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Reactivity of 1,2-dithioles

V A Ogurtsov, O A Rakitin

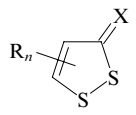
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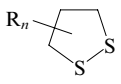
Abstract. Available data concerning the chemistry of 1,2-dithioles published over the past 15 years have been summarized and systematized. Different transformations of these compounds have been considered, including reactions with participation of substituents in the dithiole ring. The bibliography includes 96 references.

I. Introduction

Derivatives of 1,2-dithioles **1** – **4** considered in this review constitute one of the most important classes of sulfur-containing heterocycles. The name of these heterocyclic systems is somewhat ambiguous. They can be easily confused with vicinal disulfanyl derivatives $R^1C(SH)=C(SH)R^2$, which are referred to as 1,2-dithiols. Therefore, in the early review [1] published in 1976, heterocyclic compounds **1** – **4** were named 1,2-dithiolenes as unsaturated derivatives of 1,2-dithiolane (**5**). However, at present, 1,2-dithiole is the common term for compounds **1** – **4**



1 – **4**



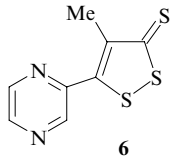
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and is used hereinafter in this review.

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In this review, we consider chemical transformations of derivatives of neutral 1,2-dithioles — 1,2-dithiole-3-thiones **1** (X = S), 1,2-dithiol-3-ones **2** (X = O), 1,2-dithiol-3-imines **3** (X = NR) and 1,2-dithiol-3-ylidenes **4** ($X = CR^1R^2$). The first compound of this class — 4,5-dimethyl-1,2-dithiole-3-thione — was synthesized in 1884,[2] at present, more than five thousand compounds of this class are known. A major reason why these compounds attract the attention of organic chemists is the existence of a large number of biologically active derivatives. For example, the most widely studied 1,2-dithiole is 4-methyl-5-(pyrazin-2-yl)-1,2-dithiole-3-thione (**6**) — the active substance of the antitumour drug Oltipraz.[3, 4]



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The chemistry of 1,2 dithioles is extremely diverse. Until recently, it has mainly dealt with reactions of 1,2-dithiole-3-thiones **1**; however, in the last years, an ever-increasing interest has also been focused on other representatives of this family, especially on 1,2-dithiol-3-ones **2**. In addition, the capacity of such compounds to form complexes with metals, which can find a multitude of practical applications, is currently actively studied.

Various aspects of the chemistry of 1,2-dithioles have been covered in some reviews. The reviews published in 1982 and 1995 by Pedersen [5, 6] should be ranked among the most interesting ones. Some data concerning the chemistry of 1,2-dithioles available in the 1980s – 1990s have been summarized in separate chapters of the monographs *Comprehensive Heterocyclic Chemistry II* and *III* (Refs 3 and 4). In the last years, an ever-increasing attention has been paid to various transformations of 1,2-dithioles. This issue is

addressed in the present review, which covers available data published in the past 15 years to March 2011 inclusive.

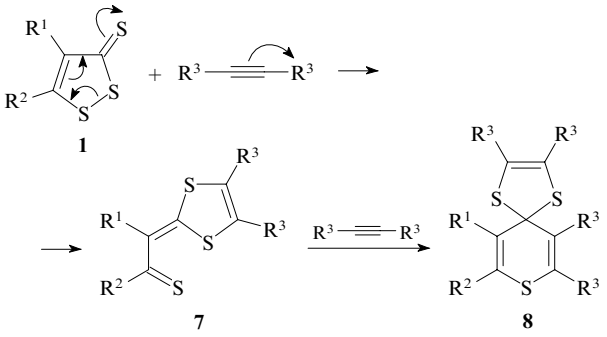
II. Reactions with dipolarophiles

1,3-Dipolar cycloaddition reactions are, as a rule, typical of 1,2-dithiole-3-thiones **1**; for other derivatives, such transformations have almost not been studied. This is explained by the fact that dithiolethione can act as 1,3-dipole and that the exocyclic sulfur atom is of crucial importance in this reaction. Alkynes activated by two electron-withdrawing groups are most frequently used as dipolarophiles.

1. Reaction with alkynes

Dithiolethione **1** can react with one or successively with two alkyne molecules. The first stage involves recyclization to give 1,3-dithioles **7**, which can be further converted into spiro-1,3-dithiolothiopyrans **8** (Scheme 1).[7,8]

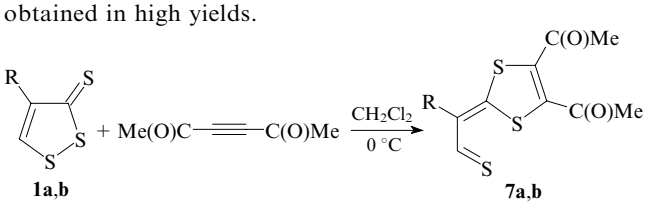
Scheme 1



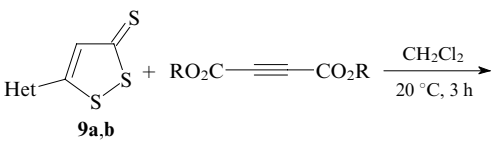
R^1 = H: R^2 = Alk, Ar; R^2 = H: R^1 = Alk, Ar; R^3 = C(O)Alk, CO_2Alk, *etc.*

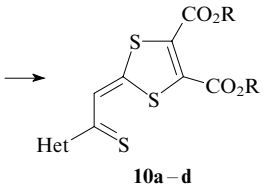
The reaction can be stopped after the formation of 1,3-dithiole, most easily, this is done in the case of non-fused 1,2-dithiole-3-thiones **1**. As a rule, to obtain 1,3-dithioles **7**, one equivalent of alkyne should be introduced into the reaction, which should be carried out at room or lower temperature. The product yields can vary within wide limits: from 20% to quantitative.

In particular, diacetylacetylene has been reacted with unsubstituted dithioletione (**1a**) and its 4-aryl-substituted derivative **1b**,[7] while acetylenedicarboxylic acid and its dimethyl ester (DMAD) have been reacted with 5-hetaryl-substituted dithioles **9a**,**b**.[8] The yields of products **7** have not been reported, and compounds **10a**–**d** have been obtained in high yields.



R = H (**a**), 4-MeC_6H_4 (**b**)

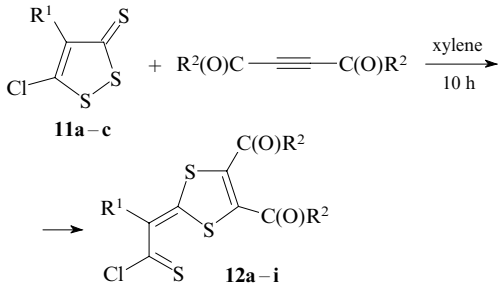




10a–**d**

Het = 2-Th (**9a**): R = H (**10a**), Me (**10b**); Het = 2-Fu (**9b**): R = H (**10c**), Me (**10d**); Th is thienyl, Fu is furyl

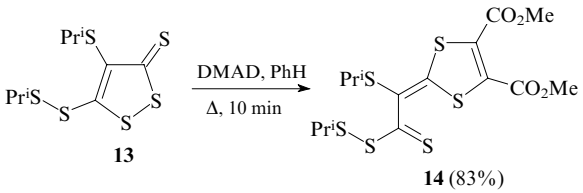
Activated alkynes readily react with both 5-chloro- (**11a**,**b**)[9] and 4,5-dichloro-1,2-dithiole-3-thiones (**11c**)[10] to give 1,3-dithioles **12a**–**i** in quantitative yield.



R^1 = N(Pr^i)CH_2CH_2Phth (**11a**): R^2 = OMe (**12a**), OEt (**12b**), Ph (**12c**); R^1 = N(neo-C_5H_{11})CH_2CH_2Phth (**11b**): R^2 = OMe (**12d**), OEt (**12e**), Ph (**12f**); R^1 = Cl (**11c**): R^2 = OMe (**12g**), OEt (**12h**), Ph (**12i**); Phth is *N*-phthalimido

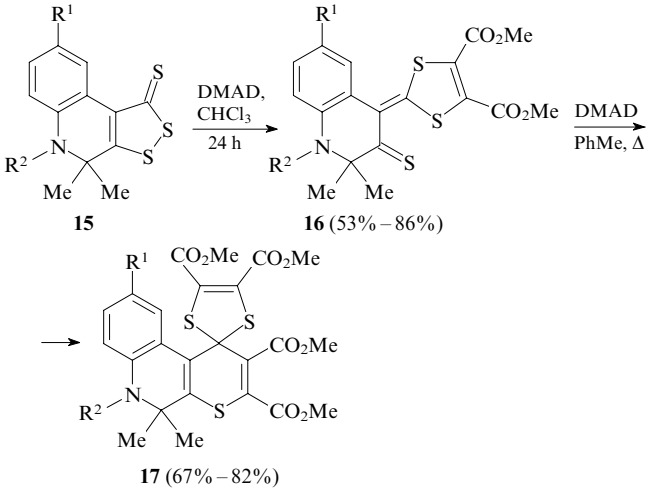
It is worth noting that the resulting compounds contain thioacyl chloride group, which is usually unstable. The stability of compounds **12** is explained by intramolecular interaction between the thiocarbonyl function and the heterocyclic sulfur atom, and this interaction can reduce the electrophilicity of the former. For compounds **12i**, this suggestion was confirmed by X-ray crystallography, which demonstrated planarity of the quasi-bicyclic moiety of the molecule with the S···S distance of 2.91 Å. This contact is intermediate between the ordinary S–S bond length (2.05 Å) and the sum of the van der Waals radii of sulfur atoms (3.68 Å).[11]

The reaction of dithio-substituted 1,2-dithiole-3-thione **13** with dimethyl acetylenedicarboxylate under refluxing in benzene for 10 min yields only 1,3-dithiole **14**, even if 2.5 equiv. of alkyne is introduced into the reaction.[12]



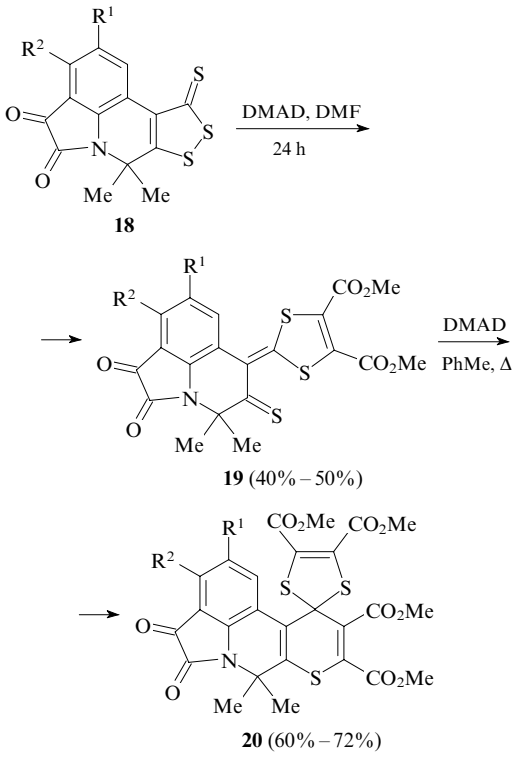
14 (83%)

1,2-Dithiole-3-thione derivatives fused with nonaromatic or heteroaromatic rings, as a rule, add successively one and then a second molecule of activated alkyne (usually, DMAD). The reaction is often difficult to stop at the first stage (see Scheme 1), so that 1,3-dithioles are obtained in low yield. For example, 1,2-dithiolo[3,4-*c*]quinolines **15** react with DMAD at room temperature in chloroform to form 1,3-dithioles **16**,[13,14] whereas the addition of the second equivalent of DMAD resulting in spirocyclic 1,3-dithiolothiopyrans **17** occurs under refluxing in toluene.



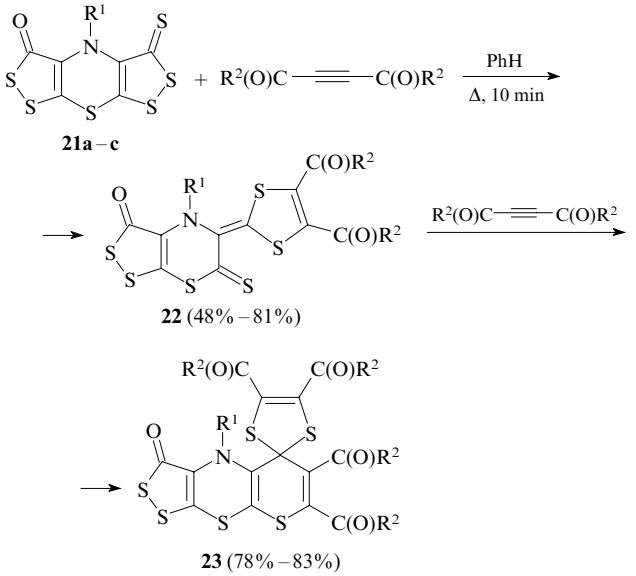
R^1 = H, Me, OMe; R^2 = H, Me, Ac, Bz, *etc.*

Structurally related tetracyclic systems **18** react with DMAD in dimethylformamide to give first pyrrolo[3,2,1-*ij*]quinolin-6-ylidene-1,3-dithioles **19** and then spirocyclic compounds **20**.[15]



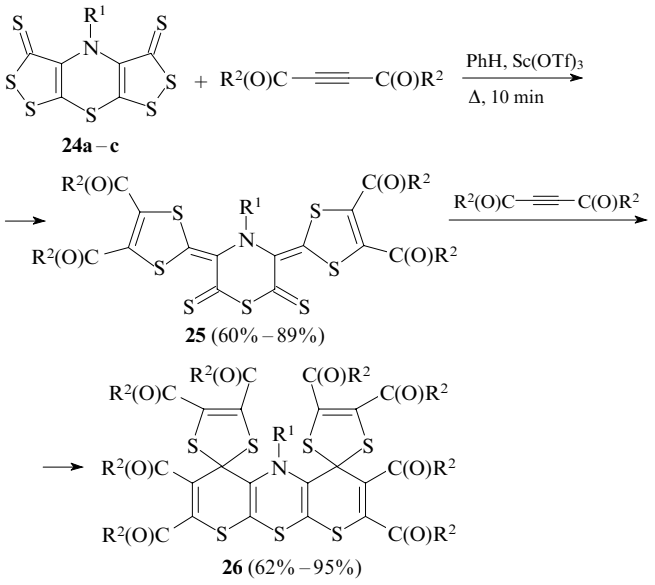
R^1 = H, Me; R^2 = H, Me, OMe, OEt

Analogous results have been obtained in the reaction of thiazines annelated with two dithiole rings with DMAD and dibenzoylacetylene.[16,17] In particular, short-term heating (10 – 45 min) of monothiones **21a – c** with 1 equiv. of alkyne in benzene under reflux gives mono-1,3-dithioles **22** in moderate to high yields. The use of scandium triflate as a catalyst significantly increases the yields (to 60% – 80%). The introduction of excess alkyne into the reaction and heating the reaction mixture in toluene or benzene under reflux result in dithiolothiopyrans **23**. It is noteworthy that the yields of compounds **22** and **23** are nearly the same; this is evidence that the addition of the second alkyne molecule occurs quantitatively.



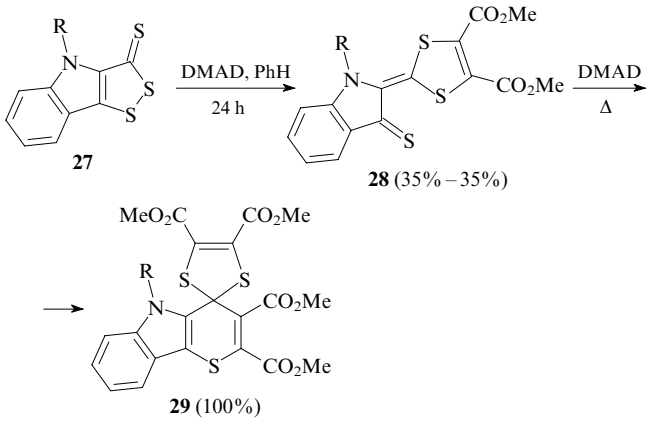
R^1 = Et (**a**), $(CH_2)_2Cl$ (**b**), n-$C_{18}H_{37}$ (**c**); R^2 = OMe, OEt, Ph

It should be noted that the reaction of bis(thiones) **24a – c** yields first bis(1,3-dithioles) **25** and then pentacyclic compounds **26**.



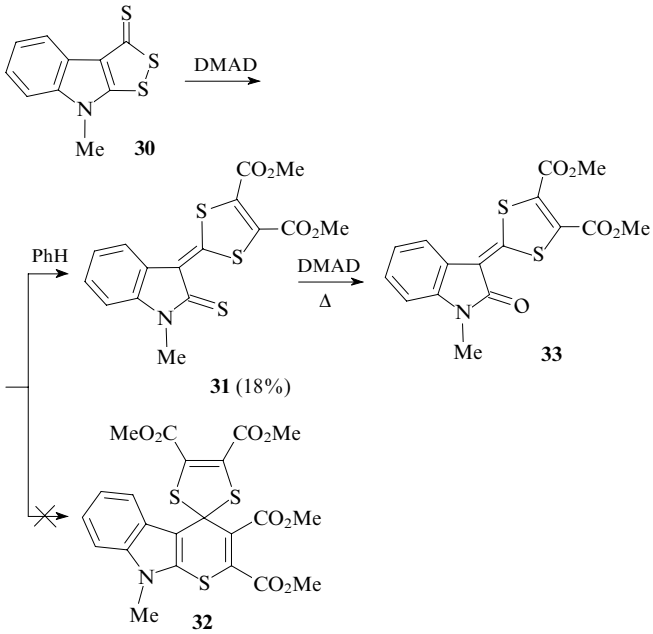
R^1 = Et (**a**), $(CH_2)_2Cl$ (**b**), n-$C_{18}H_{37}$ (**c**); R^2 = OMe, OEt, Ph

Study of the reactions of dithioloindoles **27** with DMAD has led to unusual results.[18] The addition of the first alkyne molecule is somewhat slower than the addition of the second molecule, and in all cases, the reaction yields mixtures of products of mono- (**28**) and bis-addition (**29**). The highest yields of 1,3-dithioles **28** (25% – 35%) have been achieved when compounds **27** react with 1 equiv. of DMAD in benzene at room temperature for three days. Monoadducts **28** react with 1 equiv. of DMAD in boiling benzene for few minutes to form adducts **29** in quantitative yield.



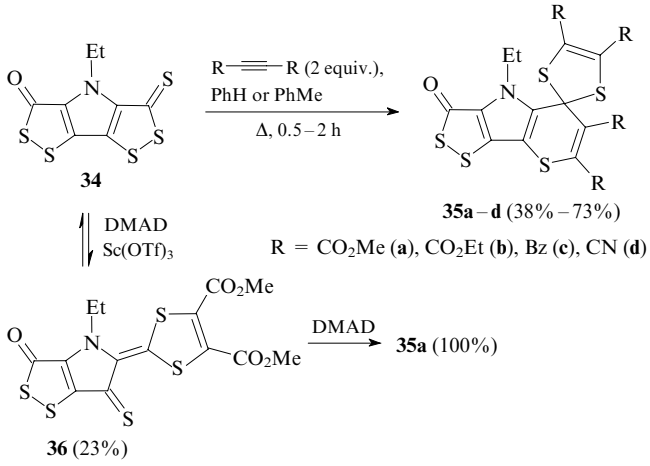
R = Me, Et, Pr^i, Bn

The treatment of isomeric dithioloindole **30** with a DMAD excess in benzene on heating under reflux for 1 h affords only adduct **31** in low yield.[18] The expected product of bis-addition **32** was not identified in the reaction mixture; rather, only 1,3-dithiolydene-substituted indolone **33** was isolated (yield, 23%). The formation of this product was a surprise. Compound **33** is formed in 65% yield by the reaction of thione **31** with DMAD. Thus, thione **31**, as distinct from regioisomer **28**, does not react with DMAD as with dienophile. It is evident that this is due to the difference in reactivity between the thione groups in these compounds. The thione group in compound **31** is, in essence, a thioamide group, which is not involved, as a rule, in 1,3-dipolar cycloaddition reactions.

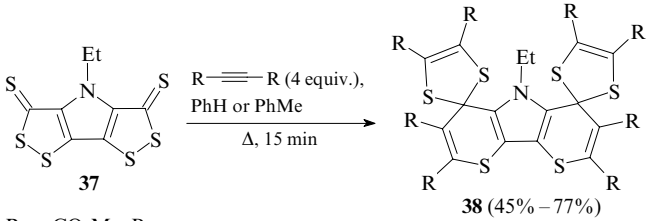


Monothioxobis(1,2-dithiolo)pyrrole **34** reacts with 2 equiv. of activated alkyne to form spiro(1,3-dithiole-2,4′-thiopyrans) **35a**–**d** (Scheme 2).[16,17] Only the reaction of thione **34** with 1 equiv. of DMAD in methylene chloride in the presence of scandium triflate enables the isolation of the product of addition of one alkyne molecule (**36**) in low yield. This product is unstable and is converted back into thione **34**. The reaction of **36** with another equivalent of DMAD produces spiro-1,3-dithiole thiopyran **35a** in quantitative yield. The authors attribute the instability of product **36** to the loss of aromaticity by the pyrrole ring, which can be restored when **36** either reacts with the second dienophile molecule or is converted into the initial bis(dithiolo)pyrrole **34**.[16]

Scheme 2

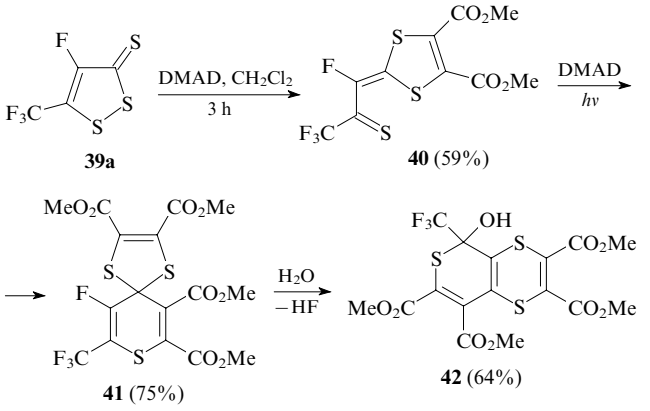


Analogous di(thioxo)bis(1,2-dithiolo)pyrrole **37** rapidly reacts with 4 equiv. of activated alkyne (2 equiv. per each thione group) to give bis(spiro-1,3-dithiole thiopyran)pyrrole **38**.



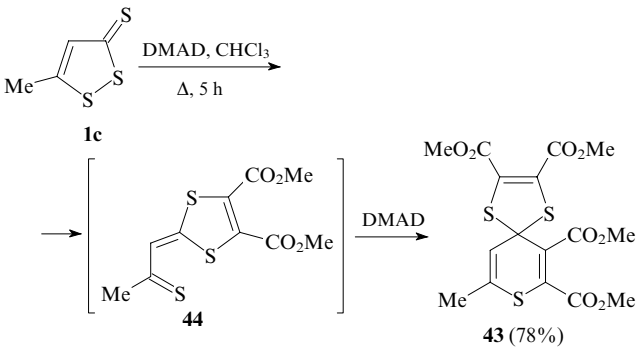
R = CO_2Me, Bz

For 4-fluoro-5-trifluoromethyl-1,2-dithiole-3-thione **39a**, it has been shown that the thiopyran structure can form not only on heating but also on irradiation. As expected, the reaction of thione **39a** with DMAD in methylene chloride at room temperature yielded 1,3-dithiole **40**.[19] An exposure of a mixture of 1,3-dithiole **40** with DMAD to light from a 500 W tungsten lamp for 0.5 h led to thiopyran **41** in 75% yield. However, the latter appeared to be sensitive to the moisture in silica gel and was converted into hydroxy adduct **42** (yield 64%) after filtration through a bed of silica gel. It is worth noting that all



transformations can be carried out as one-pot syntheses: thione **39a** can be converted into compound **42** without isolation of intermediate products.

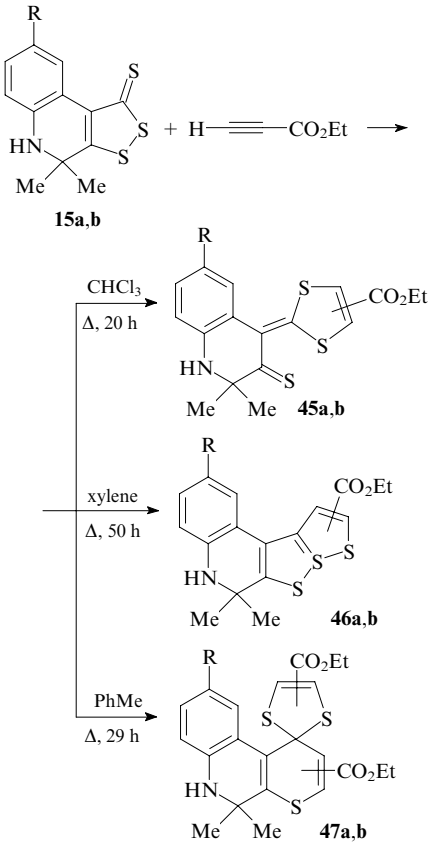
In the context of the aforesaid data, the result afforded by the reaction of 5-methyl-1,2-dithiole-3-thione (**1c**) with DMAD is rather surprising. After heating these reactants under reflux in chloroform for 5 h, only the product of addition of two DMAD molecules, thiopyran **43**, was isolated.[20] At the same time, it should be noted that the authors have made no attempts to obtain intermediate 1,3-dithiole **44**.



1,3-Dipolar cycloaddition involving asymmetric alkynes has been less intensively studied. The introduction of hydrogen atoms or phenyl group into the molecule instead of strong electronegative substituents, such as an ester, benzoyl or nitrile group, significantly suppresses the activity of alkynes in such reactions. In addition, reactions with asymmetric alkynes yield, as a rule, mixtures of regioisomers, which are difficult or almost impossible to separate. This decreases the synthetic value of the method.

Shikhaliev and co-workers[21] have studied the cycloaddition of ethyl propiolate to 4,4-dimethyl-4,5-dihydro-1,2-dithiolo[5,4-*c*]quinoline-1-thiones **15a**,**b** (Scheme 3). It has been shown that, depending on conditions (solvent and temperature), the reaction can occur rather selectively either as 1,3-dipolar cycloaddition of one or two alkyne molecules or with the thioketone bond cleavage as [2 + 2]-cycloaddition with subsequent recyclization. In particular, boiling equimolar amounts of the reactants in chloroform leads to 1,3-dithioles **45a**,**b**. The reaction of ethyl propiolate with thiones **15a**,**b** at higher temperatures (in boiling xylene) involves the cleavage of the thioketone bond with subsequent recyclization to give trithiapentalenes **46a**,**b**. The reaction in toluene with 2 equiv. of ethyl propiolate gives 1 : 2 adducts (**47a**,**b**) in high yields. In all cases, the ^{1}H NMR spectra show several sets of signals of carbethoxy groups and quasi-aromatic protons, which is evidence of the lack of regioselectivity of these transformations.

Scheme 3

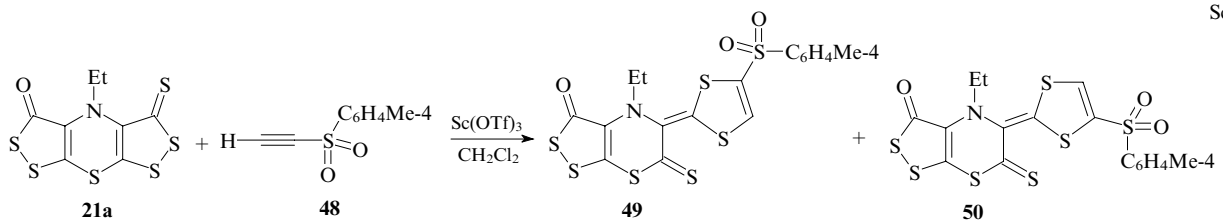


Compound	R	Yield (%)		
		45	**46**	**47**
a	H	65	48	47
b	Me	67	53	78

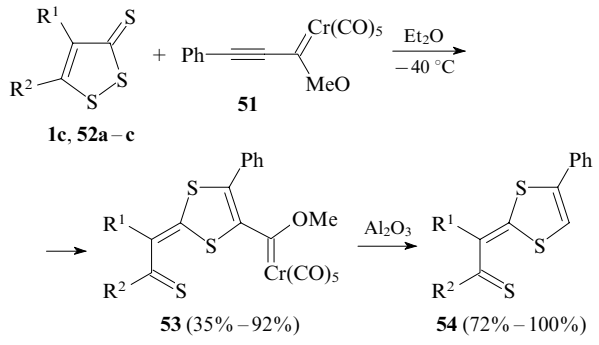
The reaction of tricyclic bis(dithiolo)thiazine **21a** with an excess of monosubstituted alkyne **48** activated by sulfonyl group in the presence of scandium triflate leads to the addition of only 1 equiv. of the alkyne. As a result, a pair of regioisomers **49** and **50** is formed (the total yield 56%) and their structure has been proved by ^{1}H NMR (Scheme 4).[22]

A noteworthy and rare example of regioselective addition of phenylethynyl Fischer carbene complex **51** to 1,2-dithiole-3-thiones of different structure has been described by Torroba and co-workers[23] In this case, the carbene moiety of alkyne **51** acts as an electron-withdrawing group, thus enhancing its electrophilic character. The reaction was carried out with 5-methyl- (**1c**) and 5-alkylthio-substituted 1,2-dithiole-3-thiones (**52a**–**c**). The reaction occurs at −40 °C in diethyl ether; the yields of products **53** vary from rather low (35%) to high (92%). The treatment of compounds **53** with neutral alumina followed by

Scheme 4

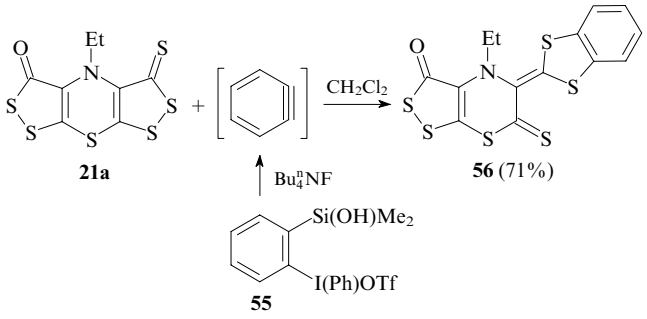


chromatographing produces (*E*)-dithiafulvene thiones **54** in high yield.



R^1 = H: R^2 = Me (**1c**), SBu^n (**52a**), SC_5H_9-cyclo (**52b**);
R^1 = Ph, R^2 = SEt (**52c**)

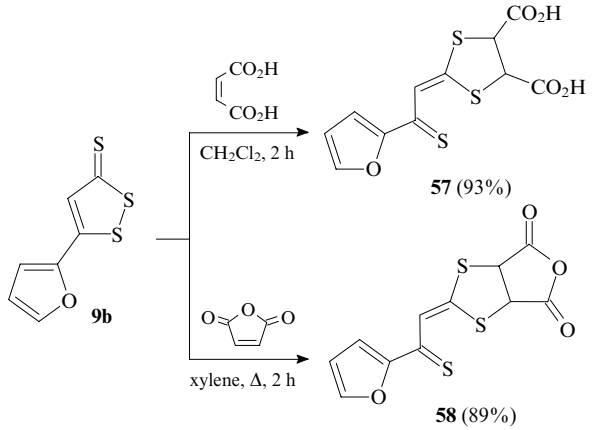
The possibility of addition of dehydrobenzene to dithiolethione **21a** has been studied.[22] It was a surprise that dehydrobenzene generated by most of the known methods did not form adducts with thione **21a**. One of the gentlest methods, conversion of iodonium salt **55**, was the only successful one. The cycloaddition of dehydrobenzene to thione **21a** gives product **56** in high yield.



2. Reactions with alkenes

Activated alkenes can also react with 1,2-dithiole-3-thiones; however, such reactions are used rather rarely. This is presumably due to the possibility of formation of a mixture of stereoisomers, which are difficult to separate and identify.

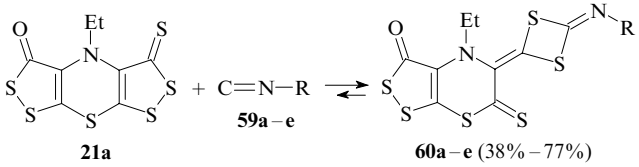
It has been shown that 5-(2-furyl)-1,2-dithiole-3-thione (**9b**) reacts with maleic acid in methylene chloride at room temperature to produce 1,3-dithiolane **57** in high yield.[8]



Unexpected was the fact that the reaction with maleic anhydride required heating under reflux in xylene for 2 h, although product **58** was also isolated in high yield.

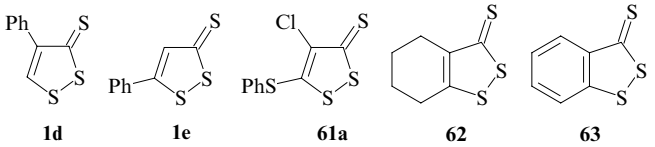
3. Reactions with isonitriles

Isonitriles are prone to cycloaddition to 1,3-dipoles and compounds with multiple bonds, including those containing sulfur atom.[24] More than 10 years ago, the reaction of ketothione **21a** with *p*-toluenesulfonylmethyl isocyanide (TOSMIC, **59a**) was reported.[25] This reaction yields the product that was assigned to have the structure of imino-1,3-dithietane **60a**. It was found that other isonitriles (**59b–e**) readily react with ketothione **21a**, forming corresponding imino-1,3-dithietane **60b–e** in moderate to high yields.[26]

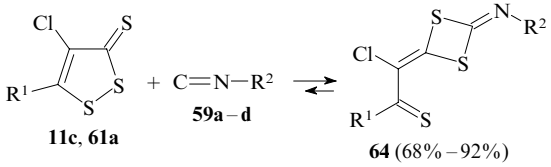


59, **60**: R = CH_2Ts (**a**), Ph (**b**), C_6H_4OMe-4 (**c**), $C_6H_4NO_2$-4 (**d**), CH_2CO_2Et (**e**); Ts is *p*-toluenesulfonyl

To study the effect of the structure of 1,2-dithiole-3-thione derivatives on this reaction, isonitriles **59a–e** were reacted with different 1,2-dithiole-3-thiones: monocyclic with one (**1d**,**e**) or two (**11c**, **61a**) substituents and annelated with heterocyclic (**24a**, **34**, **37**), cyclohexane (**62**) and benzene (**63**) moieties. It turned out that the structure of 1,2-dithiole-3-thione has an effect on the possibility of its transformation into 1,3-dithietane, the decisive factor being the presence of electron-withdrawing groups in the initial molecule and the retention of its aromaticity.



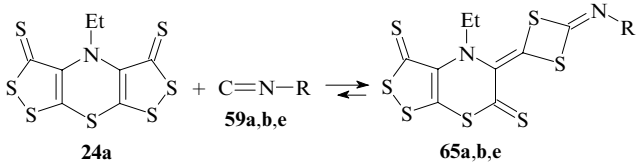
In particular, monocyclic dithiolethiones **11c** and **61a**, containing electron-withdrawing chlorine atom, react with isonitriles **59a–d** at room temperature in benzene to form 1,3-dithietanes **64** in high yields.[26]



R^1 = Cl (**11c**), SPh (**61a**); R^2 = CH_2Ts (**59a**), Ph (**59b**), C_6H_4OMe-4 (**59c**), $C_6H_4NO_2$-4 (**59d**)

At the same time, monocyclic dithiolethiones **1d**,**e** with the less electron-withdrawing phenyl group does not react with isonitriles **59a–d**. In the case of bis(1,2-dithiolo)-1,4-thiazinedithione **24a**, both 1,2-dithiole-3-thione rings can be theoretically involved in the reaction with isonitrile. However, study of the reaction of dithione **24a** with isonitriles **59a**,**b**,**e** has shown that, in all cases, only one isonitrile group is added at room temperature to give 1,3-dithietanes

65a,**b**,**e** in moderate yields.[26] The introduction of a twofold excess of isonitrile and heating the reaction mixture does not lead to the formation of new compounds, as judged from TLC data.



24a **59a**,**b**,**e** **65a**,**b**,**e**

59, **65**: R = CH_2Ts (**a**, 61%), Ph (**b**, 42%), CH_2CO_2Et (**e**, 39%)

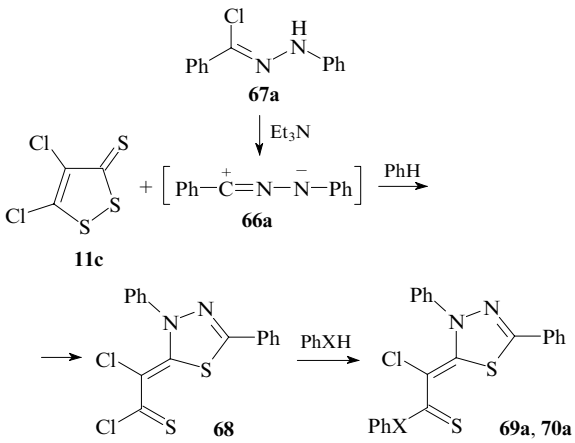
Bis(1,2-dithiolo)pyrroles **34** and **37** do not react with isonitriles **59a**–**d**, presumably because of the loss of aromaticity of the pyrrole ring upon the formation of 1,3-dithietanes. Condensed dithiolethiones **62** and **63** also do not react with isonitriles **59a**–**e** or at room temperature on heating.

As demonstrated by ^{1}H NMR and IR spectroscopy, 1,3-dithietanes **60**, **64** and **65** in solutions in deuteriochloroform and chloroform are at equilibrium with the initial compounds used for their synthesis, *i.e.*, the corresponding 1,2-dithiole-3-thione and isonitrile. On cooling these solutions to −20 °C and keeping them at this temperature for a week, the equilibrium is completely shifted toward 1,3-dithietane **60**, **64** or **65**, while on heating of its solution in chloroform, only the dithiolethione and isonitrile are identified within 10 min. It has been shown that the equilibrium position depends on the structure of both the dithiolethione and the isonitrile, and the amount of 1,3-dithietane in solution can vary from 20% to 98%.[26]

4. Reactions with nitrilimines

The reaction of nitrilimines with 1,2-dithiole-3-thiones occurs as the 1,3-dipolar cycloaddition reaction at the thione group and is accompanied by a spontaneous dithiole ring opening with elimination of the sulfur atom and formation of of 1,3,4-thiadiazole ring.

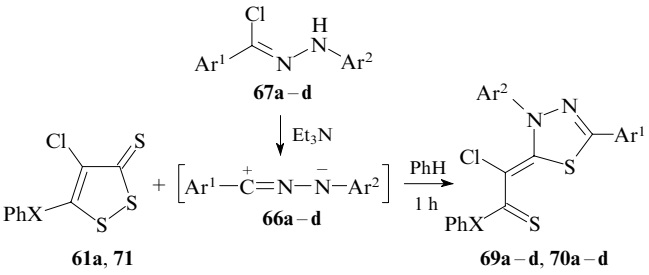
Studying the reaction of 4,5-dichloro-1,2-dithiole-3-thione (**11c**) with diphenylnitrilimine **66a**, obtained *in situ* from the corresponding *N*-phenyl-α-chlorophenylhydrazone **67a** and triethylamine, has shown that unstable products are formed.[27] It has been suggested that the instability of product **68** is due to the fact that it contains the highly reactive thioacyl chloride group. Indeed, the addition of thiophenol or phenol to the reaction mixture led to thiadiazoles **69a** or **70a**, even if in low yield.



67a **11c** **66a** **68** **69a**, **70a**

X = S (**69a**, 25%), O (**70a**, 29%)

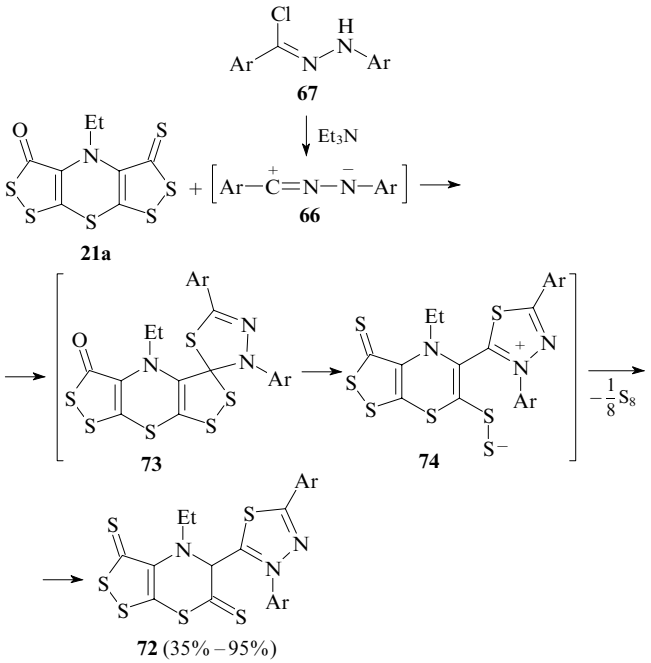
The reaction of nitrilimine **66a** with 5-phenylthio- (**61a**) or 5-phenoxy-1,2-dithiole-3-thiones (**71**) occurs more smoothly, and thiadiazoles **69a** and **70a** form in higher yields. These conditions have been extended to nitrilimines **66b**–**d**; in all cases, corresponding thiadiazoles **69b**–**d** and **70b**–**d** have been obtained in moderate yields (55%–65%).



67a–**d** **66a**–**d** **61a**, **71** **69a**–**d**, **70a**–**d**

X = S (**61a**, **69**), O (**70**, **71**); Ar^2 = Ph: Ar^1 = Ph (**a**), $C_6H_4NO_2$-4 (**b**), C_6H_4Me-4 (**c**); Ar^1 = Ph, Ar^2 = $C_6H_4NO_2$-4 (**d**)

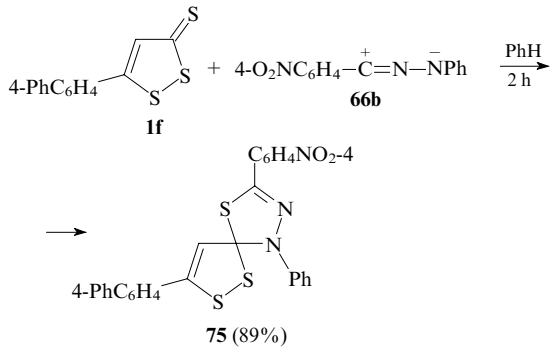
The reaction of fused 1,2-dithiole-3-thione **21a** with symmetric diarylnitrilimines **66** also gives 1,3,4-thiadiazoles **72** in moderate to high yields.[25] It is evident that the process begins with formation of spiro-1,2-dithiolo-1,3,4-thiadiazolines **73**. The electron-withdrawing effect of the trigonal nitrogen atom of the thiadiazole ring can favour the opening of the 1,2-dithiole ring resulting in the formation of intermediate zwitterion **74**, which is converted into product **72** after elimination of a sulfur atom. It is worth noting that sulfur is isolated from these reactions as S_8 in nearly quantitative yield.[27]



67 **21a** **66** **73** **74** **72** (35%–95%)

Ar = $C_6H_{5-n}R_n$ (R_n = H, 4-Cl, 4-Br, 4-I, 4-CN, 2,4-Cl_2)

It has been reported[28] that the reaction of 1,2-dithiole-3-thione **1f** with nitrilimine **66b** afforded intermediate product **75** of the type of **73**. However, no serious proofs of its structure have been presented.



III. Ring transformation reactions

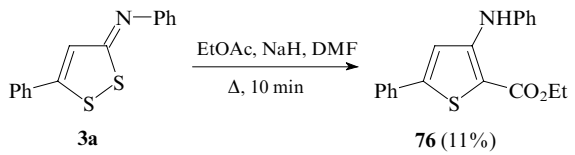
Reactions of transformation of the 1,2-dithiole ring into another heterocycle can be divided into two types. Reactions of the first type are the reaction that occur with formal substitution of carbon- or nitrogen-containing fragments for one or even two sulfur atoms of the 1,2-dithiole. Reactions of the second type are the reactions of insertion of, most frequently, a metal-containing fragment between two sulfur atoms of 1,2-dithiole. In some cases, reactions of the second type can be accompanied by more profound transformations (see Section III.1.f).

1. Reactions with the exchange of the sulfur atom for carbon- or nitrogen-containing fragments

Notwithstanding the fact that the chemistry of 1,2-dithioles, especially reactions with the substitution of an amine residue for sulfur atom, has rather long been studied, reliable information on the structure of the synthesized compounds is often lacking in the available literature. The question of which of the sulfur atoms of the 1,2-dithiole ring is replaced (for 1,2-dithiole-3-thiones, the exocyclic sulfur atom can also be involved in the reaction) often remains unanswered. The replacement of a sulfur atom by a two-atom fragment can lead to regioisomers, and the structure of the resulting products is often not evident. Therefore, in what follows, the processes reported in the literature are critically considered, and the suggested mechanisms of reactions are not discussed if the structure of the target product has not been strictly proved.

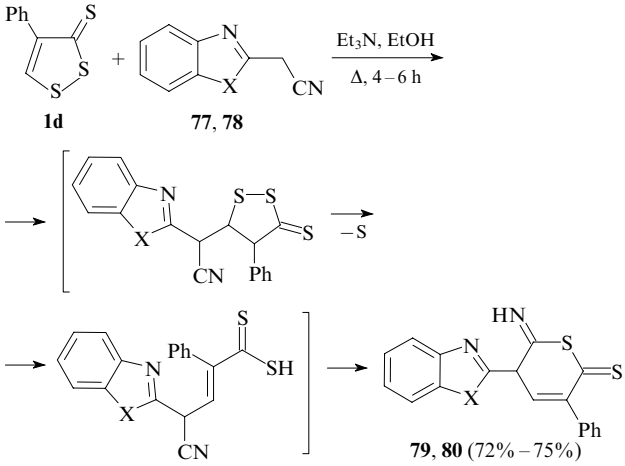
a. Exchange of the sulfur atom for a one-carbon fragment

The only known example of such transformations can be deemed to be the reaction of 5-phenyl-3-phenylimino-1,2-dithiole (**3a**) with ethyl acetate in the presence of sodium hydride in dimethylformamide.[29] The reaction affords small amounts of thiophene **76**, a product of the formal substitution of a $C(CO_2Et)$ carbon fragment for the sulfur atom in the 2-position. The proof of the structure of the resulting compound and the mechanism of this uncommon reaction have not been reported by the authors.



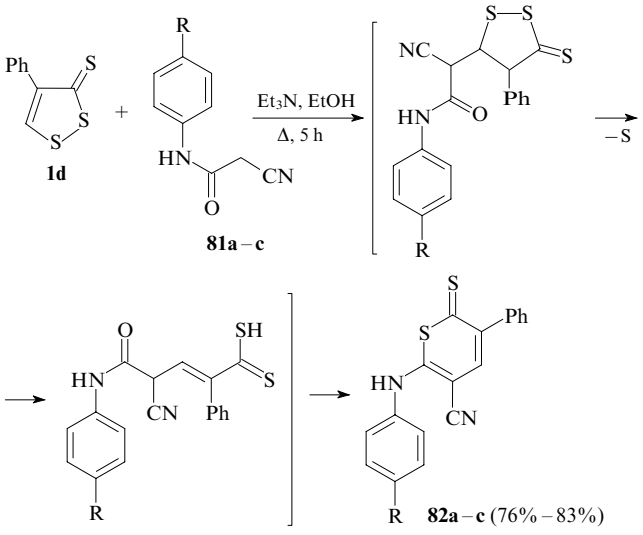
b. Exchange of the sulfur atom for a carbon–carbon fragment

It has been shown[30–32] that, in the reactions of 4-phenyl-1,2-dithiole-3-thione (**1d**) with nitriles containing an active methylene group or with α,β-unsaturated nitriles, a sulfur atom is exchanged for a C–C bond, so that the new ring contains the nitrile carbon atom and the adjacent carbon atom. In particular, the reaction of thione **1d** with 2-cyanomethylbenzothiazole (**77**) or -benzimidazole (**78**) in the presence of triethylamine yields products assigned to 6-imino-2*H*-thiopyran-2-thiones **79**, **80**.[30] The authors suggest the scheme involving the initial nucleophilic attack of the active methylene group on the C(5) atom of 1,2-dithiole, ring opening with S–S bond cleavage and elimination of the sulfur atom followed by recyclization.



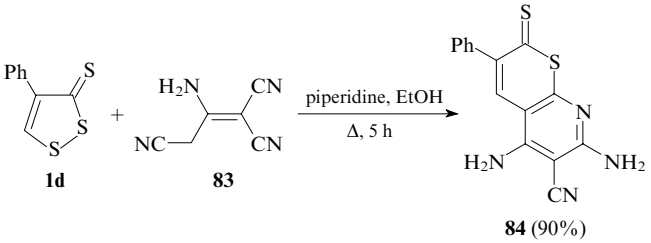
X = S (**77**, **79**), NH (**78**, **80**)

At the same time, in the reaction of nitriles **81a–c** with thione **1d** under analogous conditions, the final stage of cyclization involves the amide function rather than the nitrile group as might be expected from the above scheme.[30] Thus, the reaction produces 2*H*-thiopyran-2-thiones **82a–c** in high yields.



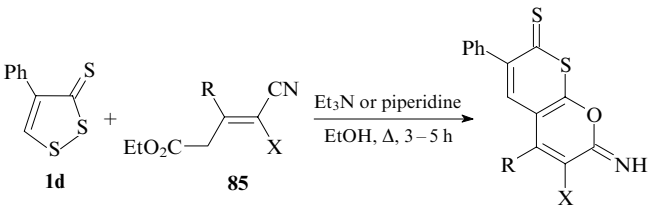
81, **82**: R = H (**a**), Me (**b**), OH (**c**)

It is noteworthy that the cyanomethyl group attached to the double bond in compound **83** reacts in a similar way, which leads to bicyclic 2*H*-thiopyrano[2,3-*b*]pyridine-2-thione **84**.[31]



1d **83** **84** (90%)

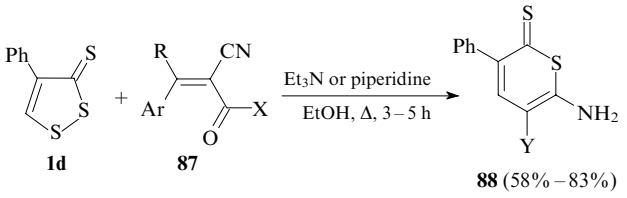
If the reactant contains ethoxycarbonyl group, as in **85**, rather than the cyanomethyl group, the reaction involves the ester group and yields 2-imino-2*H*,7*H*-thiopyrano[2,3-*b*]pyran-7-thione derivatives **86**.[30,31]



1d **85** **86** (75%–83%)

R = Me: X = CN, CO_2Et; R = NH_2, X = CN

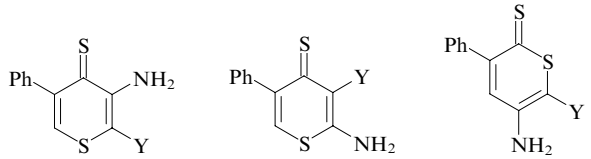
It is worth noting that the reaction with conjugated nitriles **87** also involves the nitrile group and leads to 2*H*-thiopyran-2-thiones **88**.[30,32] The condensation conditions are the same as in all previous transformations: boiling in ethyl alcohol in the presence of a base (piperidine or triethylamine). If a conjugated nitrile contains the amide group, it is concurrently dehydrated to the nitrile group.[30]



1d **87** **88** (58%–83%)

R = H, X = NH_2, Y = CN; X = OEt, Y = CO_2Et: R = H, Me

In all cases described in this section, authors assume that the endocyclic sulfur atom in the 1-position is replaced. Unfortunately, the structures of the above compounds have been proved only by elemental analysis, IR spectra and NMR data. These methods do not enable unambiguous determination of the structures of the compounds. We can easily suggest alternative structures **89**–**91** for compound **88**, as an example. To decide between these structures on the basis of the available data in the cited works is difficult.

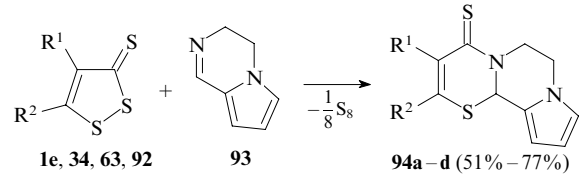


89 **90** **91**

A disadvantage of these studies is that the 'fate' of the eliminated sulfur atom is traced in none of the cases.

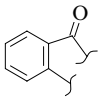
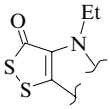
c. Exchange of the sulfur atom for a carbon–nitrogen fragment

A new transformation of the dithiole ring has been recently discovered.[33] It consists in the addition of the imine fragment with elimination of the sulfur atom. The reaction of monocyclic (**1e**) or fused 1,2-dithiole-3-thiones (**34**, **63** and **92**) with an excess of 3,4-dihydropyrrolo[1,2-*a*]pyrazine (**93**) gives fused 1,3-thiazine-4-thiones **94a**–**d** in high yields. Sulfur was isolated from the reaction mixture as S_8 in nearly quantitative yield.



1e, **34**, **63**, **92** **93** **94a**–**d** (51%–77%)

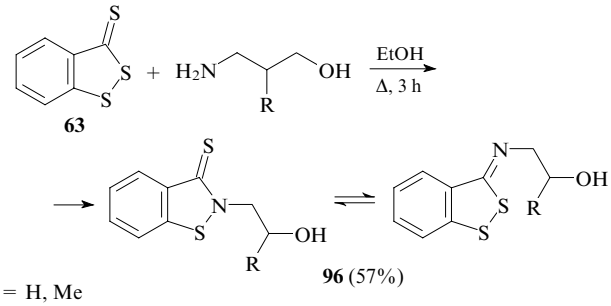
R^1 = H, R^2 = Ph (**1e**, **94a**); R^1–R^2 =  (**63**, **94b**),

 (**92**, **94c**),  (**34**, **94d**)

As distinct from the reactions described in the previous section the sulfur atom in the 2-position is replaced, which has been reliably proved by X-ray crystallography of one of the products, namely, compound **94b**.

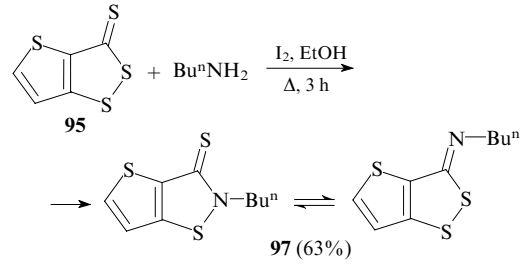
d. Exchange of the sulfur atom for nitrogen-containing functions

The reaction of 1,2-dithiole-3-thione with amines has been studied for a relatively long time (see reviews [1,3–6]). Reactions have been described in which the imine function is substituted for both the endocyclic (in the 1- and 2-positions) and exocyclic sulfur atoms. However, the mechanisms of these reactions have heretofore been unknown. For example, the reactions of aliphatic amines in ethanol with 1,2-dithiole-3-thiones annelated with aromatic (**63**) and heteroaromatic (**95**) rings have been studied.[34,35] The authors have insisted that the reactions lead to inseparable mixtures of isomers **96** and **97**, in which, respectively, the endocyclic sulfur atom in the 2-position and the exocyclic sulfur atom are replaced. The yields of the products are moderate in both cases.



63 **96** (57%)

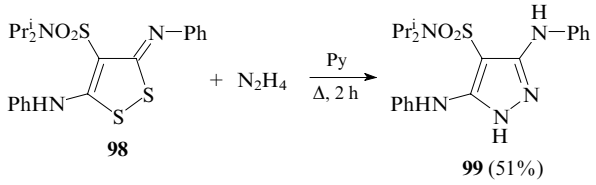
R = H, Me



95 **97** (63%)

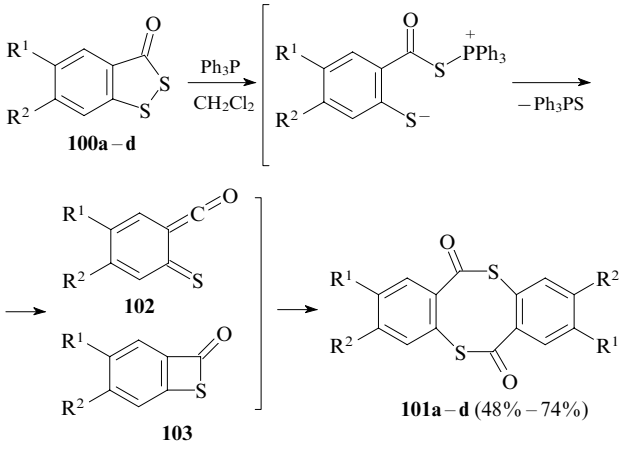
It has been shown that, in the reaction of 1,2-dithiol-3-imine **98** with hydrazine in pyridine, the hydrazine fragment

can be substituted for two endocyclic sulfur atoms;[36] as a result, the 1,2-dithiole ring is converted into the pyrazole ring to give compound **99**.



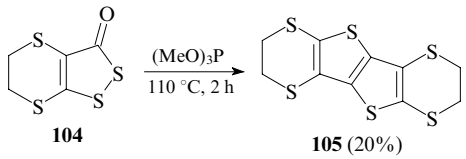
e. Elimination of sulfur atoms under the action of phosphorus-containing reagents

As is known, phosphorus-containing reagents (phosphines and phosphites) can split sulfur atoms from different sulfur-containing compounds. It has been demonstrated that the reaction of substituted benzo-1,2-dithiol-3-ones **100a–d** with triphenylphosphine in methylene chloride at room temperature affords dithiosalicylides **101a–d** in moderate yields.[37,38] As intermediate compounds, the authors suggest either ketenes **102** or benzothietan-2-ones **103**, which dimerize to form products **101**.



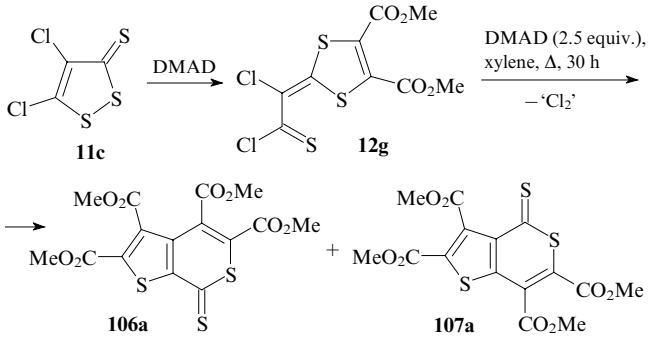
R^2 = H: R^1 = H (**a**), Me (**b**), Br (**c**); R^1–R^2 = CH=CH–CH=CH (**d**)

Under more severe conditions (2 h at 110 °C), the dimerization of fused dithiolone **104** under the action of trimethyl phosphite can be accompanied by elimination of not only the sulfur atom but also carbon monoxide.[39] The reaction yields tetracyclic product **105**; however, the mechanism of this unique reaction is not discussed.

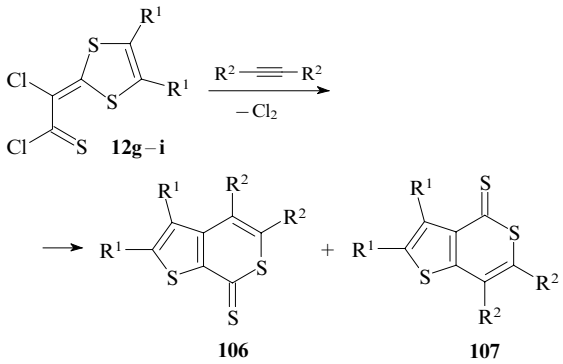


f. Insertion reactions resulting in thienothiopyrans

It is worth noting that the thienothiopyran system can form in the reactions of 1,2-dithiole-3-thione with very different reagents, namely, DMAD and sodium sulfide. The reaction of 4,5-dichloro-1,2-dithiole-3-thione (**11c**) with a DMAD excess in xylene, first, at room temperature and, then, on heating the reaction mixture under reflux affords good yields of isomeric thienothiopyranthiones **106a** and **107a**, which are free of chlorine atoms.[11] Thus, the reaction follows a different pathway than in the case of 1,2-dithiole-3-thiones that do not contain two chlorine atoms as substituents (see Section II.1). As expected, the first stage of this reaction is the addition of the first DMAD molecule to form thiochloride **12g**, which then reacts with the second DMAD molecule with rearrangement to give isomeric products.



Analogous thienothiopyranthiones **106** and **107** have also been isolated in the reactions of dithiolethione **11c** with other activated alkynes — diethyl acetylenedicarboxylate (DEAD) and dibenzoylacetylene (DBA). To elucidate the mechanism of formation of **106** and **107**, the behaviour of three intermediate 1,3-dithioles **12g–i** with three alkynes — DMAD, DEAD and DBA — has been studied. In each of the reactions, two isomeric thienothiopyranthiones **106** and **107** have been isolated (in a 1:1 to 1:2 ratio, yields 30%–57%). It has been demonstrated that, in all cases, substituents R^1 of molecule **12** are attached to the thiophene ring of products **106** and **107** and substituents R^2 of the alkyne add to the thiopyran ring.

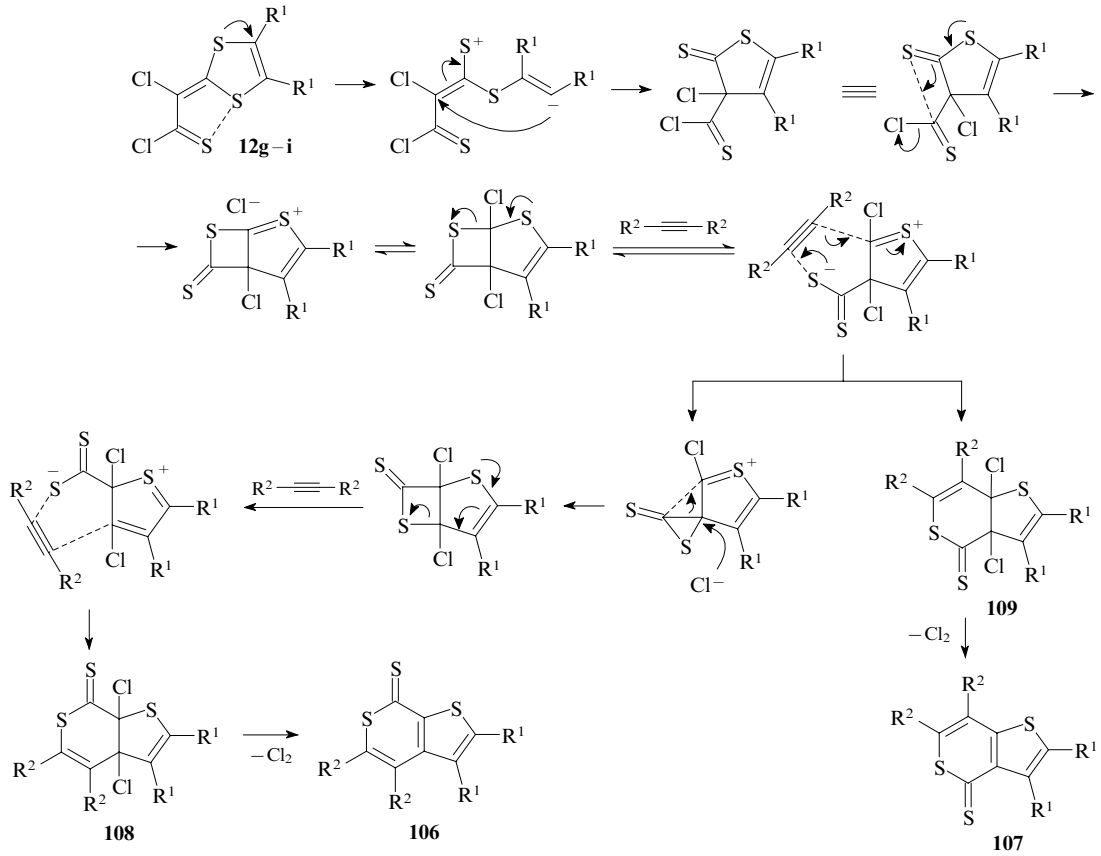


R^1, R^2 = CO$_2$Me, CO$_2$Et, Bz

Possible ways of formation of thiopyrans **106** and **107** have been suggested (Scheme 5).

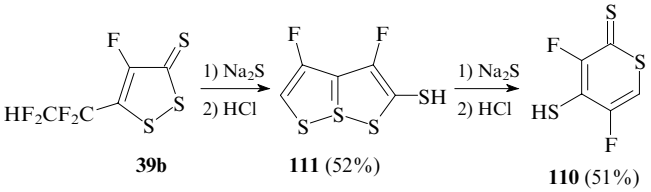
The authors believe that the existence of the intramolecular S···S bond in the molecule of **12** (proved by single-crystal X-ray diffraction of compound **12g**) is mainly responsible for such rearrangements.[11] This bond suppresses the ability of 1,3-dithioles **12** to enter into the 1,3-dipolar cycloaddition reaction and, at high temperatures, leads to a sequence of transformations involving the opening and closure of different heterocycles. Target heteroaromatic products **106** and **107** can form with removal of a chlorine molecule from dichloro-substituted adducts **108** and **109**. The presence of a chlorine molecule in the reaction mixture has been proved by isolation of xylene chlorination

Scheme 5

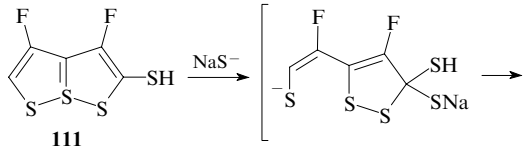


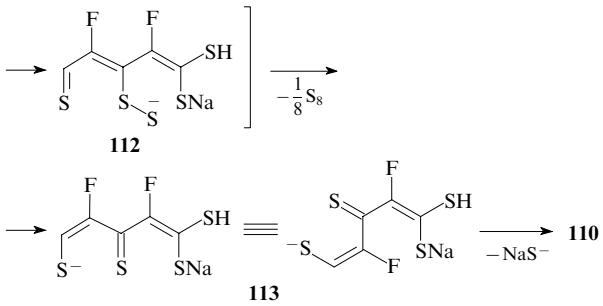
products identical to those that form when chlorine gas is bubbled through boiling xylene.

Another example of formation of the thiopyran ring from the 1,2-dithiole-3-thione one is the reduction reaction of 4-fluoro-5-(1,1,2,2-tetrafluoroethyl)-1,2-dithiole-3-thione (**39b**) with sodium sulfide.[40] It has been found that heating dithiolethione **39b** with an excess of sodium sulfide in a benzene–ethanol mixture leads to thiopyranthione **110**. The reaction of equimolar amounts of the reactants under the same conditions yields trithiapentalene **111**.



The formation of the trithiapentalene system is represented by consecutive reactions of reduction and fluorine substitution under the action of sulfide anion with its subsequent addition. The rearrangement occurs through elimination of the vinyl sulfur atom from intermediate **112**, which leads to anion **113**. The mechanism is shown below.

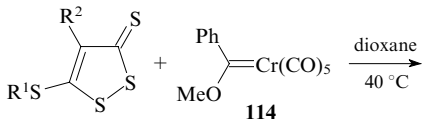


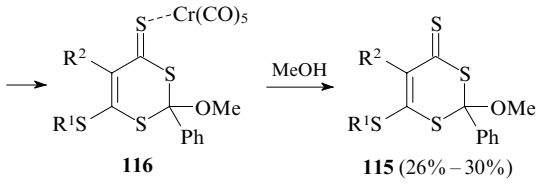


2. Insertion of fragments between the sulfur atoms of the 1,2-dithiole ring

a. Insertion of carbon fragments

Some monocyclic 5-alkylsulfanyl-1,2-dithiole-3-thiones have been studied in reactions with Fischer carbene complex **114** in dioxane.[41] The basic direction of the reaction is insertion of the carbene fragment into the S–S bond to give 1,3-dithiin-4-thiones **115**, which are the products of treatment of intermediate complexes **116** with methanol.

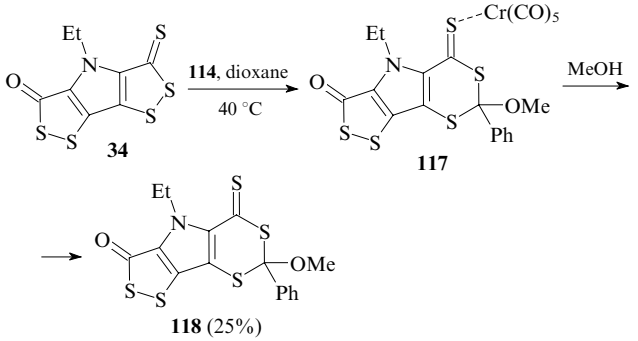




116 **115** (26% – 30%)

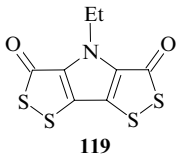
R^2 = H: R^1 = Bu^n (**52a**), Et (**52d**);
R^2 = Cl: R^1 = Bu^n (**61b**), Et (**61c**)

Fused monothione **34** also enters into an analogous reaction. In this case, the decomposition of complex **117** leads to the formation of annelated 1,3-dithiin-4-thione **118**.[41]



34 **117** **118** (25%)

It is worth noting that ketone **119** does not react with Fischer carbene complex **114**.

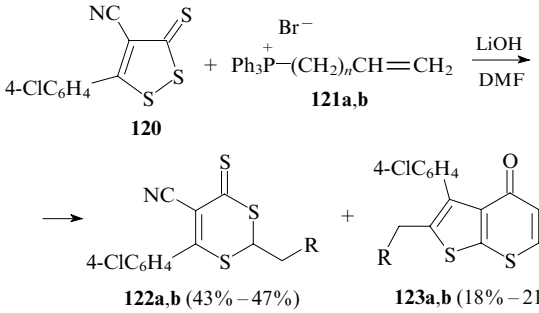


119

Thus, the presence of the thiocarbonyl groups is a necessary prerequisite for the insertion of the C(OMe)Ph fragment into the 1,2-dithiole ring. This statement is also supported by the fact that the reaction of complex **114** with tricyclic compound **34**, containing both the 1,2-dithiole-3-thione and 1,2-dithiol-3-one rings, yields only the product of insertion into the 1,2-dithiole-3-thione ring, *i.e.*, compound **118**. According to the authors,[41] this selectivity is evidence that the reaction begins with the attack of the nucleophilic thiocarbonyl group on the electrophilic carbenium carbon atom of Fischer carbene complex.

It is of interest that, in the first report [42] on the reaction of 1,2-dithiole-3-thiones with Fischer carbene complex **114**, the authors claimed that the insertion of the carbene ligand occurs into the C(3)–C(4) bond of the dithiole ring. Later,[41] the products were studied by X-ray crystallography, which enabled the correction of the initial data.

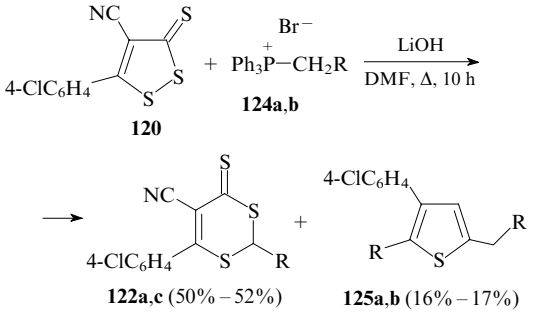
The possibility of insertion of a carbon-containing particle has been demonstrated by the reaction of 1,2-dithiole-3-thione **120** with phosphonium ylides.[43] After treatment of thione **120** with phosphonium salts **121a**,**b** in the presence of lithium hydroxide in dimethylformamide, 1,3-dithiin-4-thiones **122a**,**b** have been isolated as the major product and thienothiopyranones **123a**,**b** were the minor product.



120 **121a**,**b** **122a**,**b** (43% – 47%) **123a**,**b** (18% – 21%)

n = 0, R = H (**a**); n = 1, R = Me (**b**)

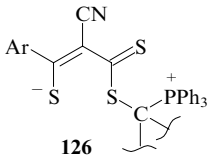
An analogous reaction has been performed for phosphonium salts **124a**,**b**. In this case also, the reaction mainly affords 1,3-dithiins **122a**,**c** together with thiophene derivatives **125**.[43]



120 **124a**,**b** **122a**,**c** (50% – 52%) **125a**,**b** (16% – 17%)

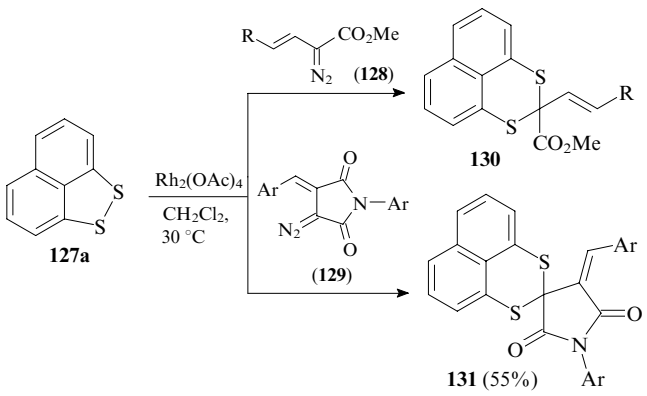
R = H (**122c**, **124a**, **125a**), Me (**122a**, **124b**, **125b**)

Complicated mechanisms of these transformations were reported.[43] The authors believe that all transformations begin with formation of zwitterionic intermediates **126**.



126

The insertion of the carbon residue into the 1,2-dithiole moiety has also been described for naphtho[1,8-*cd*]-1,2-dithiole (**127a**), which can be formally considered a derivative of 1,2-dithiol-3-ylidenes **4**.[44] This compound reacts with vinyldiazo compounds **128** or diazosuccinimide **129** in the



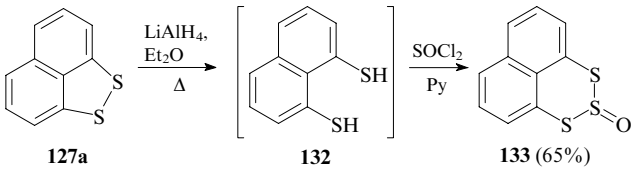
127a

R = CO_2Me (96%), $C_6H_4NO_2$-4 (67%); Ar = C_6H_4Me-4

presence of rhodium acetate as the catalyst. Conjugated 1,3-dithiins **130** and **131** form in moderate to high yields.

b. Insertion of the sulfur atom

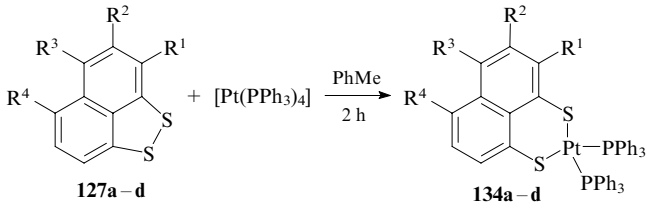
The S=O fragment is formally inserted into the 1,2-dithiole molecule in the course of reduction of naphtho[1,8-*cd*]-1,2-dithiole (**127a**) with lithium aluminium hydride. First, dithiole **132**, which is unstable in air, is formed, and it is reacted with thionyl chloride in the presence of pyridine.[45] The resulting trisulfide 2-oxide **133** can be stored without decomposition for several months in a refrigerator.



127a **132** **133** (65%)

c. Insertion of metals

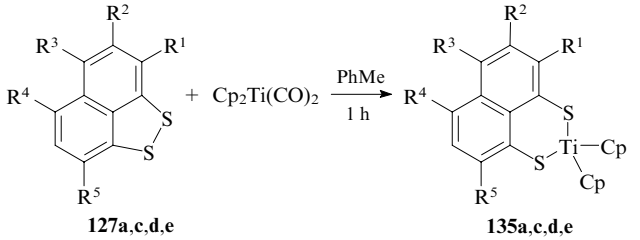
In recent years, transition metal complexes that are inserted between two sulfur atoms have attracted increasing attention of researchers. Among the most promising initial compounds for their synthesis are 1,2-dithiol-3-ylidenes, first of all naphtho[1,8-*cd*]-1,2-dithiole derivatives (**127a**). Naphthalene-, *tert*-butylnaphthalene-, acenaphthylene- and phenanthrenedithiolate platinum complexes **134a**–**d** have been synthesized by oxidative condensation of corresponding 1,2-dithioles **127a**–**d** with a Pt^0 complex in toluene at room temperature.[46] The yields of the products are mainly high.



127a–**d** **134a**–**d**

$R^1 = R^2 = R^3 = R^4 = H$ (**a**, 92%);
$R^1 = Bu^t$, $R^2 = R^3 = R^4 = H$ (**b**, 76%);
$R^1 = R^2 = H$, $R^3–R^4 = CH_2—CH_2$ (**c**, 94%);
$R^1 = R^4 = H$, $R^2–R^3 = CH=CH—CH=CH$ (**d**, 80%)

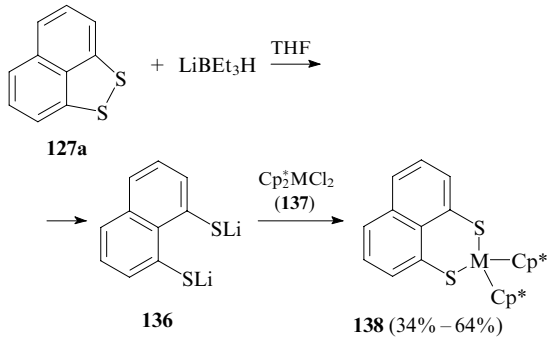
Bis(cyclopentadienyl) titanocene complexes of naphthalene-1,8-dithiolates **135** have been synthesized analogously.[47] However, the yields of these compounds are not always high.



127a,**c**,**d**,**e** **135a**,**c**,**d**,**e**

$R^1 = R^2 = R^3 = R^4 = R^5 = H$ (**a**, 55%);
$R^1 = R^2 = R^5 = H$, $R^3–R^4 = CH_2—CH_2$ (**c**, 80%);
$R^1 = R^4 = R^5 = H$, $R^2–R^3 = CH=CH—CH=CH$ (**d**, 19%)
$R^1 = R^5 = Bu^t$, $R^2 = R^3 = R^4 = H$ (**e**, 21%);
Cp is cyclopentadienyl

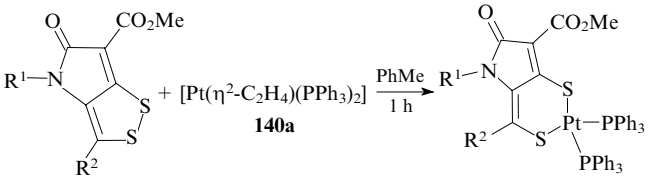
Another method of synthesis of Group IV metal dithiolate complexes is the reduction of 1,2-dithiole **127a** with the lithium triethylhydridoborate $LiBEt_3H$. First, dilithium salt of 1,2-dithiole **136** is formed, which reacts with bis(pentamethyl)metallocene dichlorides **137** in tetrahydrofuran at room temperature to give the corresponding titanium, zirconium and hafnium complexes **138**.[48]



127a **136** **138** (34%–64%)

M = Ti, Zr, Hf; Cp* is pentamethylcyclopentadienyl

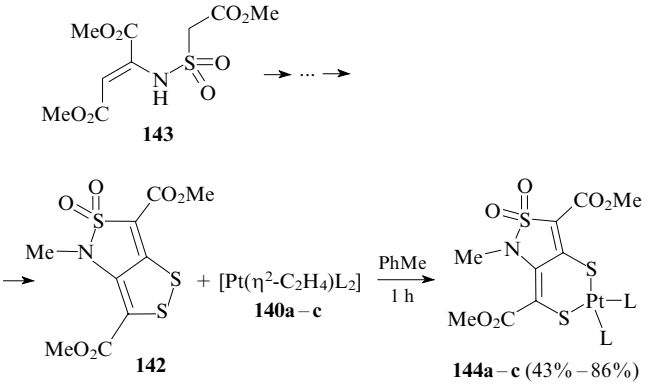
Bicyclic 1,2-dithiol-3-ylidenes **139** have been used for synthesizing platinum dithiolate complexes.[49] Mixing these compounds with platinum(0) complex **140a** in toluene at room temperature readily affords moderate yields of dithiolate complexes **141**.



139 **140a** **141** (64%–67%)

R^1 = H, Ph; R^2 = Ph, CO_2Me

Analogous insertion of the platinum atom also occurs in the reaction of complexes **140a**–**c** with 4*H*-1,2-dithiolo[4,3-*c*]isothiazole 1-dioxide **142**, synthesized from sulfonylaminobut-2-enedioate **143**.[50] The reaction affords dithiolate complexes **144a**–**c**.



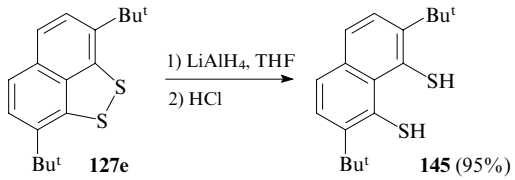
144a–**c** (43%–86%)

L = PPh_3 (**a**), 2 L = dppf (**b**), (*R*,*R*)-diop (**c**);
dppf is 1,1′-bis(diphenylphosphino)ferrocene;
diop is bis[(diphenylphosphino)methyl]-2,2-dimethyl-1,3-dioxolane

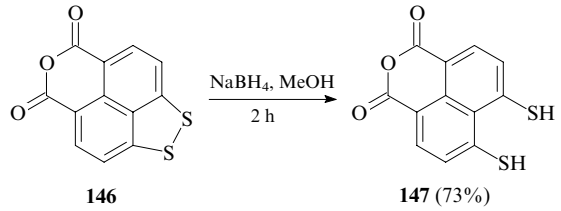
IV. 1,2-Dithiole ring opening reactions

Reduction reactions are used most frequently for opening the 1,2-dithiole ring with formation of dithiols. These reactions were partially considered in the previous section dealing with the description of insertion of organic and inorganic fragments into the dithiole ring. As a rule, 1,2-dithiols are readily oxidized by air oxygen; therefore, they are not isolated and are used *in situ* in further transformations. However, in some cases, such compounds can be obtained in the individual form.

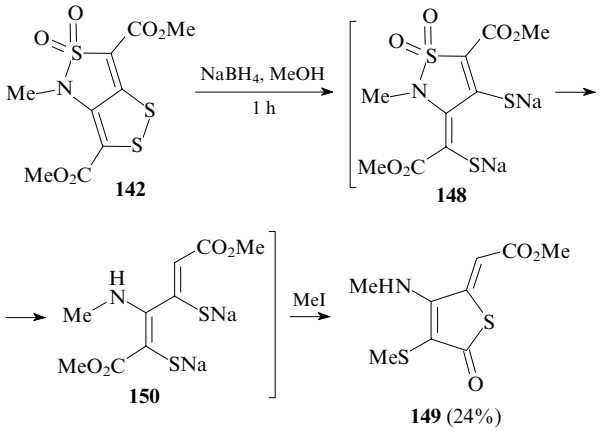
The reduction of 3,8-di(*tert*-butyl)naphtho[1,8-*cd*]-1,2-dithiole (**127e**) with lithium aluminium hydride in tetrahydrofuran followed by the treatment with hydrochloric acid affords dithiol **145** in high yield.[51] It is likely that the moderate stability of two sulfanyl groups to air oxygen is caused by the steric effect of *tert*-butyl groups.



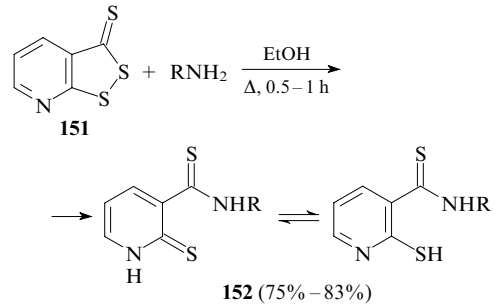
To reduce 5*H*,7*H*-1,2-benzodithiolo[5,4,3-*def*]isochromene-5,7-dione (**146**) containing more reactive ester groups, sodium borohydride in methanol is used.[51] The yield of disulfanyl derivative **147** in this case is considerably lower.



The reduction of bicyclic 1,2,-dithiol-3-ylidene **142** with sodium borohydride is more profound and involves not only the 1,2-dithiole ring but also the isothiazole ring.[50] Although the authors suggest the formation of salt **148** as an intermediate product, we believe that the precursor of thiophenone **149,** the only product isolated upon treatment with methyl iodide, is quite a different salt, presumably having structure **150**.

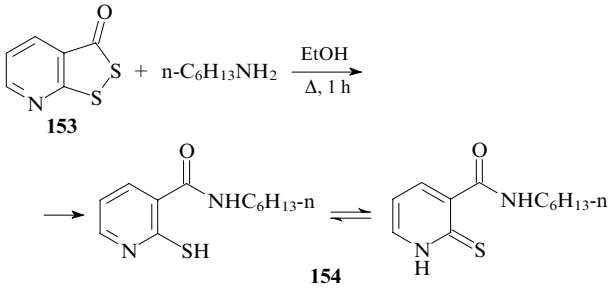


Another method of 1,2-dithiole ring opening is the reaction of 1,2-dithioles with amines. It was noted in Section III.1.d that the reaction of fused 1,2-dithiole-3-thione with amines followed by the treatment of the reaction mixture with iodine occurs with ring transformation of 1,2-dithiole into isothiazole. However, if the oxidant is not used at the last stage, the reaction yields the product containing thiol and carbothioamide groups in the *ortho* position. In particular, the reaction of 3*H*-1,2-dithiolo[3,4-*b*]pyridine-3-thione (**151**) with aliphatic amines in ethanol gives high yields of 2-thioxo-1,2-dihydropyridine-3-thiocarboxamide **152**, which exist in tautomeric equilibrium with corresponding 2-thioxothionicotinamides.[52, 53] The form in which the sulfur atom is eliminated has not been reported.

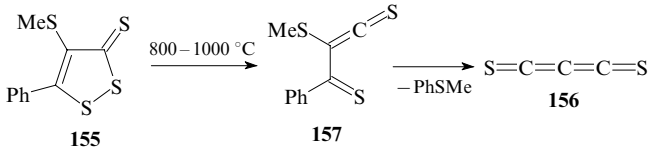


R = Me, Et, CH_2CH_2OH, n-C_5H_{11}, *etc.*

The reaction of 3*H*-1,2-dithiolo[3,4-*b*]pyridin-3-one (**153**) with hexylamine under the same conditions exemplifies that fused 1,2-dithiol-3-ones can also be involved in this transformation.[52] The yield of product **154** has not been reported.

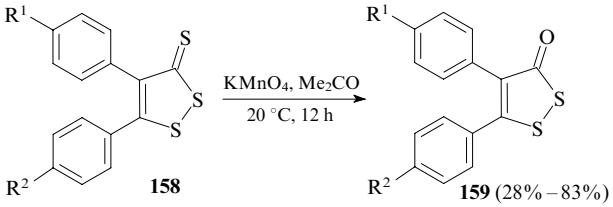


1,2-Dithiole-3-thione **155** was subjected to vacuum flash pyrolysis at 800 – 1000 °C.[54] The major product characterized in an argon matrix at 10 K was allene-1,3-dithione **156**. The author suggested the mechanism of formation of this compound involving the initial generation of thioacylthioketene **157** followed by transfer of the phenyl substituent to the sulfur atom of the thiomethyl group and elimination of thioanisole.



V. Oxidation of 1,2-dithioles

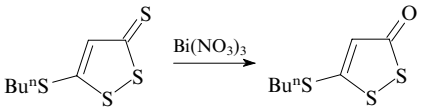
Oxidation of 1,2-dithiole-3-thiones and 1,2-dithiol-3-ones, -3-ylidenes and -3-imines leads, as a rule, to 1-*S*-oxides. In rare cases (for example, in 1,2-dithiole-3-thiones) when potassium permanganate is used, the thione group is converted into the ketone one. In particular, the reaction of 4,5-diaryl-1,2-dithiole-3-thiones **158** with $KMnO_4$ in acetone at room temperature affords dithiolones **159**.[55]



158 **159** (28% – 83%)

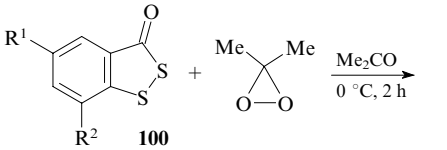
R^1 = H, R^2 = SO_2Me; R^1 = Me, R^2 = Cl; R^1 = Cl, R^2 = Me; R^1 = R^2 = OMe; R^1 = SO_2Me, R^2 = H

Bismuth nitrate was also tested as the oxidant for 5-butylthio-1,2-dithiole-3-thione (**52a**);[56] however, the yield of target dithiolone **160** turned out to be low. Therefore, other methods were used for conversion of the thione group into the ketone one (see below).

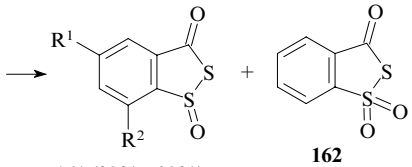


52a **160** (30%)

Various reagents are used to oxidize 1,2-dithioles to 1-*S*-oxides. The most frequently used reagent is dimethyldioxirane (DMDO), despite the fact that it should be prepared *in situ*. 1,2-Dithiol-3-ones fused with benzene ring **100** are oxidized with DMDO in acetone at 0 °C to give *S*-oxides **161** in low yields.[57]



100

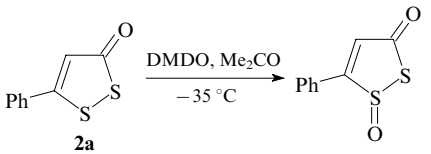


161 (20% – 30%) **162**

R^1, R^2 = H, Cl, Me, OMe

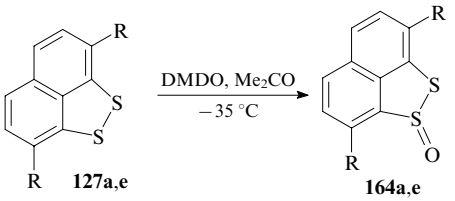
When unsubstituted compound **100** (R^1 = R^2 = H) reacts with DMDO at room temperature, mono-*S*-oxide **161** (R^1 = R^2 = H) cannot be isolated from a mixture with 1,1-dioxide **162**.[58]

In the case of non-fused 1,2-dithiol-3-ones, as shown by the example of 5-phenyl-1,2-dithiol-3-one (**2a**), high yields of *S*-oxide **163** can be achieved if the reaction is carried out at low temperature (−35 °C).[59]



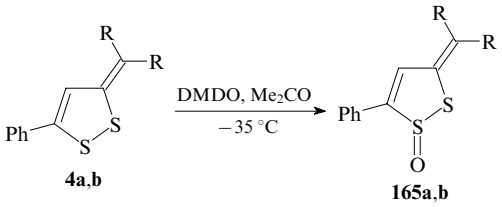
2a **163** (92%)

1,2-Dithiol-3-ylidenes are also oxidized to *S*-oxides at low temperatures. Under these conditions, derivatives **127a**,**e** annelated with the naphthalene ring form *S*-oxides **164a**,**e** in moderate yields,[60] whereas the reaction of monocyclic 1,2-dithiol-3-ylidenes **4a**,**b** affords compounds **165a**,**b** in high yields.[59]



127a,**e** **164a**,**e**

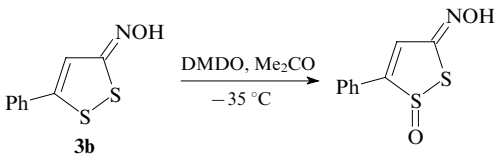
R = H (**a**, 68%), Bu^t (**e**, 72%)



4a,**b** **165a**,**b**

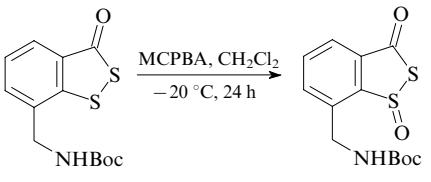
R = CO_2Et (**a**, 87%), CN (**b**, 90%)

It is noteworthy that DMDO is a very mild oxidant so that it can oxidize the dithiole ring in oxime **3b**, not affecting the oxidation-sensitive oxime group.[59]



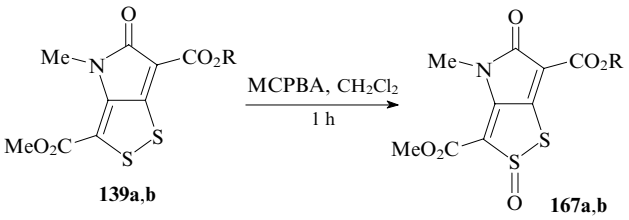
3b (90%)

Another oxidant, more available than DMDO, is *meta*-chloroperoxybenzoic acid (MCPBA). The latter is also used for preparing 1,2-dithiol-3-one 1-*S*-oxides (for example, compounds **166**)[61] and 1,2-dithiol-3-ylidene 1-*S*-oxides (**167**).[62] In the former case, the reaction should be carried out at low temperature (−20 °C) in order to avoid side reactions, whereas in the latter case, it suffices to cool the reaction mixture with ordinary ice. The yields of the products obtained with the use of this oxidant are generally lower than those provided by oxidation with DMDO.



100e **166** (60%)

Boc is *tert*-butyloxycarbonyl

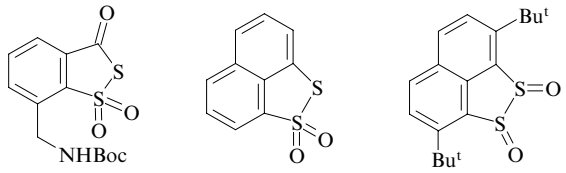


139a,b **167a,b**

R = Me (**a**, 30%), Et (**b**, 35%)

However, comparison of the yields of products **164a,e** obtained with the use of both reagents demonstrates that MCPBA leads to better results (99% and 80%, respectively) than DMDO (68% and 72%, respectively; see above).[60]

In some cases, the use of an excess of DMDO or MCPBA makes it possible to oxidize the 1,2-dithiole ring to the thiosulfonate one, leading, for example, to compounds **162** ($R^1 = R^2 = H$), **168**, **169**.[58,60,61] Quite unexpectedly, the oxidation of di-*tert*-butyl derivative **127e** leads to vicinal, rather than to thiosulfonate, disulfoxide **170**.[60]

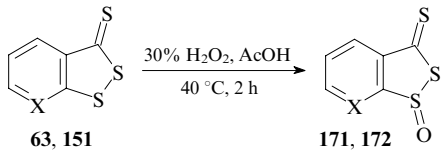


168 **169** **170**

The yields of *S,S*-dioxides obtained from corresponding 1,2-dithioles with the used of these oxidants are listed below.

Reagent	Yield (%)			
	162	**168**	**169**	**170**
DMDO	100	–	95	80
MCPBA	–	80	85	92

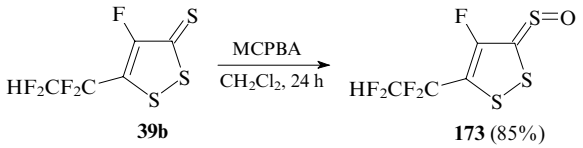
Peracetic acid is used much more rarely.[63] However, it can selectively oxidize the sulfur atom of the dithiole ring in benzo- (**63**) and pyrido-1,2-dithiole-3-thiones (**151**), the thione group remaining intact. The yield of benzodithiole *S*-oxide **171** is rather high (86%), whereas pyridodithiole *S*-oxide **172** is synthesized in 20% yield.



63, **151** **171**, **172**

X = CH (**63**, **171**), N (**151**, **172**)

The oxidation of fluorinated 1,2-dithiole-3-thione **39b** with MCPBA in methylene chloride affording product **173** has been described.[64] The authors assign it the structure of *S*-oxide at the exocyclic sulfur atom. However, the structure of this compound cannot be deemed as rigorously proven since the original work lacks detailed analysis of spectral data.

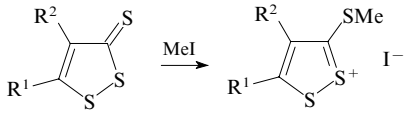


39b **173** (85%)

VI. Reactions of substituents in the 3-position of the 1,2-dithiole ring

1. Synthesis of 1,2-dithiolium salts from 1,2-dithiole-3-thiones and their reactions

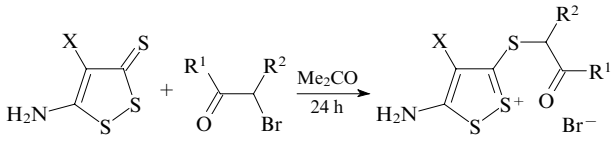
There are two basic methods of formation of 1,2-dithiolium salts from 1,2-dithiole-3-thiones: alkylation with alkyl iodides and chlorination. Monocyclic 1,2-dithiole-3-thiones react with alkyl or benzyl iodide at room temperature. For example, the reaction with methyl iodide is carried out in acetone,[65,66] benzene[67] or dimethylformamide.[68] 1,2-Dithiole-3-thiones containing ferrocenyl[65] and aryl substituents,[66,67] as well as functional groups (nitrile, ester and carboxamide groups), can enter the reaction.[68] The yields of salts **174** in these reactions are, as a rule, high (70% – 90%), although the product with the carboxamide functionality has been obtained in low yield (17%).



174

R^1, R^2 = H, Ar, Fc, NH_2, CO_2Et, CN, $C(O)NH_2$

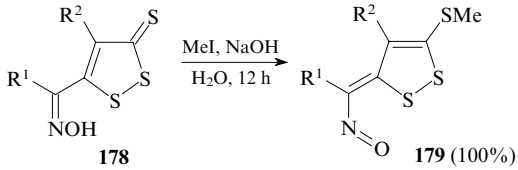
Bromo derivatives activated with the α-carbonyl group are more rarely used for alkylation.[69] In particular, 5-amino-1,2-dithiole-3-thiones **175a,b** containing electron-withdrawing substituents in the heterocycle react with bromides **176** to form salts **177** in low yields.



175a,b **176** **177** (27% – 47%)

X = CO_2Et (**175a**), CN (**175b**); R^1 = Ph, C_6H_4OMe-4; R^2 = H, Ph

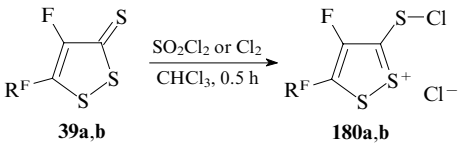
The reaction of 5-(hydroxyiminoalkyl)-1,2-dithiole-3-thiones **178** with methyl iodide in water in the presence of sodium hydroxide results not only in the alkylation of the exocyclic sulfur atom but also in the rearrangement of bonds in the 1,2-dithiole ring and oxime group. As a result, nitroso derivatives **179** are produced in quantitative yield. These compounds can be treated as heteropentalenes owing to the interaction between the oxygen atom of the nitroso group and the sulfur atom of the heterocycle.[70]



178 **179** (100%)

R^1 = H, Me, Et, Ph; R^2 = H, Me, Et, Bn, Ph, OMe

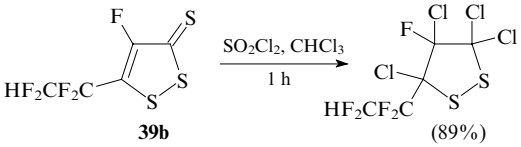
The reactions of fluorinated 1,2-dithiole-3-thiones **39a**,**b** with chlorinating agents (molecular chlorine or sulfuryl chloride) afford, as stated in Refs 64 and 71, the products of chlorination of the exocyclic sulfur atom **180a**,**b**. As a rule, these compounds are used *in situ* for reactions. However, in one case, product **180b** was isolated as an individual compound and was characterized by spectral methods.



39a,**b** **180a**,**b**

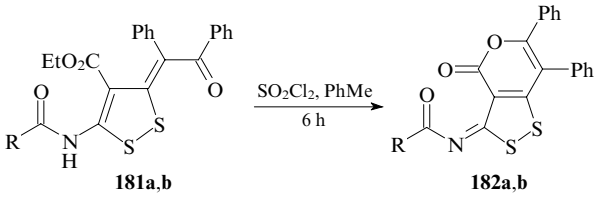
R^F = CF_3 (**a**), CF_2CF_2H (**b**)

If fluorinated 1,2-dithiole-3-thione **39b** reacts with an excess of the chlorinating agent (SO_2Cl_2), two chlorine atoms are substituted for the thione group and the double bond of the 1,2-dithiole ring is also halogenated.[64]



39b (89%)

The reactions of 1,2-dithiol-3-ylidenes (for example, **181a**,**b**) with thionyl chloride follow a different scenario [69] and produce bicyclic lactones **182a**,**b** in high yields.

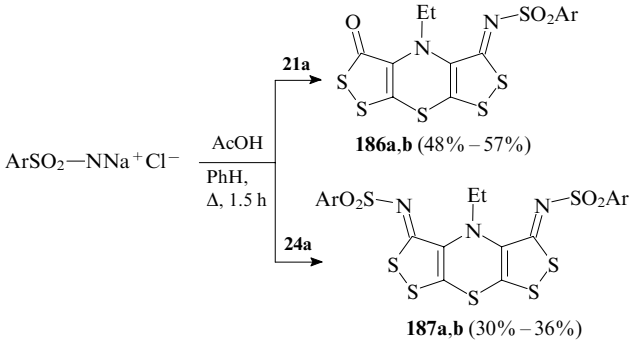


181a,**b** **182a**,**b**

R = Me (**a**, 71%), Bu^t (**b**, 94%)

1,2-Dithiolium salt **180b** obtained *in situ* was introduced into the reactions with amines or their trimethylsilyl derivatives.[71] The reactions afforded good yields of 1,2-dithiol-3-imines **183** (Scheme 6). In the case of trimethylsilyldiethylamine, an analogous reaction gives dithiole immonium salt **184** in high yield. It is assumed that the process occurs through the formation of intermediate salt **185**, from which the sulfur atom is eliminated.

1,2-Dithiol-3-imines can be formed from 1,2-dithiole-3-thiones by the reaction of the latter with chloramines B and T. It has been demonstrated that the reaction of tricyclic dithiolethiones **21a** and **24a** with these reagents in benzene in the presence of acetic acid yields mono- (**186a**,**b**) and bisimines (**187a**,**b**).[72] It is worth noting that the use of Lewis acid (scandium triflate) instead of acetic acid considerably promotes the process and increases the yields of the products. In particular, the reaction of **21a** with chloramines B and T in the presence of 50 mol.% scandium triflate in methylene chloride at room temperature for 5–15 min affords imines **186a**,**b** in 73% and 89% yield, respectively.

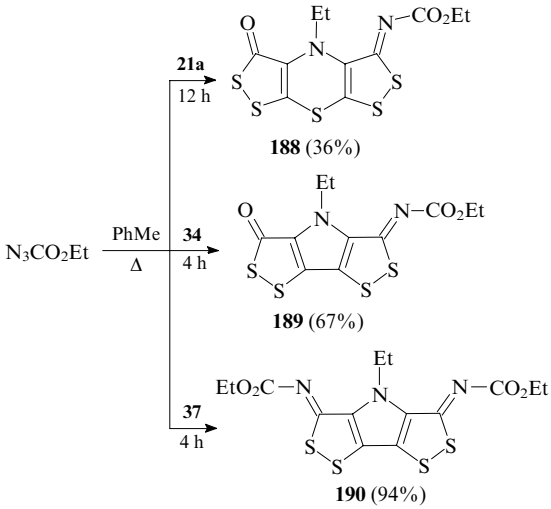


186,**b** (48%–57%)

187a,**b** (30%–36%)

186, **187**: Ar = Ph (**a**), 4-MeC_6H_4 (**b**)

Other reagents that favour the conversion of 1,2-dithiole-3-thiones into 1,2-dithiol-3-imines are azides. However, among the azides studied,[25] only ethoxycarbonyl azide gives stable imines in the reaction with fused 1,2-dithiole-3-thiones **21a**, **34** and **37**. The reaction is carried out in boiling toluene, and the yields of imines **188**–**190** vary from low to nearly quantitative.



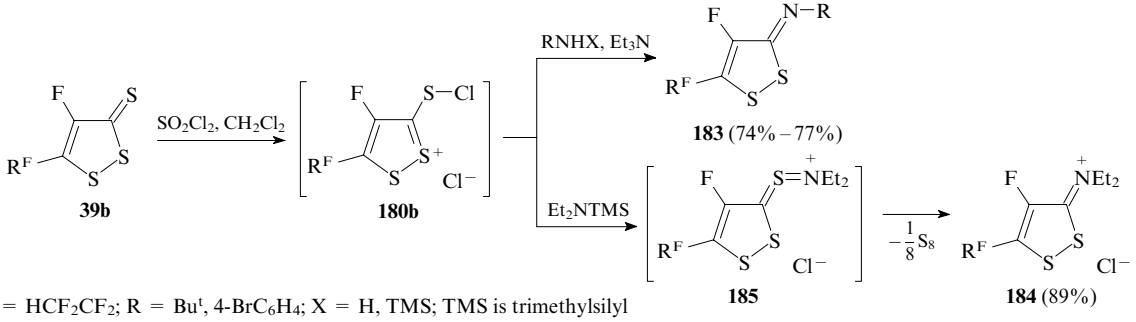
188 (36%)

189 (67%)

190 (94%)

The mechanism of formation of imines **188**–**190** can be presented as 1,3-dipolar cycloaddition of the azide group to

Scheme 6

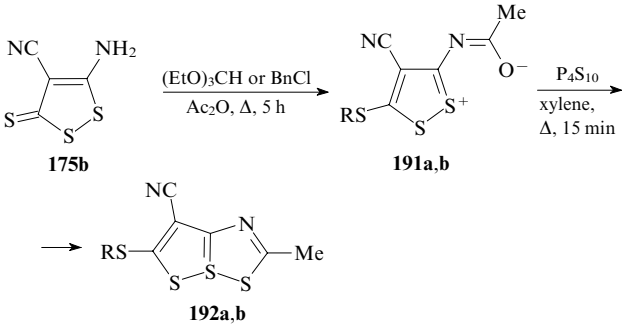


39b **180b** **183** (74%–77%) **185** **184** (89%)

R^F = HCF_2CF_2; R = Bu^t, 4-BrC_6H_4; X = H, TMS; TMS is trimethylsilyl

the thione one followed by elimination of the nitrogen molecule. This leads to thiaziridine derivatives, which lose the sulfur atom to give the target products.

The alkylation of 5-amino-3-thioxo-1,2-dithiole-4-carbonitrile (**175b**) with ethyl orthoformate or benzyl chloride in acetic anhydride leads, in addition to the salt structure, to acylation of the primary amino group. This results in inner salts of 1,2-dithiolium **191a**,**b**.[68] Under the action of P_4S_{10} in xylene, they are converted into triazapentalenes **192a**,**b**.

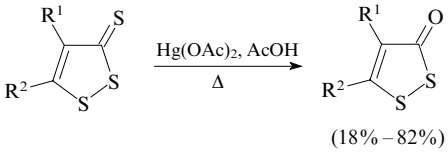


Compound **191**, **192**	R	Yield (%)	
		191	**192**
a	Et	59	17
b	Bn	25	12

2. Synthesis of 1,2-dithiol-3-ones from 1,2-dithiole-3-thiones

It has been noted in Section V that the oxidation of 1,2-dithiole-3-thiones rarely leads to 1,2-dithiol-3-ones, and the yields of target products in such reactions are low. For this transformation, other methods have been developed.

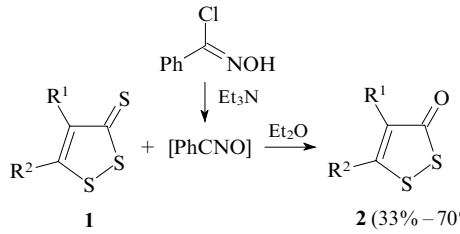
The reaction with mercury acetate, an available and low-cost reagent, is used most frequently; chloroform, acetic acid or their mixtures are used as solvents. As followed from analysis of literature data, the basic criterion for choosing the solvent is the solubility of 1,2-dithiole-3-thione and mercury acetate in it. Recently, monocyclic 1,2-dithiole-3-thiones with almost any substituents have been most frequently studied as substrates, and the reaction have been carried out on heating in acetic acid.[56, 64, 73, 74] Unfortunately, the yields of the products vary within wide limits (from 18% to 82%) so that the attempts to trace their dependence on the nature of substituents in the 4- and 5-positions of the heterocycle are unsuccessful.



R^1, R^2 = H, Alk, Ar, F, HCF_2CF_2, Cl, CO_2Me, *etc.*

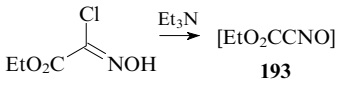
The reaction of 1,2-dithiole-3-thiones with nitrile oxides is considered a more versatile method. As is known, nitrile oxides are unstable compounds easily dimerizing into 1,2,5-oxadiazole 1-oxides (furoxans). Nitrile oxides are synthesized *in situ* by the reaction of hydroxamic acid chlorides with triethylamine. Both the commercially available aliphatic acid chloride — ethylchloroximidoacetate[75] — and the easily synthesized phenylhydroxamic acid chloride[65, 76] are used for this purpose.

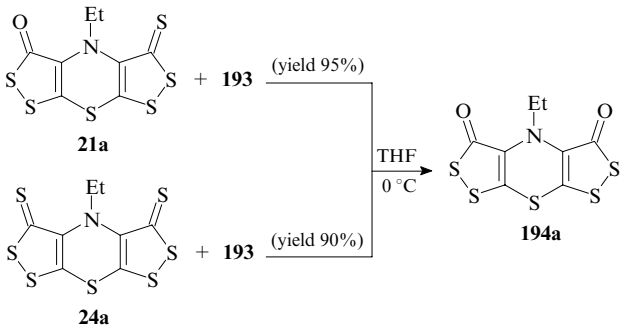
In particular, phenylnitrile oxide converts different monocyclic 1,2-dithiole-3-thiones **1** into corresponding oxides **2** in moderate yields.[77]



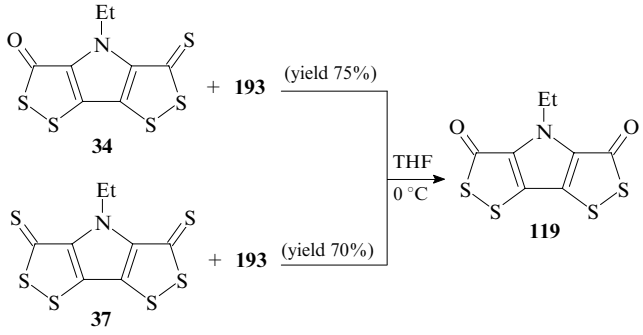
R^1 = H, OH, morpholino, Fc; R^2 = H, Me, Ph, Fc

At the same time, for the reactions of annelated mono- (**21a**, **34**) and dithiones (**24a**, **37**), ethoxycarbonylnitrile oxide (**193**) is used; in these cases, the reaction readily affords products **194a** and **119**, respectively.[75]



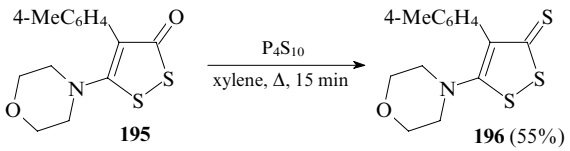


It is worth noting that, for comparison, the authors[75] carried out the reaction of dithiolethione **37** with mercury acetate in a methylene chloride – acetic acid mixture; the yield of dioxide **119** (35%) turned out to be considerably lower than in the case of nitrile oxide.



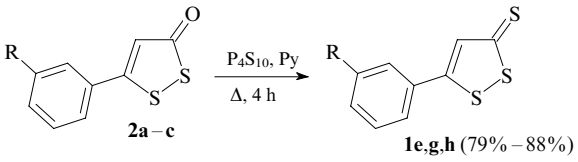
3. Conversion of 1,2-dithiol-3-ones into 1,2-dithiole-3-thiones

A basic method of this conversion is to reflux substrates with P_4S_{10} in different solvents: xylene,[76] toluene[77] and pyridine.[66] For example, 5-morpholino-4-*p*-tolyl-1,2-dithiol-3-one (**195**) is converted into thione **196** within a short time in moderate yield.[76]



195 **196** (55%)

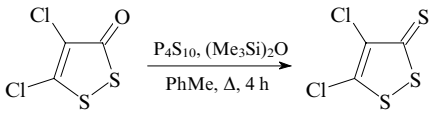
The highest yields of the products have been achieved in the reaction carried out in pyridine, which is likely caused by the absence of functional substituents in initial 5-aryl-1,2-dithiol-3-ones **2a**–**c**.[66]



2a–**c** **1e**,**g**,**h** (79%–88%)

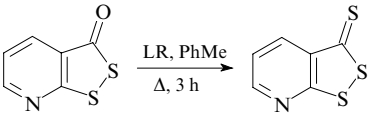
R = H (**2a**, **1e**), Cl (**2b**, **1g**), OMe (**2c**, **1h**)

In the case of 4,5-dichloro-1,2-dithiol-3-one (**197**), the authors used hexamethyldisiloxane, presumably with the aim of achieving milder conditions.

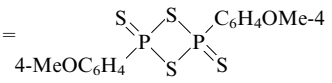


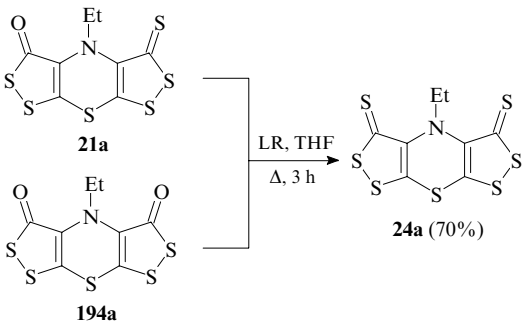
197 **11c** (32%)

For conversion of fused 1,2-dithiol-3-ones, the Lawesson reagent (LR) in toluene[53] or tetrahydrofuran[78] is used. The yields of the corresponding products in these reactions are rather high.[77]



153 **151** (77%)

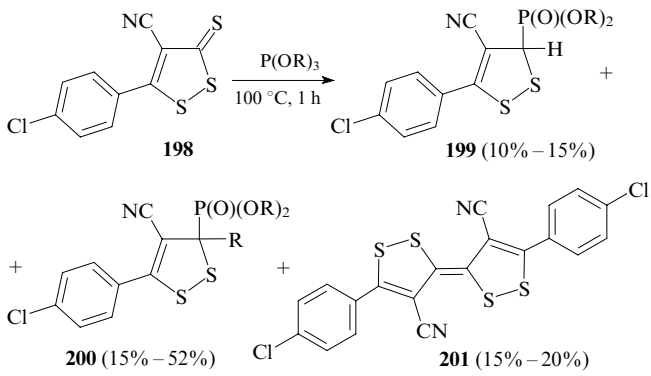
LR = 



21a **194a** **24a** (70%)

4. Reaction of 1,2-dithiole-3-thiones with trialkyl phosphites

It has been shown that 4-cyano-substituted 1,2-dithiole-3-thione **198** reacts with trialkyl phosphites,[79] only the thione group being involved in the reaction. Several compounds have been isolated: two of them (**199** and **200**) are the products of substitution of a phosphorus-containing fragment for the thione group, and the third (**201**) is the product of 1,2-dithiole dimerization.



198 **199** (10%–15%)

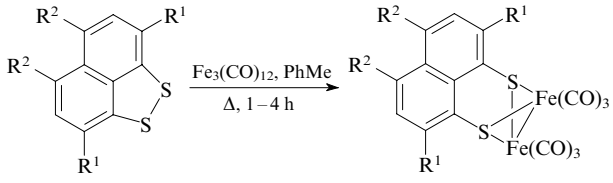
200 (15%–52%) **201** (15%–20%)

R = Me, Et, Pr^i

Complicated mechanisms of formation of these products have been reported;[79] however, no information on how the structures were determined is available.

VII. Formation of 1,2-dithiole complexes with metals

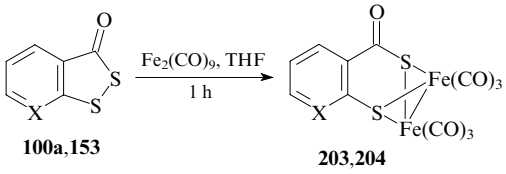
In the last years, interest in 1,2-dithiole complexes with metals has increased. Such complexes can be formed by 1,2-dithiole-3-thiones, 1,2-dithiol-3-ones and 1,2-dithiol-3-ylidenes. Iron dithiolate complexes have been studied in most detail. For example, the reaction of naphthalene-1,8-dithiole derivatives **127a**,**e**,**f**,**g** with $Fe_3(CO)_{12}$ in boiling toluene yields iron complexes **202a**,**e**,**f**,**g**.[80,81]



127a,**e**,**f**,**g** **202a**,**e**,**f**,**g** (24%–56%)

$R^1 = R^2 =$ H (**a**), Cl (**f**); $R^1 =$ Bu^t, $R^2 =$ H (**e**);
$R^1 =$ H, $R^2–R^2 =$ C(O)N(C$_6$H$_4$Me-4)C(O) (**g**)

Fused dithiolones **100a** and **153** react with $Fe_2(CO)_9$ in tetrahydrofuran at room temperature to form complexes **203** and **204**, respectively.[82] It is worth noting that the yields of the latter strongly depend on the nature of the annelated ring.

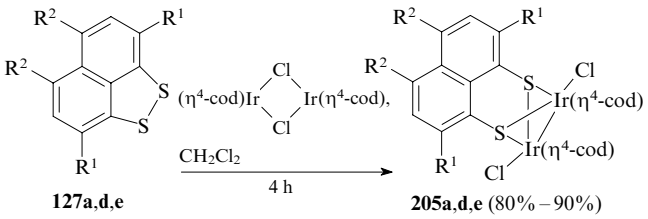


100a,**153** **203**,**204**

X = CH (**100a**, **203**, 78%), N (**153**, **204**, 18%)

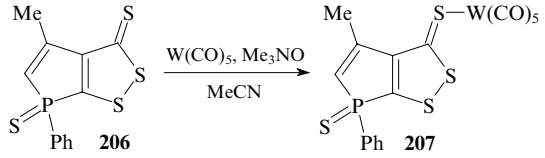
The complexes contain a butterfly-shaped Fe_2S_2 core in which each iron atom is coordinated to two sulfur atoms and is bonded to the other iron atom.

Bimetallic diiridium complexes **205a**,**d**,**e** containing the naphthalene-1,8-dithiole bridge and cyclooctadiene ligands have an analogous structure.[83] These complexes are synthesized in high yields under even milder conditions (in methylene chloride at room temperature).

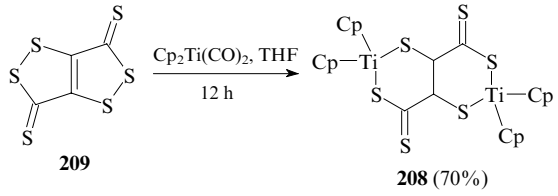


$R^1 = R^2 = H$ (**a**); $R^1 = H$, $R^2–R^2 = CH{=}CH–CH{=}CH$ (**d**); $R^1 = Bu^t$, $R^2 = H$ (**e**); cod is 1,5-cyclooctadiene

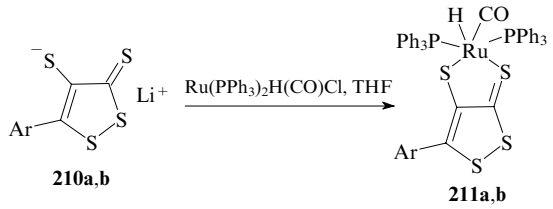
Complexes of other metals have a different structure. In particular, tungsten pentacarbonyl is coordinated to the exocyclic sulfur atom of dithiolethione **206**, while the endocyclic sulfur atoms are not involved in complexation. This fact has been established by single-crystal X-ray diffraction analysis of product **207**.[84]



Titanocene chelate complex **208** has been synthesized by the reaction of 1,2-dithiolo-1,2-dithiole-3,6-dithione **209** with titanocene dicarbonyl in tetrahydrofuran.[85] In this case, one titanium atom bonded to two cyclopentadienyl rings is coordinated to two sulfur atoms of the 1,2-dithiole ring.

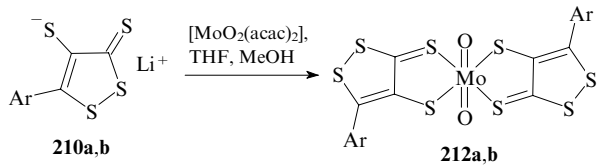


Lithium salts of 4-sulfanyl-1,2-dithiole-3-thiones **210a**,**b** react with ruthenium compounds $Ru(PPh_3)_2H(CO)Cl$ to form complexes **211a**,**b**, in which the ruthenium atom is coordinated to two exocyclic sulfur atoms.[86]



Ar = Ph (**a**, 72%), Mes (**b**, 89%); Mes = 2,4,6-$Me_3C_6H_2$

It should be noted that molybdenum complexes **212a**,**b**, obtained from the same 4-sulfanyl-1,2-dithiole-3-thiones **210a**,**b** and $[MoO_2(acac)_2]$, have a different structure. The molybdenum atom is coordinated to two molecules of the corresponding thione **210**.[86]

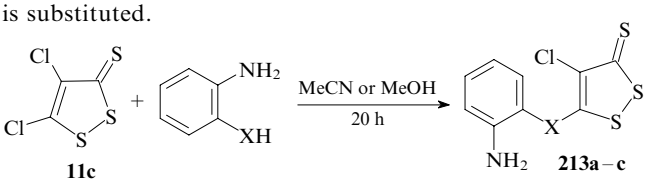


Ar = Ph (**a**, 43%), Mes (**b**, 63%); acac is acetylacetonate

VIII. Reactions of substituents in the 4- and 5-positions of the 1,2-dithiole ring

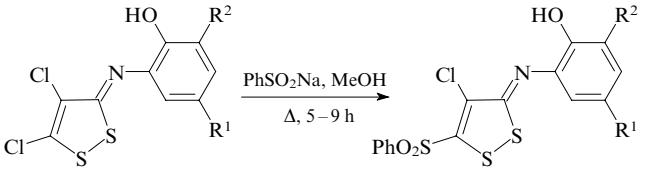
1. Substitution for chlorine atoms

To elucidate the feasibility of formation of bicyclic products containing the 1,2-dithiole ring, the behaviour of 4,5-dichloro-1,2-dithiole-3-thione (**11c**) in the reaction with some nucleophiles — *o*-phenylenediamine, *o*-aminophenol and *o*-aminothiophenol — has been studied.[87] The reaction in acetonitrile or methanol always leads to **213**, in which only one chlorine atom in the 5-position of the dithiole ring is substituted.



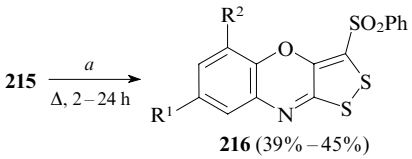
213: X = NH (**a**, 19%), O (**b**, 85%), S (**c**, 86%)

The chlorine atom in the 4-position is insufficiently activated to be substituted under the action of nucleophiles, and a further attack on the sulfur atoms leads to the opening of the heterocycle. To enhance the reactivity of the chlorine atom in the 4-position, *N*-arylimines **214** have been used.[88] It has been shown that the nucleophilic substitution reaction of **214** with sodium phenylsulfinate leads to 4-chloro-1,2-dithiol-3-imines **215** substituted with the phenylsulfonyl group, which has a stronger electron-withdrawing effect than the chlorine atom.



$R^1 = R^2 = H$, Me; $R^1 = Me$, $R^2 = H$

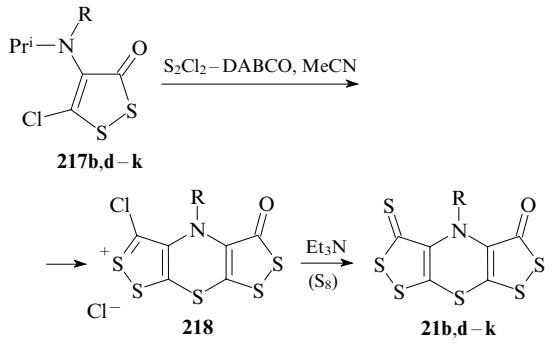
Treatment of compounds **215** with a base (sodium hydride or *N*-ethyldiisopropylamine in tetrahydrofuran, potassium carbonate in acetonitrile) leads to the substitution of the chlorine atom in the 4-position and formation of the previously unknown heterocyclic system — 1,2-dithiolo[4,3-*b*]-1,4-benzoxazines **216** in moderate yields.[87]



$R^1 = R^2 = H$, Me; $R^1 = Me$, $R^2 = H$;
(*a*) NaH, THF; or $EtNPr^i_2$, THF; or K_2CO_3, MeCN

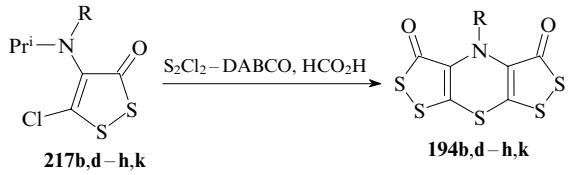
Thus, this is the first example of substitution for the chlorine atom in the 4-position of the 1,2-dithiole ring.

4-Dialkylamino-5-chloro-1,2-dithiol-3-ones **217b**,**d**–**k** have been introduced into the reaction with sulfur monochloride.[89] The reaction in acetonitrile (rarely used in reactions with S_2Cl_2) followed by the treatment with triethylamine affords tricyclic bis(dithiolo)thiazineketothiones **21** in moderate to high yields.



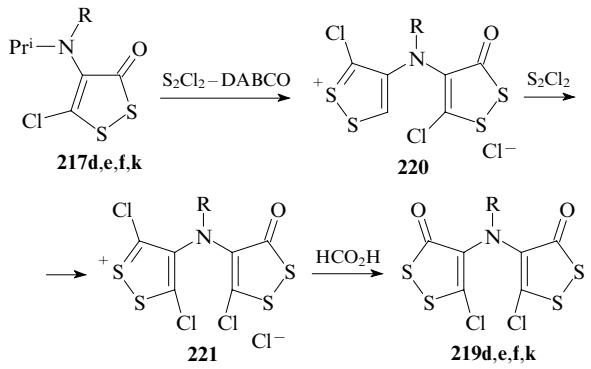
R = CH_2CH_2Cl (**b**, 40%), CH_2CH_2Phth (**d**, 68%), $CH_2CH_2N_3$ (**e**, 65%), $CH_2CH_2CO_2Et$ (**f**, 73%), CH_2CH_2SPh (**g**, 54%), CH_2CH_2CN (**h**, 49%), $CH_2CH_2SO_2Ph$ (**i**, 44%), $CH_2CH_2CO_2H$ (**j**, 78%), Bn (**k**, 62%); DABCO is 1,4-diazabicyclo[2.2.2]octane

3-Chlorodithiolium salt **218** has been suggested as a key intermediate compound in these reactions. The latter is converted into thione **21** by the reaction with sulfur-containing nucleophilic moieties formed from a base (triethylamine) and molecular sulfur (S_8) released in the course of the reaction with S_2Cl_2.[75] The authors suggest that the use of an oxygen-containing compound (*e.g.*, formic acid) instead of a sulfur-containing nucleophile should lead to diketones **194**. Indeed, the reaction of dithiolones **217b,d–h,k** with S_2Cl_2 and diazabicyclooctane in acetonitrile followed by the treatment with formic acid leads to diketones **194b,d–h,k** in moderate yields.



R = CH_2CH_2Cl (**b**, 78%), CH_2CH_2Phth (**d**, 54%), $CH_2CH_2N_3$ (**e**, 58%), $CH_2CH_2CO_2Et$ (**f**, 65%), CH_2CH_2SPh (**g**, 56%), CH_2CH_2CN (**h**, 49%), Bn (**k**, 41%)

Interesting results have been obtained in studying the reaction of chloroketones **217** with S_2Cl_2 and DABCO when the base is in deficiency with respect to sulfur monochloride (the ratio S_2Cl_2 : DABCO = 2 : 1). In all cases, after treatment with formic acid, the reaction affords bis(dithiolyl)amines **219** in moderate yields.[89] It is evident that the 1,4-thiazine ring closure, which occurs in the reaction with DABCO, does not occur at this reactant ratio; rather,

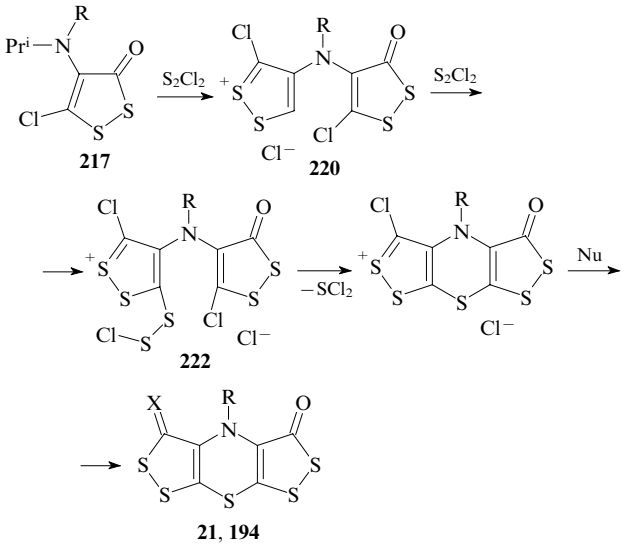


R = CH_2CH_2Phth (**d**, 44%), $CH_2CH_2N_3$ (**e**, 41%), $CH_2CH_2CO_2Et$ (**f**, 51%), Bn (**k**, 46%)

intermediate salt **220** is chlorinated with an excess of S_2Cl_2 to salt **221**. The latter is converted into bis(dithiolyl)amine **219** when treated with an oxygen-containing donor (formic acid).

Novelty of the transformations described in this section is that sulfur atoms are substituted for chlorine atoms in the reactions with an electrophilic sulfur-containing reagent — sulfur monochloride — and its mixtures with tertiary amines. The key stages of this process can be envisioned as the insertion of S_2Cl_2 into the C—H and C—Cl bonds followed by SCl_2 extrusion from intermediate compounds like **222** (Scheme 7), as was suggested for the formation of pentathiepines (see above).[90]

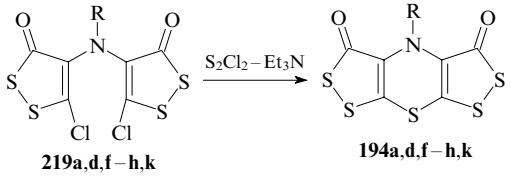
Scheme 7



X = S (**21**), O (**194**); Nu is nucleophile

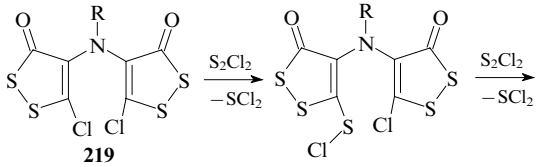
To extend the synthetic possibilities of sulfur monochloride in these reactions, the reaction of bis(dithiolyl)amines **219** with sulfur monochloride and a base has been studied.[89] DABCO turned out to be inert in this reaction, which is not surprising if we take into account the fact that bis(dithiolyl)amines **219** are formed in the presence of this reagent.

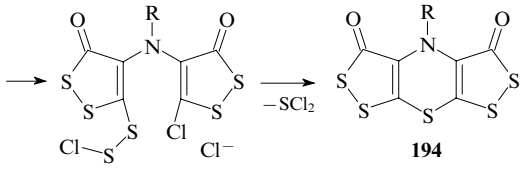
The treatment of compounds **219** with sulfur monochloride in chloroform for three days followed by refluxing the reaction mixture affords tricyclic bis(dithiolo)thiazines **94** in high yields.



R = Et (**a**, 93%), CH_2CH_2Phth (**d**, 95%), $CH_2CH_2CO_2Et$ (**f**, 82%), CH_2CH_2SPh (**g**, 87%), CH_2CH_2CN (**h**, 80%), Bn (**k**, 79%)

The mechanism of this reaction is analogous to that shown in Scheme 7.

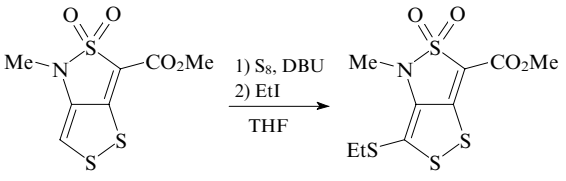




194

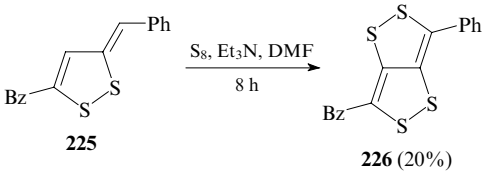
2. Sulfurization of 1,2-dithioles and reactions of sulfur-containing compounds

Bicyclic 1,2-dithiol-3-ylidene **223** reacts with sulfur in the presence of 1,8-bicycloundec-7-ene (DBU) in tetrahydrofuran. The subsequent treatment of the reaction mixture with ethyl iodide affords high yield of stable *S*-ethyl derivative **224**.[50]



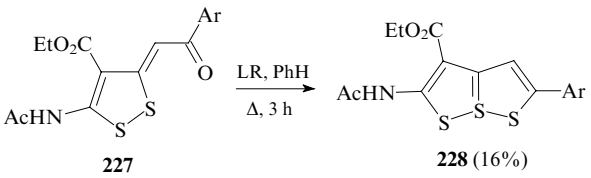
223 **224** (80%)

The reaction of monocyclic 1,2-dithiol-3-ylidene **225** with sulfur and triethylamine in dimethylformamide leads to the closure of the second 1,2-dithiole ring to give compound **226**, even if in low yield.[91]



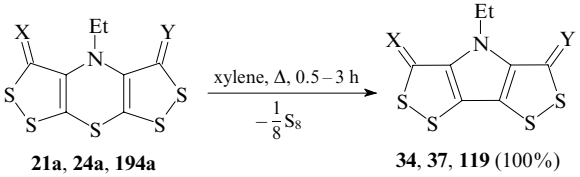
225 **226** (20%)

Thionation of dithiole **227** with the Lawesson reagent in benzene yields trithiapentalene **228**. It is evident that the reaction involves the exchange of the ketone group for the thione one with subsequent closure into the pentalene structure.[69]



227 **228** (16%)

Tricyclic bis(dithiolo)thiazines **21a**, **24a** and **194a** readily lose a sulfur atom on heating in xylene to form bis(dithiolo)pyrroles **34**, **35** and **119**, respectively.[92] Sulfur is isolated as an S_8 molecule. The ease of extrusion depends on the number of thione groups in a tricyclic system. In particular, for complete conversion, dithione **24a** should be heated in xylene for 0.5 h, monothione **21a** should be heated for 1 h, and diketone **194a** requires heating for 3 h.

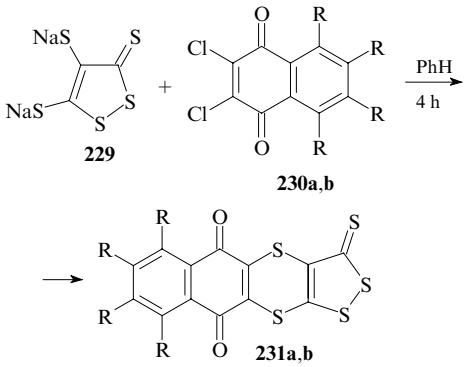


21a, **24a**, **194a** **34**, **37**, **119** (100%)

X = S, Y = O (**21a**, **34**); X = Y = S (**24a**, **37**); X = Y = O (**194a**, **119**)

The disodium salt of 1,2-disulfanyl-1,2-dithiole-3-thione **229** reacts with dichlorobenzoquinones **230a**,**b** in benzene to form tetracyclic 1,4-dithiins **231a**,**b**.[93] The yields of the products are fairly good (Scheme 8).

Scheme 8

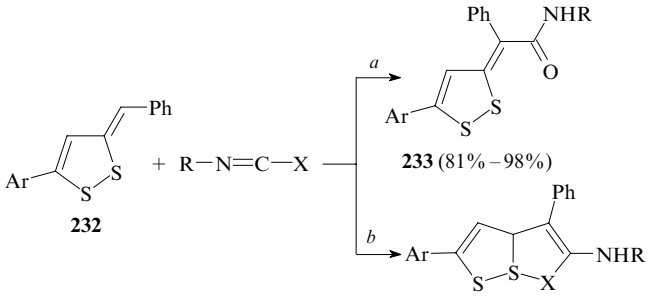


229 **230a**,**b** **231a**,**b**

R = H (**a**, 78%), Cl (**b**, 83%)

3. Reactions of 1,2-dithiol-3-ylidenes with arylisothiocyanates and related compounds

Reactions of 5-aryl-1,2-dithiole-3-phenylidenes **232** with isocyanates (X = O), isothiocyanates (X = S) and isoselenocyanates (X = Se) have been studied.[94] It has been demonstrated that, in all cases, the reaction begins with addition of a cyanate to the ylidene group. Then, at X = O, tautomerization occurs resulting in 1,2-dithiol-3-ylideneacetamides **233**, and at X = S, Se, cyclization into pentalene bicycles **234**, **235** is observed. The yields of the products vary from moderate to high.



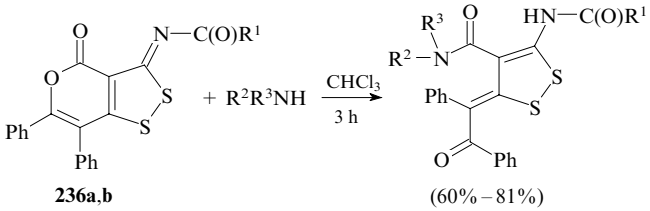
232 **233** (81%–98%)

234: X = S (41%–95%);
235: X = Se (66%–78%)

Ar = Ph, C_6H_4Me-4, C_6H_4Cl-4, Th; R = Bn, C_6H_4Cl-3; X = O, S, Se; (*a*) X = O, 160–200 °C; (*b*) X = S, Se, 220–230 °C

IX. Other reactions

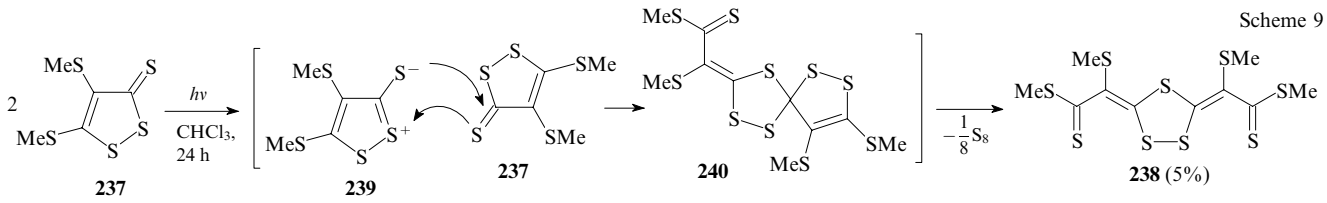
The pyran ring in 1,2-dithiolopyranones **236a**,**b** can be easily opened under the action of basic and nucleophilic reagents.[69] It is noteworthy that, in these transformations, the 1,2-dithiole ring remains intact. In particular, the reaction of compounds **236a**,**b** with primary (n-butylamine)



236a,**b** (60%–81%)

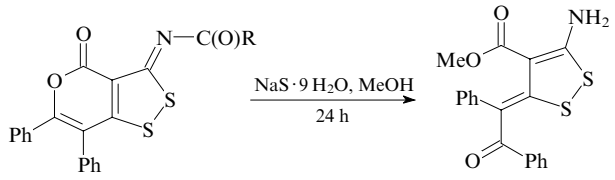
R^1 = Me (**a**), Bu^t (**b**); R^2 = R^3 = Me; R^2 = H, R^3 = Bu^n

Scheme 9



and secondary (dimethylamine) amines in chloroform at room temperature affords the corresponding 1,2-dithiol-3-ylidenes in high yields.

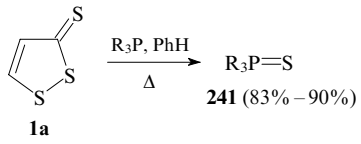
Sodium sulfide in methanol reacts with 1,2-dithiolopyranones **236a**,**b** as a base. In the reaction, the pyran ring is opened under the action of the methoxide ion to form the ester group, and the acyl group at the imine nitrogen atom is saponified.[69]



R = Me (**a**), Bu^t (**b**)

A solution of 4,5-bis(methylthio)-1,2-dithiole-3-thione (**237**) in chloroform has been exposed to UV light for 24 h.[95] Despite the long duration, the conversion is only 20% (80% of the initial compound is returned), and the only isolated product is trithiolane **238** (yield 5%). The authors have suggested the mechanism of this unexpected reaction, involving dimerization of thione **237** in the canonical zwitterionic form **239** resulting in intermediate spiro compound **240**. The latter is then rearranged with extrusion of the sulfur atom to form target product **238** (Scheme 9).

It has been shown that unsubsituted 1,2-dithiole-3-thione (**1a**) is an excellent sulfurizing agent and converts trialkyl- and triarylphosphines into corresponding phosphine sulfides **241** in high yields.[96]



R = Bu^n, C_6H_4X-4 (X = H, Me, Cl, F, OMe)

* * *

In summary, it is worth noting that 1,2-dithioles represent one of the well-studied classes of five-membered sulfur-containing heterocycles. The chemistry of these compounds includes some well-known reactions (for example, 1,3-dipolar cycloaddition of 1,2-dithiole-3-thiones to alkynes). Interest in these compounds is not abated. On the one hand, this is due to the fact that 1,2-dithiol-3-ones often exhibit more diverse biological activity than the corresponding 3-thiones. On the other hand, novel transformation of 1,2-dithioles, including 5-oxo and 5-imino derivatives, have been discovered in recent years. These compounds are considerably less active than 1,2-dithiole-3-thiones, but their reactions involving the exchange of one or two endocyclic sulfur atoms for C- and CN-containing fragments lead to formation of new heterocyclic systems. A small number of examples are known for many transformations of this kind, and the structures of the target compounds have not always been reliably determined. Hence, further studies in this promising area of the chemistry of heterocyclic compounds are necessary.

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