately for overnight with the respective solvent and filtered to determine the pH of each solution. The pH of each filtrate was observed at neutral position which confirmed no leaching of metal component or any fragment to the solvent under study.

3C.2.1.10. Acidity measurement by Hammett method

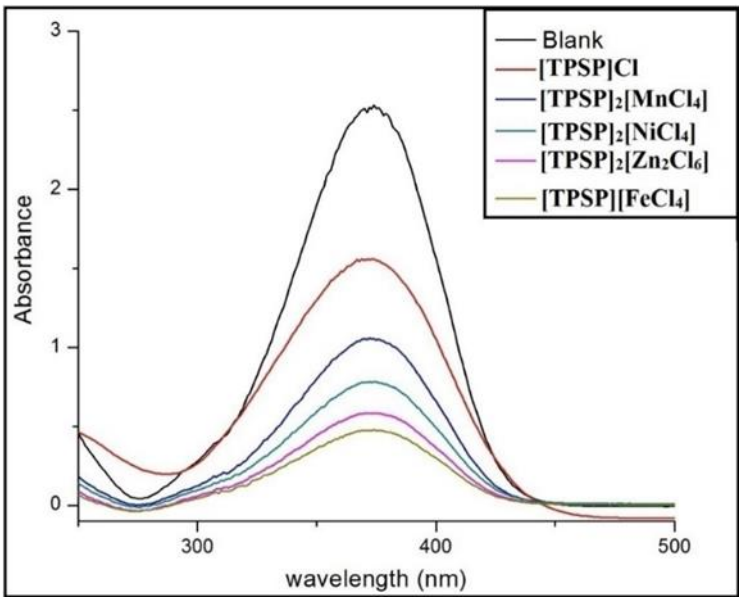


Fig.3C.9: Hammett plot of phosphonium salts

The Brønsted acidity of these salts (**IL-4 to IL-8)** was calculated by determining the Hammett function using UV visible spectrophotometer **(Fig.3C.9** and **Table-3C.1**) [37]. The process involved was same with that of the **Chapter 2.** From this experiment the Brønsted acidity order of the five acidic catalysts are:- [TPSP][$FeCl_4$] (**IL-8**)> $[TPSP]_2[Zn_2Cl_6]$ (**IL-7**)> $[TPSP]_2[NiCl_4]$ (**IL-5**)> $[TPSP]_2[MnCl_4]$ (**IL-6**)> [TPSP][Cl] (**IL-4**).

Table-3C.1: Calculation of Hammett acidity of ionic salts

Entry	IL	λ_{max}	[I]%	[IH]%	H^o
1	Blank	2.477	100.0	0	-
2	[TPSP]Cl	1.523	61.49	38.51	1.19
3	$[TPSP]_2[MnCl_4]$	1.030	41.58	58.42	0.84
4	$[TPSP]_2[NiCl_4]$	0.766	30.92	69.08	0.64
5	$[TPSP]_2[Zn_2Cl_6]$	0.573	23.13	76.87	0.47
6	[TPSP][$FeCl_4$]	0.466	18.81	81.19	0.35

3C.2.1.11. Elemental analysis

The amount of C and H content was estimated in CHN elemental analyzer for the parent and chlorometallate salts after thermal treatment at 100 °C in vacuum oven for two hour that included in the spectral data. Inductive Coupled Plasma (ICP) elemental analysis of the four chlorometallates was performed using 10 ppm solution in aqua regia to determine the amount of metal content in each ionic salt. The experimental values were found very close to the original metal amount, thus ensuring the actual composition of metal halides with respect to the basic [TPSP][Cl] (**table-3C.2**).

Table-3C.2: ICP analyses for metal content of the triphenylsulfophosphonium chlorometallates

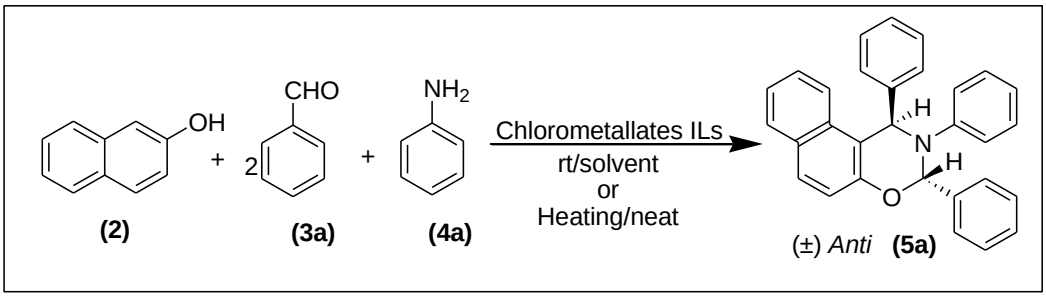
Entry	Sample	Mol. weight (gm/mol)	Atomic weight of metal (gm/mol)	Amt. of the metal (mg/liter)		
				Exp.	Cal.	Used sample (after 8^{th} cycle)
1	[TPSP][$FeCl_4$]	541.01	55.85	1.05	1.03	0.77
2	$[TPSP]_2[Zn_2Cl_6]$	1030.21	130.76	1.27	1.25	0.91
3	$[TPSP]_2[NiCl_4]$	887.22	58.69	0.66	0.69	--
4	$[TPSP]_2[MnCl_4]$	883.46	54.94	0.62	0.64	--

3C.2.2 Catalytic activity study

3C.2.2.1. Optimization of reaction condition

Initially, the catalytic activity of more acidic salts, [TPSP][$FeCl_4$] (**IL-8**) and [TPSP]$_2$[Zn_2Cl_6] (**IL-7**) was tested for the synthesis of 1, 2, 3-trisubstituted naphthoxazine derivatives **(5a)** using 15 mol % of each by stirring a mixture of 2-naphthol (1 mmol), benzaldehyde (2 mmol) and aniline (1 mmol) in ethanol at ambient temperature (method-A) and under neat condition at 90 °C (method-B) (table-3C.3, entries 1, 6). Keeping the amount of catalyst same for both at 80 °C also showed identical results but further decrease in temperature up to 70°C reduced the formation of product (table-3C.3, entries 2, 7).

Table-3C.3: Optimization of reaction condition for the synthesis of naphthoxazine **(5a)**



Entry	Catalyst	Amount of catalyst mol%	Time (min) (method)[b]	% of yield [a] (5a)
1	[TPSP][$FeCl_4$]	15	10(A)/05(B)	93(A)/97(B)
2	[TPSP][$FeCl_4$]	15	05(C)/15(D)	97(C)/88(D)
3	[TPSP][$FeCl_4$]	10	10(A)/05(C)	93(A)/97(C)
4	[TPSP][$FeCl_4$]	7	10(A)/05(C)	93(A)/97(C)
5	[TPSP][$FeCl_4$]	5	25(A)/15(C)	73(A)/80(C)
6	[TPSP]$_2$[Zn_2Cl_6]	15	12(A)/05(B)	91(A)/94(B)
7	[TPSP]$_2$[Zn_2Cl_6]	15	05(C)/15(D)	94(C)/85(D)
8	[TPSP]$_2$[Zn_2Cl_6]	10	12(A)/05(C)	91(A)/94(C)
9	[TPSP]$_2$[Zn_2Cl_6]	7	12(A)/05(C)	91(A)/94(C)
10	[TPSP]$_2$[Zn_2Cl_6]	5	05(A)/20(C)	65(A)/74(C)
11	[TPSP]$_2$[$NiCl_4$]	15	15(A)/10(C)	77(A)/82(C)
12	[TPSP]$_2$[$MnCl_4$]	15	15(A)/10(C)	80(A)/84(C)

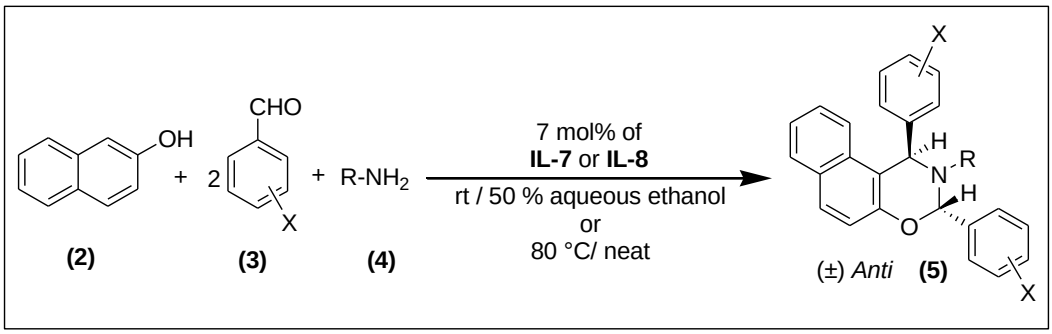
13	[TPSP][$FeCl_4$]	7	10(E)/50(F)	94(E)/50(F)
14	$[TPSP]_2[Zn_2Cl_6]$	7	12(E)/60(F)	90(E)/48(F)

[a] Isolated yields ; [b] Methods : A: Reaction at room temperature in ethanol; B: reaction at 90 °C under neat condition; C: reaction at 80 °C under neat condition; D: reaction at 70 °C under neat condition; E: reaction at room temperature in 50 % aqueous ethanol solution; F: reaction at room temperature in water.

The amount of catalyst was optimized as 7 mol % for (**IL-8**) and (**IL-7**) (table-3C.3, entries 4, 9) by observing the results of three different amounts such as 10, 7 and 5 mol % in neat at 80° C and in ethanol at room temperature stirring (table-3C.3, entries 3-5 and 8-10). At the same time, 15 mol % of $[TPSP]_2[NiCl_4]$ (**IL-5**) and $[TPSP]_2[MnCl_4]$ (**IL-6**) salts produced around 77-84% of **(5a)** within 10-15 min reaction at 80° C in solvent-less method and in ethanol at mild condition (table-3C.3, entries 11, 12). The order of catalytic activity of chlorometallates (**IL-5 to IL-8**) agreed with their relative acidity order as measured from the Hammett plot (**Fig.3C.9**).

The effects of other polar solvents were studied by conducting the model reaction in water and 50% aqueous EtOH at room temperature for 10-60 min with 7 mol% of [TPSP][$FeCl_4$] and $[TPSP]_2[Zn_2Cl_6]$ respectively (table-3C.3, entries 13-14). The reaction in water took more time (1 h) to give around 50% of product as compared to ethanol (table-3C.3, entries 13-14). In non-polar solvent such as dichloromethane, the reaction displayed good activity like ethanol. For solution phase reaction, we selected 50 % aqueous ethanol as the suitable-choice in terms of environmentally acceptable-medium.

Table-3C.4: Substrate scope studies for the preparation of (**5**) using [TPSP][$FeCl_4$] and $[TPSP]_2[Zn_2Cl_6]$ salts as reusable catalysts



Entry	X	R	[TPSP][$FeCl_4$] (**IL-8**)		[$TPSP]_2[Zn_2Cl_6$] (**IL-7**)	
			Time (min) (A/B)[b]	% of yield[a] **(5)**	Time (min) (A/B)[b]	% of yield[a] **(5)**
1	H	C_6H_5	10/05	93/98**(5a)**	12/05	91/96**(5a)**
2	H	*n*-C_4H_9	12/05	92/96**(5d)**	11/05	90/95**(5d)**
3	H	4-CH_3-C_6H_4	10/05	94/98**(5h)**	12/06	92/97**(5h)**
4	H	4-Cl-C_6H_4	15/08	90/94**(5j)**	17/09	89/94**(5j)**
5	4-Cl	4-CH_3-C_6H_4	12/07	93/96**(5k)**	12/08	92/95**(5k)**
6	4-Cl	4-Cl-C_6H_4	13/08	91/95**(5l)**	17/10	90/94**(5l)**
7	4-NO_2	4-CH_3-C_6H_4	10/05	94/99**(5m)**	11/06	91/95**(5m)**
8	4-NO_2	4-Cl-C_6H_4	13/07	91/95**(5n)**	15/09	90/93**(5n)**
9	4-CH_3	4-CH_3-C_6H_4	13/10	91/95**(5o)**	15/10	90/94**(5o)**
10	4-CH_3	4-Cl-C_6H_4	16/10	89/94**(5p)**	18/11	88/92**(5p)**

[a] Isolated yields ; [b] Methods : A : reaction at room temperature in 50% ethanol; B : reaction at 80 °C under neat condition

3C.2.2.2. Substrate scope study

The synthesis of complex derivatives of substituted naphthoxazines was achieved through reaction of 2-naphthol with varieties of nucleophilic aliphatic/aromatic primary amines and aromatic aldehydes bearing either electron withdrawing or donating groups under the optimized methods. The results are summarized in **Table-3C.4.** The products were formed within the range of 88-98% for all types of substituted aryl aldehydes (table-3C.4). This three-component reaction again failed to produce the desired product from the reaction of benzaldehyde and 2-naphthol with electron-deficient amines likes 4-nitroaniline under optimized condition [19-20].

3C.2.2.3. Reusability test

This reusability study was executed only with 7 mol % of the two catalysts [TPSP][$FeCl_4$] and [$TPSP]_2[Zn_2Cl_6$] up to 8th cycle in 5 mmol scale for the synthesis of model compound **(5a)** in aqueous ethanol at room temperature. The bar diagram in **Fig.3C.10** displayed slight variation of product yields and reaction time from 3rd cycle. The powder-XRD patterns of reused catalysts also indicated small changes from the fresh powder XRD in **Fig.3C.11**. Furthermore, the ICP-analysis of used catalysts also expressed the decrease in

the amount of metal content to a small extent as compared to original after 8th cycle of reactions (table-3C.2). All these characterizations of spent catalysts supported the greater stability and higher catalytic activity of the two phosphonium chlorometallates of iron and zinc chloride.

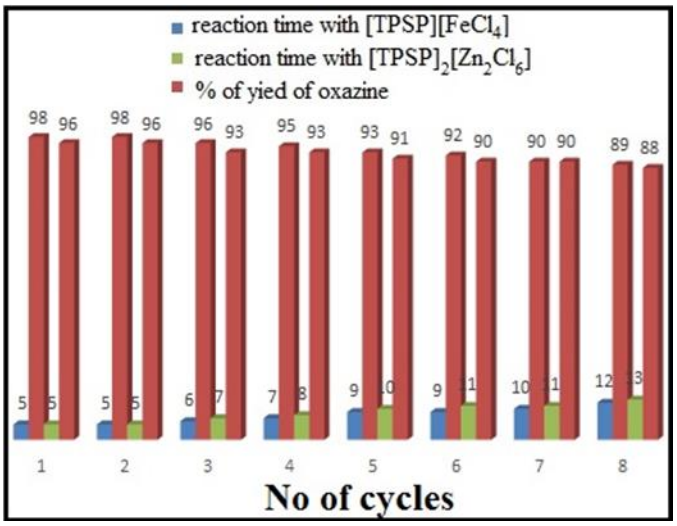


Fig.3C.10: Reusability bar diagram of [TPSP][$FeCl_4$] and [TPSP]$_2$[Zn_2Cl_6] catalysts

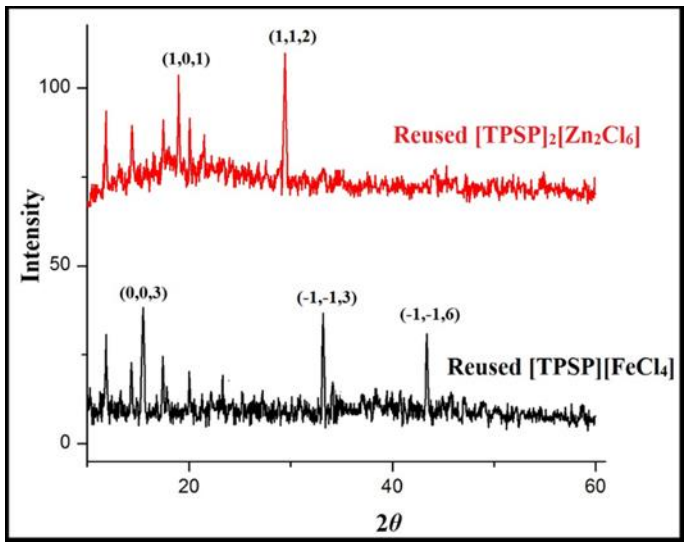


Fig.3C.11: Powder-XRD of reused catalysts after 8thcycle

3C.2.3. UV/Visible and fluorescence study of 1, 2, 3-trisubstituted naphthoxazines

The absorption spectra of naphthoxazine derivatives were recorded on UV/Visible spectrophotometer using 2 x 10^{-3} molar solution in CH_2Cl_2 with maximum absorption peaks around 320-324 nm and 333-337 nm. Then the same solutions of sample were subjected for excitation in the wavelength range of λ_{ex}= 333-337 nm using a fluorescence spectrophotometer. The emission spectra of different derivatives showed fluorescence

emission maxima around λ_{emi} = 424-431 nm as indicated in **Fig.3C.12 and Table-3C.5.** The quenching of fluorescence observed for substituted naphthoxazines with electron withdrawing group (**5m** and **5n**) as shown in the **Fig.3C.12**. Furthermore the fluorescence quantum yields were calculated with the help of equation-1 by considering anthracene as reference as its emission spectra lies in the same range with that of the naphthoxazine derivative. The quenching of fluorescence is well supported by the calculated quantum yield. The fluorescence quantum yield and all other related details of the naphthoxazine derivatives were presented in the **Table-3C.5**.

$$\phi_S = \phi_R \frac{A_S \times OD_R \times n_S^2}{A_R \times OD_S \times n_R^2} \qquad \text{(Eq-2)}$$

Where ϕ_S and ϕ_R are the fluorescence quantum yield of sample and reference respectively. A_S and A_R are areas under the fluorescence spectra of the sample and reference respectively. OD_R and OD_S are respective optical density or absorbance of the reference and sample at the excitation wavelength. n_S and n_R are refractive index values of the respective solvent used for the sample and reference respectively [38].

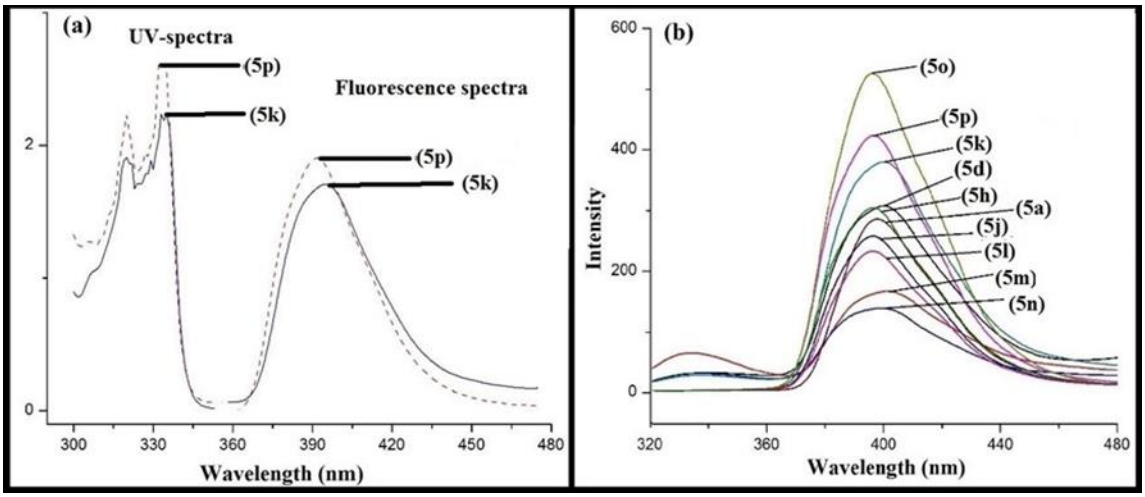


Fig.3C.12: UV/Visible absorption and fluorescence emission spectra of naphthoxazine derivatives

Table-3C.5: Absorption-emission maxima and fluorescence quantum yields of 1,2,3-trisubstituted naphthoxazines in chloroform using anthracene as the standard sample.

Entry	Sample	λ_{abs}	λ_{emi}	Φ_S
1	**(5a)**	333	427	0.27
2	**(5d)**	334	426	0.29
3	**(5h)**	333	430	0.29

4	**(5j)**	336	424	0.24
5	**(5k)**	336	429	0.33
6	**(5l)**	334	427	0.21
7	**(5m)**	335	428	0.16
8	**(5n)**	334	431	0.11
9	**(5o)**	337	425	0.40
10	**(5p)**	333	427	0.39

3C.3. Conclusion

In summary, we have developed a new series of $–SO_3H$ group bearing triphenylsulfophosphonium chlorometallate ionic systems $[TPSP]_n[X]$, where n =1 or 2; X= $FeCl_4^-$, $Zn_2Cl_6^{-2}$, $NiCl_4^{-2}$, $MnCl_4^{-2}$ as solid acidic materials. They were fully characterized by various analytical tools such as NMR, FT-IR, UV/Vis, Raman, PXRD, SEM-EDX, ICP-OES, TGA and CHN analyser. The anionic composition of the chlorometallate salts was confirmed from their electronic absorption spectra and Raman spectra analysis. They were also found to exhibit semiconductor properties with necessary band gap energies. After determining their acidity and thermal stability, $[TPSP][FeCl_4]$ and $[TPSP]_2[Zn_2Cl_6]$ salts were employed as efficient heterogeneous acidic catalysts for the one pot multicomponent synthesis of 1, 2, 3-trisubstituted naphthoxazines derivatives for eight consecutive cycles. The fluorescence properties of the synthesized naphthoxazine derivatives were studied for the first time and thus can be used further in the field of material science.

3C.4. Experimental Section

3C.4.1. General Information

JEOL 400 spectrometer was used to take the ^{1}HNMR and ^{13}CNMR of various products in DMSO-d_6 and $CDCl_3$ solvents. The Scanning Electron Microscopy (SEM) images were obtained from a JEOL JSM-6390LV SEM, equipped with an Energy-Dispersive X-ray analyser. The powder X-ray diffraction patterns were obtained from a RigakuMultiflex instrument using a nickel-filtered CuKα (0.15418 nm) radiation source and scintillation counter detector. Horiba Lab RAMHR spectrometer containing He−Ne laser was used to study the laser micro-Raman spectroscopy of the bifunctional catalysts with an excitation

wavelength of 514.5 nm. ICP-OES analysis of the chlorometallates was done using ICP-OES Perkin Elmer Optima 2100DV instrument. The fluorescence emission spectra were recorded in Perkin Elmer fluorescence spectrometer. The spectral data and melting points of known naphthoxazines **(5)** were compared with the literature data [19-20].

3C.4.2. Preparation of triphenylsulfophosphonium chlorometallates $[TPSP]_n[X]$ (IL-5 to IL-8) , where n = 1 or 2; X = $FeCl_4^-$, $Zn_2Cl_6^{-2}$, $NiCl_4^{-2}$, $MnCl_4^{-2}$

The synthesis of triphenylsulfophosphonium chlorometallates were carried out by reacting [TPSP][Cl] **(IL-4)** with corresponding metal chlorides in two steps (**Scheme-1**). At first, triphenyl phosphine (20 mmol) was taken in a 100 mL two necked round bottomed flask as fine powder and after that equimolar amount of $ClSO_3H$ acid was added dropwise under N_2 atmosphere for 5 minute at room temperature. Then the mixture was heated upto 60 ºC and stirred for 1 hour to get gummy triphenylsulfophosphonium chloride [TPSP][Cl] (**IL-4**). The crude ionic salt was washed three times with dry CH_2Cl_2 (3 x 5 mL) through decantation to eliminate less amount of chlorosulfonic acid. The light reddish gummy material was dried under vacuum to get analytically pure 98% of **IL-4**. In next step, the transition metal chlorides were added to the [TPSP][Cl] in their respective mole fractions (0.5 for $FeCl_3$ and $ZnCl_2$, 0.33 for $MnCl_2$ and $NiCl_2$) and heated up to 80 ºC for 1 hour under nitrogen atmosphere to get the corresponding chlorometallate $[TPSP]_n[X]$ (**IL-5** to **IL-8**) in solid state. The solid salts were washed with dry CH_2Cl_2 (3 x 5 mL) and dried in vacuum oven to get 95-96% of (**IL-5 to IL-8**).

3C.4.3. General method of synthesis of 1, 2, 3-trisubstituted naphthoxazines derivatives (5):

A mixture of 2-naphthol (1 mmol), aldehyde (2 mmol) and primary amine (1 mmol) was stirred in 50 % aqueous ethanol at room temperature or heated at 80 ºC under solvent-free medium in presence of 7 mol% of chlorometallate ILs (**IL-7** or **IL-8**). After completion of the reaction as monitored by TLC, the ethanol solution was evaporated under vacuum to get the solid residue of product with catalyst. The catalyst was recovered as solid form on the filter paper for both methods (and solvent-free reaction) through filtration of dichloromethane (5 mL) solution of the crude product. The catalyst remains in the filter paper washed further with DCM (2 x 3 ml) and reused for the next cycle of reaction. The dichloromethane filtrate containing reaction mixture was dried over anhydrous sodium

sulphate and decanted. Finally the product was isolated in solid state after removal of dichloromethane solvent in rotary evaporator which was again recrystallized from ethanol to get the analytically pure product.

References

[1] Bradaric, C.J., et al. *Green Chem.* **5,** 143--152, 2003.

[2] Scammells, P.J., et al. *Aust. J. Chem.* **58,** 155--169, 2005.

[3] Handy, S.T. *Curr. Org. Chem.* **9,** 959--988, 2005.

[4] Keglevich, G., et al. *Curr. Org. Chem.* **11,** 107--126, 2007.

[5] Adamov´a, G., et al. *Dalton Trans.* **40,** 12750--12764, 2011.

[6] Bradaric, C.J., et al. *Green Chem.* **5,** 143--152, 2003.

[7] Badri, M., et al. *Tetrahedron Lett.* **33,** 4435--4438, 1992.

[8] Knifton, J.F. *J. Am. Chem. Soc*. **103,** 3959--3961, 1981.

[9] Knifton, J.F. *J. Mol. Catal.* **43,** 65--77, 1987.

[10] Knifton, J.F. *J. Mol. Catal.* **47,** 99--116, 1988.

[11] Bonnet, L.G., & Kariuki, B.M. *Eur. J. Inorg. Chem.* 437--446, 2006.

[12] Korodia, N., et al. *Chem. Commun.* 2341--2342, 1998.

[13] Ludley, P., & Korodia, N. *Tetrahedron Lett.* **42,** 2011--2014, 2001.

[14] Johnson, C.L., et al. *Tetrahedron Lett*. **45,** 7359--7361, 2004.

[15] Shaterian, H.R., et al. *J. Mol. Liq.* **162,** 95--99, 2011.

[16] Khazaei, A., et al. *J. Chem. Res*. **37,** 617--619, 2013.

[17] Essawi, M.M.E. *Transit. Met. Chem.* **22,** 117--122, 1997.

[18] Gogoi, P., et al. *Appl. Catal. A-Gen.* **492,** 133--139, 2015.

[19] Borah, R., et al. *RSC Adv.* **4,** 10912--10917, 2014.

[20] Dutta, A.K., et al. *Catal. Lett.* **146,** 902--908, 2016.

[21] Fleming, G.R., et al. *J. Am. Chem. Soc*. **99,** 4306--4311, 1977.

[22] Daasch, L.W., & Smith, D.C. *Analytical Chemistry* **23**, 853--868, 1951.

[23] Zhang, W., et al. *Catal. Commun.* **11,** 151--154, 2009.

[24] Amatore, C., et al. *Organometallics* **11,** 3009--3013, 1992.

[25] LinLin, W., et al. *Chin. Sci. Bull.* **58,** 3624--3629, 2013.

[26] Babushkina, O.B., & Volkov, S.V. *J. Mol. Liq.* **83,** 131--140, 1999.

[27] Yannopoulos, S.N., et al. *J. Chem. Phys.* **118,** 3197--3214, 2003.

[28] Pitula, S., & Mudring, A.-V. *Chem. Eur. J.* **16,** 3355--3365, 2010.

[29] Yatsimirskii, K.B. *Pure Appl. Chem.* **49,** 115--124, 1977.

[30] Devashankar, S., et al. *J. Crys. Growth* **311,** 4207--4212, 2009.

[31] Kumar, A., et al. *J. Fundam. Appl. Sci.* **7,** 422--435, 2015.

[32] Lever, A. *Inorganic Electronic Spectroscopy*, Elsevier, Amsterdam, 1984.

[33] Griffiths, T.R., & Scarrow, R.K. *Trans. Faraday Soc.* **65,** 1727--1733, 1969.

[34] Bouma, R.J., et al. *Inorg. Chem.* **23,** 2715--2718, 1984.

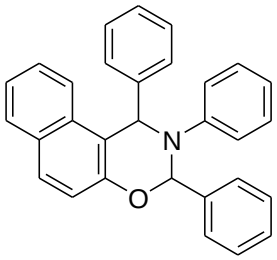
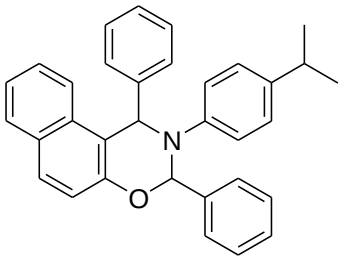
[35] Cotton, F.A., et al. *J. Am. Chem. Soc.* **84,** 167--172, 1962.

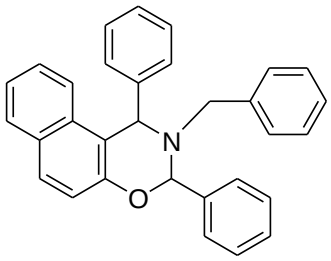
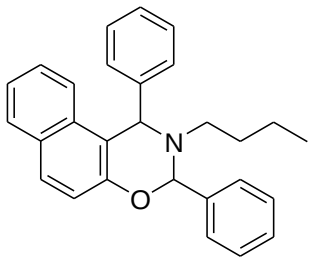
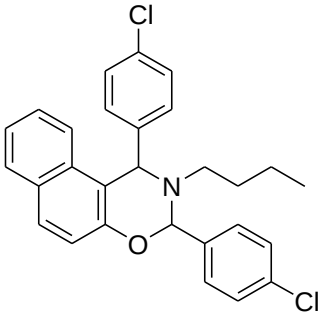
[36] Cotton, F.A., et al. *Inorg. Chem.* **40,** 3576--3578, 2001.

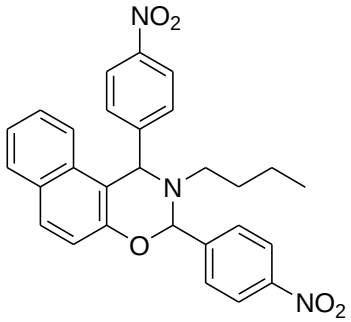
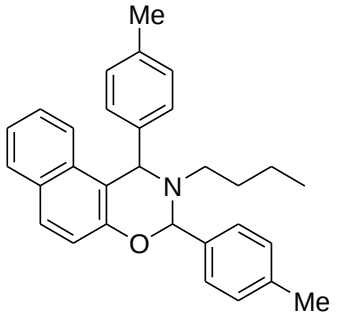
[37] Thomazeau, C., et al. *J. Am. Chem. Soc.* **125,** 5264--5265, 2003.

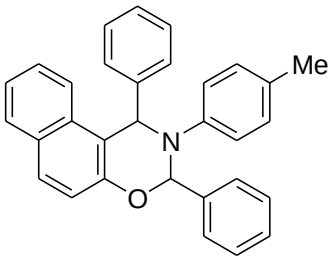
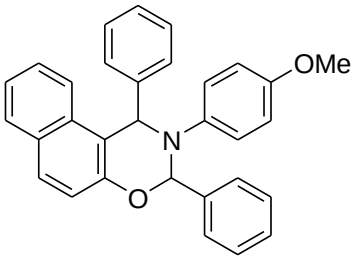
[38] Barik, A., et al. *Photochem. Photobiol.* **77,** 597--603, 2003.

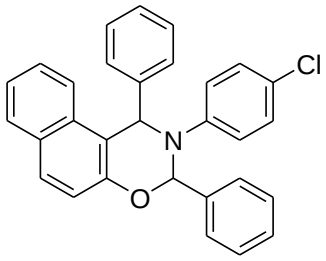
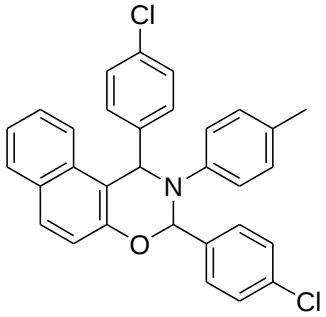
Spectral data of naphthoxazine derivatives

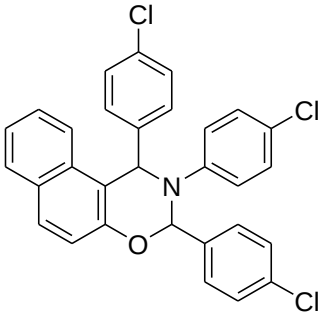
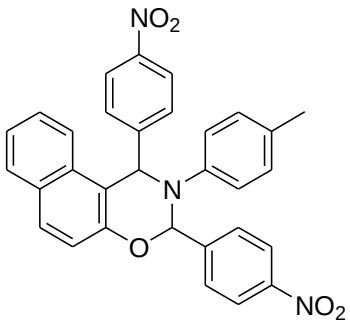
Products	Spectral data
	**2, 3-Dihydro-1, 2, 3-triphenyl-1*H*-naphth[1, 2-e][1, 3]oxazine (5a):** White amorphous solid, m.p. 206-207 °C; FT-IR (KBr): 3030, 2918, 1596, 1494, 1449, 1396, 1335, 1222, 944, 703 cm^{-1}; ^{1}H NMR (400M Hz, $CDCl_3$): δ 6.08 (d, 1H, *J*= 4.1 Hz), 6.25 (d, 1H, *J*= 5.1 Hz), 6.85-6.88 (m, 1H), 7.01-7.06 (m, 2H), 7.18-7.37 (m, 12H), 7.48 (d, 2H, *J*= 6.9 Hz), 7.55 (d, 2H, *J*= 6.9 Hz), 7.78-7.83 (m, 2H)*;* ^{13}C NMR (100M Hz, $CDCl_3$) : δ 65.3, 84.3, 113, 119.1, 123.1, 123.4, 123.6, 125.4, 126.6, 127.6, 127.9, 128.4, 128.5, 129.2, 129.3, 129.5, 137.3, 142.8, 147.1, 153; CHN analysis calculated for $C_{30}H_{23}NO$ (%): C 87.17, H 5.57, N 3.39; Found C 87.23, H 5.54, N 3.43.
	**2, 3-Dihydro-2-(4-isopropylphenyl)-1, 3-diphenyl-1*H*-naphth[1, 2-e][1, 3]oxazine (5b):** White solid; m.p. 171-173 °C*;* FT-IR (KBr): 3026, 2953, 2379, 2150, 1606, 1507, 1451, 1397, 1336, 1222, 954, 813, 704 cm^{-1}; ^{1}H NMR (400 M Hz, $CDCl_3$): δ 1.08 (s, 6H), 2.68-2.71 (m, 1H), 6.04 (d, 1H, *J*= 5.1 Hz,), 6.21 (d, 1H, *J*= 5.1 Hz), 6.87-6.90 (m, 2H), 7.08-7.11 (m, 2H), 7.20-7.38 (m, 10H), 7.45-7.48 (m, 2H), 7.54 (m, 2H), 7.78-7.82 (m, 2H); ^{13}C NMR (100 M Hz, $CDCl_3$): δ 23.8, 23.9, 30.9, 33.2, 65.2, 84.5, 113.6, 119.2, 123.2, 123.4, 125.2, 126.4, 126.6, 126.7, 127.5, 127.9, 128.4, 128.5, 129.3, 129.4, 137.5, 143, 144, 144.8, 153.1; CHN analysis calculated for $C_{33}H_{29}NO$ (%): Cal.C 87.03, H 6.37, N 3.08*;* Found C 87.12, H 6.41, N 3.11.
	Benzyl-2, 3-dihydro-1, 3-diphenyl-1*H*-naphth[1, 2e][1, 3]oxazine (5c): White crystalline solid*;* m.p. 191–193^{0}C; FT-IR (KBr): 3023, 2881, 2837, 1595,

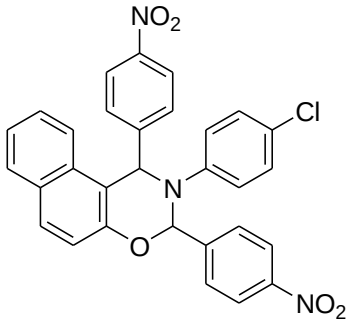
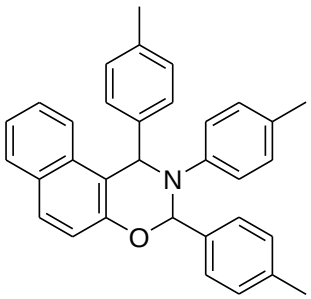
	1496, 1449, 1391, 1331, 1229, 935, 813, 744, 693 cm^{-1}; ^{1}H NMR (400 M Hz, $CDCl_3$): δ 3.34 (d, 1H, *J*= 13.7), 3.88 (d, 1H, *J*= 14.2 Hz), 5.39 (s, 1H), 5.99 (s, 1H), 7.22-7.24 (m, 7H), 7.30-7.33 (m, 8H), 7.40 (t, 2H, *J*= 7.8 Hz), 7.68 (d, 2H, *J*= 7.3 Hz), 7.81-7.85 (m, 2H); ^{13}C NMR (100M Hz, $CDCl_3$): δ 49.6, 57.8, 85.5, 112.1, 118.8, 123, 123.4, 126.4, 126.6, 127.2, 127.9, 128, 128.2, 128.3, 128.6, 129.2, 129.4, 133.5, 138.1, 139.5, 143.1, 152.6; CHN analysis calculated for $C_{31}H_{25}NO$ (%): C 87.12, H 5.85, N 3.28*;* Found C 87.17, H 5.88, N 3.30.
	**Butyl-2, 3-dihydro-1, 3-diphenyl-1*H*-naphth[1, 2-e][1, 3]oxazine (5d):** White crystalline solid; m.p. 133–135 °C; FT-IR (KBr): 3062, 2946, 2848, 1601, 1507, 1452, 1392, 1333, 1233, 1125, 945, 813, 700 cm^{-1}; ^{1}H NMR (400 M Hz, $CDCl_3$): δ 0.77 (t, 3H, *J*= 7.3 Hz), 1.12-1.19 (m, 1H), 1.29-1.36 (m, 1H), 1.53-1.64 (m, 2H), 2.35-2.40 (m, 1H), 2.58-2.64 (m, 1H), 5.54 (s, 1H), 5.82 (s, 1H), 7.22-7.37 (m, 11H), 7.44 (d, 1H, *J*= 7.4 Hz), 7.55 (d, 2H, *J*= 6.8 Hz), 7.78-7.82 (m, 2H); ^{13}C NMR (100M Hz, $CDCl_3$): δ 13.9, 20.2, 31.1, 44.8, 58.9, 85.9, 112.5, 119, 123.1, 123.3, 126.5, 127.1, 127.7, 127.9, 128.2, 128.6, 129.1, 129, 129.5, 138.2, 143.2, 152.9; CHN analysis calculated for $C_{28}H_{27}NO$ (%): C 85.5, H 6.87, N 3.56*;* Found C 85.54, H 6.91, N 3.58.
	**2-Butyl-1, 3-bis (4-chlorophenyl)-2, 3-dihydro-1*H*-naphth[1, 2-e][1, 3]oxazine (5e):** Yellow solid; m.p. 163-165 °C; FT-IR (KBr): 3227, 2954, 2859, 2377, 1617, 1483, 1399, 1331, 1235, 1088, 948, 815, 745 cm^{-1}; ^{1}H NMR (400M Hz, $CDCl_3$): δ 0.78 (t, 3H, *J*= 7.2 Hz,), 1.12-1.16 (m, 1H), 1.32-135 (m, 1H), 1.54-1.58 (m, 2H), 2.35-2.38 (m, 1H), 2.53-2.56 (m, 1H),

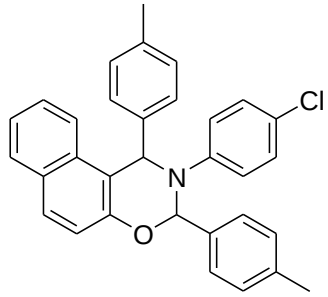
	5.46 (s, 1H), 5.69 (s, 1H), 7.25-7.27 (m, 5H), 7.32-7.38 (m, 5H), 7.46 (d, 2H, *J*= 8.7 Hz), 7.79-7.83 (m, 2H); ^{13}C NMR (100 M Hz, $CDCl_3$): δ 13.9, 20.2, 31.1, 44.9, 58.3, 85.4, 111.9, 118.9, 122.8, 123.5, 126.8, 127.9, 128.2, 128.4, 128.7, 129.4, 130.8, 136.5, 141.7, 152.6; CHN analysis Calculated for $C_{28}H_{25}NO$ (%): C 72.73, H 5.41, N 3.03*;* Found C 72.75, H 5.46, N 3.07.
	**2-Butyl-2, 3-dihydro-1, 3-bis(4-nitrophenyl)-1*H*-naphth[1, 2-e][1, 3]oxazine (5f):** Yellow solid; m.p. 168-171 °C; FT-IR (KBr): 3465, 2931, 2854, 1646, 1594, 1531, 1411, 1344, 1184, 1104, 982, 847, 696 cm^{-1}; ^{1}H NMR (400 M Hz, $CDCl_3$): δ 0.78 (t, 3H, *J*= 7.4 Hz), 1.14-1.16 (m, 1H), 1.31-1.34 (m, 1H), 1.58-1.62 (m, 2H), 2.44-2.48 (m, 2H), 5.58 (s, 1H), 5.69 (s, 1H), 7.31 (d, 2H, *J*= 8.7 Hz), 7.39-7.40 (m, 2H), 7.55-7.58 (m, 2H), 7.72 (d, 2H, *J*= 8.7 Hz), 7.88 (d, 2H, *J*= 8.7 Hz), 8.21 (d, 2H, *J*= 8.3 Hz), 8.24 (d, 2H, *J*= 8.7 Hz); ^{13}C NMR (100 M Hz, $CDCl_3$): δ 14, 20.3, 31.2, 45.6, 58.6, 85.5, 111, 118.9, 123.5, 123.8, 124.1, 127.3, 127.6, 129.1, 130.5, 144.8, 147.4, 147.9, 150.1, 152.5; CHN analysis Calculated for $C_{28}H_{25}NO$ (%): C 69.57, H 5.17, N 8.70*;* Found C 69.60, H 5.20, N 8.72
	**2-Butyl-2, 3-dihydro-1, 3-dip-tolyl-1*H*-naphth[1, 2-e][1, 3]oxazine (5g):** Shiny brown solid; m.p.165-166 ˚C; FT-IR (KBr): 3297, 2919, 1618, 1510, 1458, 1394, 1234, 938, 809 cm^{-1}; ^{1}H NMR (400M Hz, $CDCl_3$): δ 0.77 (t, 3H, *J*= 7.4 Hz), 1.12-1.18 (m, 1H), 1.30-1.37 (m, 1H), 1.53-1.61 (m, 2H), 2.33 (s, 3H), 2.35 (s, 3H), 2.37-2.38 (m, 1H), 2.63-2.66 (m, 1H), 5.49 (s, 1H), 5.8 (s, 1H), 7.09 (d, 2H, *J*= 7.8 Hz), 7.14 (d, 2H, *J*= 8.3 Hz), 7.23-7.34 (m, 5H), 7.41-7.45

	(m, 3H), 7.75-7.78 (m, 2H); ^{13}C NMR (100 M Hz, $CDCl_3$): δ 14, 20.3, 21.2, 21.3, 44.9, 58.8, 86.1, 112, 119.1, 123.2, 123.3, 126.5, 128.6, 128.7, 128.9, 128.9, 129.5, 135.4, 136.7, 137.3, 153.1; CHN analysis calculated for $C_{30}H_{31}NO$ (%): C 85.51, H 7.36, N 3.33; Found C 85.58 H 7.42, N 3.31
	**2, 3-Dihydro-1, 3-diphenyl-2-p-tolyl-1*H*-naphth[1, 2-e][1, 3]oxazine (5h):** White solid; m.p. 216-218°C; FT-IR (KBr): 3431, 3231, 3018, 2926, 2377, 1633, 1583, 1485, 1401, 1330, 1185, 1086, 983, 819 cm^{-1}; ^{1}H NMR (400 M Hz, $CDCl_3$): δ 2.13 (s, 3H), 6.02 (s, 1H), 6.20 (s, 1H), 6.83 (d, 2H, *J*= 8.2 Hz), 7.07 (d, 2H, *J*= 8.2 Hz), 7.33-7.38 (m, 4H), 7.28-7.31 (m, 3H), 7.17-7.25 (m, 3H), 7.46-7.48 (d, 2H, *J*= 8.0 Hz), 7.52-7.54 (d, 2H, *J*= 8.0 Hz), 7.78-7.82 (m, 2H); ^{13}C NMR (100 M Hz, $CDCl_3$):δ 20.6, 65.3, 84.3, 114.0, 119.1, 123.1, 123.3, 125.6, 126.6, 127.5, 127.9, 128.4, 128.6, 129.1, 129.2, 129.4, 129.5, 129.7, 129.9, 152.9; CHN analysis Calculated for $C_{31}H_{25}NO$ (%): C87.09, H 5.89, N 3.28; Found C87.06, H 5.91, N 3.26.
	**2, 3-Dihydro-2-(4-methoxyphenyl)-1, 3-diphenyl-1*H*-naphth[1, 2-e][1, 3]oxazine (5i):** White solid; m.p. 220-223°C; FT-IR (KBr): 3408, 3068, 2924, 2377, 1593, 1523, 1455, 1401, 1344, 1247, 1078, 970, 808, 745, 700 cm^{-1}; ^{1}H NMR (400 M Hz, $CDCl_3$): δ 3.60 (s, 3H), 5.91 (s, H), 6.17 (s, H), 6.57 (d, 2H, *J*= 9.2 Hz,), 7.07 (d, 2H, *J*= 8.7 Hz), 7.16-7.26 (m, 3H), 7.29-7.31 (m, 3H), 7.36-7.38 (t, 4H, *J*= 8.8 Hz), 7.41 (d, 2H, *J*= 7.8 Hz), 7.50-7.52 (d, 2H, *J*= 7.4 Hz), 7.79-7.84 (m, 2H); ^{13}C NMR (100 M Hz, $CDCl_3$): δ 55.2, 64.9, 84.7, 113.6, 119.3, 123.1, 123.4, 126.7, 126.9, 127.3, 127.4, 127.6127.7, 127.9,

	128.4, 128.6 129.1, 129.4, 129.5, 129.9, 153.0, 156.1; CHN analysis Calculated for $C_{31}H_{25}NO_2$ (%): C 83.95, H 5.68, N 3.16; Found C 83.74 , H 5.71, N 3.16.
	**2-(4-Chlorophenyl)-2,3-dihydro-1,3-diphenyl-1*H*-naphth[1, 2-e][1, 3]oxazine (5j):** White solid; m.p. 212-213 °C; FT-IR (KBr): 3420, 3060, 2914, 2378, 1619, 1489, 1399, 1328, 1240, 1088, 1026, 980, 935, 816, 746, 700 cm^{-1}; ^1H NMR (400 M Hz, $CDCl_3$): δ 6.01 (s, H), 6.21 (s, H), 6.978 (d, 2H, *J*= 9.2 Hz), 7.11 (d, 2H, *J*= 8.2 Hz), 7.20-7.28 (m, 3H), 7.30-7.33 (m, 3H), 7.35-7.39 (m, 4H), 7.45 (d, 2H, *J*= 7.8 Hz,), 7.51 (d, 2H, *J*= 7.9 Hz), 7.79-7.83 (m, 2H); ^{13}C NMR (100 M Hz, $CDCl_3$):δ 65.4, 84.0, 112.9, 119.5, 124.2, 124.4, 126.6, 126.7, 127.8, 127.9, 128.2, 128.4, 128.6, 128.7, 129.1 129.3, 129.8, 129.9, 132.0, 134.1, 134.5, 142.3, 145.7, 152.7; CHN analysis Calculated for$C_{30}H_{22}NOCl$ (%): C 80.44, H 4.95, N 3.13; Found C 80.4, H 4.99, N 3.13.
	**1, 3-Bis(4-chlorophenyl)-2,3-dihydro-2-p-tolyl-1*H*-naphth[1, 2-e][1, 3]oxazine (5k):** White solid; m.p. 234-237 °C; FT-IR (KBr): 3434, 3056, 2910, 2387, 1622, 1488, 1404, 1332, 1240, 1078, 1022, 975, 752, 703 cm^{-1}; ^1H NMR (400 M Hz, CDCl3): δ 2.14 (s, 3H), 5.91 (s, H), 6.08 (s, H), 6.84 (d, 2H, *J*= 8.24 Hz), 7.01 (d, 2H, *J*= 8.68 Hz), 7.21 (d, 2H, *J*= 8.68 Hz), 7.30-7.34 (m, 6H), 7.38 (d, 2H, *J*= 8.24 Hz), 7.44 (d, 2H, *J*= 8.24 Hz), 7.78-7.83 (m, 2H); ^{13}C NMR (100 M Hz, CDCl3): δ 29.7, 64.5, 83.9, 119.0, 122.8, 123.6, 125.6, 126.8, 128.1, 128.6, 129.2, 129.4, 129.7, 130.6, 130.9, 133.5, 141.2, 144.2, 152.7; CHN analysis Calculated for $C_{31}H_{23}NOCl_2$ (%): C 75.01, H 4.67, N 2.82; Found C 75.0, H 4.71,

	N 2.80.
	**1, 2, 3-Tris(4-chlorophenyl)-2, 3-dihydro-1*H*-naphth[1, 2-e][1, 3]oxazine (5l):** White solid ; m.p. 229-231 °C; FT-IR (KBr): 3322, 2963, 2864, 2381, 1618, 1477, 1404, 1322, 1224, 1084, 945, 807, 727 cm^{-1}; ^{1}H NMR (400 M Hz, $CDCl_3$): δ 5.91 (s, 1H), 6.08 (s, 1H), 7.00 (d, 2H, J= 8.7 Hz), 7.06 (d, 2H, J= 9.1 Hz), 7.23 (d, 2H, J= 8.2 Hz), 7.31-7.37 (m, 6H), 7.41-7.45 (m, 2H), 7.48 (d, 2H, J= 8.7 Hz), 7.79-7.84 (m, 2H); ^{13}C NMR (100 M Hz, $CDCl_3$):δ 64.6, 83.6, 112.5, 118.1, 119.5, 124.3, 126.9, 127.2, 127.9, 128.1, 128.4, 128.7, 128.9, 129.2, 129.6, 130.1, 130.6, 140.7, 145.1, 148.6, 152.4; CHN analysis Calculated for$C_{30}H_{20}NOCl_3$ (%): C 69.72, H 3.90, N 2.71; Found C 69.69, H 3.94, N 2.70
	**2, 3-Dihydro-1, 3-bis (4-nitrophenyl)-2-p-tolyl-1*H*-naphth[1, 2-e][1, 3]oxazine (5m):** Yellow solid; m.p. 244-245 °C ; FT-IR (KBr): 3444, 2933, 2868, 1630, 1588, 1408, 1360, 1177, 1098, 988, 909, 844, 703 cm^{-1} ; ^{1}H NMR (400 M Hz, $CDCl_3$): δ 2.15 (s, 3H), 6.0 (s, 1H), 6.08 (s, 1H), 6.86 (d, 2H, *J*= 8.2 Hz), 7.03 (d, 2H, *J*= 8.2 Hz), 7.20-7.25 (m, 2H), 7.32-7.43 (m, 2H), 7.62 (d, 2H, *J*= 8.2 Hz), 7.73 (d, 2H, *J*= 8.2 Hz), 7.83-7.90 (m, 2H), 8.11 (d, 2H, *J*= 9.2 Hz), 8.26 (d, 2H, *J*= 8.7 Hz); ^{13}C NMR (100 M Hz, $CDCl_3$): δ 20.8, 64.6, 84.1, 112.0, 119.0 , 122.5, 123.4, 123.9, 125.9, 127.3, 127.8, 129.0, 129.7, 130.3, 130.5, 143.5, 143.9, 147.6, 149.6, 152.6; CHN analysis Calculated for $C_{31}H_{23}N_3O_5$ (%): C 71.94, H 4.48, N 8.12; Found C 71.96, H 4.51, N 8.10.
	2-(4-Chlorophenyl)-2, 3-dihydro-1, 3-bis(4-nitrophenyl)-1*H*-naphth[1, 2-e][1, 3]oxazine (5n): Yellow solid; 228-231 °C; FT-IR (KBr): 3336, 3046,

	2922, 2404, 1616, 1477, 1403, 1322, 1222, 1101, 1018, 943, 786, 746, 710 cm^{-1}; ^1H NMR (400 M Hz, $CDCl_3$): δ 6.0 (s, 1H), 6.09 (s, 1H), 7.05 (d, 2H, *J*= 8.7 Hz), 7.10 (d, 2H, *J*= 8.7 Hz) , 7.23-7.26 (m, 2H), 7.34-7.42 (m, 2H), 7.63 (d, 2H, *J*= 8.2 Hz), 7.69 (d, 2H, *J*= 8.2 Hz), 7.85 (d, 1H, *J*= 7.8 Hz), 7.91 (d, 1H, *J*= 8.7 Hz), 8.13 (d, 2H, *J*= 8.7 Hz), 8.28 (d, 2H, *J*= 8.7 Hz); ^{13}C NMR (100 M Hz, $CDCl_3$): δ 64.7, 83.8, 111.0, 118.9, 123.5, 124.1, 127.2, 127.7, 129.1, 129.3, 130.2, 130.8, 143.4, 144.6, 147.8, 149.0, 152.3; CHN analysis Calculated for $C_{30}H_{20}N_3O_5Cl$ (%): C 66.98, H 3.75, N 7.81; Found C 66.94, H 3.78, N 7.85
	**2, 3-Dihydro-1, 2, 3-tris-tolyl-1*H*-naphth[1, 2-e][1, 3]oxazine (5o):** White solid; m.p. 252-254 °C; ; FT-IR (KBr): 3404, 3054, 2933, 2396, 1624, 1488, 1396, 1307, 1208, 1096, 1012, 909, 710 cm^{-1}; ^1H NMR (400 M Hz, $CDCl_3$): δ 1.25 (s, 6H), 2.14 (s, 3H), 5.92 (s, 1H), 6.08 (s, 1H), 6.84 (d, 2H, *J*= 8.3 Hz), 7.03 (d, 2H, *J* = 7.8 Hz), 7.22 (d, 2H, *J*= 8.2 Hz), 7.30-7.33 (m, 6H), 7.36 (d, 2H, *J*= 8.3 Hz), 7.43-7.45 (m, 2H), 7.79-7.85 (m, 2H); ^{13}C NMR (100M Hz, $CDCl_3$): δ 20.8, 64.6, 84.1, 112.9, 119.1, 122.9, 123.7, 125.8, 126.9, 128.2, 128.7, 129.4, 129.8, 130.7, 133.6, 133.9, 135.9, 141.4, 144.0, 152.9; CHN analysis Calculated for $C_{33}H_{29}NO$ (%): C 87.00, H 6.42, N 3.07; Found C 86.96, H 6.44, N 3.10.
	2-(4-Chlorophenyl)-2, 3-dihydro-1, 3-dip-tolyl-1*H*-naphth[1, 2-e][1, 3]oxazine (5p): Creamy white solid; m.p. 231-234°C; FT-IR (KBr): 3376, 3026, 2882, 2420, 1611, 1501, 1408, 1296, 1199, 1088, 913, 808, 710 cm^{-1}; ^1H NMR (400 M Hz, $CDCl_3$): δ 1.58 (s, 6H), 5.91 (s, 1H), 6.08 (s, 1H), 6.99-7.10 (m,

	4H), 7.22-7.26 (m, 2H), 7.29-7.48 (m, 10H), 7.79-7.85 (m, 2H); ^{13}C NMR (100 M Hz, $CDCl_3$): δ 20.81, 64.57, 84.08, 111.99, 123.38, 123.98, 125.90, 127.32, 127.83, 129.02, 129.73, 130.25, 130.53, 143.53, 143.99, 147.64, 149.58, 152.57; CHN analysis Calculated for $C_{32}H_{26}NOCl$ (%): C 80.74, H 5.51, N 2.94; Found C 80.78, H 5.54, N 2.96.