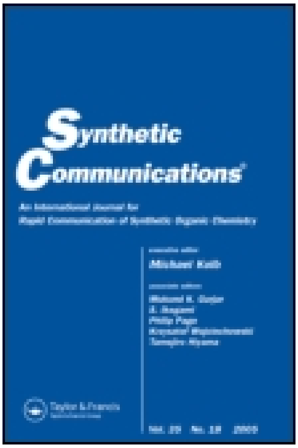


Synthetic Communications: An International Journal for Rapid Communication of Synthetic Organic Chemistry

Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/lsyc20

Green Procedure for the Synthesis of β-Nitro Sulfides by Michael Addition of Thiols to Nitroolefins

Xin-Ping Hui [a] , Chao Yin [a] , Jun Ma [a] & Peng-Fei Xu [a]

[a] State Key Laboratory of Applied Organic Chemistry, College of Chemistry and Chemical Engineering Lanzhou University, Lanzhou, China

To cite this article: Xin-Ping Hui , Chao Yin , Jun Ma & Peng-Fei Xu (2009) Green Procedure for the Synthesis of β-Nitro Sulfides by Michael Addition of Thiols to Nitroolefins, Synthetic Communications: An International Journal for Rapid Communication of Synthetic Organic Chemistry, 39:4, 676-690, DOI: 10.1080/00397910802431065

To link to this article: http://dx.doi.org/10.1080/00397910802431065

Synthetic Communications®, 39: 676–690, 2009
Copyright © Taylor & Francis Group, LLC
ISSN: 0039-7911 print/1532-2432 online
DOI: 10.1080/00397910802431065

Green Procedure for the Synthesis of β-Nitro Sulfides by Michael Addition of Thiols to Nitroolefins

Xin-Ping Hui, Chao Yin, Jun Ma, and Peng-Fei Xu
State Key Laboratory of Applied Organic Chemistry, College of Chemistry
and Chemical Engineering, Lanzhou University, Lanzhou, China

Abstract: Michael addition of thiols to nitroolefins was carried out in water at room temperature without any catalyst, and β-nitro sulfides were obtained in excellent yields. This is the first example of Michael addition of thiols to nitroolefins in water without use of any catalyst. It provides a highly efficient, general, and practical green route to synthesis of β-nitro sulfides. Twenty-four new β-nitro sulfides were synthesized using this technique.

Keywords: Nitroolefin, β-nitro sulfide, thia-Michael addition, thiol

Environmentally benign reactions have become the targets of synthetic organic chemists today. Organic reactions in water have received increasing attention particularly because of their environmental acceptability and low cost.[1] The development of efficient transformations in water without any catalyst is highly appreciated.

Conjugated addition is one of the most powerful bond-forming reactions to construct highly functionalized building blocks for the total synthesis of natural and biologically active compounds. In synthetic organic chemistry, the scope and applications of organo-sulfur compounds have increased tremendously because sulfur-containing groups

Received March 19, 2008.

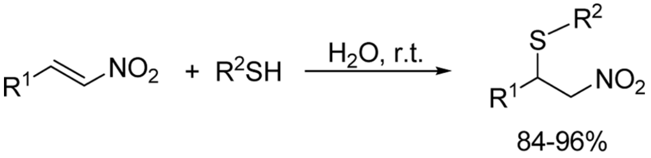
Address correspondence to Xin-Ping Hui, State Key Laboratory of Applied Organic Chemistry, College of Chemistry and Chemical Engineering, Lanzhou University, Lanzhou 730000, China. E-mail: huixp@lzu.edu.cn

serve as important auxiliaries in many synthetic sequences.[2] Their importance both in biochemical process[3] and in synthesis[4] is well recognized. Among Michael acceptors, nitroolefin is very attractive because of the strong electron deficiency of nitro group within it and is often described as a "synthetic chameleon"[5] because the nitro group is readily converted into other functional groups such as keto, cyano, and amino groups.[6,7]

Although thiols are good reagents for Michael addition to nitroolefins, the reactions are conventionally promoted in the presence of butyllithium, base,[8] or tetramethylammonium fluoride[9] in organic solvent. Ranu et al.[10] reported an efficient conjugate addition of thiols to electron-deficient alkenes catalyzed by molten tetrabutylammonium bromide under solvent-free conditions. To our knowledge, there is no report of thia-Michael addition of nitroolefins in water without any catalyst. Herein, we report a very simple and green procedure for the conjugated addition of thiols to nitroolefins in water at room temperature without any catalyst, leading to an efficient synthesis of β-nitro sulfides (Scheme 1).

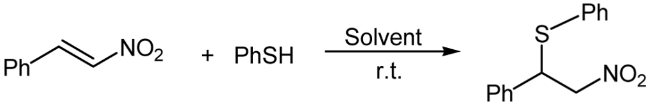
Michael addition of benzenthiol to 2-nitroethenylbenzene in various solvents was first examined, and the results are summarized in Table 1. When toluene, THF, and CH_2Cl_2 were used as solvents, no product was obtained after 36 h at room temperature (Table 1, entries 1–3). It was observed that the reaction in methanol or diethyl ether under identical conditions was very slow (Table 1, entries 4 and 5). To our delight, thia-Michael addition proceeded extremely fast in water without any catalyst or additive, giving the desired product in 95% isolated yield (Table 1, entry 6). The amount of water used in the reaction did not have any significant influence on the overall rate and the yield of the reaction. When 2-nitroethenylbenzene (0.5 mmol) was treated with benzenethiol (0.55 mmol) in 2 mL and 10 mL of water for 5 min, the product was afforded in 91 and 93% yields, respectively.

Generality of this thia-Michael addition was then examined on a variety of thiols including aromatic thiols and alkyl thiols with nitroolefins under the optimized reaction conditions. The results are listed in



Scheme 1. Michael addition of thiols to nitroolefins in water.

Table 1. Comparison of Michael addition of benzenethiol to 2-nitroethenylbenzene in organic solvents and water



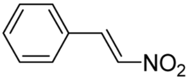
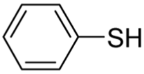
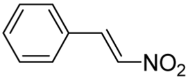
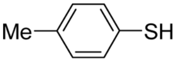
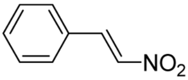
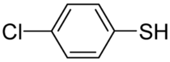
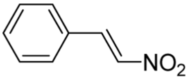
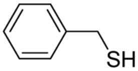
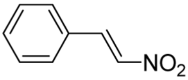
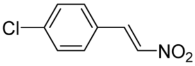
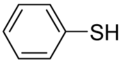
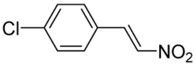
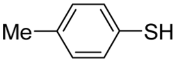
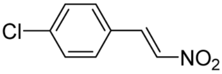
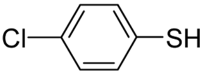
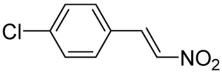
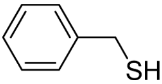
Entry	Solvent (5.0 mL)	Time	Yield (%)
1	toluene	36 h	NR
2	THF	36 h	NR
3	CH_2Cl_2	36 h	NR
4	CH_3OH	48 h	92
5	Et_2O	36 h	95
6	H_2O	5 min	95

Table 2, and β-nitro sulfides could be obtained in good yields of 84–96%. The reaction rate of aromatic thiols was found to be faster than that of alkyl thiols (Table 2, products **1**–**5**). For 4-substituted phenyl nitroolefins, the moderate electron-withdrawing and electron-donating substituents were unfavorable to thia-Michael addition (Table 2, products **2** and **3**). However, alkyl nitroolefins were favorable to this reaction (Table 2, products **4** and **5**).

The reaction proceeds faster in water than that in organic solvents without catalyst, which might be due to the promotion of water by the hydrogen bond between water and oxygen atom of the nitroolefin, increasing electrophilic property of the β-carbon. The proposed mechanism is depicted in Scheme 2. On the other hand, the hydrogen bond between water and hydrogen atom of the thiol increases the nucleophilic property of the thiol. Thus, simultaneous activation of the nitroolefin and the thiol takes place through hydrogen bond formation with water via **I**. Then Michael addition *via* **II** followed by one proton transfer leads to the conjugated adduct. In fact, the reaction rate of various thiols with nitroolefins was affected by the ability of the hydrogen bond formation between the thiol and water. This explains why the reaction rate of aromatic thiol was found to be faster than that of alkyl thiol (Table 2).

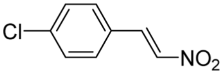
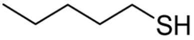
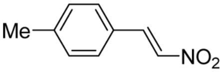
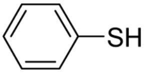
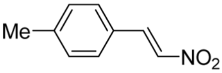
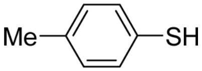
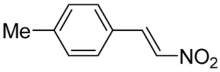
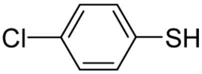
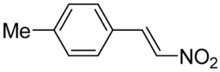
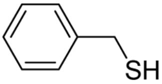
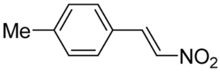
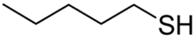
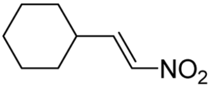
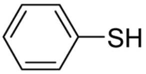
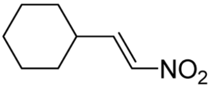
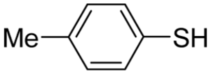
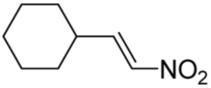
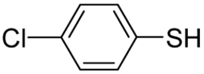
In summary, we have described herein an efficient and fast method for synthesis of β-nitro sulfides by virtue of water-mediated conjugated addition of thiols to nitroolefins in excellent yields. This methodology

Table 2. Michael addition of thiols to nitroolefins in water

Entry	Products	Michael acceptors	Thiols	Time	Yield (%)[a]
1	**1a**			5 min	95
2	**1b**			10 min	94
3	**1c**			10 min	96
4	**1d**			1 h	91
5	**1e**			2 h	93
6	**2a**			30 min	93
7	**2b**			30 min	90
8	**2c**			30 min	95
9	**2d**			4 h	91

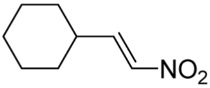
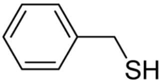
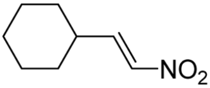
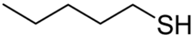
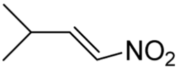
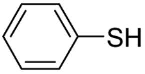
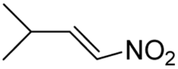
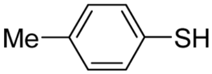
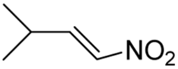
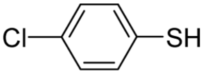
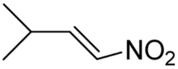
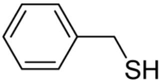
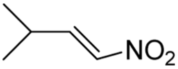
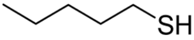
(*Continued*)

Table 2. Continued

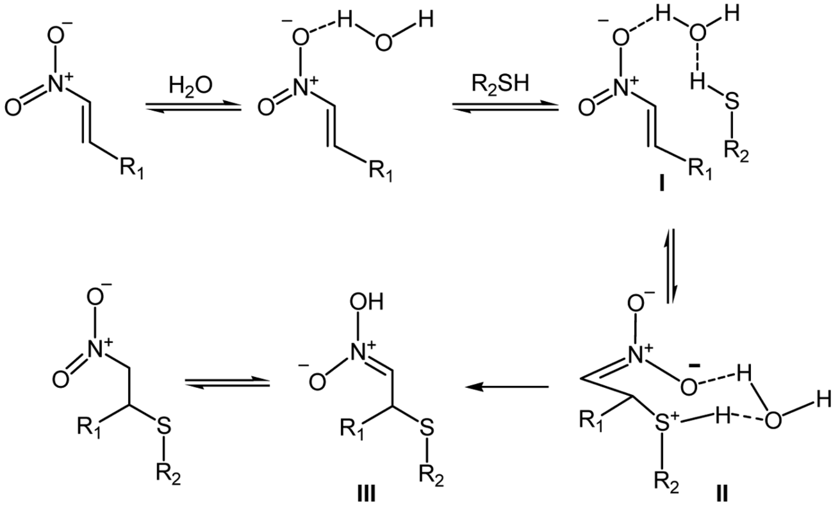
Entry	Products	Michael acceptors	Thiols	Time	Yield (%)[a]
10	**2e**			8 h	90
11	**3a**			2 h	96
12	**3b**			2 h	92
13	**3c**			2 h	94
14	**3d**			6 h	90
15	**3e**			8 h	91
16	**4a**			15 min	85
17	**4b**			15 min	87
18	**4c**			15 min	89

(*Continued*)

Table 2. Continued

Entry	Products	Michael acceptors	Thiols	Time	Yield (%)[a]
19	**4d**			2 h	88
20	**4e**			4 h	89
21	**5a**			15 min	92
22	**5b**			15 min	91
23	**5c**			15 min	90
24	**5d**			2 h	84
25	**5e**			4 h	85

is of interest because of the use of water as the solvent without any catalyst; thus it minimizes the cost and environmental pollution produced by the solvent.



Scheme 2. Proposed mechanism of Michael addition of thiols to nitroolefins in water.

EXPERIMENTAL

Melting points were determined on an X-4 melting-point apparatus and were uncorrected. ^{1}H NMR and ^{13}C NMR spectra were obtained using the Varian Mercury Plus 300BB or Bruker AM-400 in $CDCl_3$. IR spectra were recorded using a Nicolet Nexus 670 Fourier transform infrared (FT-IR) spectrometer in KBr disk. Elemental analyses were determined by Elemental Vario EL instrument. Mass spectra were performed on Thermo DSQ mass instrument (EI at 70 eV).

Nitroolefins were synthesized according to literature methods.[11]

General Procedure for Thia-Michael Addition of Thiols to Nitroolefins

Thiol (0.55 mmol) was added to a mixture of nitroolefin (0.5 mmol) in water (5 mL), and the mixture was vigorously stirred at room temperature until the nitroolefin was consumed completely (5 min). The reaction mixture was extracted with EtOAc (5 mL × 3), and the combined organic phase was washed with saturated Na_2CO_3 solution (15 mL × 3) and brine (15 mL × 3), dried over anhydrous $MgSO_4$, and concentrated under reduced pressure to give the crude product. The crude product was purified by flash-column chromatography to afford desired β-nitro sulfides.

Data

(2-Nitro-1-phenylethyl)(phenyl) Sulfide (**1a**)

^{1}H NMR (300 MHz, $CDCl_3$): $\delta = 4.69$–4.92 (m, 3H, CH_2, CH), 7.25–7.42 (m, 10H, ArH), which is in accord with Ref. 12.

(2-Nitro-1-phenylethyl)(p-tolyl) Sulfide (**1b**)

White solid, mp 84–85 °C. ^{1}H NMR (300 MHz, $CDCl_3$): $\delta = 2.35$ (s, 3H, CH_3) 4.69–4.84 (m, 3H, CH_2, CH), 7.13 (d, $J = 7.8$ Hz, 2H, ArH), 7.23–7.33 (m, 7H, ArH). ^{13}C NMR (75 MHz, $CDCl_3$): $\delta = 139.20$, 136.38, 134.25, 130.08, 128.88, 128.50, 128.06, 127.59, 78.46, 50.08, 21.16. IR (KBr): 1555, 1537, 13756, 805, 746, 698, 496 cm^{-1}. MS (EI, 70 eV): m/z (%) = 273.0 (72) [M^+]. Anal. calcd. for $C_{15}H_{15}NO_2S$: C, 65.91; H, 5.53; N, 5.12. Found: C, 65.71; H, 5.61; N, 4.96.

(4-Chlorophenyl) (2-Nitro-1-phenylethyl) Sulfide (**1c**)

Yellowish oil; ^{1}H NMR (300 MHz, $CDCl_3$): $\delta = 4.69$–4.84 (m, 3H, CH_2, CH), 7.20–7.33 (m, 9H, ArH). ^{13}C NMR (75 MHz, $CDCl_3$): $\delta = 135.91$, 135.15, 135.07, 129.96, 129.36, 128.91, 128.62, 127.50, 78.13, 49.90. Anal. calcd. for $C_{14}H_{12}ClNO_2S$: C, 57.24; H, 4.12; N, 4.77. Found: C, 57.20; H, 4.14; N, 4.86.

Benzyl (2-Nitro-1-phenylethyl) Sulfide (**1d**)

Yellowish oil. ^{1}H NMR (300 MHz, $CDCl_3$): $\delta = 3.57$ (d, $J = 13.5$ Hz, 1H, $PhCH_2$), 3.67 (d, $J = 13.5$ Hz, 1H, $PhCH_2$), 4.40 (dd, $J = 9.3$, 6.9 Hz, 1H, CH), 4.59–4.72 (m, 2H, CH_2NO_2), 7.22–7.37 (m, 10H, ArH). ^{13}C NMR (75 MHz, $CDCl_3$): $\delta = 136.86$, 136.75, 128.85, 128.77, 128.53, 128.31, 127.61, 127.34, 78.79, 45.69, 35.75. MS (EI, 70 eV): m/z (%) = 273.0 (38) [M^+]. Anal. calcd. for $C_{15}H_{15}NO_2S$: C, 65.91; H, 5.53; N, 5.12. Found: C, 65.82; H, 5.64; N, 4.98.

(2-Nitro-1-phenylethyl) (Pentyl) Sulfide (**1e**)

Yellowish oil. ^{1}H NMR (300 MHz, $CDCl_3$): $\delta = 0.87$ (t, $J = 7.2$ Hz, 3H, CH_3), 1.23–1.32 (m, 4H, CH_2), 1.51–1.56 (m, 2H, CH_2), 2.44 (t, $J = 7.5$ Hz, 2H, CH_2), 4.55 (dd, $J = 7.5$, 4.2 Hz, 1H, CH), 4.75 (d,

$J = 7.5$ Hz, 2H, CH_2NO_2), 7.30–7.36 (m, 5H, ArH). ^{13}C NMR (75 MHz, $CDCl_3$): $\delta = 137.38$, 128.90, 128.31, 127.53, 79.22, 46.43, 31.52, 30.76, 28.71, 22.07, 13.83. MS (EI, 70 eV): m/z (%) = 253.1 (35) [M^+]. Anal. calcd. for $C_{13}H_{19}NO_2S$: C, 61.63; H, 7.56; N, 5.53. Found: C, 61.47; H, 7.60; N, 5.43.

(1-(4-Chlorophenyl)-2-nitroethyl) (Phenyl) Sulfide (**2a**)

White solid, mp 76–77 °C. ^1H NMR (400 MHz, $CDCl_3$): $\delta = 4.69$–4.87 (m, 3H, CH_2, CH), 7.17–7.21 (m, 2H, ArH), 7.29–7.39 (m, 7H, ArH). ^{13}C NMR (100 MHz, $CDCl_3$): $\delta = 134.77$, 134.27, 133.82, 131.15, 129.31, 129.02, 128.89, 78.07, 49.01. IR (KBr): 1549, 1374, 1090, 799, 749, 687 cm^{-1}. MS (EI, 70 eV): m/z (%) = 292.9 (18) [M^+]. Anal. calcd. for $C_{14}H_{12}ClNO_2S$: C, 57.24; H, 4.12; N, 4.77. Found: C, 57.26; H, 4.02; N, 4.71.

(1-(4-Chlorophenyl)-2-nitroethyl) (p-Tolyl) Sulfide (**2b**)

White solid, mp 64–65 °C. ^1H NMR (400 MHz, $CDCl_3$): $\delta = 2.28$ (s, 3H, CH_3), 4.58–4.73 (m, 3H, CH2, CH), 7.05–7.12 (m, 4H, ArH), 7.18–7.25, (m, 4H, ArH). ^{13}C NMR (100 MHz, $CDCl_3$): $\delta = 139.44$, 134.94, 134.39, 134.24, 130.13, 129.02, 128.92, 127.42, 78.11, 49.32, 21.12. Anal. calcd. for $C_{15}H_{14}ClNO_2S$: C, 58.53; H, 4.58; N, 4.55. Found: C, 58.69; H, 5.74; N, 4.32.

(4-Chlorophenyl) (1-(4-Chlorophenyl)-2-nitroethyl) Sulfide (**2c**)

Yellowish oil. ^1HNMR (400 MHz, $CDCl_3$): $\delta = 4.68$–4.83 (m, 3H, CH_2, CH), 7.15–7.17 (m, 2H, ArH), 7.28–7.31 (m, 6H, ArH). ^{13}C NMR (100 MHz, $CDCl_3$): $\delta = 135.36$, 135.30, 134.56, 134.45, 129.50, 129.13, 128.88, 77.92, 49.29. MS (EI, 70 eV): m/z (%) = 328.1 (22) [M^+]. Anal. calcd. for $C_{14}H_{11}Cl_2NO_2S$: C, 51.23; H, 3.38; N, 4.27. Found: C, 51.12; H, 3.56; N, 4.53.

Benzyl (1-(4-Chlorophenyl)-2-nitroethyl) Sulfide (**2d**)

Yellowish oil. ^1H NMR (400 MHz, $CDCl_3$): $\delta = 3.58$ (d, $J = 13.6$ Hz, 1H, $PhCH_2$), 3.69 (d, $J = 13.6$ Hz, 1H, $PhCH_2$), 4.37 (dd, $J = 7.2$, 8.8 Hz, 1H, CH), 4.64 (dd, $J = 1.6$, 8.4 Hz, 2H, CH_2), 7.19–7.36 (m, 9H, ArH). ^{13}C NMR (100 MHz, $CDCl_3$): $\delta = 136.51$, 135.53, 134.08,129.05, 128.76, 128.62, 127.48, 78.60, 45.01, 35.84. MS (EI, 70 eV): m/z (%) = 307.0 (20) [M^+]. Anal. calcd. for $C_{15}H_{14}ClNO_2S$: C, 58.53; H, 4.58; N, 4.55. Found: C, 58.67; H, 4.43; N, 4.72.

(1-(4-Chlorophenyl)-2-nitroethyl) (Pentyl) Sulfide (**2e**)

Yellowish oil. ^{1}H NMR (400 MHz, CDCl$_3$): δ = 0.86 (t, *J* = 7.2 Hz, 3H, CH$_3$), 1.23–1.30 (m, 4H, CH$_2$), 1.49–1.56 (m, 2H, CH$_2$), 2.42 (t, *J* = 7.2 Hz, 2H, CH$_2$), 4.51 (dd, *J* = 8.8, 7.6 Hz, 1H, CH), 4.68–4.76 (m, 2H, CH$_2$NO$_2$), 7.27–7.33 (m, 4H, ArH). ^{13}C NMR (100 MHz, CDCl$_3$): δ = 136.02, 133.95, 128.99, 128.88, 78.86, 45.64, 31.45, 30.65, 28.58, 21.99, 13.73. Anal. calcd. for $C_{13}H_{18}ClNO_2S$: C, 54.25; H, 6.30; N, 4.87. Found: C, 54.42; H, 6.47; N, 4.94.

(2-Nitro-1-p-tolyl-ethyl) (Phenyl) Sulfide (**3a**)

White solid, mp 80–81°C. ^{1}H NMR (300 MHz, CDCl$_3$): δ = 2.33 (s, 3H, CH$_3$), 4.65–4.89 (m, 3H, CH$_2$,CH), 7.12–7.42 (m, 9H, ArH). ^{13}C NMR (75 MHz, CDCl$_3$): δ = 138.42, 133.46, 133.10, 132.08, 129.59, 129.26 128.58, 127.42, 78.55, 49.51, 21.07. IR (KBr): 1551, 1537, 1375, 845, 787, 750, 488 cm^{-1}. MS (EI, 70 eV): *m/z* (%) = 273 (27) [M$^+$]. Anal. calcd. for $C_{15}H_{15}NO_2S$: C, 65.91; H, 5.53; N, 5.12. Found: C, 65.90; H, 5.61; N, 4.96.

(2-Nitro-1-p-tolylethyl) (p-Tolyl) Sulfide (**3b**)

White solid, mp 86–87 °C. ^{1}H NMR (300 MHz, CDCl$_3$): δ = 2.33 (s, 3H, CH$_3$), 2.34 (s, 3H, CH$_3$), 4.64–4.84 (m, 3H, CH$_2$, CH), 7.11–7.17 (m, 6H, ArH), 7.29 (d, *J* = 7.5 Hz, 2H, ArH). ^{13}C NMR (75 MHz, CDCl$_3$): δ = 139.03, 138.33, 134.05, 133.25, 130.05, 129.56, 128.32, 127.42, 78.57, 49.82, 21.12, 21.08. Anal. calcd. for $C_{16}H_{17}NO_2S$: C, 66.87; H, 5.96; N, 4.87. Found: C, 66.65; H, 5.74; N, 4.98.

(4-Chlorophenyl) (2-Nitro-1-p-tolylethyl) Sulfide (**3c**)

White solid, mp 62–63 °C. ^{1}H NMR (300 MHz, CDCl$_3$): δ = 2.33 (s, 3H, CH$_3$), 4.66–4.85 (m, 3H, CH$_2$, CH), 7.27 (s, 4H, ArH); 7.27–7.32 (m, 4H, ArH). ^{13}C NMR (75 MHz, CDCl$_3$): δ = 138.47, 134.90, 134.85, 132.77, 130.24, 129.56, 129.30, 127.32, 78.23, 49.61, 21.01. MS (EI, 70 eV): *m/z* (%) = 307.0 (24) [M$^+$]. Anal. calcd. for $C_{15}H_{14}ClNO_2S$: C, 58.53; H, 4.58; N, 4.55. Found: C, 58.35; H, 5.69; N, 4.69.

Benzyl (2-Nitro-1-p-tolylethyl) Sulfide (**3d**)

Yellowish oil. ^{1}H NMR (300 MHz, CDCl$_3$): δ = 2.34 (s, 3H, CH$_3$), 3.68 (d,*J* = 13.5 Hz, 1H, PhCH$_2$), 3.59 (d, *J* = 13.5 Hz, 1H, PhCH$_2$), 4.39

(dd, $J = 8.7, 6.3$ Hz, 1H, CH), 4.59–4.72 (m, 2H, CH_2), 7.16 (s, 4H, ArH), 7.25–7.37 (m, 5H, ArH). ^{13}C NMR (75 MHz, $CDCl_3$): $\delta = 138.28$, 136.93, 133.82, 129.64, 128.86, 128.62, 127.58, 127.41, 79.05, 45.56, 38.85, 21.09. MS (EI, 70 eV): m/z (%) = 287.0 (41) [M^+]. Anal. calcd. for $C_{16}H_{17}NO_2S$: C, 66.87; H, 5.96; N, 4.87. Found: C, 66.99; H, 5.73; N, 4.64.

(2-Nitro-1-p-tolylethyl) (Pentyl) Sulfide (**3e**)

Yellowish oil. ^1H NMR (300 MHz, $CDCl_3$): $\delta = 0.87$ (t, $J = 6.9$ Hz, 3H, CH_3), 1.27–1.32 (m, 4H, CH_2), 1.51–1.56 (m, 2H, CH_2), 2.33 (s, 3H, CH_3), 2.43 (t, $J = 7.2$ Hz, 2H, CH_2), 4.52 (t, $J = 8.1$ Hz, 1H, CH), 4.73 (d, $J = 8.1$ Hz, 2H, CH_2), 7.15 (d, $J = 8.1$ Hz, 2H, ArH), 7.22 (d, $J = 8.1$ Hz, 2H, ArH). ^{13}C NMR (75 MHz, $CDCl_3$): $\delta = 138.17$, 134.29, 129.61, 127.42, 79.37, 46.23, 31.54, 30.82, 28.77, 22.12, 21.07, 13.85. Anal. calcd. for $C_{14}H_{21}NO_2S$: C, 62.89; H, 7.92; N, 5.24. Found: C, 62.70; H, 7.71; N, 5.12.

(1-Cyclohexyl-2-nitroethyl) (Phenyl) Sulfide (**4a**)

Yellow oil. ^1H NMR (300 MHz, $CDCl_3$): $\delta = 1.13$–1.34 (m, 4H, ChH), 1.39–1.51 (m, 1H, ChH), 1.62–1.92 (m, 6H, ChH), 3.65–3.71 (m, 1H, CH), 4.42 (dd, $J = 12.9, 6.6$ Hz, 1H, CH_2), 4.64 (dd, $J = 12.9, 7.2$ Hz, 1H, CH_2), 7.27–7.36 (m, 3H, ArH), 7.42–7.47 (m, 2H, ArH). ^{13}C NMR (75 MHz, $CDCl_3$): $\delta = 133.48$, 132.27, 129.19, 127.74, 76.90, 52.85, 39.63, 30.44, 28.54, 26.01, 25.96, 25.91. IR: 2928, 2854, 1554, 1445, 1376, 746, 694 cm^{-1}. MS (EI, 70 eV): m/z (%) = 265.0 (26) [M^+]. Anal. calcd. for $C_{14}H_{19}NO_2S$: C, 63.36; H, 7.22; N, 5.28. Found: C, 63.58; H, 6.87; N, 5.23.

(1-Cyclohexyl-2-nitroethyl) (p-Tolyl) Sulfide (**4b**)

Yellowish oil. ^1H NMR (300 MHz, $CDCl_3$): $\delta = 1.09$–1.33 (m, 4H, ChH), 1.39–1.59 (m, 1H, ChH), 1.62–1.92 (m, 6H, ChH), 2.31 (s, 3H, CH_3), 3.56–3.62 (m, 1H, CH), 4.40 (dd, $J = 12.9, 6.6$ Hz, CH_2), 4.63 (dd, $J = 12.9, 8.7$ Hz, CH), 4.59–4.63 (m, 1H, CH), 7.14 (d, $J = 7.8$ Hz 2H, ArH), 7.34 (d, $J = 7.8$ Hz, 2H, ArH). ^{13}C NMR (75 MHz, $CDCl_3$): $\delta = 138.12$, 133.03, 129.08, 129.67, 76.95, 53.36, 36.61, 30.47, 28.62, 26.06, 26.00, 25.90, 20.99. Anal. calcd. for $C_{15}H_{21}NO_2S$: C, 64.48; H, 7.58; N, 5.01. Found: C, 64.30; H, 7.65; N, 4.91.

(4-Chlorophenyl) (1-cyclohexyl-2-nitroethyl) Sulfide (**4c**)

Yellowish oil. ^{1}H NMR (300 MHz, CDCl$_3$): δ = 1.10–1.29 (m, 4H, ChH), 1.38–1.43 (m, 1H, ChH), 1.61–1.89 (m, 6H, ChH), 3.58–3.65 (m, 1H, CH), 4.40 (dd, *J* = 12.9, 6.9 Hz, 1H, CH_2NO_2), 4.63 (dd, *J* = 12.9, 7.8 Hz, 1H, CH_2NO_2), 7.28–7.39 (m, 4H, ArH). ^{13}C NMR (75 MHz, CDCl$_3$): δ = 133.94, 133.71, 132.11, 129.33, 76.94, 53.38, 39.86, 30.41, 28.73, 25.98, 25.93, 25.88. Anal. calcd. for $C_{14}H_{18}ClNO_2S$: C, 56.08; H, 6.05; N, 4.67. Found: C, 56.29; H, 6.27; N, 4.86.

Benzyl (1-Cyclohexyl-2-nitroethyl) Sulfide (**4d**)

Colorless oil. ^{1}H NMR (300 MHz, CDCl$_3$): δ = 0.97–1.29 (m, 6H, ChH), 1.40–1.49 (m, 1H, ChH), 1.62–1.71 (m, 4H, ChH), 3.11–3.18 (m, 1H, CH), 3.71 (d, *J* = 12.9 Hz, 1H, $PhCH_2$), 3.76 (d, *J* = 12.9 Hz, 1H, $PhCH_2$), 4.35 (dd, *J* = 12.9, 7.5 Hz, 1H, CH_2NO_2), 4.55 (dd, *J* = 12.9, 7.5 Hz, 1H, CH_2NO_2), 7.27–7.33 (m, 5H, ArH). ^{13}C NMR (75 MHz, CDCl$_3$): δ = 137.49, 128.98, 128.58, 127.36, 77.93, 48.62, 40.07, 37.13, 30.15, 28.30, 26.00, 25.95. MS (EI, 70 eV): *m/z* (%) = 279.1 (48) [M$^+$]. Anal. calcd. for $C_{15}H_{21}NO_2S$: C, 64.48; H, 7.58; N, 5.01. Found: C, 64.31; H, 7.68; N, 4.95.

(1-Cyclohexyl-2-nitroethyl) (Pentyl) Sulfide (**4e**)

Colorless oil. ^{1}H NMR (300 MHz, CDCl$_3$): δ = 0.89 (t, *J* = 6.9 Hz, 3H, CH$_3$), 1.06–1.43 (m, 9H, ChH, CH$_2$), 1.52–1.77 (m, 8H, ChH, CH$_2$), 2.52 (t, *J* = 7.5 Hz, 2H, CH$_2$), 3.15–3.21 (m, 1H, CH), 4.44 (dd, *J* = 12.3, 7.8 Hz, 1H, CH_2NO_2), 4.60 (dd, *J* = 12.3, 7.5 Hz, 1H, CH_2NO_2). ^{13}C NMR (75 MHz, CDCl$_3$): δ = 78.26, 49.86, 40.35, 32.96, 30.87, 30.43, 29.31, 28.45, 26.12, 26.05, 26.02, 22.20, 13.91. MS (EI, 70 eV): *m/z* (%) = 259.1 (18) [M$^+$]. Anal. calcd. for $C_{13}H_{25}NO_2S$: C, 60.19; H, 9.71; N, 5.40. Found: C, 60.32; H, 9.60; N, 5.62.

(3-Methyl-1-nitrobutan-2-yl) (Phenyl) Sulfide (**5a**)

Yellowish oil. ^{1}H NMR (300 MHz, CDCl$_3$): δ = 1.06 (d, *J* = 5.4 Hz, 3H, CH$_3$), 1.52 (d, *J* = 5.4 Hz, 3H, CH$_3$), 2.08–2.08 (m, 1H, CH), 3.67–3.73 (m, 1H, CH), 4.44 (dd, *J* = 12.9, 8.1 Hz, 1H, CH$_2$), 4.61 (dd, *J* = 11.7, 8.1 Hz, 1H, CH$_2$), 7.25–7.36 (m, 3H, ArH), 7.43–7.48 (m, 2H, ArH). ^{13}C NMR (75 MHz, CDCl$_3$): δ = 133.33, 132.43, 129.26, 127.84, 77.30, 53.68, 29.87, 20.16, 17.87. IR: 2966, 2875, 1554, 1475, 1433, 1376, 746, 693 cm^{-1}. MS (EI, 70 eV): *m/z* (%) = 224.9 (35) [M$^+$]. Anal. calcd. for $C_{14}H_{19}NO_2S$: C, 58.64; H, 6.71; N, 6.22. Found: C, 58.45; H, 6.51; N, 6.21.

(3-Methyl-1-nitrobutan-2-yl) (p-Tolyl) Sulfide (**5b**)

Yellowish oil. ^{1}H NMR (300 MHz, $CDCl_3$): δ = 1.00 (d, *J* = 6.3 Hz, 3H, CH_3), 1.14 (d, *J* = 6.3 Hz, 3H, CH_3), 1.99–2.05 (m, 1H, CH), 2.34 (s, 3H, CH_3), 3.59–3.65 (m, 1H, CH), 4.42 (dd, *J* = 12.9, 7.2 Hz,, 1H, CH_2), 4.59 (dd, *J* = 12.9, 8.7 Hz, 1H, CH_2), 7.14 (d, *J* = 7.8 Hz, 2H, ArH), 7.36 (d, *J* = 7.8 Hz, 2H, ArH). ^{13}C NMR (75 MHz, $CDCl_3$): δ = 138.29, 138.16, 130.08, 129.44, 77.35, 54.21, 29.76, 21.09, 20.24, 17.91. Anal. calcd. for $C_{12}H_{17}NO_2S$: C, 60.22; H, 7.16; N, 5.85. Found: C, 60.04; H, 7.28; N, 5.99.

(4-Chlorophenyl) (3-Methyl-1-nitrobutan-2-yl) Sulfide (**5c**)

Colorless oil. ^{1}H NMR (300 MHz, $CDCl_3$): δ = 1.05 (d, *J* = 7.2 Hz, 3H, CH_3), 1.13 (d, *J* = 7.2 Hz, 3H, CH_3), 2.00–2.07 (m, 1H, CH), 3.61–3.68 (m, 1H, CH), 4.42 (dd, *J* = 12.9, 7.2 Hz, 1H, CH_2), 4.60 (dd, *J* = 12.9, 8.1 Hz, CH_2), 7.28–7.32 (m, 2H, ArH), 7.37–7.40 (m, 2H, ArH). ^{13}C NMR (75 MHz, $CDCl_3$): δ = 134.09, 133.83, 131.90, 129.39, 77.26, 54.13, 30.06, 20.09, 17.99. MS (EI, 70 eV): *m/z* (%) = 259.0 (26) [M$^+$]. Anal. calcd. for $C_{11}H_{14}ClNO_2S$: C, 50.86; H, 5.43; N, 5.39. Found: C, 50.74; H, 5.60; N, 5.30.

Benzyl (3-Methyl-1-nitrobutan-2-yl) Sulfide (**5d**)

Colorless oil. ^{1}H NMR (300 MHz, $CDCl_3$): δ = 0.89 (d, *J* = 5.1 Hz, 3H, CH_3), 0.91 (d, *J* = 5.1 Hz, 3H, CH_3), 1.84–1.90 (m, 1H, CH), 3.14–3.20 (m, 1H, CH), 3.71 (d, *J* = 13.2 Hz, 1H, $PhCH_2$), 3.77 (d, *J* = 13.2 Hz, 1H, $PhCH_2$), 4.36 (dd, *J* = 12.6, 7.5 Hz, 1H, CH_2), 4.52 (dd, *J* = 12.6, 7.8 Hz, 1H, CH_2), 7.25–7.35 (m, 5H, ArH). ^{13}C NMR (75 MHz, $CDCl_3$): δ = 137.47, 128.95, 128.54, 127.33, 78.24, 49.23, 36.91, 29.96, 19.90, 17.53. Anal. calcd. for $C_{12}H_{17}NO_2S$: C, 60.22; H, 7.16; N, 5.85. Found: C, 60.43; H, 7.01; N, 5.71.

(3-Methyl-1-nitrobutan-2-yl) (Pentyl) Sulfide (**5e**)

Colorless oil. ^{1}H NMR (300 MHz, $CDCl_3$): δ = 0.91 (d, *J* = 7.2 Hz, 3H, CH_3), 0.95 (d, *J* = 9.6 Hz, 3H, CH_3), 1.05 (d, *J* = 9.6 Hz, 3H, CH_3), 1.31–1.36 (m, 4H, CH_2), 1.52–1.59 (m, 2H, CH_2), 1.92–1.98 (m, 1H, CH), 2.53 (t, $J = 7.2$ Hz, 2H, CH_2), 3.17–3.24 (m, 1H, CH), 4.45 (dd, $J = 12.3$, 8.1 Hz, 1H, CH_2), 4.65 (dd, $J = 12.6$, 8.1 Hz, 1H, CH_2). ^{13}C NMR (75 MHz, $CDCl_3$): $\delta = 78.48$, 50.50, 32.80, 30.80, 30.24, 29.29, 22.15, 20.11, 17.66, 13.87. MS (EI, 70 eV): m/z (%) = 219.0 (27) [M^+]. Anal. calcd. for $C_{10}H_{21}NO_2S$: C, 54.76; H, 9.65; N, 6.39. Found: C, 54.57; H, 9.43; N, 6.20.

ACKNOWLEDGMENTS

This work was supported by National Natural Science Foundation of China (NSFC 20702022, 20621091).

REFERENCES

1. (a) Grieco, P. A. *Organic Synthesis in Water*; Blackie Academic and Professional: London, 1998; (b) Li, C. J.; Chan, T. H. *Organic Reactions in Aqueous Media*; Wiley: New York, 1997.
2. Metzner, P.; Thuillier, A. *Sulfur Reagents in Organic Synthesis*; Academic Press: New York, 1994.
3. (a) Fluharty, A. L. In *The Chemistry of the Thiol Group, Part 2*; S. Patai, (Ed.); Wiley: New York, 1974; (b) Jocelyn, P. C. *Biochemistry of the SH Group*; Academic Press: London, **1972**; (c) Ivanetich, K. M.; Santi, D. V. 5,6-Dihydropyrimidine adducts in the reactions and interactions of pyrimidines with proteins.*Prog. Nucleic Acid Res. Mol. Biol.* **1992**, *42*, 127–156; (d) Talalay, P.; DeLong, M. J.; Prochaska, H. J. Identification of a common chemical signal regulating the induction of enzymes that protect against chemical carcinogenesis.*Proc. Natl. Acad. Sci. USA* **1988**, *85*, 8261–8265.
4. (a) Wynberg, H. In *Topics in Stereochemistry*, E. L. Eliel, S. H. Wilen, N. L. Allinger (Eds.); Wiley: New York, 1986; vol. 16; (b) Emori, E.; Arai, T.; Sasai, H.; Shibasaki, M. A catalytic Michael addition of thiols to α, β-unsaturated carbonyl compounds: Asymmetric Michael additions and asymmetric protonations. *J. Am. Chem. Soc.* **1998**, 120, 4043–4044, and references cited therein.
5. Calderari, G.; Seebach, D. Asymmetric michael additions: Stereoselective alkylation of chiral, non-racemic enolates by nitroolefins: Preparation of enantiomerically pure γ-aminobutyric and succinic acid derivatives. *Helv. Chim. Acta* **1985**, *68*, 1592–1604.
6. (a) Seebach, D.; Colvin, E. W.; Lehr, F.; Weller, T. Nitroaliphatic compounds–Ideal intermediates in organic synthesis. *Chimia* **1979**, *33*, 1–18; (b) Yoshikoshi, A.; Miyashita, M. Oxoalkylation of carbonyl compounds with conjugated nitro olefins. *Acc. Chem. Res.* **1985**, *18*, 284–290. (c) Rajappa, S. Nitroenamines: Preparation, structure and synthetic

potential. *Tetrahedron* **1981**, *37*, 1453–1480. (d) Barrett, A. G. M.; Graboski, G. G. Conjugated nitroalkenes: Versatile intermediates in organic synthesis. *Chem. Rev.* **1986**, *86*, 751–762.

7. (a) Ram, S.; Ehrenkaufer, R. E. A general procedure for mild and rapid reduction of aliphatic and aromatic nitro compounds using ammonium formate as a catalytic hydrogen transfer agent. *Tetrahedron Lett.* **1984**, *25*, 3415–3418; (b) Tamura, R.; Oda, D.; Kurokawa, H. Synthesis of α-amino ketone hydrochlorides via chemoselective hydrogenation of α-nitro ketones. *Tetrahedron Lett.* **1986**, *27*, 5759–5762; (c) Kraus, G. A.; Thurston, J.; Thomas, P. J.; Jacobson, R. A.; Su, Y. 2-Benzoyloxynitroethylene as a cis-2-aminoethenol equivalent. *Tetrahedron Lett.* **1988**, *29*, 1879–1882; (d) Barrett, A. G. M.; Spilling, C. D. Transfer hydrogenation: A stereospecific method for the conversion of nitro alkanes into amines. *Tetrahedron Lett.* **1988**, *29*, 5733–5734.
8. Kamimura, A.; Sasatani, H.; Hashimoto, T.; Kawai, T.; Hori, K.; Ono, N. Anti-selective Michael addition of thiols and their analogs to nitro olefins. *J. Org. Chem.* **1990**, *55*, 2437–2442.
9. Ménand, M.; Dalla, V. TMAF-Catalyzed conjugate addition of oxazolidinone and thiols. *Synlett* **2005**, 95–98.
10. Ranu, B. C.; Dey, S. S.; Hajra, A. Catalysis by an ionic liquid: Efficient conjugate addition of thiols to electron deficient alkenes catalyzed by molten tetrabutylammonium bromide under solvent-free conditions. *Tetrahedron* **2003**, *59*, 2417–2421.
11. Côté, A.; Lindsay, V. N. G.; Charette, A. B. Application of the chiral bis(phosphine) monoxide ligand to catalytic enantioselective addition of dialkylzinc reagents to β-Nitroalkenes. *Org. Lett.* **2007**, *9*, 85–87.
12. Kotrusz, P.; Toma, Š. *L* -Proline catalyzed Michael additions of thiophenols to α,β-unsaturated compounds, particularly α-enones, in the ionic liquid [bmim]PF_6. *Molecules* **2006**, *11*, 197–205.