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4-Aryl-2-Imino-1,3-Dithiolanes from the Room Temperature Coupling of Sodium Dithiocarbamates with Sulfonium Salts

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A series of 4-aryl-2-imino-1,3-dithiolanes was synthesized by means of a straightforward strategy starting from readily available precursors: reactions of dithiocarbamates and arylsulfonium salts, at room temperature in water/CH_2Cl_2 as biphasic medium, afforded the five-membered cyclic products in good yields. The reaction mechanism was investigated by DFT calculations.

Introduction

2-Imino-1,3-dithiolanes are five-membered heterocyclic compounds containing two sulfur atoms adjacent to the iminium function, which display interesting activities as insecticides,[1,2] and pharmaceuticals against several diseases.[3–6] Furthermore, this class of molecules has been also incorporated as ligands in metal complexes.[7,8]

Some documented synthetic methods to access 2-imino-1,3-dithiolanes require starting materials difficult to handle due to their physical nature or their toxicity and corrosive character.[9–12] Furthermore, substituted 2-imino-1,3-dithiolanes (or the corresponding iminium cations) have been obtained from dithiocarbamate salts and epoxides in the presence[13] or not[14] of $BF_3 \cdot OEt_2$ as catalyst (Scheme 1A) or from the diiodine-induced cyclization of S-allyl dithiocarbamates (Scheme 1B).[4,15,16] Regioselective [3 + 2]-cycloaddition of 2-aryl/alkylthiiranes with isothiocyanates mediated by Pd catalysts in combination with a phosphine ligand,[17] a boron Lewis acid,[9] or triethylamine in hot DMF[18] has also been used to yield the 2-imino-dithiolane frameworks (Scheme 1C). On the other hand, a more simple strategy employing sodium dithiocarbamates in combination with 1,2-dihaloalkanes as C_2-synthons was reported in several papers,[19–21] however the procedures required the use of reflux conditions and additives such as K_2CO_3, NEt_3, or Br_2 (Scheme 1D). The one-pot synthesis of 2-imino-1,3-dithiolanes starting from allyl chloride, N-alkylamines, and CS_2 was recently described (Scheme 1E).[3]

Here, we report a new reaction leading to the synthesis of a series of unprecedented N-alkyl-4-phenyl-2-imino-1,3-dithiolanes, carried out in dichloromethane/water medium at room temperature, consisting in the assembly of dithiocarbamate salts, as nitrogen and sulfur source,[22,23] with sulfonium reagents $[Me_2SCH(Ar)CH_2Br]Br$ acting as C_2-synthon. This class of sulfonium salts has aroused interest due to the presence of fragments with an enhanced leaving ability, facilitating the functionalization of complex substrates.[24] Inter alia, arylsulfonium bromide salts have been employed as traditional, convenient precursors to aryl-aziridines by combination with amines,[25,26] and in the synthesis of aryl-oxazolidinones under mild conditions.[27]

Results and Discussion

A series of sodium dithiocarbamate salts, Na[**1a–e**], was prepared in almost quantitative yield from the exothermic reaction of carbon disulfide with primary amines in diethyl ether in the presence of sodium hydroxide, Equation 1.[28] The use of an excess of isopropylamine led to the ammonium dithiocarbamate $[NH_3{}^iPr][\mathbf{1b}]$, Equation 2.[29]

$$CS_2 + NH_2R + NaOH \rightarrow Na[S_2CNHR] + H_2O$$
$$R = Me,\ {}^iPr,\ {}^tBu,\ CH_2Ph,\ Cy \quad Na[\mathbf{1a\text{-}e}] \tag{1}$$

$$CS_2 + 2NH_2{}^iPr \rightarrow [{}^iPrNH_3][S_2CNH{}^iPr]$$
$$[NH_3{}^iPr][\mathbf{1b}] \tag{2}$$

The air-stable products Na[**1a–e**] and $[NH_3{}^iPr][\mathbf{1b}]$ were previously described.[30] Yields and reaction conditions for the synthesis of these compounds are reported in Table 1.

The spectroscopic characterization of the compounds, being rather sparse in the literature, has been performed for all the compounds described in the paper and it is detailed in the Experimental section. The IR spectra (solid state) display an absorption assigned to the $\{CS_2\}$ moiety in the range 984–949 cm^{-1},[31] while the thioureide $\{N\text{–}CS_2\}$ carbon-nitrogen bond stretching is observed in the interval 1526–1479 cm^{-1}, suggesting a bond order in between a single (1350–1250 cm^{-1}) and a double one (1690–1640 cm^{-1}).[32,33] Resonances around 210 ppm due to the $\{CS_2\}$ carbon are observed in the ^{13}C NMR spectra (in $CDCl_3$).

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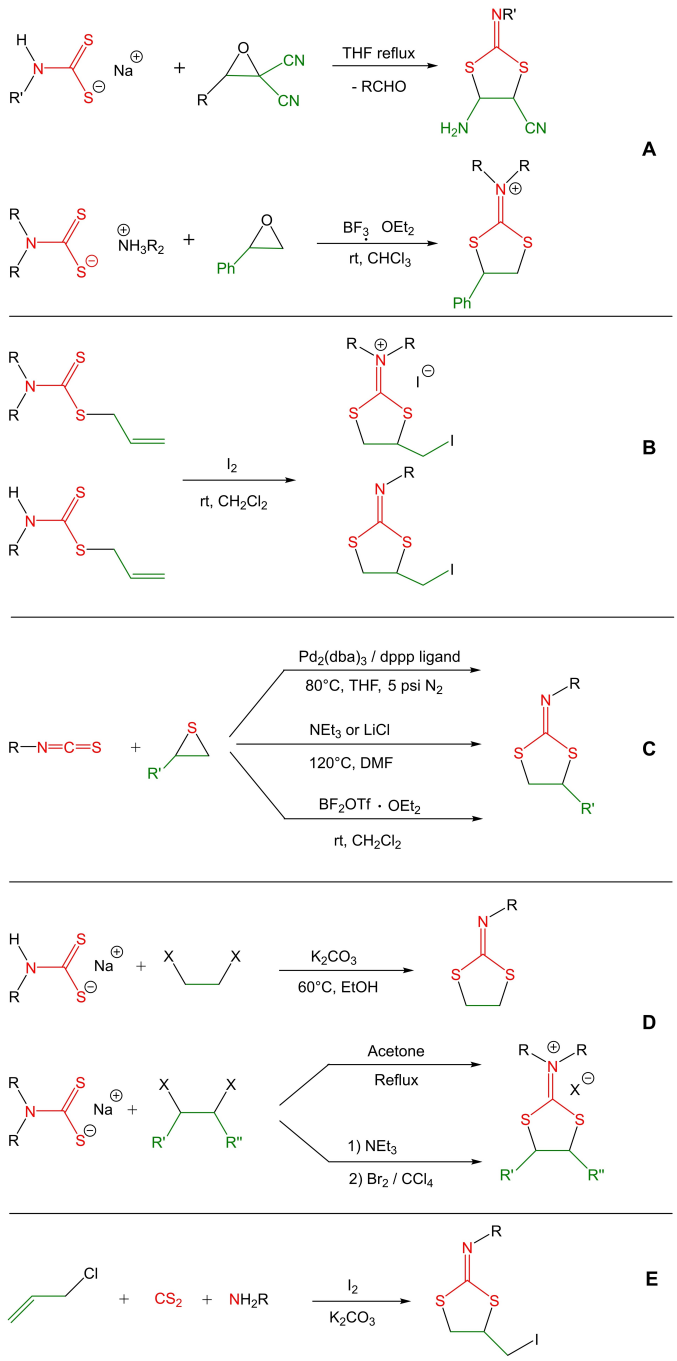
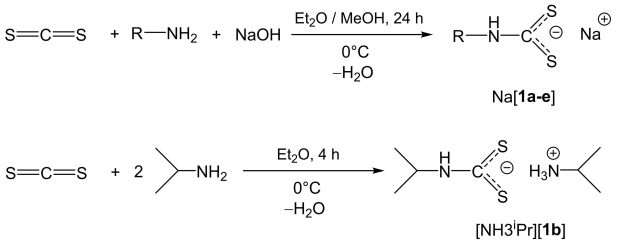


Scheme 1. Preparation routes to 2-imino-1,3-dithiolanes (or to the corresponding iminium cations).

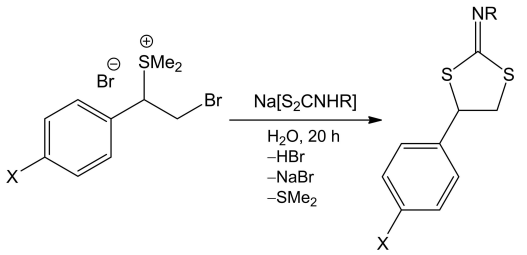
Table 1. Synthesis of N-alkyldithiocarbamates from carbon disulfide, amine, and sodium hydroxide.



R		Yield [%][a]
CH_3[b]	**Na[1 a]**	98
$CH(CH_3)_2$[b]	**Na[1 b]**	88
$CH(CH_3)_2$[c]	**[$NH_3{}^iPr$][1 b]**	98
$^tBu=CMe_3$[b]	**Na[1 c]**	97
$Bn=CH_2Ph$[b]	**Na[1 d]**	97
$Cy=C_6H_{11}$[b]	**Na[1 e]**	98

[a] Yields referred to isolated products. [b] Reaction conditions: Et_2O 25 mL, T = 0 °C, t = 24 h, amine (17 mmol), CS_2 (17 mmol), NaOH (17 mmol) in MeOH (5 mL); [c] Reaction conditions: Et_2O 25 mL, T = 0 °C, t = 4 h, amine (42 mmol), CS_2 (16.6 mmol).

Table 2. Synthesis of 2-imino-1,3-dithiolanes from (2-bromo-1-arylethyl) dimethylsulfonium bromide and sodium dithiocarbamates.



	X	R		Yield [%][a]
2	H	CH_3	**7 a**	54
		$CH(CH_3)_2$	**7 b**	56
		$^tBu=CMe_3$	**7 c**	49
		$Bn=CH_2Ph$	**7 d**	57
3	CH_3	CH_3	**8 a**	63
		$CH(CH_3)_2$	**8 b**	74
		$Bn=CH_2Ph$	**8 d**	74
5	F	CH_3	**10 a**	72
		$Bn=CH_2Ph$	**10 d**	47
6	CO_2Me	CH_3	**11 a**	76

[a] Yields referred to isolated products. Reaction conditions: H_2O 30 mL, CH_2Cl_2 15 mL, T = 25 °C, t = 20 h, **2**–**6** (2.15 mmol), **1 a**–**d** (2.15 mmol).

Sulfonium salts can be easily obtained from styrene and ring-substituted derivatives, and are versatile reagents in organic chemistry, providing a C_2 unit.[24] Thus, compounds [$Me_2SCH(Ar)CH_2Br$]Br, **2**–**6**, reacted with Na[**1 a**–**d**] in water/CH_2Cl_2 biphasic medium at ambient temperature, affording **7**–**11** which were isolated in good yields after work-up, Table 2. The use of [$NH_3{}^iPr$][**1 b**] in the place of Na[**1 b**] for the synthesis of **7 b** led to a comparable outcome. Isolated products were characterized by elemental analysis, IR, and NMR spectroscopy.

The possible formation of thiazolidine-2-thiones (cyclic dithiocarbamates) was ruled out by ^{13}C NMR. Note that cyclic dithiocarbamates are isomers of dithiolanes and their {SC=S} group is typically featured by a ^{13}C resonance at ca. 200 ppm,[32–36] whereas a diagnostic signal was found around 165 ppm in products spectra and assigned to the C=N moiety of dithiolanes.[9,16] All the IR spectra of prepared 2-amino-1,3-dithiolanes display an intense absorption from 1590 to 1605 cm^{-1} due to the C=N stretching.

As for other synthetic procedures, the products were obtained as a mixture of E/Z isomers in an almost 1:1 ratio..[9,15–17,19]

In order to elucidate the mechanism of the reaction between dithiocarbamate and sulfonium salts, a DFT study (B3LYP-D3/def2-TZVP level of theory) was carried out on the model reaction of **1a** with **2** leading to **7a**. The solvent effect was considered with the conductor-like polarizable continuum model, CPCM, as implemented in ORCA (solvent = water).

As **1a** comprises two nucleophilic centers (i.e., N and S), while two electrophilic sites are present in **2** (i.e., the carbon bound to S, C1, and the carbon bound to Br, C2), in principle four coupling reactions may be envisaged (see paths TS1, TS4, TS6 and TS9 in Scheme 2). After the first attack, the cyclization can take place. Three different isomers can be finally generated, i.e. the experimentally observed 1,3-dithiolane **7a**, 3-methyl-4-phenylthiazolidine-2-thione (**Prod-NS**), and 3-methyl-5-phenyl-thiazolidine-2-thione (**Prod-SN**). The latter two are accessible from the initial nucleophilic addition by nitrogen (TS4, TS9), whereas all of the three compounds are theoretically obtainable through TS1 and TS6. In particular, the formation of **7a** appears the result of two consecutive S-attacks to **2**.

The reactant complex (**RC1**) is not stable with respect to the isolated reactants ($\Delta G = +6.9$ kcal mol^{-1}), but it is easily accessible at room temperature. The following transition states (TSs) for the different nucleophilic additions have been optimized: **TS1** (S→C1), **TS4** (N→C1), **TS6** (S→C2), and **TS9** (N→C2). The corresponding Gibbs energies are 23.1, 34.8, 15.9, and 27.8 kcal mol^{-1}, respectively, indicating that the attack of sulfur to C2 (**TS6**) is much more favorable than the others. This is probably due to the less steric hindrance around S and C2, and to the fact that, in water, a bromide is a better leaving group than SMe_2 because it is more stabilized by solvation. In addition to this, a weak hydrogen bond between a CH of **2** and a sulfur of **1a** (H···S distance = 2.309 Å) further stabilizes **TS6** with respect to the others (Figure 1).

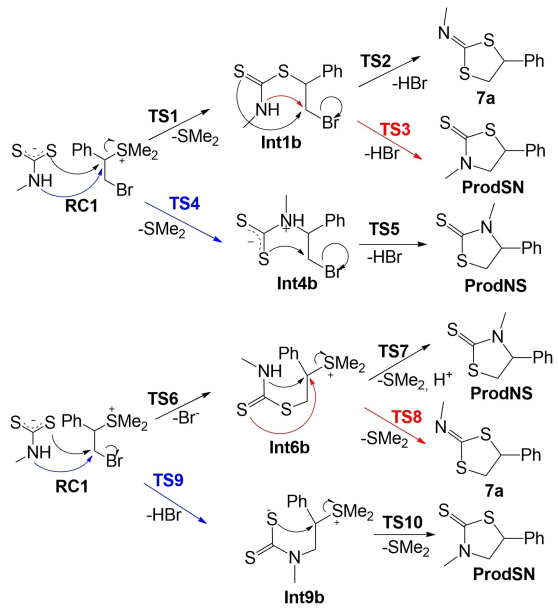
In the intermediate species **Int6b**, either the nitrogen of the thiocarbamate (**TS7**) or the other sulfur atom (**TS8**) is potentially able to attack C1 (Scheme 2). The DFT-computed activation energies for these processes are 31.6 and 15.8 kcal mol^{-1}, respectively (Figure 2). Also, in this case, the attack of the nitrogen involves a more sterically hindered transition state because of the methyl substituent on the nitrogen, which is not present on the sulfur. Obviously, bulkier substituents will even amplify the difference, explaining why only **7a** (and dithiolanes in general) are experimentally found. Noteworthy, **7a** is a kinetic product, since **ProdNS** is thermodynamically more stable by 9 kcal mol^{-1}. The large difference of energy between **TS7** and **TS8** implies that cyclic dithiocarbamates are quite difficult to obtain through this procedure, which remains extremely chemoselective.

Conclusion

A series of 4-aryl-2-imino-1,3-dithiolanes has been prepared in good yields by using a novel and straightforward synthetic strategy, consisting of the reaction between dithiocarbamates and aryl-sulfonium salts at room temperature in water/CH_2Cl_2 as a biphasic medium. A plausible reaction mechanism has been outlined by DFT calculations, evidencing that the products are selectively obtained instead of possible heterocyclic isomers essentially due to kinetic reasons.

Experimental Section

Methods and materials. Organic reactants (Merck or TCI Europe) were of the highest purity available and were stored under N_2 atmosphere as received. Compounds $[Me_2SCH(Ar)CH_2Br]Br$, **3–7**, were prepared according to the literature.[27,37] Infrared spectra of solid samples were recorded on a Perkin Elmer Spectrum One FT-IR spectrometer equipped with a UATR sampling accessory (4000-400 cm^{-1} range) and were processed with Spectragryph software.[38] NMR spectra were recorded at 298 K on a Bruker Avance II DRX400 instrument equipped with a BBFO broadband probe. Chemical shifts (expressed in parts per million) are referenced to the residual solvent peaks (^{1}H, ^{13}C).[39] NMR signals due to a second isomeric form (where it has been possible to clearly distinguish them) are



Scheme 2. Theoretically possible reaction paths for the reaction of **1a** with **2**.

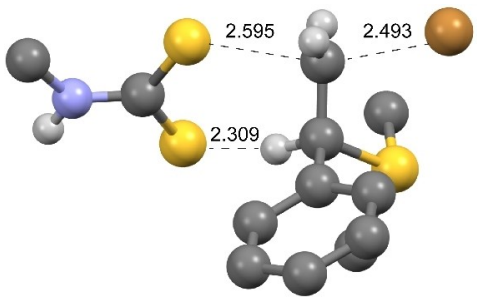


Figure 1. DFT-optimized geometry of **TS6**.

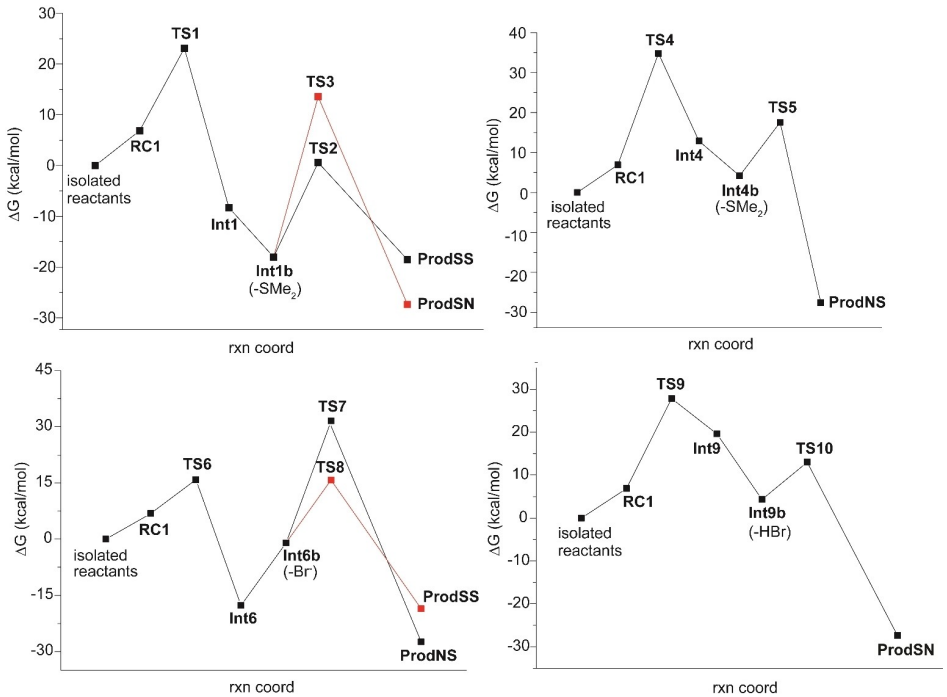


Figure 2. DFT-computed energy paths for the reaction between **1 a** and **2**.

italicized. NMR spectra were assigned with the assistance of ^{1}H-^{13}C (*gs*-HSQC and *gs*-HMBC) correlation experiments.[40] Elemental analyses were performed on an Elementar Vario MICRO cube instrument.

Synthesis and characterization of sodium N-alkyl-dithiocarbamates, Na[S_2CNHR] (Na[1 a–e])

The title compounds were prepared by modification of published procedures.[30]

General procedure. A round bottom flask was filled with 25 mL of diethyl ether, the selected amine (17 mmol), and carbon disulfide (17 mmol), in the order given. The system was cooled to 0 °C, thus a solution of NaOH (1 eq.) in MeOH (5 mL) was added. The mixture was stirred for 24 hours, then the resulting precipitate was separated, washed with Et_2O (2 x 15 mL), and dried under vacuum.

Sodium N-methyldithiocarbamate, **Na[1 a]**.[41] Colourless solid, from NH_2Me and CS_2. Yield: 2.15 g, 98 %. Anal. Calc. for $C_2H_4NNaS_2$: C, 18.60; H, 3.12; N, 10.84; S, 49.64. Found: C, 18.52; H, 3.20; N, 10.93; S, 49.42. IR (solid state): ν = 3372s, 3282m-s, 3174s, 3016 m, 2111w-m, 1643w-m, 1625 m, 1526s, 1426w-m, 1338m-s, 1163m, 1019w-m, 949vs, 929vs, 755 m, 672w cm^{-1}. ^{1}H NMR (D_2O): δ = 3.01 (s, 3H, CH_3) ppm. $^{13}C\{^{1}H\}$ NMR (D_2O): δ = 210.9 (SCS), 34.5 (CH_3) ppm.

Sodium N-isopropyldithiocarbamate, **Na[1 b]**.[42,43] Colourless solid, from $NH_2{}^{i}Pr$ and CS_2. Yield: 2.35 g, 88 %. Anal. Calc. for $C_4H_8NNaS_2$: C, 30.55; H, 5.13; N, 8.91; S, 40.79. Found: C, 30.38; H, 5.18; N, 9.02; S, 40.65. IR (solid state): ν = 3362m-s, 2967w-m, 2112w, 1627w-m, 1479 m, 1449 m, 1387w-m, 1356 m, 1329w-m, 1298w-m, 1167m, 1123m, 1050w-m, 1001w, 967vs, 937m-s, 864w, 832w-m, 699w, 666w-m cm^{-1}. ^{1}H NMR (D_2O): δ = 4.38 (m, $^{3}J_{HH}$ = 6.7 Hz, 1H, CH); 1.19 (d, $^{3}J_{HH}$ = 6.6 Hz, 6H, CH_3) ppm. $^{13}C\{^{1}H\}$ NMR (D_2O): δ = 208.1 (SCS); 50.2 (CH); 20.2 (CH_3) ppm.

Sodium tert-butyldithiocarbamate, **Na[1 c]**.[44] Pale-pink solid, from $NH_2{}^{t}Bu$ and CS_2. Yield: 2.82 g, 97 %. Anal. Calc. for $C_5H_{10}NNaS_2$: C, 35.07; H, 5.89; N, 8.18; S, 37.45. Found: C, 35.16; H, 5.78; N, 8.04; S, 37.56. IR (solid state): ν = 3335vs, 2978 m, 2122w, 1625m, 1476w-m, 1446w-m, 1393m, 1363m, 1349m, 1241w-m, 1201w-m, 1046w-m, 969 m, 925w-m, 882w-m, 756w, 679w cm^{-1}. ^{1}H NMR (D_2O) δ = 1.47 (s, 9H, CH_3) ppm. $^{13}C\{^{1}H\}$ NMR (D_2O) δ = 210.1 (SCS); 56.2 (NC); 27.4 (CH_3) ppm.

Sodium N-benzyldithiocarbamate, **Na[1 d]**.[45] Pale pink solid, from NH_2Bn and CS_2. Yield: 3.38 g, 97 %. Anal. Calc. for $C_8H_8NNaS_2$: C, 46.81; H, 3.93; N, 6.82; S, 31.24. Found: C, 46.65; H, 3.98; N, 6.68; S, 31.32. IR (solid state): ν = 3313 m, 3244 m, 3058w-m, 3025w-m, 2927w-m, 1955w, 1617w, 1604w-m, 1503s, 1451m, 1429w-m, 1370w-m, 1331m, 1321m, 1298m, 1262m, 1233m, 1194w-m, 1155w, 1084m, 1066m, 1045m, 1028m, 984w-m, 968m, 933s, 915s, 893m-s, 885s, 816w, 743w-m, 728m-s, 692s, 656w cm^{-1}. ^{1}H NMR (D_2O): δ = 7.42–7.31 (m, 5H, Ph), 4.75 (s, 2H, CH_2) ppm. $^{13}C\{^{1}H\}$ NMR (D_2O): δ = 211.7 (SCS); 138.8, 128.8, 127.9, 127.1 (Ph); 51.0 (CH_2) ppm.

Sodium N-cyclohexyldithiocarbamate, **Na[1 e]**.[46,47] Colourless solid, from NH_2Cy and CS_2. Yield: 3.29 g, 98 %. Anal. Calc. for $C_7H_{12}NNaS_2$: C, 42.61; H, 6.13; N, 7.10; S, 32.51. Found: C, 42.75; H, 6.18; N, 7.01; S, 32.40. IR (solid state): *v* = 3334 vs, 3262vs, 2949w-m, 2932m, 2854w-m, 2131vw, 1636m, 1609m, 1491m, 1447 w, 1367 w-m, 1353w, 1337m, 1246w, 1153w, 1091w, 976m-s, 945m, 885m, 795 w, 756w cm^{-1}. ^{1}H NMR (D_2O): δ = 4.08 (m, 1H, CH); 1.93 (m, 2H, CH_2); 1.73 (m, 2H, CH_2); 1.63–1.16 (m, 6H, CH_2) ppm. $^{13}C\{^{1}H\}$ NMR (D_2O): δ = 207.9 (SCS); 57.3 (CH); 31.2, 24.9, 24.6 (CH_2) ppm.

Synthesis and characterization of isopropylammonium N-isopropyldithiocarbamate, [$NH_3{}^{i}Pr$][S_2CNH ^{i}Pr] ([$NH_3{}^{i}Pr$][1 b])[29]

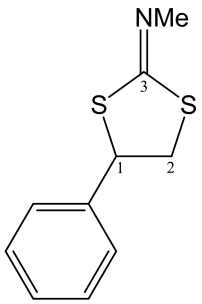
Isopropylamine (3.4mL, 42mmol) was added to a solution of CS_2 (1.00mL, 16.6mmol) in Et_2O (25mL), at 0 °C. The mixture was stirred for 4 hours, and the resulting colourless precipitate was separated, washed with cold Et_2O (3×10mL) and dried under vacuum. Yield 3.16 g, 98 %. Anal. Calc. for $C_7H_{18}N_2S_2$: C, 43.26; H, 9.33; N, 14.41; S,

33.00. Found: C, 43.16; H, 9.22; N, 14.50; S, 33.04. IR (solid state): ν = 3304m, 2966m, 2770m, 2699m, 2582w, 2502w, 1578w, 1481s, 1386m, 1282m, 1159s, 966 vs, 943s, 834s, 658 vs cm^{-1}. ^1H NMR (D_2O): δ = 4.26 (m, $^3J_{HH}$ = 6.5 Hz, 1H, CH, anion); 3.39 (m, $^3J_{HH}$ = 6.5 Hz, 1H, CH, cation); 1.19 (d, $^3J_{HH}$ = 6.5 Hz, 6H, CH_3, anion); 1.07(d, $^3J_{HH}$ = 6.5 Hz, 6H, CH_3, cation) ppm. $^{13}C\{^1H\}$ NMR (D_2O): δ = 208.1 (SCS); 50.0 (CH, anion); 44.0 (CH, cation); 20.6 (CH_3, anion); 19.8 (CH_3, cation) ppm.

Synthesis and characterization of N-alkyl-4-aryl-2-imino-1,3-dithiolanes

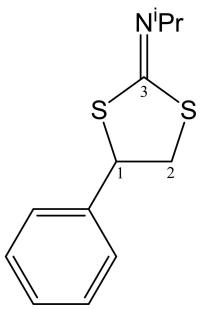
General procedure. The appropriate reagents, respectively **2–6** (2.15 mmol) and [Na][**1a-d**] or [NH_3^iPr][**1b**] (2.15 mmol), were introduced into a round bottom flask containing 30 mL of H_2O. After 20 minutes of stirring, 15 mL of CH_2Cl_2 were added to the system and the resulting mixture was stirred vigorously for 20 hours. After separation of the organic and aqueous phases, the latter phase was further extracted with dichloromethane (2 x 10 mL). The organic liquors were collected together and dried with anhydrous $MgSO_4$, then the volatiles were removed under vacuum affording an oily product. This oil was purified by flash chromatography on Al_2O_3 using a dichloromethane/hexane mixture (4/1 v/v).

N-methyl-4-phenyl-1,3-dithiolan-2-imine, 7a



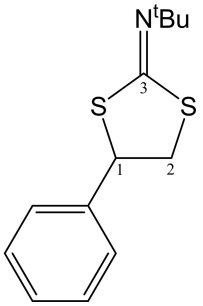
Yellow oil. Yield 0.256 g, 54%. Anal. Calc. for $C_{10}H_{11}NS_2$: C, 57.38; H, 5.30; N, 6.69; S, 30.64. Found: C, 57.22; H, 5.20; N, 6.76; S, 30.51. IR (solid state): ν = 3028w, 2925w, 1600vs, 1452m, 1395m, 1224w, 1158w, 997m, 903s, 767m, 695vs cm^{-1}. ^1H NMR ($CDCl_3$): δ = 7.49-7.29 (m, 5H, Ph); 5.15, *5.03* (m, 1H, C^1H); *3.76-3.65*, 3.61-3.49 (m, 2H, C^2H_2); *3.26*, 3.25 (s, 3H, Me) ppm. Isomer ratio = 1.1. $^{13}C\{^1H\}$ NMR ($CDCl_3$): δ = 168.6, 168.0 (C^3); 136.8, 136.5, 129.0, 128.9, 128.7, 128.6, 127.6, 127.5 (Ph); 58.2, 54.8 (C^1); 45.2, 44.4 (Me); 43.9, 41.3 (C^2) ppm.

N-isopropyl-4-phenyl-1,3-dithiolan-2-imine, 7b



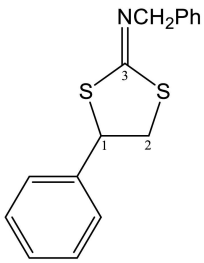
Yellow Oil. Yield 0.285 g, 56%. Anal. Calc. for $C_{12}H_{15}NS_2$: C, 60.71; H, 6.37; N, 5.90; S, 27.02. Found: C, 60.58; H, 6.42; N, 5.82; S, 27.09. IR (solid state): ν = 2966m, 2868w, 1592vs, 1452m, 1338m, 1229w, 1123m, 985w, 904s, 820w, 767m, 695vs cm^{-1}. ^1H NMR ($CDCl_3$): δ = 7.54–7.33 (m, 5H, Ph); 5.10, *4.98* (m, 1H, C^1H); 3.73–3.39 (m, 3H, C^2H_2 + $CHMe_2$); 1.30-1.23 (m, 6H, $CHMe_2$) ppm. Isomer ratio = 1.1. $^{13}C\{^1H\}$ NMR ($CDCl_3$): δ = 164.3, 163.7 (C^3); 137.0, 136.7, 129.0, 128.9, 128.7, 128.6, 127.7, 127.6 (Ph); 60.7, 59.8 ($CHMe_2$); 58.1, 54.3 (C^1); 43.8, 40.7 (C^2); 23.1, 23.0, 22.9, 22.8 ($CHMe_2$) ppm.

N-(tert-butyl)-4-phenyl-1,3-dithiolan-2-imine, 7c



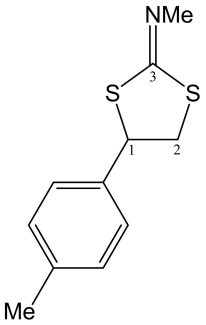
Yellow Oil. Yield 0.265 g, 49%. Anal. Calc. for $C_{13}H_{17}NS_2$: C, 62.10; H, 6.82; N, 5.57; S, 25.51. Found: C, 61.92; H, 6.75; N, 5.67; S, 25.41. IR (solid state): ν = 2968m, 1593vs, 1453m, 1361s, 1203s, 986w, 893s, 695vs cm^{-1}. ^1H NMR ($CDCl_3$): δ = 7.51–7.36 (m, 5H, Ph); 5.18, *4.93* (m, 1H, C^1H); *3.78-3.76*, 3.54–3.42 (m, 2H, C^2H_2); *1.39*, 1.37 (s, 9H, CMe_3) ppm. Isomer ratio = 1.3. $^{13}C\{^1H\}$ NMR ($CDCl_3$): δ = 160.2, 159.2 (C^3); 137.2, 137.0, 129.0, 128.7, 128.5, 128.0, 127.8, 127.7 (Ph); 60.6 (CMe_3); 58.1, 53.2 (C^1); 46.4, 39.9 (C^2); 28.6 (CMe_3) ppm.

N-benzyl-4-phenyl-1,3-dithiolan-2-imine, 7d



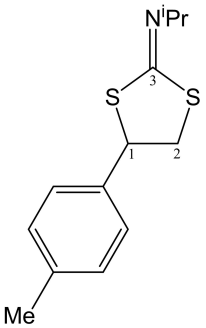
Yellow Oil. Yield 0.359 g, 57%. Anal. Calc. for $C_{16}H_{15}NS_2$: C, 67.33; H, 5.30; N, 4.91; S, 22.47. Found: C, 67.21; H, 5.30; N, 5.01; S, 22.54. IR (solid state): ν = 3028w, 2917w, 1578s, 1452s, 1308m, 1222m, 1073w, 1002m, 934s, 694vs cm^{-1}. ^1H NMR ($CDCl_3$) δ = 7.55–7.34 (m, 10H, Ph); 5.19, *5.08* (m, 1H, C^1H); 4.72–4.56 (m, 2H, CH_2Ph); *3.80-3.71*, 3.65–3.52 (m, 2H, C^2H_2) ppm. Isomer ratio = 1.1 $^{13}C\{^1H\}$ NMR ($CDCl_3$) δ = 168.0, 167.5 (C^3); 138.9, 138.8, 136.7, 136.5, 129.0, 128.9, 128.7, 128.6, 128.5, 128.4, 128.1, 127.8, 127.6, 127.5, 127.0 (Ph); 62.7, 61.9 (CH_2Ph); 58.4, 54.8 (C^1); 44.1, 41.1 (C^2) ppm.

N-methyl-4-(p–tolyl) −1,3-dithiolan-2-imine, 8 a



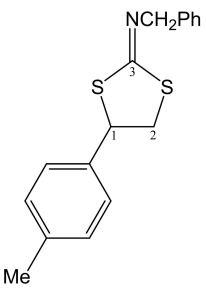
Yellow oil. Yield 0.326 g, 68 %. Anal. Calc. for $C_{11}H_{13}NS_2$: C, 59.15; H, 5.87; N, 6.27; S, 28.71. Found: C, 59.03; H, 5.75; N, 6.42; S, 28.85. IR (solid state): ν = 2967m, 2868w, 1711w, 1594vs, 1512m, 1455w, 1361m, 1220w, 1126m, 986w, 906s, 816vs, 736w cm^{-1}. ^1H NMR ($CDCl_3$): δ = 7.37–7.34, 7.19-7.17 (m, 4H, C_6H_4); 5.10, 4.98 (m, 1H, C^1H); 3.69–3.48 (m, 2H, C^2H_2); 3.24, 3.23 (s, 3H, NMe); 2.36, 2.35 (s, 3H, C_6H_4*Me*) ppm. Isomer ratio = 1.0. $^{13}C\{^1H\}$ NMR ($CDCl_3$): δ = 168.1, 167.5 (C^3); 138.7, 138.5, 134.0, 133.6, 129.6, 127.6, 127.5 (C_6H_4); 58.2, 54.7 (C^1); 45.4, 44.6 (NMe); 44.0, 41.3 (C^2); 21.2 (C_6H_4*Me*) ppm.

N-isopropyl-4-(p–tolyl) −1,3-dithiolan-2-imine, 8 b



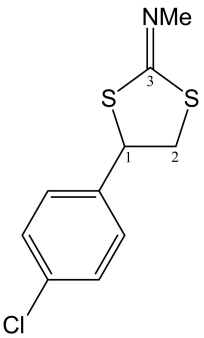
Yellow Oil. Yield 0.378 g, 70 %. Anal. Calc. for $C_{13}H_{17}NS_2$: C, 62.10; H, 6.82; N, 5.57; S, 25.51. Found: C, 62.21; H, 6.72; N, 5.69; S, 25.45. IR (solid state): ν = 3022vw, 2919w, 1710w, 1602vs, 1513m, 1395m, 1221w, 1161vw, 998m, 905s, 816vs, 716w cm^{-1}. ^1H NMR ($CDCl_3$): δ = *7.36–7.33*, 7.19–7.16 (m, 4H, C_6H_4); 5.06, *4.94* (m, 1H, C^1H); 3.68–3.38 (m, 3H, $C^2H_2 + CHMe_2$); 2.35, *2.34* (s, 3H, C_6H_4*Me*); 1.24, *1.22* (s, 6H, $CHMe_2$) ppm. Isomer ratio = 1.1. $^{13}C\{^1H\}$ NMR ($CDCl_3$): δ = 165.3, 164.6 (C^3); 138.6, 138.5, 133.8, 133.5, 129.6, 127.6, 127.5 (C_6H_4); 60.7, 59.7 ($CHMe_2$); 58.0, 54.4 (C^1); 43.9, 40.9 (C^2); 23.1, 23.0 ($CHMe_2$); 21.2 (C_6H_4*Me*) ppm.

N-benzyl-4-(p–tolyl) −1,3-dithiolan-2-imine, 8 d



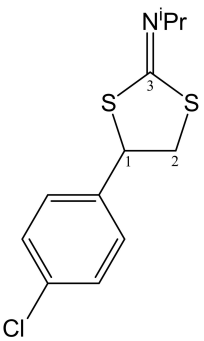
Yellow Oil. Yield 0.418 g, 65 %. Anal. Calc. for $C_{17}H_{17}NS_2$: C, 68.19; H, 5.72; N, 4.68; S, 21.41. Found: C, 68.21; H, 5.70; N, 4.61; S, 21.48. IR (solid state): ν = 3027w, 2919w, 1596s, 1512m, 1452m, 1344w-m, 1185w, 1089w, 1019m, 908m, 814s, 695vs cm^{-1}. ^1H NMR ($CDCl_3$) δ = 7.44–7.31 (m, 9H, Ph + C_6H_4); 5.20, *5.06* (m, 1H, C^1H); 4.62 (m, 2H, CH_2Ph); 3.75–3.53 (m, 2H, C^2H_2) ppm. Isomer ratio = 1.1 $^{13}C\{^1H\}$ NMR ($CDCl_3$) δ = 167.9, 167.3 (C^3); 139.0, 138.6, 138.5, 133.7, 133.5, 129.6, 128.4, 127.9, 127.5, 127.0 (Ph + C_6H_4); 62.8, 61.9 (CH_2Ph); 58.4, 54.6 (C^1); 44.1, 41.2 (C^2); 21.2 (Me) ppm.

4-(4-chlorophenyl)-N-methyl-1,3-dithiolan-2-imine, 9 a



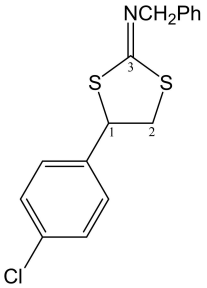
Yellow oil. Yield 0.330 g, 63 %. Anal. Calc. for $C_{10}H_{10}ClNS_2$: C, 49.27; H, 4.13; N, 5.75; S, 26.31. Found: C, 49.16; H, 4.22; N, 5.71; S, 26.42. IR (solid state): ν = 3176w, 2918w, 2763vw, 1604vs, 1490vs, 1395m, 1226w, 1162w, 1088vs, 1013s, 905s, 822vs, 734s cm^{-1}. ^1H NMR ($CDCl_3$): δ = 7.42–7.39, 7.35–7.32 (m, 4H, C_6H_4); 5.09, 4.96 (m, 1H, C^1H); 3.75–3.59, 3.53–3.49 (m, 2H, C^2H_2); 3.23 (s, 3H, Me) ppm. Isomer ratio = 1.0. $^{13}C\{^1H\}$ NMR ($CDCl_3$): δ = 167.7, 167.0 (C^3); 135.8, 135.6, 129.2, 129.1, 129.0 (C_6H_4); 57.4, 53.9 (C^1); 45.5, 44.8 (Me); 44.0, 41.3 (C^2) ppm.

4-(4-chlorophenyl)-N-ispropyl-1,3-dithiolan-2-imine, 9 b



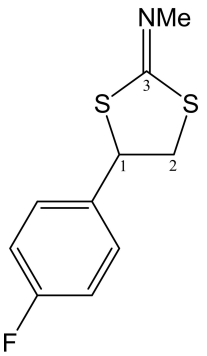
Yellow Oil. Yield 0.432 g, 74 %. Anal. Calc. for $C_{12}H_{14}ClNS_2$: C, 53.02; H, 5.19; N, 5.15; S, 23.59. Found: C, 53.09; H, 5.26; N, 5.01; S, 23.46. IR (solid state): ν = 3161vw, 2967m, 2868w, 1594vs, 1490vs, 1380m, 1089vs, 1013s, 907s, 821vs, 735m cm^{-1}. ^1H NMR ($CDCl_3$): δ = 7.40–7.37 (m, 4H, C_6H_4); 5.05, 4.92 (m, 1H, C^1H); 3.69–3.58, 3.46–3.36 (m, 3H, $C^2H_2 + CHMe_2$); 1.20 (m, 6H, $CHMe_2$) ppm. Isomer ratio = 1.0. $^{13}C\{^1H\}$ NMR ($CDCl_3$): δ = 163.6, 162.9 (C^3); 135.8, 135.6, 134.9, 134.4, 129.1, 129.0, (C_6H_4); 61.0, 60.1 ($CHMe_2$); 57.1, 53.3 (C^1); 43.9, 40.7 (C^2); 23.2, 23.1, 23.1, 23.0 ($CHMe_2$) ppm.

4-(4-chlorophenyl)-N-benzyl-1,3-dithiolan-2-imine, 9 d



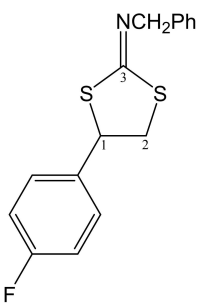
Yellow Oil. Yield 0.509 g, 74 %. Anal. Calc. for $C_{16}H_{14}ClNS_2$: C, 60.08; H, 4.41; N, 4.38; S, 20.05. Found: C, 60.11; H, 4.30; N, 4.31; S, 20.14. IR (solid state): ν = 3028w, 2917w, 1595s, 1490vs, 1453m, 1348w, 1262w, 1080s, 1013s, 930m, 821s, 695vs cm^{-1}. ^1H NMR ($CDCl_3$) δ = 7.44–7.33 (m, 9H, C_6H_4 + Ph); 5.13, 5.01 (m, 1H, C^1H); 4.54 (m, 2H, CH_2Ph); 3.76–3.64, 3.55 (m, 2H, C^2H_2) ppm. Isomer ratio = 1.0 $^{13}C\{^1H\}$ NMR ($CDCl_3$) δ = 167.3, 166.7 (C^3); 138.9, 135.7, 136.7, 135.4, 134.8, 134.6, 129.3, 129.1, 128.9, 128.6, 128.0, 127.2 (C_6H_4 + Ph); 63.0, 62.3 (CH_2Ph); 57.7, 54.0 (C^1); 44.3, 41.2 (C^2) ppm.

4-(4-fluorophenyl)-N-methyl-1,3-dithiolan-2-imine, 10 a



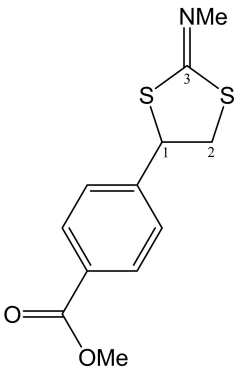
Colourless oil. Yield 0.352 g, 72 %. Anal. Calc. for $C_{10}H_{10}FNS_2$: C, 52.84; H, 4.43; N, 6.16; S, 28.21. Found: C, 52.71; H, 4.51; N, 6.31; S, 28.31. IR (solid state): ν = 2924w, 1601s, 1507vs, 1396m, 1296w, 1222s, 1159m-s, 1095w, 997m, 905m, 833s, 718w cm^{-1}. ^1H NMR ($CDCl_3$): δ = 7.48–7.45, 7.10–7.04 (m, 4H, C_6H_4); 5.14, *5.03* (m, 1H, C^1H); 3.77–3.53 (m, 2H, C^2H_2); *3.25*, 3.24 (s, 3H, Me) ppm. Isomer ratio = 1.1. $^{13}C\{^1H\}$ NMR ($CDCl_3$): δ = 168.9, 168.2 (C^3); 162.8 (d), 162.7 (d), 132.6 (d), 132.5 (d), 129.5 (d), 129.4 (d), 116.0 (d), 115.9 (d) (C_6H_4); 57.5, 54.2 (C^1); 45.2, 44.4 (Me); 44.1, 41.6 (C^2) ppm. $^{19}F\{^1H\}$ NMR ($CDCl_3$): δ = −112.5, *−112.7* (s, 1F) ppm.

4-(4-fluorophenyl)-N-benzyl-1,3-dithiolan-2-imine, 10 d



Yellow Oil. Yield 0.306 g, 47 %. Anal. Calc. for $C_{16}H_{14}FNS_2$: C, 63.34; H, 4.65; N, 4.62; S, 21.13. Found: C, 63.21; H, 4.60; N, 4.71; S, 21.18. IR (solid state): ν = 3028w, 2918w, 1598s, 1507vs, 1452m, 1341w-m, 1223s, 1159m, 1094w, 1014w, 930m, 834s, 695vs cm^{-1}. ^1H NMR ($CDCl_3$) δ = 7.50–7.07 (m, 9H, Ph + C_6H_4); 5.18, 5.04 (m, 1H, C^1H); 4.57 (m, 2H, CH_2Ph); 3.77–3.64, 3.55–3.50 (m, 2H, C^2H_2) ppm. Isomer ratio = 1.0 $^{13}C\{^1H\}$ NMR ($CDCl_3$) δ = 167.6, 166.9 (C^3); 164.0 (d), 161.5 (d), 138.9, 129.4, 129.3, 128.5, 127.9, 127.1, 116.1, 116.0, 115.9, 115.8 (Ph + C_6H_4); 62.9, 62.0 (CH_2Ph); 57.6, 53.9 (C^1); 44.3, 41.3 (C^2) ppm. 19F NMR ($CDCl_3$): δ = −112.5, −112.8 (s, 1F) ppm

Methyl-4-(2-(methylimino)-1,3-dithiolan-4-yl)benzoate, 11 a



Yellow oil. Yield 0.437 g. 76 %. Anal. Calc. for $C_{12}H_{13}NO_2S_2$: C, 53.91; H, 4.90; N, 5.24; S, 23.99. Found: C, 53.82; H, 4.82; N, 5.36; S, 24.05. IR (solid state): ν = 2949w, 1716s (C=O), 1604s, 1434m, 1361m, 1274vs, 1181m, 1104sw, 905m, 773m, 704m cm^{-1}. ^1H NMR ($CDCl_3$): δ = 8.04–7.99, 7.59–7.53 (m, 4H, C_6H_4); 5.17, 5.05 (m, 1H, C^1H); 3.91 (s, 3H, OMe); 3.81-3.64, 3.58–3.55 (m, 4H, C^2H_2); 3.23 (s, 3H, NMe) ppm. Isomer ratio = 1.0. $^{13}C\{^1H\}$ NMR ($CDCl_3$): δ = 168.4, 167.7 (C^3); 166.4, 166.3 (C=O); 142.1, 142.0, 130.5, 130.4, 130.2, 130.2, 127.7, 127.6 (C_6H_4); 57.5, 54.2 (C^1); 52.3 (OMe); 45.3, 44.6 (NMe); 43.8, 41.1 (C^2) ppm.

DFT calculations

All geometries were optimized with ORCA 4.0.1.2,[48] using the b3lyp functional in conjunction with a triple-ζ quality basis set (def2-TZVP). The dispersion corrections were introduced using the Grimme D3-parametrized correction and the Becke−Johnson damping to the DFT energy.[49] Most of the structures were confirmed to be local energy minima (no imaginary frequencies). The solvent was considered through the Continuum-like Polarizable Continuum Model (C-PCM, water).

Acknowledgements

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Conflict of Interest

The authors declare no conflict of interest.

Keywords: Carbon disulfide · Cyclization · Dithiocarbamates · Dithiolanes · Synthetic methods

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