



A concise method to prepare novel fused heteroaromatic diones through double Friedel-Crafts acylation

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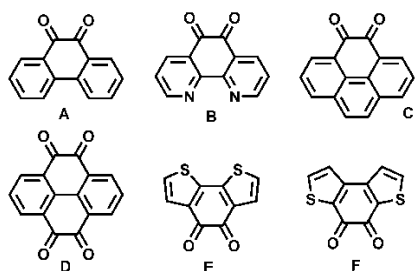
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This paper explored the intramolecular double Friedel-Crafts acylation strategy in approaching different types of novel fused heteroaromatic diones (12 samples using 2,2'-bithiophene, 2,2'-bifuran, 2,2'-biselenophene, and 2,2'-bipyrrole as cores) with 16%-85% yield.

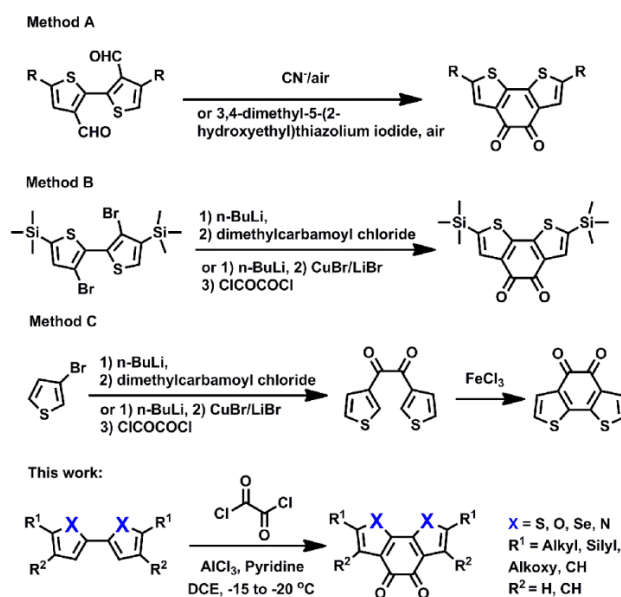
Fused aromatic or heteroaromatic diones (Scheme 1) have been demonstrated as powerful building blocks to construct versatile π -conjugated materials ranging from small molecules¹⁻⁶ to conducting polymers,⁷ which can be used in organic solar cells,⁷ organic field-effect transistor,^{5, 6b, 7d, 7e, 8} lithium-ion batteries,^{3e} sensor,^{2b, 3c, 6c} phototransistor device,^{3d} and optical waveguide^{6a} etc. Especially, fused heteroaromatic diones are more attractive because the type, position, and valance of heteroatoms could offer more chances to tune the properties and characterizes of new materials constructed from them.⁹ In fact, fused heteroaromatic diones could offer us more opportunities to vary the properties of as-prepared materials through post-modification.¹⁰ Thus, it is very urgent to develop the corresponding method to prepare these fused heteroaromatic diones.



Scheme 1. The reported structures of fused aromatic and heteroaromatic diones

There are three main types of methods in literature to prepare heteroaromatic-fused diones (using benzo[2,1-b:3,4-b']-dithiophene-4,5-dione (BDTD) core as example, Scheme 2): (a) Dialdehyde undergoes benzoin condensation in presence of cyanide anions or 3,4-dimethyl-5-(2-hydroxyethyl)thiazolium iodide, following by air oxidation (Scheme 2a),^{1c, 10a} (b) Substituted 3,3'-dibromo-2,2'-bithiophene can be converted into diones via double lithiation with *n*-butyllithium, followed by the reaction with electrophile (diethyl oxalate or *N,N*'-dimethylpiperazine-2,3-dione) or CuBr/LiBr then oxalyl chloride (Scheme 2b),^{10b, 11} (c) Diones are formed via the lithiation of 3-

bromo-thiophene with *n*-butyllithium, then the reaction with *N,N*'-dimethylpiperazine-2,3-dione or CuBr/LiBr then oxalyl chloride, followed by intramolecular thiophene-thiophene coupling with FeCl₃ (Scheme 2c).^{10b} However, these methods might not become a general method to prepare other important fused heteroaromatic diones such as 2,2'-bifuran, 2,2'-biselenophene, and *N,N*'-dimethyl-2,2'-bipyrrole for following reasons: (1) some intermediates are not commercially available and need more steps to prepare; (2) some commercial sources are expensive or highly-flammable; and (3) some chemical agents such as cyanide are very toxic and are not environment-friendly. Thus, it should be highly desirable to develop a general, concise and efficient method to address these molecules. In this work, we developed a direct and concise method to synthesize fused heteroaromatic diones (X= S, Se, O, N) through intramolecular double Friedel-Crafts acylation (Scheme 2).



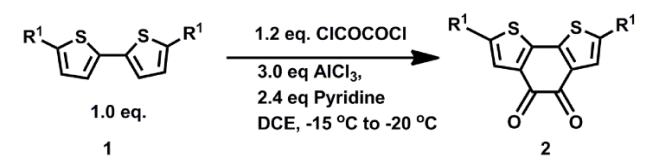
Scheme 2. The synthetic methods to approach fused heteroaromatic diones

Although it was in 1911 that Liebermann et al^{11b} demonstrated the possibility of intramolecular double Friedel-Crafts acylation on 4,4'-dimethylbiphenyl, only one recent papers suggested that Friedel-Crafts acylation could be realized on heteroaromatic rings to produce heteroaromatic diones.¹² Nevertheless, in this work,¹²

the Friedel-Crafts acylation happened on 2,2'-positions rather than 3,3'-positions, where 2,2'-positions are well known to be more reactive than 3,3'-positions. To the best of our knowledge, there is no any report regarding the Friedel-Crafts acylation

happening on 3,3'-positions of heteroaromatic rings. Hence, it is our interests to find out the possibility of Friedel-Crafts acylation on 3,3'-positions of heteroaromatic rings including 2,2'-bithiophene, 2,2'-bifuran, 2,2'-biselenophene, and N,N'-dimethyl-2,2'-bipyrrole. In order to test our ideas, we used 2,2'-bithiophene as a core and functionalized it with different substituted groups in 5 and 5'-positions (Table 1). The ratios of oxalyl chloride and aluminium chloride to reactants are 1.2 and 3.0, respectively. The effects of different substituted groups (e. g., alkyl group, electron-donating groups, and electron-withdrawing groups) have been investigated. As shown in Table 1, both alkyl groups and silyl groups underwent intramolecular double Friedel-Crafts acylation in medium yields (25 ~ 48%). When R¹ group becomes more bulky (e. g., using *t*-butyl to replace methyl), the yield increases simultaneously (see entry 1, 2 and entry 4, 5). The reason for the low yield of compound 1d (Trimethylsilyl group) might be due to the broken of C-Si bond, and accordingly, the intermolecular Friedel-Crafts acylation happens (See ESI: S5). The intramolecular double Friedel-Crafts acylation reaction proceeded very well if long chain is used (entry 3). Interestingly, when the strong electron-donating group methoxyl was employed, a relatively low yield (25%) was observed. Furthermore, when the electron-withdrawing group (e.g. CH₃CO) was introduced in 5 and 5'- positions, there was no reaction happened due to the lower reactivity of compound 1g (acetyl group). If R¹ was Br, no target molecule was observed and complex by-products formed. Thus, our results suggest that electron-rich substitutes favor the intramolecular double Friedel-Crafts Acylation.

Table 1 Intramolecular double Friedel-Crafts acylation with various bithiophene substrates

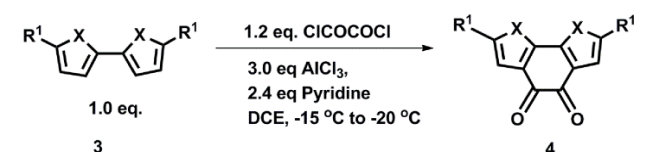


Entry	Substrate	R ¹	Product	Yield(%)
1	1a	Methyl	2a	32
2	1b	<i>t</i> -butyl	2b	48
3	1c	<i>n</i> -hexyl	2c	37
4	1d	Trimethylsilyl	2d	28
5	1e	Tri- <i>i</i> -propylsilyl	2e	45
6	1f	Methoxyl	2f	25
7	1g	Acetyl	2g	No Reaction
8	1h	Br	2h	No Target Molecule

Given our success with intramolecular double Friedel-Crafts acylation of 2,2'-bithiophene derivatives, we decided to extend our method to the systems containing 2,2'-bifuran, 2,2'-

biselenophene, and N,N'-dimethyl-2,2'-bipyrrole as cores (Table 2). As shown in Table 2, due to its high reactivity, the target compound (4a) for bifuran (3a) can only be obtained in 16% when the reaction temperature decreased to -50 °C. As to 2,2'-biselenophene (3b) and N,N'-dimethyl-2,2'-bipyrrole (3c), the reaction can proceed smoothly with medium yield. It is worth noting that it is the first time to release intramolecular double Friedel-Crafts acylation on these systems containing 2,2'-bifuran, 2,2'-biselenophene or N,N'-dimethyl-2,2'-bipyrrole as cores.

Table 2 Intramolecular double Friedel-Crafts acylation with bifuran, biselenophene and bipyrrole



Entry	Substrate	X	R ¹	Product	Yield(%)
1 ^a	3a	O	Trimethylsilyl	4a	16
2	3b	Se	Trimethylsilyl	4b	37
3	3c	N-CH ₃	Methyl	4c	32

^a reaction temperature is -50 °C

The further exploration of intramolecular double Friedel-Crafts acylation on more complicated systems (e.g. 2,2'-bibenzofuran, 2,2'-bibenzothiophene, and 1,1'-dihexyl-1H,1'H'-2,2'-biindole) have also been demonstrated (Table 3). All reactions gave good yield (35-85%) under similar reaction conditions.

Table 3 Intramolecular double Friedel-Crafts acylation with benzofuran, benzothiophene and biindole substrates



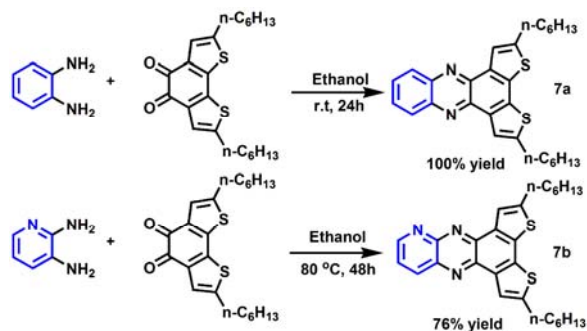
Entry	Substrate	X	Product	Yield(%)
1	5a	O	6a	35
2	5b	S	6b	58
3	5c	N- <i>n</i> -hexyl	6c	85

To demonstrate the usefulness of these intermediates, we carried out two derivative reactions (Scheme 3) and our results show that both two reactions performed well with high yields. Moreover, the as-prepared products show very good solubility in organic solvents (>40mg/mL in chloroform), which are desirable for devices' fabrication through spincoating.

Conclusions

In conclusion, this communication described our recent progress in the reinvestigation of intramolecular double Friedel-Crafts acylation for preparing fused heteroaromatic diones using 2,2'-bithiophene, 2,2'-bifuran, 2,2'-biselenophene, N,N'-dimethyl-2,2'-bipyrrole, 2,2'-bibenzofuran, 2,2'-bibenzothiophene, and 1,1'-dimethyl-1H,1'H'-2,2'-biindole as starting materials. Our

success could offer a more convenient and concise method to create high-performance materials with versatile properties.



Scheme 3. The derivative reactions based on the 2c.

Notes and references

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Electronic Supplementary Information (ESI) available: [details of experimental procedures, ¹H NMR, ¹³C NMR, HRMS etc]. See DOI: 10.1039/b000000x/

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