Efficient Synthesis of 1,3-Dithiol-2-one Derivatives via 4,5-Bis(dibromomethyl)-1,3-dithiol-2-one

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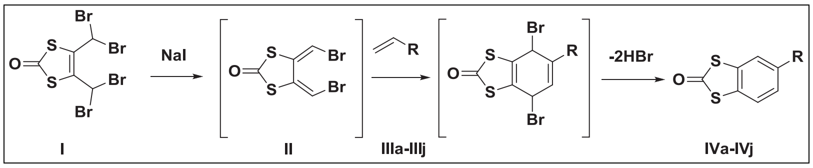

A series of 1,3-dithiol-2-one derivatives via [4 + 2] Diels–Alder cycloaddition reaction of 4,5-bis(dibromomethyl)-1,3-dithiol-2-one with vinyl-substituted compounds have been synthesized. Structures of all the newly synthesized compounds are well supported by spectral data such as ^{1}H-NMR, MS, and elemental analysis. The structures of **IVf** and **IVg** have been analyzed by X-ray crystallography.

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INTRODUCTION

Tetrathiafulvalene (TTF) and its derivatives have attracted chemists' interests since the discovery of their conductivity in the 1970s [1]. During the last few years, interests of TTF and related molecules have spread into various fields because of unique π-electron donor properties such as supramolecular and molecule-based ferromagnetic materials, field effect transistors, nonlinear optic materials, and Langmuir–Blodgett films [2–6]. As a result, a large synthetic effort has also been devoted to the preparation of TTF and its derivatives [7,8].

Among them, cross-coupling reaction is an important pathway to synthesize unsymmetrically substituted TTF derivatives (**2**) (Scheme 1). As a well-known precursor for the synthesis of TTFs, 1,3-dithiol-2-ones (**1**) has received considerable attention [9]. To sustain TTF-related studies, it is necessary to develop various synthetic routes for this kind of precursor. In our previous paper, we have reported the synthesis of π-conjugated pyridine and bipyridine TTF derivatives via [4 + 2] Diels–Alder cycloaddition reaction [10]. Our interest in the synthesis of new TTF-containing materials [11] stimulates us to design and produce novel π-conjugated 1,3-dithiol-2-ones. Herein, we report the application of the aforementioned reaction to synthesize a variety of 1,3-dithiol-2-ones with different vinyl-substituted compounds.

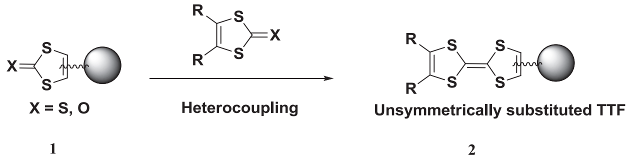
RESULTS AND DISCUSSION

Synthesis. Although the detailed mechanism of the above reaction remains not to be fully clarified, the formation of 1,3-dithiol-2-one derivatives could be explained by a reaction sequence presented in Scheme 2. After the elimination reaction of 4,5-bis(dibromomethyl)-1,3-dithiol-2-one (**I**) and sodium iodide in CH_3CN/DMF, the formed reactive intermediate, diene (**II**) was further undertaken through the Diels–Alder cycloaddition reaction with dienophile (**III**). The diene (**II**) exhibited a lower polarity than the compound **I** and was easily decomposed in the air. A variety of vinyl-substituted compounds with electron-withdrawing groups (such as **IIIa–IIIh**) could be used in this synthetic strategy with a series of 1,3-dithiol-2-one derivatives (**IVa–IVh**) obtained in quantitative yield (Table 1). However, when vinyl-substituted compounds with electron-donating groups (such as **IIIi–IIIm**) were applied to this reaction, no expected product was detected even with the prolonged reaction time and the increased reaction temperature. In addition, the dienophile with an electron-withdrawing group (such as **IIIn**) was also tried without successful reaction product, which may be due to the stereo-hindrance effect of the compound. Therefore, it can be concluded that the electronic nature and the size of dienophiles have significant effects on the reaction. All the synthetic results are summarized in Table 1.

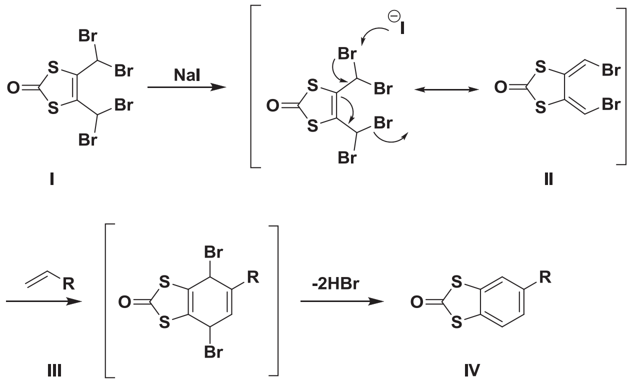
Initially, the reactions of **1**, **5**, and **6** were carried out in refluxing acetonitrile overnight, but no reaction occurred. The increase of the catalyst NaI added had no significant effect on this reaction. When the reaction temperature was at 100–110°C, using DMF instead of CH_3CN solvent had great influences on the reaction. To our delight, the corresponding products **IVa**, **IVe**, and **IVf** were successfully synthesized in good yield with the optimal conditions (Table 1).

In this study, all the synthesized compounds were characterized by different methods including high-resolution mass spectrometry (matrix-assisted laser desorption/ionization-time-of-flight mass spectrometry; MALDI–TOF), elemental analyses, and ^{1}H-NMR spectral data. To further elucidate the

Scheme 1



Scheme 2



structure of products, single crystals of **IVf** and **IVg** were prepared, and their structures were determined by X-ray diffraction (Figure 1).

Crystal structures. The crystallographic data for **IVf** and **IVg** are listed in Table 2; selected bond lengths and bond angles are collected in Table 3. Oak Ridge thermal ellipsoid plot drawings of the molecular structures for **IVf** and **IVg** with the atomic numbering scheme are given in Figure 1.

For the compound **IVf**, the C—S bonds are not equivalent with bond lengths ranging from 1.737 to 1.762 Å. The C(1)═O(1) bond length of the 1,3-dithiol-2-one derivative is 1.203 Å and is within the range for a neutral TTF. The planar-fused benzene (C2—C3—C4—C5—C6—C7) and the five-membered rings (C1—S1—C2—C3—S2) are almost coplanar with the average deviation from a least-squares plane of 0.0111 Å. However, both phenyl rings (C2—C3—C4—C5—C6—C7 and C8—C9—C10—C11—C12—C13) in the molecule are twisted, the dihedral angle being equal to 24.92°. The C—O bond lengths in methyl ester groups are 1.324 Å for C(14)—O(2) and 1.189 Å for C(14)—O(3), respectively.

As for the compound **IVg**, both cyclopentadienyl (Cp) rings in the ferrocene moiety are almost coplanar with the average deviation from a least-squares plane of 0.0003 and 0.0018 Å, respectively. Also, the C—C bond lengths vary from 1.379 to 1.425 Å for the two Cp rings. In addition, Fe1—Cp(1) (C1—C2—C3—C4—C5) and Fe1—Cp (2) (C6—C7—C8—C9—C10) distances are 1.646 and 1.644 Å, respectively, which are in accord with those reported for previous structures [12–14]. The plane of the Cp(2) ring is slightly twisted against the phenyl ring (C11—C12—C13—C14—C15—C16), with the dihedral angle being 20.21°. For the 1,3-dithiol-2-one molecule, all bond lengths are within the expected range for neutral TTF [15]. Besides, C(17)═O(1) bond length is 1.196 Å.

In conclusion, 1,3-dithiol-2-one derivatives via [4 + 2] Diels–Alder cycloaddition reaction of 4,5-bis(dibromomethyl)-1,3-dithiol-2-one (**I**) with vinyl-substituted compounds have been synthesized. Single crystals of methyl 4-(2-oxobenzo[*d*][1,3]dithiol-5-yl)benzoate (**IVf**) and 2-oxobenzo[*d*][1,3]dithiole-5-ferrocene (**IVg**) have been obtained by slow evaporation of organic solvents. Detailed crystal structure analyses have been performed to identify the molecular arrangement. Spectral analyses have also been carried out.

EXPERIMENTAL

All reagents and solvents were purchased from commercial sources (Sigma-Aldrich, Alfa, and Shanghai Sinopharm companies) and used without further purification. ^{1}H-NMR spectra were recorded on a Bruker AM 500 instrument. Chemical shifts were reported in parts per million relative to Me_4Si as an internal standard. Elemental analyses for C, H, and N were performed on a Perkine Elmer 240C analyzer. MALDI–TOF MS spectra were recorded on an Autoflex II TM TOF/TOF instrument.

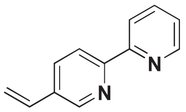
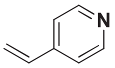
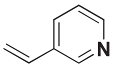
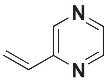
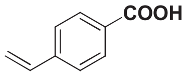
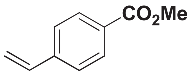
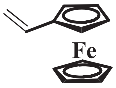
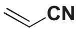
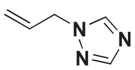
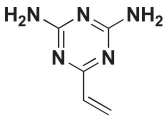
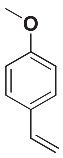
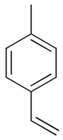
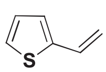
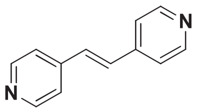
Crystal structure determination of compound IVf and IVg. The crystals of **IVf** and **IVg** suitable for X-ray structural analysis were obtained by slow evaporation of a mixture solution of CH_2Cl_2 and MeOH. The data were collected on a Bruker Smart Apex CCD diffractometer equipped with graphite-monochromated Mo Kα ($\lambda = 0.71073$ Å) radiation by using a $\omega - 2\theta$ scan mode at 293 K. The data collection and processing were performed using program SMART and SAINT [16]. The structure solution, refinement, and geometrical calculations were carried out through SHELX TL [17]. All hydrogen atoms were added theoretically. Crystallographic data for the structure analysis has been deposited at the Cambridge Crystallographic Data Centre, CCDC Nos. 903836 and 903837. Copies of these information can be obtained free of charge on application to CCDC, 12 Union Road, Cambridge CB2 1EZ, UK [fax: (44) 01223 336033 or e-mail: deposit@ccdc.cam.ac.uk].

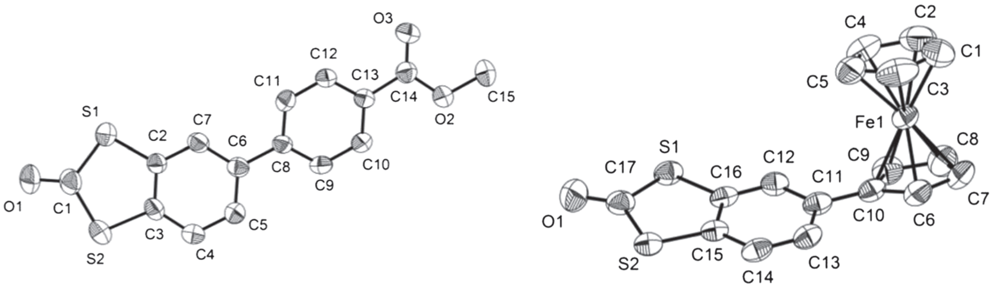
General procedure for the synthesis of 1,3-dithiol-2-one derivatives (IVa–IVh). Under an argon atmosphere, the reaction mixture of 4,5-bis(dibromomethyl)-1,3-dithiol-2-one**I** (2.00 mmol) and NaI (1.50 g, 10.00 mmol) in CH_3CN/DMF (5 mL) was heated at 70/110°C. After 30 min, the solution of vinyl-substituted compounds **IIIa–IIIh** (4.00 mmol) in CH_3CN/DMF (4 mL) was added, and the mixture solution was stirred for 2–5 h at this temperature. The solvent was removed in vacuum, and aqueous $NaHSO_3$ was added. Finally, the reaction mixture was extracted with ethyl acetate, and the combined organic phase was washed with brine, dried over Na_2SO_4 and concentrated in vacuum. The residues were purified by flash chromatography to give compounds **IVa–IVh**.

5-(2,2′-Bipyridin-5-yl)benzo[*d*][1,3]dithiol-2-one (**IVa**), 5-(pyridin-3-yl)benzo[*d*][1,3]dithiol-2-one (**IVb**) and 5-(pyridin-4-yl)benzo[*d*][1,3]dithiol-2-one (**IVc**) were reported in the literature [10].

Table 1

The synthetic results of 1,3-dithiol-2-one derivatives.

Entry	Structure (**IIIa ~ IIIj**)	Product	Solvent	Temperature (°C)	Time (h)	Yield (%)
1		**IVa**[Ref]	DMF	100	4	43
2		**IVb**[Ref]	CH_3CN	70	2	52
3		**IVc**[Ref]	CH_3CN	70	2	71
4		**IVd**	CH_3CN	70	2	55
5		**IVe**	DMF	110	5	49
6		**IVf**	DMF	110	5	76
7		**IVg**	CH_3CN	70	2	12
8		**IVh**	CH_3CN	70	2	10
9		**IVi**	DMF	150	10	0
10		**IVj**	DMF	150	10	0
11		**IVk**	DMF	150	10	0
12		**IVl**	DMF	150	10	0
13		**IVm**	DMF	150	10	0
14		**IVn**	DMF	150	10	0



IVf **IVg**

Figure 1. ORTEP view of **IVf** and **IVg** with the thermal ellipsoids drawn at the 50% probability level. Hydrogen atoms are omitted for clarity.

Table 2

Crystallographic data for **IVf** and **IVg**.

	IVf	**IVg**
Formula	$C_{15}H_{10}O_3S_2$	$C_{17}H_{12}FeOS_2$
M_r	302.35	352.24
Crystal system	monoclinic	orthorhombic
Space group	$P2_1/c$	*Pbca*
a (Å)	9.404(8)	7.6095(12)
b (Å)	30.46(2)	11.2928(18)
c (Å)	11.418(7)	33.484(5)
α (°)	90	90
β (°)	127.38(5)	90
γ (°)	90	90
V (Å^3)	2599(3)	2877.3(8)
Z	8	8
ρ_c (g cm^{-3})	1.545	1.626
F(000)	1248	1440
T/K	293(2)	293(2)
μ(Mo-Kα)/mm^{-1}	0.413	1.332
index ranges	$-11 \leq h \leq 11$	$-9 \leq h \leq 9$
	$-36 \leq k \leq 17$	$-13 \leq k \leq 13$
	$-13 \leq l \leq 14$	$-39 \leq l \leq 27$
GOF (F^2)	0.805	1.177
$R_1{}^a, wR_2{}^b (I > 2\sigma(I))$	0.0488, 0.0686	0.0588, 0.1370
$R_1{}^a, wR_2{}^b$(all data)	0.1122, 0.0833	0.0694, 0.1410

GOF, goodness of fit.

$^a R_1 = \sum ||C| - |F_c|| / \sum |F_o|$.

$^b wR_2 = \left[\sum w\left(F_o^2 - F_c^2\right)^2 / \sum w\left(F_o^2\right) \right]^{1/2}$

5-(Pyrazin-2-yl)benzo[*d*][1,3]dithiol-2-one (IVd). ^{1}H-NMR (500 MHz, $CDCl_3$): δ 9.05 (s, 1H), 8.66 (s, 1H), 8.57 (d, $J = 2.0$ Hz, 1H), 8.23 (s, 1H), 7.96 ~ 9.98 (m, 1H), 7.38 (d, $J = 8.0$ Hz, 1H); MS (MALDI–TOF): *m/z* 248.17 $[M+1]^+$. *Anal.* Calcd for $C_{11}H_6N_2OS_2$: C, 53.64; H, 2.46; N, 11.37. Found: C, 53.60; H, 2.49; N, 11.43.

4-(2-Oxobenzo[*d*][1,3]dithiol-5-yl)benzoic acid (IVe). ^{1}H-NMR (500 MHz, DMSO-d6): δ 13.00 (br s, 1H), 8.27 (d, $J = 1.5$ Hz, 1H), 8.04 (d, $J = 8.0$ Hz, 2H), 7.94 (d, $J = 8.5$ Hz, 1H), 7.86 (d, $J = 8.0$ Hz, 2H), 7.82 (dd, $J_{12} = 1.5$ Hz, $J_{13} = 8.0$ Hz, 1H); MS (MALDI–TOF): *m/z* 287.67 $[M]^+$. *Anal.* Calcd for $C_{14}H_8O_3S_2$: C, 58.32; H, 2.80. Found: C, 58.41; H, 2.78.

Methyl 4-(2-oxobenzo[*d*][1,3]dithiol-5-yl)benzoate (IVf). ^{1}H-NMR (500 MHz, $CDCl_3$): δ 8.13 (d, $J = 8.0$ Hz, 1H), 8.01 (d, $J = 8.0$ Hz, 2H), 7.64 (d, $J = 8.0$ Hz, 1H), 7.58 (s, 1H), 7.35 (d, $J = 8.0$ Hz, 2H), 3.91 (s, 3H); MS (MALDI–TOF): *m/z* 302.26 $[M]^+$. *Anal.* Calcd for $C_{15}H_{10}O_3S_2$: C, 59.58; H, 3.33. Found: C, 59.51; H, 3.41.

2-Oxobenzo[*d*][1,3]dithiole-5-ferrocene (IVg). ^{1}H-NMR (500 MHz, $CDCl_3$): δ 7.55 (s, 1H), 7.43 (d, $J = 8.5$ Hz, 1H), 7.38 (d, $J = 8.5$ Hz, 1H), 4.64 (s, 2H), 4.38 (s, 2H), 4.07 (s, 5H); MS (MALDI–TOF): *m/z* 353.24 $[M]^+$. *Anal.* Calcd for $C_{17}H_{12}FeOS_2$: C, 57.96; H, 3.43. Found: C, 58.03; H, 3.45.

2-Oxobenzo[*d*][1,3]dithiole-5-carbonitrile (IVh). ^{1}H-NMR (500 MHz, $CDCl_3$): δ 7.78 (s, 1H), 7.58 ~ 7.61 (m, 2H); MS (MALDI–TOF): *m/z* 193.21 $[M]^+$. *Anal.* Calcd for $C_8H_3NOS_2$: C, 49.72; H, 1.56. Found: C, 49.79; H, 1.58.

Table 3

Selected bond distances (Å) and angles (◦) for **IVf** and **IVg**.

	IVf		
C(1)—O(1)	1.203(4)	C(6)—C(8)	1.486(4)
C(1)—S(1)	1.762(4)	C(13)—C(14)	1.474(4)
C(2)—S(1)	1.737(3)	C(14)—O(3)	1.189(4)
C(1)—S(2)	1.760(4)	C(14)—O(2)	1.324(4)
C(3)—S(2)	1.746(3)	C(15)—O(2)	1.437(4)
C(2)—C(3)	1.379(4)	O(3)—C(14)—O(2)	122.3(3)
C(2)—S(1)—C(1)	96.65(18)	C(3)—S(2)—C(1)	96.52(18)
	IVg		
O(1)—C(17)	1.196(5)	S(2)—C(17)	1.774(5)
S(1)—C(16)	1.746(4)	C(10)—C(11)	1.473(6)
S(1)—C(17)	1.768(5)	C(15)—C(16)	1.392(6)
S(2)—C(15)	1.750(5)	C(1)—C(2)	1.379(9)
C(1)—C(3)	1.385(8)	C(2)—C(4)	1.391(9)
C(3)—C(5)	1.402(8)	C(4)—C(5)	1.397(8)
C(6)—C(7)	1.409(7)	C(6)—C(10)	1.420(6)
C(7)—C(8)	1.401(8)	C(8)—C(9)	1.410(7)
C(9)—C(10)	1.425(7)	C(11)—C(13)	1.388(6)
Fe(1)—C(1)	2.021(5)	Fe(1)—C(10)	2.040(4)
C(16)—S(1)—C(17)	97.0(2)	C(15)—S(2)—C(17)	96.7(2)
C(1)—Fe(1)—C(2)	39.8(3)	S(2)—C(17)	159.2(3)

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