Received: 17 February 2018 | Revised: 25 July 2018 | Accepted: 20 September 2018
DOI: 10.1002/jccs.201800062

JOURNAL OF THE CHINESE CHEMICAL SOCIETY

ARTICLE

A convenient one-pot method for the synthesis of symmetrical dialkyl trithiocarbonates using NH_4OAc under mild neutral conditions

Zeinab Arzehgar | Hosna Ahmadi

Department of Chemistry, Ilam University, Ilam, Iran

Correspondence
Zeinab Arzehgar, Department of Chemistry, Ilam University, Ilam, Iran.
Email: arzehgar@yahoo.com

Funding information
Ilam University Research Council

A facial, new, one-pot method for the preparation of symmetrical organic trithiocarbonates from various alkyl halides and carbon disulfide is described. This is a convenient, clean, and mild procedure, which involves the use of the neutral, non-toxic, commercially available, and inexpensive reagent NH_4OAc in the preparation of the trithiocarbonate ion from carbon disulfide.

KEYWORDS
ammonium acetate, carbon disulfide, one-pot, neutral conditions, trithiocarbonates

1 | INTRODUCTION

One of the main efforts of researchers in organic chemistry is directed toward the synthesis of compounds that include sulfur bonds.[1] Among these compounds, trithiocarbonates have been known as an important class having significant applications; for instance, they act as inhibitors in the treatment of cancer,[2] as pesticides and insecticides in agriculture, as lubricating additives, and as intermediates and synthons in organic synthesis.[3–5] These compounds have been also employed as chain transfer agents for the reversible addition fragmentation chain transfer (RAFT) in free-radical polymerization.[6,7] Recently, Chang and co-workers have reported a kind of vinylene trithiocarbonate (VTC) as the electrolyte additive for the lithium ion.[8]

The classical routes for the synthesis of symmetrical trithiocarbonates include (a) the reaction of thiols with thiophosgene,[9,10] with chlorodithioformates,[11] or with carbon disulfide and alkyl halides[12,13]; (b) the reaction of metal xanthates with epoxides[14] or episulfides[15]; and (c) the reaction of the trithiocarbonate anion (CS_3^{2-}) with alkyl and aryl halides.[16]

The most convenient method for the preparation of the trithiocarbonate anion is the *in situ* one-pot generation from carbon disulfide under basic conditions. Many common bases such as NAOH,[17] KOH,[18] NH_4OH,[19] basic Al_2O_3,[20] CS_2CO_3,[21] KF/Al_2O_3,[22] *N*-Bu_4NOH,[23] K_3PO_4,[24] KOH/TBAB/Al_2O_3,[25] K_2CO_3,[26] anion exchange resin,[27] copper-catalyzed coupling reaction,[28] and KI-tetraethylene glycol complex[29] are employed in the *in situ* preparation of the CS_3^{2-} ion from carbon disulfide. However, most of these methods require the use of expensive and strong bases and long reaction times. One of the most powerful and new approaches to improve the synthesis of organic compounds involves the use of neutral reagents and mild reaction conditions. Therefore, there is still attention paid in developing new methods that would produce the desirable symmetrical trithiocarbonates in high yields in the presence of neutral and inexpensive bases. In this regard, and in continuation of our recent report on symmetrical trithiocarbonate synthesis in the presence of KF/Al2O3,[22] *N*-Bu_4NOH,[23] and imidazole,[30] we report here an efficient and simple method for the synthesis of symmetrical dialkyl trithiocarbonates in the presence of ammonium acetate (NH_4OAc).

This method was found to be effective and suitable from the point of view of the green chemistry.[31] The use of metal bases has several disadvantages such as their cost, toxicity, and corrosive behavior. Also, the strong and basic reaction conditions that are employed, as well as the difficulty in work-up during these reactions, are drawbacks. Therefore, here we describe a new alternative approach to the one-pot synthesis of symmetrical dialkyl trithiocarbonate from carbon disulfide and alkyl halides using NH_4OAc as an inexpensive, effective, readily available, and mild neutral reagent.

2 | RESULTS AND DISCUSSION

To explore the optimal reaction conditions with respect to the solvent, reaction times, and the amount of NH_4OAc to be used, the reaction of benzyl chloride (2.0 mmol) and carbon disulfide (6.0 mmol) in the presence of NH_4OAc at room temperature was chosen as a model reaction (Scheme 1).

Initially, several solvents such as H_2O, DMF, DMSO, PEG, THF, and toluene as well as under solvent-free condition were examined at room temperature. According the results shown in Table 1, DMSO was found to be the most effective solvent for the progress of the reaction (Table 1, entry 5).

In the next step, the effect of the amount of NH_4OAc was examined. The progress of the reaction depended on the amount of NH_4OAc; the reaction was found to be completed in the presence of 3.25 equiv. of this reagent (94%), whereas in the presence of 1.75 and 2 equiv., the yield was less (89%).

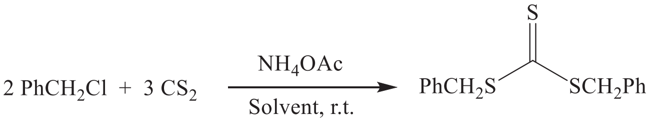
Eventually, a large number of symmetrical dialkyl trithiocarbonate were synthesized by the reaction of alkyl halides with carbon disulfide in the presence of NH_4OAc at room temperature with excellent yields under air atmosphere and optimized reaction conditions (Scheme 2). The results are summarized in Table 3.[25,32–34]

The procedure worked well with primary and secondary alkyl, benzyl, and allyl halides to give the corresponding dialkyl trithiocarbonates as the sole product in high to excellent yields (Table 2). However, the attempted reactions of aryl halides and tertiary alkyl halides failed under the same conditions, even after long reaction times (Table 2, entry 4).

Interestingly, a dialkyl trithiocarbonate containing an ester functional group was synthesized well, without any side products or changes in the functional group (Table 2, entry 13).

Furthermore, the procedure's efficiency in the synthesis of cyclic trithiocarbonates (1,3-dithiolane-2-thione) from dihalides was examined (Scheme 3). Five-, six-, and seven-membered cyclic trithiocarbonates were successfully prepared with moderate yields without any by-product (Table 2, entries 14–16).

However, the exact mechanism of this protocol is not completely understood. In alkaline media, CS_3^{2-} seems to be produced by the self-condensation reaction of carbon disulfide, according to the mechanism proposed in Scheme 4.



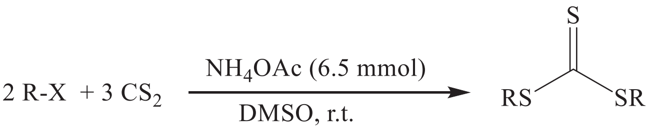
SCHEME 1 Optimal reaction conditions

TABLE 1 Influence of the solvent on dibenzyl trithiocarbonate synthesis in the presence of NH_4OAc at room temperature[a]

Entry	Solvent	Time (hr)	Yield[b] (%)
1	H_2O	4	No reaction
2	PEG	2.5	14
3	THF	2.5	19
4	DMF	2.5	43
5	DMSO	1.25	94
6	Toluene	4	No reaction
7	Solvent-free	4	No reaction

[a] *Reaction conditions*: carbon disulfide (6.0 mmol), benzyl chloride (2.0 mmol), ammonium acetate (6.5 mmol) in solvent (2 mL).

[b] Isolated yield.

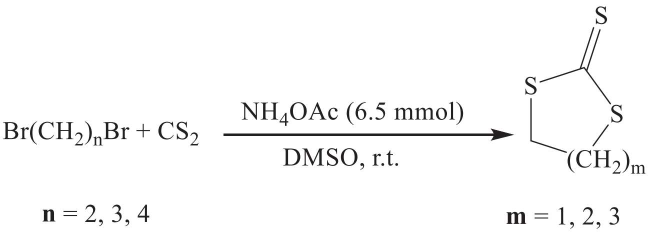


SCHEME 2 Synthesis of symmetrical dialkyl trithiocarbonate by the reaction of alkyl halides with carbon disulfide

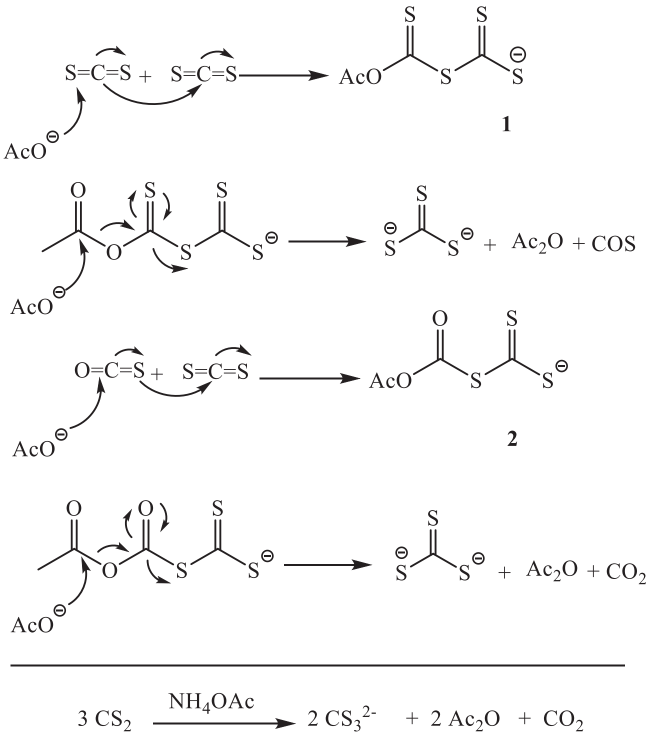
TABLE 2 Synthesis of the symmetric dialkyl trithiocarbonates under optimized reaction conditions

Entry	RX	Time (hr)	Yield (%)[a]
1	BnCl	1.25	94
2	*n*-BuBr	6	90
3	*s*-BuBr	6	78
4	*t*-BuBr	6	No reaction
5	$PhCH_2CH_2Br$	5.5	90
6	$PhCH_2CH_2CH_2Br$	6	91
7	$CH_2 = CHCH_2Br$	4	86
8	*i*-PrBr	6	74
9	MeI	3.5	52
10	EtI	1.25	80
11	PhBr	6	No reaction
12	$(4\text{-}NO_2)PhBr$	6	No reaction
13	$BrCH_2CO_2Et$	6	90
14	$BrCH_2CH_2Br$	4	87
15	$BrCH_2CH_2CH_2Br$	6.5	83
16	$BrCH_2(CH_2)_2CH_2Br$	8	85

[a] Isolated yield.



SCHEME 3 Synthesis of cyclic trithiocarbonates



SCHEME 4 Possible mechanism for the synthesis of dialkyl trithiocarbonate

In the mechanism proposed by Wertheim, however, trithiocarbonate is obtained by the addition reaction of ammonium sulfide with carbon disulfide.[19] The highly electrophilic nature of carbon in CS_2 and COS and the nucleophilicity of S^- will clearly favor the reaction, leading to the intermediate **1**. The intermediates **1** and **2** are acidic and, in the presence of a base, will give the stable trithiocarbonate ion, with the concomitant release of bubbles of CO_2.

3 | CONCLUSIONS

In summary, we have developed a facile and new protocol for the synthesis of symmetrical trithiocarbonates in the presence of NH_4OAc at room temperature under neutral and mild conditions. This process is more economical and environmentally friendly than previous methods because of the use of ammonium acetate as a neutral and commercially available reagent and the avoidance of expensive and/or dangerous and toxic reagents. Additionally, high yields, simple procedure, relatively short reaction times, easy work-up and handling, and saving energy are some attractive features of this protocol.

4 | EXPERIMENTAL

4.1 | Typical reaction procedure: dibenzyl trithiocarbonate synthesis

In a round-bottom flask equipped with a magnetic stirrer, 6.5 mmol NH_4OAc (0.50 g) and 3.0 mmol CS_2 (0.18 g) in DMSO (2 mL) were added and the mixture was stirred vigorously at room temperature for 15 min. Then, 2.0 mmol benzyl chloride (0.23 g) was added to the red-blood mixture, whereupon it immediately changed to yellow. Then the mixture was stirred for an appropriative time at room temperature (Table 2). The progress of the reaction was monitored by thin-layer chromatography (TLC). Upon completion, the reaction mixture was poured by preparative TLC (silica gel; *n*-hexane) to afford the pure dibenzyl trithiocarbonate (0.29 g, 94%) as a yellow oil.

TABLE 3 Symmetrical cyclic trithiocarbonates synthesis from alkyl dihalides under optimized conditions

Entry	Alkyl Dihalide	Product	Time (hr)	Yield[a] (%)
1	$BrCH_2CH_2Br$	$m = 1$	4	87
2	$BrCH_2CH_2CH_2Br$	$m = 2$	6.5	83
3	$BrCH_2(CH_2)_2CH_2Br$	$m = 3$	8	85

[a] Isolated yield.

Selected spectral data for representative trithiocarbonate:

Bis(3-phenylpropyl)trithiocarbonate: Table 2, entry 6: yellow oil; ^1H NMR (400 MHz, $CDCl_3$): $\delta = 7.26–7.38$ (m, 10 H), 3.4 (t, $J = 7.4$ Hz, 4 H), 2.79 (t, $J = 7.6$ Hz, 4 H), 2.1 (quin, $J = 7.4$ Hz, 4 H) ppm; ^{13}C NMR (100 MHz, $CDCl_3$): $\delta = 224.1$, 140.9, 129.5, 126.2, 36.1, 34.9, 29.7 ppm.

Diethyl 2,2′-(carbonothioyldisulfanediyl)diacetate: Table 2, entry 13: Pale yellow oil; ^1H NMR (400 MHz, $CDCl_3$): $\delta = 4.26$ (q, $J = 7.0$ Hz, 4 H), 4.20 (s, 4 H), 1.32 (t, $J = 7.2$ Hz, 6 H) ppm; ^{13}C NMR (100 MHz, $CDCl_3$): $\delta = 220.3$, 167.1, 62.2, 38.9, 14.1 ppm.

1,3-Dithiolane-2-thione: Table 3, entry 1: yellow oil; Yellow oil; ^1H NMR ($CDCl_3$, 400 MHz) $\delta = 3.98$ (s, 4H); ^{13}C NMR ($CDCl_3$, 100 MHz) $\delta = 230.0$, 45.1.

1,3-Dithiane-2-thione: Table 3, entry 2: yellow oil;^1H NMR ($CDCl_3$, 400 MHz) $\delta = 3.23$ (t, $J = 1.6$ Hz, 4H), 2.43 (m, 2H). ^{13}C NMR ($CDCl_3$, 100 MHz) $\delta = 222.0$, 35.6, 21.6.

ACKNOWLEDGMENT

This work was supported by the Ilam University Research Council.

ORCID

Zeinab Arzehgar http://orcid.org/0000-0003-3774-4348

REFERENCES

[1] (a) Y. Cui, P. E. Floreancig, *Org. Lett.* **1720**, *2012*, 14. (b) M. Nabati, *Chem. Method.* **2018**, *2*, 223.
[2] Z. O. Rzayev, M. Turk, E. A. Sylemez, *Bio-org Med. Chem.* **2012**, *20*, 5053.
[3] (a) P. C. Hamm, K. L. Godfrey, *US Patent*, **1961**, 2993774; (b) P. C. Hamm, K. L. Godfrey, *Chem. Abstr.* **1961**, *55*, 25146.
[4] I. Degani, R. Fochi, A. Gatti, V. Regondi, *Synthesis* **1986**, *11*, 894.
[5] D. Chaturvedi, A. K. Chaturvedi, N. Mishra, V. Mishra, *Tetrahedron Lett.* **2008**, *49*, 4886.
[6] B. Ebeling, P. Vana, *Macromolecules* **2013**, *46*, 4862.

[7] Q. Fu, K. Xie, T. G. McKenzie, G. G. Qiao, *Polym. Chem.* **2017**, *8*, 1519.

[8] C. C. Changa, S. H. Hsu, Y. F. Jung, C. H. Yang, *J. Power Sources.* **2011**, *196*, 9605.

[9] F. Runge, Z. El-Hewchi, H. J. Renner, E. Taeger, *J. Prakt. Chem.* **1959**, *7*, 279.

[10] Z. El-Hewchi, *J. Prakt. Chem.* **1962**, *16*, 201.

[11] H. C. Goldt, A. E. Wanns, *J. Org. Chem.* **1961**, *26*, 4047.

[12] N. Narendra, H. S. Lalithamba, V. V. Sureshbabu, *Tetrahedron Lett.* **2010**, *51*, 6169.

[13] B. Movassagh, M. Soleiman-Beigi, *Monatsh. Chem.* **2008**, *139*, 927.

[14] G. E. McCasland, A. B. Zanglungo, L. J. Durham, *J. Org. Chem.* **1976**, *41*, 1125.

[15] A. M. Craighton, L. N. Owen, *J. Chem. Soc.* **1960**, 1024.

[16] M. Saeed, M. Abbas, R. J. Abdel-Jalil, M. Zahid, W. Voelter, *Tetrahedron Lett.* **2003**, *44*, 315.

[17] A. W. M. Lee, W. H. Chan, H. C. Wong, *Synth. Commun.* **1988**, *18*, 1531.

[18] M. K. Leung, D. T. Hsieh, K. H. Lee, J. C. Liou, *J. Chem. Res.* **1995**, *478*, 826.

[19] E. Wertheim, *J. Am. Chem. Soc.* **1926**, *48*, 826.

[20] A. R. Kiasat, F. Kazemi, A. Savari, *Synth. Commun.* **2008**, *38*, 1057.

[21] N. Aoyagi, B. Ochiai, H. Mori, T. Endo, *Synlett* **2006**, *4*, 636.

[22] B. Movassagh, M. Soleiman-Beigi, M. Nazari, *Chem. Lett.* **2008**, *37*, 22.

[23] M. Soleiman-Beigi, Z. Arzehgar, B. Movassagh, *Synthesis* **2010**, 392.

[24] B. Movassagh, S. Alapour, *J. Sulfur. Chem.* **2013**, *34*, 222.

[25] A. R. Kiasat, F. M. J. Mehrjardi, *Chin. Chem. Soc.* **2008**, *55*, 639.

[26] N. Aoyagi, T. J. Endo, *Polym. Sci. Part A Polym. Chem.* **2009**, *47*, 3702.

[27] P. Takolpuckdee, C. A. Mars, S. Perrier, *Org. Lett.* **2005**, *7*, 3449.

[28] M. Gholinejad, *Eur. J. Org. Chem.* **2013**, *2013*, 257.

[29] M. Okada, R. Nishiyori, S. Kaneko, K. Igawa, S. Shirakawa, *Eur. J. Org. Chem.* **2018**, *2018*, 2022.

[30] M. Soleiman-Beigi, Z. Taherinia, *J. Sulfur. Chem.* **2014**, *35*, 470.

[31] R. A. Sheldon, I. W. C. E. Arends, U. Hanefeld, *Green Chemistry and Catalysis*, Wiley-VCH Verlag GmbH & Co. KGaA: Weinheim, Germany **2007**, p. 1.

[32] B. Tamami, A. R. Kiasat, *J. Chem. Res.* **1998**, 454.

[33] B. Tamami, A. R. Kiasat, *Iran Polym. J.* **1999**, *8*, 17.

[34] S. Motokucho, D. Takeuchi, F. Sanda, T. Endo, *Tetrahedron* **2001**, *57*, 7149.

SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of the article.

How to cite this article: Arzehgar Z, Ahmadi H. A convenient one-pot method for the synthesis of symmetrical dialkyl trithiocarbonates using NH_4OAc under mild neutral conditions. *J Chin Chem Soc*. 2018;1–4. https://doi.org/10.1002/jccs.201800062