Synthesis of Diquats Their Resolution and Derivatization

Harish R. Talele,[a,b] Anil G. Sarode,[a] Anil K. Patil,[a] Dilip B. Tayade,[a] Milind E. Chaudhari,[c] Paul E. Reyes-Gutiérrez,[b] Dušan Koval,[b]and Filip Teplý[b]1

[a] Department of Chemistry, TVES's D. N. College, Faizpur, affiliated with KBC N. M. U., Jalgaon, Maharashtra - 425503, India

[b] Institute of Organic Chemistry and Biochemistry of the Czech Academy of Sciences, Flemingovo n. 2, 166 10 Prague, Czech Republic

[c] TVES's Honble Loksevak Madhukarrao Chaudhari College of Pharmacy, Faizpur, Jalgaon,

Email: harishtalele@gmail.com

Abstract: Diquats have helical geometry and robust configurational stability to allow studies of the two separate enantiomers with opposite helicity. We synthesized the various diquats having an active methyl group to help to increase the racemization barrier and derivatized by Knoevenagel condensation reaction towards the helical/helicene like diquat dyes. The synthesized diquats and their derivatives were characterized by Mass, IR and $^{1}H/^{13}C$-NMR analysis.

Index Terms **– Helical Diquat, Resolution, Chiral anions, N-heterocyclic cations, Diquat Dyes.**

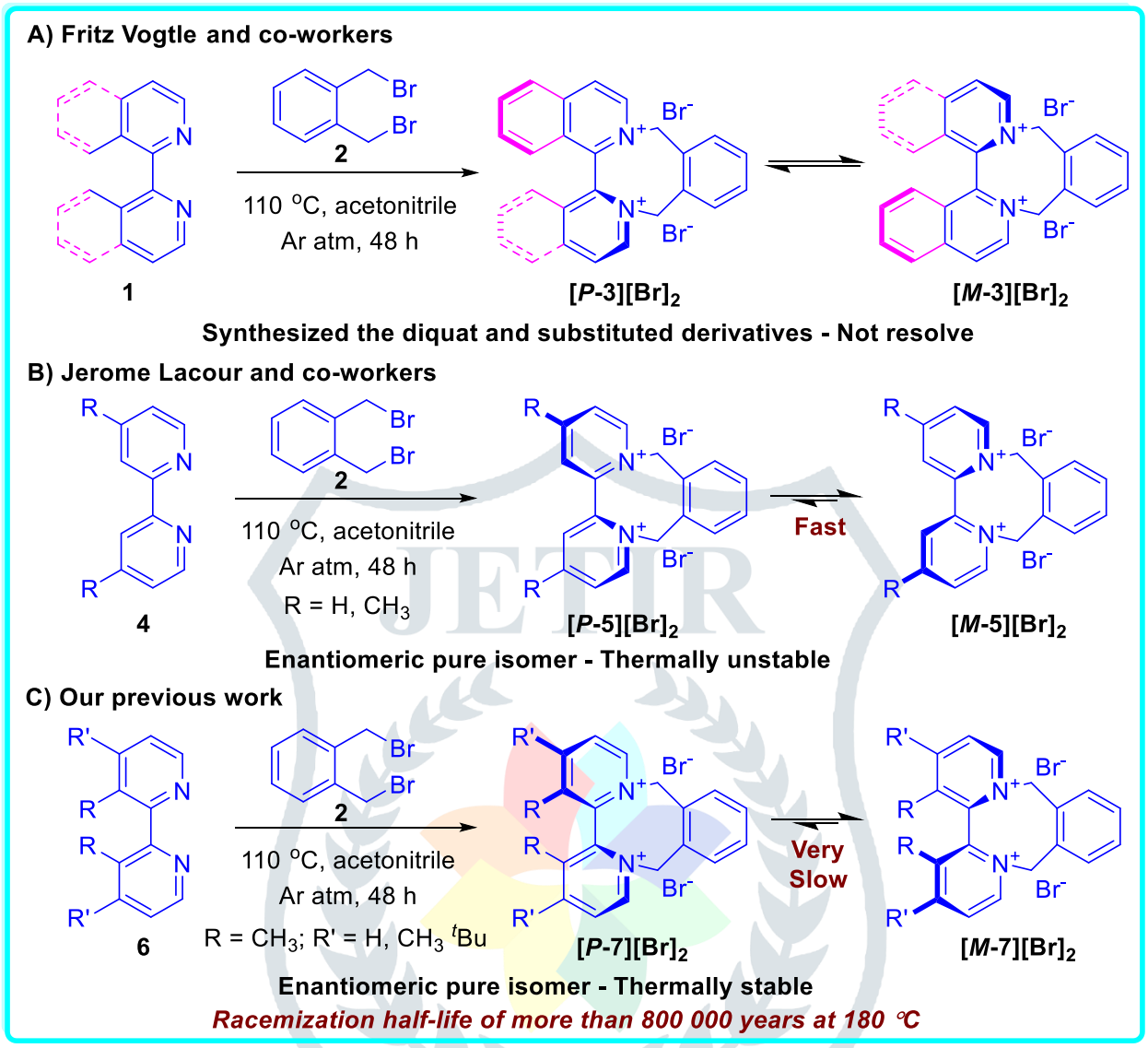
I. INTRODUCTION

As powerful herbicides, dicationic molecules were (diquats) introduced by Imperial Chemical Industry in 1958.[1] After the invention of diquat its attracted the attention of scientific community due to the its applications and fascinating properties such as electron deficient systems, building blocks in supramolecular systems,[2] and in the designing of electron transfer systems.[3] Diquat exhibit the other interesting properties such as electron acceptors in the light harvesting chromopher-quencher system,[4] for the construction of ion-pair transfer complexes,[5] and a diquat dyes in a nonlinear optics.[6] Diquat exhibit the other interesting properties such as electron acceptors in the light harvesting chromopher-quencher system, for the construction of ion-pair transfer complexes,[5] and a racemic diquat dyes in a nonlinear optics.[6]

A non-planar twisted structure towards the stereo-chemical assignment in the diquat with the dihydral angle between two pridinium ring is 19.7° was reported in 1969 by Hamor and Derry.[1b] The twist in the system well studied by Vogtle with substituted 2,2'-bipyridine and 1,1'-biisoquinoline and studies their enantiomers and confirmation by H-NMR analysis of the coalescence of the AB system could be determined, electronic as well as oxidation-redox potentials for the further applications (**Scheme 1A**).[7]

Recently, the Lacour group revisited some of these dications and reported the resolution and determination of racemization barriers. This elegant study found the barriers of the selected example diquats to be relatively low (DG¼6 =106–112 $kJmol^{-1}$ at 208°C).[8] The seven membered tricyclic diquat derivatives and a chiral anion mediated asymmetric induction of the configurationally stable atropisomeric diquat was established by using the anions TRISPHAT, HYPHAT and the most effective BINPHAT.[9] After this preliminary studies of the configurational stability experiment later they successfully resolved the enantiopure diquats using the BINPHAT and TRISPHAT and studied the ECD properties as well as the

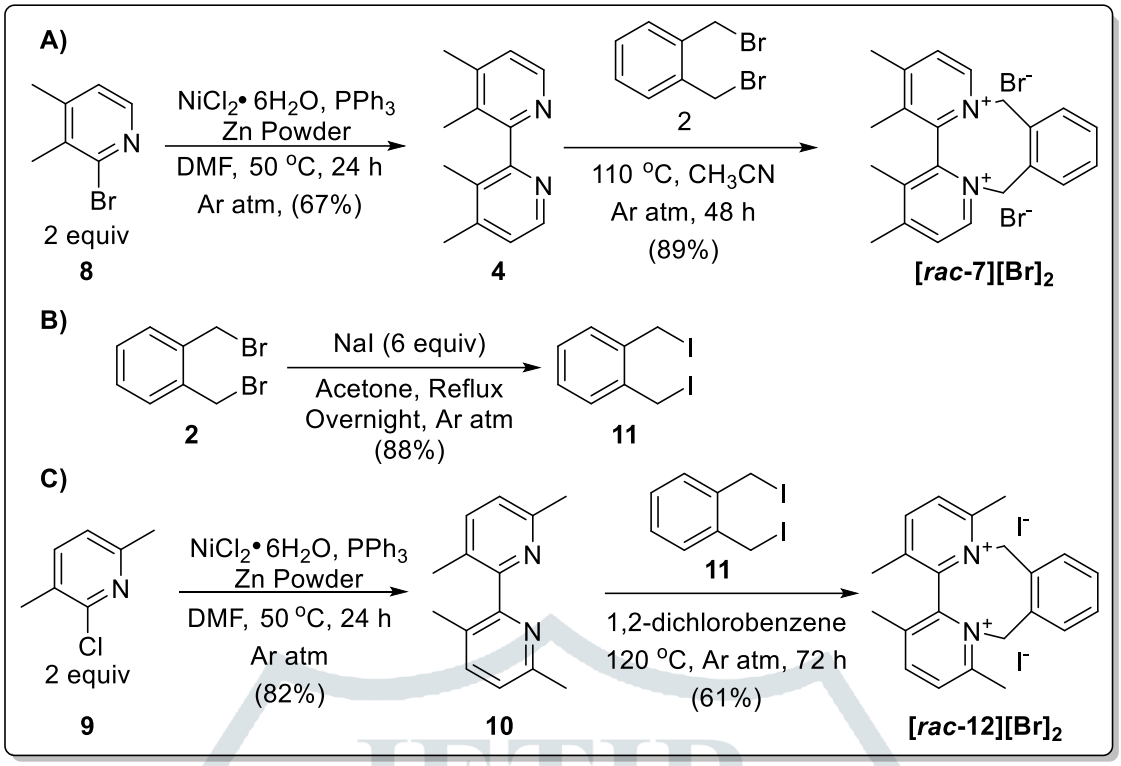
thermal stability of the molecules and they found the half lives of (R = H, 13 days), (R = CH_3, 127 days) and (R = ^{t}Bu, 9.5 days) at 20 °C (**Scheme 1B**).



Scheme 1: Diquats with low and high resolution barrier suitable for the further study

In our recent work we introduced the configurationally robust diquats, the resolution was achieved by the simple crystallization method with the help of monosodium salt of (*R*,*R*)-dibenzoyltartrate [Na][*R*,*R*-DBT] and the other enantiomer with the (*S*,*S*)-dibenzoyltartrate [Na][*S*,*S*-DBT] (**Scheme 1C**) and used for the potential applications as chiral selectors in capillary electrophoresis as well as synthesis of the first non-racemic diquat dyes.[9]

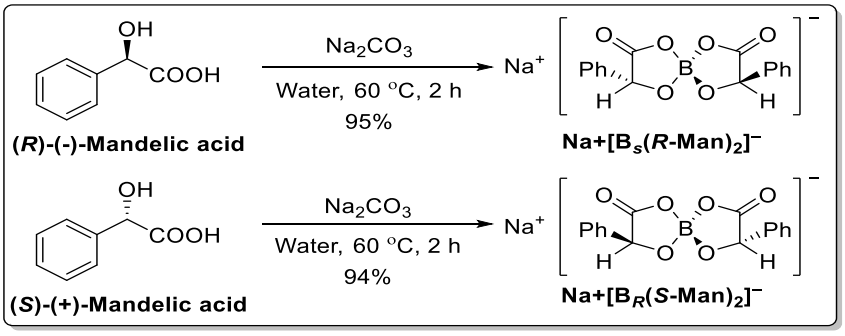
Inspired from the previous simple resolution by crystallization methodology we synthesized the another tetramethyldiquats 3,3',6,6'-tetramethyl-2,2'-bipyridine **10** with the 3,3',4,4'-tetramethyl-2,2'-bipyridine **4** by reported method using 2-bromo-3,4-dimethylpyridine **8** and 2-chloro-3,6-dimethylpyridine **9** as a starting material respectively. The homocoupling of substituted halopyridine [10] using zinc powder, $NiCl_2$•$6H_2O$ and triphenylphosphine in *N*,*N*-dimethylformamide under argon atmosphere gives the tetramethyl-bipyridines in good to excellent yields.



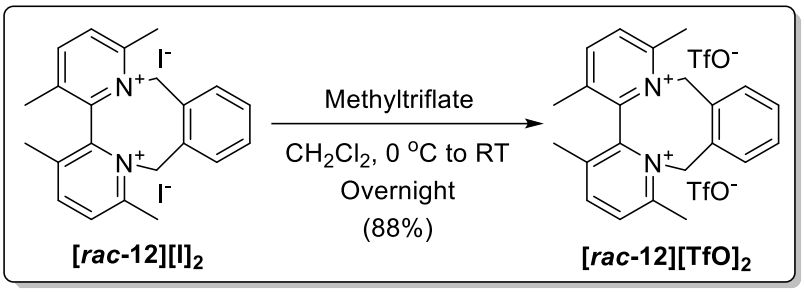
Scheme 2: Synthesis of racemic **[*rac*-7][Br]$_2$** and **[*rac*-12][I]$_2$** diquats

The substituted tricyclic diquats were synthesized by using substituted bipyridine and α,α'-dibromo-*ortho*-xylene in anhydrous acetonitrile at 110 °C under pressure in pressure tube. The racemic diquat **[*rac*-7][Br]$_2$** synthesized in good to excellent yield (**Scheme 2A**), but the reaction of 3,3',6,6'-tetramethyl-2,2'-bipyridine **10** was failed due to the steric hindrance by the methyl groups at the 6,6'-position. Then the α,α'-dibromo-*ortho*-xylene was converted to the α,α'-diiodo-*ortho*-xylene [11] (**Scheme 2B**) and its reaction with 3,3',6,6'-tetramethyl-2,2'-bipyridine **10** in the 1,2-dichloromethane under pressure to obtained the **[*rac*-12][I]$_2$ (Scheme 2C)**.

The chiral anions play an important role in the resolution of diquat [8, 9] by exchanging them to the achiral anions such as Br^-, I^-, TfO^- etc. Using the same strategy from our previous results we try to resolve the **[*rac*-12][I]$_2$** by exchanging the iodide anions with the dibenzoyltartarate anions. Unfortunately the method didn't work with the [Na][*R*,*R*-DBT] and [Na][*S*,*S*-DBT] and observe the decomposition of the diquat. To solve this problem developed a new method for the resolution, instead of the [Na][*R*,*R*-DBT] and [Na][*S*,*S*-DBT] salt used the sodium salt of borate anions with enantiopure mandelic acid **$Na^+[B_s(R\text{-Man})_2]^-$** and **$Na^+[B_R(S\text{-Man})_2]^-$** [12] (**Scheme 3**) and tried the resolution in methanol. Again the attempt was failed due to the some decomposition of diquat, then the iodide anions was exchanged with the triflate anions using the simple anion exchange method (**Scheme 4**).

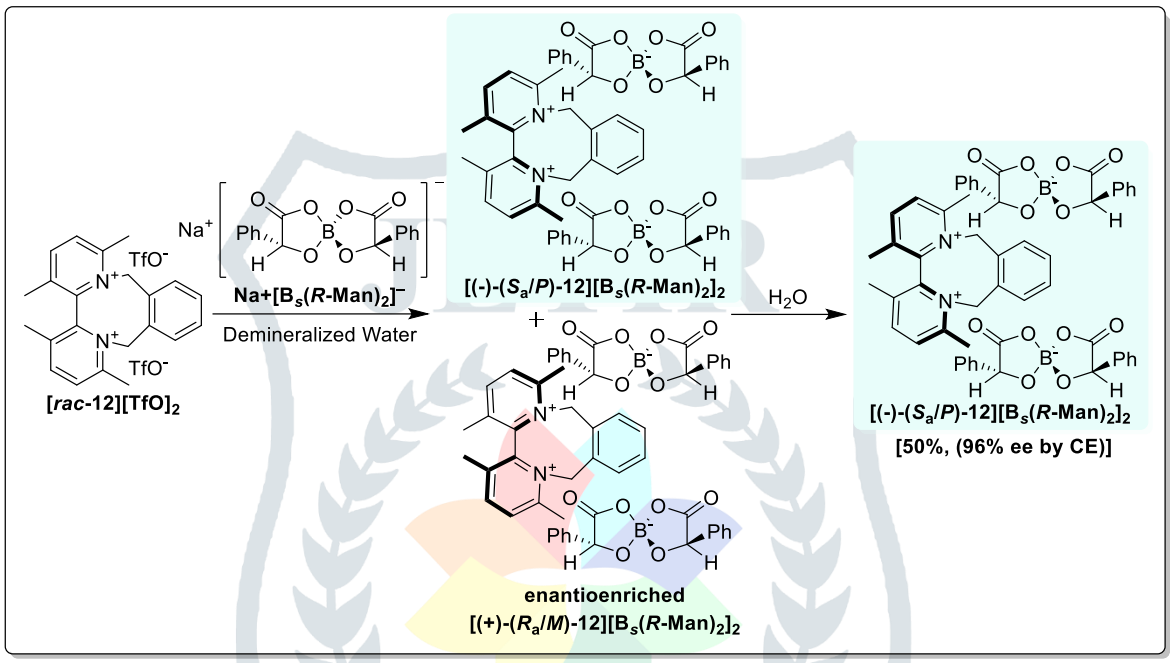


Scheme 3: Synthesis of **$Na^+[B_s(R\text{-Man})_2]^-$** and **$Na^+[B_R(S\text{-Man})_2]^-$**



Scheme 4: Synthesis of racemic **[12][OTf]$_2$** diquats

The preliminary result of successful resolution of synthesized diquat **[12][OTf]$_2$** with **$Na^+[B_s(R\text{-Man})_2]^-$** and $Na^+[B_R(S\text{-Man})_2]^-$ are discussed and reports the chiral borate anions to be suitable for the resolution of diquat or the quaternary nitrogen heterocyclic compounds [12c].



Scheme 5: Successful conversion of **[12][OTf]$_2$** diquat to its pure diastereomeric compound

The anion exchange from triflate to borate was analysed by capillary electrophoresis analysis shows that there is 96% *de* for **[(-)-(*Sa*/*P*)-12][B*s*/*R*-Man)$_2$]$_2$** and **[(+)-(*Ra*/*M*)-12][B$_s$/*R*-Man)$_2$]$_2$** (recrystallized twice with ethanol – the crude sample contains the excess of **$Na^+[B_s/R\text{-Man})_2]_2$)** salt) shows 87% *de* (**Figure 1**).

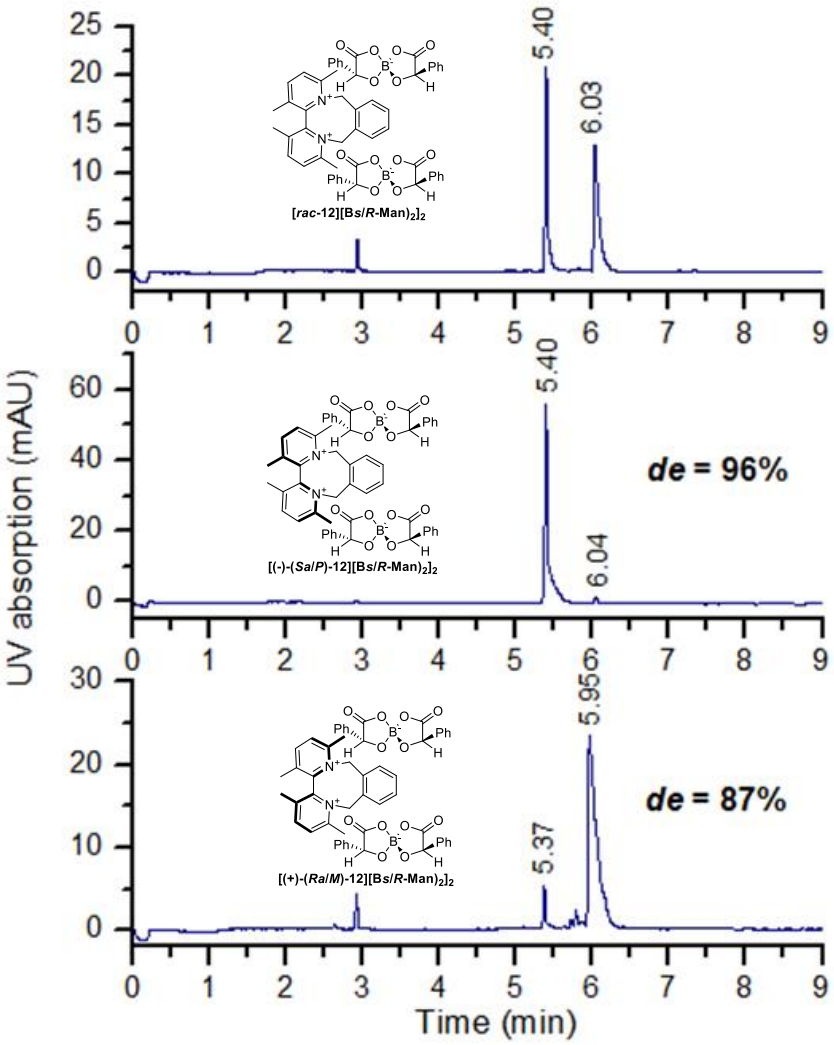
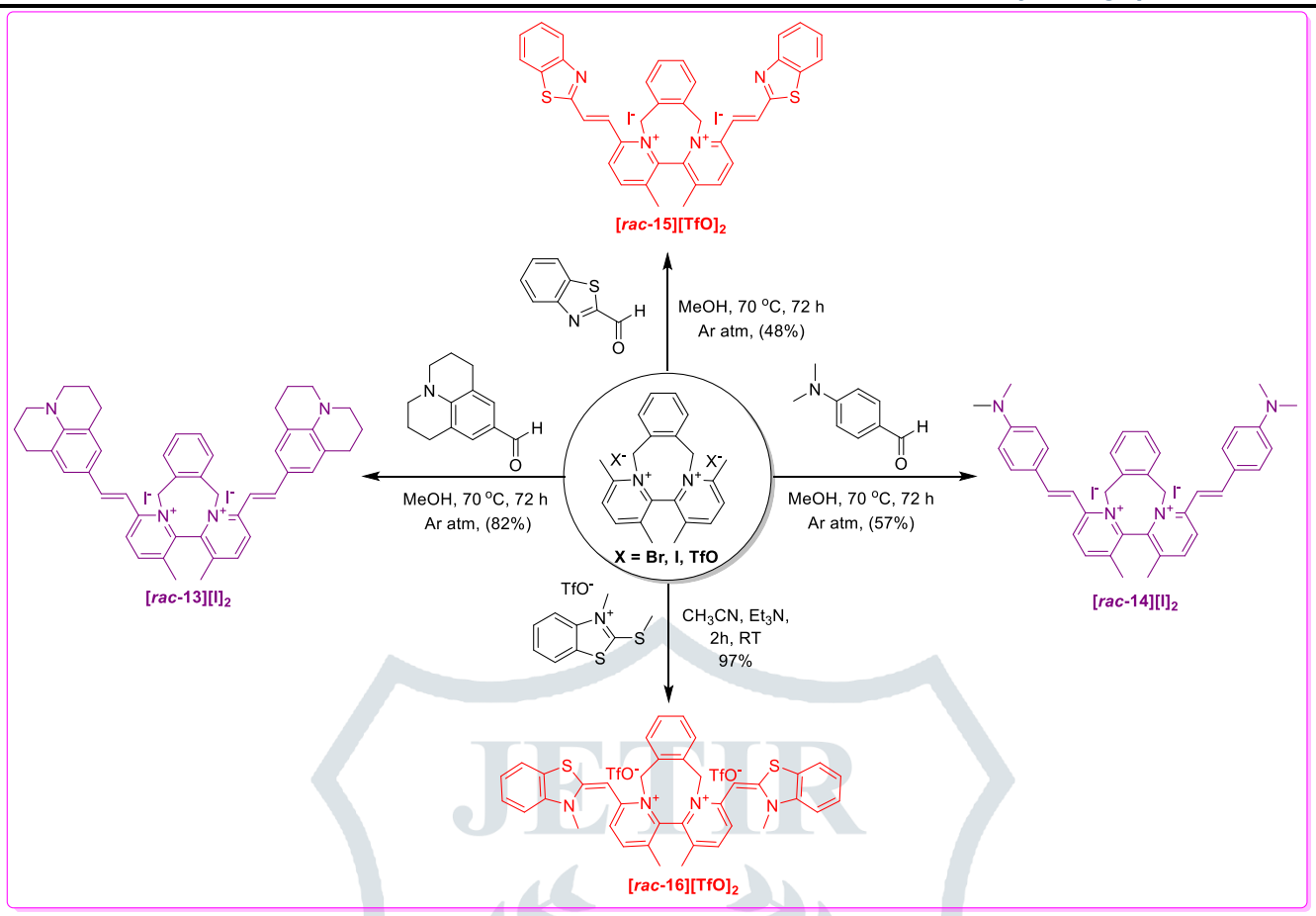


Figure 1. CE charts from the individual enantiomeric composition analyses of and [*rac*-12][B_s/*R*-Man)$_2$]$_2$ (upper chart), [(-)-(*Sa*/*P*)-12][Bs/*R*-Man)$_2$]$_2$ (middle chart), and [(+)-(*Ra*/*M*)-12][Bs/*R*-Man)$_2$]$_2$ (lower chart).

The two active methyl groups in the diquat system **[*rac*-7][Br]$_2$, [*rac*-12][I]$_2$, [*rac*-12][OTf]$_2$** to used for derivatization methods established for pyridinium type systems.[10,13] Synthesis of helical diquat dyes has addressed [10, 14], towards this approach we converted the diquats to diquat dyes with substituted benzaldehyde derivative through Knoevenagel condensation in the presence of pyrrolidine catalyst. To our delight, the desired dye can be successfully prepared in the absence of pyrrolidine and characterized (**Scheme 5**).



Scheme 5: Synthesis of racemic diquat dyes **[*rac*-13][I]$_2$, [*rac*-14][I]$_2$, [*rac*-15][I]$_2$ and [*rac*-16][OTf]$_2$**

The synthesized diquat dyes have a various applications as non linear optics in materials as well as relating to biology or bio-chemistry. The biochemical applications of these dyes for the G-quadruplex stabilization are under screening.

II EXPERIMENTAL SECTION

1) General information

Liquids and solutions were transferred *via* needle and syringe under inert atmosphere unless stated otherwise. Melting points were determined on a Wagner & Munz PolyTherm A micro melting point apparatus and on a Stuart melting point SMP30 apparatus, and are uncorrected. Thin-layer chromatography (TLC) analysis was performed on silica gel plates (Silica gel 60 F254-coated aluminium sheets, Merck, cat. no. 1.05554.0001) and visualized by UV (UV lamp 254/365 nm, Spectroline® Model ENF–240C/FE) and/or chemical staining with $KMnO_4$ [KMnO4 (1% aq.), Na_2CO_3 (2% aq.)]. TLC analysis of dications was achieved using Stoddart's magic mixture1 (MeOH : NH_4Cl aq. (2M) : $MeNO_2$ 7 : 2 : 1) as eluent on silica gel plates. NMR spectra were measured on a Bruker Avance 600 (600 MHz for 1H, 151 MHz for 13C) or Bruker Avance 500 (500 MHz for 1H, 125.7 MHz for 13C) or Bruker Avance 400 (400 MHz for 1H, 101 MHz for 13C) NMR spectrometer. In ^{1}H and ^{13}C NMR spectra, chemical shifts are referenced as follows (ppm): in DMSO-*d6* the peaks were referenced relative to the solvent peak δH = 2.50 ppm and δC = 39.52 ppm; in $CDCl_3$ relative to Me4Si signals δH = 0.00 ppm or the solvent peak δH = 7.26 ppm and δC = 77.00 ppm and acetonitrile-d_3 relative to the solvent peak δH = 1.94 ppm and δC = 118.26 ppm. Chemical shifts are given in δ-scale as parts per million (ppm); coupling constants (*J*) are given in Hertz. IR spectra were recorded on a Bruker EQUINOX55 (IFS55) spectrometer in KBr pellets. Mass spectral data were obtained at the Mass Spectrometry Facility operated by the Institute of Organic Chemistry and Biochemistry of the

Czech Academy of Sciences (IOCB, CAS), Electrospray ionization (ESI) mass spectra were recorded using a Thermo Scientific LCQ Fleet mass spectrometer equipped with an electrospray ion source and controlled by Xcalibur software. For capillary electrophoresis: The mobile phase consisted of MeOH:water (9:1), flow rate of 200 µL.min-1. The sample was dissolved, diluted with the mobile phase and injected using a 5 µL loop. Spray voltage, capillary voltage, tube lens voltage and capillary temperature were 5.5 kV, 5 V, 80 V and 275°C, respectively. High resolution mass spectra (HR MS) were obtained with the ESI instrument. For general information about capillary electrophoresis (CE), see Figure 1.

2) Materials and abbreviations

MeOH was distilled from Mg/I_2 as follows. MeOH (100 mL) was charged into a 1 L round bottom flask. Then, 5 g of Mg was added followed by addition of I_2 (500 mg). The mixture was heated to reflux under Ar atmosphere for 15 min. Then, more I_2 (500 mg) and MeOH (500 mL) were added and the mixture was refluxed under Ar atmosphere for 2 h. Degassed solvents were obtained *via* the freeze-pump-thaw method. The solvent was frozen under argon, and then thawed under vacuum. This process was repeated (3×). Finally the thawed solvent was purged with argon. DMSO-*d6* was dried over 4 Å molecular sieves. Unless otherwise stated, all other starting materials and reagents were obtained from commercial suppliers and used without further purification.

Stoddart's magic mixture1 = MeOH : 2M aq NH_4Cl : $MeNO_2$ = 7 : 2 : 1

α,α′-Dibromo-*o*-xylene (Aldrich, 97%, D44405)

Zinc Powder (Sigma-Aldrich, 14409, CAS. No. 7440-66-6)

Acetonitrile (Aldrich, ≥ 99.5%, 360457)

Et_3N (Alfa Aesar, 99%, 121-44-8)

N,*N*-Dimethylformamide (Aldrich, 99.8%, 319937)

DMSO (Aldrich, 99%, 67-68-5)

NaOH (Penta, 1310-73-2)

4-(Dimethylamino)benzaldehyde (ACS reagent, 99%, 156477 or Aldrich, 99%, 100-10-7)

2-(Methylthio)benzo[*d*]thiazole (Sigma-Aldrich, 97%, 168653, CAS No. 615-22-5)

Piperidine (ReagentPlus®, Sigma-Aldrich, 99%, 10409-4)

Pyrrolidine (99%, Aldrich, P73803)

Ethanol (Merck, ≥ 99.9%, K42555180)

Acetone, CH_2Cl_2, Et_2O, ethanol, 2-propanol, EtOAc, and MeOH were purchased from PENTA, Czech Republic (www.pentachemicals.eu).

Ethanol (Merck, Uvasol®, 100980)

Acetone-*d6* (Merck, 99.9%, 100021)

DMSO-*d6* (Euriso-Top, C.E. Saclay, H_2O<0.02%, 99.80% D, D010H Z0331, 100 mL; with 4 Å molecular sieves added)

$CDCl_3$ (Merck, 99.8%, 102450)

Acetonitrile-d_3 (water < 0.05%, Euriso-Top, D021P)

Methanol-d_4 (99.8 atom% D, Aldrich, 151947)

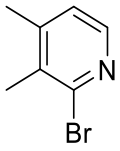
CaH_2 (Alfa Aesar, coarse powder, 7789-78-8)

Universal pH paper strips for pH 0-12 (Lachner)

MeOH for ECD measurements (Lachner)

Synthesis of 2-bromo-3,4,-dimethylpyridine (8) [CAS No. 33204-85-2]:[15,16]

Powdered 2-amino-3,4-dimethylpyridine (5.80 g, 47.4 mmol) was added under vigorous stirring in portions to aqueous 48% HBr solution (30 mL) at 20 to 30 °C in 500 mL three neck round bottom flask. After all of compound was dissolved the mixture was cooled to -20 °C. To this suspension pre-cooled bromine (11.38 g, 3.66 mL, 142 mmol, 3 equiv.) was added drop-wise over 30 min maintain the temperature at -20 °C. The resulting paste was stirred for 90 min at this temperature. The sodium nitrite (9.171 g, 133 mmol, 2.8 equiv.) in water (20 mL) was added drop-wise. The reaction mixture was warm to 15 °C and stirred continuous for 2 h. Then the solution cooled to -20 °C and added cooled NaOH (34.18 g, 854 mmol, 18 equiv.) solution (50 mL) drop-wise for 30 min. Then the extracted with ethylacetate (2x200 mL) dried over magnesium sulphate and concentrated under reduced pressure to obtained brown sticky mass. The crude product purified by column chromatography to obtained the 2-bromo-3,4-dimethylpyridine (5.150 g, 27.7mmol, 58%) (eluted with 3:7, ethylacetate:hexane).



(8)

m.p. 39-40°C. ^{1}H NMR (400 MHz, Chlorofom-*d*): δ 2.33 (s, 3H), 2.36 (s, 3H), 7.01 (d, *J* = 4.8 Hz, 1H), 8.05 (d, *J* = 4.8 Hz, 1H).

^{13}C NMR (100 MHz, Chloroform-*d*): δ 18.55, 20.90, 124.83, 133.84, 145.25, 146.79, 148.50.

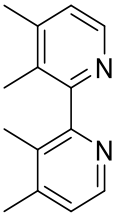
IR (KBr): υ (cm^{-1}) 508, 537, 620, 730, 799, 837, 988, 1018, 1089, 1170, 1201, 1235, 1368, 1381, 1455, 1548, 1583, 1637, 2860, 2923, 2952, 2980, 3012, 3050, 3434.

MS (ESI) m/z (%): 187 (95), 185 (98), 107 (10), 106 (100), 79 (25), 77 (20).

HRMS (ESI) m/z: $[(M-2)]^{+}$ (C_7H_8BrN-2) calc.184.9840:, found 184.9836.

Synthesis of 3,3',4,4'-tetramethyl-2,2'-bipyridine (4) [CAS No. 865074-48-2]:[16]

Zinc powder (1.7524 g, 26.8 mmol, 1 equiv.) was added to a stirred, deep blue solution of nickel(II)chloride hexahydrate ($NiCl_2 \cdot 6H_2O$, 6.3877 g, 26.8 mmol, 1 equiv.) and triphenylphosphine (28.1688 g, 107.4 mmol, 4 equiv.) in dimethylformamide (160 mL) under argon atmosphere at 50 °C. After 2 h, the color of the mixture changed to red brown and the solution of 2-bromo-3,4-dimethylpyridine (5.00 g, 26.8 mmol) in dried dimethylformamide (40 mL) was added under argon atmosphere. After stirring at 50 °C for 24 h, the progress of the reaction was monitored by TLC analysis. After completion of the reaction mixture was poured into dilute ammonia solution and stirred under a stream of air for an additional 30 min until the mixture turned blue and the solid was precipitate out. The reaction mixture was extracted by CH_2Cl_2 (2x400 mL), the organic layer was washed with water, brine and dried over $MgSO_4$ and chromatographed through a silica gel column chromatography. After large amounts of triphenylphosphine (eluted with 2:8, ethylacetate:hexane) and a small amount of triphenylphosphine oxide (eluted with 1:1, ethylacetate:hexane), the 3,3',4,4'-tetramethyl-2,2'-bipyridine **4** (2.058 g, 9.69 mmol, 86%) (eluted with 2:8, MeOH:EtOAc) were obtained.



(4)

m.p. 112-114°C. ^{1}H NMR (400 MHz, Acetonitrile-*d*$_3$): δ 1.95 (s, 6H), 2.34 (s, 6H), 7.17 (d, *J* = 4.8 Hz, 2H), 8.29 (d, *J* = 5.2 Hz, 2H).

^{13}C NMR (100 MHz, Acetonitrile-*d*$_3$): δ 15.10, 19.82, 125.09, 131.43, 146.88, 147.80, 159.10.

IR (KBr): υ (cm^{-1}) 510, 589, 830, 840, 986, 1014, 1084, 1192, 1234, 1368, 1382, 1452, 1554, 1581, 1665, 1918, 2466, 2990, 3053.

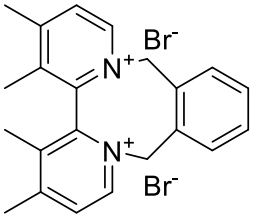
MS (ESI) m/z (%): 213 (100), 214 (30).

HRMS (ESI) m/z: [(M)] ($C_{14}H_{17}N_2$) calc.212.1313:, found 212.1315.

Elem. Anal. calc. for $C_{14}H_{16}N_2$•0.5H_2O: C, 75.98; H, 7.74; N, 12.66. Found: C, 75.61; H, 7.75; N, 12.41.

Synthesis of 1,2,15,16-tetramethyl-6,11-dihydrobenzo[*f*]dipyrido[1,2-*a*:2',1'-*c*][1,4]diazocine-5,12-diium bromide, [*rac*-7][Br]$_2$:

In a sealed tube 3,3',4,4'-tetramethyl-2,2'-bipyridine (**4)** (1.00 g, 4.71 mmol) and α,α-dibromo-*o*-xylene (1.3677 g, 5.18 mmol, 1.1 equiv.) was added in the dried acetonitrile (30 mL) under argon atmosphere. The reaction mixture was heated to 110 °C for 72 h with continuous stirring under argon atmosphere. The progress of the reaction was monitored by TLC analysis. After the completion of the reaction, reaction mixture was cooled to room temperature and Et_2O (50 mL) for the complete precipitation sonicated, centrifuged the reaction mixture and decants the solvent. The white solid was washed with CH_3CN (2x25 mL) sonicated, centrifuged and decant the solution. Then the solid was washed with Et_2O (3x50 mL) sonicated, centrifuged and decant the solution. The solid was dried under vacuum to obtained white solid (1.8983 g, 3.98 mmol, 84%) as product **[*rac*-7][Br]$_2$**.



[*rac*-7][Br]$_2$

m.p. 319-320°C. ^{1}H NMR (500 MHz, DMSO-*d*$_6$): δ 2.28 (s, 6H), 2.68 (s, 6H), 5.41 (d, *J* = 15.9 Hz, 2H), 5.86 (d, *J* = 15.9 Hz, 2H), 7.51-7.56 (m, 2H), 7.60-7.65 (m, 2H), 8.35 (bd, *J* = 6.3 Hz, 2H), 9.30 (d, *J* = 6.3 Hz, 2H).

^{13}C NMR (125.7 MHz, DMSO-*d*$_6$): δ 16.11, 21.12, 60.88, 129.84, 130.89, 131.00, 131.98, 138.92, 140.68, 145.38, 161.73.

IR (KBr): υ (cm^{-1}) 436, 521, 590, 599, 639, 727, 746, 767, 805, 846, 873, 936, 965, 976, 1023, 1058, 1161, 1172, 1226, 1259, 1289, 1327, 1380, 1392, 1453, 1463, 1481, 1498, 1569, 1614, 1637, 1960, 2044, 2740, 2877, 2966, 2994, 3024, 3254, 3400, 3456.

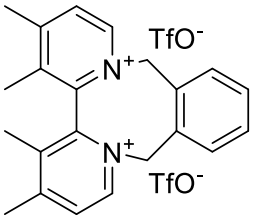
MS (ESI) m/z (%): 316 (25), 315 (100), 213 (40).

HRMS (ESI) m/z: [(M-Br_2)] ($C_{22}H_{23}N_2$) calc.315.18558:, found 315.18540.

Elem. Anal. calc. for $C_{22}H_{24}Br_2N_2$: C, 55.48; H, 5.08; Br, 33.56; N, 5.88. Found: C, 54.90; H, 5.05; Br, 33.56; N, 5.60.

Synthesis of 1,2,15,16-tetramethyl-6,11-dihydrobenzo[*f*]dipyrido[1,2-*a*:2',1'-*c*][1,4]diazocine-5,12-diium trifluoromethanesulfonate, [*rac*-7][TfO]$_2$:

A mixture of TfOH:Et_2O 1:50 (25 mL) was added to solution of diquat **[*rac*-7][Br]$_2$** (0.200 g, 0.419 mmol) in MeOH (2 mL) and then the mixture sonicated for 10 min. Then centrifuged the suspension and decanted the solvent and repeated the same procedure again one more time to obtained beige powder. Then the solid was suspended in Et_2O (25 mL) sonicated, centrifuged and decanted the solvent and repeated again this procedure one more time to obtained off-white solid (0.230 g, 0.374 mmol, 89%) as a product **[*rac*-7][TfO]$_2$**.



[*rac*-7][TfO]$_2$

m.p. 267-268°C. ^{1}H NMR (400 MHz, DMSO-d_6): δ 2.27 (s, 6H), 2.67 (s, 6H), 5.38 (d, *J* = 15.6 Hz, 2H), 5.76 (d, *J* = 16.4 Hz, 2H), 7.52-7.60 (m, 4H), 8.33 (d, *J* = 6.4 Hz, 2H), 9.20 (d, *J* = 6.4 Hz, 2H).

^{19}F NMR (400 MHz, DMSO-d_6): δ 77.75.

^{13}C NMR (100 MHz, DMSO-d_6): δ 16.01, 21.07, 61.02, 119.06, 122.26, 129.90, 130.92, 130.99, 131.93, 138.89, 140.68, 145.42, 161.74.

IR (KBr): υ (cm^{-1}) 458, 518, 574, 638, 727, 748, 769, 805, 844, 937, 974, 1031, 1166, 1227, 1260, 1274, 1327, 1392, 1464, 1482, 1617, 2739, 2928, 2967, 3018, 3452.

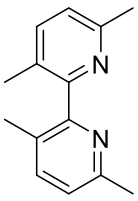
MS (ESI) m/z (%): 315 (15), 158 (100).

HRMS (ESI) m/z: [(M-TfO)] ($C_{23}H_{24}O_3N_2F_3S$) calc.465.14542:, found 465.14508.

Elem. Anal. calc. for $C_{24}H_{24}F_6N_2O_6S_2$: C, 46.90; H, 3.94; N, 4.56. Found: C, 46.70; H, 3.84; N, 4.42.

Synthesis of 3,3',6,6'-tetramethyl-2,2'-bipyridine (10):

Zinc powder (1.3849 g, 21.18 mmol) was added to a stirred, deep blue solution of nickel(II)chloride hexahydrate ($NiCl_2$·$6H_2O$, 5.036 g, 21.18 mmol) and triphenylphosphane (22.220 g, 84.72 mmol) in dry DMF (100 mL) under argon atmosphere at 50 °C. After 2 h, the colour of the mixture changed to red brown and then 2-chloro-3,6-dimethylpyridine (3.00 g, 21.18 mmol) was added under argon atmosphere. After stirring at 50 °C for 24 h, the progress of the reaction was monitored by TLC analysis. After completion of the reaction mixture was poured into dilute ammonia solution and stirred under a stream of air for an additional 30 min until the mixture turned blue and the solid was precipitate out. The reaction mixture was extracted by CH_2Cl_2 (2 x 500 mL), the organic layer was washed with water, brine and dried over Na_2CO_3 and chromatographed through a silica gel column chromatography. After large amounts of triphenylphosphine (eluted with 2:8, EtOAc:CH_2Cl_2) and a small amount of triphenylphosphine oxide (eluted with 1:1, EtOAc:CH_2Cl_2), the 3,3',6,6'-tetramethyl-2,2'-bipyridine (1.844 g, 8.68 mmol, 82%) (eluted with EtOAc) were obtained as viscous pale yellow oil.



(10)

^{1}H NMR (400 MHz, Chlorofom-*d*): δ 2.07 (s, 6H), 2.55 (s, 6H), 7.08 (d, *J* = 7.6 Hz, 2H), 7.49 (d, *J* = 7.6 Hz, 2H).

^{13}C NMR (100 MHz, Chloroform-d_6): δ 18.07, 24.08, 122.77, 128.41, 138.91, 155.34.

^{1}H NMR (400 MHz, Methanol–d_4): δ 2.03 (s, 6H), 2.52 (s, 6H), 7.29 (d, *J* = 8.0 Hz, 1H), 7.70 (d, *J* = 8.0 Hz, 2H).

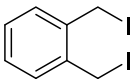
IR (KBr): υ (cm-1) 510, 589, 763, 830, 840, 989, 1014, 1045, 1085, 1192, 1234, 1261, 1368, 1382, 1452, 1554, 1581, 1725, 1918, 2921, 3054.

MS (ESI) m/z (%): 213 (10), 212 (50), 211 (25), 198 (18), 197 (100), 182 (20).

HRMS (ESI) m/z: [(M)] ($C_{14}H_{16}N_2$) calc.212.1313:, found 212.1314.

Synthesis of *α,α*'-diiodo-*o*-xylene (11):

A mixture of *α,α*'-dibromo-*o*-xylene (10.00 g, 38.1 mmol) and NaI (34.33 g, 22.9 mmol) in acetone 200 mL was refluxed for 12 h. After cooling to room temperature then the solvent was removed on rotary evaporator. To the resulting solid water (200 mL) was added and mixture was stirred for 30 min. The resulting precipitated was filtered and was with 10% $Na_2S_2O_3$ solution, water and methanol. The solid was dried in vacuum to afforded the pale yellow solid (12.1110 g, 33.83 mmol).



(11)

m.p. 103-104 °C. ^{1}H NMR (400 MHz, Chloroform–*d*): δ 4.58 (s, 4H), 7.20-7.24 (m, 2H), 7.28-7.33 (m, 2H).

^{13}C NMR (100 MHz, Chloroform–*d*): δ 1.72, 129.00, 130.79, 137.40.

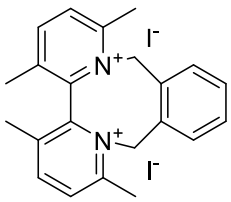
IR (KBr): υ (cm-1) 439, 520, 563, 574, 588, 601, 732, 764, 816, 950, 979, 1054, 1139, 1149, 1159, 1165, 1200, 1224, 1298, 1426, 1453, 1487, 1576, 1599, 1638, 1927, 2969, 3021, 3038, 3058, 3066.

MS (ESI) m/z (%): 358 (25), 254 (80), 231 (100), 127 (25), 104 (40).

HRMS (ESI) m/z: [(M-I)] ($C_{22}H_{24}N_2I$) calc. 357.8716:, found 357.8720.

Synthesis of 1,2,15,16-tetramethyl-6,11-dihydrobenzo[*f*]dipyrido[1,2-*a*:2',1'-*c*][1,4]diazocine-5,12-diium bromide [*rac*-12][I]$_2$:

In a sealed tube 3,3',6,6'-tetramethyl-2,2'-bipyridine (1.84 g, 8.667 mmol) and α,α-diiodo-*o*-xylene (6.204 g, 17.3 mmol) was added in the 1,2-dichlorobenzene (40 mL) under argon atmosphere. The reaction mixture was heated to 120 °C for 72 h with continuous stirring under argon atmosphere. The progress of the reaction was monitored by TLC analysis. After the completion of the reaction, reaction mixture was cooled to room temperature and Et_2O (50 mL) for the complete precipitation sonicated, centrifuged the reaction mixture and decants the solvent. The white solid was washed with CH_3CN (2x5 mL) sonicated, centrifuged and decanted the solution. Then the solid was washed with diethyl ether (2x50 mL) sonicated, centrifuged and decant the solution. The solid was dried under vacuum to obtained yellow solid (2.585 g, 4.533 mmol, 52%) as product.



[*rac*-12][I]$_2$

m.p. decomposed 248-252 °C. ^{1}H NMR (600 MHz, DMSO–*d*$_6$): δ 2.40 (s, 6H), 3.31 (s, 6H), 5.22 (d, *J* = 16.7 Hz, 2H), 5.73 (d, *J* = 16.7 Hz, 2H), 7.55-7.59 (m, 2H), 7.83-7.87 (m, 2H), 8.31 (bd, *J* = 8.4 Hz, 2H), 8.68 (d, *J* = 8.4 Hz, 2H).

^{13}C NMR (151 MHz, DMSO–*d*$_6$): δ 18.04, 20.79, 57.69, 129.79, 130.83, 132.07, 132.80, 136.54, 142.64, 148.37, 157.56.

^{1}H NMR (400 MHz, MeOH–*d*$_4$): δ 2.53 (d, *J* = 7.2 Hz, 6H), 2.96 (d, *J* = 6.8 Hz, 6H), 5.35 (d, *J* = 16.8 Hz, 2H), 5.85 (d, *J* = 16.8 Hz, 2H), 7.60-7.62 (m, 2H), 7.78-7.80 (m, 2H), 8.27 (d, *J* = 8.4 Hz, 2H), 8.66 (d, *J* = 8.4 Hz, 2H).

^{13}C NMR (125.7 MHz, MeOH–*d*$_4$): δ 19.10, 21.84, 59.89, 131.74, 131.76, 133.65, 134.58, 139.04, 144.49, 150.27, 159.81.

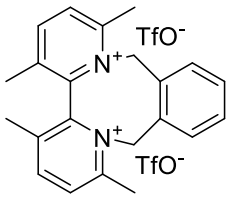
IR (KBr): υ (cm-1) 458, 486, 510, 557, 584, 620, 656, 733, 770, 804, 834, 857, 927, 949, 971, 1030, 1041, 1054, 1131, 1198, 1213, 1237, 1273, 1311, 1342, 1374, 1448, 1476, 1497, 1540, 1570, 1617, 1684, 1719, 2913, 2993, 3021, 3437.

MS (ESI) m/z (%): 315 (20), 158 (100).

HRMS (ESI) m/z: [(M-I)] ($C_{22}H_{24}N_2I$) calc.443.09787:, found 443.09776.

Synthesis of 1,4,13,16-tetramethyl-6,11-dihydrobenzo[*f*]dipyrido[1,2-*a*:2',1'-*c*][1,4]diazocine-5,12-diium trifluoromethanesulfonate [*rac*-12][TfO]$_2$:

To a suspension of diquat (1.50 g, 2.63 mmol) in dry dichloromethane (40 mL) was added dropwise methytrifluromethane sulfonate (1.942 g/1.294 mL, 11.83 mmol) at 0 °C. The mixture was brought to room temperature and left to stir for overnight. The progress of the reaction was monitored by TLC analysis. After completion Et_2O (80 mL) was added for the complete precipitation to obtained white solid. Then the solid was suspended in CH_3CN (10 mL) and repecipitated with Et_2O (50 mL) sonicated, centrifuged and decanted the solvent. This procedure was repeated two more times. Then the Et_2O (50 mL) was added sonicated, centrifuged and decanted the solvent, repeated one more time and the solid pellet was dried under vacuum to obtained beige solid (1.4159 g, 2.30 mmol, 88%) as product.



[*rac*-12][TfO]$_2$

m.p. decomposed (288-294 °C)/ > 315 °C. ^{1}H NMR (600 MHz, DMSO-*d*$_6$): δ 2.38 (s, 6H), 2.85 (s, 6H), 5.21 (d, *J* = 16.7 Hz, 2H), 5.71 (d, *J* = 16.7 Hz, 2H), 7.55-7.59 (m, 2H), 7.81-7.85 (m, 2H), 8.30 (d, *J* = 8.4 Hz, 2H), 8.66 (dq, *J* = 3 x 0.6, 8.4 Hz, 2H). ^{13}C NMR (151 MHz, DMSO-*d*$_6$): δ 17.91, 20.68, 57.63, 129.80, 130.84, 132.06, 132.79, 136.55, 142.63, 148.38, 157.56.

^{19}F NMR (400 MHz, DMSO-*d*$_6$): δ 77.74.

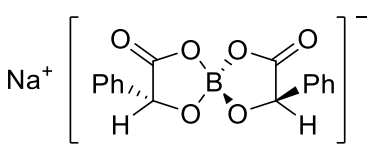
IR (KBr): υ (cm-1): 519, 575, 640, 734, 763, 804, 857, 929, 950, 975, 1032, 1168, 1227, 1262, 1344, 1385, 1449, 1481, 1573, 1621, 2926, 3064, 3435.

MS (ESI) m/z (%): 465 (10), 315 (20), 158 (100).

HRMS (ESI) m/z: [(M-TfO)] ($C_{23}H_{24}O_3N_2F_3S$) calc.465.14542:, found 465.14554. [(M-TfO)+1] ($C_{23}H_{24}O_3N_2F_3S$ +1) calc.466.14542:, found 465.14963.

Synthesis of Na$^+$[B$_s$(*R*-Man)$_2$]$^-$:

(*R*)-(-)-Mandellic acid (1.52 g, 10.0 mmol) was added to an aqueous solution of sodium carbonate (0.265 g, 2.5 mmol) and boric acid (0.309 g, 5.0 mmol) dissolved in distilled water (10 mL). The solution was stirred for 2 h at 60 °C. Then the solvent was evaporated under reduced pressure to obtained white beige powder. The solid was dried under reduced pressure to obtained the white solid Na$^+$[B$_s$(*R*-Man)$_2$]$^-$ (1.5830 g, 4.738 mmol, 95%).



Na+[B$_s$(*R*-Man)$_2$]$^-$

$[a]_D^{20}$ = -111.5 (*c* 0.294, H_2O). m.p. 318-320 °C. ^{1}H-NMR (400 MHz, DMSO-*d*$_6$): δ 5.13 (s, 2H), 7.25-7.29 (m, 2H), 7.32-7.37 (m, 4H), 7.46-7.49 (m, 4H).

^{13}C NMR (100 MHz, DMSO-*d*$_6$): δ 77.24, 126.08, 126.16, 127.18, 127.90, 140.46, 176.57.

^{11}B NMR (400 MHz, DMSO-*d*$_6$): δ 11.14.

IR (KBr): υ (cm-1) 462, 486, 520, 540, 606, 616, 650, 697, 709, 738, 769, 862, 941, 985, 1027, 1053, 1116, 1201, 1255, 1294, 1311, 1349, 1454, 1496, 1590, 1603, 1622, 1736, 2909, 3034, 3065, 3090, 3438.

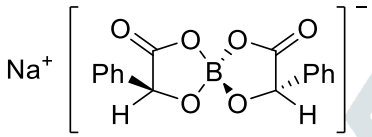
MS (ESI) m/z (%): 847 (10), 673 (22), 499 (32), 493 (18), 326 (20), 325 990), 311 (100), 310 (34).

HRMS (ESI) m/z: [(M-Na)] ($C_{16}H_{12}O_6B$) calc. 311.07324:, found 311.07333.

Elem. Anal. calc. for $C_{16}H_{12}BNaO_6$•$1.25H_2O$ ($C_{16}H_{14.5}BNaO_{7.25}$): C, 53.89; H, 4.10. Found: C, 53.74; H, 3.91.

Synthesis of $Na^+[B_R(S\text{-Man})_2]^-$:

(*S*)-(+)-Mandelic acid (1.52 g, 10.0 mmol) was added to an aqueous solution of sodium carbonate (0.265 g, 2.5 mmol) and boric acid (0.309 g, 5.0 mmol) dissolved in distilled water (10 mL). The solution was stirred for 2 h at 60 °C. Then the solvent was evaporated under reduced pressure to obtained white beige powder. The solid was dried under reduced pressure to obtained the white solid $Na^+[B_R(S\text{-Man})_2]^-$ (1.5103 g, 4.521 mmol, 94%).



Na+[B_R(*S*-Man)$_2$]$^-$

HT-820: $[a]_D^{20}$ = +113.2 (*c* 0.301, H_2O). m.p. 318-320 °C. ^{1}H-NMR (400 MHz, DMSO-*d*$_6$): δ 5.13 (bs, 2H), 7.25-7.29 (m, 2H), 7.32-7.37 (m, 4H), 7.46-7.49 (m, 4H).

^{13}C NMR (100 MHz, DMSO-*d*$_6$): δ 77.25, 126.08, 127.19, 127.91, 140.46, 176.58.

^{11}B NMR (400 MHz, DMSO-*d*$_6$): δ 11.25.

IR (KBr): υ (cm-1) 462, 486, 520, 539, 606, 616, 650, 697, 709, 738, 769, 832, 862, 941, 984, 1027, 1054, 1116, 1201, 1256, 1294, 1311, 1349, 1454, 1496, 1590, 1604, 1619, 1736, 2915, 3033, 3065, 3090, 3439.

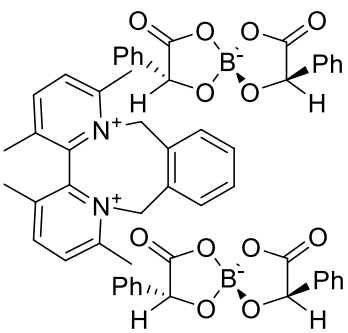
MS (ESI) m/z (%): 673 (18), 499 (24), 493 (10), 326 (20), 325 (100), 311 (40).

HRMS (ESI) m/z: [(M-Na)] ($C_{16}H_{12}O_6B$) calc. 311.07324:, found 311.07333.

Elem. Anal. calc. for $C_{16}H_{12}BNaO_6$•$1.25H_2O$ ($C_{16}H_{14.5}BNaO_{7.25}$): C, 53.89; H, 4.10. Found: C, 53.96; H, 4.03.

Resolution of [*rac*-12][TfO]$_2$ by direct precipitation method with $Na^+[B_s(R\text{-Man})_2]^-$:

A solution of $Na^+[B_s(R\text{-Man})_2]$ (0.652 g, 1.952 mmol) and tetramethyldiquat [*rac*-12][TfO]$_2$ (0.500 g, 0.813 mmol) in methanol (20 mL) was stirred overnight at room temperature. Then the methanol was evaporated to obtain the white solid as a mixture of diastereomers (1.078 g, 93.57%). Then the solid was suspended in ethanol (3 mL) sonicated, centrifuged and decanted the solid. This procedure repeated three more times with ethanol (3 mL) sonicated, centrifuged and decanted the solvent. Then the solid was dried under reduced pressure to obtained beige powder as **[(-)-(S_a/*P*)-12][B_s(*R*-Man)$_2$]$_2$** (0.1928 g, 0.205 mmol, 25.24%, 96.1% *de*, CE). The washings (ethanol) were combined and remove the volatilities on rotary evaporator under reduced pressure to obtain beige powder as enantioenriched **[(+)-(*Ra*/*M*)-12] [B_s(*R*-Man)$_2$]$_2$** (0.352 g, 47.28% *de*, CE) with excess of $Na^+[B_s(R\text{-Man})_2]$ and NaOTf.



[(±)-12][B$_s$(*R*-Man)$_2$]$_2$

m.p. 249-251 °C. ^{1}H NMR (400 MHz, DMSO-*d*$_6$): δ 2.37 (s, 6H), 2.84 (s, 6H), 5.12 (s, 4H), 5.20 (d, *J* = 16.8 Hz, 2H), 5.71 (d, *J* = 16.8 Hz, 2H), 7.18-7.58 (m, 20H), 7.55-7.58 (m, 2H), 7.81-7.84 (m, 2H), 8.29 (d, *J* = 8.4 Hz, 2H), 8.65 (d, *J* = 8.4 Hz, 2H).

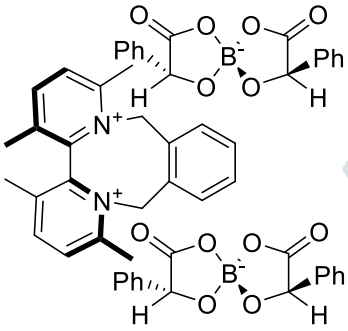
^{11}B NMR (400 MHz, DMSO-*d*$_6$): δ 11.20.

IR (KBr): υ (cm^{-1}) 487, 519, 578, 604, 617, 641, 698, 738, 762, 836, 863, 949, 1002, 1034, 1110, 1177, 1259, 1352, 1384, 1452, 1479, 1496, 1618, 1740, 2929, 2978, 3033, 3064, 3088, 3434.

MS (ESI) m/z (%): 628 (08), 627 (20), 316 (27), 315 (100).

HRMS (ESI) m/z: [(M)]$^+$ ($C_{38}H_{36}N_2O_6B$) calc. 627.26609:, found 627.26626.

HRMS (ESI) m/z: z = 2 [(M/2)]$^+$ ($C_{22}H_{24}N_2$/2) calc. 158.09643:, found 158.09643.



[(-)-(*S*$_a$/*P*)-12][B$_s$(*R*-Man)$_2$]$_2$

[(-)-(*S*$_a$/*P*)-12][B$_s$(*R*-Man)$_2$]$_2$:

$[a]_D^{20}$ = -221.1 (*c* 0.236, DMSO). $[a]_D^{20}$ = -243.2 (*c* 0.314, MeOH).

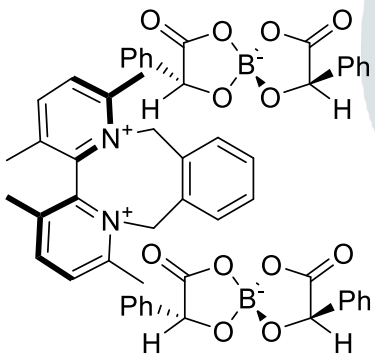
m.p. 256-260 °C.

IR (KBr): υ (cm^{-1}) 488, 517, 602, 616, 657, 697, 711, 735, 759, 767, 804, 828, 859, 930, 949, 962, 1029, 1061, 1109, 1176, 1197, 1276, 1349, 1384, 1453, 1496, 1574, 1617, 1744, 2889, 2928, 3008, 3030, 3061, 3085, 3438.

MS (ESI) m/z (%): 628 (15), 627 (40), 626 (10), 316 (25), 315 (100).

HRMS (ESI) m/z: [(M)]$^+$ ($C_{38}H_{36}N_2O_6B$) calc. 627.26609:, found 627.26630.

HRMS (ESI) m/z: z = 2 [(M/2)]$^+$ ($C_{22}H_{24}N_2$/2) calc. 158.09643:, found 158.09650.



enantioenriched

[(+)-(*R*$_a$/*M*)-12][B$_s$(*R*-Man)$_2$]$_2$

[(+)-(*Ra*/*M*)-12] [B$_s$(*R*-Man)$_2$]$_2$:

$[a]_D^{20}$ = -18.1 (*c* 0.270, DMSO). $[a]_D^{20}$ = -26.8 (*c* 0.358, MeOH).

m.p. 165-169 °C.

IR (KBr): υ (cm^{-1}) 519, 580, 606, 618, 643, 698, 737, 762, 836, 862, 948, 987, 1003, 1036, 1112, 1177, 1232, 1257, 1384, 1452, 1496, 1586, 1604, 1619, 1706, 1723, 2927, 2975, 3035, 3066, 3090, 3434.

MS (ESI) m/z (%): 637 (08), 627 (12), 465 (08), 316 (28), 315 (100), 269 (12).

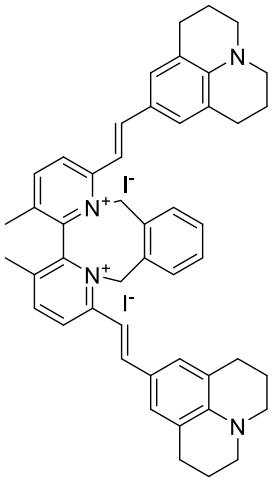
HRMS (ESI) m/z: [(M)]$^+$ ($C_{38}H_{36}N_2O_6B$) calc. 627.26609:, found 627.26638.

HRMS (ESI) m/z: z = 2 [(M/2)]$^+$ ($C_{22}H_{24}N_2$/2) calc. 158.09643:, found 158.09649.

Synthesis of 1,16-dimethyl-4,13-bis((*E*)-2-(2,3,6,7-tetrahydro-1*H*,5*H*-pyrido[3,2,1-*ij*]quinolin-9-yl)-vinyl)-6,11-dihydrobenzo[*f*]dipyrido[1,2-*a*:2',1'-*c*][1,4]diazocine-5,12-diium iodide [*rac*-13][I]$_2$:

In a sealed tube the diquat **[*rac*-12][I]$_2$** (0.030 g, 0.0528 mmol) and 9-julolidinecarboxaldehyde (0.1588 g, 0.0789 mmol) was taken and dry MeOH (1.0 mL) was added under argon atmosphere. The reaction mixture was heated at 70 °C for 48 h under argon atmosphere with stirring. The progress of the reaction was monitored by TLC analysis. After completion of the reaction, reaction mixture was cooled to room temperature and Et_2O (10 mL) was added for the complete precipitation of the product. The mixture

was sonicated, centrifuged and decanted the solvent to obtain purple colour solid. Then the solid was dissolved in MeOH (1.0 mL) sonicated and added the Et_2O (10 mL) again sonicated, centrifuged and decanted the solvent. This procedure repeated two more times with MeOH as well as with CH_3CN:Et_2O (1.0 mL:10 mL). Then washed the solid with Et_2O (2x10 mL) and dried under reduced pressure to obtained blue solid (0.0402 g = 40.2 mg, 0.0429 mmol, 82%) as product.



[*rac*-13][I]$_2$

m.p. 226-229 °C. ^{1}H NMR (600 MHz, DMSO-*d*$_6$): δ 1.87-1.93 (m, 8H), 2.37 (s, 6H), 2.70-2.78 (m, 8H), 3.30-3.34 (m, 8H), 5.19 (d, *J* = 16.7 Hz, 2H), 5.87 (d, *J* = 16.7 Hz, 2H), 7.13 (d, *J* = 15.3 Hz, 2H), 7.22 (s, 4H), 7.53-7.58 (m, 2H), 7.93 (d, *J* = 15.3 Hz, 2H), 8.08-8.13 (m, 2H), 8.36 (d, *J* = 9.0 Hz, 2H), 8.63 (d, *J* = 9.0 Hz, 2H).

^{13}C NMR (151 MHz, DMSO-*d*$_6$): δ 17.86, 20.66, 26.97, 49.29, 55.56, 107.95, 120.78, 120.99, 126.14, 128.75, 129.38, 131.23, 132.62, 132.66, 141.03, 144.74, 146.28, 146.58, 153.90.

^{1}H NMR (400 MHz, MeOH–*d*$_4$): δ 1.95-2.01 (m, 8H), 2.43 (s, 6H), 2.77-2.80 (m, 8H), 3.35-3.39 (m 8H), 5.27 (d, *J* = 16.0 Hz, 2H), 5.79 (d, *J* = 16.0 Hz, 2H), 7.085 (d, *J* = 12.0 Hz, 2H), 7.18 (s, 4H), 7.63-7.65 (m, 2H), 7.87 (d, *J* = 16.0 Hz, 2H), 7.94-7.96 (m, 2H), 8.225 (d, *J* = 12.0 Hz, 2H), 8.515 (d, *J* = 12.0 Hz, 2H).

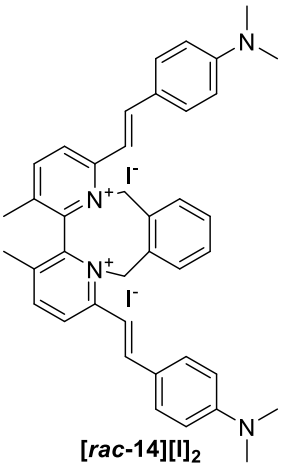
IR (KBr): υ (cm^{-1}): 412, 466, 533, 886, 929, 989, 1081, 1153, 1232, 1251, 1299, 1450, 1492, 1523, 1633, 2343, 2931, 3437.

MS (ESI) m/z (%): 809 (10), 341 (100).

HRMS (ESI) m/z: [(M-I)] ($C_{48}H_{50}IN_4$) calc. 809.30747:, found 809.30781; [(M-I)+1] ($C_{48}H_{50}IN_4$+1) calc. 810.30747:, found 810.31105; [(M-I)+2] ($C_{48}H_{50}IN_4$+2) calc. 811.30747:, found 811.31425.

Synthesis of 4,13-bis((*E*)-4-(dimethylamino)styryl)-1,16-dimethyl-6,11-dihydrobenzo[*f*]dipyrido[1,2-*a*:2',1'-*c*][1,4]diazocine-5,12-diium iodide [*rac*-14][I]$_2$:

In a sealed tube the diquat **[*rac*-12][I]$_2$** (0.030 g, 0.0528 mmol) and *N*,*N*-dimethyl-*p*-aminobenzaldehyde (0.1177 g, 0.0789 mmol) was taken and dry MeOH (1.0 mL) was added under argon atmosphere. The reaction mixture was heated at 70 °C for 72 h under argon atmosphere with stirring. The progress of the reaction was monitored by TLC analysis. After completion of the reaction, reaction mixture was cooled to room temperature and Et_2O (10 mL) was added for the complete precipitation of the product. The mixture was sonicated, centrifuged and decanted the solvent to obtain blue colour solid. Then the solid was dissolved in MeOH (1.0 mL) sonicated and added the Et_2O (10 mL) again sonicated, centrifuged and decanted the solvent. This procedure repeated two more times with methanol as well as with CH_3CN: Et_2O (1.0 mL:10 mL). Then washed the solid with Et_2O (2x10 mL) and dried under reduced pressure to obtained blue solid (0.250 g = 25.0 mg, 0.030 mmol, 57%) as product.


[*rac*-14][I]$_2$

m.p. 242-244 °C. ^{1}H NMR (600 MHz, DMSO-*d*$_6$): δ 2.39 (s, 6H), 3.06 (s, 12H), 5.22 (d, *J* = 16.7 Hz, 2H), 5.99 (d, *J* = 16.7 Hz, 2H), 6.80-6.84 (m, 4H), 7.32 (d, *J* = 15.4 Hz, 2H), 7.51-7.55 (m, 2H), 7.67-7.72 (m, 4H), 8.05 (d, *J* = 15.4 Hz, 2H), 8.07-8.11 (m , 2H), 8.47 (d, *J* = 9.0 Hz, 2H), 8.71 (d, *J* = 9.0 Hz, 2H).

^{13}C NMR (151 MHz, DMSO-*d*$_6$): δ 18.03, 39.50, 55.79, 109.82, 111.96, 122.07, 126.80, 129.60, 131.24, 131.27, 132.66, 133.77, 144.44, 145.56, 146.45, 152.60, 154.18.

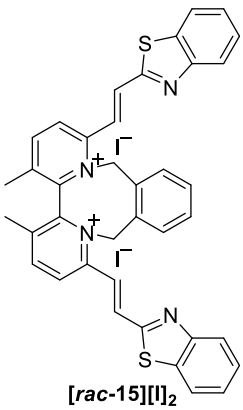
IR (KBr): υ (cm^{-1}): 489, 512, 535, 581, 627, 728, 748, 812, 825, 875, 929, 943, 1121, 1158, 1187, 1226, 1284, 1299, 1322, 1372, 1438, 1491, 1528, 1578, 1612, 2805, 2855, 2906, 2988, 3028, 3436.

MS (ESI) m/z (%): 705 (35), 289 (100).

HRMS (ESI) m/z: [(M-I)] ($C_{40}H_{42}IN_4$) calc.705.24487:, found 705.24487; [(M-I)+1] ($C_{40}H_{42}IN_4$+1) calc.706.24487:, found 706.24813; [(M-I)+2] ($C_{40}H_{42}IN_4$+2) calc.707.24487:, found 707.25134.

Synthesis of 4,13-bis((*E*)-2-(benzo[*d*]thiazol-2-yl)vinyl)-1,16-dimethyl-6,11-dihydrobenzo[*f*]dipyrido-[1,2-*a*:2',1'-*c*][1,4]diazocine-5,12-diium iodide [*rac*-15][I]$_2$:

In a sealed tube the diquat **[*rac*-12][I]$_2$** (0.030 g, 0.053 mmol) and Benzothiazole-2-carboxaldehyde (0.129 g, 0.789 mmol) was taken and dry MeOH (1.5 mL) was added under argon atmosphere. The reaction mixture was heated at 70 °C for 72 h under argon atmosphere with stirring. The progress of the reaction was monitored by TLC analysis. After completion of the reaction, reaction mixture was cooled to room temperature and Et_2O (10 mL) was added for the complete precipitation of the product. The mixture was sonicated, centrifuged and decanted the solvent to obtain purple colour solid. Then the solid was dissolved in MeOH (1.0 mL) sonicated and added the Et_2O (10 mL) again sonicated, centrifuged and decanted the solvent. This procedure repeated two more times with methanol as well as with CH_3CN: Et_2O (1 mL:10 mL). Then washed the solid with Et_2O (2x10 mL) and dried under reduced pressure to obtained solid (0.0214 g = 21.4 mg, 00.0248 mmol, 47%) as product.


[*rac*-15][I]$_2$

^{1}H NMR (600 MHz, DMSO-*d*$_6$): δ 2.53 (s, 6H), 5.43 (d, *J* = 16.9 Hz, 2H), 6.20 (d, *J* = 16.9 Hz, 2H), 7.59 (ddd, *J* = 1.3, 7.2, 8.3 Hz, 2H), 7.61-7.65 (m, 2H), 7.64 (ddd, *J* = 1.3, 7.2, 8.2 Hz, 2H), 8.01-8.05 (m, 2H), 8.05 (d, *J* = 15.6 Hz, 2H), 8.16 (ddd, *J* = 0.7, 1.3, 8.2 Hz, 2H), 8.28 (d, *J* = 15.6 Hz, 2H), 8.28 (ddd, *J* = 0.7, 1.3, 8.3 Hz, 2H), 8.85 (d, *J* = 8.7 Hz, 2H), 8.94 (d, *J* = 8.7 Hz, 2H).

^{13}C NMR (125.7 MHz, DMSO-*d*$_6$): δ 18.45, 57.64, 122.73, 123.76, 124.81, 127.09, 127.35, 129.72, 130.13, 131.26, 132.07, 135.23, 136.05, 138.44, 142.56, 148.46, 152.16, 153.35, 163.48.

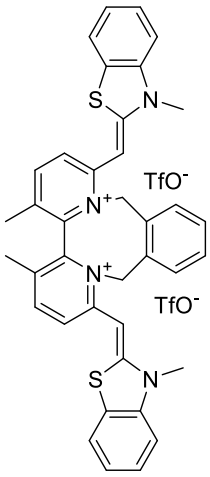
IR (KBr): υ (cm^{-1}): 435, 443, 466, 571, 583, 595, 668, 707, 731, 765, 829, 868, 917, 930, 953, 986, 1016, 1038, 1118, 1180, 1192, 1214, 1243, 1262, 1287, 1315, 1384, 1424, 1455, 1475, 1497, 1559, 1607, 1624, 2342, 3052, 3437.

MS (ESI$^+$) m/z (%): 734 (50), 733 (100), 606 (40)353 (30).

HRMS (ESI$^+$) m/z: [(M-I)] ($C_{38}H_{30}IN_4S_2$) calc. 733.09511:, found 733.09533:, [(M-I)+1] ($C_{38}H_{30}IN_4S_2$) calc. 734.09511:, found 734.09874.

Synthesis of 1,16-dimethyl-4,13-bis((*Z*)-(3-methylbenzo[*d*]thiazol-2(3*H*)-ylidene)methyl)-6,11-dihydro-benzo[*f*]dipyrido[1,2-*a*:2',1'-*c*][1,4]diazocine-5,12-diium trifluoromethanesulfonate [*rac*-16][OTf]$_2$:

Racemic diquat **[*rac*-12][OTf]$_2$** and benzothiazolium triflate salt (8.13 equiv.) were placed in a 10 mL glass-vial equipped with a stirring bar and a teflon cap. The mixture was dissolved in CH_3CN (0.5 mL) and then Et_3N (8.13 equiv.) was added. The resulting mixture was stirred for 2 h at RT while protected from ambient light using aluminum foil cover. A color change to red was observed immediately after the Et_3N was added. Progress of the reaction was monitored by TLC (mobile phase Stoddart's magic mixture). After the indicated time, crude product was precipitated from the reaction mixture by addition of Et_2O (8 mL). The suspension was sonicated, centrifuged, and the liquids were separated from the solid pellet. To remove the excess of benzothiazolium triflate salt, a solution of CH_3CN:piperidine (60:40, 0.5 mL) was added to the solid pellets. The resulting emulsion was sonicated for 30 seconds, and then Et_2O (8 mL) was added. The resulting suspension was sonicated, centrifuged, and the liquid was separated from the solid pellet. The addition of CH_3CN:piperidine solution (60:40, 0.5 mL), sonication, centrifugation, and decantation procedure was repeated six more times until the absence of the starting benzothiazolium triflate salt (monitored by TLC). Finally, Et_2O (8 mL) was added to the solid and the suspension was sonicated and then centrifuged. Removal of the liquid, and drying of the solid under vacuum of an oil pump (3.0 mbar) led to pure dye products. Compound [*rac*-16][OTf]$_2$ was isolated as a light-red solid (0.014 g, 0.015 mmol, 92% yield) from diquat (0.010 g, 0.0163 mmol) and benzothiazol triflate salt (0.045 g, 0.130 mmol), with addition of Et_3N (18 μL, 0.130 mmol) and following the procedure described above.



[*rac*-16][OTf]$_2$

m.p. 300-305 °C. ^{1}H NMR (400 MHz, DMSO-*d*$_6$): δ 2.30 (s, 6H), 3.75 (s, 6H), 5.18 (d, *J* = 16.8 Hz, 2H), 5.51 (d, *J* = 16.8 Hz, 2H), 5.86 (s, 2H), 7.38 (t, *J* = 8.0 Hz, 2H), 7.55-7.62 (m, 4H), 7.73 (d, *J* = 8.4 Hz, 2H), 7.98 (d, *J* = 8.0 Hz, 2H), 8.07-8.09 (m, 2H), 8.12 (d, *J* = 9.2 Hz, 2H), 8.18 (d, *J* = 9.2 Hz, 2H).

^{13}C NMR (101 MHz, DMSO-*d*$_6$): δ 17.78, 33.39, 55.25, 83.06, 112.65, 122.84, 122.94, 123.43, 124.37, 127.15, 128.01, 129.44, 132.01, 132.51, 140.60, 141.03, 143.76, 151.39, 159.32.

IR (KBr): υ (cm^{-1}) 450, 508, 517, 540, 581, 636, 715, 751, 801, 820, 859, 892, 932, 952, 976, 1028, 1066, 1101, 1166, 1190, 1232, 1273, 1318, 1371, 1476, 1503, 1589, 1626, 3011, 3068.

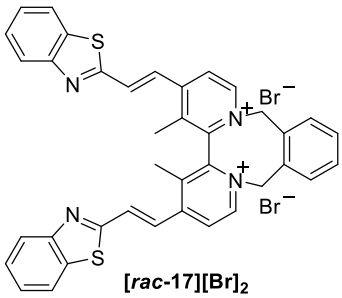
MS (ESI) m/z (%): 760 (10), 759 (20), 305 (100).

HRMS (ESI) m/z: [(M-TfO)] ($C_{39}H_{34}N_4O_3F_3S_3$) calc. 759.17396,; found 759.17410.

Synthesis of 2,15-bis((*E*)-2-(benzo[d]thiazol-2-yl)vinyl)-1,16-dimethyl-6,11-dihydrobenzo[*f*]dipyrido-[1,2-*a*:2',1'-*c*][1,4]diazocine-5,12-diium bromide [*rac*-17][Br]$_2$:

In a sealed tube the diquat **[*rac*-7][Br]$_2$** (0.030 g, 0.063 mmol) and Benzothiazole-2-carboxaldehyde (0.150 g, 0.9448 mmol) was taken and dry MeOH (1.5 mL) was added under argon atmosphere. The reaction mixture was heated at 70 °C for 72 h under argon atmosphere with stirring. The progress of the reaction was monitored by TLC analysis. After completion of the reaction, reaction mixture was cooled to room temperature and Et_2O (10 mL) was added for the complete precipitation of the product. The mixture was sonicated, centrifuged and decanted the solvent to obtain purple colour solid. Then the solid was dissolved

in MeOH (1.0 mL) sonicated and added the Et_2O (10 mL) again sonicated, centrifuged and decanted the solvent. This procedure repeated two more times with MeOH as well as with CH_3CN: Et_2O (1 mL:10 mL). Then washed the solid with Et_2O (2x10 mL) and dried under reduced pressure to obtained solid (0.295 g = 29.50 mg) as product.



[*rac*-17][Br]$_2$

^{1}H NMR (400 MHz, MeOH-d_4): δ 2.68 (s, 6H), 5.61 (d, J = 15.6 Hz, 2H), 5.91 (d, J = 15.6 Hz, 2H), 7.54-7.68 (m, 12 H), 8.05-8.13 (m, 6H), 8.23 (d, J = 16.0 Hz, 2H), 8.83 (d, J = 6.4 Hz, 2H), 9.32 (d, J = 6.8 Hz, 2H).

IR (KBr): υ (cm^{-1}): 438, 580, 708, 732, 765, 873, 918, 954, 974, 1015, 1117, 1166, 1223, 1290, 1317, 1334, 1381, 1453, 1481, 1555, 1605, 2343, 3056, 3435.

MS (ESI$^+$) m/z (%): 303 (100). HRMS (ESI$^+$) m/z: [(M-Br)] ($C_{38}H_{30}Br_2N_4S_2$) calc.685.10898:, found 685.10926; [(M-Br)+1] ($C_{38}H_{30}Br_2N_4S_2$+1) calc.686.10926:, found 686.11298:, [(M-Br)+2] ($C_{38}H_{30}Br_2N_4S_2$+2) calc.687.10926:, found 687.10719.

III CONCLUSION

In summary, 1) The manuscript introduces detailed experimental procedures for the synthesis of diquats their resolution with chiral borate anions by making its diastereomers by simple crystallization method.

2) The chiral anionic salts were synthesized by the simple method in good to excellent yield in pure form and characterized by usual analysis. The presence of boron in the sodium salt of chiral borate anion was confirmed by the ^{11}B-NMR analysis.

3) The diasteromeric excess (% *de*) or chiral purity of the diasteromeric diquat was analyzed by chiral electrophoresis analysis.

4) Synthesis of racemic diquat dyes is described.

5) Overall results show diquats as a class of attractive chiral dicationic scaffolds, which constitute useful platforms for chiral application studies.

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V CONFLICT OF INTEREST

The authors declare no conflict of interest.

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