Reinvestigation of base-induced skeletal conversion *via* a spirocyclic intermediate of dibenzodithiocinium derivatives and a computational study using the HF/6-31G* basis set

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Treatment of 6-methyl-12-oxo-5*H*,7*H*-dibenzo[*b,g*][1,5]dithiocinium salt (**1a**) with methanolic KOH afforded a mixture of dibenzothiepin derivative **5** in 66% yield. The rearrangement was explained in terms of usual [2,3]-sigmatropic shift *via* a spirocyclic intermediate. However, an unique rearrangement *via* an alternative spirocyclic intermediate was observed in 6-methyl-5*H*,7*H*-dibenzo[*b,g*][1,5]dithiocinium salt (**2**) to give an unexpected dibenzothiepin derivative **6** in 29% yield along with a small amount of a ring-opening product **7** in 5% yield under the same reaction conditions. In order to clarify the origin of the different behaviour between the sulfoxide derivative **1a** and the sulfide derivative **2** in the rearrangements, 6-methyl-12-oxo-7,12-dihydro-5*H*-dibenzo[*c,f*]thiocinium salt (**3**) as the reference compound with an electron withdrawing group (carbonyl group) was prepared and treated under the same conditions to furnish a mixture of acid **8** and ester **9**. It was considered that these products resulted from the ring-opening of a spirocyclic intermediate analogous to the intermediate from the sulfoxide derivative **1a**. On the other hand, the rigid system, 10b-phenyl-10b,11-dihydro-6*H*-[1]benzothieno[2,1-*a*][2]benzothiophenium perchlorate (**4**) afforded the compound **10** *via* the Stevens-type rearrangement. The *ab initio* MO calculations at HF/6-31G* basis set was performed on the possible reaction intermediates and products.

Introduction

The Sommelet–Hauser rearrangement is a very attractive reaction *via* [2,3]-sigmatropic dearomatization followed by [1,3]-shift rearomatization processes[1] and thus, the [2,3]-rearrangements of sulfonium ylides can be highly exothermic with low activation energies.[2] Such a rearrangement of sulfonium or ammonium ylides offers various interesting routes for preparation of substituted aromatic compounds.[3]

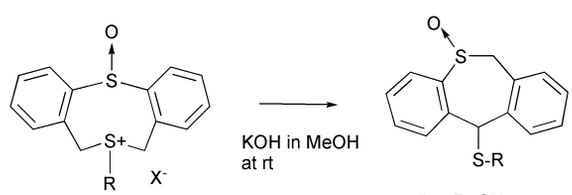
In the course of investigations of transannular interaction in heterocyclic dibenzocyclooctadiene systems (thiazocine, dithiocin etc.),[4,5] we encountered a skeletal contraction of these systems into thiepin derivatives.[6] This interesting rearrangement was reinvestigated from the points of mechanistic view on the basis of reactions of the reference compounds and stability of the intermediates. This paper describes the novel base-induced rearrangements in the title compounds **1**–**3** *via* spirocyclic intermediates of the various spiro-intermediates.

Results and discussion

Dithiocinium and related salts **1**–**4** were prepared by *S*-alkylation of the corresponding heterocycles containing sulfur atom.[5–7]

Rearrangement of 6-methyl-12-oxo-5*H*,7*H*-dibenzo[*b,g*][1,5]dithiocinium salt (1a) and the ethyl derivative 1b

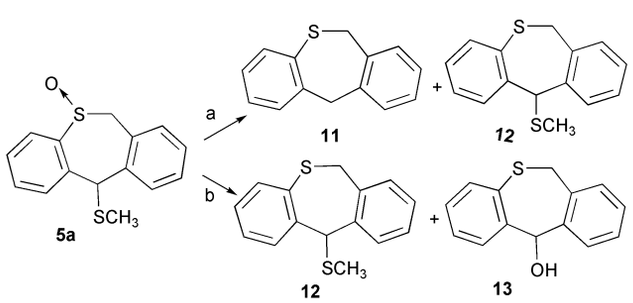
Reaction of 6-methyl-12-oxo-5*H*,7*H*-dibenzo[*b,g*][1,5]dithiocinium tetrafluoroborate (**1a**) with methanolic KOH at room temperature gave a mixture of geometric isomers **5** as shown in Scheme 1. The *cis*/*trans* isomers, S⟶O *versus* S–Me, existed in the dibenzothiepin derivatives **5**. TLC-separation on silica gel furnished two kinds of pure samples (**5a**–**1** in 41% and **5a**–**2** in 25% isolated yields). The same ring-contraction was observed in the reaction of ethyl sulfonium salt **1b** with methanolic KOH



Scheme 1

as shown in Scheme 1 but the ratio of geometric isomers **5b**–**1** (35%) and **5b**–**2** (18%) was 1.9.

The products were characteristic as dibenzothiepin derivatives **5a**–**1** and **5a**–**2** on the basis of their spectral data and their chemical behaviour. For the purpose of further confirming their skeleton, treatment of a mixture of **5a**–**1** and **5a**–**2** with $HSiCl_3$–$LiAlH_4$ gave dibenzothiepin **11** in 41% as shown in Scheme 2. Alternatively, deoxygenation of the pure sample **5a**–**1** with triphenylphosphine in carbon tetrachloride–acetonitrile solution gave dibenzothiepin derivative **12** in 38% yield along with its related alcohol **13** in 19% yield which might be hydro-



Scheme 2 *Reagents*: (a) Cl_3SiH + $LiAlH_4$; (b) Ph_3P.

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lyzed during separation on silica gel. Analogous results were observed for the isomer **5a**–**2** under the same conditions.

When a pure sample of **5a**–**1** or **5a**–**2** was allowed to stand under the reaction conditions for 20 h, equilibration was reached between **5a**–**1** and **5a**–**2**, the ratio being the same value (1.55) as that of the above products before purification. In the IR spectra of both products, a characteristic absorption was observed at ν_{max} = 1025 cm^{-1} which is assignable to a stretching vibration band for the sulfoxide group. In the ^1H NMR spectra, the C*H*SMe proton for **5a**–**1** is seen as a sharp singlet at δ 5.12 in $CDCl_3$ solution. The slightly downfield shift relative to its counterpart (δ 5.09) in **5a**–**2** is a consequence of its projection into a region of the molecule where the deshielding anisotropies of the sulfoxide group are exerting their effect. Therefore, the major isomer **5a**–**1** is assigned to a *trans* geometry, which is expected to have a comparatively strong anisotropic effect if the model study is taken into consideration.

There are considered to be at least four types of stereoisomers of **5**. Two are in the conformation (*axial*-like or *equatorial*-like) of the methylthio- group in the seven-membered ring (thiepin ring) and the other two are adopt the relative stereochemistry (*cis* or *trans*) between the sulfoxide group and the methylthio group. The orientation of the *S*-methyl substituent can be described as *axial*-like or *equatorial*-like in the seven-membered ring (subscript *ax* or *eq*) as shown in Fig. 1. It is considered that *cis*/*trans* isomerization

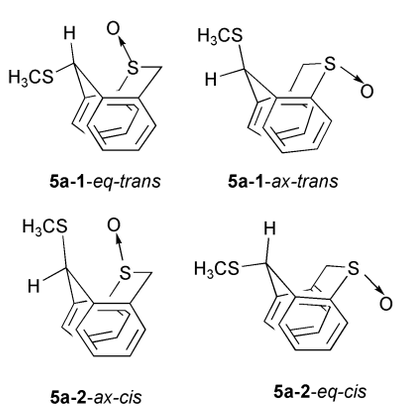


Fig. 1 The conformers of **5a**–**1** and **5a**–**2**.

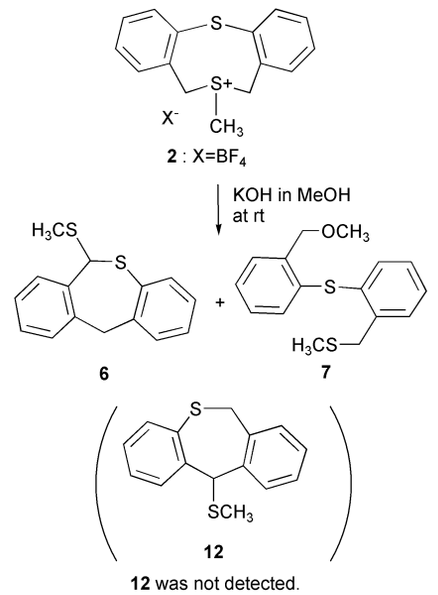
does not easily occur at room temperature but the *axiall equatorial* interconversion *via* ring-inversion of the seven-membered ring easily occurs at room temperature. Stereochemistry of the major conformer indicated the difference of chemical shifts of the C*H*SMe proton in **5a**–**1** and **5a**–**2**. The ^1H NMR signals for the *cis* and *trans* isomers were observed as the average values between those of the *axial* and *equatorial* conformations at ambient temperature.

Rearrangement of 6-methyl-5*H*,7*H*-dibenzo[*b*,*g*][1,5]dithiocinium salt (2)

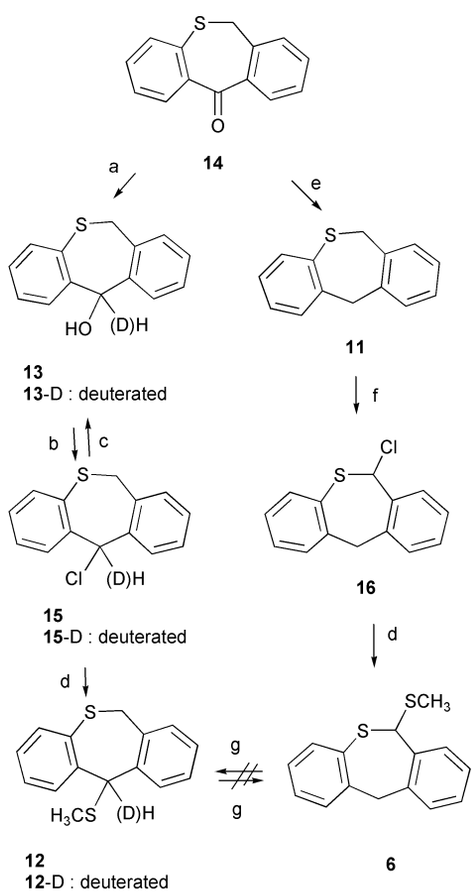
Treatment of **2** under the same conditions (methanolic KOH) did not furnish **12**, which had been expected from the rearrangement of **1**, but the structural isomer **6** in 29% yield along with a small amount of 2-methoxymethylphenyl 2-methylthiomethylphenyl sulfide (**7**) in 5% yield which was produced by way of the ring-opening by nucleophilic substitution of **2** with methanol as shown in Scheme 3.

Since the structure of **6** could not be determined on the basis of the spectral data, it was confirmed by comparing the spectra with those of an authentic sample which was prepared by the alternative route as shown in Scheme 4.

Reduction of 11-oxo-dibenzothiepin derivative **14** with $LiAlH_4$ gave alcohol **13**, followed by chlorination with $SOCl_2$ to give the corresponding chloride **15**.[8,9] Treatment of the chloride



Scheme 3



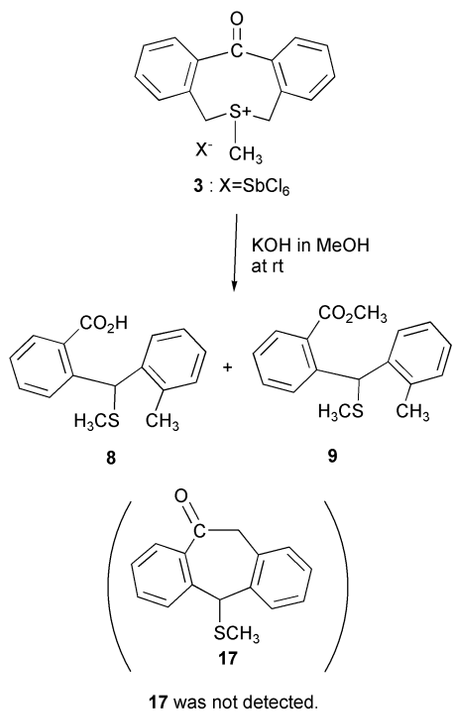
Scheme 4 *Reagents*: (a) $LiAlH_4$ or $LiAlD_4$; (b) $SOCl_2$; (c) aq NaOH; (d) MeSSMe + $LiAlH_4$; (e) $LiAlH_4$ + $AlCl_3$; (f) SO_2Cl_2; (g) methanolic KOH.

15 in acetonitrile with methane thiolate prepared freshly from dimethyl disulfide afforded thiepin derivative **12**. No hydrogen shift in the synthetic sequence was confirmed by preparation of the α-deuterated derivatives (**13**-D, **15**-D and **12**-D) and hydrolysis of **15** into **13**. Furthermore **12** did not rearrange into **6** under the reaction conditions (in methanolic KOH at room temperature for 4 h). On the other hand, **6** was prepared independently by successive treatment of **14**; reduction with $LiAlH_4$–$AlCl_3$, chlorination with SO_2Cl_2 and substitution with an MeS-anion. The spectral data of the compound, which was

obtained by such an independent route, was perfectly consistent with those of the rearranged product **6**.

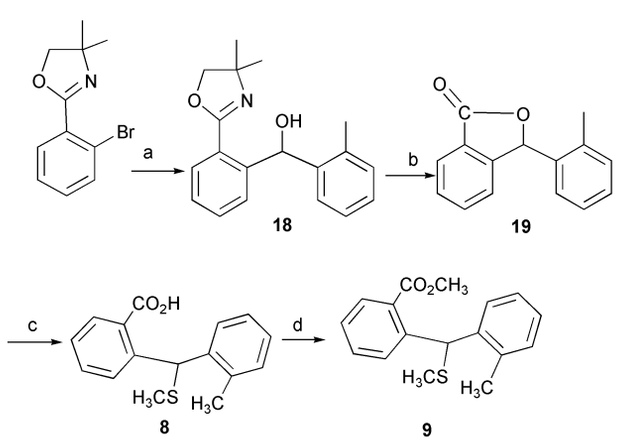
Rearrangement of 6-methyl-12-oxo-7,12-dihydro-5*H*-dibenzo-[*c*,*f*]thiocinium salt (3)

The different rearrangement pattern between the sulfoxide derivative **1** and the sulfide **2** can be attributed to the difference of the electronic effect of these groups rather than the steric effect in the starting materials **1** and **2**. In order to clarify the origin of the different rearrangements of **1** and **2**, the related derivative **3** containing a carbonyl group instead of a sulfoxide group was prepared and treated under the same reaction conditions. Reaction of **3** with methanolic KOH produced carboxylic acid **8** in 45% yield along with the methyl ester **9** in 35% yield instead of dibenzo[*a*,*d*]cycloheptene derivative **17** as shown in Scheme 5. Methylation of **8** with diazomethane gave **9**



Scheme 5

quantitatively. Structural assignments of products **8** and **9** were founded upon the spectral data and the independent synthesis (Scheme 6). In the ^{1}H NMR spectrum of **9** in $CDCl_3$ solution the following characteristic signals are observed δ 1.94 (s, 3H), 2.25 (s, 3H), 3.74 (s, 3H) and 6.33 (s,1H) together with signals for eight aromatic protons. The authentic compounds **8** and **9**



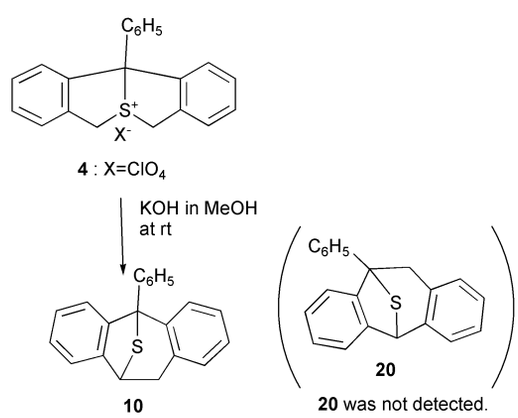
Scheme 6 *Reagents*: (a) *n*-BuLi, *o*-$CH_3C_6H_5CHO$; (b) HCl; (c) MeSSMe + $LiAlH_4$, then HMPA; (d) CH_2N_2.

were synthesized by way of an alternative route as shown in Scheme 6.

Reaction of *o*-tolualdehyde with 2-(2-bromophenyl)-4,4-dimethyl-1,3-oxazole by means of Meyer's procedure afforded benzhydryl derivative **18** in excellent yield.[10] Treatment of **18** with hydrochloric acid furnished phthalide derivatives **19**, which was ring-opened to give **8** by lithium methanethiolate in HMPA solution. Methylation of **8** with diazomethane afforded **9**. The spectral data of the compounds prepared by such an alternative route were consistent with those of the rearranged products **8** and **9**.

Rearrangement of 10b-phenyl-10b,11-dihydro-6*H*-[1]benzo-thieno[2,1-*a*][2]benzothiophenium perchlorate (4)

In order to clarify the importance of the transannular interaction in the flexible eight-membered ring systems such as **1**–**3**, the related rigid tetracyclic system **4** was prepared. There is a possibility that a Stevens-type [1,2]rearrangement could occur instead of the Sommelet–Hauser rearrangement from such a rigid sulfonium ylide. In fact, the related system **4** was treated under the same basic conditions (methanolic KOH) to afford **10** in high yield as shown in Scheme 7, while compound **20** which



Scheme 7

was expected from the Sommelet–Hauser rearrangement was not observed.

Structural assignment of **10** is founded upon ^{1}H NMR spectral data. The benzyl protons appear as double doublets (J = 15.0 and 1.5 Hz, 1H) at δ 3.10 and two doublets (J = 15.0 Hz, 1H) at δ 3.21, and (J = 1.5 Hz, 1H) at δ 4.70. In the ^{1}H NMR spectrum of **10** the following characteristic signals are observed δ 2.45 (s, 3H), 3.80 (dd, J = 13.0 and 3.1 Hz, 1H) and 4.40 (d, J = 13.0 Hz, 1H) together with the other signals.

Due to the severe stereo-demand for a [2,3]sigmatropic rearrangement in the ylide, the Stevens [1,2]rearrangement, instead of the Sommelet–Hauser rearrangement, would occur in the rigid tetracyclic derivative **4** (Scheme 8).[11]

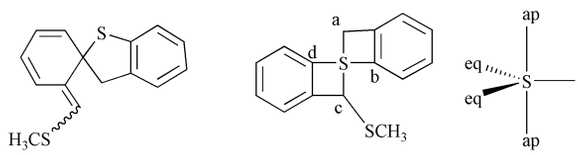
Mechanistic considerations of the rearrangements

The rearrangements into the dibenzothiepin system of **1a** and **1b** are explained in terms of consecutive [2,3]- and [1,3]-sigmatropic shifts (the Sommelet–Houser rearrangement) *via* spirocyclic intermediates **23a**,**b** as shown in Scheme 9.

In these rearrangements, the corresponding sulfonium ylides **21a** and **21b** were considered to be the first generated intermediates for the process from **1a**,**b** into **5a**,**b**, respectively. The anionic [2,3]sigmatropic shifts in **21a**,**b** give spiro-**23a**,**b** by way of a concerted process, followed by a [1,3] shift to afford the final products **5a**,**b**.

The rearrangement of dibenzothiepin **3** can also be explained by assuming the same spirocyclic intermediate **24** formed *via* a [2,3]sigmatropic shift of ylide **22**. It is considered that the [1,3]sigmatropic shift of the carbonyl group is a high-energy

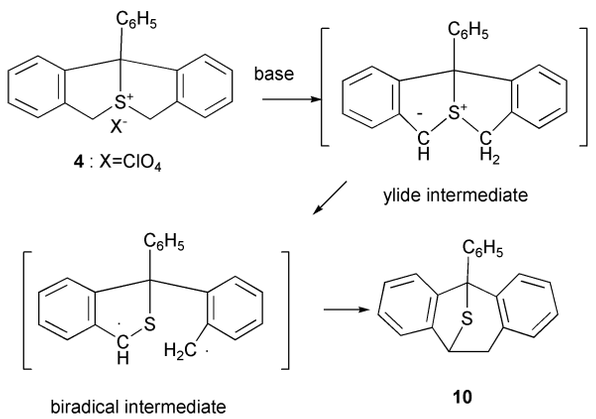
Table 1 Calculated total energies of the spirocyclic intermediate **25** and the thiaspiro compound **26** along with relative energies



25 **26**

Compound	Ap.[a]	Eq.[b]	Total energy/a.u.	Relative energy/a.u.	Relative energy/kJ mol^{-1}
trans-**25**	—	—	−1371.14931	0.0 (std.)	0.0 (std.)
cis-**25**	—	—	−1371.14742	0.0019	4.97
26	b,d	a,c	−1371.01863	0.1307	342.89
	a,c	b,d	−1371.02476	0.1245	326.63
	b,c	a,d	−1371.02675	0.1225	321.36
	a,d	b,c	−1371.02423	0.1251	328.17

[a] Apical positions of **26**. [b] Equatorial positions of **26**.

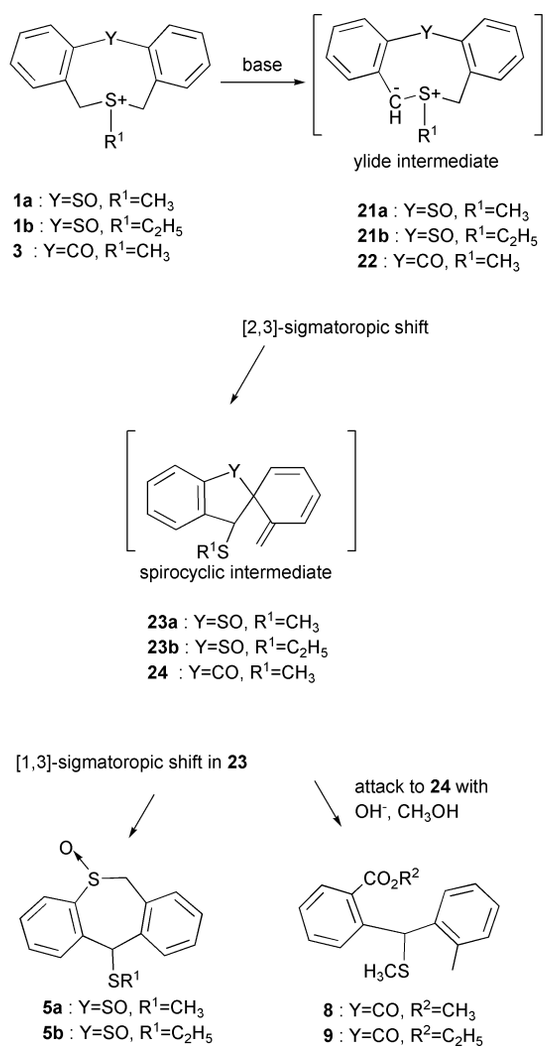


Scheme 8 A possible mechanism for the rearrangement of **4** into **10**.

process compared with that of the sulfenyl group *via* a concerted process and that the carbonyl group is more reactive to nucleophilic attack by methanol or hydroxide than the sulfenyl. Therefore, the spirocyclic intermediate **24** resulted in the ring-opening process *via* attack on the carbonyl carbon in the intermediate **24** by a hydroxide anion and MeOH as shown in Scheme 6, instead of a [1,3] shift of the carbonyl group.

On the other hand, a very strange and unique rearrangement was observed in the sulfonium salt **2**. The rearranged product **6** could not be explained by either a Sommelet–Houser rearrangement or a Stevens rearrangement. Either the spirocyclic intermediate **25** or the thiaspiro compound **26** as illustrated in Table 1 were assumed to explain the rearrangement of **2** into **6**.[6] We performed *ab initio* molecular orbital calculations at the HF/6-31G* basis set. The calculated total energies and relative energies from *trans*-**25** are summarized in Table 1. The HF methods predict the spirocyclic intermediate **25** to be favoured by more than 320 kJ mol^{-1}.

The difference in rearrangement reactions in these ring systems is understandable in terms of the electronic factor rather than the steric factor. It is considered that the anionic carbon of ylides **21** and **22** attacks transannularly the *ipso* carbon in the aromatic ring which is substituted by an electron withrawing group, in the sulfonium ion and **3**, respectively. On the other hand, the *ipso* carbon in sulfonium **2** is substituted by an electron donating group and is not reactive enough to be attacked intramolecularly by the anionic carbon of the ylide. The formation of the ring-opening (benzyl carbon) product **7** supports this assumption. Furthermore there is a possibility that the sulfide group in compound **2** assists heterolytic cleavage of the benzyl carbon. In addition it can be assumed that this electron deficient benzyl carbon attacks the *ipso* carbon to furnish the spirocyclic intermediate **25** as shown in Scheme 10.

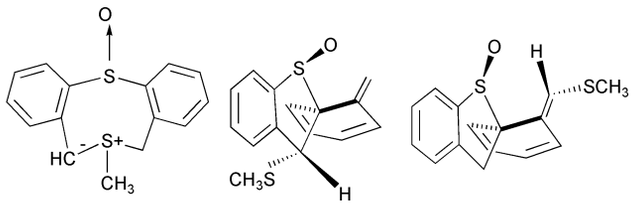


Scheme 9 A possible mechanism for the rearrangement of **1a**,**b** and **3**.

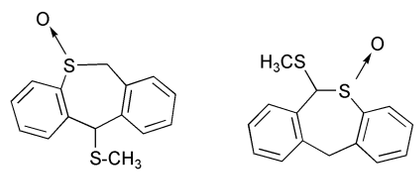
Theoretical considerations of the reaction intermediates by MO calculations

We have performed molecular orbital calculations of these various intermediates from the ylides **21a** and **30** to the final products **5** and **6**, respectively. *Ab initio* calculations were carried out at the Hartree–Fock (HF) level with the 6-31G* basis set using the HONDO-2001 program package.[12] The geometry optimisation was performed for each of the intermediates at the HF/6-31G*. Total energies for the most stable conformer in each of the derivatives are shown in Tables 2 and

Table 2 Calculated total energies of the intermediates **21a**, **23a**, **28**, product **5** and the possible product **29** along with the relative energies with respect to **21a**

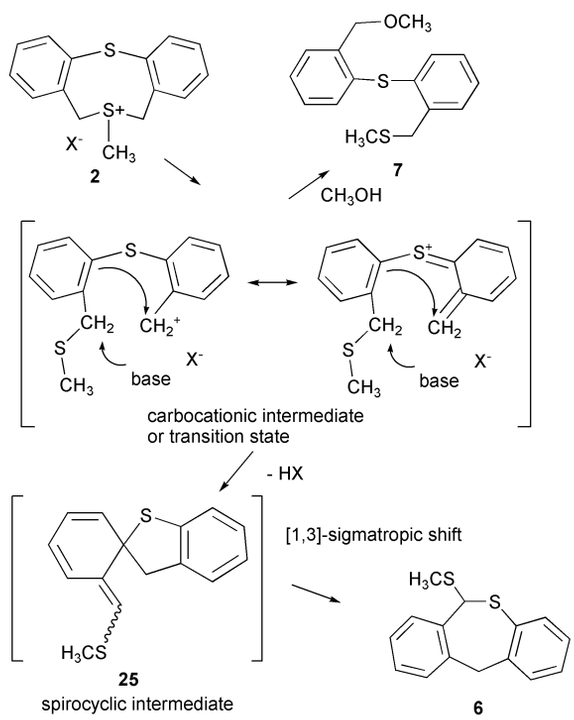


21a **23a** **28**



5a **29**

Compound	Total energy/a.u.	Relative energy/a.u.	Relative energy/ kJ mol^{-1}
21a	−1445.89676	0.0 (std.)	0.0 (std.)
23a	−1445.94489	−0.04814	−126.39
28	−1445.95349	−0.05673	−148.97
5	−1445.99161	−0.09486	−249.06
29	−1445.99779	−0.10104	−265.29

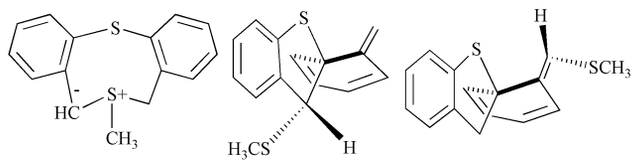


Scheme 10 A possible mechanism for the rearrangement of **2** into **6**.

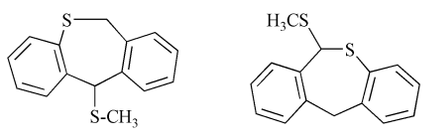
3. The spirocyclic intermediate **23a** would give the dibenzothiepin derivative **5** through a [1,3]sigmatropic migration. The [1,3]-sigmatropic migration in these systems gave the aromatic dibenzo systems.

Because the constitutional elements of **21a**, **23a**, **28**, **5a** and **29** are the same as each other, it is possible to compare the energy levels of these compounds as summarized in Table 2. In the rearrangement from **21a** into **5** the stabilized energy level of the first step ([2,3]sigmatropic shift) was about 126 kJ mol^{-1} and the second step ([1,3]-sigmatropic shift) was stabilized by approximately 123 kJ mol^{-1}. It seems that the driving force of the first step is caused by conversion of the unstable ylide into

Table 3 Calculated total energies of the intermediates **30**, **31**, **25**, the product **6** and the possible product **12** along with the relative energies with respect to **30**



30 **31** **25**



12 **6**

Compound	Total energy/a.u.	Relative energy/a.u.	Relative energy/ kJ mol^{-1}
30	−1371.09245	0.0 (std.)	0.0 (std.)
31	−1371.14445	−0.05200	−136.54
25	−1371.14931	−0.05686	−149.31
12	−1371.19484	−0.10239	−268.86
6	−1371.19237	−0.09992	−262.37

the spirocyclic intermediate in spite of the dearomatization, followed by the second step and the rearomatization to give the final product **5**. A similar calculation was carried out for the rearrangement of the dithiocinium **2** (Table 3). In our previous speculation of the rearrangement mechanism, we assumed that the mechanism *via* [3,3]sigmatropic rearrangement from **31** into **25** gave **6**.[6] However, the energy difference between the spirocyclic intermediate **31** and the previously postulated **25** was only 13 kJ mol^{-1} since the rearomatization did not occur in this step. This difference is very small compared with that of the stabilized energy (132 kJ mol^{-1}) in the [1,3]sigmatropic shift from **31** to **12**. Furthermore, the structural rigidity in the ring system of of **31** might restrict the [3,3]sigmatropic rearrangement.[13] Therefore, it can be proposed that the reaction path which rearranged directly from the sulfonium **2** into the spirointermediate **25** gave the final product **6** as shown Scheme 10.

Experimental

All the melting points are uncorrected. IR spectra were obtained with a Hitachi 215 grating IR spectrophotometer. ^{1}H NMR measurements were carried out on a Hitachi R-90H instrument, using tetramethylsilane as the internal reference.

6-Methyl-12-oxo-5*H*,7*H*-dibenzo[*b*,*g*][1,5]dithiocinium tetrafluoroborate (1a)

To a solution of 5*H*,7*H*-dibenzo[*b*,*g*][1,5]dithiocin 12-oxide[4c,5] (114 mg, 0.44 mmol) in dichloromethane (5 mL) was added excess methyl iodide (0.1 mL) and silver tetrafluoroborate (99.2 mg, 0.51 mmol) successively. The mixture was stirred at room temperature for 8 h. After filtration and concentration, a colourless solid (91.5 mg, 66%) of **1a** was obtained. Recrystallization from acetonitrile–dichloromethane gave a pure sample **1a**: mp 243–246 °C; ^{1}H NMR (δ CD_3CN) 3.20 (s, 3H), 4.77, 5.35 (ABq, J = 14.1 Hz, 4H), 7.50–7.73 (m, 6H) and 8.03–8.18 (m, 2H). Found: C, 49.59; H, 3.94. Calcd for $C_{15}H_{15}OS_2BF_4$: C, 49.74; H, 4.17%.

6-Ethyl-12-oxo-5*H*,7*H*-dibenzo[*b*,*g*][1,5]dithiocinium tetrafluoroborate (1b)

By means of the procedure described for **1a**, **1b** (19.5 mg, 26%)

was obtained from 46.3 mg (0.24 mmol) of the corresponding sulfoxide with excess ethyl iodide (0.1 mL) and silver tetrafluoroborate (46 mg, 0.24 mmol) in dichloromethane (3 mL). For **1b**: ^{1}H NMR (δ CD_3CN) 1.66 (t, J = 7 Hz, 3H), 3.69 (q, J = 7 Hz, 2H), 4.75, 5.31 (ABq, J = 14.0 Hz, 4H), 7.4–7.7 (m, 6H) and 8.0–8.1 (m, 2H).

6-Methyl-5*H*,7*H*-dibenzo[*b*,*g*][1,5]dithiocinium tetrafluoroborate (2)[5]

By means of the method described for **1a**, **2** (140 mg, 86%) was obtained from 139 mg (0.57 mmol) of 5*H*,7*H*-dibenzo-[*b*,*g*][1,5]dithiocin[2,4] in dichloromethane (3 mL). For **2**: mp 212.5–214 °C; ν_{max} (KBr) 1050 cm^{-1}; ^{1}H NMR (δ $CDCl_3$) 3.19 (s, 3H), 4.56, 5.72 (ABq, J = 13.0 Hz, 4H), 7.33–7.65 (m, 6H), and 7.85–8.06 (m, 2H). Found: C, 52.15; H, 4.49. Calcd for $C_{15}H_{15}S_2BF_4$: C, 52.04; H, 4.37%.

6-Methyl-12-oxo-7,12-dihydro-5*H*-dibenzo[*c*,*f*]thiocinium hexachloroantimonate (3)

A solution of 2,2′-dimethylbenzophenone (5.31 g, 25.3 mmol), *N*-bromosuccinimide (10.13 g, 59.6 mmol) and 0.1 g of benzoyl peroxide in 250 mL of carbon tetrachloride was irradiated with a sun-lump for 9 h at reflux. After filtration, the filtrate was dissolved in a solution of 10.8 g of sodium sulfide nonahydrate in 400 mL of methanol. The mixture was heated at reflux for 15 h, followed by concentration to give a yellow solid. The crude product was dissolved in dichlormethane and washed with water. After drying over sodium sulfate and evaporation 2.68 g (44%) of 6-methyl-12-oxo-7,12-dihydro-5*H*-dibenzo[*c*,*f*]thiocin was obtained. Recrystallization from *n*-hexane–dichloromethane gave the pure sample: mp 211.5–213 °C; ν_{max} (KBr) 1625 and 1590 cm^{-1}; ^{1}H NMR (δ $CDCl_3$) 3.49 (s, 4H), 7.2–7.7 (m, 6H) and 7.9–8.0 (m, 2H); ^{13}C NMR (δ $CDCl_3$) 31.2, 127.2, 129.7, 129.8, 133.3, 135.3, 138.9 and 193.6. Found: C, 75.23; H, 4.96. Calcd for $C_{15}H_{12}OS$: C, 74.97; H, 5.03%.

A mixture of the corresponding keto sulfide (56 mg, 0.23 mmol) and trimethyloxonium hexachloroantimonate (95 mg, 0.24 mmol) in dichloromethane (3 mL) was stirred at −78 °C for 15 h under a nitrogen atmosphere. The mixture was filtered and the solid was washed with dichloromethane. A pure sample (60 mg, 43%) of **3** was obtained by recrystallization from acetonitrile–dichloromethane: mp 155–160 °C (decomp.); ν_{max} (KBr) 1640 cm^{-1}; ^{1}H NMR (δ CD_3CN) 2.54 (s, 3H), 4.08, 4.46 (ABq, J = 14.0 Hz, 4H), 7.4–7.6 (m, 2H), 7.7–7.9 (m, 4H) and 8.1–8.2 (m, 2H). Found: C, 32.75; H, 2.54. Calcd for $C_{16}H_{15}OSSbCl_6$: C, 32.58; H, 2.56%.

10b-Phenyl-10b,11-dihydro-6*H*-[1]benzothieno[2,1-*a*][2]benzothiophenium perchlorate (4)

To a solution of Grignard reagent which was prepared from 0.52 mL of bromobenzene and 116 mg (4.8 mmol) of magnesium in 4 mL of THF, the corresponding keto sulfide (1.0 g, 4.2 mmol) in 20 mL of THF was added at 0 °C. The mixture was stirred at reflux for 1 h and poured into ice-water. The product was extracted into dichloromethane. The organic phase was washed with saturated ammonium chloride solution. Following drying and evaporation, 1.2 g (90%) of 7,12-dihydro-12-hydroxy-12-phenyl-5*H*-dibenzo[*c*,*f*]thiocin was obtained: mp 148–150 °C; ν_{max} (KBr) 3370, 1440 and 1000 cm^{-1}; ^{1}H NMR (δ $CDCl_3$ at −30 °C) 2.47 (s, 1H), [3.59, 3.91 (ABq, J = 13.0 Hz) and 3.50, 3.60 (ABq, J = 13.3 Hz), 4H], 6.59 (d, J = 8.0 Hz, 1H) and 6.9–7.6 (m, 12H). Found: C, 79.09; H, 5.82. Calcd for $C_{21}H_{18}OS$: C, 79.21; H, 5.70%.

Treatment of the above alcohol in dichloromethane with 70% aqueous $HClO_4$ solution gave the sulfonium salt (**4**) in quantitative yield: mp >300 °C; ^{1}H NMR (δ CD_3CN) 4.91, 5.21 (ABq, J = 16.0 Hz, 4H) and 7.1–7.5 (m, 13H). Found: C, 63.22; H, 4.30. Calcd for $C_{21}H_{17}O_4SCl$: C, 62.92; H, 4.27%.

Rearrangement of 1a with methanolic potassium hydroxide

A mixture of **1a** (137 mg, 0.399 mmol) and 1.25 g of potassium hydroxide in 20 mL of methanol was stirred at room temperature for 6 h. After solvent removal, the residue was dissolved in dichloromethane and was washed with water before drying. The organic solution was concentrated and thin layer chromatographic separation on silica gel (*n*-hexane–ethyl acetate; 6 : 4) gave 45 mg (41%) of **5a**–**1** and 27 mg (25%) of **5a**–**2**.

Physical data for **5a**–**1**: colourless oil; ν_{max} (neat) 1020 cm^{-1}; ^{1}H NMR (δ $CDCl_3$) 1.94 (s, 3H), 4.25, 4.94 (ABq, J = 14.5 Hz, 2H), 5.12 (s, 1H), 7.15–7.60 (m, 7H) and 7.89–8.10 (m, 1H); ^{13}C NMR (δ $CDCl_3$) 16.5 (q), 57.4 (d), 58.5 (t), 127.5, 128.1, 128.3, 128.8, 129.3, 130.4, 131.1, 132.3 and 132.4; mass (*m*/*z*) 274 (M+, 9%), 241 (M^+ − 33, 16%), 228 (M^+ − 46, 78%), 211 (M^+ − 63, 44%) and 178 (M^+ − 96, 100%). Found: C; 65.48, H; 5.22. Calcd for $C_{15}H_{14}OS_2$: C, 65.66; H, 5.14.

Physical data for **5a**–**2**: colourless oil; ν_{max} (neat) 1020 cm^{-1}; ^{1}H NMR (δ $CDCl_3$) 1.96 (s, 3H), 4.37, 5.82 (ABq, J = 13.0 Hz, 2H), 5.09 (s, 1H), 7.20–7.60 (m, 7H) and 7.9–8.0 (m, 1H); mass (*m*/*z*) 274 (M^+) and the same fragments as those of **5a**–**1**. Found: C, 65.60; H, 5.07. Calcd for $C_{15}H_{14}OS_2$: C, 65.66; H, 5.14%.

Rearrangement of 1b with methanolic potassiun hydroxide

By means of the above procedure, **1b** (19 mg, 0.054 mmol) was rearranged into a mixture of **5b**–**1** and **5b**–**2**. The resultant oil was subjected to preparative layer chromatography on silica gel (*n*-hexane–ethyl acetate; 1 : 1). There were isolated 2.6 mg (18%) of **5b**–**1** and 5.1 mg (35%) of **5b**–**2**. Spectral data for **5b**–**1**; ^{1}H NMR (δ $CDCl_3$) 1.18 (t, J = 7.3 Hz, 3H), 2.35 (q, J = 7.3 Hz, 2H), 4.25, 4.97 (ABq, J = 14.5 Hz, 2H), 5.24 (s, 1H), 7.2–7.6 (m, 7H) and 7.9–8.0 (m, 1H); mass (*m*/*z*) 288 (M^+), 211 (M^+ − 77, 100%). For **5b**–**2**; ^{1}H NMR (δ $CDCl_3$) 1.19 (t, J = 7.4 Hz, 3H), 2.36 (dq, J = 7.4 and 2.8 Hz, 2H), 4.38, 5.80 (ABq, J = 12.9 Hz, 2H), 5.21 (s, 1H), 7.2–7.6 (m, 7H) and 7.9–8.0 (m, 1H); Mass (*m*/*z*) 288 (M^+) and the same fragments as those of **5b**–**1**.

Rearrangement of 2 with methanolic potassium hydroxide

By means of a similar procedure to **1a**, treatment of **2** (135 mg, 0.468 mmol) with 0.7 g of potassium hydroxide in 5 mL of methanol afforded 29.2 mg (29%) of **6** and 5.2 mg (5%) of 2-methoxymethylphenyl 2-methylthiomethylphenyl sulfide (**7**), after thin layer chromatographic separation on silica gel (*n*-hexane–ether; 9 : 1). For **6**: mp 86–87 °C; ^{1}H NMR (δ $CDCl_3$) 2.16 (s, 3H), 4.10, 4.60 (ABq, J = 13.9 Hz, 2H), 5.42 (s, 1H) and 7.0–7.3 (m, 8H); mass (*m*/*z*) 258 (M^+, 7%), 211 (M^+ −47, 100), 178 (M^+ −-80, 68%). Found: C, 69.79; H, 5.23. Calcd for $C_{15}H_{14}S_2$: C, 69.72; H, 5.46%. For the sulfide **7**: ^{1}H NMR (δ $CDCl_3$) 2.05 (s, 3H), 3.41 (s, 3H), 3.86 (s, 2H), 4.57 (s, 2H) and 7.1–7.6 (m, 8H); Mass (*m*/*z*) 290 (M^+, 46%), 211 (M^+ − 79, 100%).

Rearrangement of 3 with methanolic potassium hydroxide

A solution of **3** (280 mg, 0.477 mmol), 0.5 g of potassium hydroxide in 30 mL of methanol was stirred at room temperature overnight. The mixture was neutralized and extracted with dichloromethane. After evaporation of the solvent, the residue was dissolved in ether and carboxylic acid **9** was extracted into aqueous sodium carbonate solution. The acid **9** was extracted again into ether after acidification. The organic layers were dried and concentrated to give **8** (58.4 mg, 45%) and **9** (47.1 mg, 35%), respectively. For **8**: ^{1}H NMR (δ $CDCl_3$) 1.94 (s, 3H), 2.25 (s, 3H), 6.40 (s, 1H), 7.0–7.8 (m, 7H), 7.96 (dd, J = 7.3 and 1.3 Hz, 1H), and 10.3 (s, 1H). Found: C, 70.55; H, 5.96. Calcd for $C_{16}H_{16}O_2S$: C, 70.57; H, 5.92. For **9**: ^{1}H NMR (δ $CDCl_3$) 1.94 (s, 3H), 2.25 (s, 3H), 3.74 (s, 3H), 6.33 (s, 1H), 7.0–7.6 (m, 7H) and 7.80 (dd, J = 7.3 and 1.3 Hz, 1H); mass (*m*/*z*) 286 (M^+, 9%), 239 (M^+ − 47, 100%).

Treatment of **8** (58.4 mg, 0.215 mmol) with excess diazomethane in ether solution afforded **9** in quantitative yield.

Rearrangement of 4 with methanolic potassium hydroxide

By means of a similar procedure to **1a**, treatment of **4** (53 mg, 0.13 mmol) with 0.25 g of potassium hydroxide in 3 mL methanol gave 37 mg of **10** (93%): ^{1}H NMR (δ $CDCl_3$) 3.10 (dd, J = 15.0 and 1.5 Hz, 1H), 3.21 (d, J = 15.0 Hz, 1H), 4.70 (d, J = 1.5 Hz, 1H) and 6.7–7.4 (m, 13H); mass (*m*/*z*) 300 (M^+), 267 ($M^+ - 33$, 94%). Found: C, 84.25; H, 5.32. Calcd for $C_{21}H_{16}S$: C, 84.00; H, 5.37%.

Deoxygenation and demethylthiolation of 5a–1 and 5a–2

(i) Treatment of a mixture of **5a**–**1** and **5a**–**2** (85 mg, 0.31 mmol) with $HSiCl_3$ (0.5 mL)–$LiAlH_4$ (20 mg) in 3 mL of ether at room temperature for 2 h afforded dibenzothiepin derivative (**11**, 27 mg, 41%) along with a small amount of **12** (3 mg, 3%). For **11**; ^{1}H NMR (δ $CDCl_3$) 4.12 (s, 2H), 4.25 (s, 2H), 6.9–7.3 (m, 8H); Mass (*m*/*z*) 212 (M^+, 78%), 178 ($M^+ - 34$, 100%). For **12**; ^{1}H NMR (δ $CDCl_3$) 2.00 (s, 3H), 3.71, 5.35 (ABq, J = 14.0 Hz, 2H), 5.07 (s, 1H) and 6.93–7.35 (m, 8H); Mass (*m*/*z*) 258 (M^+, 10%), 211 ($M^+ - 47$, 75%), 210 ($M^+ - 48$, 80%), 178 ($M^+ - 80$, 100%). The spectra were superimposable upon those of authentic samples of **11** and **12** which were prepared by way of an alternative procedure, respectively.

(ii) Reaction of **5a**–**1** (45 mg, 0.16 mmol) with triphenylphosphine (100 mg)–carbon tetrachloride (2 mL) reagents in acetonitrile (4 mL) in the presence of trifluoroacetic acid (0.1 mL) afforded a mixture of deoxygenated products. Thin layer chromatographic separation (*n*-hexane–ethyl acetate; 1 : 1) gave 16 mg (38 %) of **12**, 7 mg (19%) of **13** and the recovered substrate **5a**–**1** (9 mg, 20%).

(iii) By means of an analogous procedure, treatment of **5a**–**2** (27 mg, 0.099 mmol) with triphenylphosphine (60 mg)–carbon tetrachloride (1 mL) afforded 8 mg (32%) of **12**, 9 mg (41%) of **13** and the starting material **5a**–**2** (6 mg, 22%).

Equilibration between 5a–1 and 5a–2

A solution of **5a**–**1** (51 mg, 0.19 mmol) in methanol (6 mL) containing 0.3 g of potassium hydroxide was allowed to stand at room temperature for 20 h to result in equilibrium between **5a**–**1** and **5a**–**2**. After the predescribed workup, the ratio was determined to be **5a**–**1** : **5a**–**2** = 1.54, evaluated from the integral value of each methyl proton in the ^{1}H NMR spectrum. By the same methodology, treatment of **5a**–**2** (34 mg, 0.12 mmol) with potassium hydroxide (0.4 g) in 5 mL methanol afforded a mixture of **5a**–**1** and **5a**–**2**, the ratio being 1.57.

11-Hydroxy-6,11-dihydrodibenzo[*b*,*e*]thiepin (13)

To a stirred suspension of $LiAlH_4$ (0.7 g, 18.4 mmol) in anhydrous THF (80 mL) was added dropwise a solution of 6,12-dihydro-12-oxo-dibenzo[*b*,*e*]thiepin[8] (**14**) (3.60 g, 15.8 mmol) in the same solvent (20 mL). The mixture was stirred at 0 C for 1 h and at reflux for 3 h before the excess hydride was decomposed. Workup in the usual manner gave 3.55 mg (98%) of a solid **13**: mp 108–109 °C (lit.,[8] 107.5–109 °C); ^{1}H NMR (δ $CDCl_3$) 2.6–3.2 (br s, 1H), 4.10, 4.34 (ABq, J = 13.6 Hz, 2H), 5.96 (s, 1H) and 6.9–7.5 (m, 8H).

11-Deutero-11-hydroxy-6,11-dihydrodibenzo[*b*,*e*]thiepin (13-D)

Reduction of a 510 mg (2.24 mmol) sample of **14** with 52 mg (1.37 mmol) of lithium aluminium deuteride in 5 mL of ether as described above afforded 491 mg (95%) of **13**-D: ^{1}H NMR (δ $CDCl_3$) 2.1–3.2 (br s, 1H), 4.10, 4.34 (ABq, J = 14.4 Hz, 2H) and 7.0–7.7 (m, 8H); mass (*m*/*z*) 231 (M^+).

11-Methylthio-6,11-dihydrodibenzo[*b*,*e*]thiepin (12)

To a solution of **13** (55 mg, 0.24 mmol) in dichloromethane (0.3 mL) was added excess thionyl chloride (0.3 mL). The reaction mixture was stirred at room temperature for 30 min and concentrated to give chloride **15**.[9] The crude sample of **15** was dissolved 1 mL of DMF and the solution was treated with methane thiolate prepared from dimethyl disulfide (0.1 mL) and lithium aluminium hydride (35 mg, 0.92 mmol) in ether (2 mL). The mixture was stirred at room temperature for 1 day and poured into ice-water. Workup and TLC separation on silica gel afforded 42 mg (72%) of an oily product **12**. Found: C, 69.68; H, 5.43. Calcd for $C_{15}H_{14}S_2$: C, 69.72; H, 5.46%.

11-Deutero-11-methylthio-6,11-dihydrodibenzo[*b*,*e*]thiepin (12-D)

By the same methodology, **12**-D was obtained in 86% yield: ^{1}H NMR (δ $CDCl_3$) 2.00 (s, 3H), 3.71, 5.35 (ABq, J = 14 Hz, 2H) and 6.93–7.35 (m, 8H); mass (*m*/*z*) 258 (M^+, 12%), 212 ($M^+ - 46$, 95%), 211 ($M^+ - 47$, 100%), 179 ($M^+ - 79$, 74%).

Hydrolysis of the chloride 15 under basic conditions

Treatment of **15**, which was prepared from **13** (102 mg, 0.443 mmol), with 15% aqueous potassium hydroxide (0.5 mL) in 5 mL of acetonitrile gave 101 mg of **13**.

6,11-Dihydrodibenzo[*b*,*e*]thiepin (11)

To a stirred suspension of $LiAlH_4$ (390 mg, 10.3 mmol) and anhydrous aluminium chloride (2.8 g, 21 mmol) in anhydrous ether (5 mL) was added dropwise a solution of **14** (900 mg, 4.2 mmol) in the same solvent (1 mL). The mixture was stirred at reflux for 1 h before the excess hydride was decomposed with water. Workup in the predescribed manner gave 380 mg (45%) of a colourless oil **11**. Found: C, 69.69; H, 5.47. Calcd for $C_{15}H_{14}S_2$: C, 69.72; H, 5.46%.

6-Methylthio-6,11-dihydrodibenzo[*b*,*e*]thiepin (6)

To a solution of **11** (109 mg, 0.51 mmol) in 3 mL of dichloromethane was added sulfonyl dichloride (0.045 mL, 0.56 mmol). After being stirred for 2 h at reflux, the reaction mixture was concentrated and the residue was dissolved in 4 mL of acetonitrile. Without further purification, reaction of the crude sample **16** with methane thiolate prepared as predescribed manner afforded an oily product containing **6**. Thin layer chromatographic separation on silica gel (*n*-hexane–ether; 9 : 1) gave 20 mg of a pure sample (**6**, 20 mg) in 15% yield based on **11**.

2-Methyl-2′-(4,4-dimethyl-1,3-oxazol-2-yl)diphenylmethyl alcohol (18)

To a solution of 4,4-dimethyl-2-(2-bromophenyl)-1,3-oxazole[10] (4.0 g, 15.3 mmol) in 20 mL of THF was added 13 mL (19.5 mmol) of 1.5 M *n*-butyllithium in hexane solution at −78 °C under a nitrogen atmosphere. The mixture was stirred for 20 min at the same temperature and warmed to room temperature. After being cooled again to −78 °C, 2.4 g (20 mmol) of *o*-tolualdehyde in 20 mL THF was introduced into the anion solution. The mixture was stirred at −78 °C for 30 min and then at room temperature for 3 h. After workup, column chromatographic separation on silica gel (ether–hexane; 3 : 10 and then ethyl acetate) furnished a pure sample **18** (4.6 g, 99%): ν_{max} (neat) 3300, 3000, 1650, 1470, 1360, 1320, 1230 and 1050 cm^{-1}; ^{1}H NMR (δ $CDCl_3$) 1.39 (s, 3H), 1.43 (s, 3H), 1.97 (s, 3H), 4.15, 4.18 (ABq, J = 8.0 Hz, 2H), 6.20 (s, 1H) and 6.7–7.9 (m, 8H); mass (*m*/*z*) 295 (M^+, 93%), 223 ($M^+ - 72$, 100%).

3-(*o*-Tolyl)-1-oxy-(3*H*)-isobenzofuran (19)

A mixture of **18** (1.5 g, 5.1 mmol) and 30 mL of 3 M hydrochloric acid in 30 mL of methanol was heated at reflux for 1 h. After concentration of the solution, the product was extracted

into ether. The organic phase was washed with water prior to drying and evaporated. The residue was purified by preparative thin layer chromatography to yield 1.1 g (96%) of **19**: Mp 113 °C; ν_{max} 300, 1770, 1470, 1300, 1220 and 1170 cm^{-1}; ^1H NMR (δ $CDCl_3$) 2.50 (s, 3H), 6.65 (s, 1H) and 6.8–8.0 (m, 8H); mass (*m*/*z*) 224 (M^+, 100%) Found: C, 80.18; H, 5.50. Calcd for $C_{15}H_{12}O_2$: C, 80.34; H, 5.39%.

2-Carboxy-2′-methyldiphenylmethyl methylsulfide (8)

To a solution of methane thiolate prepared from dimethyl disulfide (200 mg, 2.1 mmol) and $LiAlH_4$ (20 mg, 0.53 mmol) in THF by heating at reflux for 1 day, was added a solution of **22** (100 mg, 0.45 mmol) in 5 mL of hexamethylphosphoric triamide (HMPA). The mixture was stirred at 100 °C for 6 h and poured into ice-water. The product was taken up in ether. The organic phase was washed with diluted hydrochloric acid and the acid product was extracted into aqueous sodium carbonate solution. After neutralization of the alkaline solution, the aqueous phase was extracted with ether. The combined extracts were dried over sodium sulfate and evaporated to yield **8** (37.4 mg, 29%). Treatment of **8** (30.4 mg, 0.112 mmol) with excess diazomethane in ether solution afforded **9** in quantitative yield. The spectral data were consistent with those of **8** and **9**, which were obtained from rearrangement of **3**.

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