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Synthesis of cyclic trithiocarbonates from cyclic ethers and carbon disulfide catalyzed by titanium complex

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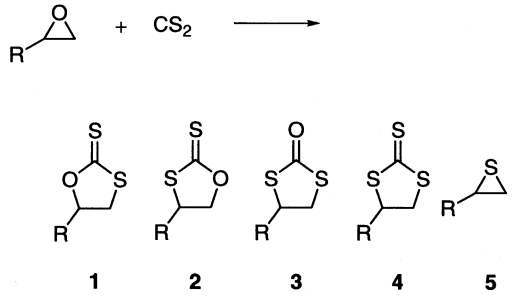
Abstract—This work deals with reaction of oxetane derivatives with carbon disulfide in the presence of (2-propanolato) titanatrane. It afforded six-membered cyclic trithiocarbonates in good yields. Reaction of propylene oxide with carbon disulfide also proceeded in a similar manner to give a five-membered cyclic trithiocarbonate in excellent yield.

1. Introduction

Cyclic thiocarbonates attract much attention in view of biological activity[1] and material science.[2] Recently, we have found that five- and six-membered cyclic thiocarbonates undergo ring-opening polymerization in controlled fashion to afford the corresponding polythiocarbonates with narrow molecular weight distribution.[2] Some efficient methods have been reported as for synthesis of five-membered cyclic thiocarbonates. Reaction of oxiranes with carbon disulfide (CS_2) is one of the most facile and effective methods for synthesizing cyclic dithiocarbonates (**1**–**3**), trithiocarbonates (**4**), and episulfide (**5**), where the product ratio depends on catalysts and reaction conditions (Scheme 1).[3,4] For example, five-membered cyclic trithiocarbonates are predominantly synthesized from oxiranes and CS_2 in the presence of base such as amines or potassium alcoholates.[3,4] Recently, we have selectively synthesized five-membered cyclic dithiocarbonates by reaction of oxiranes and CS_2 catalyzed by metal halides in high yields.[4] The reaction proceeds via nucleophilic attack of metal halides to CS_2, followed by the reaction of the produced xanthate anion with oxiranes.



Scheme 1.

In contrast, synthesis of six-membered cyclic thiocarbonates is quite limited. Kubota et al. have synthesized six-membered cyclic trithiocarbonates from 1,3-dimesylpropane derivatives and CS_2.[5] Sugawara et al. have synthesized six-membered cyclic trithiocarbonates by reaction of 1,3-dihaloalkanes with sodium trithiocarbonate in the presence of a phase-transfer catalyst in 66% yield.[6] On the other hand, no one has synthesized six-membered cyclic thiocarbonates by base-catalyzed reaction of oxetanes with CS_2 so far, presumably due to insufficient reactivity of oxetanes toward nucleophililic attack. Recently, we have reported that titanium complexes bring about nucleophilic ring-opening reaction of oxetane, leading to copolymerization of oxetane with cyclic acid anhydrides or bislactones.[7] In this case, Lewis acidity of the titanium complexes is high enough to activate oxetane molecule toward nucleophilic attack, which is considered as key importance.[8] As an extension of the study, this article deals with synthesis of five- and six-membered cyclic trithiocarbonates by reaction of oxiranes and oxetanes with CS_2 using (2-propanolato) titanatrane (**6**) as the catalyst.

2. Results and discussion

2.1. Synthesis of 1,3-dithiane-2-thione (9) from oxetane and CS_2 by titanium complex

The reaction of CS_2 with oxetane (OX) was carried out in the presence of (2-propanolato) titanatrane (**6**) at 100–140°C for 12–60 h as summarized in Table 1. At 120°C for 48 h, the corresponding trithiocarbonate **9** was obtained in 90% yield, when the feed molar ratio of CS_2/OX/**6** was

Keywords: oxetane; oxirane; molar ratio.

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Table 1. Reaction of carbon disulfide with oxetane in the presence of **6**

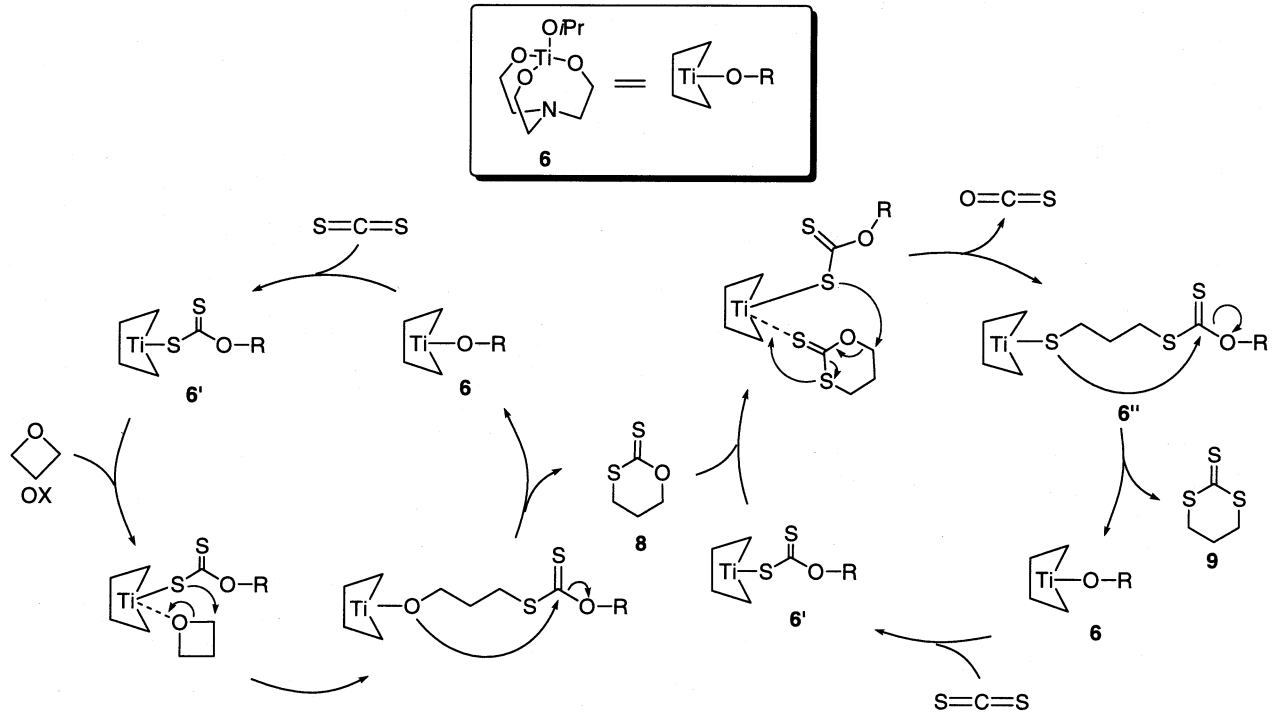
Run	CS_2/OX/**6** (molar ratio)	Temperature (°C)	Time (h)	Yield (%)
1	75/50/1	120	48	52
2	100/50/1	120	48	90
3	200/50/1	120	48	25
4	400/50/1	120	48	5
5	100/50/1	100	60	31
6	100/50/1	140	12	60
7	200/100/1	120	48	32

100/50/1 (run 2). When the CS_2/OX molar ratio was decreased from 100/50 to 75/50, the yield of **9** diminished to 52% (run 1).[9] Upon increase of the ratio to 200/50 and 400/50, the yield diminished to 25 and 5%, respectively, with recovery of unreacted OX (runs 3 and 4).[10] Employment of 1,2-dichloroethane or THF (OX: 1.25 mmol, solvent 0.5 mL) as a solvent resulted in no formation of **9** and recovery of OX. Runs 2, 5 and 6 in Table 1 show the effect of reaction temperature trithiocarbonate synthesis, which was studied by the isolated yields. At 100°C, the yield of **9** was only 31% even for elongation of the reaction time (run 5). At 140°C, the yield was 60% (run 6). These conditions were lower than that at 120°C about yield. Chloroform-insoluble compounds precipitated in run 6, suggesting some side reactions such as decomposition of the catalyst[11] and polymerization of the products. It was concluded that the trithiocarbonate could be synthesized most efficiently at 120°C with the feed molar ratio of CS_2/OX/**6**=100/50/1. Titanium complex **7**, $Ti(O^iPr)_4$ and a $Ti(O^iPr)_4/Et_3N$ (1/1) system were also examined as the catalysts, but unreacted OX was recovered quantitatively from the reaction mixture in all cases. Neither LiBr or NEt_3 was effective, although they had been reported to catalyze the reaction of oxiranes with CS_2.[3,4]

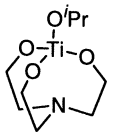
Table 2. Reaction of various cyclic ethers and thioethers with carbon disulfide in the presence of **6**

Run	Cyclic ether	Product	Yield (%)
1		 **(9)**	90
2		 **(10)**	96
3[a]		 **(11)**	quant.
4[a]		 **(12)**	94
5			–[b]
6			–[b]
7		 **(13)**	quant.
8		 **(14)**	quant.
9			–[b]

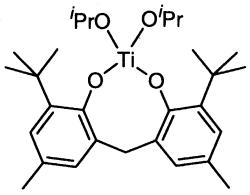
Conditions: temperature=120°C, reaction time=48 h, cyclic ether/CS_2/**6**=50/100/1 molar ratio.
[a] Oxetane/CS_2/**6**=25/50/1 molar ratio.
[b] Unreacted cyclic ether or thioether was quantitatively recovered, which was determined by ^1H NMR.



Scheme 2.



6



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2.2. Synthesis of thiocarbonates from cyclic ethers and CS_2 by titanium complex

Other cyclic ethers and thioethers, such as substituted oxetanes, oxiranes, and thietane were submitted for the reaction with CS_2 catalyzed by **6**. As shown in Table 2, 3-methyloxetane and 3,3-dimethyloxetane reacted with CS_2 satisfactorily to afford the corresponding trithiocarbonates (**10**, **11**) in excellent yields (runs 2 and 3). The reaction was tolerant with ether group at the 3-position (run 4). In contrast, 2-methyloxetane or thietane did not react with CS_2 (run 5 and 6). 2-Methyloxirane also reacted with CS_2 in the presence of **6** to afford the corresponding five-membered cyclic trithiocarbonate (**13**) quantitatively (run 7). Interestingly, 2,2-dimethyloxirane did not afford a trithiocarbonate but a dithiocarbonate, 5,5-dimethyl-1-oxa-3-thiolane-2-thione (**14**) selectively and quantitatively (run 8). On the other hand, tetrahydrofuran did not react with CS_2 (run 9).

2.3. Comments on plausible mechanism

Scheme 2 illustrates a plausible mechanism of the reaction. First, the titanatrane complex (**6′**) is formed by the one-to-one reaction with CS_2 which brings about ring-opening of oxetane, followed by intramolecular cyclization to afford a six-membered cyclic dithiocarbonate (**8**) with regeneration of **6**. At present, we have not detected the formation of **8**, presumably because it reacts rapidly with **6′** to give the thioalkanolate titanatrane intermediate (**6″**) with releasing carbonyl sulfide (COS). The complex **6″**, thus formed, affords trithiocarbonate (**9**) with regeneration of **6**. In conformity with this mechanism, we isolated a five-membered cyclic dithiocarbonate as the product in the reaction of 2,2-dimethyloxirane with CS_2 (Table 2, run 8). In this case, further reaction of dithiocarbonate with **6′** might be sterically prohibited by the dimethyl group at the 5-position.

In order to confirm the reaction process, we examined the reaction of 5-methyl-1,3-oxathiane-2-thione (5DTC) with CS_2 in the presence of **6** at 120°C. ^{1}H NMR spectroscopic studies of the reaction mixture showed that 5DTC completely converted into a trithiocarbonate after 48 h (Fig. 1 (a),(b)). When the reaction was performed in the absence of CS_2, polythiirane was formed (M_n = 14 000 M_w/M_n = 1.68) (Fig. 1(c)), presumably by the successive reaction of titanatrane with 5DTC with releasing COS. All these results were well consistent with the mechanism proposed in Scheme 2.

In summary, we demonstrated the facile synthesis of six-membered cyclic trithiocarbonates from oxetanes and CS_2 catalyzed by the titanium complex (**6**). The reaction of 2-methyloxirane proceeded in a similar manner to give a five-membered cyclic trithiocarbonates, while 2,2-dimethyloxirane afforded a cyclic dithiocarbonate.

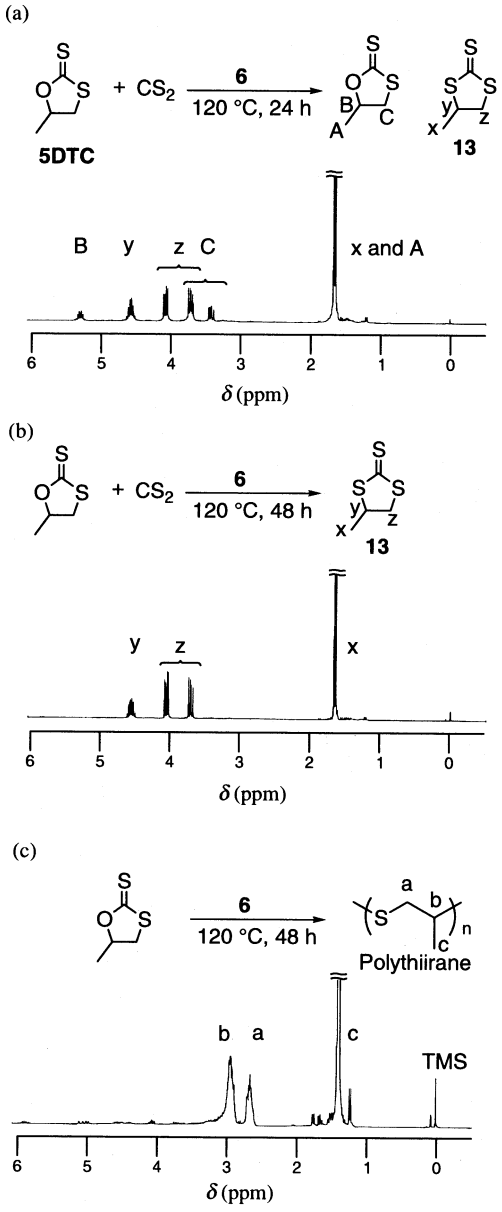

Figure 1. ^{1}H NMR spectra of the mixtures obtained by the reaction of 5DTC in the presence and absence of CS_2 catalyzed by **6** at 120°C. (a) and (b)=CS_2/5DTC/**6** of 50/50/1 molar ratio. (c)=5DTC/**6** of 20/1 molar ratio.

3. Experimental

3.1. Measurements

^{1}H and ^{13}C NMR spectra were recorded in chloroform-*d* ($CDCl_3$) on a JEOL EX-300 (^{1}H, 300 MHz; ^{13}C, 75 MHz) spectrometer, with tetramethylsilane (TMS) as an internal standard. IR spectra were obtained with a Perkin–Elmer Spectrum One. GC-mass spectra were recorded on a

Shimadzu GCMS-QP5050A. Number- and weight-average molecular weights (M_n and M_w) and polydispersity ratios (M_w/M_n) were estimated by gel permeation chromatography (GPC) on a Tosoh HPLC HLC-8120 system, equipped with two consecutive polystyrene gel columns (G2500HXL, and G5000HXL), using THF as a eluent (flow rate 1.0 mL min^{-1}, polystyrene calibration, and refractive index (RI) and ultraviolet (UV, 254 nm) detectors.

3.2. Materials

Carbon disulfide (CS_2) was dried over $CaCl_2$ and distilled under nitrogen after refluxing over CaH_2. THF was refluxed over sodium benzophenone ketyl and distilled under nitrogen. Dichloroethane was refluxed over CaH_2 and distilled under nitrogen. Chloroform, hexane, cyclohexane, $CDCl_3$ and acetone-d_6 were used as received. Oxetane was distilled from sodium under nitrogen. 2-Methyloxirane and 2,2-dimethyloxirane were distilled from CaH_2 under nitrogen. 2-Methyloxetane, 3-methyloxetane,[12] 3,3-dimethyloxetane,[14] (2-propanolato) titanatrane,[13] bis(2-propanolato) titanium 2,2′-methylenebis(6-*tert*-butyl-4-methylphenolate)[8] 5-methyl-1,3-oxathiane-2-thione[4] were prepared according to the reported procedure.

3.2.1. Synthesis of 1,3-dithiane-2-thione (9). To a 5 mL glass ample fitted with a three-way stopcock containing (2-propanolato) titanatrane (6.3 mg, 0.025 mmol) and a Teflon-coated stirring bar was added oxetane (0.081 mL, 1.25 mmol) and carbon disulfide (0.15 mL, 2.5 mmol) by a syringe under dry nitrogen at room temperature. The tube was freezed, evacuated, sealed off, and heated at 120°C for 48 h. After the mixture was cooled to room temperature and the volatile fractions were evaporated, the residue was purified by silica gel column chromatography eluted with chloroform/hexane (9/1, volume ratio), followed by recrystallization from cyclohexane to obtain 1,3-dithiane-2-thione as yellow needles in 90% yield (0.17 g). Mp: 78–79°C (lit.[5], 77–78°C). ^{1}H NMR ($CDCl_3$): δ 2.38–2.46 (2H, m, CH_2), 3.24–3.26 (4H, t, J=4.4 Hz, SCH_2). ^{13}C NMR ($CDCl_3$): δ 20.3, 34.2, 221.1. IR: 1019, 931 cm^{-1}. MS: 150 (M^+), 106.

5-Methyl-1,3-dithiane-2-thione, 5,5-dimethyl-1,3-dithiane-2-thione, 5-ethoxymethyl-5-methyl-1,3-dithiane-2-thione, 4-methyl-1,3-dithiolane-2-thione, and 5,5-dimethyl-1-oxa-3-thiolane-2-thione were synthesized in a manner similar to **9**.

3.2.2. Synthesis of 5-methyl-1,3-dithiane-2-thione (10). Yield 96%. Mp: 65–66°C (lit.[5], 63–64°C). ^{1}H NMR ($CDCl_3$): δ 1.25–1.31 (3H, d, J=13.2 Hz, CH_3), 2.53–2.63 (1H, m, CH), 2.99–3.06 (2H, dd, J=8.3, 12.7 Hz, SCH_2), 3.18 (2H, dd, J=3.9, 13.3 Hz, SCH_2). ^{13}C NMR ($CDCl_3$): δ 19.4, 25.6, 40.9, 221.7. IR: 994, 934 cm^{-1}. MS: 164 (M^+), 120.

3.2.3. Synthesis of 5,5-dimethyl-1,3-dithiane-2-thione (11). Yield quantitative. Mp: 98–99°C (lit.[5] 99–100°C). ^{1}H NMR ($CDCl_3$): δ 1.32 (6H, s, CH_3) 2.99 (4H, s, CH_2). ^{13}C NMR ($CDCl_3$): δ 26.6, 27.9, 47.0, 223.1. IR: 1005, 962, 945, 922, 889 cm^{-1}. MS: 178 (M^+), 134.

3.2.4. Synthesis of 5-ethoxymethyl-5-methyl-1,3-dithiane-2-thione (12). Yield 94%. ^{1}H NMR ($CDCl_3$): δ 1.18–1.22 (2H, t, J=7.0 Hz, CH_3CH_2O), 1.30 (3H, s, CH_3C), 2.87–2.91 (2H, d, J=13.2 Hz, SCH_2), 3.15–3.19 (2H, d, J=13.2 Hz, SCH_2), 3.44 (2H, s, OCH_2C), 3.49–3.56 (2H, J=7.0 Hz, q, CH_3CH_2O). ^{13}C NMR ($CDCl_3$): δ 14.8, 22.2, 33.2, 43.4, 66.9, 75.7, 224.5. MS: 222 (M^+), 178. EA: Calcd C, 45.72; H, 6.82; S, 40.69. Found C, 45.89; H, 6.75; S, 40.88.

3.2.5. Synthesis of 4-methyl-1,3-dithiolane-2-thione (13).[6b] Yield quantitative. ^{1}H NMR ($CDCl_3$): δ 1.63 (3H, d, J=6.6 Hz, CH_3), 3.65–3.72 (1H, dd, J=7.5, 11.7 Hz, SCH_2), 4.00–4.64 (1H, dd, J=5.1, 11.7 Hz, SCH_2), 4.44–4.51 (1H, m, SCH). ^{13}C NMR ($CDCl_3$): δ 18.8, 50.1, 55.2, 228.1. IR: 1076, 1050, 1033. MS: 150 (M^+), 106.

3.2.6. Synthesis of 5-methyl-1-oxa-3-thiolane-2-thione (14).[4] Yield quantitative. ^{1}H NMR (acetone-d_6): δ 1.68 (6H, s, CH_3), and 3.51 (2H, s, CH_2). ^{13}C NMR (acetone-d_6): δ 25.7, 45.1, 96.7, 210.7. IR: 1251, 1134 cm^{-1}. MS: 148 (M^+), 104. Bp: 114°C/2.5 mmHg (lit.[4] 111°C/2.0 mmHg).

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9. The structures of the by-products could not be elucidated. GPC of the reaction mixture indicated the formation of oligomeric compounds (M_n~400).
10. This might be responsible for formation of a titanium complex with 2 equiv. of CS_2, which hinders the reaction, but we have no concrete evidence.
11. ^{1}H NMR studies showed that titanatrane **6** was stable at 120°C for 48 h but decomposed at 140°C within 6 h.
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