International Journal of ChemTech Research
CODEN (USA): IJCRGG ISSN: 0974-4290
Vol.6, No.2, pp 1237-1245, April-June 2014

# Synthesis, Characterization and Electronic Properties of New Phenothiazine - Carboxaldehyde Derivatives

**Sappanimuthu Thirunavukkarasu*[1], Ponnusamy Senthilkumar[1] and Susaimanickam Arul Antony[2]**

**[1]Department of Medicinal Chemistry, Drug Discovery Research, Orchid Chemicals & Pharmaceuticals Limited, R & D Centre, Shollinganallur, Chennai 600 119, India.**

**[2]PG & Research, Department of Chemistry, Presidency College, Chennai 600 005, India.**

***Corres.author: thirundd@gmail.com**
**Tel.: +91-9840586110.**

**Abstract:** Presented the synthesis and studies on the electronic properties of new dumbbell shaped phenothiazine dyads explored through Buchwald -Hartwig couplings. It is a first report on their subsequent formylation and further derivative preparations. The newly synthesized compounds were characterized by modern spectral technique viz. IR, $^1$H NMR and Mass. These compounds exhibited interesting photolumine scence and HOMO, LUMO distribution patterns.
**Keywords:** Phenothiazine derivatives, Knoevenagel condensation, Buchwald-Hartwig coupling, Opto-electro chemical properties and Photoluminescence.

## Introduction

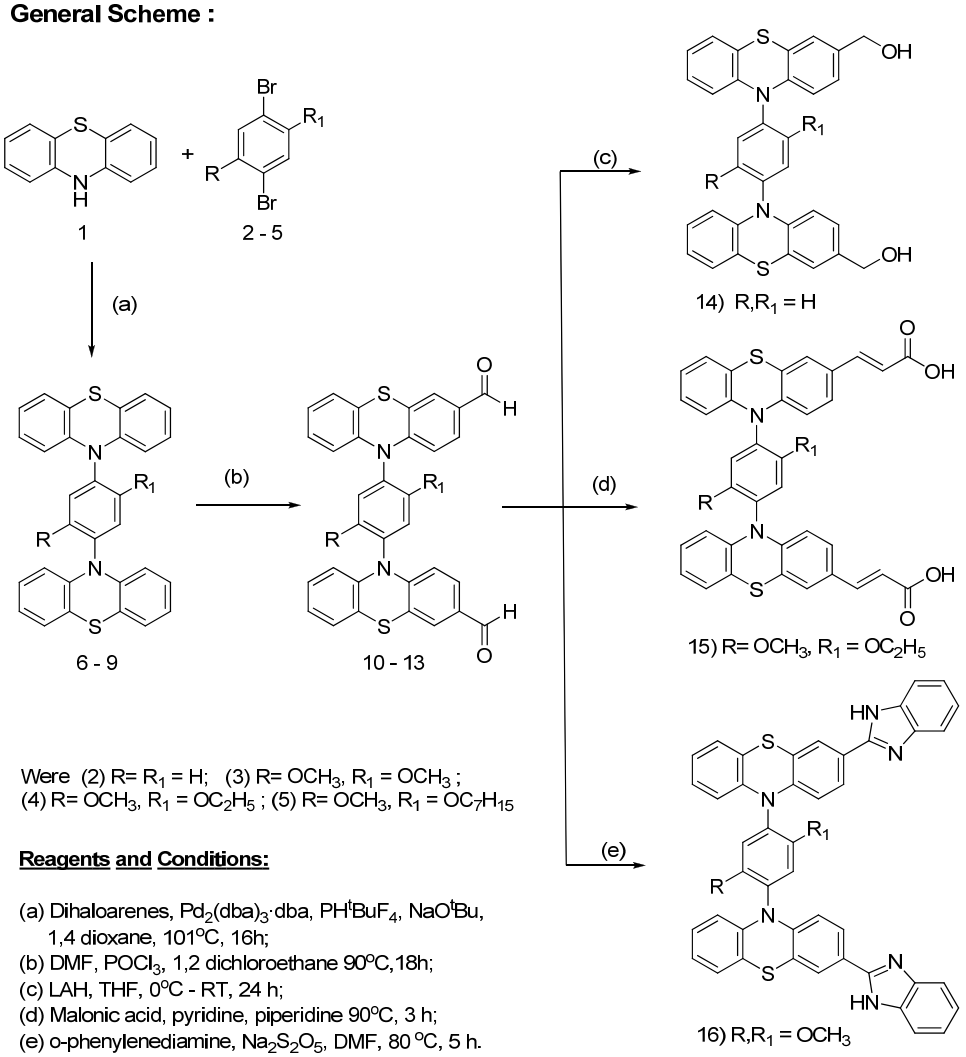
Besides extensive applications as medicine in CNS, cancer and allied fields,[1] phenothiazine, its derivatives are well explored in material science as well as in biochemistry as marker for proteins and DNA.[2,3] Uniqueness of its electron rich nitrogen and sulphur hetero atoms it was found as the redox active unit in donor-acceptor systems. As a result of low oxidation potential, they readily form stable radical cations and some of their physiological activity can be attributed to this circumstance.[4] Furthermore, the radical cations gives fingerprint characteristic, deep-colored absorptions, and are used as motifs in organic materials.[5] Polymer and organic molecules containing phenothiazine or its derivatives have attracted considerable interest on the account of their unique electro-optical properties, which makes these molecules potential candidates for diverse applications in photoluminescence and chemiluminescence.[6]

Nitrogen and sulphur atoms are positioned in centre of the phenothiazine ring and, therefore ligation of the nitrogen atoms *via* bridges appears to be a logical connection. Various synthetic methodologies are developed in preparing diphenothiazine derivatives bridged by substituted aromatic units either C-C ligated / N-C ligated. Interesting electronic properties viz. high quantum yields, large stokes shifts and electronic communication between the phenothiazine units in the molecule are reported.[7] Besides above properties few authors also reported other interesting properties like photo physical, light emission, molecular aggregation and

charge transfer of π conjugated polymers.[8] Furthermore, increased steric rigidness and enhanced electronic communication has been demonstrated for *p*-phenylene bridges.[9] At present we focussed on the synthesis, electronic and geometrical modulation of (un)substituted benzene bridged diphenothiazine dumbbells (**General Scheme**).

Generally, there are two well-established methods in the literature for preparation of N-arenes viz. the copper-mediated Ullmann-coupling,[10] and the palladium-catalyzed Buchwald-Hartwig reaction.[11] Buchwald also reported a catalytic, palladium-free protocol of the Ullmann-coupling.[12] In this work, the dibromo synthones (compounds **2 - 5**) are prepared as per the literature procedures,[13] further N-arylation of these compounds with phenothiazine afforded compounds **6 - 9** in good yields (95%, 88%, 96% and 85% respectively).

**General Scheme :**




## Experimental:

***General procedure for Compounds 6–9*:** On Buchwald-Hartwig approach,[14] reactions are carried out in an inert condition by taking 10*H*-phenothiazine **1** (32.62 mmol), dibromo derivatives **2-5** (14.83 mmol), tris (dibenzylideneacetone)dipalladium(0) ($Pd_2(dba)_3$·dba, 0.44 mmol), tri-tert-butyl phosphonium tetraflouro borate (PH*t*Bu$F_4$, 0.74 mmol), Sodium tert-butoxide (NaO*t*Bu, 34.1 mmol) and anhydrous 1,4-dioxane in a pressure tube. Reaction mixture heated to 101°C and continued for 16h, cooled to room temperature and added aqueous $Na_2SO_3$ solution and extracted with methylene chloride. The organic layer dried on anhydrous $Na_2SO_4$ and

concentrated under vacuum. The crude material triturated with ethyl acetate to furnish the pure products (Compounds **6 - 9)**.

**1,4-di(10H-phenothiazin-10-yl)benzene** (Compound **6**)**:** Yield 95%, mp 223-225 °C, $^1$H NMR (400 MHz, $CDCl_3$): $\delta$ 6.50-6.53 (m, 2H); 6.89-6.93 (m, 2H); 6.97-7.02 (m, 2H); 7.11-7.13 (m, 2H); 7.49 (s, 1H), ESI mass *m/z*: 473.06 (M+1); IR (KBr)cm$^{-1}$: υ 3433, 2918, 1500, 1462, 1306, 743; Elemental Anal. Calcd for $C_{30}H_{20}N_2S_2$: C, 76.24; H, 4.27; N, 5.93; Found: C, 76.52; H, 4.32; N, 5.97.

**10,10'-(2,5-dimethoxy-1,4-phenylene)bis(10H-phenothiazine)** (Compound **7**)**:** Yield 88%, mp ≥ 350°C, $^1$H NMR (400 MHz, DMSO-$d_6$): δ 3.72 (s, 6H, -$OCH_3$); 6.21 (d, 4H, *J* = 8.04 Hz); 6.85-6.89 (m, 4H); 6.99-7.07 (m, 8H); 7.38 (s, 2H); ESI mass *m/z*: 533.6 (M+1); IR (KBr)cm$^{-1}$: υ 3433, 2925, 1508, 1461, 1302, 1243, 1030, 738, 706; Elemental Anal. Calcd for $C_{32}H_{24}N_2O_2S_2$: C, 72.15; H, 4.54; N, 5.26. Found: C, 72.46; H, 4.58; N, 5.28.

**10,10'-(2-ethoxy-5-methoxy-1,4-phenylene)bis(10H-phenothiazine)** (Compound **8**)**:** Yield 96%, mp 323-325°C, $^1$H NMR (400 MHz, DMSO-$d_6$): δ 1.03 (t, 3H, -$OCH_2CH_3$, *J* = 13.2 Hz); 3.71 (s, 3H, -$OCH_3$); 4.05 (q, 2H, -$OCH_2$, *J* = 8 Hz); 6.20 (d, 2H, *J* = 8 Hz); 6.26 (d, 2H, *J* = 8 Hz); 6.87 (m, 4H); 7.03 (m, 8H); 7.36 (d, 2H, *J* = 3.32 Hz); ESI mass *m/z*: 547.1 (M+1); IR (KBr)cm$^{-1}$: υ 3431, 2928, 1505, 1461, 1308, 1212, 1040, 745; Elemental Anal. Calcd for $C_{33}H_{26}N_2O_2S_2$: C, 72.50; H, 4.79; N, 5.12. Found: C, 72.12; H, 4.81; N, 5.17.

**10,10'-(2-(heptyloxy)-5-methoxy-1,4-phenylene)bis(10H-phenothiazine)** (Compound **9**): Yield 85%, mp 202-204°C, $^1$H NMR (400 MHz, $CDCl_3$): δ 0.80 (t, 3H, -$CH_2CH_3$, *J* = 12 Hz); 1.08-1.15 (m, 7H, alkyl H); 1.52-1.56 (m, 2H, -$CH_2$); 3.70-3.73 (m, 4H); 3.88 (t, 2H, *J* = 8 Hz); 6.19-6.24 (m, 4H); 6.83-6.87 (m, 4H); 6.91-6.96 (m, 4H), 7.03-7.18 (m, 4H); 7.26 (s, 2H); ESI mass m/z: 617.2 (M+1); IR (KBr)cm$^{-1}$: υ 3434, 2925, 1506, 1461, 1310, 1212, 746; Elemental Anal. Calcd for $C_{38}H_{36}N_2O_2S_2$: C, 73.99; H, 5.88; N, 4.54. Found: C, 73.53; H, 5.93; N, 4.59.

***General procedure for Compounds 9*-13:** To a solution of DMF (40.2 mmol) was added dropwise $POCl_3$ (26.05 mmol) under $N_2$ atmosphere and stirred at 0°C for 10 min. After 10 min 1,2 dichloroethane(50mL) was added drop wise and heated to 90°C for 18h, monitored the completion of reaction by TLC. The reaction mass was cooled to ambient temperature, poured into ice-water, neutralized with aqueous $NaHCO_3$ and then extracted with ethyl acetate (100mL). The organic layer was dried over $Na_2SO_4$ concentrated under reduced pressure and dried under vacuum to yield corresponding dialdehydes (compounds **10 - 13**).

**10,10'-(1,4-phenylene)bis(10H-phenothiazine-3-carbaldehyde)** (Compound **10**): Yield 85%, mp 302-304°C, $^1$H NMR (400 MHz, DMSO-$d_6$): δ 6.35 (d, 1H, *J* = 8 Hz); 6.44 (d, 1H, *J* = 8.4 Hz); 6.96-7.07 (m, 2H); 7.15 (d, 1H, *J* = 8 Hz); 7.53-7.59 (m, 2H); 7.80 (s, 2H); 9.76 (s, 1H, -CHO); ESI mass *m/z*: 529.0 (M+1); IR (KBr)cm$^{-1}$: υ 3433, 2718, 1683, 1595, 1503, 1465, 1310, 1041, 1019, 751; Elemental Anal. Calcd for $C_{32}H_{20}N_2O_2S_2$: C, 72.70; H, 3.81; N, 5.30. Found: C, 72.39; H, 3.85; N, 5.32.

**10,10'-(2,5-dimethoxy-1,4-phenylene)bis(10H-phenothiazine-3-carbaldehyde)** (Compound **11**): Yield 77%, mp ≥ 350°C, $^1$H NMR (400 MHz, $CDCl_3$): δ 3.77 (s, 6H, -$OCH_3$); 6.15-6.22 (m, 4H); 6.93-7.06 (m, 6H); 7.26 (s, 2H); 7.43 (d, 2H, *J* = 8 Hz); 7.54 (s, 2H); 9.76 (s, 2H, -CHO); ESI mass *m/z*: 589.1 (M+1); IR (KBr)cm$^{-1}$: υ 3433, 2839, 1681, 1469, 1309, 1253, 1205, 1032, 738; Elemental Anal. Calcd for $C_{34}H_{24}N_2O_4S_2$: C, 69.37; H, 4.11; N, 4.76. Found: C, 69.02; H, 4.15; N, 4.79.

**10,10'-(2-ethoxy-5-methoxy-1,4-phenylene)bis(10H-phenothiazine-3-carbaldehyde)** (Compound **12**) : Yield 76%, mp 295-297°C, $^1$H NMR (400 MHz, DMSO-$d_6$): δ 1.03 (t, 3H, -$OCH_2CH_3$, *J* = 13.2 Hz); 3.74 (s, 3H, -$OCH_3$); 4.07 (q, 2H, -$OCH_2$, *J* = 8 Hz); 6.24-6.38 (m, 4H); 6.94-6.97 (m, 4H); 7.01-7.10 (m, 2H); 7.49-7.54 (m, 6H); 9.74 (s, 2H, -CHO); ESI mass *m/z*: 603.7 (M+1); IR (KBr)cm$^{-1}$: υ 3434, 2838, 1681, 1504, 1307, 1250, 1205, 1037, 737; Elemental Anal. Calcd for $C_{32}H_{26}N_2O_4S_2$: C, 69.75; H, 4.35; N, 4.65. Found: C, 69.42; H, 4.37; N, 4.66.

**10,10'-(2-(heptyloxy)-5-methoxy-1,4-phenylene)bis(10H-phenothiazine-3-carbaldehyde)** (Compound **13**) **:** Yield 78%, mp 295°C, $^1$H NMR (400 MHz, $CDCl_3$): δ 0.80 (t, 3H, -$CH_2CH_3$, *J* = 12 Hz); 1.08-1.15 (m, 8H, alkyl H); 1.25 (m, 2H, -$CH_2$); 3.77 (s,1H, -$OCH_3$); 3.91 (t, 2H, *J* = 8 Hz); 6.18-6.25 (m, 4H); 6.91-6.96 (m, 4H); 7.04 (d, 2H, *J* = 6 Hz), 7.17 (d, 2H, *J* = 11 Hz); 7.41-7.44 (m, 2H); 7.53 (s, 2H); 9.75 (s,2H); ESI mass *m/z*: 673 (M+1); IR (KBr)cm$^{-1}$: υ 3435, 2927, 1687, 1595, 1309, 1250, 1203, 1023, 747; Elemental Anal. Calcd for $C_{40}H_{36}N_2O_4S_2$: C, 71.40; H, 5.39; N, 4.16. Found: C, 69.12; H, 4.27; N, 4.18.

**Synthesis of (10,10'-(1,4-phenylene)bis(10H-phenothiazine-10,3-diyl))dimethanol** (Compound **14**) : To the solution of Compound **10** (1.87 mmol) in THF (25 mL) LAH (5.3 mmol) was added portion wise at 0-10$^{o}$C and stirred for 24h, after completion of reaction added 1N aqueous NaOH to the reaction mixture and extracted with ethyl acetate. Organic layer dried over $Na_2SO_4$ and concentrated under reduced pressure to get the corresponding di-alcohol. Yield 80%, mp 225-227°C, $^1$H NMR (400 MHz, DMSO-$d_6$): δ 4.38 (d, 2H, -$CH_2$, *J* = 5.4 Hz), 5.14 (t, 1H, -OH, $D_2O$ exchangeable *J* = 5.56 Hz), 6.54 (d, 1H, *J* = 8 Hz), 6.58 (d, 1H, *J* = 8 Hz), 6.96-7.04 (m, 2H), 7.08-7.014 (m, 1H), 7.21 (d, 1H, *J* = 8 Hz), 7.47 (s, 2H); ESI mass *m/z*: 533.1 (M+1); IR (KBr)cm$^{-1}$: υ 3357, 2921, 2864, 1504, 1465, 1305, 1207, 1034, 1024, 815, 748; Elemental Anal. Calcd for $C_{32}H_{24}N_2O_2S_2$: C, 72.15; H, 4.54; N, 5.26. Found: C, 72.49; H, 4.59; N, 5.29.

**Synthesis of (2E,2'E)-3,3'-(10,10'-(2-ethoxy-5-methoxy-1,4-phenylene)bis(10H-phenothiazine-10,3-diyl)) diacrylic acid** (Compound **15**) : A mixture of Compound **12** (4 mmol) in 10 mL of pyridine stirred at 0$^{o}$C, added malonic acid (16 mmol) and 0.1 eq of piperidine, heated to 90$^{o}$C for 5h. Monitored the TLC in regular intervals. Upon completion of reaction, poured the reaction mass in to ice water, and filtered the solid settled. Yield 88%, mp ≥ 300 °C, $^1$H NMR (400 MHz, $CDCl_3$+DMSO-$d_6$): δ 1.16 (t, 3H, -$OCH_2CH_3$, *J* = 12 Hz); 3.76 (s, 3H, -$OCH_3$); 4.04 (q, 2H, -$OCH_2$, *J* = 12 Hz); 6.15-6.27 (m, 5H); 6.88-7.01 (m, 10H); 7.3 (d, 2H, *J* = 3.6 Hz); 7.79-7.91 (m, 1H); 8.34-8.84 (m, 2H); ESI mass *m/z*: 685.4 (M+1); IR (KBr)cm$^{-1}$: υ 3428, 2921, 2850, 1579, 1465, 1313, 1215, 1034, 743; Elemental Anal. Calcd for $C_{39}H_{30}N_2O_6S_2$: C, 68.20; H, 4.40; N, 4.08. Found: C, 68.52; H, 4.44; N, 4.13.

**Synthesis of 10,10'-(2,5-dimethoxy-1,4-phenylene)bis(3-(1H-benzo[d]imidazol-2-yl)-10H-phenothiazine)** (Compound **16**) : To the solution of compound **11** (40.2 mmol) and o-phenylenediamine (40.2 mmol) in 15 mL of DMF, added sodium metabisulphite (40.2 mmol), heated to 90$^{o}$C for 3h. In regular intervals monitored the reaction by TLC, on completion of the reaction cooled to ambient temperature and poured into ice-water. The solid settled was filtered and triturated with 10% ethyl acetate in n-hexane, to get the pure title product. Yield 80%; mp 302-305°C; $^1$H NMR (400 MHz, DMSO-$d_6$): δ 6.49 (d, 1H, *J* = 8 Hz); 6.59 (d, 1H, *J* = 8 Hz); 7.01 (t, 1H, *J* = 8 Hz); 7.09-7.11 (m, 1H); 7.21-7.29 (m, 3H); 7.62-7.65 (m, 2H); 7.78 (s, 1H); 7.85-7.87 (m, 1H); 7.94-7.95 (m, 1H); ESI mass *m/z*: 765.2 (M+1); IR (KBr)cm$^{-1}$: υ 3414, 2934, 1685, 1595, 1468, 1312, 1210, 1038, 746; Elemental Anal. Calcd for $C_{46}H_{32}N_6O_2S_2$: C, 72.23; H, 4.22; N, 10.99. Found: C, 72.52; H, 4.26; N, 11.01.

***Physico-chemical parameters of Compounds 10-16*:**

All the synthesised phenothiazine dyads shows UV–Vis absorption maxima from 280 to 300 *nm* except compound **14**, which shows the absorption maxima at 260 *nm* and the PL emission spectra of these dyads show typical vibronically structured bands in the range of 453 - 543 □max (*nm)* (**Table 1**) corresponding to red shift (bathochromic). Surprisingly, Compound **15** showed UV-Vis absorption at 305 *nm* (**Fig 1**) and corresponding emission in greenish yellow region at 468 *nm* (**Fig 2**). The absorption and emission bands are very broad and without any vibrational structure. The positions of the absorption and emission bands can be attributed to the decreased planarity of the molecules caused by large steric interactions within the molecules.

**Table 1:** Optical properties of phenothiazine dyads recorded in DMF (1 x10$^{-5}$ M).

| Compound No. | λmax (*nm*) | | Stokes shift (cm$^{-1}$) |
|---|---|---|---|
| | Absorption | Emission | |
| 10 | 290 | 532 | 242 |
| 11 | 291 | 533 | 242 |
| 12 | 290 | 530 | 240 |
| 13 | 290 | 527 | 237 |
| 14 | 260 | 453 | 193 |
| 15 | 305 | 468 | 163 |
| 16 | 300 | 543 | 243 |

**Table 2:** Electrochemical parameters of phenothiazine dyads in DMF (1 x$10^{-5}$ M).

| Compound No. | $E_{pa1}$ | $E_{pa2}$ | $E_{pa3}$ | $E_{pc1}$ | $E_{pc2}$ |
|---|---|---|---|---|---|
| 10 | - | - | - | 0.178 | - |
| 11 | - | - | - | 0.175 | - |
| 12 | - | - | - | 0.427 | - |
| 13 | - | - | - | 0.574 | - |
| 14 | 1.076 | - | - | 0.1668 | -0.3764 |
| 15 | -0.819 | 0.288 | 0.805 | 0.7902 | -1.07 |
| 16 | 0.896 | - | - | 0.7189 | - |

***Electronic structure:***

The electronic structure of the aromatic-bridged phenothiazine dyads are pre-optimized using Gaussian 98 programme at the HF/6-31G level; and then the single point energy was computed at the B3LYP/6-31G* level based on the optimized configuration[15]**.** Further these structures (Compounds **10 - 16**) are geometrically optimized and the electron density distributions in the frontier orbitals (HOMO and LUMO) of the lowest energy conformation structures were exclusively taken into account.

## Results and discussions

A total of eleven dumbbell shaped phenothiazine compounds are synthesised using Buchwald-Hartwig approach. All these compounds characterised using modern spectroscopic data viz. IR, $^{1}$H NMR and Mass. The physico-chemicals parameters and their electronic structure were well discussed here.

***Physico-chemical parameters*:**

A relatively concomitant large stokes shift of 243 *nm* is observed between the absorption and emission spectra maxima, which could be subjected to significant geometrical changes upon excitation from a highly non planar ground state to largely planarised excited state.[16]

Upon the excitation of phenothiazine dyads, the energy difference between the geometrically relaxed ground state and the non-relaxed excited singlet state becomes larger than that of energy difference between the geometrically relaxed excited state and the non-relaxed ground state. This shift is not only due to different arrangement of solvent molecules in the transition ground state and the singlet excited state, but also to the presence of flexible bridges between the dyads.[17]

Additionally, it is observed that the two phenothiazine groups are not in the same plane and their molecular orbitals do not interact strongly with each other. More extensive delocalisation between the two phenothiazine groups would have caused a significant shift in the absorption emission bands.

Cyclic voltammetry experiments for the compounds **10 - 16** in DMF at room temperature (scan rate 100 $mVs^{-1}$, supporting electrolyte 0.1 M tetrabutyl ammonium perchlorate; working electrode glassy carbon electrode; counter electrode Pt wire) are executed. The electrochemical parameters of obtained phenothiazine dyads are shown in Table **2**.

Phenothiazine dyads with aldehyde (compounds **10 - 13**) are not showing any electro anodic oxidation peaks attributed to resistant to oxidation. But, they show cathodic reduction peaks due to the formation of corresponding cations in the excited state. Dyad **15** shows single anodic oxidation peak which is quasi-reversible may be due to electronically decoupled cations (**Fig 3**). Where as the dyad substituted with benzimidazole **(**compound **16**) exhibits two redox peaks (**Fig 4**). The broad quasi-reversible as well as broad irreversible nature is attributed to the formation of respective unstable cations.

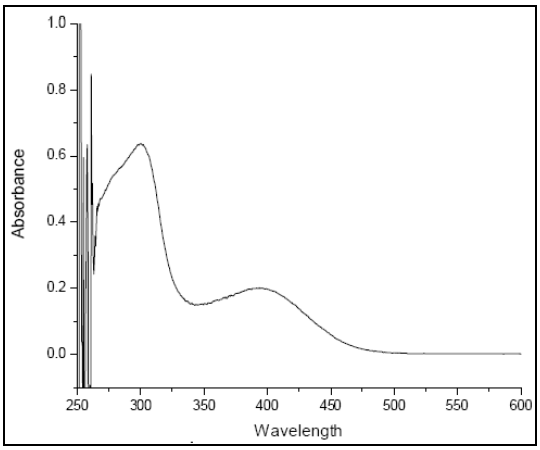



**Fig 1.** UV - Vis spectrum of phenothiazine dyad (Compound **15** in DMF, $1x10^{-5}$ M).

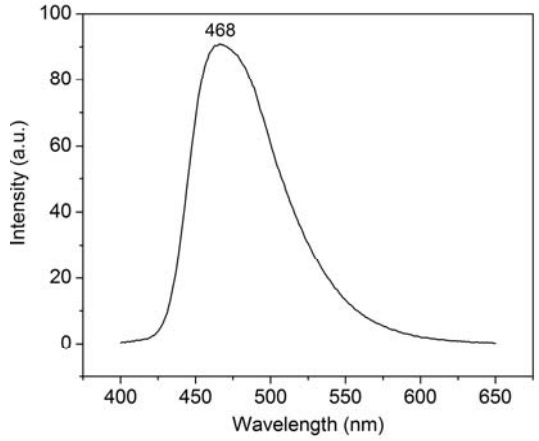



**Fig 2.** PL emission spectrum of phenothiazine dyad (Compound **15** in DMF, $1x10^{-5}$ M).

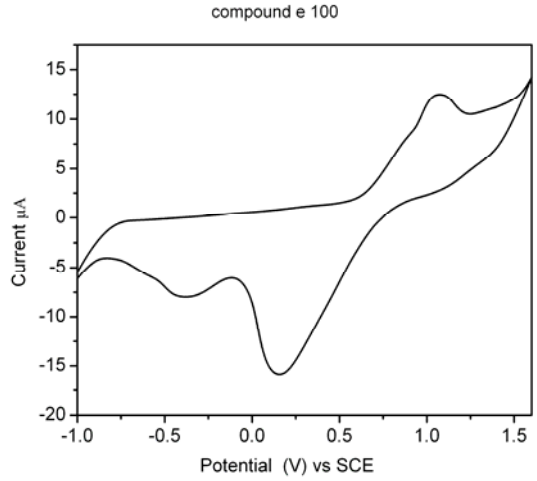



**Fig 3.** Cyclic voltammogram of phenothiazine dyad (Compound **15** in 0.1M tetrabutyl ammonium perchlorate in DMF, scanning range -1 to 1.5 at the scanning rate of 100mv/s).

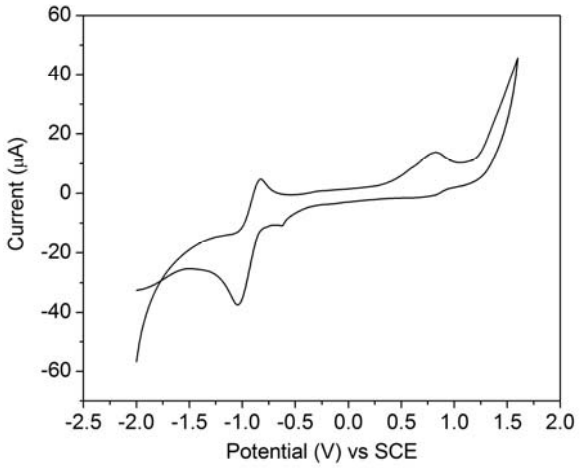



**Fig 4.** Cyclic voltammogram of phenothiazine dyad (Compound **16** in 0.1M tetrabutyl ammonium perchlorate in DMF, scanning range -2.5 to 2.0 at the scanning rate of 100mv/s).

### *Electronic structure (HOMO&LUMO)*

The computed HOMO is predominately localized on one of the phenothiazine ring and sulphur, nitrogen atoms of another phenothiazine ring (compounds **10 - 14)**. For the compounds **15** & **16** it is observed that the HOMO distribution is present on bridged phenyl ring as well as hetero atoms of both the phenothiazine rings (**Fig 5**). It can be due to bulky group substitutions on the phenothiazine ring**,** where as the substitutions on bridged ring have not shown any significance in HOMO distributions.

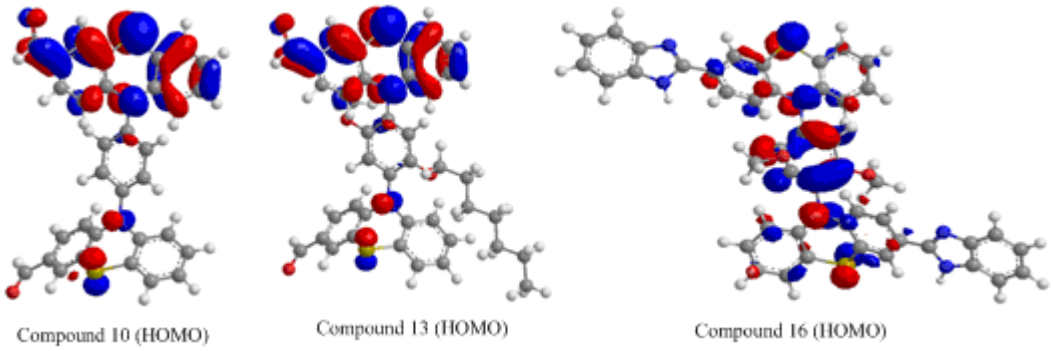



**Fig 5.** HOMO distribution of the phenothiazine dyad (Compound **10**, **13** & **16**)

For the compounds **10-12, 14 & 16,** LUMO is localized on the un-substituted phenyl portion of the phenothiazine moiety as well as bridged aromatic ring of the dyad. Interestingly compound **13** in which substitution on bridged aromatic ring has significant role in the distribution of LUMO on one of the phenothiazine moiety and the un-substituted portion of another phenothiazine moiety (**Fig 6**).

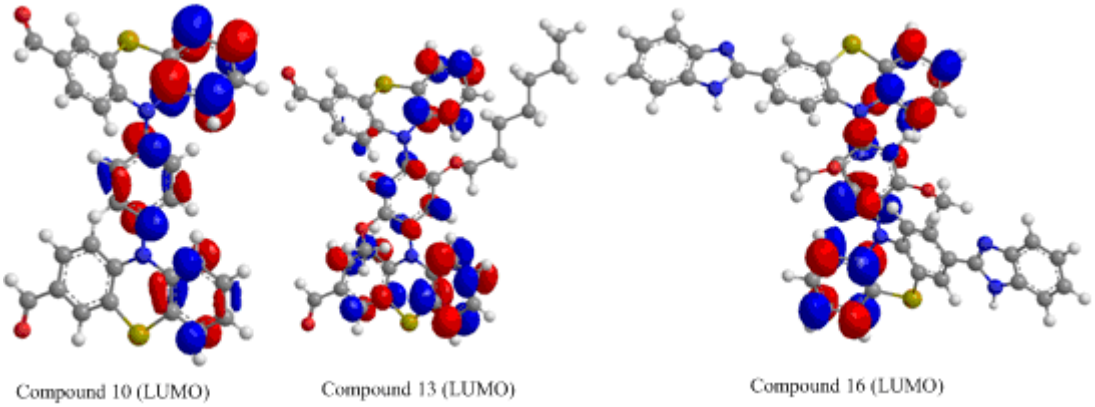



**Fig 6**. LUMO distribution of the phenothiazine dyad (Compound **10**, **13** & **16)**

## Conclusion

In conclusion, the formylation and further derivatization of these phenothiazine dyads (Compounds **10 - 16**) are reported for the first time. These compounds also exhibited interesting electronic properties including HOMO and LUMO distribution patterns. Further exploration of these phenothiazine dyads compounds are under way.

## Acknowledgements

One of the authors, S.Thirunavukkarasu is highly thankful to the management of Orchid Chemicals & Pharmaceuticals Limited, Chennai, India for providing the facilities, consent to perform the research and Dr. K. Narasimhan for his technical support.

## References

1. (a) Zong, D.; Haag, P.; Yakymovych, I.; Lewensohn, R.; Viktorsson, K. Cell Death Dis. 2011, 21(2), e181; (b) Ikediobi, O.N.; Reimers, M.; Durinck, S.; Blower, P. E.; Futreal, A. P.; Stratton, M. R.; Weinstein, J. N. Mol Cancer Ther. 2008, 7(6), 1337.
2. (a) Simokaitiene, J.; Sakalyte, A.; Grigoriev, T. E.; Makhaeva, E. E.; Grazulevivius, J.V. Mat. Sci. 2009, 15(3), 236; (b) Marotta, G.; Anil Reddy, M.; Singh, S.-P.; Ashraful, I.; Han, L.; De-Angelis, F.;Pastore, M.; Chandrasekharam, M. Appl. Mater. Interfaces, **2013**, 5(19), 9635.
3. (a) Schlauderer, F.; Lammens, k. ; Nagel, D.; Vincendeau, M.; Eitelhuber, A. C.; Verhelst, S. H. L.; Kling, D.; Chrusciel, A. L.; Ruland, J.; Krappmann, D.; Hopfner, K-P. Angewa. Chemie. 2013, 52 (39), 10384; (b) Sharon, R.; Sanket, A.; Abhijit, R.; Jennifer, C.; Floyd, G.; Donard, D.; Heather, K-H.; Mathis, J. M.; Simon,V.; Arrigo, D. B.; Ronald, S.; Awate, S.; Rath, A.; Carroll, J.; Galiano, F.; Dwyer, D.; Hancock, H. K.; Mathis, J.-M.; Vigod, S.; De-Benedetti, A. Genes & Can. 2013, 4(1-2), 39.
4. Pereţeanu, I. S.; Müller, T. J. Org. Biomol.Chem. 2013, 11, 5127.
5. Barbosa, L. R. S.; Caetano, W.; Rosangela, I.; Homem-de-Mello, P.; Santiago, P-. S.; Tabak, M. J. Phys. Chem. B. 2006, 110, 13086.
6. Elkassih, S. A.; Prakash S.; Harsha D. M.; Papadimitratos, A.; Zakhidov, A. A.; Biewer, M. C.; Stefan, M. C.; Macromol. Chem. and Phy. 2013, 214(5), 572.
7. (a) Franz, A. W.; Popa, L. N.; Rominger, F.; Muller, T. J. J. Org. Biomol.Chem. 2009, 7, 469; (b) Hauck, M.; Schonhaber, J.; Zucchero, A. J.; Hardcastle, K. I.; Muller, T. J. J.; Bunz, U. H. F. J. Org. Chem. 2007, 72, 6714.
8. (a) Barbosa, L. R. S.; Rosangela I.; Caetano, W.; Neto, D.-S. D.-g. ; Tabak, M. ; J. Phys. Chem. B, 2008, 112, 4261; (b) Wenjum W. V.; yang, J.; Hua, J.; Tang, J.; Zhang, L.; Long, Y.; Tian, H.; J. Mater. Chem. 2010, 20, 1772.
9. Sun, D.; Rosokha, S. V.; Jay, K. K. J. Am. Chem. Soc. 2004, 126 , 1388.

10. Ullmann, F. Ber. Dtsch. Chem. Ges. 1903, 36, 2382.
11. Louie, J.; Hartwig, J. F. Tet. Lett. 1995, 36(21), 3609.
12. Kwong, F. Y.; Buchwald, S. L. Org. Lett. 2003, (5)6, 793.
13. Palmgreen, A.; Thorarensen, A.; Backwall, J.-E. J. Org. Chem. 1998, 63, 3764.
14. Okamoto, T.; Kuratsu, M.; Kozaki, M.; Hirotsu, K.; Ichimura, A.; Matsushita, T.; Okada, K. Org. Lett. 2004, 6(20), 3493.
15. Frisch, M. J.; Trucks, G. W.; et. al. pre-optimized using Gaussian98 program at the HF/6-31G level; and then the single, Gaussian, Inc, Wallingford CT, 2004.
16. Lai, R. Y.; Kong, X.; Jenekhe, S. A.; Bard, A. J. J. Am. Chem. Soc. 2003, 125, 12631.
17. Rajakumar, P.; Kanagalatha, R. Tet. Lett**.** 2007, 48, 8496.

*****