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A General Synthetic Route to 3,5-Substituted Boron Dipyrromethenes: Applications and Properties

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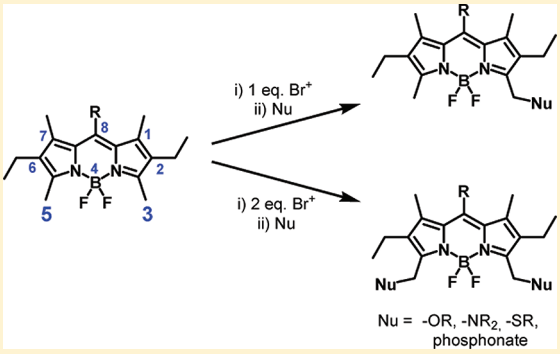
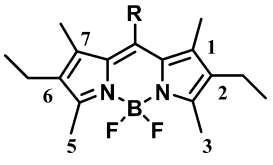
Supporting Information

ABSTRACT: An efficient protocol for the direct synthesis of 3-substituted and 3,5-disubstituted BODIPY derivatives via electrophilic attack with NBS was developed. Various substituents like ethers, sugar, hydroxyl, thiophene, sulfur, azide, tertiary amines, alkyne, vinyl, or phosphonate groups were obtained in moderate to excellent yields. The amine-substituted derivatives display unusual spectroscopic and electrochemical properties which were analyzed in solution in the presence of HCl. The diethylamino-substituted derivative has a proton association constant of log β = 4.7, and the disubstituted derivative has two association constants of log β = 6.2 and 12.1 in ethanol. In both cases, the quenching of the fluorescence is explained by photoinduced electron transfer from the tertiary amine to the Bodipy excited state.



INTRODUCTION

The search for easily prepared generic families of fluorescent dyes carrying multiple functionalities and with improved luminescence, electrochemical and charge transport properties is a thriving subject undergoing rapid development.[1] This widespread interest is motivated by their use as light-emitting films,[2] electro-luminescent materials,[3] and molecular probes.[4] The applicability of fluorescent dyes is often hampered by the chemical availability of the starting materials and depends critically upon their photostability, solvatochromism, molar absorptivity, luminescence quantum yields, solubility, and processability. Difluoroboradiaza-*s*-indacenes, commonly termed boron−dipyrromethene (BODIPY) dyes,[5] have become very popular and are outstanding fluorescent probes providing new opportunities to vary properties and import recognition sites by modification of their architecture. Their properties combine high molar absorption coefficients and high fluorescence quantum yields with respectable chemical and photochemical stability in solution and in the solid state and remarkable redox characteristics. Furthermore, their optical properties are sensitive to modification of the pyrrole core,[6] the central pseudo *meso* position,[7,8] and the boron substituents.[9] In some cases, the central position is occupied by a nitrogen atom, providing aza-BODIPYs which display extended near-infrared absorption and emission.[10] Up to now, major efforts have been devoted to the engineering of classical BODIPY structures and the investigation of their salient physical and spectroscopic properties.[11] However, the postfunctionalization of the BODIPY core allows the preparation of sophisticated BODIPY dyes, offering the possibility to tackle specific problems linked to (i) sensing of protons[12] or various cations[13,14] by opto-electronic switching, (ii) light-harvesting in porphyrin based arrays[15] or other elaborate architectures,[16,17] (iii) Stokes shift discrimination in energy transfer based on molecular cassettes,[18,19] and (iv) water-soluble dyes as bioconjugates or bioprobes for imaging applications.[20] Clear advantages associated with the use of BODIPY moieties are their absorptive properties in the visible region and the absence of deactivation complications through triplet-state population. However, there is still a need for new synthetic methodologies for their construction or structure modification. We have recently shown that the connection of polyaromatics or other useful residues via an ethynyl spacer to the boron atom of boradiazaindacene is a means to considerably increase the solubility and the virtual Stokes shifts and to tether several energy-absorbing units to the dyes. In some cases, adequate tailoring induces special sensing properties[21] including fluorescence amplification[22] and chirality,[23] and neutral dyes of this type may also be interesting for the preparation of well-organized thin films, liquid crystals, or organogelators[24] which could find application as light-emitting diodes, organic field-effect transistors,[25,26] and purely organic solar cells.[27,28]



Activation of the 3,5-positions is a particularly interesting prospect in that a Knoevenagel reaction with activated aromatic aldehydes can be a facile means of extending the π-system and thus modifying the optical properties of the dye.[29] In addition,

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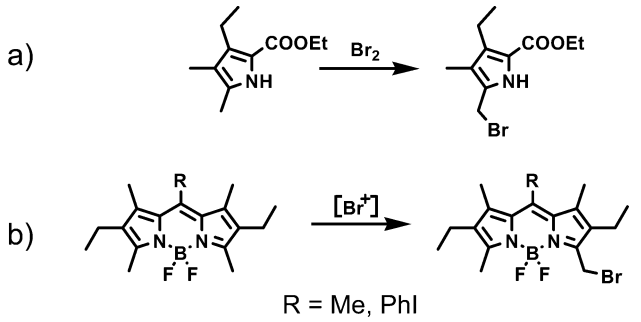
the construction of 3,5-dichloro-BODIPYs can be a clever pathway to the linking of a directly conjugated framework to the dye by metal-promoted cross-coupling reactions.[30] Blocked substituent's rotation by ring fusion of the 3,5- and 2,6-positions causes flattening of the core, improving the radiative properties.[31] Further, the introduction of 2-hydroxyphenyl groups in the 3,5-positions provides red emitters,[32] while selective oxidation of one methyl group to an aldehyde[33] allows specific intramolecular interactions promoting the resolution of chiral BODIPY dyes with the chirality held by the boron center.[23] These known methodologies prompted us to develop a new functionalization protocol based on the nucleophilic character of the methyl groups located at the 3,5-positions. We disclose here a new functionalization method making use of the nucleophilic character of the formally deprotonated 3,5-methyl groups on BODIPY derivatives. This postsynthetic transformation allows for the first time the introduction of new substituents in a nonconjugated manner unlike other oxidation or Knoevenagel-type transformations on these positions.

RESULTS AND DISCUSSION

We were interested in the transformations developed by Hayes and Kleinspehn in the 1960s for the modification of pyrroles in order to prepare unsymmetrical dipyrromethanes.[34] They reported a selective bromination of methyl groups in the α-position of pyrroles, and thus, we tried to extend this reaction to a BODIPY analogue bearing similar substituents (Scheme 1). Many electrophilic brominations of BODIPY were reported,

Scheme 1. (a) Kleinspehn's Work and (b) First Attempt on a BODIPY Skeleton (This Work)



beginning with the work of Boyer,[35] and more recently, bromination in 1,7-, 2,6-, or 3,5-positions were reported,[36] but no bromomethyl group was described.

Unfortunately, the bromo derivative was not stable enough to be isolated but could be observed in solution, allowing us to characterize this compound by its NMR spectrum. The reaction conditions involved the use of *N*-bromosuccinimide (NBS) as a bromonium ion source in dichloromethane at room temperature in the absence of light. The NMR spectra shown in Figure 1 were recorded at 15-min intervals.

Since the reaction was carried in the absence of light and without a radical initiator, it is likely to be an electrophilic substitution. In the NMR spectrum, the aromatic proton peaks are less sensitive to the reaction than are others. The greatest shift is seen in the singlet assigned to the α-methyl group, which passes from 2.5 to 4.8 ppm. After 15 min, splitting of the ethyl group signals (quartet 2 and triplet 2′) indicated formation of the monosubstituted BODIPY. This was followed by further modification of the signals of the protons in the 4

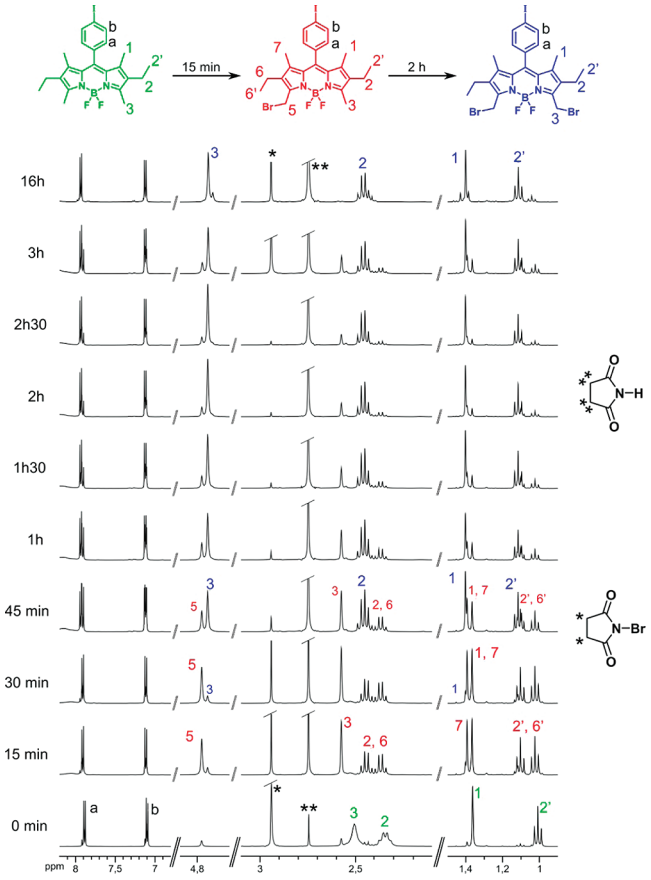


Figure 1. ^{1}H NMR experiment (rt, CD_2Cl_2, 400 MHz), under an Ar atmosphere, 2 equiv of NBS.

and 4′ positions, for example, which ultimately gave rise to a new singlet, for which the chemical shift corresponds neither to that of the starting material nor any of those of the monosubstituted compound. Similar changes were observed in the 4.8 ppm region. After 2 h, the bis(bromomethyl) derivative was the major compound. Attempts to isolate the mono- or disubstituted compounds failed due to their high reactivity toward nucleophiles.

After 3 h, an excess of NBS was added to see if any formation of tri- or tetrabromo compounds would occur, but none was detectable within one night at room temperature. This detailed monitoring of the solution reactions enabled us to develop a methodology for selective preparation of mono- or dibromo intermediates, which could be substituted in situ after addition of a nucleophile in a one-pot experiment.

Scheme 2 summarizes the different compounds obtained by this method. BODIPYs monosubstituted in the 3 position were obtained after 15 min of bromination and then addition of 1 equiv of nucleophile, and bis-3,5-substituted compounds were obtained after 2 h of bromination followed by the addition of 2 equiv or more of nucleophile. We first studied this reaction with ethanol as nucleophile and two different BODIPYs (1,3,5,7,8-pentamethyl-2,6-diethyl-4,4-difluoro-4-bora-3a,4a-diaza-*s*-indacene (**BOD-1**) and 8-(*p*-iodophenyl)-1,3,5,7-tetramethyl-2,6-diethyl-4,4-difluoro-4-bora-3a,4a-diaza-*s*-indacene (**BOD-2**). Reactions in dichloromethane gave, as implied above, the monobrominated derivatives within 15 min and the dibrominated derivatives after 2 h. Several tests were conducted in DMF, but none of them gave satisfactory results. For **BOD-1**,

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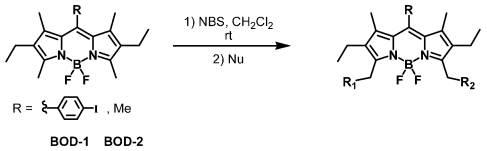
Scheme 2. Scope of the Reaction of BOD-1 and BOD-2 with Various Nucleophiles



Comp.	Nu	R	R_1	R_2	Yield (%)
1	ethanol	$-CH_3$	-H		74
2	ethanol	$-CH_3$			38
3	ethanol		-H		95
4	ethanol				quant.
5			-H		83
6					53
7			-H		56
8					35
9	H_2O		-H	-OH	85
10	H_2O		-OH	-OH	79
11			-H		28
12			-H		40
13					53
14			-H		67
15			-H		63
16					8
17			-H		68
18			-H		70
19					83
20			-H		85
21					85
22	NaN_3		-H	$-N_3$	90
23	NaN_3		$-N_3$	$-N_3$	86
24	$P(OEt)_3$		-H		85
25	$P(OEt)_3$				21

even with an excess of NBS (3 equiv) no sign of bromination of the methyl group in the meso position was observed. The one-pot nucleophilic substitutions were achieved by adding a large excess of ethanol to the brominated derivatives. This substitution was very fast and took only a few minutes, allowing the isolation of the mono- and diethoxy BODIPY derivatives (**1**–**4**) in excellent yields (Scheme 2). At this point, it was decided to develop the methodology on **BOD-2**, not only because it gave better yields but also because of the presence of the functionalizable iodophenyl group, leaving open the prospect of further substitution of this immediate product.

A library of 22 other derivatives was synthesized (Scheme 2) following this two-step procedure. Various O-based nucleophiles such as aliphatic alcohols, ethylene glycol (giving **5** and **6**), a protected sugar (**7** and **8**), and benzylic alcohol (**11**–**13**) were successfully used to afford the corresponding ethers in interesting yields. The use of water as nucleophile provided an easy access to the 3-hydroxymethyl- and 3,5-di-(hydroxymethyl)-BODIPY derivatives **9** and **10**. Interestingly, BODIPY derivatives with reactive functionality in the 3- or 3,5-positions could be obtained by this procedure, leading to dyes with free vinylic (**14**) or acetylenic (**15** and **16**) functions, paving the way to polymerization or click reactions. By the use of an aliphatic thiol as nucleophile the corresponding thioether (**17**) was obtained in good yield.

The second part of this survey of methodology concerned the use of N-based nucleophiles. In the case of amines, only secondary species gave the corresponding alkylated derivatives **18**–**21** in good yields. The use of primary amines or ammonia led to intractable mixtures of compounds. Proton NMR indicated the formation of trace amounts of formyl derivatives, allowing concluding that an imminum could be transiently formed during the course of the reaction, which by hydrolysis would provide formyl derivatives. Because this reaction provided many compounds, detailed studies were not pursued. The use of sodium azide afforded the mono- and diazido derivatives (**22** and **23**) in very good yields. Finally, we also demonstrated that even P nucleophiles can be successfully used in this one-pot reaction by using triethyl phosphite as nucleophile to obtain compounds **24** and **25**.

All compounds were unambiguously identified by ^1H and ^{13}C NMR spectra, mass spectra, and elemental analysis. In the case of the dialcohol derivative **10**, an interesting through-space coupling with the fluorine is observed. This kind of through space coupling was previously observed in BODIPY derivatives bearing an aldehyde group in the 3 position.[23] Its consequence is that the multiplet corresponding to the hydroxy proton becomes a triplet when decoupled at the CH_2 frequency. Since the measured coupling constants J_{H-F} and $^3J_{H-H}$ are similar (7 Hz), the hydroxy peak has a quintet shape in the standard experiment. Irradiation in the OH pattern at 2.7 ppm causes collapse of the methylene doublet to a singlet, confirming the coupling pathway (Figure 2c).

The versatility of the protocol developed is illustrated by the introduction of two different substituents, an amino function on one side and a monoethoxy function on the other side, in compound **26**, which could be easily purified due to the presence of a polar group (Scheme 3).

In order to further demonstrate the versatility of the method and its possible application to the synthesis of more complex derivatives, the azide derivative **22** was reacted with an aliphatic and an aromatic copper-catalyzed Huysgen azide alkyne cycloaddition[37] (Scheme 4). The monoazido compound **22** reacted with 3-(2-methoxyethoxy)prop-1-yne under standard conditions involving a catalytic amount of copper sulfate and sodium ascorbate at 60 °C overnight. This procedure was not suitable for the reaction of **22** with an aromatic alkyne, but CuI in DMF[38] provided **28** in good yields.

Optical Properties. A complete study of the optical properties for the new compounds was performed in order to establish the influence of the "benzylic" substituent at the 3 and 5 positions (Table 1).

All compounds present normal BODIPY absorption spectra, with a strong S_0-S_1 transition band around 520–535 nm with

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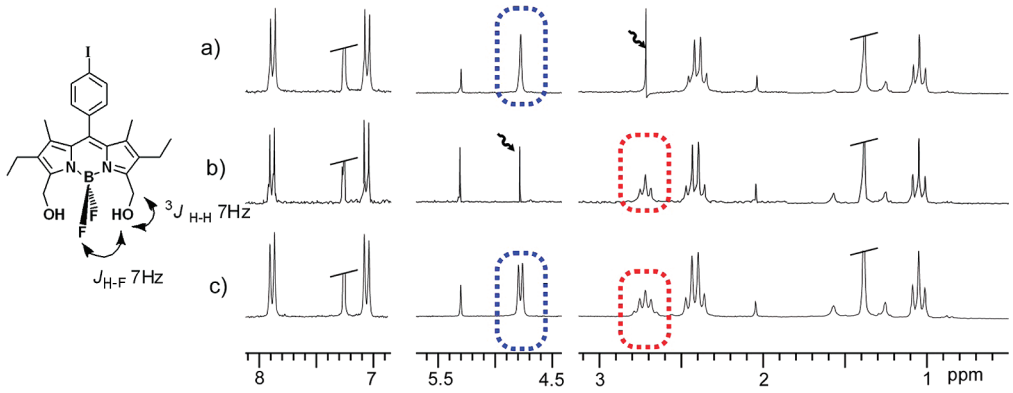
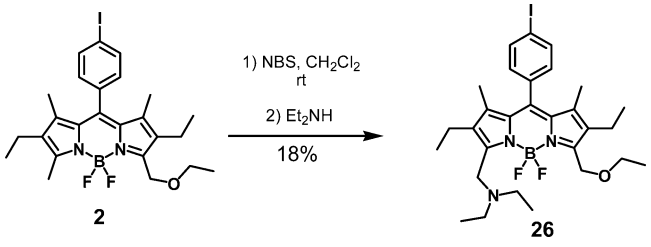


Figure 2. ^{1}H NMR spectra of **10**: (a) decoupled at 2.7 ppm; (b) decoupled at 4.8 ppm; (c) standard (200 MHz, $CDCl_3$, rt).

Scheme 3. One-Pot Synthesis of the Heterodisubtituted Compound 26



absorption coefficient of 60000−70000 $M^{-1}cm^{-1}$ and a weak broad band around 350−400 nm traditionally attributed to the S_0-S_2 band.[40] In the case of the ether derivatives, the monosubstitution has negligible effect on the band maximum, and a slight bathochromic shift of ca. 6 nm is observed in the case of the 3,5-diether derivatives compared to **BOD-2** for the S_0-S_1 transition (Figure 3). A stronger influence on the high energy absorption band is apparent, with a 10 nm bathochromic shift. The thioether function seems to have a stronger influence on the absorption with a shift of 7 nm for the monosubstituted derivative **17**.

Similarly, when amino, azido or phosphonato groups are present on the 3 or 3,5 positions only a weak bathochromic shift of ca. 6 nm is observed in the case of the disubstituted derivatives. The absorption coefficients are not affected and remain normal for this family of BODIPY dyes (Figure 3).

The emission of all compounds (except **18** and **19**) is essentially identical to that of the parent **BOD-2** compound (Figure 4). Only a small red-shift is observed, and emission peaks are in the range 540−550 nm, while the quantum yields are high (60−80%), as usually observed for BODIPY derivatives. The emission lifetimes are in the nanosecond regime, and the emission properties are insensitive to change in the solvent dipole moment and to air, confirming the singlet nature of the emission. The case of the compounds **18** and **19** bearing a tertiary amine substituent is discussed below.

Properties of Amino Derivatives. A tertiary amine substituent in the 3 and 3,5 positions has no effect on absorption but a major effect on emission. Indeed, the emission is strongly quenched, with a residual emission of 1% for **18** and 0.3% for **19** in EtOH, with lifetimes decreasing to ca. 0.1 ns. This quenching is probably due to a photoinduced electron transfer from the tertiary amine to the BODIPY in its excited state. Such behavior has been described previously for BODIPY derivatives[14,41] and is further analyzed presently in relation to the electrochemical measurements (vide infra).

The protonation of these compounds induced a small hypsochromic shift in absorption and the appearance of a second band (470 nm) concomitant with a decrease in intensity of the lower energy band in EtOH or dichloromethane, compared to the less polar solvent dioxan (Figure 5). The emission properties are almost fully restored with a quantum yield of 60% for **18**·H^+ in dioxane and around 50% in the other solvents. The excited state lifetime is in keeping with the restoration of the singlet state emission (Table 2).

Protonation measurements were performed on dyes **18** and **19** by addition of aliquots of increasing amounts of HCl in ethanol. In the case of **18**, the absorption spectrum shows a strong perturbation of the S_0-S_1 transition with a maximum shifted from 525 to 516 nm. A clear isosbestic point appears at 511 nm. Using SPECFIT,[42] we were able to determine a association constant for the formation of the **18**·H^+ species in ethanol of log β = 4.7 ± 0.1 (Figure 6).

A similar titration was performed with the bis-diethylamino derivative **19** (Figure 7). For clarity, we separate the parts corresponding to the first (a) and the second (b) protonation

Scheme 4. 1,3-Dipolar Cycloaddition on Compound 22

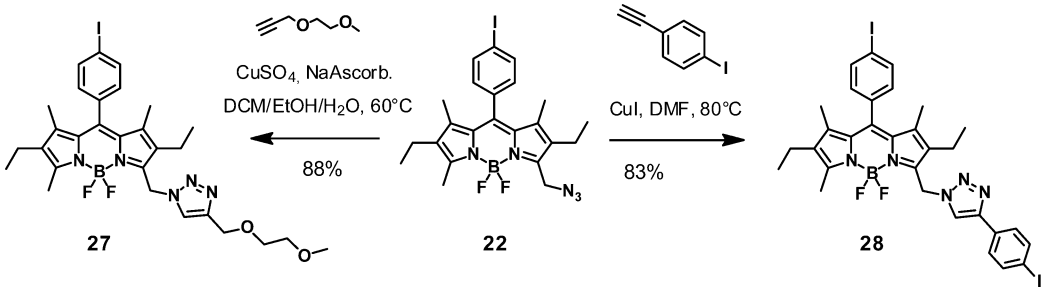


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Table 1. Optical Data for Selected Compounds[a]

compd	λ_{abs} (nm)	ε (M^{-1} cm^{-1})	λ_{em} (nm)	Φ (%)	τ (ns)	k_r 10^7 (s^{-1})	k_{nr} 10^7 (s^{-1})
BOD-1	517	64500	538	83	6.20	13.40	2.74
1	519	65100	539	85	6.79	12.52	2.21
2	521	71300	540	80	7.26	11.02	2.75
BOD-2	526	74900	541	70	5.42	12.92	5.54
3	526	65200	541	65	5.55	11.71	6.31
4	529	67200	544	65	5.30	12.26	6.60
5	525	53300	541	65	5.14	12.65	6.81
7	527	65800	543	75	6.18	12.14	4.05
8	530	65000	545	75	5.81	12.91	4.30
9	527	61900	542	75	6.71	11.18	3.73
10	531	63600	546	68	5.86	11.60	5.46
11	527	59800	543	60	5.73	10.47	6.98
12	528	62100	542	70	6.13	11.42	4.89
13	532	66000	547	72	6.23	11.56	4.49
14	527	61600	542	75	6.37	11.77	3.92
15	526	63200	540	62	5.57	11.10	6.82
16	530	64000	545	65	5.34	12.17	6.55
17	533	70700	548	70	5.14	13.62	5.84
20	529	62100	544	75	6.97	10.76	3.59
21	533	65600	549	60	5.02	11.95	7.97
22	526	54200	541	60	5.60	10.71	7.14
23	532	61600	547	70	5.62	12.46	5.34
24	530	76100	544	70	5.92	11.82	5.07
25	534	67500	550	40	4.72	8.47	12.71
27	523	48500	540	65	5.29	12.29	6.62
28	525	51600	541	75	6.71	11.18	3.73

[a]Measured in dichloromethane at rt. Quantum yields calculated with using rhodamine 6G (Φ_F = 0.78 in water, λ_{exc} = 488 nm).[39] All Φ_F are corrected for changes in refractive index. k_r and k_{nr} were calculated using the following equations: $k_r = \Phi_F/\tau$, $k_{nr} = (1 - \Phi_F)/\tau$ assuming that the excited state is obtained with unit efficiency.

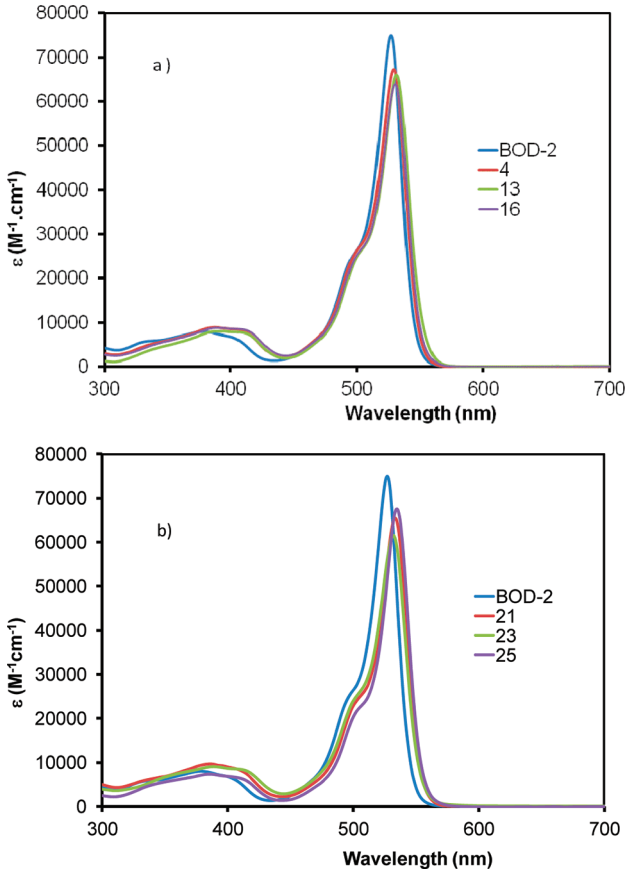

Figure 3. (a) Absorption spectra of 3,5-diether derivatives (**4**, **13**, and **16**) and reference BOD-2 in CH_2Cl_2 at rt. (b) Absorption spectra of 3,5-diamino **21**, 3,5-diazido **23**, and 3,5-diphosphonato **25** derivatives in CH_2Cl_2 at rt.

steps. For the first step, similar effects on the S_0-S_1 transition to those seen for **18** were observed, with an isosbestic point at 515 nm. The second protonation produces a bathochromic and a hyperchromic shift of the S_0-S_1 transition. After diprotonation, the dipyrromethene core regains 2-fold symmetry and a normal BODIPY dye absorption spectrum is observed. Analysis of the full titration data (Figure 7) provided association constant values in ethanol of log β 6.2 ± 0.2 and 12.1 ± 0.1 for **19**·H^+ and **19**·$2H^+$, respectively. The calculated spectrum (SPECFIT) of the monoprotonated species is similar to that of the **18**·H^+ species (Figure 8).

These protonation reactions could also be monitored in emission (Figure 9). For **18**, the luminescence intensity rises immediately following the first addition of acid. For **19**, the fluorescence remains weak up to the addition of 2.4 equiv of H^+ and then gradually begins to rise. This indicates that the luminescence remains quenched in the monoprotonated species but is restored in the diprotonated species(Figure 9). A single free diethylamino group seems sufficient to quench the fluorescence of the dye, presumably by a photoinduced electron transfer (PET) mechanism.

Electrochemical Behavior. Cyclic voltammograms were recorded in dichloromethane using the ferricinium/ferrocene couple as internal reference. Those of **BOD-1** and dye **18** are shown in Figure 10a. A reversible anodic wave is observed at −1.28 V (ΔE_p = 70 mV), corresponding to a monoelectronic exchange, and is attributed to the reduction of the BODIPY core to its radical anion (BOD/$BOD^{\bullet-}$).[36] By comparison with **BOD-1**, dye **18** is slightly easier to reduce by about 100 mV, reflecting the electronic influence of the iodophenyl substituent. An irreversible cathodic wave at +0.94 V is attributed to the amine oxidation. A second monoelectronic, reversible oxidation wave at +1.42 V (ΔE_p = 70 mV) is attributed to the formation of the BODIPY radical cation (BOD/$BOD^{+\bullet}$). This oxidation potential is shifted by 400 mV compared to the reference **BOD-1**, probably due to electrostatic effect of the first charge created by the amine oxidation, which depletes the electron density of the BODIPY core.

Assignment of these oxidation waves is further supported by spicing the solution with trace amounts of HCl(g), which clearly confirms that protonation of the amine renders the oxidation of this center much more difficult while the oxidation of the ferrocene and the BODIPY units are unaffected (Figure 10b). Visually, the deep-red and nonfluorescent solution turned orange and fluorescent as the acid was added. Note that with a large excess HCl(g) the reduction window is inaccessible because of the reduction of the protons and residual water.

The voltammogram of dye **19** was recorded under the same conditions and shows a BODIPY reduction wave at −1.30 V (ΔE_p = 70 mV; corresponding to BOD/$BOD^{\bullet-}$) that is monoelectronic and reversible. This potential is similar to that of **18**, proving that the second amine has a negligible influence on the electron density of the boradiazaindacene core. Cathodically, two irreversible waves are observed at +0.94 and +1.16 V, corresponding presumably to successive

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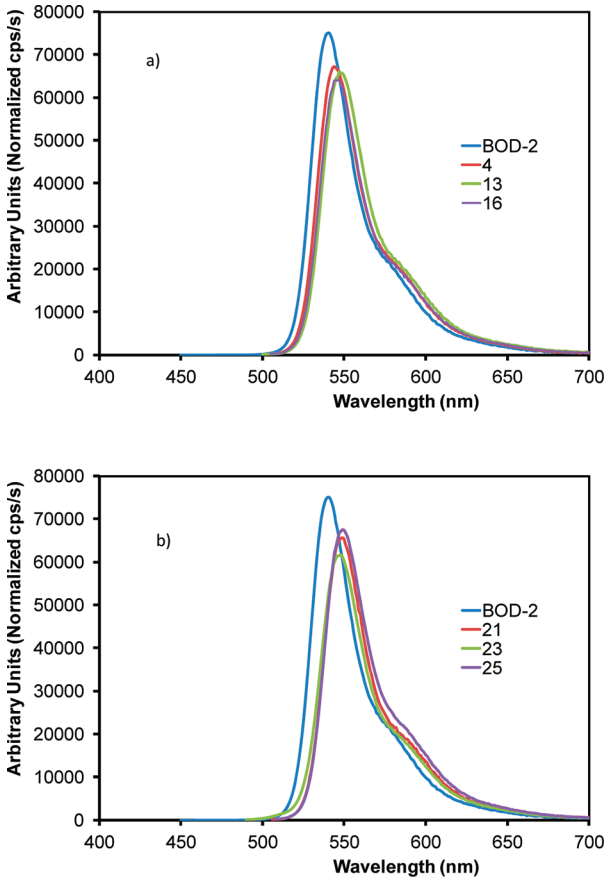

Figure 4. (a) Emission spectra of 3,5-diether derivatives (**4**, **13**, and **16**) and reference BOD-2 in CH_2Cl_2 at rt. (b) Emission spectra of 3,5-diamino **21**, 3,5-diazido **23**, and 3,5-diphophonato **25** derivatives in CH_2Cl_2 at rt.

oxidations of the two tertiary amine groups. Note that the oxidation of the BODIPY core falls outside this potential range. The potential difference of 220 mV between the waves is significant, given that the system is not conjugated. The close proximity of the two moieties attached in the 3,5-positions and possible hydrogen bonding with the BF_2 group could explain such a difference in potential. These two oxidation steps presumably perturb that of the BODIPY core, causing it to fall outside the experimental window. Protonation of the dye with HCl(g) (Figure 11) inhibits oxidation of both the N-centers and the BODIPY core. The BODIPY core is still reduced at the same potential as under neutral conditions, excluding any degradation of the dye. Note that the additional peak around −0.6 V is due to the reduction of H^+/H_2O (due to residual water introduced by the addition of HCl(g) into the electrochemical cell).

By combining the photophysical and electrochemical data obtained for **18** and **19**, it is possible to determine the oxidation potentials of the BODIPY excited states. The value of the redox potential in the excited state is obtained by subtracting from the redox potential in the ground state the energy needed to obtain the excited state. The excited-state energy E_{00} was estimated (±5%) from the tangent to the high energy side of the residual emission peaks of the dyes. Expressed in eV (ΔE(eV) ≈ 1240/λ (nm)), the values are 2.33 eV for **18** and 2.29 eV for **19**. Applying the Rehm−Weller equation[43] to our system and neglecting Coulombic factors we obtain the simplified equation: $\Delta G = E(N^{\bullet+}Et_2/NEt_2) - E\ (BOD^*/BOD^{\bullet-})$. From these data, we obtain free energy values of ca. −110 meV and −70 meV, respectively, for the photoinduced electron transfer from the amine to the BODIPY in **18** and **19**. The thermodynamic driving force is clearly favorable for a PET mechanism and explains the quenching of luminescence in the presence of the tertiary amine functions.

CONCLUSION

We have demonstrated here that methylated BODIPY dyes are easily substituted in the 3- or 3,5-positions by a variety of O, N, P, and S substituents. Some of these substituents like azide, alkyne, vinyl, or phosphonate groups are key building blocks for the construction of more sophisticated molecules. The intermediate mono- and dibromo derivatives could not be isolated due to their high reactivity but were unambiguously identified by proton NMR spectroscopy. The introduction of a tertiary amine unit on the 3- and/or 3,5-positions led to efficient quenching of luminescence by photoinduced electron transfer, the luminescence being restored by protonation. Cyclic voltammetry confirms the ease of tertiary amine oxidation, although protonation inhibits this oxidation under

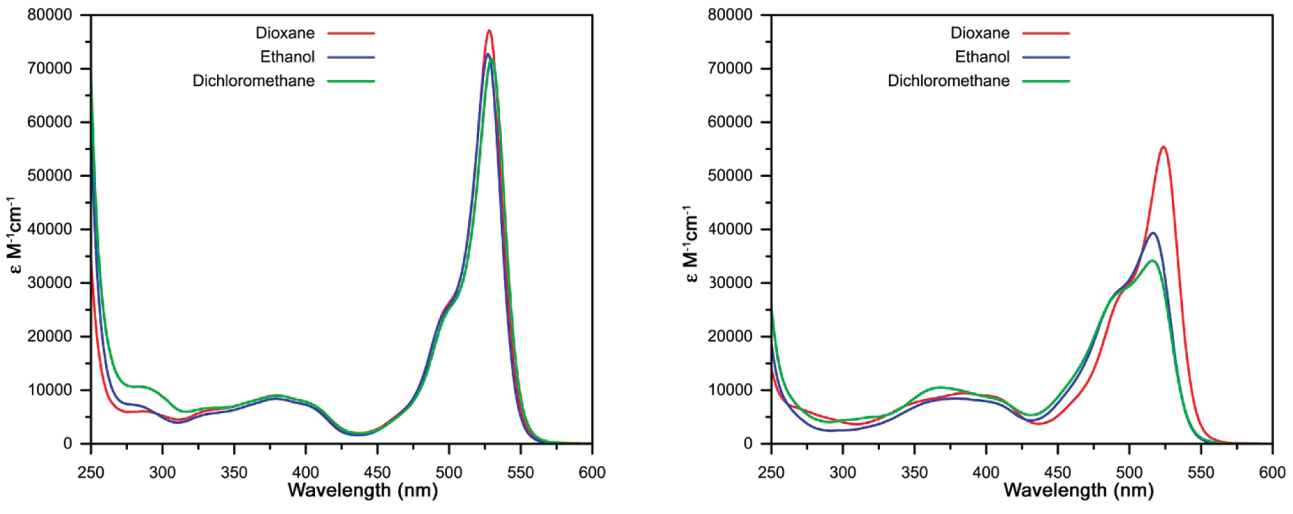

Figure 5. Absorption spectra of **18** (left) and **18** + H^+ (right) in dioxane (red), ethanol (blue), and dichloromethane (green) at rt.

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Table 2. Optical Data of Amino Derivatives[a]

compd (solvent)	λ_{abs} (nm)	ε (M^{-1} cm^{-1})	λ_{em} (nm)	Φ (%)	τ (ns)	k_r 10^7 (s^{-1})	k_{nr} 10^7 (s^{-1})
18 (dioxane)	527	77100	542	1	0.16	6.25	618.75
18 + H^+	524	55400	542	60	5.35	11.21	7.48
18 (CH_2Cl_2)	528	71800					
18 + H^+	517	34200	539	47			
18 (EtOH)	525	72800	540	1	0.08	12.50	1237.50
18 + H^+	516	39300	538	50	5.00	10.00	10.00
19 (EtOH)	530	70100	555	0.3			
19 + H^+	519	33100	551				
19 + $2H^+$	532	46800	550	42	3.80	11.05	15.26

[a]Measured at rt. Quantum yields calculated using rhodamine 6G (Φ_F = 0.78 in water, λ_{exc} = 488 nm)[37] All Φ_F are corrected for changes in refractive index. k_r and k_{nr} were calculated using the equations $k_r = \Phi_F/\tau$ and $k_{nr} = (1 - \Phi_F)/\tau$, assuming that the excited state is attained with unit efficiency.

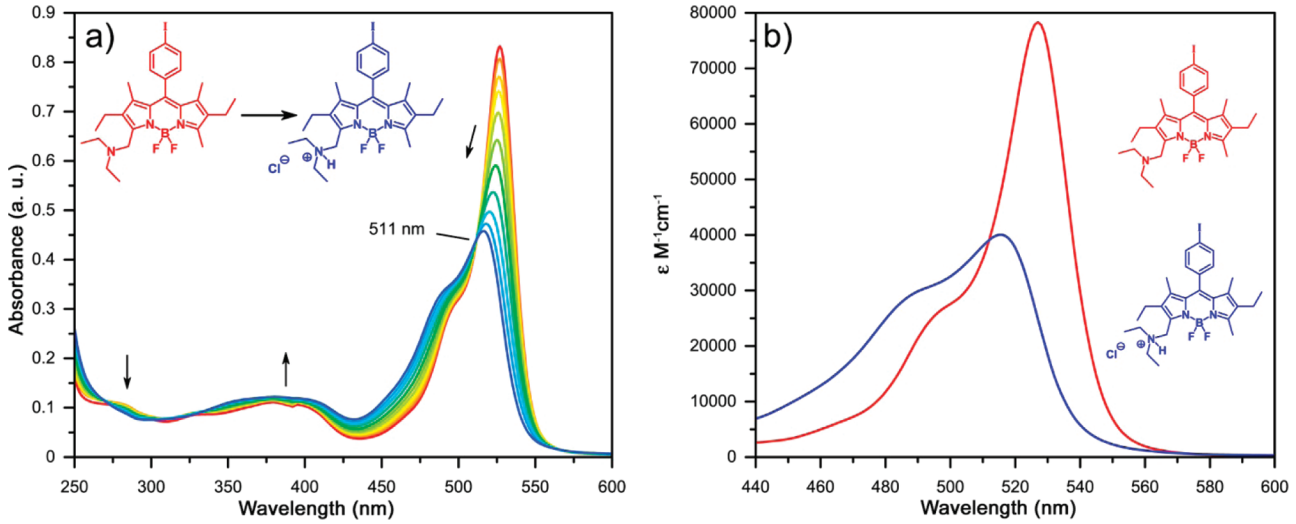

Figure 6. (a) Spectrophotometric titration (corrected for dilution) for the protonation of **18** (c = 1.13.10^{-5} M) with aliquots of HCl in EtOH (0.01 M $TBAPF_6$). (b) Calculated absorption spectra of **18** and **18**·H^+ using SPECFIT.

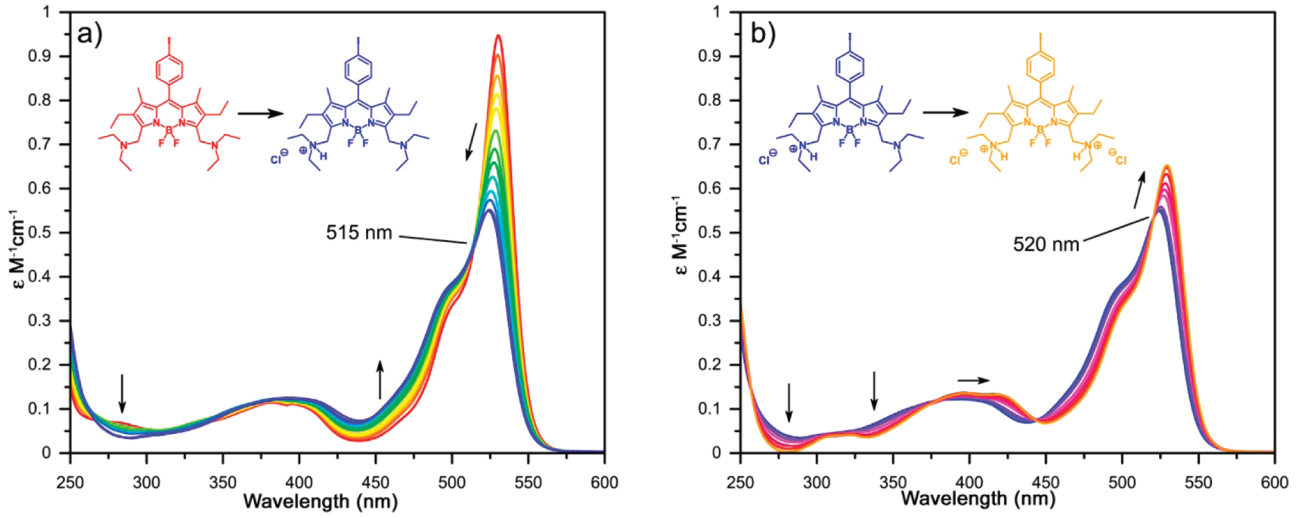

Figure 7. Titration spectra (corrected for dilution) of the protonation of **19** (c = 1.35 × 10^{-5} M) with aliquots of HCl in EtOH (0.01 M $TBAPF_6$).

standard conditions. This model system could be used to develop more selective fluorogenic sensors by introduction of a selective coordination pocket in place of a simple amine. We are currently investigating such opportunities.

EXPERIMENTAL SECTION

General Methods. ^1H and ^{13}C spectra were recorded at room temperature on 200, at 300, or 400 MHz spectrometers using perdeuterated solvents as internal standards. Chemical shifts of the ^1H and ^{13}C spectra are given in ppm relative to residual protiated solvent or relative to the solvent, respectively. ^{11}B spectra were recorded at room temperature on a 400 MHz spectrometer using BF_3·Et_2O

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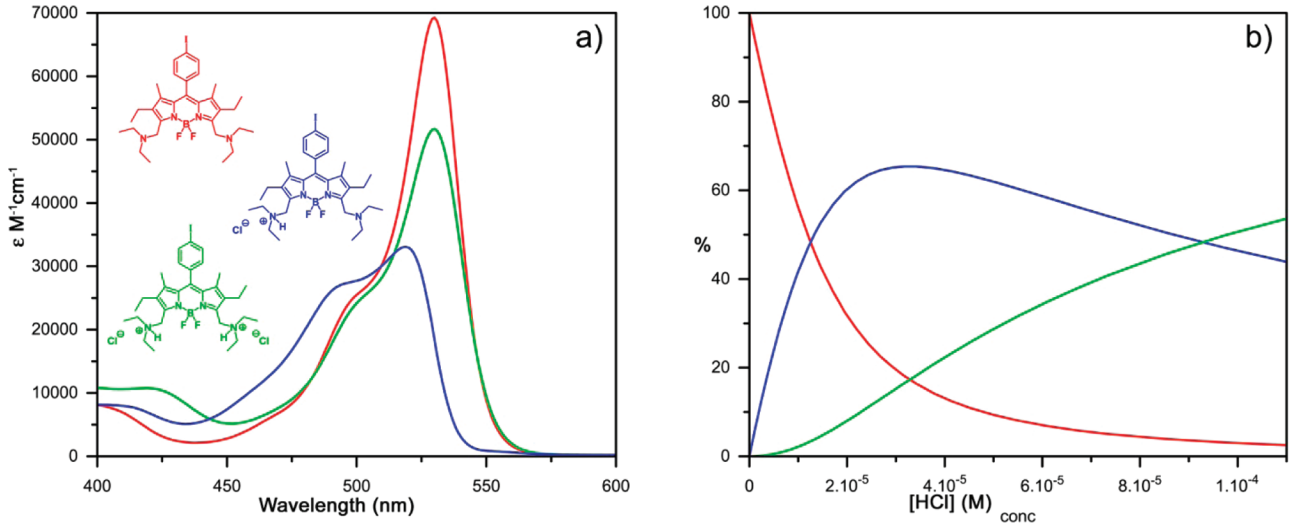

Figure 8. (a) Calculated absorption spectra of **19** (red), **19**·H^+ (blue), and **19**·$2H^+$ (green). (b) Calculated amount of each species during the titration (c = 1.35.10^{-5} M).

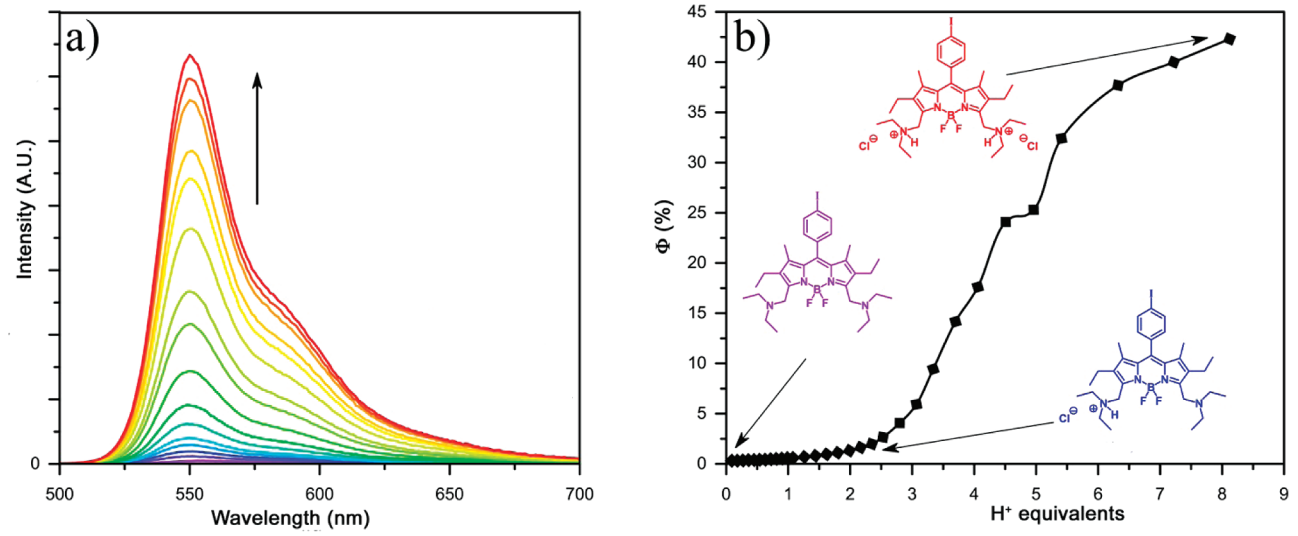

Figure 9. (a) Evolution of spectra of **19** (c = 1.35.10^{-5} M in EtOH (0.01 M $TBAPF_6$)) with increasing amounts of HCl (corrected emission spectra), λ_{exc} = 400 nm. (b) Evolution of the quantum yield during the titration.

chemical shift as reference. FT-IR spectra were recorded on thin solid layers with an ATR "diamond" apparatus. UV−vis spectra were recorded using a dual-beam grating spectrophotometer and 1 cm quartz cells. Electrochemical studies employed cyclic voltammetry with a conventional three-electrode system using a voltammetric analyzer equipped with a platinum micro disk (2 mm^2) working electrode and a silver wire counter electrode. Ferrocene was used as an internal standard and was calibrated against a saturated calomel reference electrode solution (SSCE) separated from the electrolysis cell by a glass frit presoaked with electrolyte solution. Solutions contained the electroactive substrate in deoxygenated and anhydrous dichloromethane containing doubly crystallized tetra-*n*-butylammonium hexafluorophosphate (0.1 M) as supporting electrolyte. All fluorescence spectra were corrected. The fluorescence quantum yield (Φ_{cmp}) was calculated from eq 1:

$$\Phi_{cmp} = \Phi_{ref}\frac{I}{I_{ref}}\frac{OD_{ref}}{OD}\frac{n^2}{n_{ref}^2}$$

Here, I denotes the integral of the corrected emission spectrum, OD is the optical density at the excitation wavelength, and η is the refractive index of the medium. The reference system used were rhodamine 6G (Φ_{em} = 0.78 in H_2O) and cresyl violet (Φ_{em} = 0.53 in CH_3OH).[37] Emission wavelengths were selected by a monochromator. Lifetimes were deconvoluted with adequate software using a light-scattering solution (LUDOX) for instrument response.

Reagents. Chromatographic purification was conducted using standard silica gel 60 (0.063−0.200 mm) or deactivated aluminum oxide (Act. III). Thin-layer chromatography (TLC) was performed on silica gel plates coated with fluorescent indicator. All mixtures of solvents are given in v/v ratio. Anhydrous solvents were obtained by distillation using anhydrous CH_2Cl_2 over P_2O_5. Standard reagents were purchased from commercial sources and used without further purification. *N*-Bromosuccinimide was recrystallized from hot water, and 2,6-diethyl-4,4-difluoro-1,3,5,7,8-pentamethyl-4-bora-3a,4a-diaza-*s*-indacene (**BOD-1**),[44] 3-(2-methoxyethoxy)-1-propyne,[45] 8-(*p*-iodophenyl)-1,3,5,7-tetramethyl-2,6-diethyl-4,4-difluoro-4-bora-3a,4a-diaza-*s*-indacene (**BOD-2**)[46] were obtained according to literature procedures.

General Procedure for 3- and 3,5-Functionalization. To a solution of BODIPY starting material in dry CH_2Cl_2 was added NBS. The solution was stirred at room temperature in the dark (30 min and 2 h for mono- and bis-functionalization, respectively). Anhydrous DMF and nucleophile were added subsequently. The reaction mixture

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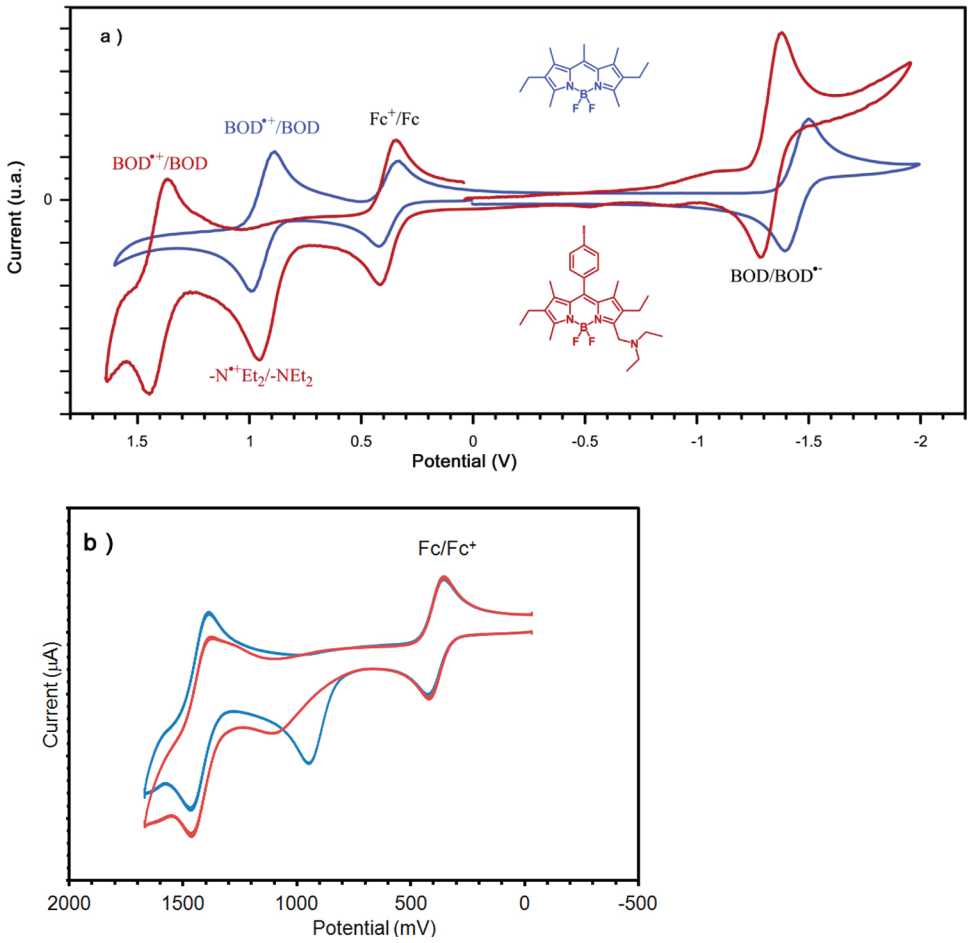

Figure 10. (a) Cyclic voltammograms of **BOD-1** (blue) and **18** (red), $c = 1.5 \times 10^{-3}$ M in CH_2Cl_2 (0.1 M nBu$_4$NPF$_6$), Fc^+/Fc refers to the ferricinium/ferrocene couple used as internal reference $E_{1/2}$ (Fc^+/Fc) = +0.38 V (ΔE_p = 60 mV). (b) Cyclic voltammograms of **18** (blue line under nitrogen) and under excess HCl(g) (red line); the voltamogram is restricted to the cathodic window.

was stirred at room temperature (from several minutes to a few days). At this stage, the course of the reaction was followed by thin-layer chromatography. The solution was extracted with EtOAc, washed with water (5 × 25 mL) and NaCl (2 × 20 mL), dried over $MgSO_4$, and evaporated. The residue was purified by column chromatography.

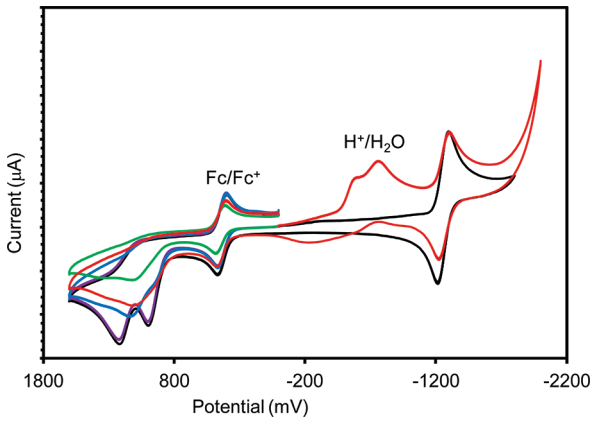

Figure 11. Cyclic voltamogramm of **19** (black line, $c = 1.5 \times 10^{-3}$ M in CH_2Cl_2 (0.1 M nBu$_4$NPF$_6$), Fc/Fc^+ denoting the ferricinium/ferrocene couple used as internal reference ($E_{1/2}$ (Fc^+/Fc) = +0.38 V). The plum, blue, and green lines are obtained by progressive addition of anhydrous HCl(g) into the electrochemical cell. The red trace is obtained by addition of HCl(g) yielding a maximum of fluorescence intensity.

Compound **1**. Prepared according to the general procedure; from **BOD-1** (89 mg, 0.28 mmol), NBS (50 mg, 0.28 mmol), CH_2Cl_2 (2 mL), ethanol (10 mL), and without DMF; stirred for 15 min (for nucleophilic substitution); column chromatography on silica gel eluting with petroleum ether/CH_2Cl_2/EtOAc (gradient from 80:18:2 to 70:27:3) to give **1** as an orange powder (75 mg, 74%). Some starting material was recovered (20 mg, 22%): mp 130.1−130.5 °C; ^{1}H NMR (300 MHz, $CDCl_3$) δ = 1.04 (t, 3H, ^3J = 7.7 Hz), 1.10 (t, 3H, ^3J = 7.5 Hz), 1.21 (t, 3H, ^3J = 7.1 Hz), 2.33 (s, 6H), 2.40 (q, 2H, ^3J = 7.6 Hz), 2.51 (s, 3H), 2.53 (q, 2H, ^3J = 7.5 Hz), 2.61 (s, 3H), 3.58 (q, 2H, ^3J = 7.0 Hz), 4.8 (s, 2H); ^{13}C NMR {^{1}H} (75.4 MHz, $CDCl_3$) δ = 12.8, 14.3, 14.6, 14.9, 15.2, 15.5, 17.2, 17.3, 17.4, 64.0, 65.9, 131.5, 132.8, 133.4, 133.7, 136.1, 138.2, 141.4, 148.7, 154.9; ^{11}B NMR (128.4 MHz, $CDCl_3$) δ = 0.59 (t, J_{B-F} = 33.4 Hz); UV−vis (CH_2Cl_2) λ nm (ε, M^{-1} cm^{-1}) 519 (65100), 492 (sh, 26900), 373 (8200); EI-MS m/z 362.1 (100), 317.1 (20). Anal. Calcd for $C_{20}H_{29}BF_2N_2O$: C, 66.31; H, 8.07; N, 7.73. Found: C, 66.28; H, 8.02; N, 7.54.

Compound **2**. Prepared according to the general procedure; from **BOD-1** (105 mg, 0.33 mmol), NBS (117 mg, 0.66 mmol), CH_2Cl_2 (2 mL), ethanol (5 mL), and without DMF; stirred for 30 min (for nucleophilic substitution); column chromatography on silica gel eluting with petroleum ether/CH_2Cl_2/EtOAc (gradient from 80:18:2 to 70:27:3) to give **2** as red-orange needles (51 mg, 38%): mp 141.5−141.7 °C; ^{1}H NMR (300 MHz, $CDCl_3$) δ = 1.10 (t, 6H, ^3J = 7.5 Hz), 1.21 (t, 6H, ^3J = 7.1 Hz), 2.35 (s, 6H), 2.54 (q, 4H, ^3J = 7.5 Hz), 2.66 (s, 3H), 3.57 (q, 4H, ^3J = 7.0 Hz), 4.79 (s, 4H); ^{13}C NMR {^{1}H} (75.4 MHz, $CDCl_3$) δ = 14.5, 15.1, 15.4, 17.4, 17.6, 64.2, 66.1, 132.4, 134.4,

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138.0, 143.4, 151.6; ^{11}B NMR (128.4 MHz, $CDCl_3$) δ = 0.49 (t, J_{B-F} = 33.4 Hz); UV−vis (CH_2Cl_2) λ nm (ε, M^{-1} cm^{-1}): 521 (71300), 495 (sh, 29900), 380 (8200); EI-MS *m*/*z* 406.1 (100), 387.1 (30). Anal. Calcd for $C_{22}H_{33}BF_2N_2O_2$: C, 65.03; H, 8.19; N, 6.89. Found: C, 64.89; H, 7.89; N, 6.75.

Compound **3**. Prepared according to the general procedure; from **BOD-2** (150 mg, 0.3 mmol), NBS (53 mg, 0.3 mmol), CH_2Cl_2 (8 mL), ethanol (5 mL), and without DMF; stirred for 15 min (for nucleophilic substitution); dried over hydrophilic cellulose instead of $MgSO_4$; column chromatography on silica gel eluting with petroleum ether/CH_2Cl_2(80:20) to give **3** as red shiny crystals (155 mg, 95%): mp 157.5−157.8 °C; ^{1}H NMR (300 MHz, $CDCl_3$) δ = 0.98 (t, 3H, ^3J = 7.4 Hz), 1.03 (t, 3H, ^3J = 7.2 Hz), 1.23 (t, 3H, ^3J = 7.1 Hz), 1.32 (s, 3H), 1.33 (s, 3H), 2.30 (q, 2H, ^3J = 7.6 Hz), 2.43 (q, 2H, ^3J = 7.5 Hz), 2.54 (s, 3H), 3.61 (q, 2H, ^3J = 7.0 Hz), 4.79 (s, 2H), 7.44 (AB sys, 4H, J_{AB} = 8.1 Hz, $\nu_o\delta$ = 241.6 Hz); ^{13}C NMR {^{1}H} (75.4 MHz, $CDCl_3$) δ = 11.9, 12.2, 12.9, 14.6, 14.9, 15.4, 17.2, 17.3, 64.0, 66.2, 94.7, 130.3, 131.6, 134.0, 134.3, 135.3, 138.1, 138.5, 139.8, 140.0, 150.9, 157.3; ^{11}B NMR (128.4 MHz, $CDCl_3$) δ = 3.72 (t, J_{B-F} = 33.0 Hz); UV−vis (CH_2Cl_2) λ nm (ε, M^{-1} cm^{-1}) 526 (65200), 501 (sh, 27200), 386 (8200); EI-MS, *m*/*z* 550.0 (100), 531.1 (35), 512.0 (15). Anal. Calcd for $C_{25}H_{30}BF_2IN_2O$: C, 54.57; H, 5.50; N, 5.09. Found: C, 54.24; H, 5.29; N, 4.89.

Compound **4**. Prepared according to the general procedure; from **BOD-2** (50 mg, 0.10 mmol), NBS (35 mg, 0.20 mmol), CH_2Cl_2 (4 mL), ethanol (2 mL), and without DMF; stirred for 15 min (for nucleophilic substitution); extracted with CH_2Cl_2 and dried over hydrophilic cellulose; column chromatography on silica gel eluting with petroleum ether/CH_2Cl_2 (gradient from 70:30 to 0:100) to give **4** as red-orange needles (60 mg, 99%). This compound can be recrystallized by evaporation in CH_2Cl_2/MeOH: mp 119.3−119.6 °C; ^{1}H NMR (300 MHz, $CDCl_3$) δ = 1.02 (t, 6H, ^3J = 7.5 Hz), 1.23 (t, 6H, ^3J = 7.0 Hz), 1.34 (s, 6H), 2.43 (q, 4H, ^3J = 7.5 Hz), 3.60 (q, 4H, ^3J = 7.0 Hz), 4.80 (s, 4H), 7.45 (AB sys, 4H, J_{AB} = 8.37 Hz, $\nu_o\delta$ = 247.0 Hz); ^{13}C NMR {^{1}H} (75.4 MHz, $CDCl_3$) δ = 12.1, 14.7, 15.4, 17.4, 64.2, 66.4, 94.9, 130.1, 131.2, 135.0, 135.1, 138.6, 139.9, 141.7, 153.8. ^{11}B NMR (128.4 MHz, $CDCl_3$) δ = 3.62 (t, J_{B-F} = 33.4 Hz); UV−vis (CH_2Cl_2) λ nm (ε, M^{-1} cm^{-1}) 529 (67200), 500 (sh, 26800), 389 (9200); EI-MS, *m*/*z* 594.0 (100), 575.0 (25). Anal. Calcd for $C_{27}H_{34}BF_2IN_2O_2$: C, 54.57; H, 5.77; N, 4.71. Found: C, 54.43; H, 5.65; N, 4.64.

Compound **5**. Prepared according to the general procedure; from **BOD-2** (60 mg, 0.12 mmol), NBS (21 mg, 0.12 mmol), CH_2Cl_2 (1 mL), DMF (2 mL), and ethylene glycol (2 mL); stirred for 1 h (for nucleophilic substitution); column chromatography on silica gel eluting with petroleum ether/EtOAc (70:30) to give **5** as orange amorphous solid (56 mg, 83%): ^{1}H NMR (300 MHz, $CDCl_3$) δ = 0.99 (t, 3H, ^3J = 7.5 Hz), 1.03 (t, 3H, ^3J = 7.4 Hz), 1.33 (s, 3H), 1.34 (s, 3H), 2.31 (q, 2H, ^3J = 7.5 Hz), 2.41 (q, 2H, ^3J = 7.5 Hz), 2.55 (s, 3H), 3.69−3.76 (m, 4H), 4.78 (s, 2H), 7.45 (AB sys, 4H, J_{AB} = 8.5 Hz, $\nu_o\delta$ = 243.0 Hz); ^{13}C NMR {^{1}H} (75.4 MHz, $CDCl_3$) δ = 12.0, 12.3, 13.1, 14.5, 15.2, 17.2, 17.3, 61.8, 63.6, 71.9, 94.8, 130.2, 130.5, 132.2, 133.7, 134.9, 135.2, 137.6, 138.5, 140.3, 140.6, 148.6, 158.7; ^{11}B NMR (128.4 MHz, $CDCl_3$) δ = 3.74 (t, J_{B-F} = 32.7 Hz); UV−vis (CH_2Cl_2) λ nm (ε, M^{-1} cm^{-1}) 525 (55300), 501 (sh, 24700), 382 (7200); EI-MS *m*/*z* 566.1 (100), 547.1 (35). Anal. Calcd for $C_{25}H_{30}BF_2IN_2O_2{\cdot}H_2O$: C, 51.39; H, 5.52; N, 4.79. Found: C, 51.11; H, 5.37; N, 4.48.

Compound **6**. Prepared according to the general procedure; from **BOD-2** (200 mg, 0.40 mmol), NBS (140 mg, 0.80 mmol), CH_2Cl_2 (8 mL), DMF (6 mL), and ethylene glycol (440 μL, 8.0 mmol); stirred overnight (for nucleophilic substitution); column chromatography on silica gel eluting with petroleum ether/EtOAc (gradient from 80:20 to 0:100) to give **6** as a deep-red powder (130 mg, 53%): mp 153.0−153.5 °C; ^{1}H NMR (300 MHz, $CDCl_3$) δ = 1.02 (t, 6H, ^3J = 7.5 Hz), 1.35 (s, 6H), 2.41 (q, 4H, ^3J = 7.5 Hz), 2.53 (br s, 2H), 3.68−3.75 (m, 8H), 4.79 (s, 4H), 7.45 (AB sys, 4H, J_{AB} = 8.3 Hz, $\nu_o\delta$ = 249.9 Hz); ^{13}C NMR {^{1}H} (75.4 MHz, $CDCl_3$) δ = 12.2, 15.0, 17.2, 61.7, 63.6, 72.1, 95.1, 129.9, 131.6, 134.8, 135.0, 138.7, 140.3, 142.5, 152.7; ^{11}B NMR (128.4 MHz, $CDCl_3$) δ = 0.64 (t, J_{B-F} = 32.7 Hz); EI-MS *m*/*z* 626.1 (100). Anal. Calcd for $C_{27}H_{34}BF_2IN_2O_4{\cdot}2H_2O$: C, 48.96; H, 5.78; N, 4.23. Found: C, 48.77; H, 5.52; N, 4.07.

Compound **7**. Prepared according to the general procedure; from **BOD-2** (50 mg, 0.10 mmol), NBS (18 mg, 0.10 mmol), CH_2Cl_2 (2 mL), DMF (2 mL), and 1,2:3,4-di-*O*-isopropylidene-D-galactopyranose (129 mg, 0.49 mmol); stirred for 24 h (for nucleophilic substitution); extraction with CH_2Cl_2 and dried over hydrophilic cotton; column chromatography on silica gel eluting with petroleum ether/EtOAc (90:10) to give **7** as a red powder (42 mg, 56%). The conversion was not complete, and 30% of bromo derivative was still present: mp >180 °C dec; ^{1}H NMR (300 MHz, $CDCl_3$) δ = 0.98 (t, 3H, ^3J = 7.5 Hz), 1.01 (t, 3H, ^3J = 7.5 Hz), 1.32 (br.s, 12H), 1.44 (s, 3H), 1.54 (s, 3H), 2.30 (q, 2H, ^3J = 7.5 Hz), 2.43 (q, 2H, ^3J = 7.5 Hz), 2.52 (s, 3H), 3.71−3.75 (m, 2H), 4.06 (dt, 1H, ^3J = 6.5 Hz, ^3J = 1.8 Hz), 4.28−4.31 (m, 2H), 4.58 (dd, 1H, ^3J = 7.9 Hz, ^4J = 2.2 Hz), 4.85 (AB sys, 2H, J_{AB} = 11.1 Hz, $\nu_o\delta$ = 19.9 Hz), 5.54 (d, 1H, ^3J = 4.9 Hz), 7.44 (AB sys, 4H, J_{AB} = 8.1 Hz, $\nu_o\delta$ = 240.7 Hz); ^{13}C NMR {^{1}H} (75.4 MHz, $CDCl_3$) δ = 11.9, 12.3, 13.0, 14.6, 15.0, 17.2, 17.3, 24.6, 25.2, 26.1, 26.2, 64.3, 66.5, 69.0, 70.9, 71.3, 94.8, 96.5, 108.7, 109.3, 130.3, 134.2, 134.4, 135.4, 138.0, 138.5, 139.9, 140.1, 150.2, 157.5; ^{11}B NMR (128.4 MHz, $CDCl_3$) δ = 0.66 (t, J_{B-F} = 32.7 Hz); UV−vis (CH_2Cl_2) λ nm (ε, M^{-1} cm^{-1}) 527 (63700), 502 (sh, 28300), 385 (7600); EI-MS *m*/*z* 764.1 (100), 505.1 (20). Anal. Calcd for $C_{35}H_{44}BF_2IN_2O_6$: C, 54.99; H, 5.80; N, 3.66. Found: C, 54.75; H, 5.62; N, 3.54.

Compound **8**. Prepared according to the general procedure; from **BOD-2** (165 mg, 0.33 mmol), NBS (116 mg, 0.66 mmol), CH_2Cl_2 (2 mL), DMF (3 mL), and 1,2:3,4-di-*O*-isopropylidene-D-galactopyranose (424 mg, 1.63 mmol); stirred for 24 h (for nucleophilic substitution); column chromatography on silica gel eluting with petroleum ether/EtOAc (90:10) to give **8** as an orange powder (117 mg, 35%): mp 169.2−169.7 °C; ^{1}H NMR (300 MHz, $CDCl_3$) δ = 1.01 (t, 6H, ^3J = 7.5 Hz), 1.32 (br.s, 18H), 1.44 (s, 6H), 1.54 (s, 6H), 2.44 (q, 4H, ^3J = 7.4 Hz), 3.72 (d, 4H, ^3J = 6.0 Hz), 4.05 (t, 2H, ^3J = 6.2 Hz), 4.26−4.31 (m, 4H), 4.58 (dd, 2H, ^3J = 7.9 Hz, ^4J = 2.3 Hz), 4.85 (AB sys, 4H, J_{AB} = 13.0 Hz, $\nu_o\delta$ = 21.4 Hz), 5.54 (d, 2H, ^3J = 5.3 Hz), 7.45 (AB sys, 4H, J_{AB} = 8.3 Hz, $\nu_o\delta$ = 246.1 Hz); ^{13}C NMR {^{1}H} (75.4 MHz, $CDCl_3$) δ = 12.1, 14.5, 17.3, 24.6, 25.1, 26.2, 64.5, 66.5, 69.2, 70.8, 71.2, 94.9, 96.5, 108.6, 109.3, 130.0, 131.2, 135.1, 138.6, 139.9, 141.8, 153.3; ^{11}B NMR (128.4 MHz, $CDCl_3$) δ = 0.54 (t, J_{B-F} = 33.4 Hz); UV−vis (CH_2Cl_2) λ nm (ε, M^{-1} cm^{-1}) 530 (65000), 504 (sh, 26800), 391 (8500); EI-MS *m*/*z* calcd for opened galactose 1026.4, found 1026.2 (100), 847.2 (25), 345.8 (10). Anal. Calcd for $C_{47}H_{62}BF_2IN_2O_{12}$: C, 55.20; H, 6.11; N, 2.74. Found: C, 55.91; H, 5.82; N, 2.57.

Compound **9**. Prepared according to the general procedure; from **BOD-2** (73 mg, 0.14 mmol), NBS (26 mg, 0.14 mmol), CH_2Cl_2 (2 mL), DMF (2 mL), and water (0.5 mL); stirred 45 min (for nucleophilic substitution); this compound did not require chromatographic purification and was recrystallized by evaporation in CH_2Cl_2/cyclohexane to give **9** as red crystals (64 mg, 85%): mp >240 °C dec; ^{1}H NMR (200 MHz, $CDCl_3$) δ = 1.00 (t, 3H, ^3J = 7.8 Hz), 1.04 (t, 3H, ^3J = 7.8 Hz), 1.34 (s, 3H), 1.35 (s, 3H), 2.32 (q, 2H, ^3J = 7.6 Hz), 2.40 (q, 2H, ^3J = 7.7 Hz), 2.55 (s, 3H), 4.76 (s, 2H), 7.46 (AB sys, 4H, J_{AB} = 8.6 Hz, $\nu_o\delta$ = 161.3 Hz); ^{13}C NMR {^{1}H} (50.1 MHz, $CDCl_3$) δ = 12.0, 12.4, 13.0, 14.5, 15.6, 17.1, 17.2, 55.2, 94.9, 130.2, 130.5, 132.7, 132.9, 134.8, 135.1, 137.8, 138.6, 140.3, 140.7, 151.4, 158.4; UV−vis (CH_2Cl_2) λ nm (ε, M^{-1} cm^{-1}) 527 (61900), 502 (sh, 27700), 388 (7400); EI-MS *m*/*z* 522.0 (100), 505.1 (20). Anal. Calcd for $C_{23}H_{26}BF_2IN_2O{\cdot}H_2O$: C, 51.14; H, 5.22; N, 5.19. Found: C, 51.02; H, 4.97; N, 4.84.

Compound **10**. Prepared according to the general procedure; from **BOD-2** (50 mg, 0.10 mmol), NBS (35 mg, 0.20 mmol), CH_2Cl_2 (2 mL), DMF (2 mL), and water (1 mL); stirred 2 h (for nucleophilic substitution); this compound did not require chromatographic purification and was recrystallized by evaporation in CH_2Cl_2/cyclohexane to give **10** as a lustrous red crystal (42 mg, 79%): mp >230 °C dec; ^{1}H NMR (200 MHz, $CDCl_3$) δ = 1.05 (t, 6H, ^3J = 7.7 Hz), 1.39 (s, 6H), 2.42 (q, 4H, ^3J = 7.6 Hz), 2.69 (br.s, 2H), 4.78 (s, 4H), 7.48 (AB sys, 4H, J_{AB} = 8.3 Hz, $\nu_o\delta$ = 165.3 Hz); ^{13}C NMR {^{1}H} (75.4 MHz, $CDCl_3$) δ = 12.3, 15.4, 17.1, 55.2, 95.2, 129.9, 131.9,

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134.4, 134.7, 136.7, 140.7, 142.7, 155.0; UV−vis (CH_2Cl_2) λ nm (ε, M^{-1} cm^{-1}): 531 (63600), 506 (sh, 27000), 400 (8500); EI-MS m/z 538.0 (100). Anal. Calcd for $C_{23}H_{26}BF_2IN_2O_2{\cdot}2H_2O$: C, 48.11; H, 5.27; N, 4.88. Found: C, 47.90; H, 4.90; N, 4.66.

Compound **11**. Prepared according to the general procedure; from **BOD-2** (50 mg, 0.10 mmol), NBS (18 mg, 0.10 mmol), CH_2Cl_2 (2 mL), 4,5-dimethoxy-2-nitrobenzyl alcohol (63 mg, 0.30 mmol), and DMF (1 mL); stirred for 3 days at rt and 15 h at 40 °C (for nucleophilic substitution); column chromatography on silica gel eluting with petroleum ether/EtOAc (90:10) to give **11** as a deep-red gum (20 mg, 28%): ^{1}H NMR (200 MHz, $CDCl_3$) δ = 0.99 (t, 3H, ^3J = 8.8 Hz), 1.03 (t, 3H, ^3J = 8.6 Hz), 1.33 (s, 3H), 1.34 (s, 3H), 2.31 (q, 2H, ^3J = 8.6 Hz), 2.45 (q, 2H, ^3J = 8.7 Hz), 2.52 (s, 3H), 3.95 (s, 3H), 4.00 (s, 3H), 4.90 (s, 2H), 5.08 (s, 2H), 7.46 (AB sys, 4H, J_{AB} = 8.4 Hz, $\nu_o\delta$ = 160.1 Hz), 7.47 (s, 1H), 7.70 (s, 1H); ^{13}C NMR {^{1}H} (50.2 MHz, $CDCl_3$) δ = 11.9, 12.3, 13.0, 14.5, 15.2, 17.2, 17.3, 56.5, 56.6, 64.3, 70.0, 94.9, 107.9, 110.1, 130.2, 131.5, 135.2, 138.5, 139.3, 140.3, 140.5, 147.6, 148.5, 154.0, 158.5; ^{11}B NMR (128.4 MHz, $CDCl_3$) δ = 0.72 (t, J_{B-F} = 33.3 Hz); UV−vis (CH_2Cl_2) λ nm (ε, M^{-1} cm^{-1}) 526 (59800), 502 (sh, 27300), 361 (12200); EI-MS m/z 717.1 (100), 505.1 (20). Anal. Calcd for $C_{32}H_{35}BF_2IN_3O_5$: C, 53.58; H, 4.92; N, 5.86. Found: C, 53.27; H, 4.72; N, 5.64.

Compound **12**. Prepared according to the general procedure; from **BOD-2** (50 mg, 0.10 mmol), NBS (18 mg, 0.10 mmol), CH_2Cl_2 (2 mL), thiophenemethanol (46 μL, 0.50 mmol), and DMF (1 mL); stirred for 24 h (for nucleophilic substitution); extracted with CH_2Cl_2 and dried over hydrophilic cellulose instead of $MgSO_4$; column chromatography on silica gel eluting with petroleum ether/CH_2Cl_2 (gradient from 70:30 to 50:50) to give **12** as a red powder (24 mg, 40%): mp 144.6−144.8 °C; ^{1}H NMR (300 MHz, $CDCl_3$) δ = 0.99 (t, 3H, ^3J = 7.5 Hz), 1.01 (t, 3H, ^3J = 7.4 Hz), 1.33 (s, 3H), 1.34 (s, 3H), 2.32 (q, 2H, ^3J = 7.5 Hz), 2.41 (q, 2H, ^3J = 7.5 Hz), 2.56 (s, 3H), 4.78 (s, 2H), 4.8623 (s, 2H), 6.96 (dd, 1H, ^3J = 5.1 Hz, ^4J = 3.4 Hz), 7.05 (m, 1H), 7.27 (dd, 1H, ^3J = 4.3 Hz, ^4J = 1.9 Hz), 7.45 (AB sys, 4H, J_{AB} = 8.4 Hz, $\nu_o\delta$ = 240.2 Hz); ^{13}C NMR {^{1}H} (75.4 MHz, $CDCl_3$) δ = 11.9, 12.3, 13.0, 14.6, 15.0, 17.2, 17.3, 63.6, 67.2, 94.8, 125.8, 126.6, 126.7, 130.3, 130.4, 131.8, 134.1, 134.5, 135.3, 138.0, 138.5, 140.1, 141.3, 149.9, 157.7; ^{11}B NMR (128.4 MHz, $CDCl_3$) δ = 0.72 (t, J_{B-F} = 32.7 Hz); UV−vis (CH_2Cl_2) λ nm (ε, M^{-1} cm^{-1}) 527 (62100), 501 (sh, 26200), 386 (7200); EI-MS m/z 618.0 (100), 505.1 (20). Anal. Calcd for $C_{28}H_{30}BF_2IN_2OS$: C, 54.39; H, 4.89; N, 4.53. Found: C, 54.15; H, 4.62; N, 4.22.

Compound **13**. Prepared according to the general procedure; from **BOD-2** (60 mg, 0.12 mmol), NBS (42 mg, 0.24 mmol), CH_2Cl_2 (2 mL), thiophenemethanol (300 μL), and DMF (1 mL); stirred for 36 h (for nucleophilic substitution); column chromatography on silica gel eluting with petroleum ether/CH_2Cl_2/EtOAc (80:18:2) to give **13** as a red powder (46 mg, 53%): mp 143.5−143.9 °C; ^{1}H NMR (200 MHz, $CDCl_3$) δ = 1.00 (t, 6H, ^3J = 7.5 Hz), 1.34 (s, 6H), 2.42 (q, 4H, ^3J = 7.4 Hz), 4.78 (s, 4H), 4.88 (s, 4H), 6.95−7.07 (m, 6H), 7.28 (dd, 2H, ^3J = 5.1 Hz, ^4J = 1.1 Hz), 7.87 (d, 2H, ^3J = 8.4 Hz); ^{13}C NMR {^{1}H} (50.2 MHz, $CDCl_3$) too insoluble to be measured currently; ^{11}B NMR (128.4 MHz, $CDCl_3$) δ = 0.65 (t, J_{B-F} = 34.0 Hz); UV−vis (CH_2Cl_2) λ nm (ε, M^{-1} cm^{-1}) 531 (66000), 504 (sh, 26600), 396 (8000); EI-MS m/z 730.0 (100), 711.1 (20). Anal. Calcd for $C_{33}H_{34}BF_2IN_2O_2S_2$: C, 54.26; H, 4.69; N, 3.83. Found: C, 53.93; H, 4.51; N, 3.52.

Compound **14**. Prepared according to the general procedure; from **BOD-2** (100 mg, 0.20 mmol), NBS (35 mg, 0.20 mmol), CH_2Cl_2 (4 mL), DMF (3 mL), and allyl alcohol (0.5 mL, 7.31 mmol); stirred overnight (for nucleophilic substitution); column chromatography on silica gel eluting with petroleum ether/CH_2Cl_2 (gradient from 50:50 to 40:60) to give **14** as a red-orange solid (70 mg, 67%): mp 123.5−124.0 °C; ^{1}H NMR (300 MHz, $CDCl_3$) δ = 0.98 (t, 3H, ^3J = 7.5 Hz), 1.02 (t, 3H, ^3J = 7.5 Hz), 1.32 (s, 3H), 1.33 (s, 3H), 2.31 (q, 2H, ^3J = 7.5 Hz), 2.43 (q, 2H, ^3J = 7.5 Hz), 2.55 (s, 3H), 4.09 (d, 2H, ^3J = 5.7 Hz), 4.80 (s, 2H), 5.17 (dd, 1H, ^3J = 10.4 Hz, ^4J = 0.9 Hz), 5.31 (dd, 1H, ^3J = 17.3 Hz, ^4J = 1.5 Hz), 5.97 (ddt, 1H, $^3J_1$ = 17.3 Hz, $^3J_2$ = 10.53 Hz, $^3J_3$ = 5.7 Hz), 7.45 (AB sys, 4H, J_{AB} = 8.1 Hz, $\nu_o\delta$ = 240.7 Hz); ^{13}C NMR {^{1}H} (75.4 MHz, $CDCl_3$) δ = 11.9, 12.3, 13.0, 14.6, 14.9, 17.2, 17.3, 63.7, 71.6, 94.8, 117.0, 130.2, 131.7, 134.0, 134.4, 135.0, 135.3, 138.0, 138.5, 140.0, 140.1, 150.4, 157.5; ^{11}B NMR (128.4 MHz, $CDCl_3$) δ = 0.69 (t, J_{B-F} = 33.4 Hz); UV−vis (CH_2Cl_2) λ nm (ε, M^{-1} cm^{-1}) 527 (61600), 501 (sh, 25900), 388 (6800); EI-MS m/z 562.0 (100), 505.1 (20). Anal. Calcd for $C_{26}H_{30}BF_2IN_2O$: C, 55.54; H, 5.38; N, 4.98. Found: C, 55.22; H, 4.99; N, 4.62.

Compound **15**. Prepared according to the general procedure; from **BOD-2** (60 mg, 0.12 mmol), NBS (21 mg, 0.12 mmol), CH_2Cl_2 (2 mL), DMF (2 mL), and propargyl alcohol (120 μL, 1.20 mmol); stirred for 36 h (for nucleophilic substitution); column chromatography on silica gel eluting with petroleum ether/CH_2Cl_2 (gradient from 50:50 to 40:60) to give **15** as deep red crystals (42 mg, 63%): mp 158.0−158.6 °C; ^{1}H NMR (300 MHz, $CDCl_3$) δ = 0.99 (t, 3H, ^3J = 7.7 Hz), 1.04 (t, 3H, ^3J = 7.5 Hz), 1.33 (s, 3H), 1.34 (s, 3H), 2.31 (q, 2H, ^3J = 7.5 Hz), 2.43 (q, 2H, ^3J = 7.4 Hz), 2.45 (t, 1H, ^3J = 2.6 Hz), 2.55 (s, 3H), 4.25 (d, 2H, ^3J = 2.3 Hz), 4.84 (s, 2H), 7.45 (AB sys, 4H, J_{AB} = 7.9 Hz, $\nu_o\delta$ = 242.8 Hz); ^{13}C NMR {^{1}H} (75.4 MHz, $CDCl_3$) δ = 11.9, 12.3, 13.1, 14.5, 15.1, 17.2, 17.3, 58.0, 63.2, 74.5, 80.1, 94.8, 130.2, 135.2, 138.5, 140.2, 140.3, 140.9, 141.6, 148.7, 153.8; ^{11}B NMR (128.4 MHz, $CDCl_3$) δ = 0.68 (t, J_{B-F} = 33.5 Hz); EI-MS m/z 560.1 (100). Anal. Calcd for $C_{26}H_{28}BF_2IN_2O$: C, 55.74; H, 5.04; N, 5.00. Found: C, 55.68; H, 4.92; N, 4.95.

Compound **16**. Prepared according to the general procedure; from **BOD-2** (200 mg, 0.40 mmol), NBS (140 mg, 0.80 mmol), CH_2Cl_2 (4 mL), DMF (3 mL), and propargyl alcohol (240 μL, 4.00 mmol); stirred for 15 h at rt and 2 days at 40 °C (for nucleophilic substitution); column chromatography on silica gel eluting with petroleum ether/CH_2Cl_2/EtOAc (70:27:3) to give **16** as a red powder (20 mg, 8%): mp 112.5−112.8 °C; ^{1}H NMR (300 MHz, $CDCl_3$) δ = 1.03 (t, 6H, ^3J = 7.5 Hz), 1.35 (s, 6H), 2.44 (q, 4H, ^3J = 7.6 Hz), 2.47 (t, 2H, ^3J = 2.5 Hz), 4.25 (d, 4H, ^3J = 2.2 Hz), 4.86 (s, 4H), 7.45 (AB sys, 4H, J_{AB} = 8.1 Hz, $\nu_o\delta$ = 249.3 Hz); ^{13}C NMR {^{1}H} (75.4 MHz, $CDCl_3$) δ = 12.1, 14.9, 17.3, 58.2, 63.3, 74.7, 79.8, 95.1, 129.9, 131.5, 134.9, 135.3, 138.7, 140.2, 142.3, 152.5; ^{11}B NMR (128.4 MHz, $CDCl_3$) δ = 0.57 (t, J_{B-F} = 33.2 Hz); UV−vis (CH_2Cl_2) λ nm (ε, M^{-1} cm^{-1}) 530 (64000), 505 (sh, 27200), 394 (8800); EI-MS m/z 614.1 (100). Anal. Calcd for $C_{29}H_{30}BF_2IN_2O_2$: C, 56.70; H, 4.92; N, 4.56. Found: C, 56.62; H, 4.83; N, 4.47.

Compound **17**. Prepared according to the general procedure; from **BOD-2** (55 mg, 0.11 mmol), NBS (19 mg, 0.11 mmol), CH_2Cl_2 (2 mL), DMF (2 mL), and dodecanethiol (260 μL, 1.10 mmol); stirred for 5 min (for nucleophilic substitution); column chromatography on silica gel eluting with petroleum ether/CH_2Cl_2 (70:30) to give **17** as a red gum (52 mg, 68%): ^{1}H NMR (200 MHz, $CDCl_3$) δ = 0.88 (t, 3H, ^3J = 6.5 Hz), 0.97 (t, 3H, ^3J = 7.7 Hz), 1.05 (t, 3H, ^3J = 7.4 Hz), 1.25 (s, 18H), 1.32 (s, 6H), 1.50−1.65 (m, 2H), 2.30 (q, 2H, ^3J = 7.6 Hz), 2.42 (q, 2H, ^3J = 7.6 Hz), 2.54 (s, 3H), 2.69 (t, 2H, ^3J = 7.3 Hz), 4.01 (s, 2H), 7.44 (AB sys, 4H, J_{AB} = 8.1 Hz, $\nu_o\delta$ = 158.6 Hz); ^{13}C NMR {^{1}H} (50.2 MHz, $CDCl_3$) δ = 12.1, 12.2, 12.9, 14.2, 14.8, 17.2, 17.4, 22.8, 27.6, 29.0, 29.4, 29.5, 29.7, 29.8, 32.1, 33.2, 34.3, 94.7, 130.3, 131.3, 133.2, 133.9, 135.4, 138.4, 138.6, 139.2, 152.2, 156.2; UV−vis (CH_2Cl_2) λ nm (ε, M^{-1} cm^{-1}) 533 (70700), 509 (sh, 27000), 384 (8400); EI-MS m/z 706.1 (100), 505.1 (20). Anal. Calcd for $C_{35}H_{50}BF_2IN_2S$: C, 59.50; H, 7.13; N, 3.96. Found: C, 59.75; H, 7.37; N, 3.72.

Compound **18**. Prepared according to the general procedure; from **BOD-2** (1 g, 1.98 mmol), NBS (350 mg, 1.98 mmol), CH_2Cl_2 (25 mL), DMF (20 mL), and diethylamine (1.5 mL); stirred for 30 min (for nucleophilic substitution); column chromatography on silica gel eluting with CH_2Cl_2/AcOEt/AcOH (90:10:1) then with CH_2Cl_2/EtOAc (gradient from 70:30 to 30:70) to give **18** as a deep red powder (800 mg, 70%): mp 142.5−143.7 °C; ^{1}H NMR (300 MHz, $CDCl_3$) δ = 0.97 (t, 3H, ^3J = 7.5 Hz), 1.01 (t, 3H, ^3J = 7.4 Hz), 1.05 (t, 6H, ^3J = 7.0 Hz), 1.32 (s, 6H), 2.30 (q, 2H, ^3J = 7.6 Hz), 2.49−2.59 (m, 9H), 3.88 (s, 2H), 7.45 (AB sys, 4H, J_{AB} = 8.5 Hz, $\nu_o\delta$ = 232.4 Hz); ^{13}C NMR {^{1}H} (75.4 MHz, $CDCl_3$) δ = 12.0, 12.1, 12.3, 12.8, 14.5, 14.7, 17.2, 17.3, 47.5, 50.7, 94.6, 130.5, 133.4, 134.9, 135.6, 138.4, 139.0, 154.6, 156.2; ^{11}B NMR (128.4 MHz, $CDCl_3$) δ = 3.79 (t, J_{B-F} = 33.2 Hz); UV−vis (EtOH + NEt_3) λ nm (ε, M^{-1} cm^{-1}) 527 (72800), 503 (sh, 27000), 384 (8300); UV−vis (EtOH + HCl) λ nm (ε, M^{-1} cm^{-1}) 517 (39300), 499 (sh, 30300), 383 (8400); EI-MS m/z 578.2 (100, M

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+ H), 558.2 (25). Anal. Calcd for $C_{27}H_{35}BF_2IN_3$: C, 56.17; H, 6.11; N, 7.28. Found: C, 56.32; H, 6.38; N, 7.42.

Compound **19**. Prepared according to the general procedure; from **BOD-2** (50 mg, 0.10 mmol), NBS (35 mg, 0.20 mmol), CH_2Cl_2 (5 mL), diethylamine (1.5 mL), and without DMF; stirred for 15 min (for nucleophilic substitution) the solution stayed deep red; extracted with CH_2Cl_2 and dried over hydrophilic cotton; column chromatography on silica gel eluting with CH_2Cl_2/MeOH (gradient from 100:0 to 95:5) to give **19** as a deep red powder (53 mg, 83%): mp >150 °C dec; ^{1}H NMR (300 MHz, $CDCl_3$) δ = 0.99 (t, 6H, ^3J = 7.4 Hz), 1.04 (t, 12H, ^3J = 7.2 Hz), 1.31 (s, 6H), 2.53 (q, 4H, ^3J = 7.2 Hz), 2.55 (q, 8H, ^3J = 6.4 Hz), 3.89 (s, 4H), 7.46 (AB sys, 4H, J_{AB} = 8.3 Hz, $\nu_o\delta$ = 228.6 Hz); ^{13}C NMR {^{1}H} (75.4 MHz, $CDCl_3$) δ = 12.0, 12.3, 14.5, 17.3, 47.5, 50.7, 94.7, 130.5, 135.1, 135.6, 138.4, 139.2, 139.3, 156.4; ^{11}B NMR (128.4 MHz, $CDCl_3$) δ = 3.75 (t, J_{B-F} = 33.6 Hz); UV−vis (EtOH + NBu_4OH) λ nm (ε, M^{-1} cm^{-1}) 531 (70000), 505 (sh, 25800), 387 (8500); UV−vis (EtOH + HCl) λ nm (ε, M^{-1} cm^{-1}) 532 (46800), 507 (sh, 24000), 426 (9400), 395 (9800); EI-MS *m*/*z* 649.2 (100, M + H), 648.2 (80). Anal. Calcd for $C_{31}H_{44}BF_2IN_4$: C, 57.42; H, 6.84; N, 8.64. Found: C, 55.72; H, 6.69; N, 8.19.

Compound **20**. Prepared according to the general procedure; from **BOD-2** (100 mg, 0.20 mmol), NBS (35 mg, 0.20 mmol), CH_2Cl_2 (4 mL), DMF (3 mL), and ethyl iminodiacetate (110 μL, 0.60 mmol); stirred overnight (for nucleophilic substitution); column chromatography on silica gel eluting with petroleum ether/CH_2Cl_2 (gradient from 30:70 to 20:80) to give **20** as a red glassy solid (117 mg, 85%): ^{1}H NMR (300 MHz, $CDCl_3$) δ = 0.97 (t, 3H, ^3J = 7.4 Hz), 1.01 (t, 3H, ^3J = 7.4 Hz), 1.27 (t, 6H, ^3J = 7.2 Hz), 1.31 (s, 6H), 2.29 (q, 2H, ^3J = 7.5 Hz), 2.51 (s, 3H), 2.54 (q, 2H, ^3J = 7.6 Hz), 3.58 (s, 4H), 4.17 (q, 4H, ^3J = 6.8 Hz), 4.20 (s, 2H), 7.45 (AB sys, 4H, J_{AB} = 8.2 Hz, $\nu_o\delta$ = 236.5 Hz); ^{13}C NMR {^{1}H} (75.4 MHz, $CDCl_3$) δ = 12.0, 12.2, 12.9, 14.4, 14.5, 14.6, 17.1, 17.2, 50.3, 54.8, 60.5, 94.7, 130.3, 131.2, 134.0, 134.9, 135.4, 138.4, 138.6, 139.4, 139.6, 152.0, 156.3, 171.3; ^{11}B NMR (128.4 MHz, $CDCl_3$) δ = 0.66 (t, J_{B-F} = 33.4 Hz); UV−vis (CH_2Cl_2) λ nm (ε, M^{-1} cm^{-1}) 530 (62100), 502 (sh, 24000), 386 (7300); EI-MS *m*/*z* 693.1 (100), 505.1 (25). Anal. Calcd for $C_{31}H_{39}BF_2IN_3O_4$: C, 53.70; H, 5.67; N, 6.06. Found: C, 53.52; H, 5.40; N, 5.84.

Compound **21**. Prepared according to the general procedure; from **BOD-2** (100 mg, 0.20 mmol), NBS (70 mg, 0.40 mmol), CH_2Cl_2 (4 mL), DMF (3 mL), and ethyl iminodiacetate (220 μL, 1.20 mmol); stirred for 2 days (for nucleophilic substitution); column chromatography on silica gel eluting with petroleum ether/EtOAc (gradient from 85:15 to 80:20) to give **21** as a red gum (147 mg, 85%): ^{1}H NMR (300 MHz, $CDCl_3$) δ = 1.00 (t, 6H, ^3J = 7.4 Hz), 1.27 (t, 12H, ^3J = 7.1 Hz), 1.32 (s, 6H), 2.55 (q, 4H, ^3J = 7.4 Hz), 3.56 (s, 8H), 4.17 (q, 8H, ^3J = 7.2 Hz), 4.20 (s, 4H), 7.46 (AB sys, 4H, J_{AB} = 8.4 Hz, $\nu_o\delta$ = 235.7 Hz); ^{13}C NMR {^{1}H} (75.4 MHz, $CDCl_3$) δ = 12.1, 14.3, 14.4, 17.1, 50.6, 54.9, 60.5, 94.8, 130.2, 130.9, 135.3, 135.7, 138.5, 139.8, 140.7, 154.1, 171.1; ^{11}B NMR (128.4 MHz, $CDCl_3$) δ = 3.57 (t, J_{B-F} = 33.5 Hz); UV−vis (CH_2Cl_2) λ nm (ε, M^{-1} cm^{-1}) 533 (65600), 510 (sh, 26800), 386 (9700); EI-MS *m*/*z* 880.1 (100), 793.2 (15). Anal. Calcd for $C_{39}H_{52}BF_2IN_4O_8$: C, 53.20; H, 5.95; N, 6.36. Found: C, 53.04; H, 5.86; N, 6.29.

Compound **22**. Prepared according to the general procedure; from **BOD-2** (50 mg, 0.10 mmol), NBS (18 mg, 0.10 mmol), CH_2Cl_2 (2 mL), DMF (2 mL), and sodium azide (50 mg, 0.77 mmol); stirred for 1 h (for nucleophilic substitution); column chromatography on silica gel eluting with petroleum ether/CH_2Cl_2 (gradient from 80:20 to 70:30) to give **22** as an orange solid (50 mg, 90%): mp 161.5−161.9 °C; ^{1}H NMR (300 MHz, $CDCl_3$) δ = 0.99 (t, 3H, ^3J = 7.52 Hz), 1.04 (t, 3H, ^3J = 7.7 Hz), 1.35 (s, 3H), 1.36 (s, 3H), 2.32 (q, 2H, ^3J = 7.5 Hz), 2.38 (q, 2H, ^3J = 7.7 Hz), 2.57 (s, 3H), 4.58 (s, 2H), 7.47 (AB sys, 4H, J_{AB} = 8.3 Hz, $\nu_o\delta$ = 240.5 Hz); ^{13}C NMR {^{1}H} (75.4 MHz, $CDCl_3$) δ = 12.0, 12.4, 13.2, 14.5, 15.1, 17.2, 17.3, 45.3, 94.9, 130.2, 132.5, 133.2, 135.1, 135.3, 137.4, 138.6, 140.3, 141.1, 145.3, 159.6; ^{11}B NMR (128.4 MHz, $CDCl_3$) δ = 0.66 (t, J_{B-F} = 32.7 Hz); UV−vis (CH_2Cl_2) λ nm (ε, M^{-1} cm^{-1}) 526 (54200), 502 (sh, 26600), 486 (7400); EI-MS *m*/*z* 547.1 (30), 506.1 (100, M − N3). Anal. Calcd for $C_{23}H_{25}BF_2IN_5$: C, 50.48; H, 4.61; N, 12.80. Found: C, 50.22; H, 4.40; N, 12.59.

Compound **23**. Prepared according to the general procedure; from **BOD-2** (50 mg, 0.10 mmol), NBS (35 mg, 0.20 mmol), CH_2Cl_2 (2 mL), DMF (2 mL), and sodium azide (115 mg, 1.77 mmol); stirred for 1 h (for nucleophilic substitution); column chromatography on silica gel eluting with petroleum ether/CH_2Cl_2 (gradient from 60:40 to 50:50) to give **23** as luster red crystals (50 mg, 86%): mp 104.2−104.5 °C, dec >114 °C; ^{1}H NMR (300 MHz, $CDCl_3$) δ = 1.04 (t, 6H, ^3J = 7.6 Hz), 1.39 (s, 6H), 2.39 (q, 4H, ^3J = 7.6 Hz), 4.60 (s, 4H), 7.49 (AB sys, 4H, J_{AB} = 8.4 Hz, $\nu_o\delta$ = 244.6 Hz); ^{13}C NMR {^{1}H} (75.4 MHz, $CDCl_3$) δ = 12.3, 14.8, 17.2, 45.3, 95.3, 129.8, 131.7, 134.6, 134.8, 138.8, 140.9, 143.1, 150.3; ^{11}B NMR (128.4 MHz, $CDCl_3$) δ = 3.57 (t, J_{B-F} = 33.3 Hz); UV−vis (CH_2Cl_2) λ nm (ε, M^{-1} cm^{-1}) 532 (61600), 506 (sh, 26400), 395 (8800); IR (ATR, cm^{-1}) 2967.8, 2929.5, 2870.7, 2175.4, 2097.6, 1586.2, 1534.5, 1413.9, 1385.6, 1319.9, 1278.9, 1212.9, 1173.9, 1150.6, 1060.9, 1048.6, 1004.9, 966.8, 885.5, 863.5; EI-MS *m*/*z* 588.1 (20), 546.2 (50, M − N3), 504.1 (100, M − 2N3). Anal. Calcd for $C_{23}H_{24}BF_2IN_8$: C, 46.96; H, 4.11; N, 19.05. Found: C, 46.67; H, 3.78; N, 18.50.

Compound **24**. Prepared according to the general procedure; from **BOD-2** (100 mg, 0.20 mmol), NBS (35 mg, 0.20 mmol), CH_2Cl_2 (4 mL), DMF (3 mL), and triethylphosphite (200 μL, 1.20 mmol); stirred for 20 min. (for nucleophilic substitution); extracted with CH_2Cl_2; column chromatography on silica gel eluting with petroleum ether/EtOAc (gradient from 70:30 to 60:40) to give **24** as a red glassy solid (108 mg, 85%): ^{1}H NMR (200 MHz, $CDCl_3$) δ = 0.98 (t, 3H, ^3J = 7.5 Hz), 1.00 (t, 3H, ^3J = 7.7 Hz), 7.26 (t, 6H, ^3J = 7.1 Hz), 1.33 (s, 6H), 2.30 (q, 2H, ^3J = 7.6 Hz), 2.50 (q, 2H, ^3J = 7.5 Hz), 1.33 (s, 3H), 3.63 (d, 2H, $^2J_{P-H}$ = 24.1 Hz), 4.12 (dq, 4H, $^3J_{H-H}$ = 6.9 Hz, $^3J_{P-H}$ = 6.9 Hz), 7.44 (AB sys, 4H, J_{AB} = 7.9 Hz, $\nu_o\delta$ = 159.6 Hz). ^{13}C NMR {^{1}H} (75.4 MHz, $CDCl_3$) δ = 12.2, 12.3, 13.0, 14.4, 14.6, 16.4 (d, $^3J_{C-P}$ = 4.4 Hz), 17.1, 17.2, 26.9 (d, $^1J_{C-P}$ = 104.2 Hz), 62.4 (d, $^2J_{C-P}$ = 4.9 Hz), 94.8, 130.4, 130.8, 131.4, 133.9, 133.9, 134.1, 135.3, 138.4, 138.6, 139.3, 139.5, 145.4, 145.5, 156.7; ^{11}B NMR (128.4 MHz, $CDCl_3$) δ = 0.74 (t, J_{B-F} = 33.4 Hz). UV−vis (CH_2Cl_2) λ nm (ε, M^{-1} cm^{-1}) 530 (76000), 504 (sh, 27900), 387 (7500); EI-MS *m*/*z* 642.1 (100), 543.2 (15). Anal. Calcd for $C_{27}H_{35}BF_2IN_2O_3P.H_2O$: C, 49.11; H, 5.65; N, 4.24. Found: C, 48.82; H, 5.42; N, 4.02

Compound **25**. Prepared according to the general procedure; from **BOD-2** (50 mg, 0.10 mmol), NBS (35 mg, 0.20 mmol), CH_2Cl_2 (2 mL), DMF (2 mL), and triethyl phosphite (200 μL, 1.20 mmol); stirred for 5 h (for nucleophilic substitution); column chromatography on silica gel eluting with petroleum ether/AcOEt (gradient from 60:40 to 0:100) then with EtOAc/EtOH (98:2) to give monophosphonate **24** (40 mg, 63%) and **25** (16 mg, 21%) as a red glassy solid: ^{1}H NMR (200 MHz, $CDCl_3$) δ = 0.99 (t, 6H, ^3J = 7.4 Hz), 1.29 (t, 12H, ^3J = 7.1 Hz), 1.33 (s, 6H), 2.49 (q, 4H, ^3J = 7.3 Hz), 3.64 (d, 4H, $^2J_{P-H}$ = 23.1 Hz), 4.12 (dq, 8H, $^3J_{H-H}$ = 7.3 Hz, $^3J_{P-H}$ = 7.3 Hz), 7.45 (AB sys, 4H, J_{AB} = 8.2 Hz, $\nu_o\delta$ = 160.6 Hz); ^{13}C NMR {^{1}H} (75.4 MHz, $CDCl_3$) δ = 12.3, 14.4, 16.5, 17.0, 27.1 (d, $^1J_{C-P}$ = 143.3 Hz), 62.6, 95.0, 130.2, 130.3, 131.6, 134.7, 134.8, 135.1, 137.7, 138.5, 140.8, 147.8; ^{11}B NMR (128.4 MHz, $CDCl_3$) δ = 0.70 (t, J_{B-F} = 33.4 Hz); UV−vis (CH_2Cl_2) λ nm (ε, M^{-1} cm^{-1}) 535 (67300), 511 (sh, 24600), 389 (7300); EI-MS *m*/*z* 778.2 (100), 753.1 (50), 688.1 (20). Anal. Calcd for $C_{31}H_{44}BF_2IN_2O_6P_2$ (crystallized with $2H_2O$): C, 45.72; H, 5.94; N, 3.44. Found: C, 45.49; H, 5.72; N, 3.17.

Compound **26**. Prepared according to the general procedure; from **2** (40 mg, 0.07 mmol), NBS (13 mg, 0.07 mmol), CH_2Cl_2 (2 mL), DMF (2 mL), and diethylamine (500 μL); stirred for 2 h (for nucleophilic substitution); column chromatography on silica gel eluting with CH_2Cl_2/MeOH (gradient from 100:0 to 97:3) to give **26** (8 mg, 18%) as a red amorphous solid: ^{1}H NMR (300 MHz, $CDCl_3$) δ = 0.97−1.07 (m, 12H), 1.23 (t, 3H, ^3J = 7.0 Hz), 1.32 (s, 3H), 1.33 (s, 3H), 2.42 (q, 2H, ^3J = 7.5 Hz), 2.54 (q, 2H, ^3J = 7.3 Hz), 2.55 (q, 4H, ^3J = 7.3 Hz), 3.60 (q, 2H, ^3J = 7.0 Hz), 3.90 (s, 2H), 4.79 (s, 2H), 7.45 (AB sys, 4H, J_{AB} = 8.3 Hz, $\nu_o\delta$ = 138.4 Hz); ^{13}C NMR {^{1}H} (75.4 MHz, $CDCl_3$) δ = 11.9, 12.1, 12.2, 14.4, 14.9, 17.2, 17.3, 47.6, 50.1, 64.1, 66.2, 94.8, 130.3, 131.4, 134.2, 135.4, 135.9, 138.4, 138.5, 140.4, 140.5, 151.3. ^{11}B NMR (128.4 MHz, $CDCl_3$) δ = 0.66 (t,

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J_{B-F} = 34.0 Hz); EI-MS m/z 622.1 (100, $[M + H]^+$), 621.1 (30, $[M]$). Anal. Calcd for $C_{29}H_{39}BF_2IN_3O$: C, 56.06; H, 6.33; N, 6.76. Found: C, 55.82; H, 6.18; N, 6.44.

Compound 27. To a solution of **22** (30 mg, 0.05 mmol) and 3-(2-methoxyethoxy)prop-1-yne (8 μL, 0.06 mmol) in a mixture of CH_2Cl_2/EtOH/H_2O (2:2:2 mL) were added $CuSO_4$ (5 mol %) and sodium ascorbate (10 mol %). The solution was stirred at 60 °C overnight, extracted with CH_2Cl_2, washed with water (3×), dried over $MgSO_4$, and evaporated. The residue was purified by column chromatography on silica gel, eluting with CH_2Cl_2/EtOAc (gradient from 100:0 to 70:30) to give **27** as an orange powder (32 mg, 88%): mp 91.3−93.9 °C; ^{1}H NMR (300 MHz, $CDCl_3$) δ = 0.73 (t, 3H, ^3J = 7.5 Hz), 1.01 (t, 3H, ^3J = 7.5 Hz), 1.30 (s, 3H), 1.38 (s, 3H), 2.34 (q, 2H, ^3J = 7.4 Hz), 2.36 (q, 2H, ^3J = 7.5 Hz), 2.58 (s, 3H), 3.34 (s, 3H), 3.51−3.54 (m, 2H), 3.63−3.66 (m, 2H), 4.64 (s, 2H), 5.80 (s, 2H), 7.47 (AB sys, 4H, J_{AB} = 8.4 Hz, $\nu_o\delta$ = 242.1 Hz), 7.89 (s, 1H); ^{13}C NMR {^{1}H} (75.4 MHz, $CDCl_3$) δ = 11.9, 12.5, 13.2, 14.5, 14.6, 16.9, 17.2, 45.1, 59.1, 64.8, 69.5, 71.9, 95.1, 123.7, 130.0, 130.2, 132.7, 133.5, 134.8, 135.7, 137.7, 138.6, 140.7, 141.7, 143.0, 145.1, 160.4; ^{11}B NMR (128.4 MHz, $CDCl_3$) δ = 0.79 (t, J_{B-F} = 33.6 Hz); UV−vis (CH_2Cl_2) λ nm (ε, M^{-1} cm^{-1}) 523 (48500), 500 (sh, 27500), 385 (8200); EI-MS m/z 661.1 (100), 543.6 (20). Anal. Calcd for $C_{29}H_{35}BF_2IN_5O_2$: C, 52.67; H, 5.33; N, 10.59. Found: C, 52.44; H, 5.21; N, 10.34.

Compound 28. To a solution of **22** (30 mg, 0.05 mmol) in DMF (1.5 mL) were added 1-ethynyl-4-iodobenzene (12.5 mg, 0.06 mmol) and CuI (1 mg, 10 mol %). The reaction mixture was stirred at room temperature for 36 h and at 80 °C for 1 h (until complete consumption of starting material, monitored by TLC). The solution was extracted with EtOAc, washed with water (6×) and NaCl (1×), dried over $MgSO_4$, and evaporated. The residue was purified by column chromatography on silica gel, eluting with CH_2Cl_2/ EtOAc (gradient from 100:0 to 90:10) to give **28** as an orange powder (35 mg, 83%): mp >210 °C dec; ^{1}H NMR (300 MHz, $CDCl_3$) δ = 0.76 (t, 3H, ^3J = 7.5 Hz), 1.02 (t, 3H, ^3J = 7.5 Hz), 1.30 (s, 3H), 1.38 (s, 3H), 2.35 (q, 2H, ^3J = 7.7 Hz), 2.40 (q, 2H, ^3J = 7.7 Hz), 2.61 (s, 3H), 5.85 (s, 2H), 7.46 (AB sys, 4H, J_{AB} = 8.3 Hz, $\nu_o\delta$ = 242.4 Hz), 7.63 (AB sys, 4H, J_{AB} = 8.6 Hz, $\nu_o\delta$ = 39.1 Hz), 8.12 (s, 1H); ^{13}C NMR {^{1}H} (75.4 MHz, $CDCl_3$) δ = 11.9, 12.5, 13.3, 14.5, 14.6, 16.9, 17.2, 45.2, 93.4, 95.2, 120.7, 127.5, 130.0, 130.2, 130.5, 132.8, 133.6, 134.7, 135.8, 137.7, 137.9, 138.7, 140.8, 141.9, 142.8, 147.0, 160.5; UV−vis (CH_2Cl_2) λ nm (ε, M^{-1} cm^{-1}) 524 (51600), 501 (sh, 27800), 388 (7400), 262 (31200); EI-MS m/z 775.1 (100), 675.2 (15). Anal. Calcd for $C_{31}H_{30}BF_2I_2N_5$: C, 48.03; H, 3.90; N, 9.03. Found: C, 47.74; H, 3.72; N, 8.64.

■ ASSOCIATED CONTENT

Supporting Information

Proton and carbon NMR traces for all compounds. Absorption, emission, and excitation spectra for compounds **1**−**5**, **7**−**14**, **16**, **17**, **20**−**25**, **27**, and **28**. This material is available free of charge via the Internet at http://pubs.acs.org.

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Notes

The authors declare no competing financial interest.

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