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ARTICLE

An expeditious method to synthesize difluoroboron complexes of β-keto amides from β-keto nitriles and BF_3·OEt_2

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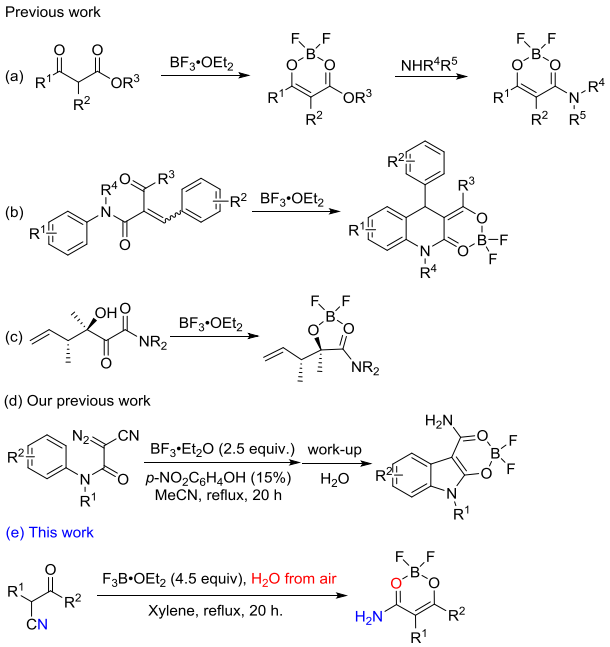
A convenient and expeditious strategy to synthesize difluoroboron complexes of β-keto amides has been developed from β-keto nitriles and BF_3·OEt_2. BF_3·OEt_2 serves as both BF_2 source and Lewis acid catalyst in the synthetic strategy. The formation mechanism of the difluoroboron complexes from β-keto nitriles and BF_3·OEt_2 was proposed. The difluoroboron complexes can be further converted into β-keto amides with treatment of sodium acetate. The strategy features advantages of wide substrate scope, non-metal catalysis, and easy operation. Some of difluoroboron complexes display good fluorescent properties in solid state and potential application in solid-state luminescent materials.

Introduction

Difluoroboron complexes have attracted considerable attention in the area of organic chemistry, biomedical and material sciences because of their highly thermal stability, excellent electronic and photophysical properties.[1] Recently, difluoroboron complexes of *N*,*N*- and *N*,*O*-based ligands have been intensively investigated.[2] To *O*,*O*-ligand-based difluoroboron complexes, much work has focused on difluoroboron complexes of β-diketonates[3] and β-keto esters.[4] Notably, synthetic and application studies on difluoroboron complexes of β-keto amides are very limited to date.[4b,5-7] General synthetic methods mainly involve aminolysis of difluoroboron complexes of β-keto esters with amines, while difluoroboron complexes of β-keto esters can be easily obtained by treating β-keto esters with boron trifluoride etherate (BF_3·OEt_2) (Scheme 1, a).[4b,5] Furthermore, difluoroboron complexes of fused polycyclic β-keto amides are prepared through the BF_3·OEt_2-mediated intramolecular cyclization of *N*-aryl-α-arylmethylene-β-ketoamides (Scheme 1, b).[6] In addition, difluoroboron complexes of α-hydroxy amides are generated via the stereospecific BF_3-mediated α-ketol rearrangement of β-hydroxy-α-ketoamides (Scheme 1, c).[7] So far, photophysical properties of difluoroboron complexes of β-keto amides have not been reported till now. Moreover, the electrophilicity of their carbonyl group is enhanced when it chelates with BF_2 group. By application of the enhanced electrophilicity, Štefane's group focused on the synthetic application of *O*,*O*-ligand-based difluoroboron complexes and found that they had been successfully used in the synthesis of enaminones, pyrazoles, β-keto amides, β-enamino carboxamides, and pyrazolones.[4,5] Christoffers and his co-workers also reported a regioselective enamine formation via β-diketonatoboron difluorides and their application in the asymmetric Michael reaction.[8]



Scheme 1. Synthesis of difluoroboron complexes of β-keto amides.

In our previous work,[9] we found that, when BF_3·OEt_2 was used as both a catalyst and reactant in the presence of 4-nitrophenol as an additive in acetonitrile, 2-cyano-2-diazoacetanilides underwent a carbene aromatic C-H insertion to generate 3-cyanooxindoles. Subsequent hydrolysis of the cyano group and difluoroboronation of the two carbonyl groups afforded the corresponding difluoroboron complexes of 2-oxoindoline-3-carboxamides (Scheme 1, d).[9] To develop an expeditious and general method for the synthesis of

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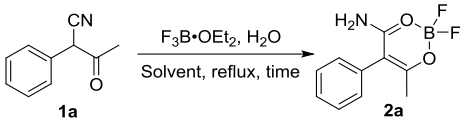
Electronic Supplementary Information (ESI) available: [Copies of ^1H, ^{13}C, and ^{19}F NMR and HRMS spectra of products **2** and **3**. See DOI: 10.1039/x0xx00000x

difluoroboron complexes of β-keto amides, we conducted reactions of β-keto nitriles and $BF_3{\cdot}OEt_2$ and realized convenient preparation of difluoroboron complexes of β-keto amides in refluxing xylene under open air conditions (Scheme 1, e). Additionally, some of difluoroboron complexes display good fluorescent properties in solid state, showing their potential application in solid-state luminescent materials. Herein, we present our results.

Results and Discussions

Optimization on the preparation of difluoroboron complexes of β-keto amides

Table 1. Optimization on the reaction conditions[a]



Entry	$BF_3{\cdot}OEt_2$ (equiv.)	Solvent	Time (h)	Yields (%)
1	2	MeCN	20	7
2	2.5	MeCN	20	12
3	3	MeCN	20	20
4	3.5	MeCN	20	21
5	4	MeCN	20	25
6	4.5	MeCN	20	29
7	5	MeCN	20	23
8[b]	4.5	MeCN	20	trace
9	4.5	DCM	20	trace
10	4.5	DCE	20	22
11	4.5	THF	20	NR
12	4.5	Toluene	12	42
13	4.5	Xylene	12	81
14	4.5	Mesitylene	12	74
15	**4.5**	**Xylene**	**20**	**88**
16	3.5	Xylene	20	67
17	2.5	Xylene	20	56
18[c]	4.5	Xylene	20	7
19[d]	4.5	Xylene	20	77

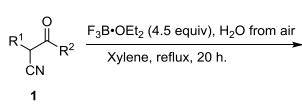
[a] Reactions were carried out on a 0.5 mmol scale of **1a** under open air. All yields are isolated yields. [b] Sealed at 81 °C. [c] Conducted under N_2 atmosphere conditions in xylene dried with Na. [d] 15 mol% of 4-nitrophenol was added as an additive.

We first employed 3-oxo-2-phenylbutanenitrile (**1a**) as a model substrate to optimize reaction conditions and the results were summarized in Table 1. Initially, substrate **1a** (0.5 mmol) was treated with $BF_3{\cdot}OEt_2$ (1 mmol) in refluxing MeCN under open air conditions for 20 h, and the desired product 2,2-difluoro-6-methyl-5-phenyl-2*H*-1,3λ^3,2λ^4-dioxaborinin-4-amine (**2a**) was obtained in a yield of 7% (Table 1, Entry 1). To improve the yield of product **2a**, the amount of $BF_3{\cdot}OEt_2$ was tested. The yield of **2a** was slightly improved with increase of the amount of $BF_3{\cdot}OEt_2$ and the yield reached 29% when 4.5 equivalents of $BF_3{\cdot}OEt_2$ were employed (Table 1, Entries 2–7). Sealed reaction was also attempted at 81 °C and just trace amount of the desired product **2a** was obtained (Table 1, Entry 8). Moreover, different solvents were screened. When the reaction was performed in a low-boiling solvent, such as DCM, the desired product **2a** was obtained in very low yield (Table 1, Entry 9). In DCE, whose boiling point is similar to that of MeCN, a similar yield was obtained as that in MeCN (Table 1, Entry 10). No product was obtained except for some unidentified compounds when THF was employed possible because it is hard bases and can easily chelate with hard acid BF_3 (Table 1, Entry 11). With the above results in hand, we thought that non-chelating and high boiling point solvents should be suitable solvents for the reaction. Thus, toluene, xylene, and mesitylene were selected. When toluene, xylene, and mesitylene were evaluated, the yield was greatly improved by refluxing the mixture for 12 h only, and the highest yield was obtained in xylene (Table 1, Entries 12–14). The yield was further improved to 88% when reaction time was extended from 12 h to 20 h in refluxing xylene (Table 1, Entry 15). To examine whether the lower amount of $BF_3{\cdot}OEt_2$ in xylene can get better yields, 3.5 and 2.5 equivalents of $BF_3{\cdot}OEt_2$ were evaluated and the yields of 67% and 56% were obtained, respectively (Table 1, Entries 16 and 17), indicating that 4.5 equivalents of $BF_3{\cdot}OEt_2$ were necessary. However, only 7% yield was obtained in anhydrous solvent under N_2 atmosphere (Table 1, Entry 18), revealing that water should be necessary in this reaction. Eventually, 15 mol% of 4-nitrophenol was added as an additive just like that in our previous work,[9] yield was not improved further (Table 1, Entry 19).

Preparation of difluoroboron complexes of β-keto amides

With the optimized conditions in hand, the scope and generality of this reaction were investigated and the results are illustrated in Table 2. Firstly, different 3-oxo-2-phenylalkanenitriles **1a**-**e** were investigated. only 3-oxo-2-phenylpropanenitrile (**1b**) gave product **2b** in a relatively lower yield of 66%. Linear 3-oxo-2-phenylpentanenitrile (**1c**), branched 4-methyl-3-oxo-2-phenylpentanenitrile (**1d**), and 3-oxo-2,4-diphenylbutanenitrile (**1e**) were converted into the corresponding products **2c**-**e** in good to excellent yields from 82% to 93%. The above results indicated that different 2-phenyl aliphatic β-keto nitriles are well suitable substrates to the reaction. Aromatic and heteroaromatic 3-aryl-3-oxo-2-phenylpropanenitiles **1f**-**h** were also checked. Representative 3-phenyl, 3-(furan-2-yl), and 3-(thiophen-2-yl)-3-oxo-2-phenylpropanenitriles (**1f**-**h**) generated the corresponding products **2f**-**h** in 80%, 71%, and 47% yields, respectively. 3-(Furan-2-yl)-3-oxo-2-phenylpropanenitrile (**1h**) led to a low yield because of the chelating action between boron trifluoride and the oxygen atom in furan. Furan shows stronger coordination with $BF_3{\cdot}OEt_2$ than thiophene because the oxygen atom in furan is a hard base and BF_3 is a hard acid. However, the sulfur atom in thiophene is a soft base.

Table 2. Preparation of difluoroboron complexes of β-keto amides[a]



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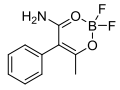
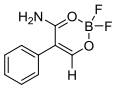
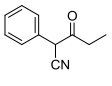
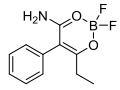
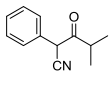
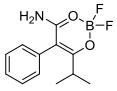
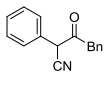
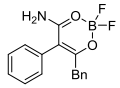
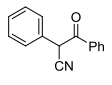
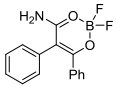
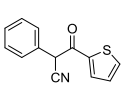
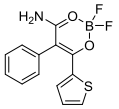
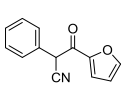
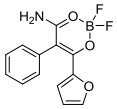
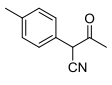
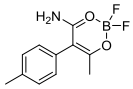
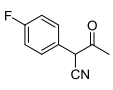
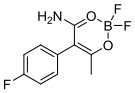
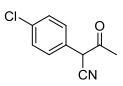
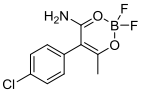
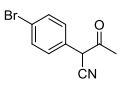
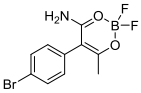
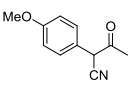
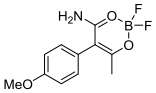
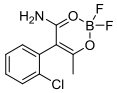
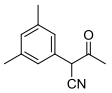
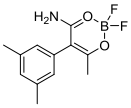
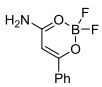
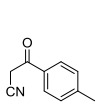
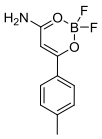
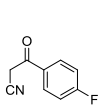
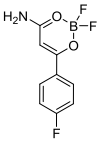
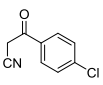
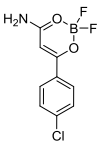
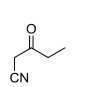
 1a	 2a 88%	 1b	 2b 66%
 1c	 2c 93%	 1d	 2d 82%
 1e	 2e 86%	 1f	 2f 80%
 1g	 2g 71%[b]	 1h	 2h 47%[c]
 1i	 2i 92%	 1j	 2j 77%
 1k	 2k 92%	 1l	 2l 94%
 1m	 2m 34%	 1n	 2n 74%
 1o	 2o 79%	 1p	 2p 77%
 1q	 2q 63%	 1r	 2r 68%
 1s	 2s 64%	 1t	2t 40%
1u	2u 48%	1v	2v 18%
1w	2w 10% + 2p 26%		

[a] All reactions were performed under the optimized conditions on a 0.5 mmol scale of compound **1** in 5 mL of xylene with yields of isolated products. [b] Refluxed for 40 h. [c] Refluxed for 28 h.

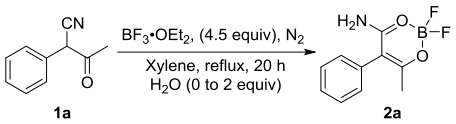
2-Aryl-3-oxobutanenitriles **1i**–**l**,**n**,**o** with 4-methyl, 4-fluoro, 4-chloro, 4-bromo, 2-chloro, and 3,5-dimethyl groups on the phenyl group produced the corresponding BF_2 complexes **2i**–**l**,**n**,**o** in 74–94% yields. But, 3-(4-methoxyphenyl)-3-oxobutanenitrile (**1m**) gave product **2m** in a low 34% yield due to the chelating action between boron trifluoride and the oxygen atom in the methoxy group as well. Furthermore, 3-aryl-3-oxopropanenitiles (**1p**–**s**) were also investigated. All of them produced the corresponding products **2p**–**s** in moderate yields (63%–77%). Aliphatic 3-oxopentanenitrile (**1t**) easily underwent this reaction as well, giving the corresponding product **2t** in a low yield of 40%. Additionally, 2-alkyl-3-oxo-3-phenylpropanenitriles **1u**–**w** were tested. The products **2u**–**w** were obtained in 48%, 18%, and 10% yields, respectively. To our surprise, when **1w** underwent the reaction under optimized conditions, it gave **2p** in 26% yield as the major product. These results feature the reaction with a wide substrate scope, but low to excellent yields.

Mechanistic investigation on the formation of difluoroboron complexes of β-keto amides

In our previous report,[9] the cyclic and rigid *cis*-β-keto nitriles can be converted into difluoroboron complexes of β-keto amides in acetonitrile as solvent and 4-nitrophenol as an additive. However, flexible linear β-keto nitriles, for example, 3-oxo-3-phenylpropanenitrile (**1p**), hardly work under those conditions. But they work very well in refluxing xylene without any additives. The results reveal that the flexible β-keto nitriles require strong reaction conditions, in non-coordinated solvent at higher temperature.

To understand the reaction mechanism, we performed water-controlled experiments (Table 3). The selected reaction of 3-oxo-2-phenylpropanenitrile (**1a**) and $BF_3{\cdot}OEt_2$ was refluxed in commercial xylene under open air for 20 h to afford product **2a** in 88% yield (Table 3, entry 1). The same reaction under nitrogen atmosphere afforded product **2a** in only 32% yield (Table 3, entry 2). However, when the reaction was refluxed in anhydrous xylene under nitrogen atmosphere or open air, the yield dropped to 7% and 58% (Table 3, entries 3 and 4). The results indicated that water was very important to the reaction and it came from undried solvent and environment. We further added 1 equiv., 1.3 equiv., and 1.5 equiv. of water into reaction mixture in anhydrous xylene under nitrogen atmosphere at the beginning of the reaction, the yield was improved to 33%, 42%, and 44%, respectively (Table 3, entries 5–7). Further increasing amount of water to 1.7 and 2.0 equiv. resulted in decrease of the yield to 28% and some white solid (boric acid) was observed (Table 3, entries 8 and 9). At last, we smoothly added 1 equiv., 1.2 equiv., and 1.5 equiv. of water into reaction mixture in anhydrous xylene under nitrogen atmosphere within 10 h with a syringe pump, and the product was obtained in yields of 42%, 67%, and 28%, respectively (Table 3, entries 10–12). The results indicated that 1.2 equiv. of water was suitable. When 1.2 equiv. of water was slowly added with the syringe pump in 5 h, the yield dropped to 17% (Table 3, entry 14), and the better yield of 76% was obtained for the addition in 20 h (Table 3, entry 13). An acceptable yield of 71% was observed when 1.2 equiv. of water was added into reaction mixture in commercial xylene under nitrogen atmosphere within 10 h with the syringe pump (Table 3, entry 15). The results suggest that addition of one equivalent or more than one equivalents of water at beginning of the reaction could not reach high yield and the high yield was realized by continuously slow addition of water (1.2 equiv.) along with the reaction in progress. That is the reason why the reaction gave the desired product **2a** in high yield under open air conditions, in which water came from environment continuously and slowly. More water in reaction mixture would result in the formation of fluoroboric acid and boric acid, and they should be not active species for the reaction.

Table 3. Water controlled experiments[a]

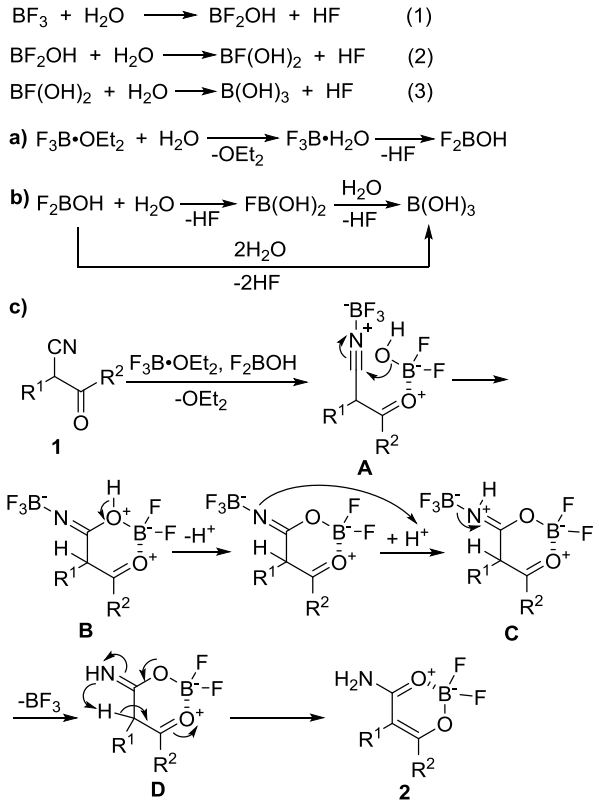


Entry	H_2O (equiv.)	Time (h)	Yield (%)
1[b]	0	20	88
2[c]	0	20	32
3[d]	0	20	58
4	0	20	7
5	1	20	33
6	1.3	20	42
7	1.5	20	44
8	1.7	20	28
9	2	20	28
10[e]	1	10	42
11[e]	1.2	10	67
12[e]	1.5	10	28
13[e]	1.2	20	76
14[e]	1.2	5	17
15[f]	1.2	10	71

[a] Reactions were carried out on a 0.5 mmol scale of **1a** under N_2 atmosphere in 5 mL of anhydrous xylene dried with Na. All yields are isolated yields. [b] Conducted in commercial xylene under open air. [c] Conducted in commercial xylene under N_2 atmosphere. [d] Conducted in anhydrous xylene under open air. [e] Carried out under N_2 atmosphere in 5 mL of anhydrous xylene and 0.2 mL of MeCN containing the indicated equivalent of water was slowly added with a syringe pump in the indicated time (Entries 10-14). [f] Carried out under N_2 atmosphere in 5 mL of commercial xylene and 0.2 mL of MeCN containing 1.2 equivalents of water was slowly added using a syringe pump in 20 h.

On the basis of previously reported results,[10] hydrolysis of BF_3 can be divided into three steps (Scheme 2, equations 1–3). Both difluoroboric acid (BF_2OH) and fluoroboric acid ($BF(OH)_2$) are intermediates generated from boron trifluoride and water and observed experimentally. Thus, we propose that difluoroboric acid should be an efficient boron species for our reactions and unstable in refluxing xylene with excess water. It is generated in

situ from boron trifluoride and water came slowly from environment and participates reaction immediately. If more water exists in reaction system, difluoroboric acid further reacts with water to yield fluoroboric acid, finally boric acid.[11] Neither fluoroboric acid nor boric acid should be efficient boron species for our reaction (Scheme 2).

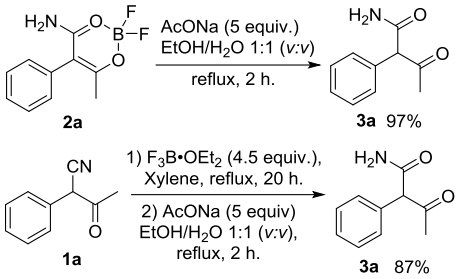


Scheme 2. Proposed mechanism for the preparation of difluoroboron complexes of β-keto amides from β-keto nitriles and $BF_3{\cdot}OEt_2$.

On the basis of previously reported[10] and our results, we propose the following mechanism for our reaction (Scheme 2). Boron trifluoride first reacts with trace amount of water in reaction system to afford difluoroboric acid (F_2BOH), which coordinates with the carbonyl group of substrates **1**. Another molecule of boron trifluoride coordinates with the cyano group in substrates **1** to generate intermediates **A**. The first coordination increases the nucleophilicity of the hydroxy group in difluoroboric acid and the second coordination enhances the electrophilicity of the cyano group. Thus, the hydroxy group readily undergoes an intramolecular nucleophilic addition to the activated cyano group in intermediates **A**, giving rise to intermediates **B**. After a proton transfer from the oxygen atom to the nitrogen atom, intermediates **B** become intermediates **C**. Intermediates **C** further lose boron trifluoride to produce intermediates **D**, which undergo electron and proton transfer to afford final products **2**.

Application of difluoroboron complexes of β-keto amides

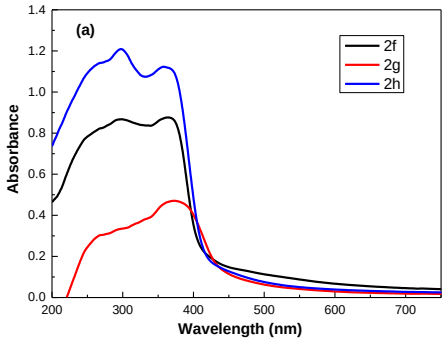
Compounds **2** can be considered as protected β-keto amides, which can be obtained after a suitable deprotection. Indeed, the treatment of compound **2a** with sodium acetate (5 equiv.) in boiling ethanol/water (1:1, *v*/*v*) for 2 h afforded a useful building block of β-keto amide **3a** in 97% yield (Scheme 3). The combined two reactions can be considered as a convenient method to convert β-keto nitriles into β-keto amides. To simplify hydrolysis procedures, this strategy was attempted in one-pot two steps mode and the desired β-keto amide **3a** was obtained in 87% yield (Scheme 3). This provides a convenient and mild method to synthesize useful building blocks of β-keto amides from β-keto nitriles.



Scheme 3. Preparation of β-keto amides from β-keto nitriles.

The fluorescent properties of β-keto amide difluoroboron complexes **2** were also investigated and mainly focused on three compounds **2f**, **2g**, and **2h**, which show strong fluorescence in solid state under 365 nm UV-light (Figure 1 (c)). These compounds have high fluorescence in solid state, whereas they have very weak fluorescence in dilute solutions possibly due to the aggregation-induced emission (AIE). UV–vis absorption and fluorescence spectra for the powders of **2f**, **2g**, and **2h** were investigated and the results are illustrated in Figure 1 and Table 4. The maximum absorption wavelengthes are 364 nm, 374 nm, and 317 nm, respectively, and the maximum emission wavelengths are 474 nm, 467 nm, and 466 nm, respectively.

The fluorescence quantum yields of **2f**, **2g**, and **2h** were determined as 10.4%, 35.5%, and 20.1%, respectively (Table 4). The fluorescent properties above show that some β-keto amide difluoroboron complexes possess good fluorescent properties in solid state, indicating their potential application in solid-state luminescent materials.



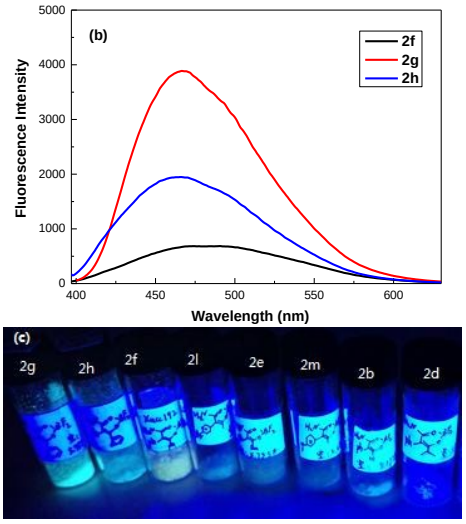


Figure 1. (a) UV-Vis absorption of compounds **2f-2h** in their powders; (b) Fluorescence spectra of compounds **2f-2h** in their powders (Ex Slit = 2.5 nm; Em Slit = 2.5 nm; PMT Voltage = 600 V). (c) Compounds **2b-h**,**l**,**m** possess strong fluorescence in solid state under 365 nm UV-light.

Table 4. Optical properties of **2f**, **2g**, and **2h** in their powders.

Compound	λ_{abs}^{max}/nm	λ_{ex}[a]/nm	λ_{em}^{max}/nm	QYs[b]/%
2f	364	370	474	10.4
2g	374	388	467	35.5
2h	317	389	466	20.1

[a] Excited wavelength. [b] Fluorescent quantum yields.

Conclusions

We have developed a convenient and efficient method to synthesize difluoroboron complexes of β-keto amides from various β-keto nitriles and BF_3·OEt_2. BF_3·OEt_2 works as both BF_2 source and Lewis acid catalyst. The strategy features advantages of wide substrate scope, non-metal catalysis, and easy operation. The formation mechanism of the difluoroboron complexes from β-keto nitriles and BF_3·OEt_2 was proposed on the basis of designed water-controlled experiments. The difluoroboron complexes can be converted into β-keto amides, revealing that the combined two reactions are a convenient method to convert β-keto nitriles into β-keto amides as well. Some of difluoroboron complexes of β-keto amides possess good fluorescent properties in solid state and potential application in solid-state luminescent materials.

Experimental

General Information

General Information. Melting points were measured on a Yanaco MP-500 melting point apparatus and are uncorrected. ^{1}H, ^{13}C, and ^{19}F NMR spectra were recorded on a Bruker 400 MHz spectrometer. Chemical shifts are reported in ppm with TMS as an internal standard. IR spectra (KBr pellets, ν [cm^{-1}]) were taken on a Nicolet 5700 FT-IR spectrometer. The high resolution mass spectra were obtained under ESI ionization using an agilent LC/MSD TOF mass spectrometer. UV-Vis absorption and fluorescence spectra were measured on commercial spectrophotometers. Fluorescence quantum yields were recorded on steady state transient fluorescence spectrometer. Column chromatography was carried out on silica gel (200–300 mesh) with petroleum ether (PE, 60 °C–90 °C) and ethyl acetate (EA) as the eluent. All reactions were followed by thin layer chromatography (TLC) where practical, using silica gel 60 F254 fluorescent treated silica gel plates, which were visualized under UV light (254 nm). Commercial grade reagents and solvents were used without further purification unless otherwise noted. β-Keto nitriles **1p-t** are commercially available.

General procedure for the preparation of β-keto nitriles 1a-o.

To a 50 mL three-necked flask equipped with a reflux condenser and a mechanical stirrer were added 7 mL of absolute ethanol and clean sodium (600 mg, 26 mmol), respectively. Then the last neck was sealed with a rubber seal and the resulting mixture was stirred until sodium dissolved. Phenylacetonitrile or substituted phenylacetonitrile (20 mmol) and ester (30 mmol) were added, respectively. The reaction mixture was refluxed for 2 h (if there was much solid precipitated, appropriate absolute ethanol was added to keep the reaction system suspension) and then stirred at room temperature overnight. If there was much solid precipitated, filtered under reduced pressure, the resulting crude product was washed with 3×10 mL of DCM, dissolved in 15 mL of water. 20 mL of EtOAc was added. Subsequently, 2 mol/L HCl was dropwise added under extremely shake until aqueous phase without any solid precipitated. The organic phase was separated and dried over anhydrous Na_2SO_4. Removal of solvent under reduced pressure afforded pure product **1a-o**. If there was little solid precipitated, water (15 mL) was added followed by the addition of 20 mL of EtOAc. Then 2 mol/L HCl was dropwise added under extremely shake until aqueous phase without any solid precipitated. The organic phase was separated and the aqueous phase was extracted with 20 mL of EtOAc. The combined organic phase was dried over anhydrous Na_2SO_4 and concentrated under reduced pressure. The resulting residue was purified by silica gel column chromatography with petroleum ether and ethyl acetate (PE/EA = 10/1, *v/v*) as eluent to give pure product **1a-o**. All products **1a-o** are known compounds and their analytical data are identical to previously reported ones.[13]

General procedure for the preparation of β-keto nitriles 1u-w.

To a solution of 3-oxo-3-phenylpropanenitrile (**1p**) (1 g, 6.89 mmol) in 10 mL of DMF was added 60% NaH (276 mg, 6.89 mmol) at 0 °C. The resulting mixture was stirred for 15 min. Methyl iodide (978 mg, 6.89 mmol) for **1u**, bromoethane (752 mg, 6.89 mmol) for **1v** or benzyl bromide (1.178 g, 6.89 mmol) for **1w** was added at 0 °C and the solution was stirred at room temperature for 1 h. After addition of EtOAc (20 mL) and water (20 mL), the organic layer was washed with 20 mL of water twice. The organic layer was dried over anhydrous sodium sulfate and

evaporated under reduced pressure. The crude product was purified by column chromatography to afford the corresponding products **1u-w**, respectively. Products **1u-w** are known compounds and their analytical data are identical to previously reported ones.[14]

General procedure for the preparation of difluoroboron complexes of β-keto amides 2

A solution of β-keto nitrile **1** (0.5 mmol) and $BF_3{\cdot}OEt_2$ (0.3 mL, 2.25 mmol) in 5 mL of xylene was refluxed for 20 h under open air. After cooling to room temperature, the system was directly purified by silica gel column chromatography with petroleum ether and ethyl acetate (PE/EA = 8/1, *v/v*) as eluent to give the pure difluoroboron complex of β-keto amide **2**.

2,2-Difluoro-6-methyl-5-phenyl-2*H*-1,3λ³,2λ⁴-dioxaborinin-4-amine (2a)

Colorless crystals, m.p. 148–151 °C. Yield: 99 mg, 88 %. ^{1}H NMR (400 MHz, $CDCl_3$) *δ*: 7.51–7.42 (m, 3H), 7.27–7.25 (m, 2H), 6.28 (s, 1H), 5.62 (s, 1H), 1.96 (s, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) *δ*: 178.5, 170.4, 131.5, 131.2, 129.9, 129.2, 100.9, 21.5. ^{19}F NMR (376 MHz, $CDCl_3$) *δ*: -142.8, -142.8. IR (KBr) *ν* (cm^{-1}): 705, 764, 1007, 1042, 1107, 1290, 1331, 1502, 1595, 1608, 1644, 3359, 3457. HRMS (ESI, *m/z*) calcd. for $C_{10}H_{10}BF_2NO_2Na^+$ ([M + Na]$^+$): 248.0665, found: 248.0664.

2,2-Difluoro-5-phenyl-2*H*-1,3λ³,2λ⁴-dioxaborinin-4-amine (2b)

Colorless crystals, m.p. 119–123 °C. Yield: 69 mg, 66 %. ^{1}H NMR (400 MHz, $CDCl_3$) *δ*: 7.48 (s, 1H), 7.43–7.35 (m, 3H), 7.24–7.19 (m, 2H), 6.59 (s, 1H), 6.11 (s, 1H). ^{13}C NMR (100 MHz, $CDCl_3$) *δ*: 170.4, 167.1, 130.0, 129.82, 129.75, 129.2, 104.6, 21.5. ^{19}F NMR (376 MHz, $CDCl_3$) *δ*: -141.1, -141.1, -142.4, 142.4. IR (KBr) *ν* (cm^{-1}): 704, 760, 776, 1039, 1098, 1142, 1298, 1342, 1459, 1492, 1508, 1561, 1618, 1648, 1654, 1686, 2922, 3361, 3464. HRMS (ESI, *m/z*) calcd. for $C_9H_8BF_2NO_2Na^+$ ([M + Na]$^+$): 234.0508, found: 234.0502.

6-Ethyl-2,2-difluoro-5-phenyl-2*H*-1,3λ³,2λ⁴-dioxaborinin-4-amine (2c)

Colorless crystals, m.p. 119–121 °C. Yield: 111 mg, 93 %. ^{1}H NMR (400 MHz, $CDCl_3$) *δ*: 7.51–7.42 (m, 3H), 7.27–7.25 (m, 2H), 6.30 (s, 1H), 5.59 (s, 1H), 2.19 (q, *J* = 7.6 Hz, 2H), 1.09 (t, *J* = 7.6 Hz, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) *δ*: 182.2, 170.6, 131.3, 131.2, 129.8, 129.2, 100.2, 27.7, 10.4. ^{19}F NMR (376 MHz, $CDCl_3$) *δ*: -142.6, -142.6. IR (KBr) *ν* (cm^{-1}): 705, 928, 1083, 1291, 1361, 1419, 1468, 1561, 1578, 1624, 1645, 2849, 2920, 3179, 3305, 3393, 3479. HRMS (ESI, *m/z*) calcd. for $C_{11}H_{12}BF_2NO_2Na^+$ ([M + Na]$^+$): 262.0821, found: 262.0830.

2,2-Difluoro-6-isopropyl-5-phenyl-2*H*-1,3λ³,2λ⁴-dioxaborinin-4-amine (2d)

Colorless crystals, m.p. 175–179 °C. Yield: 103 mg, 82 %. ^{1}H NMR (400 MHz, $CDCl_3$) *δ*: 7.51–7.43 (m, 3H), 7.26 (d, *J* = 6.8 Hz, 2H), 6.18 (s, 1H), 5.52 (s, 1H), 2.50 (heptet, *J* = 6.8 Hz, 1H), 1.09 (d, *J* = 6.8 Hz, 6H). ^{13}C NMR (100 MHz, $CDCl_3$) *δ*: 185.3, 170.9, 131.4, 131.3, 129.9, 129.2, 99.2, 32.1, 19.2. ^{19}F NMR (376 MHz, $CDCl_3$) *δ*: -143.4, -143.5. IR (KBr) *ν* (cm^{-1}): 978, 1035, 1075, 1142, 1180, 1255, 1280, 1341, 1384, 1458, 1509, 1589, 1605, 1638, 2852, 2924, 3358, 3464. HRMS (ESI, *m/z*) calcd. for $C_{12}H_{14}BF_2NO_2Na^+$ ([M + Na]$^+$): 276.0978, found: 276.0973.

6-Benzyl-2,2-difluoro-5-phenyl-2*H*-1,3λ³,2λ⁴-dioxaborinin-4-amine (2e)

Colorless crystals, m.p. 156–159 °C. Yield: 129 mg, 86 %. ^{1}H NMR (400 MHz, $CDCl_3$) *δ*: 7.50–7.46 (m, 3H), 7.26–7.20 (m, 5H), 7.05 (d, *J* = 6.8 Hz, 2H), 6.11 (s, 1H), 5.58 (s, 1H), 3.49 (s, 1H). ^{13}C NMR (100 MHz, $CDCl_3$) *δ*: 178.8, 170.9, 134.9, 131.6, 130.9, 129.9, 129.5, 128.9, 128.5, 127.0, 101.1, 40.4. ^{19}F NMR (376 MHz, $CDCl_3$) *δ*: -142.7, -142.8. IR (KBr) *ν* (cm^{-1}): 704, 765, 1027, 1047, 1142, 1180, 1283, 1335, 1385, 1416, 1454, 1470, 1494, 1538, 1557, 1593, 1634, 1644, 1650, 1657, 1682, 1699, 1715, 1730, 1738, 2850, 2921, 3365, 3465. HRMS (ESI, *m/z*) calcd. for $C_{16}H_{14}BF_2NO_2Na^+$ ([M + Na]$^+$): 324.0978, found: 324.0982.

2,2-Difluoro-5,6-diphenyl-2*H*-1,3λ³,2λ⁴-dioxaborinin-4-amine (2f)

Colorless crystals, m.p. 158–162 °C. Yield: 114 mg, 80 %. ^{1}H NMR (400 MHz, $CDCl_3$) *δ*: 7.42–7.40 (m, 3H), 7.34–7.28 (m, 3H), 7.23–7.21 (m, 2H), 7.18–7.15 (m, 2H), 6.39 (s, 1H), 5.93 (s, 1H). ^{13}C NMR (100 MHz, $CDCl_3$) *δ*: 173.2, 171.6, 133.8, 132.0, 131.6, 131.1, 129.7, 129.1, 127.8. ^{19}F NMR (376 MHz, $CDCl_3$) *δ*: -142.8, -142.8, -142.9, -142.9. IR (KBr) *ν* (cm^{-1}): 575, 696, 768, 1033, 1075, 1141, 1283, 1442, 1478, 1567, 1591, 1603, 1638, 3062, 3271, 3356, 3473. HRMS (ESI, *m/z*) calcd. for $C_{15}H_{12}BF_2NO_2Na^+$ ([M + Na]$^+$): 310.0821, found: 310.0820.

2,2-Difluoro-5-phenyl-6-(thiophen-2-yl)-2*H*-1,3λ³,2λ⁴-dioxaborinin-4-amine (2g)

Pale yellow crystals, m.p. 182–186 °C. Yield: 104 mg, 71 %. ^{1}H NMR (400 MHz, $CDCl_3$) *δ*: 7.57–7.56 (m, 3H), 7.45 (dd, *J* = 5.2, 1.2 Hz, 1H), 7.38–7.36 (m, 2H), 7.15 (dd, *J* = 4.0, 1.2 Hz, 1H), 6.91 (dd, *J* = 5.2, 4.0 Hz, 1H), 6.11 (s, 1H), 5.60 (s, 1H). ^{13}C NMR (100 MHz, $CDCl_3$) *δ*: 171.3, 166.1, 137.0, 134.3, 133.8, 132.3, 131.1, 130.6, 130.2, 127.5, 98.0. ^{19}F NMR (376 MHz, $CDCl_3$) *δ*: -143.9, -144.0, -144.9, -144.9. IR (KBr) *ν* (cm^{-1}): 649, 668, 702, 720, 1030, 1097, 1143, 1180, 1285, 1416, 1456, 1470, 1504, 1515, 1519, 1557, 1574, 1615, 1633, 1644, 1651, 1660, 3359, 3460, 1646, 3673. HRMS (ESI, *m/z*) calcd. for $C_{13}H_{10}BF_2NO_2SNa^+$ ([M + Na]$^+$): 316.0386, found: 316.0389.

2,2-Difluoro-6-(furan-2-yl)-5-phenyl-2*H*-1,3λ³,2λ⁴-dioxaborinin-4-amine (2h)

Pale yellow crystals, m.p. 171–175 °C. Yield: 65 mg, 47 %. ^{1}H NMR (400 MHz, $CDCl_3$) *δ*: 7.54–7.51 (m, 3H), 7.38 (d, *J* = 0.8 Hz, 1 H), 7.34–7.31 (m, 2H), 6.32 (dd, *J* = 7.2, 1.6 Hz, 1H), 6.27 (s, 1H), 6.26 (s, 1H), 5.69 (s, 1H). ^{13}C NMR (100 MHz, $CDCl_3$) *δ*: 171.4, 161.4, 146.6, 131.6, 131.1, 130.1, 129.6, 119.8, 112.3, 97.8. ^{19}F NMR (376 MHz, $CDCl_3$) *δ*: -143.6, -143.7, -144.7, -144.7. IR (KBr) *ν* (cm^{-1}): 592, 704, 751, 764, 1030, 1087, 1143, 1231, 1287, 1337, 1384, 1443, 1481, 1583, 1605, 1638, 2849, 2921, 3361, 3469. HRMS (ESI, *m/z*) calcd. for $C_{13}H_{10}BF_2NO_3Na^+$ ([M + Na]$^+$): 300.0614, found: 300.0617.

2,2-Difluoro-6-methyl-5-(4-methylphenyl)-2*H*-1,3λ³,2λ⁴-dioxaborinin-4-amine (2i)

Colorless crystals, m.p. 138–142 °C. Yield: 110 mg, 92 %. ^{1}H NMR (400 MHz, $CDCl_3$) δ: 7.28 (d, J = 8.0 Hz, 2H), 7.13 (d, J = 8.0 Hz, 2H), 6.23 (s, 1H), 5.62 (s, 1H), 2.40 (s, 3H), 1.95 (s, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ: 178.5, 170.5, 139.2, 131.0, 130.5, 128.3, 100.7, 21.5, 76.7. ^{19}F NMR (376 MHz, $CDCl_3$) δ: -142.48, -142.50, -142.5, -142.6. IR (KBr) ν (cm^{-1}): 820, 998, 1041, 1110, 1292, 1332, 1376, 1425, 1503, 1596, 1637, 2850, 2921, 3357, 3482. HRMS (ESI, m/z) calcd. for $C_{11}H_{12}BF_2NO_2Na^+$ ([M + Na]$^+$): 262.0821, found: 262.0820.

2,2-Difluoro-5-(4-fluorophenyl)-6-methyl-2*H*-1,3λ³,2λ⁴-dioxaborinin-4-amine (2j)

Colorless crystals, m.p. 181–184 °C. Yield: 93 mg, 77 %. ^{1}H NMR (400 MHz, DMSO-d_6) δ: 9.14 (s, 1H), 7.88 (s, 1H), 7.32–7.25 (m, 4H), 1.80 (s, 3H). ^{13}C NMR (100 MHz, DMSO-d_6) δ: 174.7, 169.2, 163.3, 160.9, 133.7, 133.6, 128.39, 128.36, 116.2, 116.0, 100.2, 21.0. ^{19}F NMR (376 MHz, DMSO-d_6) δ: -134.0, -140.8, -140.9. IR (KBr) ν (cm^{-1}): 740, 1044, 1075, 1116, 1141, 1292, 1383, 1406, 1458, 1508, 1560, 1594, 1618, 1647, 1655, 1686, 1719, 2924, 3358. HRMS (ESI, m/z) calcd. for $C_{10}H_9BF_3NO_2Na^+$ ([M + Na]$^+$): 266.0571, found: 266.0565.

5-(4-Chlorophenyl)-2,2-difluoro-6-methyl-2*H*-1,3λ³,2λ⁴-dioxaborinin-4-amine (2k)

Colorless crystals, m.p. 134–136 °C. Yield: 119 mg, 92 %. ^{1}H NMR (400 MHz, $CDCl_3$) δ: 7.49–7.46 (m, 2H), 7.24–7.20 (m, 2H), 6.29 (s, 1H), 5.60 (s, 1H), 1.96 (s, 1H). ^{13}C NMR (100 MHz, $CDCl_3$) δ: 179.0, 170.2, 135.6, 132.6, 130.2, 129.9, 99.8, 21.7. ^{19}F NMR (376 MHz, $CDCl_3$) δ: -142.4, -142.5. IR (KBr) ν (cm^{-1}): 772, 831, 999, 1018, 1043, 1092, 1289, 1333, 1384, 1397, 1427, 1456, 1505, 1538, 1557, 1591, 1606, 1644, 1651, 2920, 3357, 3459. HRMS (ESI, m/z) calcd. for $C_{10}H_9BClF_2NO_2Na^+$ ([M + Na]$^+$): 282.0275, found: 282.0268.

5-(4-Bromophenyl)-2,2-difluoro-6-methyl-2*H*-1,3λ³,2λ⁴-dioxaborinin-4-amine (2l)

Colorless crystals, m.p. 150–153 °C. Yield: 142 mg, 94 %. ^{1}H NMR (400 MHz, $CDCl_3$) δ: 7.63 (d, J = 8.0 Hz, 2H), 7.16 (d, J = 8.0 Hz, 2H), 6.37 (s, 1H), 5.63 (s, 1H), 1.96 (s, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ: 178.8, 170.1, 133.2, 132.9, 130.4, 123.7, 99.9, 21.6. ^{19}F NMR (376 MHz, $CDCl_3$) δ: -142.36, -142.42. IR (KBr) ν (cm^{-1}): 998, 1043, 1074, 1099, 1142, 1180, 1290, 1332, 1400, 1459, 1502, 1560, 1585, 1603, 1618, 1647, 1686, 2850, 2922, 3137, 3360, 3448. HRMS (ESI, m/z) calcd. for $C_{10}H_9BBrF_2NO_2Na^+$ ([M + Na]$^+$): 325.9770, found: 325.9767.

2,2-Difluoro-5-(4-methoxyphenyl)-6-methyl-2*H*-1,3λ³,2λ⁴-dioxaborinin-4-amine (2m)

Colorless crystals, m.p. 175–179 °C. Yield: 43 mg, 34 %. ^{1}H NMR (400 MHz, DMSO-d_6) δ: 9.09 (s, 1H), 7.78 (s, 1H), 7.16 (d, J = 8.8 Hz, 2H), 7.01 (d, J = 8.8 Hz, 1H), 3.79 (s, 3H), 1.79 (s, 3H) . ^{13}C NMR (100 MHz, DMSO-d_6) δ: 174.5, 169.5, 159.1, 132.5, 124.0, 114.6, 100.7, 55.1, 21.0. ^{19}F NMR (376 MHz, DMSO-d_6) δ: -140.9, -141.0. IR (KBr) ν (cm^{-1}): 739, 774, 835, 882, 996, 1044, 1095, 1179, 1247, 1266, 1295, 1332, 1377, 1412, 1469, 1506, 1596, 1645, 2849, 2921, 3354, 3459. HRMS (ESI, m/z) calcd. for $C_{11}H_{12}BF_2NO_3Na^+$ ([M + Na]$^+$): 278.0771, found: 278.0774.

5-(2-Chlorophenyl)-2,2-difluoro-6-methyl-2*H*-1,3λ³,2λ⁴-dioxaborinin-4-amine (2n)

Colorless crystals, m.p. 175–178 °C. Yield: 96 mg, 74 %. ^{1}H NMR (400 MHz, $CDCl_3$) δ: 7.58–7.56 (m, 1H), 7.46–7.42 (m, 1H), 7.42–7.38 (m, 1H), 7.34–7.31 (m, 1H), 6.03 (s, 1H), 5.39 (s, 1H), 1.93 (s, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ: 180.1, 169.6, 136.2, 133.4, 131.2, 130.7, 130.0, 128.2, 98.4, 21.5. ^{19}F NMR (376 MHz, $CDCl_3$) δ: -142.3, -142.4, -142.5, -142.6, -143.5, -143.6, -143.7, -143.8; . IR (KBr) ν (cm^{-1}): 761, 1040, 1074, 1142, 1180, 1250, 1301, 1335, 1382, 1431, 1505, 1589, 1604, 1643, 2853, 2924, 3358, 3454. HRMS (ESI, m/z) calcd. for $C_{10}H_9BClF_2NO_2Na^+$ ([M + Na]$^+$): 282.0275, found: 282.0278.

5-(3,5-Dimethylphenyl)-2,2-difluoro-6-methyl-2*H*-1,3λ³,2λ⁴-dioxaborinin-4-amine (2o)

Colorless crystals, m.p. 164–168 °C. Yield: 100 mg, 79 %. ^{1}H NMR (400 MHz, $CDCl_3$) δ: 7.06 (s, 1H), 6.85 (s, 2H), 6.04 (s, 1H), 5.61 (s, 1H), 2.34 (s, 6H), 1.96 (s, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ: 178.6, 170.5, 139.6, 131.3, 130.8, 128.7, 101.0, 21.6, 21.2. ^{19}F NMR (376 MHz, $CDCl_3$) δ: -142.9, -143.0. IR (KBr) ν (cm^{-1}): 711, 853, 997, 1042, 1148, 1208, 1326, 1378, 1423, 1505, 1603, 1640, 2924, 3356, 3453. HRMS (ESI, m/z) calcd. for $C_{12}H_{14}BF_2NO_2Na^+$ ([M + Na]$^+$): 276.0978, found: 276.0978.

2,2-Difluoro-6-phenyl-2*H*-1,3λ³,2λ⁴-dioxaborinin-4-amine (2p)

Colorless crystals, m.p. 176–178 °C, Lit[4b] 183–184 °C. Yield: 81 mg, 77 %. ^{1}H NMR (400 MHz, DMSO-d_6) δ: 9.24 (s, 1H), 9.21 (s, 1H), 7.84–7.82 (m, 2H), 7.60–7.51 (m, 3H), 6.06 (s, 1H). ^{13}C NMR (100 MHz, DMSO-d_6) δ: 170.7, 170.3, 132.7, 132.3, 129.0, 126.6, 84.6. ^{19}F NMR (376 MHz, DMSO-d_6) δ: -141.7, -141.8, -148.2, -148.3. IR (KBr) ν (cm^{-1}): 687, 770, 800, 1045, 1367, 1459, 1489, 1523, 1577, 1607, 1654, 3362. HRMS (ESI, m/z) calcd. for $C_9H_9BF_2NO_2^+$ ([M + H]$^+$): 212.0689, found: 212.0685.

2,2-Difluoro-6-(4-methylphenyl)-2*H*-1,3λ³,2λ⁴-dioxaborinin-4-amine (2q)

Colorless crystals, m.p. 203–205 °C. Yield: 71 mg, 63 %. ^{1}H NMR (400 MHz, DMSO-d_6) δ: 9.16 (s, 1H), 9.13 (s, 1H), 7.73 (d, J = 8.0 Hz, 2H), 7.33 (d, J = 8.0 Hz, 2H), 6.01 (s, 1H), 2.37 (s, 3H). ^{13}C NMR (100 MHz, DMSO-d_6) δ: 170.8, 170.3, 142.6, 130.0, 129.5, 126.5, 83.8, 21.1. ^{19}F NMR (376 MHz, DMSO-d_6) δ: -141.70, -141.76. IR (KBr) ν (cm^{-1}): 790, 1048, 1244, 1374, 1523, 1571, 1605, 1646, 1743, 2985, 3361, 3453. HRMS (ESI, m/z) calcd. for $C_{10}H_{10}BF_2NO_2Na^+$ ([M + Na]$^+$): 248.0665, found: 248.0668.

2,2-Difluoro-6-(4-fluorophenyl)-2*H*-1,3λ³,2λ⁴-dioxaborinin-4-amine (2r)

Colorless crystals, m.p. 213–215 °C. Yield: 78 mg, 68 %. ^{1}H NMR (400 MHz, DMSO-d_6) δ: 9.25 (s, 1H), 9.22 (s, 1H), 7.90 (dd, J = 8.8, 5.6 Hz, 2H), 7.36 (m, 2H), 6.03 (s, 1H). ^{13}C NMR (100 MHz, DMSO-d_6) δ: 170.2, 169.5, 164.4 (d, J = 249 Hz), 129.2 (d, J = 9 Hz), 116.0 (d, J = 22 Hz), 84.44. ^{19}F NMR (376 MHz, DMSO-d_6) δ: -107.37, -141.79, -141.85. IR (KBr) ν (cm^{-1}): 607, 791, 846, 1046,

1121, 1165, 1236, 1373, 1498, 1523, 1613, 1660, 1744, 3365, 3460. HRMS (ESI, *m/z*) calcd. for $C_9H_7BF_3NO_2Na^+$ ([M + Na]$^+$): 252.0414, found: 252.0413.

6-(4-Chlorophenyl)-2,2-difluoro-2*H*-1,3λ^3,2λ^4-dioxaborinin-4-amine (2s)

Colorless crystals, m.p. 233–235 °C. Yield: 78 mg, 64 %. ^{1}H NMR (400 MHz, DMSO-d_6) δ: 9.30 (s, 1H), 9.28 (s, 1H), 7.84 (d, J = 8.4 Hz, 2H), 7.59 (d, J = 8.4 Hz, 2H), 6.06 (s, 1H). ^{13}C NMR (100 MHz, DMSO-d_6) δ: 170.2, 169.3, 137.0, 131.5, 129.1, 128.3, 85.0. ^{19}F NMR (376 MHz, DMSO-d_6) δ: -141.73, -141.79. IR (KBr) ν (cm^{-1}): 791, 1042, 1127, 1404, 1487, 1527, 1570, 1608, 1648, 3360, 3461. HRMS (ESI, *m/z*) calcd. for $C_9H_7BClF_2NO_2Na^+$ ([M + Na]$^+$): 268.0119, found: 268.0125.

6-Ethyl-2,2-difluoro-2*H*-1,3λ^3,2λ^4-dioxaborinin-4-amine (2t)

Colorless crystals, m.p. 68–70 °C. Yield: 33 mg, 40 % (0.5 mmol scale). ^{1}H NMR (400 MHz, DMSO-d_6) δ: 8.99 (s, 1H), 8.92 (s, 1H), 5.30 (s, 1H), 2.27 (q, J = 7.6 Hz, 2H), 1.04 (t, J = 7.6 Hz, 3H). ^{13}C NMR (100 MHz, DMSO-d_6) δ: 181.3, 170.1, 85.5, 28.5, 10.1. ^{19}F NMR (376 MHz, DMSO-d_6) δ: -141.31, -141.37. IR (KBr) ν (cm^{-1}): 807, 933, 1044, 1124, 1245, 1305, 1384, 1464, 1537, 1604, 1655, 3373, 3460. HRMS (ESI, *m/z*) calcd. for $C_5H_8BF_2NO_2Na^+$ ([M + Na]$^+$): 186.0508, found: 186.0507.

2,2-Difluoro-5-methyl-6-phenyl-2*H*-1,3λ^3,2λ^4-dioxaborinin-4-amine (2u)

Colorless crystals, m.p. 186–189 °C. Yield: 54 mg, 48 %. ^{1}H NMR (400 MHz, DMSO-d_6) δ: 9.42 (s, 1H), 8.93 (s, 1H), 7.56–7.47 (m, 5H), 1.85 (s, 3H). ^{13}C NMR (100 MHz, DMSO-d_6) δ: 171.2, 169.6, 134.8, 130.5, 128.6, 128.3, 93.4, 12.0. ^{19}F NMR (376 MHz, DMSO-d_6) δ: -142.52, -142.58, -142.62, -142.69. IR (KBr) ν (cm^{-1}): 1016, 1204, 1450, 1460, 1487, 1514, 1597, 1649, 2923, 2954, 3278, 3356, 3445. HRMS (ESI, *m/z*) calcd. for $C_{10}H_{10}BF_2NO_2Na^+$ ([M + Na]$^+$): 248.0665, found: 248.0669.

5-Ethyl-2,2-difluoro-6-phenyl-2*H*-1,3λ^3,2λ^4-dioxaborinin-4-amine (2v)

Colorless crystals, m.p. 151–154 °C. Yield: 22 mg, 18 %. ^{1}H NMR (400 MHz, DMSO-d_6) δ: 9.44 (s, 1H), 8.94 (s, 1H), 7.52–7.45 (m, 5H), 2.25 (q, J = 7.3 Hz, 2H), 0.95 (t, J = 7.3 Hz, 3H). ^{13}C NMR (100 MHz, DMSO-d_6) δ: 170.6, 170.3, 135.1, 130.2, 128.4, 127.6, 100.0, 18.0, 14.3. ^{19}F NMR (376 MHz, DMSO-d_6) δ: -141.98, -142.05. IR (KBr) ν (cm^{-1}): 699, 760, 1038, 1203, 1380, 1466, 1482, 1502, 1590, 1655, 2925, 2958, 3193, 3367, 3457. HRMS (ESI, *m/z*) calcd. for $C_{11}H_{13}BF_2NO_2^+$ ([M + H]$^+$): 240.1002, found: 240.1001.

5-Benzyl-2,2-difluoro-6-phenyl-2*H*-1,3λ^3,2λ^4-dioxaborinin-4-amine (2w)

Colorless crystals, m.p. 145–148 °C. Yield: 16 mg, 10 %. ^{1}H NMR (400 MHz, DMSO-d_6) δ: 9.43 (s, 1H), 8.84 (s, 1H), 7.51–7.42 (m, 5H), 7.30 (t, J = 7.3 Hz, 2H), 7.19 (t, J = 7.3 Hz, 1H), 7.08 (d, J = 7.3 Hz, 2H), 3.72 (s, 1H). ^{13}C NMR (100 MHz, DMSO-d_6) δ: 172.10, 170.76, 139.04, 134.80, 130.59, 128.50, 128.43, 127.80, 127.30, 126.26, 96.69, 29.93. ^{19}F NMR (376 MHz, DMSO-d_6) δ: -141.51, -141.57, -141.70, -141.72, -141.76, -141.78, -143.11, -143.17. IR (KBr) ν (cm^{-1}): 700, 766, 1040, 1207, 1340, 1500, 1604, 1655, 2925, 3367, 3463. HRMS (ESI, *m/z*) calcd. for $C_{16}H_{14}BF_2NO_2Na^+$ ([M + Na]$^+$): 324.0978, found: 324.0983.

Procedure for the preparation of β-keto amide 3a.

Method A: A solution of **2a** (0.5 mmol, 113 mg), NaOAc (2.5 mmol, 205 mg) in 3 mL of water and 3 mL of ethanol as mixed solvent was refluxed for 2 h. Then water (5 mL) was added followed by the addition of 5 mL of EtOAc. The organic phase was separated and the aqueous phase was extracted with 5 mL of EtOAc. The combined organic phase was dried over anhydrous sodium sulfate and concentrated under reduced pressure. The resulting residue was purified by silica gel column chromatography with petroleum ether and ethyl acetate (PE/EA = 5/1, *v/v*) as eluent to afford pure product **3a**, 86 mg, 97 %.

Method B: A solution of **1a** (0.5 mmol, 80 mg), $BF_3{\cdot}OEt_2$ (0.3 mL, 2.25 mmol) in 5 mL of xylene was refluxed for 20 h. After cold to room temperature, 3 mL of water ,3 mL of ethanol and NaOAc (2.5 mmol, 205 mg) wereadded. After refluxing for 2 h, water (5 mL) was added followed by addition of 5 mL of EtOAc. The organic phase was separated and the aqueous phase was extracted with 5 mL of EtOAc. The combined organic phase was dried over anhydrous sodium sulfate and concentrated under reduced pressure. The resulting crude product was purified by silica gel column chromatography with petroleum ether and ethyl acetate (PE/EA = 5/1, *v/v*) as eluent to give pure product **3a**, 77 mg, 87 %.

3-Oxo-2-phenylbutanamide (3a)

Colorless crystals, m.p. 135–138 °C Lit.[12] 123–125 °C. ^{1}H NMR (400 MHz, $CDCl_3$) δ: 14.66 (s, 1H), 7.45–7.30 (m, 4H), 7.26–7.22 (m, 2H), 6.87 (s, 1H), 5.70 (s, 1H), 5.29 (s, 1H), 5.04 (s, 1H), 4.66 (s, 1H), 2.24 (s, 1H), 1.78 (s, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ: 205.0, 174.4, 172.8, 135.7, 133.5, 131.4, 129.4, 129.2, 128.5, 127.9, 104.1, 65.2, 30.1, 19.8.

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