Dalhousie University, Halifax, NS, Canada

INVESTIGATIONS INTO THE NUCLEOPHILIC *meso*-SUBSTITUTION OF *F*-BODIPYs AND IMPROVEMENTS TO THE SYNTHESIS OF 4,4-DIFLUORO-4-BORA-3a,4a-DIAZA-*s*-INDACENE

Sarah M. Crawford and Alison Thompson*

Department of Chemistry, Dalhousie University, Halifax, Nova Scotia, B3H 4J3, Canada; alison.thompson@dal.ca

Abstract – A series of three *F*-BODIPYs, with varying levels of steric crowding about the *meso*-position were selected to investigate nucleophilic *meso*-substitution of *F*-BODIPYs. The synthesis of one of these *F*-BODIPYs, 4,4-difluoro-4-bora-3a,4a-diaza-s-indacene (totally unsubstituted dipyrrin skeleton), was optimized to give higher yields over routine literature procedures. This modified procedure involves oxidation of a dipyrromethane using *p*-chloranil, instead of DDQ, to give a dipyrrin which is then trapped *in situ* as its BF_2 complex. Nucleophilic *meso*-alkylation of the series of *F*-BOIDPYs with *n*-butyllithium gave *meso*-butyl *F*-BODIPYs in moderate to good yields. This work represents a new, synthetically viable method for the synthesis of *meso*-alkylated *F*-BODIPYs. Extension of the nucleophilic substitution methodology to *meso*-arylation was possible. However, the reaction was unselective: substitution at boron, to give the boron-diaryl *C*-BOIDPYs, occurred preferentially to nucleophilic *meso*-substitution and thus a mixture of products was obtained.

INTRODUCTION

Molecules containing the 4,4-difluoro-4-bora-3a,4a-diaza-s-indacene (*F*-BODIPY) framework have wide applications as dyes, fluorescent probes in biological systems, and materials for incorporation into electroluminescent devices.[1, 2] Both symmetrical and unsymmetrical *F*-BODIPYs are routinely synthesized in high yields from the isolated dipyrrins free-bases or HX salts or by trapping the dipyrrin *in situ*.[3] However, dipyrrin free-bases and salts are historically difficult to manipulate and purify. Furthermore, there are only a few methods available to synthesize *meso*-substituted dipyrrins.

To produce *meso*-substituted dipyrrins (Figure 1), one can condense two equivalents of an α-unsubstituted pyrrole with a carboxylic acid,[4] an acid chloride[5] or an orthoformate[6] (method 1) or oxidize a 5-unsubstituted dipyrromethane to the corresponding *meso*-unsubstituted dipyrrin (method 2).[7] The first method is limited to the synthesis of symmetrical dipyrrins, while the second method is currently limited to the synthesis of dipyrrins with *meso*-aryl substituents and it requires the synthesis of the dipyrromethane starting material. Dipyrrins with *meso*-alkyl substituents can be synthesized from alkyl acid chlorides (method 1); however, the *meso*-alkyl dipyrrins are generally unstable and are thus trapped *in situ* using boron trifluoride diethyletherate and then isolated as their corresponding *F*-BODIPYs, with overall yields often below 20%.[8-11]

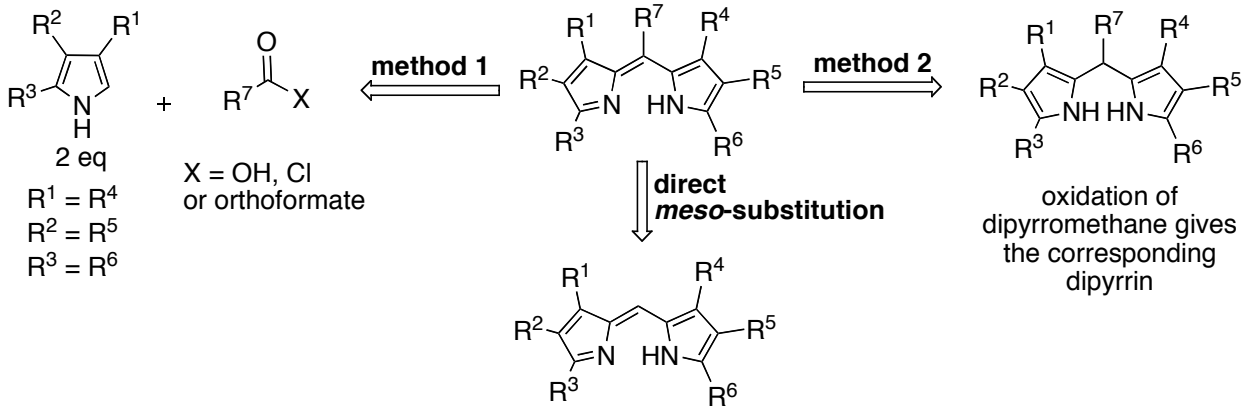


Figure 1. Strategies for the preparation of meso-substituted dipyrrins.

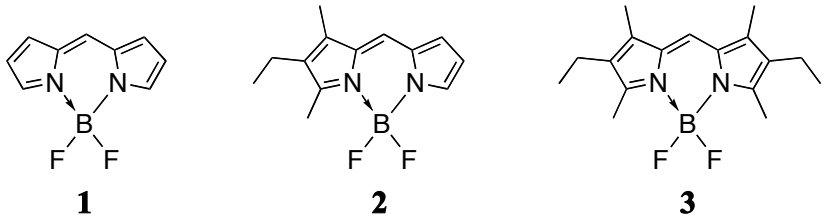
As shown in Figure 1, another potential strategy to *meso*-substituted dipyrrins involves substitution of *meso*-unsubstituted dipyrrins. However, examples of such direct *meso*-substitution of dipyrrins or dipyrrinato complexes are rare in the literature. *meso*-Cyano dipyrrins can be directly generated from *meso*-unsubstituted dipyrrins through cyanide anion attack at the *meso*-position to give the corresponding dipyrromethane, which can then be oxidized back to the dipyrrin.[8] Oligopyrrolic bile pigments,[9, 10] containing one or more dipyrrin units, are reported to undergo *meso*-substitution in the presence of ethanethiole. A prodigiosin analogue,[11] which contains a dipyrrin unit, was also reported to undergo photo-induced substitution with sulfur-based nucleophiles to give *meso*-substituted derivatives.

Direct *meso*-modification of *F*-BODIPYs has recently received interest and attempts at modification have utilized a *meso*-thioalkyl *F*-BODIPY as starting material.[12] The *meso*-thioalkyl substituent was shown to undergo nucleophilic substitution with amines,[12, 13] and it was also coupled with aryl boronic acids, *via* the Liebeskind-Srögl cross-coupling reaction,[14] to generate other *meso*-substituted *F*-BODIPYs. Although this approach represents a great improvement in the synthesis of *meso*-aryl *F*-BODIPYs, it is limited to the generation of symmetrical derivatives as the *meso*-thioalkyl *F*-BODIPY is generated by the reaction of thiophosgene with two equivalents of a substituted pyrrole to give the corresponding dipyrrolthione, which is then alkylated and trapped as its BF_2 complex.[12]

meso-Unsubstituted porphyrins and their metal complexes are susceptible to nucleophilic substitution at the *meso*-position, and the resulting intermediate is oxidized *in situ* to give *meso*-aryl and *meso*-alkyl substituted porphyrins.[15, 16] Aryl and alkyl lithium reagents, with varying levels of functionalization, are the nucleophiles employed in these reactions. Interestingly, a small amount of a *meso*-butyl substituted BODIPY was isolated from the reaction of a *meso*-unsubstituted BODIPY with 2 equivalents of a perfluorinated aryl lithium reagent (prepared from reacting the perfluorinated bromobenzene with *n*-butyl lithium).[17] Based on this knowledge, we aimed to develop a methodology for the generation of *meso*-substituted *F*-BODIPYs *via* nucleophilic substitution at the *meso*-position of *meso*-unsubstituted *F*-BODIPYs.

RESULTS AND DISCUSSION

An ideal synthetic route for the synthesis of a *meso*-substituted *F*-BODIPY would be to begin with a chemically robust *meso*-unsubstituted *F*-BODIPY, which would undergo nucleophilic substitution at the *meso*-position. Three *F*-BODIPYs (Figure 2), containing examples with increasing steric crowding flanking the *meso*-position, were selected as test compounds to investigate a methodology for the nucleophilic *meso*-modification of *meso*-unsubstituted *F*-BOIDPYs to give the corresponding *meso*-substituted *F*-BOIDPYs.



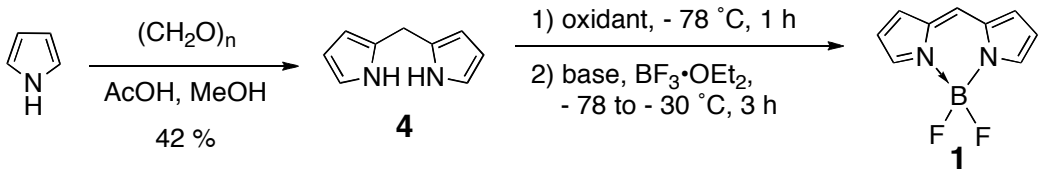
1 **2** **3**

Figure 2. F-BODIPY Test Compounds

F-BODIPYs **2** and **3** were synthesized from the corresponding dipyrrins using traditional methods.[18] The synthesis of *F*-BODIPY **1** has only very recently been reported.[23-25] One synthesis involves a

four-step procedure from pyrrole, in 35 % overall yield.[16, 23, 26] The other two methods are one-pot reactions and involve trapping the unstable dipyrrin intermediate: both have reported yields under 10 %.[19, 20] In order for this one-pot method for the preparation of **1** to be synthetically viable as a starting point for preparing derivatized *F*-BODIPYs, the yields needed to be increased.

The one-pot procedure involving the oxidation of an unsubstituted dipyrrin was selected for optimization.[20] The dipyrrin starting material (**4**) was synthesized using a literature method.[21] A series of trials were conducted in order to optimize the reaction conditions, the oxidant used in the dipyrrin formation reaction, and the base used in the *F*-BODIPY formation reaction. The results of these trials are outlined in Scheme 1.

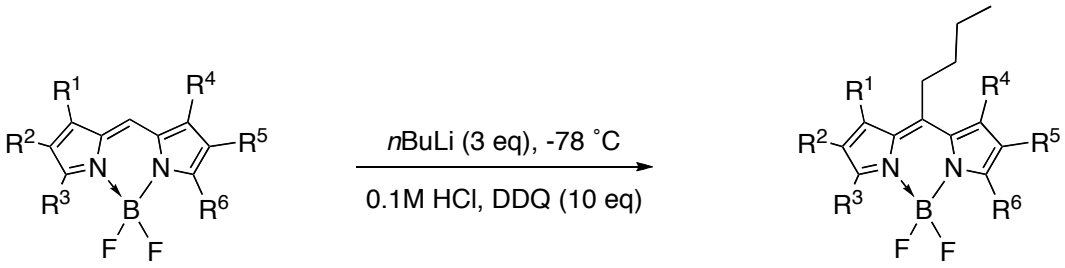


Trial	Oxidant	Base	Isolated Yield /%
1	DDQ	TEA	0
2		DIPEA	0.76
3		DBU	0.61
4-6	*p*-chloranil	DIPEA	10-29

Scheme 1. Optimization of the Synthesis of *F*-BODIPY 1

The bases used in the *F*-BODIPY formation were explored first (Trial 1 through Trial 3), using DDQ as an oxidant to generate the dipyrrin. When triethylamine was used as a base, none of the desired unsubstituted *F*-BODIPY **(1)** was formed; however, when DIPEA or DBU were used, **1** was isolated in very low yield (Trials 2 and 3) in our hands, even though the literature reports indicate yields between 8 and 10 % when using DIPEA.[19, 20] DIPEA was thus selected as the base to use in further trials as it reproducibly gave the best yield (e.g. Trial 2). After the base for the *F*-BODIPY formation was selected, the oxidant for the dipyrrin formation was investigated. The isolated yield of the *F*-BODIPY **1** increased substantially when the oxidant was modified from DDQ to the milder *p*-chloranil (Trials 4-6). Using these modified conditions, the *F*-BODIPY **1** was generated in an average yield of 21 % on a 100 mg scale.

With *F*-BODIPYs **1**, **2** and **3** in hand, investigations proceeded regarding nucleophilic *meso*-substitution. Solutions of each compound were treated with *n*-butyllithium at -78 °C. The reaction mixture was slowly warmed to room temperature and then treated with DDQ. The *meso*-butyl substituted *F*-BODIPYs **5**, **6**,[22] and **7**[22] were isolated in moderate yields as shown in Scheme 2.



1 $R^1 = R^2 = R^3 = R^4 = R^5 = R^6 = H$
2 $R^1 = R^3 = Me$, $R^2 = Et$, $R^4 = R^5 = R^6 = H$
3 $R^1 = R^3 = R^4 = R^6 = Me$, $R^3 = R^5 = Et$

5 $R^1 = R^2 = R^3 = R^4 = R^5 = R^6 = H$; 26%
6 $R^1 = R^3 = Me$, $R^2 = Et$, $R^4 = R^5 = R^6 = H$; 42 %
7 $R^1 = R^3 = R^4 = R^6 = Me$, $R^3 = R^5 = Et$; 61 %

Scheme 2. *meso*-Butylation of *F*-BODIPYs **1**, **2**, and **3**

This transformation represents a new method for the synthesis of alkyl substituted *F*-BODIPYs in better yields that the existing published methods.[8-11] In the only previous example of the synthesis of a *meso*-butylated BODIPY from the *meso*-unsubstituted analogue, the authors speculated that a perfluorinated aryl lithium reagent (prepared from reacting the perfluorinated bromobenzene with *n*-butyl lithium) deprotonated the *meso*-position of the BODIPY, followed by reaction of the resultant monoanionic species with the residual *n*-butylbromide.[17] We postulate,[22] based on color changes during the course of the reaction, that the alkylation addition occurs by the nucleophilic attack of the *n*-butyl anion at the *meso*-position to give a charged dipyrromethane-type intermediate, as shown in Figure 3.

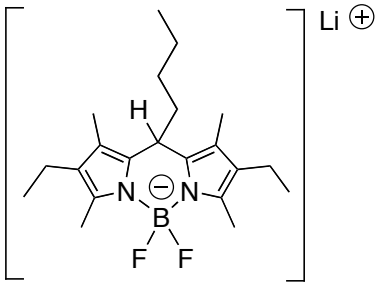
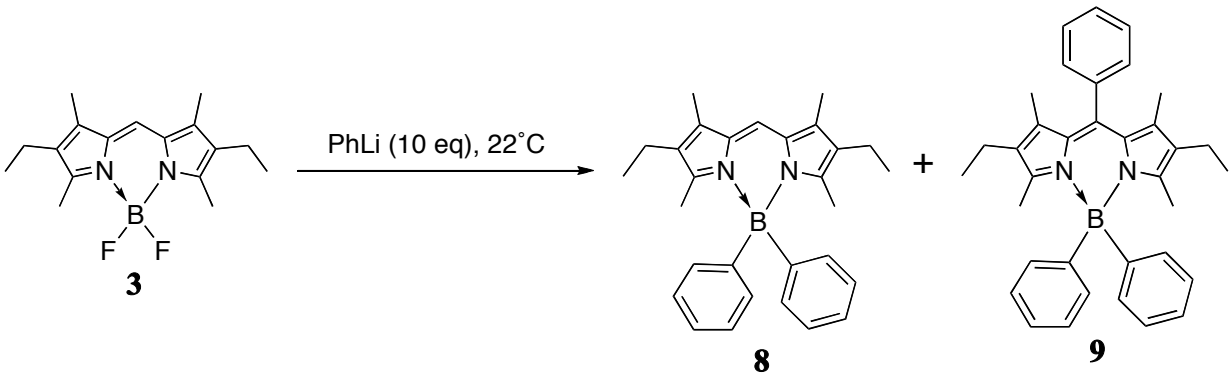


Figure 3. Postulated Alkylation Intermediate

The decrease in yield of the *meso*-butyl *F*-BODIPYs with decreasing substitution about the *F*-BODIPY is likely due to a decrease in the stability of boron-containing dipyrromethane-type intermediate with decreasing substitution, analogous to that of the corresponding dipyrrin series.[23] Isolated yields of the *meso*-butylated *F*-BODIPYs **5**, **6** and **7** increased with increasing substitution from 26 %, for the least substituted, to 61%, for the most substituted. Nevertheless, this strategy provides a reasonable and reliable route to *meso*-butyl substituted *F*-BODIPYs.

We also investigated the *meso*-arylation of the *F*-BODIPYs **1**, **2** and **3**. We have previously reported that when the *F*-BODIPY **3** is treated phenyllithium the *meso*-phenyl product was not produced; however, the *B*-diphenyl *C*-BODIPY **8** was isolated in 22 % yield.[22] Interestingly, when the reaction

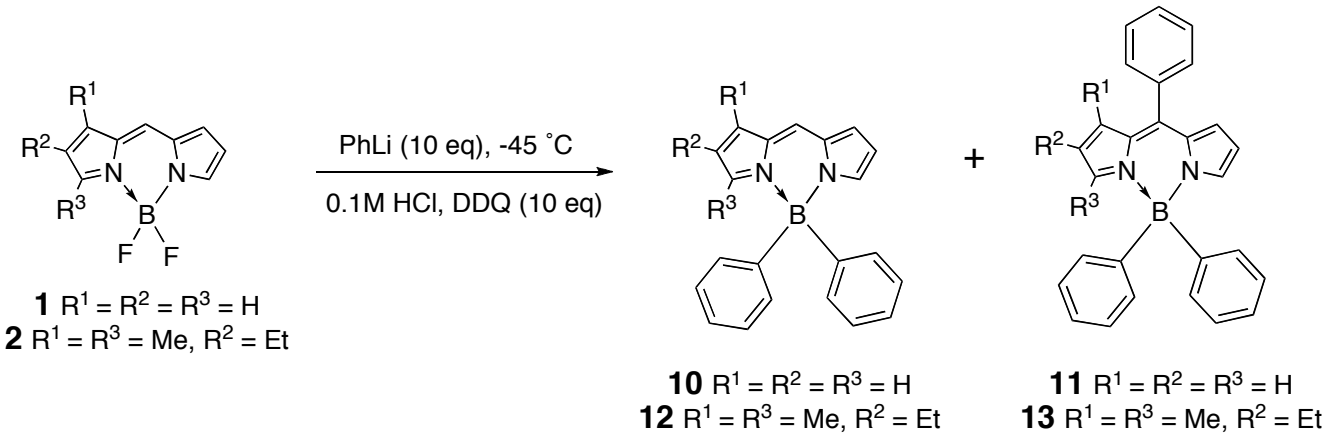
with 10 eq phenyllithium was conducted at room temperature, in the absence of DDQ, a mixture of the *C*-BODIPY **8** and the *C*-BODIPY **9**, with the desired *meso*-phenyl substituent, were generated as shown in Scheme 3. Presumably the substitution at boron is accompanied/followed by nucleophilic attack and then elimination at the *meso*-position.



Scheme 3. *meso*-Arylation of *F*-BODIPY **2** at Room Temperature

Integration of the corresponding peaks in the ^{1}H NMR spectrum, from the reaction carried out at room temperature, showed BODIPY **8** and BODIPY **9** to be isolated in a 0.2:1.0 ratio. The absence of *F*-BODIPY material in the reaction mixture indicates that nucleophilic attack at the boron centre appears to occur preferentially to nucleophilic attack at the *meso*-position in the case of the aryllithium reagent. This reactivity has been exploited to synthesize *C*-BODIPYs from *meso*-substituted *F*-BODIPYs although the products are generally isolated in yields below 50 %.[24] The absence of DDQ in this reaction also indicates that this transformation may be occurring through an alternate mechanism than the analogous *meso*-alkylation.Color observations are not useful in this case because the phenyllithium reagent itself is a red color and obscures any loss of color due to the dipyrrinato construct.

When *F*-BODIPY **1** and *F*-BODIPY **2** were treated with phenyllithium, mixtures of *meso*-unsubstituted *C*-BODIPYs and *meso*-phenyl *C*-BODIPYs were isolated in yields of 10% and 6%, respectively (Scheme 4).



1 $R^1 = R^2 = R^3 = H$
2 $R^1 = R^3 = Me$, $R^2 = Et$

10 $R^1 = R^2 = R^3 = H$
12 $R^1 = R^3 = Me$, $R^2 = Et$

11 $R^1 = R^2 = R^3 = H$
13 $R^1 = R^3 = Me$, $R^2 = Et$

Scheme 4. *meso*-Arylation of *F*-BODIPYs **1** and **2**

The reaction of the *F*-BODIPY **1** with phenyllithium resulted in two products, which could not be fully characterized. The mass spectrum (ESI^+) the mixture indicated the formation of a mixture of *C*-BODIPY **10** and *C*-BODIPY **11**, as shown in Scheme 4. A comparison of the relative integrations of the pyrrolic hydrogen peaks in the proton NMR spectrum of the product indicated that *C*-BODIPY **10** and *C*-BODIPY **11** were present in a 1 to 0.6 ratio. The reaction of *F*-BODIPY **2** with phenyllithium gave the *C*-BODIPY **12** and the *C*-BODIPY **13** in a 1 to 0.7 ratio. Under the same conditions, the *meso*-arylated *C*-BODIPY **9** could not be isolated. This indicates that steric factors play a role in *meso*-arylation, with low temperature *meso*-arylation being favored when the *meso*-position is not blocked by nearby substituents; however, *B*-arylation is favored over *meso*-arylation in all cases when using phenyllithium.

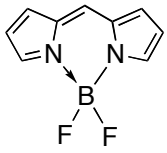
To conclude, as the interest in and possible applications of BODIPYs grows, methods for the direct modification of *F*-BODIPYs will be needed. In order to investigate the *meso*-modification of *F*-BODIPYs we optimized a reported synthesis[19, 20] of the totally unsubstituted *F*-BODIPY such that **1** can now be routinely isolated in 20-30 % yield. We have also developed a synthetically viable, alternative method for the production of *meso*-butylated *F*-BODIPYs by exploiting the nucleophilic attack of *n*-butyllithium at the *meso*-position of *F*-BODIPYs. Expansion of this methodology to other alkyllithium reagents is currently under investigation. *meso*-Arylation, using the same method, was not successful as nucleophilic attack at the boron centre was more favorable to nucleophilic attack at the *meso*-position and mixtures of products were isolated.

EXPERIMENTAL

All ^1H NMR (500 MHz), ^{13}C NMR (125 MHz), and ^{11}B NMR (160 MHz) spectra were recorded using a Bruker Avance AV-500 spectrometer. Chemical shifts are expressed in parts per million (ppm) using the solvent signal [$CDCl_3$ (^1H 7.26 ppm; ^{13}C 71.16 ppm)] as an internal reference for ^1H and ^{13}C and $BF_3 \bullet OEt_2$

as an external reference for ^{11}B. Splitting patterns are indicated as follows: br, broad; s, singlet; d, doublet; t, triplet; q, quartet; m, multiplet. All coupling constants (J) are reported in Hertz (Hz). Mass spectra were obtained using ion trap time-of-flight (ESI) instruments. Column chromatography was performed using 230-400 mesh ultra pure silica or 150 mesh Brockmann III activated, basic aluminum oxide, as indicated. Spectral data for compounds **1**,[23-25] **2**,[3, 22, 28, 31] **3**,[18, 22] **4**,[21] **6**,[22] **7**,[22] and **8**[22] have been previously reported in the literature.

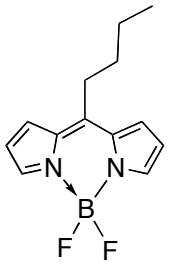
4-Bora-3a,4a-diaza-*s*-indacene (1)



1

Following a modified literature procedure,[20] a suspension of 2,3,5,6-tetrachloro-*p*-benzoquinone (174 mg, 0.71 mmol) in DCM (7.5mL) under a nitrogen atmosphere was added drop-wise to a stirred solution of di(1*H*-pyrrol-2-yl)methane[21] (100 mg, 0.68 mmol) in DCM (7.5 mL) at -80 ˚C under nitrogen. Once the addition was complete, the solution was stirred at -80 ˚C for 1 h. Diisopropylethylamine (0.71 mL, 4.08 mmol) was added drop-wise to the reaction mixture followed by BF_3•OEt_2 (0.68 mL, 6.12 mmol) and the reaction mixture was stirred for 3 h while warming to -30 ºC. The reaction mixture was filtered through celite and the solvent was removed *in vacuo*. The crude solid was purified over silica gel eluting with 50 % DCM in hexanes. The combined fractions were concentrated *in vacuo* and then purified over silica gel eluting with 15 % ethyl acetate in hexanes and the combined fractions were then concentrated *in vacuo* to give **1** as a red solid (30 mg, 23 %). δ_H (500 MHz, $CDCl_3$) 7.90 (s, 2H), 7.42 (s, 1H), 7.16 (d, *J = 4.0*, 2H), 6.55 (d, *J* = 4.5, 2H); δ_C (125 MHz, $CDCl_3$) 145.2, 135.0, 131.5 (q, *J=2*), 131.4, 118.9 (q, *J=2*); δ_B (160 MHz, $CDCl_3$) 0.15 (t, *J* = 30); *m/z* ESI^+ found 215.0564 $[M+Na]^+$ calculated for $C_9H_7BF_2N_2Na$ 215.0568. ^{13}C NMR data matches that previously reported.[23-25]

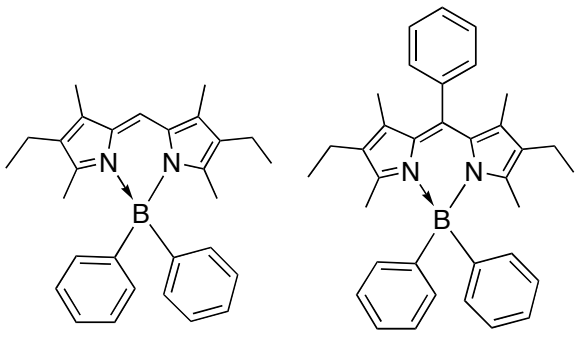
8-Butyl-4-bora-3a,4a-diaza-*s*-indacene (5)



5

n-Butyllithium (1.9 mL of a 1.6 M solution in hexanes, 3.1 mmol) was slowly added under a nitrogen atmosphere to a round-bottom flask containing a solution of **1** (60 mg, 0.31 mmol) in THF (10 mL) at -78 ˚C. The solution was stirred while slowly warming to -30 ˚C. At -30 ˚C, methanol (2 mL) was added drop-wise followed by a 0.1 M aqueous solution of HCl (2 mL) and the mixture was stirred for 10 min. The mixture was removed from the cooling bath and 2,3-dichloro-5,6-dicyano-*p*-benzoquinone (541 mg, 2.4 mmol) was added and the reaction mixture was stirred for 3 h at room temperature. The reaction mixture was diluted with DCM (75 mL) and water (150 mL). The layers were separated and the organic layer was washed with water (3 x 150 mL). The organic layer was dried over anhydrous Na_2SO_4 and the solvent was removed *in vacuo*. The crude solid was dissolved in DCM and the solution was filtered through a pad of silica eluting with DCM. Purification over silica gel eluting with 50 % DCM in hexanes gave **5** as an orange solid (20 mg, 26 %). δ_H (500 MHz, $CDCl_3$) 7.85 (s, 2H), 7.27-7.28 (m, 2H), 6.53-6.54 (m, 2H), 2.95-2.92 (m, 2H), 1.81-1.75 (m, 2H), 1.47 (sextet, *J = 7.5*, 2H), 0.97 (t, *J = 7.5*, 3H); δ_C (125 MHz, $CDCl_3$) 151.4, 143.4, 135.3, 127.9, 118.1, 36.1, 31.3, 23.3, 13.9; δ_B (160 MHz, $CDCl_3$) 0.02 (t, *J* = 30); *m/z* ESI^+ found 271.1178 $[M+Na]^+$ calculated for $C_{13}H_{15}BF_2N_2Na$ 271.1194.

4,4-Diphenyl-1,3,5,7-tetramethyl-2,6-diethyl-8-*H*-4-bora-3a,4a-diaza-*s*-indacene (8) and 4,4-diphenyl-1,3,5,7-tetramethyl-2,6-diethyl-8-phenyl-4-bora-3a,4a-diaza-*s*-indacene (9)



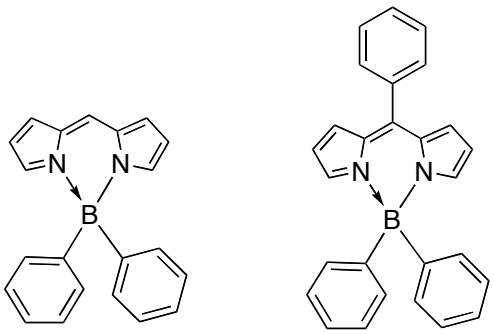
8 **9**

Phenyllithium (4.6 mL of a 1.8 M solution in di-*n*-butyl ether, 8.2 mmol) was slowly added under a nitrogen atmosphere to a round-bottom flask containing a solution of **3** (250 mg, 0.82 mmol) in diethyl ether (15 mL) at 25 ˚C. The solution was allowed to stir at room temperature for 18 h. Methanol (5 mL)

was added drop-wise and the reaction mixture was concentrated *in vacuo* to give an orange oil. The crude oil was purified over silica gel eluting with 4 % EtOAc in hexanes to give a mixture of **8** and **9** as an orange solid (28 mg **8**, 7 %, and 142 mg **9**, 29 %). δ_H (500 MHz, $CDCl_3$) 7.49-7.47 (m, 3H, **9**), 7.42-7.40 (m, 4H, **9**), 7.36-7.34 (m, 2H, **9**), 7.30-7.16 (m, 8.5H, **8** and **9**), 7.13 (s, 0.20H, **8**), 2.33 (q, *J = 7*.0, 0.84H, **8**), 2.22 (m, *J = 7*, 5H, **8** and **9**), 1.77-1.76 (m, 6.7H, **8** and **9**), 1.31 (s, 6H, **9**), 0.99 (t, *J = 7*, 1.3H, **8**), 0.90 (t, *J = 7*, 6H, **9**); δ_C (125 MHz, $CDCl_3$) 154.0, 153.1 140.8, 137.1, 135.4, 134.1, 133.9, 133.8, 132.9, 131.6, 130.9, 129.0, 128.9, 128.5, 127.28, 127.26, 125.7, 125.6, 119.5, 19.5, 17.7, 17.5, 14.9, 14.7, 14.5, 12.1, 9.5; δ_B (160 MHz, $CDCl_3$) -0.34 (broad s); *m/z* ESI^+ $[M+Na]^+$ 443.3, 519.3. Although this mixture could not be separated, assignments are based on those of a pure sample of the *C*-BODIPY **8**.[22]

4,4-Diphenyl-8*H*-4-bora-3a,4a-diaza-*s*-indacene (10) and

4,4-diphenyl-8-phenyl-4-bora-3a,4a-diaza-*s*-indacene (11)

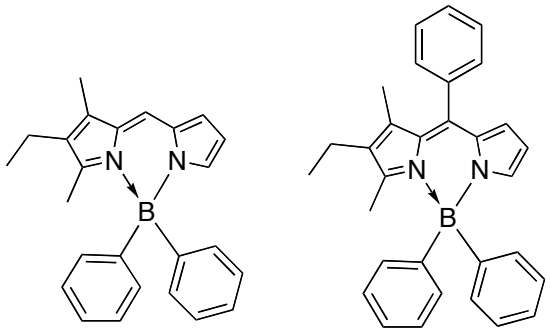


10 **11**

Phenyllithium (0.65 mL of a 1.8 M solution in di-*n*-butyl ether, 1.2 mmol) was slowly added under a nitrogen atmosphere to a round-bottom flask containing a solution of **1** (56 mg, 0.29 mmol) in THF (11 mL) at -45 ˚C. The solution was stirred for 30 min and then the cooling bath was removed and the mixture was stirred at room temperature 1 h. A 0.1 M aqueous solution of HCl (4 mL) was added drop-wise and the reaction mixture was stirred for 5 min. 2,3-Dichloro-5,6-dicyano-*p*-benzoquinone (658 mg, 10 mmol) was added and the reaction mixture was stirred for 1 h at room temperature. The reaction mixture was filtered through a pad of Brockman III neutral alumina, dried over Na_2SO_4, and concentrated *in vacuo* to give a brown oil. The crude oil was filtered through silica gel eluting with 15 % EtOAc in hexanes and the combined fractions were concentrated *in vacuo* to give an orange solid. Purification over silica using a gradient of 1 % EtOAc in hexanes to 3 % EtOAc in hexanes, and concentration *in vacuo* gave a mixture of **10** (3.4 mg, 4 %) and **11** (2.1 mg, 2 %) as a orange solid. δ_H (500 MHz, $CDCl_3$) 7.55-7.54 (m, 1H), 7.52-7.51 (m, 0.5H), 7.50-7.49 (m, 0.5H), 7.40-7.39 (m, 0.5H), 7.31 (d, *J = 4,* 0.50H), 7.25-7.17 (m, 4H), 7.13-7.11 (m, 2H), 7.07-7.01 (m, 6H), 6.91-6.87 (m, 2H), 6.59 (d, *J = 4.5*, 0.5H), 6.53 (d of d, *J = 2.0, 4.0*, 1H), 6.40 (d of d, *J = 1.5, 4.0*, 0.5H); δ_C (125 MHz, $CDCl_3$) 145.9, 144.5, 136.9, 135.0, 132.8, 132.4, 131.4, 130.6, 129.8, 129.3, 129.2, 128.4, 128.1, 127.6, 127.2, 127.1, 126.4,

126.0, 125.3, 121.2, 117.92, 117.86; δ_B (160 MHz, $CDCl_3$) 0.80 (broad s); *m/z* ESI^+ found 331.1375 $[M+Na]^+$ calculated for $C_{21}H_{17}BN_2Na$ 331.1382 (**10**) and found 407.1675 $[M+Na]^+$ calculated for $C_{27}H_{21}BN_2Na$ 407.1695 (**11**).

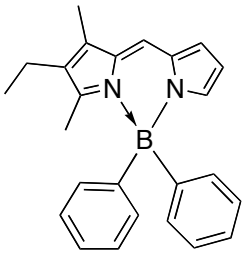
4,4-Diphenyl-1,3-dimethyl-2-ethyl-8*H*-4-bora-3a,4a-diaza-*s*-indacene (12) and 4,4-diphenyl-1,3-dimethyl-2-ethyl-8-phenyl-4-bora-3a,4a-diaza-*s*-indacene (13)



12 **13**

Phenyllithium (2.2 mL of a 1.8 M solution in di-*n*-butyl ether, 4.0 mmol) was slowly added under a nitrogen atmosphere to a round-bottom flask containing a solution of **2** (100 mg, 0.40 mmol) in THF (15 mL) at -45 ˚C. The solution was stirred for 30 min and then the cooling bath was removed and the mixture was stirred at room temperature 1 h. A 0.1 M aqueous solution of HCl (5 mL) was added drop-wise and the reaction mixture was stirred for 5 min. 2,3-Dichloro-5,6-dicyano-*p*-benzoquinone (908 mg, 10 mmol) was added and the reaction mixture was stirred for 1 h at room temperature. The reaction mixture was filtered through a pad of Brockmann III neutral alumina, dried over Na_2SO_4, and concentrated *in vacuo* to give a brown oil. The crude oil was purified over silica gel eluting with 2 % EtOAc in hexanes to give a mixture of **12** and **13** as a bright orange solid. The mixture was purified over silica gel eluting with a gradient of hexanes to 2 % EtOAc in hexanes. Concentration *in vacuo* gave a mixture of **12** and **13** as a bright orange solid (14 mg **12**, 10 % and 10 mg **13**, 6 %). The crude mixture of **12** and **13** was again purified over silica eluting with a gradient of hexanes to 2 % EtOAc in hexanes. Concentration of the pure fractions *in vacuo* gave **12** as an orange solid and **13** as an orange solid.

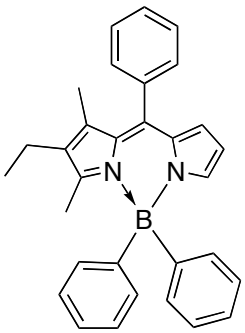
4,4-Diphenyl-1,3-dimethyl-2-ethyl-8 *H*-4-bora-3a,4a-diaza-*s*-indacene (12)



12

δ_H (500 MHz, $CDCl_3$) 7.29 (s, 1H), 7.23-7.14 (m, 11H), 6.89 (d of d, *J = 1.0, 4.0*, 1H), 6.31 (d of d, *J = 1.0, 4.0*, 1H), 2.41 (q, *J = 7.5*, 2H), 2.26 (s, 3H), 1.84 (s, 3H), 1.06 (t, *J = 7.5*, 3H); δ_C (125 MHz, $CDCl_3$) 139.6, 138.0, 136.1, 134.2, 133.3, 132.0, 127.4, 126.0, 124.3, 123.6, 114.9, 105.6, 17.7, 15.0, 14.7, 9.6 (1 C missing); δ_B (160 MHz, $CDCl_3$) 0.19 (broad s); *m/z* ESI^+ found 387.1985 $[M+Na]^+$ calculated for $C_{25}H_{25}BN_2Na$ 387.2003.

4,4-Diphenyl-1,3-dimethyl-2-ethyl-8-phenyl-4-bora3a,4a-diaza-*s*-indacene (13)



13

δ_H (500 MHz, $CDCl_3$) 7.48-7.46 (m, 3H), 7.39-7.37 (m, 2H), 7.28-7.23 (m, 8H, overlaps with $CHCl_3$ solvent signal), 7.21-7.17 (m, 3H), 6.36 (d of d, *J = 1.0, 4.0*, 1H), 6.24 (d of d, *J = 1.0, 4.0*, 1H), 2.34 (q, *J = 7.5*, 2H), 1.85 (s, 3H), 1.50 (s, 3H), 1.00 (t, *J = 7.5*, 3H); δ_C (125 MHz, $CDCl_3$) 160.3, 142.4, 139.2, 139.0, 135.6, 135.4, 134.2, 133.5, 133.3, 129.2, 128.9, 128.3, 127.4, 125.9, 124.1, 114.6, 17.6, 15.3, 14.7, 12.7 (1 C missing); δ_B (160 MHz, $CDCl_3$) - 0.09 (broad s); *m/z* ESI^+ found 463.2288 $[M+Na]^+$ calculated for $C_{31}H_{29}BN_2Na$ 463.2316.

ACKNOWLEDGEMENTS

This work was supported by the Natural Sciences and Engineering Research Council (NSERC) of Canada.

REFERENCES

1. A. Loudet and K. Burgess, *Chem. Rev.*, 2007, **107**, 4891.
2. G. Ulrich, R. Ziessel, and A. Harriman, *Angew. Chem. Int. Ed.*, 2008, **47**, 1184.

3. L. Wu and K. Burgess, *Chem. Commun.*, 2008, 4933.
4. B. Tu, C. Wang, and J. Ma, *Organic Preparations and Procedures International: The New Journal for Organic Synthesis*, 1999, **31**, 349.
5. A. Treibs, M. Strell, I. Strell, and D. Grimm, *Liebigs Ann. Chem.* , 1978, 289.
6. C. B. Reese and H. Yan, *Tetrahedron Lett.*, 2001, **42**, 5545.
7. C. Bruckner, V. Karunaratne, S. J. Rettig, and D. Dolphin, *Can. J. Chem.*, 1996, **74**, 2182.
8. G. Sathyamoorthi, J. H. Boyer, T. H. Allik, and S. Chandra, *Heteroat. Chem.*, 1994, **5**, 403.
9. H. Falk and H. Flîdl, *Monatsh. Chem.*, 1986, **117**, 57.
10. M. Holzl, C. Klampfl, and K. Grubmayr, *Monatsh. Chem.*, 2005, **136**, 755.
11. J. T. Tomlinson, G. Park, J. A. Misenheimer, G. L. Kucera, K. Hesp, and R. A. Manderville, *Org. Lett.*, 2006, **8**, 4951.
12. T. V. Goud, A. Tutar, and J.-F. Biellmann, *Tetrahedron*, 2006, **62**, 5084.
13. C. F. A. Gomez-Duran, I. Garcia-Moreno, A. Costela, V. Martin, R. Sastre, J. Banuelos, F. L. Arbeloa, I. L. Arbeloa, and E. Peña-Cabrera, *Chem. Commun.*, 2010, **46**, 5103.
14. E. Peña-Cabrera, A. Aguilar-Aguilar, M. González-Domínguez, E. Lager, R. Zamudio-Vázquez, J. Godoy-Vargas, and F. Villanueva-García, *Org. Lett.*, 2007, **9**, 3985.
15. X. Feng and M. O. Senge, *J. Chem. Soc. Perkin Trans. 1*, 2001, 1030-.
16. M. O. Senge, *Acc. Chem. Res.*, 2005, **38**, 733.
17. C. Bonnier, W. E. Piers, A. Al-Sheikh Ali, A. Thompson, and M. Parvez, *Organometallics*, 2009, **28**, 4845.
18. E. Vos de Wael, J. A. Pardoen, J. A. van Koeveringe, and J. Lugtenburg, *Recl. Trav. Chim. Pays-Bas*, 1977, **96**, 306.
19. A. Schmitt, B. Hinkeldey, M. Wild, and G. Jung, *J. Fluoresc.*, 2009, **19**, 755.
20. K. Tram, H. Yan, H. A. Jenkins, S. Vassiliev, and D. Bruce, *Dyes and Pigm.*, 2009, **82**, 392.
21. Q. M. Wang and D. W. Bruce, *Synlett*, 1995, **12**, 1267.
22. S. M. Crawford and A. Thompson, *Org. Lett.*, 2010, **12**, 1424.
23. T. E. Wood and A. Thompson, *Chem. Rev.*, 2007, **107**, 1831.
24. G. Ulrich, C. Goze, S. Goeb, P. Retailleau, and R. Ziessel, *New J. Chem.*, 2006, **30**, 982.