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Novel Conversion of 6*H*-1,3,5-Oxathiazine *S*-Oxides into 3*H*-1,2,4-Dithiazoles by Treating with Lawesson's Reagent

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ABSTRACT: *Treatment of 6H-1,3,5-oxathiazine* S-*oxides by Lawesson's reagent (LR) at high temperature furnished 3H-1,2,4-dithiazoles in moderate to good yields. Deoxygenation of 6H-1,3,5-oxathiazine* S-*oxides was performed by LR in the presence of EtOH.* © 2004 Wiley Periodicals, Inc. Heteroatom Chem 15:208–215, 2004; Published online in Wiley InterScience (www.interscience.wiley.com). DOI 10.1002/hc.20011

INTRODUCTION

The importance of sulfur-containing heterocyclic compounds concerning their unique structures and biological activities has led to increase in the number of synthetic methods for the synthesis of various heterocyclic compounds, and especially various reactive species containing thiocarbonyl functionalities have long been investigated as versatile and useful building blocks for such heterocycles. However, in contrast to the common thiocarbonyl functionalities, unusual species containing a S=S double bond functionality, i.e. thiosulfoxides, have long been proposed only as intermediates and, in some special cases, as stable cyclic thiosulfinate esters, and the generation and synthesis of novel thiosulfoxides have been considered as vibrant area of current research [1–22]. However, only a few methods to generate such species are available, and one of the general and simple methods to generate such species is the conversion of sulfoxides into the corresponding thio variants by treating with some thiating agents. Concerning thiocarbonyl *S*-sulfides (thiosulfines) possessing higher π-conjugation systems, no methods for the generation of such species has been reported to date, in spite of their synthetic potentiality of novel intermediates for new cyclic polysulfide ring systems.

During our attempts to generate various reactive species bearing a chalcogenocarbonyl fuctionality by using the selective ring fission of precursors, heterocycles, we have already reported novel methods for the generation of 1,3-thiaza-1,3-butadiene **A** and their *S*-oxides **B** through retro [4 + 2]-type thermal cycloreversion of 6*H*-1,3,5-oxathiazines **1** and 6*H*-1,3,5-oxathiazine *S*-oxides **2**, respectively [23,24]. It is strongly expected that the above findings must be applicable to a new strategy for the corresponding thio-variants, i.e. thiosulfines, through an analogous cycloreversion of the thio-variants (thiosulfoxides **C**) involving the thiation of 6*H*-1,3,5-oxathiazine *S*-oxides **2** (Scheme 1). Furthermore, the new thiosulfine-type heterodienes, 1,3-thiaza-1,3-butadiene *S*-sulfides **D**, are expected to undergo facile ring closure to give 3*H*-1,2,4-dithiazole **3** through a similar manner of conversion of

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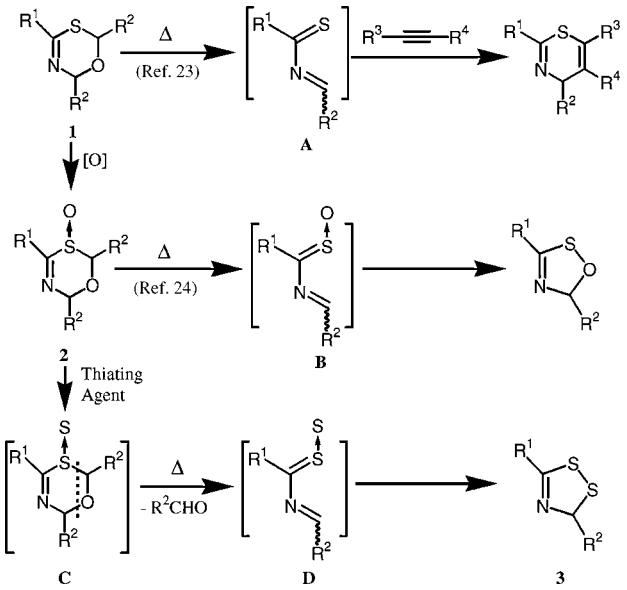


SCHEME 1

1,3-thiaza-1,3-butadiene *S*-oxides **B** into the corresponding 5*H*-1,2,4-oxathiazoles.

According to the expectation shown above, we started the attempts for the thiation of **2** and the subsequent heating at an ambient condition. Now, we would like to report an efficient conversion of 6*H*-1,3,5-oxathiazine *S*-oxides **2** into 3*H*-1,2,4-dithiazoles **3** by treating with LR at high temperature and also wish to demonstrate some salient features of this transformation.

RESULTS AND DISCUSSION

Preparation of 6H-1,3,5-Oxathiazine S-Oxides **2**

6*H*-1,3,5-Oxathiazines **1a–h** were prepared as single stereoisomers by treating an alkanethioamide or an arenethioamide with an aliphatic aldehyde or 2,4,6-trimethyl-1,3,5-trioxane and $BF_3{\cdot}OEt_2$ according to the reported procedure [23,25].

When a $CHCl_3$ solution of **1a–f** was treated with *m*CPBA (1.1 mol amt) at 0°C, the corresponding *S*-oxides **2a–f** were afforded as single isomers in quantitative yields. The treatment of **1g–h** with *m*CPBA afforded a mixture of unstable compounds assigned as the isomers of **2g–h** along with recovery of **1g–h** (ca. 25%).

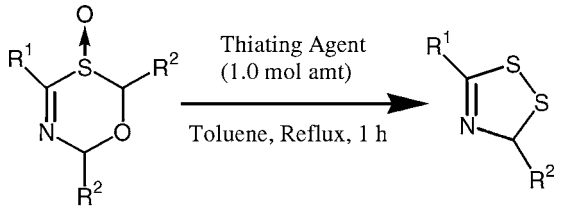
Conversion of 6H-1,3,5-Oxathiazine S-Oxides **2** *into 3H-1,2,4-Dithiazoles* **3** *by the Treatment with Lawesson's Reagent or Phosphorus Pentasulfude*

When a toluene solution of **2a–h** was treated with LR at refluxing temperature for 1 h, the corresponding 3*H*-1,2,4-dithiazoles **3a–h** were afforded in moderate to good yields. Characterization of compounds **3a–h** was carried out on the basis of microanalytical, and spectroscopic data (IR, ^1H and ^{13}C NMR, and mass spectrometric data). The use of P_2S_5 in place of LR under the similar reaction conditions was also effective for the conversion of **2** into **3**, but the yields of **3** were relatively lower than those cases using LR as a thiating agent. In contrast, when a toluene solution of **2** was treated with LR or P_2S_5 at room temperature, only a complex mixture was obtained and compounds **3** were found in a trace amount in the crude reaction mixture. All results of the treatment of **2a–h** with thiating agents are summarized in Table 1.

Plausible Reaction Mechanism of Conversion of **2** *into* **3**

It is commonly recognized that sulfoxides react with phosphorus sulfide reagents to afford the corresponding sulfides via the intermediary thiosulfoxides [1,2,26–32]. But, in our cases, we could find a new preparation of 3*H*-1,2,4-dithiazoles **3** through the reaction of **2** with LR. ^1H and ^{13}C NMR monitoring of the reaction of **2a** with LR or P_2S_5 in $CDCl_3$ in an NMR tube at 25°C showed the instantaneous

TABLE 1 Synthesis of 3*H*-1,2,4-dithiazoles **3** by Treating **2** with a Thiating Agent



2 **3**

Run	Substrate R^1	Substrate R^2	**2**	Thiating Agent	Yield (%)[a] **3**
1	C_6H_5	*t*-C_4H_9	**2a**[b]	LR	66
2	C_6H_5	*t*-C_4H_9	**2a**[b]	P_2S_5	57
3	*p*-ClC_6H_4	*t*-C_4H_9	**2b**[b]	LR	60
4	*p*-FC_6H_4	*t*-C_4H_9	**2c**[b]	LR	62
5	*p*-$MeOC_6H_4$	*t*-C_4H_9	**2d**[b]	LR	54
6	α-Naphthyl	*t*-C_4H_9	**2e**[b]	LR	51
7	CH_3	*t*-C_4H_9	**2f**[b]	LR	32[c]
8	C_6H_5	CH_3	**2g**[d]	LR	40[e]
9	C_6H_5	*n*-C_4H_9	**2h**[d]	LR	37[e]

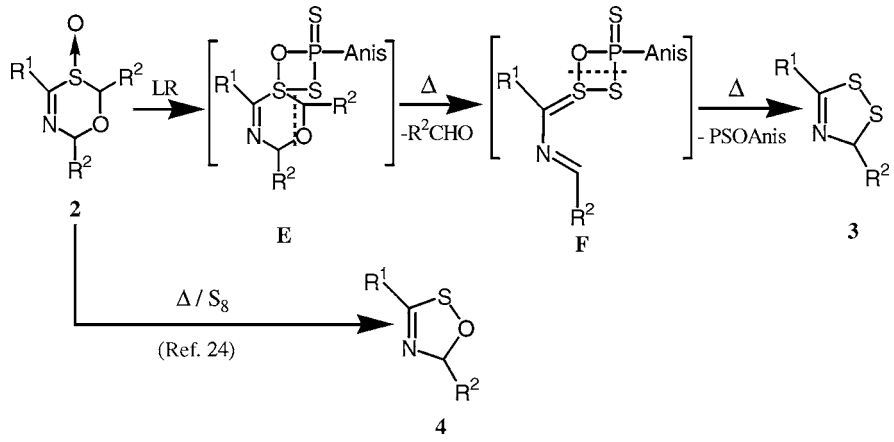
[a]Isolated yield.
[b]A single stereoisomer.
[c]Unstable.
[d]Isomeric mixture including ca. 25% of oxathiazine **1**.
[e]Yield was based on oxathiazine **1**.

facile disappearance of **2a** along with the formation of some intermediary compounds, small amounts of pivalaldehyde, and **3a**. In the primary stage, the similarity in the patterns of the ^{1}H and ^{13}C spectra of the intermediate showed the retention of the similar heterocyclic ring system to that of the starting **2**. When the above crude reaction mixture was subjected to standing for an hour, the quantitative formation of pivalaldehyde was observed along with ring cleavage of **2a**. However, the isolation of the intermediates was not successful, and in all cases a complex mixture was obtained as a crude product after the usual workup of the reaction mixture. It was also noteworthy that the deoxygenated product **1a** was not observed at all in the reaction mixture during the ^{1}H NMR monitoring at 25°C. However, in the mass spectrum of the crude product, several characteristic ion peaks involving a fragment ion peak at *m/z* 237, assigned to **D** or **3**, a peak at *m/z* 186, assigned to PSOAnis fragment, and an ion peak at *m/z* 86, assigned to the parent ion peak of pivalaldehyde, were observed in spite of the lack of any parent ion peak of **E** and/or **F**. Furthermore, when a toluene solution of the crude products of **2a** with LR obtained through the reaction carried out at R.T., was subjected to heating at refluxing temperature for a few hours, **3a** was obtained in 65% yield. In contrast, the similar heating of **1a** in toluene in the presence of LR only afforded a trace amount of **3a** along with the recovery of **1a**. So, the formation of **3** involving the deoxygenation of **2** and the subsequent thermal reaction of **1** with LR was excluded out. Independent heating of **2a** in toluene at refluxing temperature in the presence or absence of elemental sulfur only resulted in the formation of 5*H*-1,2,4-oxathiazole **4a** in almost quantitative yield through the pathway involving thermal cycloreversion of **2a** and the subsequent ring closure of transiently generated heterodiene **B** [24]. These results showed that the deoxygenation pathway of **2a** only by heating was ruled out.

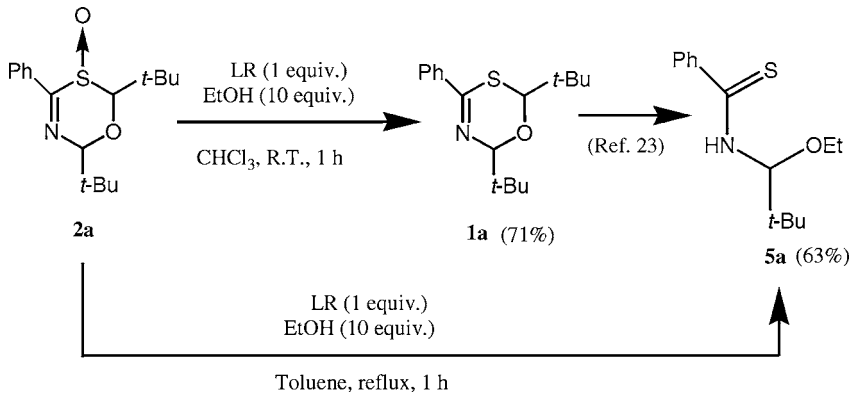
Compounds **2** having a sulfoxide moiety are generally expected to undergo oxygen-sulfur exchanging through the treatment with thiating agents via the four-membered phosphorus- and sulfur-containing intermediates [1,2,26–32]. Unequivocal mechanism for the reaction of sulfoxides **2** with a phosphorus sulfur reagent has not yet been established. Based on the analogous mechanism proposed during several decades for the thiation of sulfoxide with phosphorus sulfur reagents [1,2,26–32] and by taking the present findings into account, the most likely formation pathway of **3** involving the formation of **E** and **F** through the reaction of **2** with LR is proposed. It was assumed that **E** might undergo stepwise mass fragmentation involving cycloreversion to give **F** along with the formation of pivalaldehyde and the further removal of PSOAnis from **F** to give the likely thiosulfine intermediates **D**, which causes facile ring closure to afford **3** as shown in Scheme 2. However, an alternative formation pathway of **3** from **F** by simultaneous elimination of PSOAnis and concomitant ring formation through concerted manner can not be ruled out at this time.

Deoxygenation of 6H-1,3,5-Oxathiazine S-Oxides **2** *by the Treatment with LR in the Presence of Ethanol*

Interestingly, deoxygenation of **2a–b** was successfully performed to give **1a–b** in 71 and 69% yield, respectively, by treating with LR in the presence of ethanol in $CHCl_3$ at room temperature. On the other hand, the reaction of **2a** with LR in toluene at refluxing temperature gives **5a** in 63% yield as



SCHEME 2 Plausible formation pathway of compounds **3**.



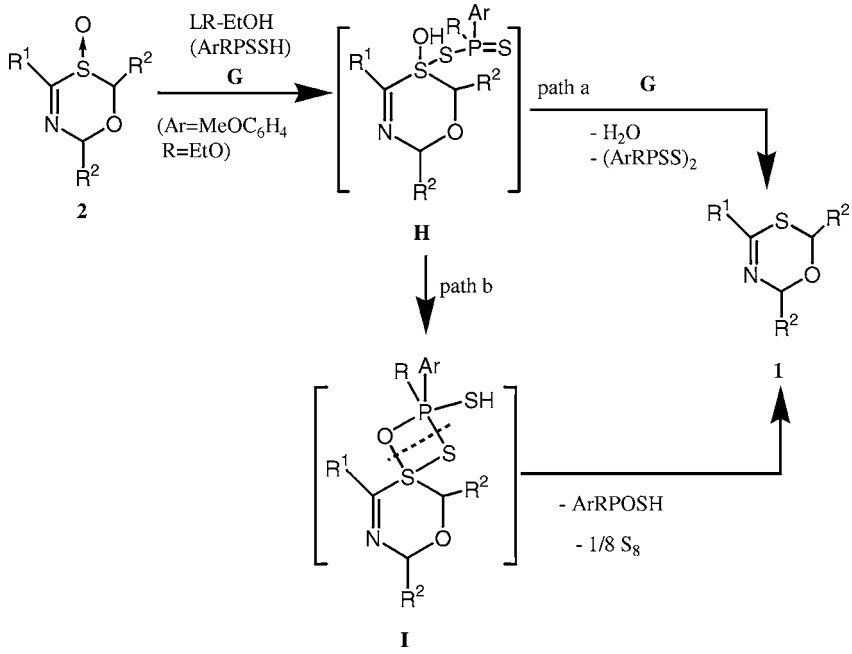
SCHEME 3 Deoxygenation of **2a** by LR-EtOH system.

shown in Scheme 3. The formation of **5a** can be explained by the pathway that the reaction of **2a** with LR-EtOH system initially gives deoxygenation product **1a** and the subsequent thermal cycloreversion of **1a** at toluene refluxing temperature generates 1,3-thiaza-1,3-butadiene **A**, followed by 1,4-addition of ethanol to the resulting heterodiene **A** to afford **5a**. However, attempts for the detection or trapping of the intermediates in this transformation were unsuccessful.

Two plausible mechanistic pathways for the deoxygenation of **2** by LR in the presence of EtOH could be proposed. In the primary stage, the reaction of LR with EtOH might form dithiophosphoric acid **G**, which then follows either path a [33] or path b [34] for the formation of deoxygenated product **1** as shown in Scheme 4.

CONCLUSION

A novel conversion of 6*H*-1,3,5-oxathiazine *S*-oxides **2** into 3*H*-1,2,4-dithiazoles **3** was achieved by the reaction of **2** with LR at high temperature, and the in situ formation of 1,3-thiaza-1,3-butadiene *S*-sulfides **D** through thermal reaction of intermediary phosphorus compounds is suggested through the spectral data of the intermediates and the results of ^{1}H NMR monitoring of the reaction. On the other hand,



SCHEME 4 Plausible mechanism of the deoxygenation of **2** by LR in the presence of ethanol.

deoxygenation of **2** occurred by the treatment with LR in the presence of ethanol. Further studies on the discreet mechanistic investigation and the general synthetic expansion of this approach for various cyclic polysulfides are currently being explored.

EXPERIMENTAL

General

Melting points were measured in open capillary tubes with a Buchi 535 micro-melting point apparatus and are uncorrected. ^{1}H NMR spectra were determined at 400 MHz (Bruker AC-400P spectrometer), and ^{13}C NMR spectra were determined at 100 MHz (Bruker AC-400P spectrometer). Chemical shifts are expressed in parts per million (δ units) downfield from tetramethylsilane (TMS) used as an internal reference. Mass spectra were recorded on a Hitachi M-2000 mass spectrometer with electron-impact ionization at 20 or 70 eV using a direct inlet system. IR spectra were recorded for thin film (neat) or KBr disks on a JASCO FT/IR-7300 spectrometer. Elemental analyses were performed using a Yanagimoto CHN recorder MT-5. Column chromatography was performed using silica gel (Merck, Cat. No. 7734) without pretreatment. All substrates and reagents were commercially available reagent grade and were used without further pretreatment.

*General Procedure for the Preparation of 2,4,6-Trisubstituted 6H-1,3,5-Oxathiazines (***1***)*

A chloroform solution (20 ml) of alkanethioamide or an arenethioamide (10.0 mmol) was treated with 2,4,6-trimethyl-1,3,5-trioxane (paraldehyde, 1.04 g, 8.00 mmol), pivalaldehyde (2.06 g, 24.0 mmol), pentanal (2.06 g, 24.0 mmol), or isobutyraldehyde (1.73 g, 24.0 mmol) and $BF_3{\cdot}OEt_2$ (2.84 g, 20 mmol) at 0°C, and the reaction mixture was stirred for 4–5 h at room temperature. The reaction mixture was then quenched with an aqueous $NaHCO_3$ solution, and was extracted with chloroform. The organic layer was washed with water, and was dried over anhydrous Na_2SO_4. After removing the solvent in vacuo, the crude product was purified using column chromatography on silica gel to afford 2,6-dialkyl-4-aryl-6*H*-1,3,5-oxathiazine or 2,4,6-trialkyl-6*H*-1,3,5-oxathiazine (**1**) in good yields. Further purification of solid products was carried out by recrystallization from hexane.

*2,6-Di-tert-butyl-4-phenyl-6H-1,3,5-oxathiazine (***1a***).* Colorless plates, mp 95.1–95.9°C (Lit. [19], 95.4–96.0°C).

*2,6-Di-tert-butyl-4-(p-chlorophenyl)-6H-1,3,5-oxathiazine (***1b***).* Colorless crystals, mp 95.5–96.1°C (decomp.) (Lit. [19], 95.4–96.0°C decomp.).

*2,6-Di-tert-butyl-4-(p-fluorophenyl)-6H-1,3,5-oxathiazine (***1c***).* Colorless plates, mp 55.5–56.5°C (decomp.); MS *m/z* (%) 309 (M^+; 2), 252 ($M^+ - t$-C_4H_9; 42), 223 ($M^+ - t$-C_4H_9CHO; 5), 139 (*p*-FC_6H_4CS; 36), 103 (base peak); IR (KBr) 2954, 1610, 1506, 1478, 1362, 1237, 1068, 837 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ 1.05 (9H, s), 1.06 (9H, s), 4.82 (1H, s), 4.97 (1H, s), 7.06 (2H, t, $J_{H\text{-}F} = J_{H\text{-}H} = 8.6$ Hz), 7.85 (2H, dd, $J_{H\text{-}H} = 8.6$ Hz, $J_{H\text{-}F} = 5.3$ Hz); ^{13}C NMR ($CDCl_3$) δ 25.1 (q), 25.3 (q), 36.1 (s), 36.9 (s), 88.8 (s), 96.9 (br s), 115.2 (dd, $J_{C\text{-}F} = 21.6$ Hz), 128.3 (dd, $J_{C\text{-}F} = 8.6$ Hz), 135.4 (d, $J_{C\text{-}F} = 2.5$ Hz), 156.4 (s), 164.2 (d, $J_{C\text{-}F} = 248.0$ Hz). Found: C, 65.90; H, 7.80; N, 4.55%. Calcd for $C_{17}H_{24}FNOS$: C, 65.98; H, 7.82; N, 4.53%.

*2,6-Di-tert-butyl-4-(p-methoxyphenyl)-6H-1,3,5-oxathiazine (***1d***).* Colorless needles, mp 101°C; MS *m/z* (%) 321 (M^+; 2), 264 ($M^+ - C_4H_9$; base peak); IR (neat) 2914, 2353, 1683, 1538, 1071, 562 cm^{-1}; ^{1}H NMR (400 MHz, $CDCl_3$): δ 1.05 (9H, s), 1.06 (9H, s), 3.82 (3H, s), 4.82 (1H, s), 4.94 (1H, s), 6.89 (2H, d, $J = 9.0$ Hz), 7.81 (2H, d, $J = 8.8$ Hz); ^{13}C NMR ($CDCl_3$): δ 25.1 (q) 25.3 (q), 36.0 (s), 36.9 (s), 55.36 (q), 88.6 (s), 96.8 (br s), 113.5 (d), 127.8 (d), 132.0 (s), 156.5 (s), 161.6 (s). Found: C, 67.21; H, 8.51; N, 4.39%. Calcd for $C_{18}H_{27}NO_2S$: C, 67.25; H, 8.47; N, 4.36%.

*2,6-Di-tert-butyl-4-naphthalen-1-yl-6H-1,3,5-oxathiazine (***1e***).* Colorless crystals; mp 54–56°C (decomp.); MS *m/z* (%) 341 (M^+; 7), 284 ($M^+ - C_4H_9$; 50), 254 (base peak); IR (neat): 2908, 1619, 1460, 1362, 1097, 1063, 999, 799 cm^{-1}; ^{1}H NMR ($CDCl_3$): δ 1.05 (9H, s), 1.11 (9H, s), 4.77 (1H, s), 5.15 (1H, s), 7.42–7.51 (3H, m), 7.63 (1H, d, $J = 7.1$ Hz), 7.82 (2H, dd, $J = 13.1$, 6.7 Hz), 8.40 (1H, d, $J = 8.2$ Hz); ^{13}C NMR ($CDCl_3$): δ 24.9 (q), 25.4 (q), 36.1 (s), 36.6 (s), 89.4 (br s), 97.3 (br s), 124.9 (s), 125.4 (d), 126.0 (s), 126.1 (d), 126.4 (d), 128.1 (d), 129.7 (d), 133.8 (s), 137.8 (s), 159.6 (s). Found: C, 74.23; H, 8.21; N, 4.07%. Calcd for $C_{21}H_{27}NOS$: C, 73.86; H, 7.97; N, 4.10%.

*2,6-Di-tert-butyl-4-methyl-6H-1,3,5-oxathiazine (***1f***).* Colorless plates, mp 58.4–58.8°C; MS *m/z* (%) 229 (M^+; 1), 38 (base peak); IR (KBr) 2958, 2868, 1642, 1478, 1460, 1204, 1091 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ 0.97 (9H, s), 0.98 (9H, s), 2.14 (3H, s), 4.49 (1H, s), 4.87 (1H, s); ^{13}C NMR ($CDCl_3$) δ 24.9 (q), 25.1 (q), 29.0 (q), 35.8 (s), 36.2 (s), 88.4 (br s), 96.5 (d), 157.3

(s). Found: C, 62.48; H, 9.96; N, 6.06%. Calcd for $C_{12}H_{23}NOS$: C, 62.83; H, 10.11; N, 6.11%.

*2,6-Dimethyl-4-phenyl-6H-1,3,5-oxathiazine (***1g***).* Pale yellow oil, (Lit. 19); MS *m/z* (%) 207 (M^+; 17), 165 (21), 39 (base peak); IR (neat) 2985, 1614, 1447, 1373, 1323, 1231, 1161, 1114, 961, 766, 692, cm^{-1}; ^1H NMR ($CDCl_3$): δ 1.60 (3H, d, $J = 6.1$ Hz), 1.61 (3H, d, $J = 6.2$ Hz), 5.28 (1H, q, $J = 6.2$ Hz), 5.35 (1H, q, $J = 6.1$ Hz), 7.35–7.43 (3H, m), 7.78–7.80 (2H, m); ^{13}C NMR ($CDCl_3$): 22.2 (q), 22.5 (q), 75.6 (s), 87.4 (d), 126.2 (d), 128.3 (d), 130.7 (d), 138.5 (s), 157.0 (s). Found: C, 63.45; H, 6.54; N, 6.37%. Calcd for $C_{11}H_{13}NOS$: C, 63.74; H, 6.32; N, 6.76%.

*2,6-Di-n-butyl-4-phenyl-6H-1,3,5-oxathiazine (***1h***).* Pale yellow oil; MS *m/z* (%) 292 ($M^+ + 1$; 1), 162 (base peak); IR (neat): 2960, 1687, 1615, 1448, 1213, 1080, 1006, 766, 691 cm^{-1}; ^1H NMR ($CDCl_3$): δ 0.96 (3H, t, $J = 7.4$ Hz), 0.99 (3H, t, $J = 7.4$ Hz), 1.45–1.65 (4H, m), 1.68–1.81 (4H, m), 1.82–1.98 (4H, m), 5.17–5.22 (2H, m), 7.35–7.39 (3H, m), 7.79–7.81 (2H, m); ^{13}C NMR ($CDCl_3$): 13.6 (q), 13.9 (q), 17.8 (t), 38.2 (t), 38.4 (t), 79.5 (d), 90.2 (d), 126.1 (d), 128.1 (d), 130.6 (d), 138.7 (s), 156.8 (s); Found: C, 69.62; H, 8.49; N, 5.02%. Calcd for $C_{17}H_{25}NOS$: C, 70.06; H, 8.65; N, 4.81%.

*Preparation of 2,4,6-Trisubstituted 6H-1,3,5-Oxathiazine S-Oxides (***2***) by mCPBA Oxidation of 6H-1,3,5-Oxathiazines (***1***)*

A chloroform solution (20 ml) of 6*H*-1,3,5-oxathiazine (**1**, 1.0 mmol) was treated with *m*CPBA (1.1 mol amt) at 0°C in the presence of $NaHCO_3$ (2 mol amt). The reaction mixture was quenched with aqueous Na_2SO_3 solution and was extracted with chloroform. The mixture was then subjected to the usual workup. After removing the solvent in vacuo, product **2** was obtained in almost quantitative yield as single isomers (**2a–f**), or diastereomeric mixtures (**2g–h**).

*2,6-Di-tert-butyl-4-phenyl-6H-1,3,5-oxathiazine S-Oxide (***2a***).* Pale yellow oil; MS *m/z* (%) 221 ($M^+ - t$-C_4H_9CHO; 15), 164 ($M^+ - t$-C_4H_9CHO-t-C_4H_9; base peak); IR (neat) 2961, 2870, 1634, 1479, 1365, 1064, 769, 690, 638 cm^{-1}; ^1H NMR ($CDCl_3$) δ 1.01 (9H, s), 1.21 (9H, s), 4.25 (1H, s), 4.99 (1H, s), 7.41–7.47 (3H, m), 7.91–7.93 (2H, m); ^{13}C NMR ($CDCl_3$) δ 24.9 (q), 25.6 (q), 35.8 (s), 37.0 (s), 97.7 (d), 98.6 (d), 128.9 (d), 129.9 (d), 130.8 (d), 132.0 (s), 163.3 (s). Found: C, 66.17; H, 8.10; N, 4.64%. Calcd for $C_{17}H_{25}NO_2S$: C, 66.41; H, 8.20; N, 4.56%.

*2,6-Di-tert-butyl-4-(p-chlorophenyl)-6H-1,3,5-oxathiazine S-Oxide (***2b***)* . Pale yellow oil; MS *m/z* (%) 255 ($M^+ - t$-C_4H_9CHO; 60), 169 ($M^+ - 2t$-C_4H_9; 38), 103 (base peak); IR (neat) 2960, 2339, 1626, 1592, 1488, 1364, 1092, 1067, 832 cm^{-1}; ^1H NMR ($CDCl_3$) δ 1.00 (9H, s), 1.19 (9H, s), 4.24 (1H, s), 4.98 (1H, s), 7.42 (2H, br d, $J = 8.0$ Hz), 7.87 (2H, br d, $J = 8.0$ Hz); ^{13}C NMR ($CDCl_3$) δ 25.0 (q), 25.7 (q), 35.9 (s), 37.1 (s), 97.9 (d), 98.9 (br s), 128.6 (d), 130.4 (d), 131.1 (s), 137.3 (s), 162.5 (s). Found: C, 59.21; H, 6.79; N, 3.95%. Calcd for $C_{17}H_{24}ClNO_2S$: C, 59.72; H, 7.08; N, 4.10%.

*2,6-Di-tert-butyl-4-(p-fluorophenyl)-6H-1,3,5-oxathiazine S-Oxide (***2c***).* Pale yellow oil; MS *m/z* (%) 239 ($M^+ - t$-C_4H_9CHO; 11), 182 ($M^+ - t$-C_4H_9CHO-t-C_4H_9; base peak); IR (neat) 2977, 2358, 1633, 1600, 1506, 1365, 1234, 1160, 1066, 839 cm^{-1}; ^1H NMR ($CDCl_3$) δ 1.00 (9H, s), 1.19 (9H, s), 4.24 (1H, s), 4.98 (1H, s), 7.12 (2H, t, $J = 8.7$ Hz), 7.95 (2H, dd, $J = 8.7$, $J = 5.4$ Hz); ^{13}C NMR ($CDCl_3$) δ 25.0 (q), 25.7 (q), 35.9 (s), 37.1 (s), 97.9 (d), 98.7 (s), 115.5 (dd, $J_{C\text{-}F} = 21.8$ Hz), 128.9 (d, $J_{C\text{-}F} = 2.5$ Hz), 131.3 (dd, $J_{C\text{-}F} = 8.7$ Hz), 162.2 (s), 164.2 (d, $J_{C\text{-}F} = 250.8$ Hz). Found: C, 62.46; H, 7.12; N, 4.28%. Calcd for $C_{17}H_{24}FNO_2S$: C, 62.74; H, 7.43; N, 4.30%.

*2,6-Di-tert-butyl-4-(p-methoxyphenyl)-6H-1,3,5-oxathiazine S-Oxide (***2d***).* Colorless prisms, mp 84–85°C; MS *m/z* (%) 251 ($M^+ - t$-C_4H_9CHO; 17), 165 ($M^+ - p$-$CH_3OC_6H_4CN$; 6), 134 (t-C_4H_9CHOSO; 66), 139 (base peak); IR (KBr) 2960, 1604, 1510, 1259, 1175, 1066, 1034 cm^{-1}; ^1H NMR ($CDCl_3$): δ 1.00 (9H, s), 1.19 (9H, s), 3.83 (3H, s), 4.27 (1H, s), 4.96 (1H, s), 6.93 (2H,d, $J = 8.9$ Hz), 7.92 (2H, d, $J = 8.9$ Hz); ^{13}C NMR ($CDCl_3$): δ 25.0 (q) 25.6 (q), 35.9 (s), 37.0 (s), 55.3 (q), 97.8 (d), 98.5 (br s), 113.7 (d), 125.3 (s), 130.7 (d), 161.8 (s), 162.0 (s). Found: C, 63.60; H, 7.88; N, 4.19%. Calcd for $C_{18}H_{27}NO_3S$: C, 64.06; H, 8.06; N, 4.15%.

*2,6-Di-tert-butyl-4-naphthalen-1-yl-6H-1,3,5-oxathiazine S-Oxide (***2e***).* Pale yellow oil; MS *m/z* (%) 271 ($M^+ - t$-C_4H_9CHO; 2), 185 ($M^+ - 2$-t-C_4H_9CHO; 3), 153 ($C_{10}H_7CN$; base peak); IR (neat): 2963, 1645, 1480, 1365, 1100, 1062, 774 cm^{-1}; ^1H NMR ($CDCl_3$): δ 1.06 (9H, s), 1.21 (9H, s), 4.28 (1H, s), 5.15 (1H, s), 7.51–7.53 (3H, m), 7.71 (1H, d, $J = 7.0$ Hz), 7.87 (1H, d, $J = 7.7$ Hz), 7.92 (1H, d, $J = 8.2$ Hz), 8.21 (1H, d, $J = 8.3$ Hz); ^{13}C NMR ($CDCl_3$): δ 25.1 (q), 25.6 (q), 36.0 (s), 36.9 (s), 97.9 (d), 99.5 (br s), 124.6 (d), 124.9 (d), 126.3 (s), 127.0 (d), 126.4 (d), 128.0 (d), 128.6 (d), 130.6 (d), 130.9 (d), 133.7 (s), 167.1 (s). Found: C, 74.23; H, 8.21; N, 4.07%. Calcd for $C_{21}H_{27}NOS$: C, 73.86; H, 7.97; N, 4.10%.

*2,6-Di-tert-butyl-4-methyl-6H-1,3,5-oxathiazine S-Oxide (**2f**).* Pale yellow oil; MS *m/z* (%) 158 ($M^+ - t$-C_4H_9CHO; 5), 42 (base peak); IR (neat) 2960, 1662, 1541, 1481, 1369, 1255, 1049 cm^{-1}; ^1H NMR ($CDCl_3$) δ 0.95 (9H, s), 1.14 (9H, s), 2.45 (3H, d, $J = 2.5$, 2.4 Hz), 4.02 (1, s); ^{13}C NMR ($CDCl_3$) δ 19.6 (q), 24.8 (q), 25.4 (q), 35.6 (s), 36.4 (s), 96.7 (d), 99.0 (d), 165.4 (s); Found: C, 58.93; H, 9.41; N, 5.68%. Calcd for $C_{12}H_{23}NO_2S$: C, 58.74; H, 9.45; N, 5.71%.

The Thiation and Thermal Reaction of **2**

A toluene solution of **2a–h** was treated with 1.0 molar amount of LR at refluxing temperature for 1 h. After cooling to room temperature, the solvent was evaporated in vacuo. The residue was chromatographed on Al_2O_3 to afford 3*H*-1,2,4-dithiazoles **3** in moderate to good yields.

3-tert-Butyl-5-phenyl-3H-1,2,4-dithiazole, **3a**. Pale yellow oil; MS *m/z* (%) 237 (M^+; 18), 205 ($M^+ - S$, 1), 180 ($M^+ - C_4H_9$; base peak); IR (neat): 2961, 1633, 1448, 1363, 1046, 928, 689, 602 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$): δ 1.13 (9H, s), 6.31 (1H, s), 7.40–7.48 (3H, m), 7.83–7.85 (2H, m); ^{13}C NMR ($CDCl_3$): δ 26.7 (q), 38.9 (s), 104.1 (d), 128.7 (d), 128.9 (d), 131.7 (d), 132.1 (s), 165.1 (s). Found: C, 60.91; H, 6.56; N, 5.89%. Calcd. for $C_{12}H_{15}NS_2$: C, 60.71; H, 6.37; N, 5.90%.

3-tert-Butyl-5-(4-chloro-phenyl)-3H-1,2,4-dithiazole, **3b**. Pale yellow oil; MS *m/z* (%) 271 (M^+; 15), 239($M^+ - S$, 2), 214 ($M^+ - C_4H_9$; base peak); IR (neat): 2961, 1623, 1488, 1363, 1253, 1093, 927, 832, 590 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$): δ 1.10 (9H, s), 6.29 (1H, s), 7.39 (2H, d, $J = 8.4$ Hz), 7.77 (2H, $d = 8.5$ Hz); ^{13}C NMR ($CDCl_3$): δ 26.7 (q) 38.9 (s), 104.0 (d), 128.4 (s), 128.5 (s), 128.9 (d), 130.2 (d), 69.6 (s). Found: C, 53.28; H, 5.33; N, 4.62%. Calcd. for $C_{12}H_{14}ClNS_2$: C, 53.02; H, 5.19; N, 5.15%.

3-tert-Butyl-5-(4-fluoro-phenyl)-3H-1,2,4-dithiazole, **3c**. Pale yellow oil; MS *m/z* (%) 255 (M^+; 18), ($M^+ - S$, 223), 198 ($M^+ - C_4H_9$; base peak); IR (neat): 2962, 1629, 1507, 1236, 1046, 929, 840, 601 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$): δ 1.10 (9H, s), 6.28 (1H, s), 7.10 (2H, t, $J = 8.5$ Hz), 7.84 (2H, dd = 5.3, 5.4 Hz); ^{13}C NMR ($CDCl_3$): δ 26.6 (q), 38.8 (s), 104.0 (d), 115.7 (d), 115.9 (d), 131.0 (d), 131.1 (d), 163.8 (s), 164.8 (d, $J = 251.4$ Hz). Found: C, 56.89; H, 5.48; N, 5.17%. Calcd. for $C_{12}H_{14}FNS_2$: C, 56.44; H, 5.53; N, 5.48%.

3-tert-Butyl-5-(4-methoxy-phenyl)-3H-1,2,4-dithiazole, **3d**. Pale yellow oil; MS *m/z* (%) 267 (M^+; 11), 235($M^+ - S$, 3), 210 ($M^+ - C_4H_9$; base peak); IR (neat): 2961, 1606, 1509, 1257, 1173, 926, 835, 600 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$): δ 1.10 (9H, s), 3.84 (3H, s), 6.26 (1H, s), 6.91 (2H, d, $J = 8.8$ Hz), 7.80 (2H, $d = 8.8$ Hz); ^{13}C NMR ($CDCl_3$): δ 26.7 (q), 38.8 (s), 55.4 (q), 104.0 (d), 113.9 (d), 124.8 (s), 130.7 (d), 139.1 (s), 164.3 (s). Found: C, 58.67; H, 6.23; N, 4.96%. Calcd. for $C_{13}H_{17}NOS_2$: C, 58.39; H, 6.41; N, 5.24%.

3-tert-Butyl-5-naphthalen-1-yl-3H-1,2,4-dithiazole, **3e**. Pale yellow oil; MS *m/z* (%) 287 (M^+; 19), 255 ($M^+ - S$; 49); 230 ($M^+ - C_4H_9$; 53), 41 (base peak); IR (neat): 2959, 1738, 1628, 1477, 1364, 1096, 796, 774, 580 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$): δ 1.21 (9H, s), 6.49 (1H, s), 7.53–7.59 (3H, m), 7.88 (1H, d, $J = 8.3$ Hz), 7.93 (1H, d, $J = 8.3$ Hz), 8.57 (1H, d, $J = 8.4$ Hz); ^{13}C NMR ($CDCl_3$): δ 26.9 (q) 38.6 (s), 105.3(d), 124.7 (d), 125.5 (d), 126.5 (s), 127.4 (d), 128.5 (d), 128.6 (d), 129.3 (d), 129.7 (d), 130.5 (d), 131.7 (s), 164.3 (s).

3-tert-Butyl-5-methyl-3H-1,2,4-dithiazole, **3f**. Pale yellow oil; MS *m/z* (%) 175 (M^++1; 2), 64 (base peak); IR (neat) 2959, 1656, 1463, 1366, 1169, 890, 602 cm^{-1}; ^1H NMR ($CDCl_3$) δ 1.04 (9H, s), 2.29 (3H, s), 6.01 (1H, s); ^{13}C NMR ($CDCl_3$) δ 19.5 (q), 26.5 (q), 38.3 (s), 104.5 (d), 162.6 (s).

3-Methyl-5-phenyl-3H-1,2,4-dithiazole, **3g**. Red oil; MS *m/z* (%) 195 (M^+; 61), 163 ($M^+ - S$, 4), 180 ($M^+ - CH_3$; 2), 104 (base peak); IR (neat): 2925, 1624, 1476, 1443, 1368, 1265, 1089, 920, 765, 689 cm^{-1}; ^1H NMR ($CDCl_3$): δ 1.74 (3H, d, $J = 6.4$ Hz), 6.34 (1H, q, $J = 6.4$ Hz), 7.42–7.50 (3H, m), 7.84–7.86 (2H, m); ^{13}CNMR ($CDCl_3$): 22.5 (q), 85.7 (d), 128.7 (d), 129.1 (d), 131.9 (d), 136.4 (s), 165.8 (s). Found: C, 54.82; H, 4.41; N, 6.98%. Calcd. for $C_9H_9NS_2$: C, 55.35; H, 4.64; N, 7.17%.

3-n-Butyl-5-phenyl-3H-1,2,4-dithiazole, **3h**. Pale yellow oil; MS *m/z* (%) 237 (M^+; 1), 180 ($M^+ - C_4H_9$, 16), 55 (base peak); IR (neat): 2959, 1622, 1622, 1449, 1350, 919, 766, 691, 607 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$): δ 1.00 (3H, t, $J = 7.4$ Hz), 1.58 (2H, sextet, $J = 7.4$ Hz), 1.91–1.96 (2H, m), 2.70–2.13 (2H, m), 6.31(1H, dd, $J = 7.2$ Hz, 5.6 Hz), 7.40–7.49 (3H, m), 7.83–7.85 (2H, m); ^{13}C NMR ($CDCl_3$): δ 13.7 (q), 19.9 (t), 38.6 (t), 91.3 (d), 128.7 (d), 129.1 (d), 131.8 (d), 132.0 (s), 165.6 (s). Found: C, 59.03; H, 5.99; N, 5.86%. Calcd. for $C_{12}H_{15}NS_2$: C, 60.71; H, 6.37; N, 5.90%.

REFERENCES

[1] Baechler, R. D.; Daley, S. K. Tetrahedron Lett 1978, 101–104.
[2] Still, I. W. J.; Hasan, S. K.; Turnbull, K. Can J Chem 1978, 56, 1423–1428.
[3] Colman, E. Z.; Abraham, C. B.; Harpp, D. N. J Org Chem 2003, 68, 7059–7062.
[4] Tanaka, S.; Suguhara, Y.; Sakamoto, A.; Ishii, A.; Nakayama, J. J Am Chem Soc 2003, 125, 9024–9025.
[5] Naik, K. G. J Chem Soc 1921, 119, 1231–1232.
[6] Kutney, G. W.; Still, I. W. J. Can J Chem 1980, 58, 1233–1238.
[7] Huisgen, R.; Rapp, J. J Am Chem Soc 1987, 109, 902–903.
[8] Machiguchi, T.; Minoura, M.; Yamabe, S.; Minato, T. Chem Lett 1995, 103–104.
[9] Kuipers, J. A. M.; Lammerink, B. H. M.; Still, I. W. J.; Zwanenburg, B. Synthesis 1981, 295–297.
[10] Takikawa, Y; Makabe, T.; Hirose, T.; Hiratsuka, T.; Takoh, R.; Shimada, K. Chem Lett 1988, 1517–1520.
[11] Senning, A. Angew Chem Int Ed Engl 1979, 18, 941–942.
[12] Shimada, K.; Kodaki, K.; Aoyagi, S.; Takikawa, Y.; Kabuto, C. Chem Lett 1999, 695–696.
[13] Okazaki, R.; Inoue, K.; Inamoto, N. Bull Chem Soc Jpn 1981, 54, 3541–3545.
[14] Still, I. W. J.; Kutney, G. W.; McLean, D. J Org Chem 1982, 47, 555–560.
[15] Kutney, G. W.; Turnbull, K. Chem Rev 1982, 82, 333–357.
[16] Senning, A.; Hansen, H. C.; Abdel-Megeed, M. F.; Mazurkiewicz, W.; Jensen, B. Tetrahedron 1986, 42, 739–746.
[17] Ishii, A.; Nakayama, J.; Ding, M.; Kotaka, N.; Hoshino, M. J Org Chem 1990, 55, 2421–2427.
[18] Huisgen, R.; Rapp, J. Tetrahedron 1997, 53, 939–960.
[19] Fabian, J.; Senning, A. Sulfur Rep 1998, 21, 1–42.
[20] El-Essawy, F. A. G.; Yassin, S. M.; El-Sakka, I. A.; Khattab, A. F.; Søtofte, I.; Madsen, J. Ø.; Senning, A. J Org Chem 1998, 63, 9840–9845.
[21] Mloston, G.; Romanski, J.; Reisenauer, H. P.; Maier, G. Angew Chem Int Ed Engl 2001, 40, 393–396.
[22] Mloston, G.; Majchrzak, A.; Senning, A.; Søtofte, I. J Org Chem 2002, 67, 5690–5695.
[23] Shimada, K.; Aikawa, K.; Fujita, T; Sato, M.; Goto, K.; Aoyagi, S.; Takikawa, Y.; Kabuto, C. Bull Chem Soc Jpn 2001, 74, 511–525.
[24] Shimada, K.; Rafiqul, I. M.; Sato, M.; Aoyagi, S.; Takikawa, Y. Tetrahedron Lett 2003, 44, 2517–2519.
[25] Giordano, C.; Belli, A. Synthesis 1975, 789–791.
[26] Still, I. W. J.; Hasan, S. K.; Turnbull, K. Synthesis 1977, 468–469.
[27] Still, I. W. J.; Reed, J. N.; Turnbull, K. Tetrahedron Lett 1979, 1481–1484.
[28] Scheibye, S.; Shabana, R.; Lawesson, S.-O.; Roming, C. Tetrahedron 1982, 38, 993–1001.
[29] Cherkasov, R. A.; Kutyrev, G. A.; Pudovik, A. N. Tetrahedron 1985, 41, 2567–2624.
[30] Cava, M. P.; Levinson, M. I. Tetrahedron 1985, 41, 5061–5087.
[31] Rauchfuss, T. B.; Zank, G. A. Tetrahedron Lett 1986, 27, 3445–3448.
[32] Ishii, A.; Yamashita, R.; Saito, M.; Nakayama, J. J Org Chem 2003, 68, 1555–1558.
[33] Oae, S.; Nakanishi, A.; Tsujimoto, N. Tetrahedron 1972, 28, 2981–2990.
[34] Mikolajczyk, M. Chem Ind 1966, 2059–2060.