REACTIVITY STUDIES OF [1]BENZOTHIENO[3,2-*b*][1]BENZOFURAN

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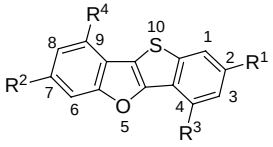
Electrophilic substitution and metallation reactions of the title compound **1** were studied. Bromination, acetylation, benzoylation, formylation, and nitration usually afforded nonseparable mixtures of 2- and 7-substituted derivatives as the main product. Disubstitution reactions preferably led to 2,7-disubstituted derivatives. [1]Benzothieno-[3,2-*b*][1]benzofuran 10,10-dioxide (**17**) and [1]benzothieno[3,2-*b*][1]benzofuran 10-oxide (**18**) can be selectively obtained by oxidation of **1**. Mononitration of **17** and **18** led selectively to corresponding 7-nitro derivatives **19** and **21**, respectively. Only sulfoxides **19** and **20** were successfully reduced. Reduction of the 5-oxide moieties was successful only at the sulfoxide stage. Metallation of **1** with butyllithium preferably proceeds in positions 1 and 6; subsequent reaction with methyl iodide or carbon dioxide led to the corresponding dimethyl derivative **25** or esters **26** and **27**, respectively. An unusual addition of butyllithium to the central double bond of **1** was also observed in a small extent producing 9b-butyl-4b,9b-dihydro[1]benzothieno[3,2-*b*][1]benzofuran-4b-ol (**29**). The structures of all products were elucidated by NMR.

Key words: [1]Benzothieno[3,2-*b*][1]benzofuran; Fused heterocycles; Electrophilic substitutions; Oxidations; Bromination; Acetylation; Benzoylation; Formylation; Nitration; Metallation.

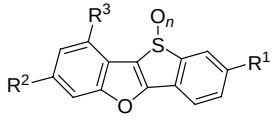
In our systematic research on fused benzothieno[3,2-*b*]furans, we studied synthesis and reactivity of isomeric [1]benzothieno[3,2-*b*]furan[1,2] and thieno[3,2-*b*][1]benzofuran[3]. We showed that [1]benzothieno[3,2-*b*]furan and its vinyl derivatives due to their imperfect aromaticity underwent a series of Diels–Alder reactions[4,5] leading to a new type of condensed heterocyclic system, [1]benzothieno[3,2-*b*][1]benzofuran (**1**). The reactivity of analogous dibenzo [1,4]-diheteropentalenes has hardly been studied[6]. In several cases it was shown that electrophilic substitution proceeded in positions 2 and 7; on the other hand, nitration[7] of [1]benzothieno[3,2-*b*]-[1]benzothiophene led to a mixture of 2- and 4-substituted products. Formylation of 10-methyl[1]benzothieno[3,2-*b*]indole showed a quite different regioselectivity[8]. With one exception[8], metallation of dibenzo-

[1,4]diheteropentalenes has not been studied so far. Here we wish to summarize results of our study of electrophilic substitution and metallation reactions of the heterocyclic system **1**.

In analogy with the known results, we expected that an electrophilic species would preferably attack positions 2 and 7. With respect to the fact that dibenzofuran is more reactive than dibenzothiophene[9], one can also anticipate that the benzofuran moiety of the molecule **1** could be more prone to



	R^1	R^2	R^3	R^4
1	H	H	H	H
2	Br	Br	H	H
8	H	COPh	H	H
9	COPh	H	H	H
10	COPh	COPh	H	H
11	H	CHO	H	H
12	CHO	H	H	H
13	H	NO_2	H	H
14	NO_2	H	H	H
15	H	H	NO_2	H
16	NO_2	NO_2	H	H



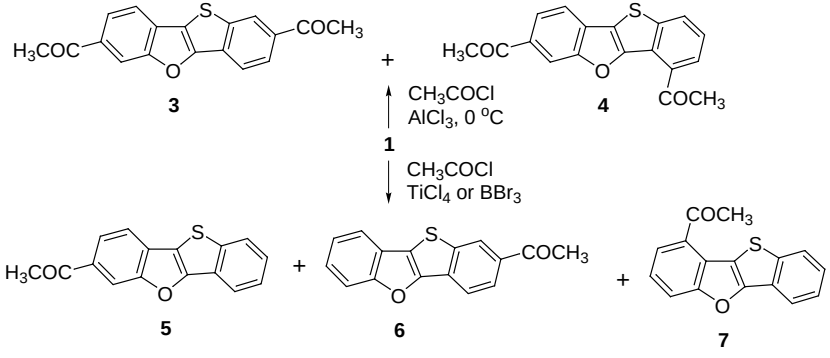
	R^1	R^2	R^3	*n*
17	H	H	H	2
18	H	H	H	1
19	H	NO_2	H	1
20	H	H	NO_2	1
21	H	NO_2	H	2
22	NO_2	NO_2	H	2
23	H	NH_2	H	0
24	H	NH_2	H	2

the electrophilic attack than the benzothiophene moiety. For prediction of the reactivity, we also carried out[10] a series of *ab initio* calculations (base G 6-31/G 6-31). While calculation of electron densities at individual carbon atoms of the system **1** did not show a clear tendency, the calculation of HOMO orbital coefficients predicted a higher activation of positions 2 and 7. Lower activation was obtained for carbon atoms 4 and 9.

Bromination of the compound **1** with one equivalent of bromine afforded a mixture of products, probably monobromo derivatives of **1**, which could not be separated into individual compounds. The same result was obtained with milder brominating agents – dioxane dibromide or *N*-bromosuccinimide in *N*,*N*-dimethylformamide[11]. Because the ^{1}H NMR spectrum of the product mixture was very complicated and lacked characteristic signals, it was impossible to assign the structures of the components. Application of two bromine equivalents led to disubstitution of the ring system **1** providing high yield of 2,7-dibromo[1]benzothieno[3,2-*b*][1]benzofuran (**2**)

(see structure above). Compound **2** was accompanied in the crude reaction mixture by trace quantities of other isomeric bromo derivatives. However, due to their similar behavior with the major product, it could not be separated by column chromatography. Also, because of similarity of ^{1}H NMR spectra, their structures could not be exactly determined.

Therefore we turned our attention to Friedel–Crafts acylation reactions where we hoped to obtain products that could be more easily separated by chromatographic methods into individual regioisomers. Reaction of **1** with an excess of acetyl chloride in the presence of aluminum chloride at 0 °C afforded 84% yield of a mixture of 2,7-diacetyl[1]benzothieno[3,2-*b*]-[1]benzofuran (**3**) and 4,7-diacetyl[1]benzothieno[3,2-*b*][1]benzofuran (**4**) in the ratio 3 : 1 (based on the integral intensities of characteristic signals in ^{1}H NMR spectrum) (Scheme 1). These compounds were separated by multiple column chromatography. If the reaction was carried out at –78 °C, monoacetylation took place and a nonseparable mixture of 7-acetyl-[1]benzothieno[3,2-*b*][1]benzofuran (**5**) and 2-acetyl[1]benzothieno[3,2-*b*]-[1]benzofuran (**6**) in the ratio 2 : 1 was obtained (yield 88%).



SCHEME 1

Analogous acetylation of **1** catalyzed with titanium tetrachloride or boron tribromide proceeded at room temperature and, in addition to a mixture of compounds **5** and **6** (ratio 3 : 2, yields 85 and 79%), a minor product, 9-acetyl[1]benzothieno[3,2-*b*][1]benzofuran (**7**), was detected and subsequently isolated in a low yield (1–2%). Both acetylations led only to monosubstitued products, no disubstitution was observed even at heating to reflux in dichloromethane. Regioselectivity of acetylation reactions can be hence influenced by reaction conditions.

Benzoylation, which proceeds slower and more selectively than acetylation[9], was performed with benzoyl chloride at 0 °C under aluminum chloride catalysis affording again a mixture of 7-benzoyl[1]benzothieno-[3,2-*b*][1]benzofuran (**8**) and 2-benzoyl[1]benzothieno[3,2-*b*][1]benzofuran (**9**) in the ratio 3 : 2 (87% yield). Disubstitution was achieved by refluxing **1** with an excess of benzoyl chloride in dichloromethane and 2,7-dibenzoyl-[1]benzothieno[3,2-*b*][1]benzofuran (**10**) was isolated (73%) as the sole product. No minor product was detected by thin layer chromatography and ^{1}H NMR spectroscopy.

An attempted Vilsmeier–Haack reaction of **1** was not successful even by long-term heating of the reaction mixture to 60 °C. Neither did formylation take place with the zinc cyanide–aluminum chloride–hydrogen chloride system. Formylation proceeded in this case with butyl dichloromethyl ether[12] under titanium tetrachloride catalysis; again, in agreement with previous results, a nonseparable mixture of [1]benzothieno[3,2-*b*][1]benzofuran-7-carbaldehyde (**11**) and [1]benzothieno[3,2-*b*][1]benzofuran-2-carbaldehyde (**12**) was obtained (ratio 2 : 1, 75% yield). No other monosubstituted product was detected. An attempt to introduce additional formyl group into the molecules of **11** and **12** with butyl dichloromethyl ether under aluminum chloride catalysis at elevated temperature was unsuccessful.

Nitration of **1** with fuming nitric acid at –60 °C led to mononitro products: the major product (92%) was a nonseparable mixture of 7-nitro-[1]benzothieno[3,2-*b*][1]benzofuran (**13**) and 2-nitro[1]benzothieno[3,2-*b*]-[1]benzofuran (**14**) in the 1 : 1 ratio, which was accompanied by a minor portion (4%) of 4-nitro[1]benzothieno[3,2-*b*][1]benzofuran (**15**). Nitration of the mixture of **13** and **14** with 100% nitric acid at room temperature led to a high yield of 2,7-dinitro[1]benzothieno[3,2-*b*][1]benzofuran (**16**) as the sole product. Surprisingly, in no experiment a product of sulfur oxidation[9] was detected.

We attempted to influence the reactivity of the ring system **1** by modification of the benzothiophene moiety of the skeleton of **1**. Oxidation of sulfur in [1]benzothiophene to [1]benzothiophene 1,1-dioxide leads to a full deactivation of positions 2 and 3 and an electrophilic species enters[13–15] position 6. An analogous change in the regioselectivity was observed[16–18] for dibenzothiophene 5-oxide and 5,5-dioxide. We assumed that oxidation of sulfur atom in **1** to sulfoxide or sulfone would create an electron-acceptor center that would deactivate the benzothiophene moiety of **1** affecting the regioselectivity of electrophilic substitution of **1**.

For the preparation of [1]benzothieno[3,2-*b*][1]benzofuran 10,10-dioxide (**17**), we applied, besides usual agents as hydrogen peroxide in acetic acid[6,19] and 3-chloroperoxybenzoic acid[6,20], also system of urea–hydrogen peroxide adduct and phthalic anhydride[21]. All three methods provided the expected sulfone **17** in excellent yields. Monitoring the course of the reaction showed the presence of an oxidation intermediate [1]benzothieno-[3,2-*b*][1]benzofuran 10-oxide (**18**). The best results of the selective oxidation of **1** to sulfoxide **18** were obtained with hydrogen peroxide in acetic acid at 40 °C (72% yield).

To study the regioselectivity of electrophilic substitution, we chose nitration as a model reaction. Nitration of sulfoxide **18** with fuming nitric acid in dichloromethane afforded in a moderate yield (39%) 7-nitro[1]benzothieno[3,2-*b*][1]benzofuran 10-oxide (**19**), accompanied by a trace amount (4%) of 9-nitro[1]benzothieno[3,2-*b*][1]benzofuran 10-oxide (**20**). The use of nitronium tetrafluoroborate in nitromethane[22] at –30 °C led to an increased yield (65%) of **19**. 9-Nitro derivative **20** was also isolated in a low yield (7%).

In comparison with sulfoxide **18**, the sulfone **17** showed a substantially lower reactivity and was resistent to 100% nitric acid even at reflux in dichloromethane. On the other hand, the reaction with nitronium tetrafluoroborate at –30 °C afforded 7-nitro[1]benzothieno[3,2-*b*][1]benzofuran 10,10-dioxide (53%) (**21**) and 2,7-dinitro[1]benzothieno[3,2-*b*][1]benzofuran 10,10-dioxide (14%) (**22**) as the dinitration products.

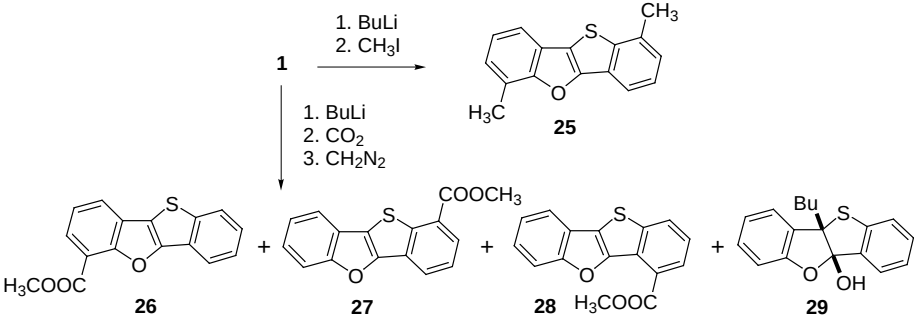
Subsequently, we studied reduction of the main products **19** and **21** with the aim to prepare derivatives of **1**. Reduction of 7-nitro sulfoxide **19** with zinc and hydrochloric acid in acetic acid[23] at room temperature produced smoothly almost quantitative yield of [1]benzothieno[3,2-*b*][1]benzofuran-7-amine (**23**). Analogous reduction of 7-nitro sulfone **21** afforded only a product of the nitro group reduction, [1]benzothieno[3,2-*b*][1]benzofuran-7-amine 10,10-dioxide (**24**). Increasing the reaction temperature to 60 °C led only to decomposition of the starting material. The use of reducing hydrides (lithium aluminum hydride, diisobutylaluminum hydride)[24,25] at 0 °C as well as at room temperature was also unsuccessful.

Substitution in sulfone **17** and sulfoxide **18** leads to a regioselective introduction of substituent into the benzofuran part of heterocycle **1**. Subsequently, the sulfoxide **18** can be reductively transformed in derivatives of **1**. Thus, this sequence of reactions enables a regioselective synthesis of 7-substituted derivatives of **1**.

Metallation of heterocyclic compounds enables introduction of many functional groups into their skeletons. Especially lithiations are very impor-

tant. In the group of dibenzo[1,4]diheteropentalenes only lithiation of *N*-methyl[1]benzofuro[3,2-*b*]indole, leading to 6-substituted derivatives, has been studied[8].

First attempt to metallate compound **1** with the goal to identify its reactive centers was made with an excess of butyllithium. Trapping the intermediate lithium derivatives with methyl iodide afforded 1,6-dimethyl-[1]benzothieno[3,2-*b*][1]benzofuran (**25**) as the major product (Scheme 2). In the mother liquor after separation of **25**, other minor methylated compounds were detected by ^{1}H NMR spectroscopy. However, due to their chromatographic behavior identical with **25**, we were unable to isolate and identify these minor products. But, the positions 1 and 6 were found to be preferred in an attack of a strong base.



SCHEME 2

To explore the regioselectivity and reactivity of the individual positions of metallation, we chose transformation of the formed lithium derivatives to the corresponding carboxylic esters, where we expected different chromatographic properties of individual regioisomers. Metallation of compound **1** with butyllithium was followed by a reaction with solid carbon dioxide and subsequent esterification of the crude product with diazomethane. All the reactions performed afforded mixtures of regioisomeric methyl esters (Scheme 2): methyl [1]benzothieno[3,2-*b*][1]benzofuran-6-carboxylate (**26**), methyl [1]benzothieno[3,2-*b*][1]benzofuran-1-carboxylate (**27**), and, surprisingly, also methyl [1]benzothieno[3,2-*b*][1]benzofuran-4-carboxylate (**28**). The ratio of products **26**, **27**, and **28** was under various reaction conditions approximately the same (12 : 3 : 1). The preference of **26** to **27** was in a good agreement with the higher reactivity of dibenzofuran in comparison with dibenzothiophene[9]. Compound **28** seems to be the product a thermodynamic control[26] of lithiation. The fourth product de-

tected and isolated in a low yield (6%) was a very unstable 9b-butyl-4b,9b-dihydro[1]benzothieno[3,2-*b*][1]benzofuran-4b-ol (**29**). From the structure of **29**, it can be inferred that, to a small extent, addition of butyllithium to the central double bond took place and the formed lithium intermediate was oxidized, either by traces of oxygen in the reaction mixture or during the workup, to provide compound **29**.

The structure of newly prepared compounds was confirmed by NMR, IR, mass spectra, and elemental analyses. To elucidate the regioselectivity of the substitution reactions, we made use of detailed assignment of ^{1}H and ^{13}C NMR signals of compounds **2**–**4**, **7**, **15**–**23**, and **25**–**27** (Tables I–III). This process, based on detection of mutiplicities of ^{13}C NMR signals, ^{3}J(H,H), ^{1}J(C,H) and long-range proton–carbon interactions, was described in detail for [1]benzothieno[3,2-*b*][1]benzofuran (**1**) earlier[4,5]. Due to complexity of ^{1}H NMR spectra of **10** and **17**, spin-spin coupling could not be exactly established. From the results, it can be emphasized that chemical shifts of quaternary carbons C-4b, C-5a, and C-10a (Table III) are in all cases characteristic. Therefore, they served as starting points for the assignments. However, due to the absence of any characteristic signal around 155 ppm in the ^{13}C NMR spectrum of ester **28**, it was not possible to assign its NMR data. The multiplicity of signals in ^{1}H NMR spectrum of **28** shows that the substituent entered the position 1, 4, 6 or 9. Because the ^{1}H and ^{13}C NMR spectra of methyl [1]benzothieno[3,2-*b*][1]benzofuran-9-carboxylate[4], methyl [1]benzothieno[3,2-*b*][1]benzofuran-6-carboxylate (**26**), and methyl [1]benzothieno[3,2-*b*][1]benzofuran-1-carboxylate (**27**) were fully assigned, it was possible to establish also the structure of compound **28**.

The assignment of ^{1}H and ^{13}C NMR signals of compounds **3** and **16** enabled also analyses of spectra of mixtures of monosubstituted isomers (except brominated ones). Introduction of an electron-withdrawing substituent (acetyl or nitro group) into position 2 and 7 shifts the signals of adjacent protons downfield. Especially chemical shifts of H-1 and H-6 become characteristic. Spectra of acetylation and nitration mixtures contain signals which by their chemical shifts and multiplicities fit to the above discussed signals of disubstituted derivatives **3** and **16** (Table I). Hence, it was possible to assign these signals to the corresponding monosubstituted isomers **5** and **6** and to determine their ratio in the reaction mixture. In the same way, the ratios of monosubstituted isomers **8** and **9**, **11** and **12**, **13** and **14** in the reaction mixtures could also be determined.

A comparison of chemical shifts of protons of sulfone **17** and sulfoxide **18** with the parent system **1** shows no significant changes (from 0 to 0.18 ppm). Only proton H-4 is shifted upfield (0.26 and 0.31 ppm, respectively)

TABLE I
^{1}H NMR data of [1]benzothieno[3,2-*b*][1]benzofuran derivatives

Compound	H-1	H-2	H-3	H-4	H-6	H-7	H-8	H-9
1	7.85 d	7.36 m	7.45 ddd	7.98 d	7.63 dd	7.36 m	7.32 ddd	7.70 dd
2	8.04 d	–	7.62 dd	7.87 d	7.84 d	–	7.51 dd	7.60 d
3[a]	8.54 s	–	8.11 s[b]	8.11 s[b]	8.28 s	–	8.03 d	7.84 d
4[c]	8.04 d	7.48 dd	7.88 d	–	8.32 bs	–	8.00 dd	7.78 d
5[d]	n.d.[e]	n.d.	n.d.	n.d.	8.24 d	–	n.d.	n.d.
6[d]	8.50 bs	–	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
7[f]	7.96 dd	7.46 m	7.50 ddd	8.04 dd	7.85 dd	7.46 m	7.90 dd	–
8	n.d.	n.d.	n.d.	n.d.	8.14 bs	–	n.d.	n.d.
9	8.38 bs	–	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
10[g]	8.40 bs	–	n.d.	n.d.	8.17 bs	–	n.d.	n.d.
11	n.d.	n.d.	n.d.	n.d.	8.15 s	–	n.d.	n.d.
12	8.14 s	–	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
13	n.d.	n.d.	n.d.	n.d.	8.53 d	–	n.d.	n.d.
14	8.81 d	–	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
15	8.15 d	7.48 dd	8.31 d	–	7.77 d	7.51 ddd	7.41 dd	7.79 d
16	8.91 d	–	8.45 dd	8.23 d	8.64 d	–	8.39 dd	7.96 d
17	7.80 m[b]	7.57 ddd	7.63 m	7.67 d	7.63 m	7.45 m	7.43 m	7.80[b]
18	7.98 d	7.53 ddd	7.60 ddd	7.72 d	7.62 m	7.41 m[b]	7.41[b]	7.88 m
19	8.05 d	7.66 ddd	7.70 ddd	7.84 d	8.55 d	–	8.37 dd	8.00 d
20	8.08 m	7.67 m[b]	7.67 m[b]	7.83 m	7.98 d	7.57 dd	8.36 d	–
21	7.87 bd	7.69 ddd	7.73 ddd	7.77 dd	8.57 d	–	8.39 dd	7.93 d
22[h]	8.94 bs	–	8.63 dd	8.20 d	8.90 bs	–	8.38 bd	8.23 d
23[i]	7.85 d	7.32 dd	7.44 dd	7.92 d	6.95 d	–	6.72 dd	7.48 d
24[j]		7.42–7.58 m			6.85 d	–	6.74 dd	7.73 d
25[k]	–	7.24 d	7.45 dd	7.94 d	–	7.22 d	7.29 dd	7.60 d
26[l]	7.91 d	7.44 dd	7.52 dd	8.16 d	–	8.06 d	7.43 dd	7.93 d
27[m]	–	8.16 d	7.58 dd	8.20 d	7.68 d	7.43 ddd	7.39 dd	7.81 d
28[n]	8.06 d	7.52 dd	8.15 d	–	7.96 d	7.43 dd	7.49 dd	7.93 d

[a] Other signals: 2.73 s, 6 H (2 × $COCH_3$); [b] Collapsed of multiplets of two coupled protons with close chemical shifts; [c] Other signals: 2.85 s, 3 H ($COCH_3$) and 2.70 s, 3 H ($COCH_3$); [d] Another signal: 2.75 s, 3 H ($COCH_3$); [e] Not determined; [f] Another signal: 2.78 s, 3 H ($COCH_3$); [f] Other signals: 7.46–7.68 m, 7 H; 7.76–7.92 m, 5 H; 7.99 dd, 1 H, J_1 = 8.2, J_2 = 1.1; 8.14 d, 1 H, J = 8.2; [h] in DMSO-d_6; [i] Another signal: 3.86 bs, 2 H (NH_2); [j] Another signal: 3.97 bs, 2 H (NH_2); [k] Other signals: 2.63 s, 3 H (1-CH_3) and 2.69 s, 3 H (6-CH_3); [l] Another signal: 4.11 s, 3 H (OCH_3); [m] Another signal: 4.09 s, 3 H (OCH_3); [n] Another signal: 4.05 s, 3 H (OCH_3).

and loses its position of the proton with the highest chemical shift. However, the ^{1}H NMR spectra are too complicated to determine ^3J(H,H).

^{13}C NMR spectra of **17** and **18** showed more significant changes. Carbon C-4b is, in comparison with compound **1**, shifted downfield (8.3 and 16.0 ppm, respectively) and becomes the carbon with the highest chemical shift. In the case of sulfoxide **18**, another quaternary carbon, C-10a, is shifted (9.5 ppm) downfield. The oxidation of sulfur atom causes that the chemical shifts of carbons C-2 and C-3 are above 130 ppm and are quite characteristic. Sulfoxide **18** exhibits also a shifted signal of tertiary carbon C-1 (+ 8.4 ppm). Such changes in NMR spectra correspond only partly to the analogous [1]benzothiophene[27,28] and dibenzothiophene[29,30] dioxides.

TABLE II
^{1}H-^{1}H coupling constants J of [1]benzothieno[3,2-*b*][1]benzofuran derivatives

Compound	J(1,2)	J(1,3)	J2,3)	J(2,4)	J(3,4)	J(6,7)	J(6,8)	J(7,8)	J(7,9)	J(8,9)
1	8.1	0.9	7.1	n.o.	7.9	7.2	1.1	7.2	1.6	7.3
2	–	1.6	–	–	8.4	–	1.5	–	–	8.3
3	–	n.o.[a]	–	–	n.o.	–	n.o.	–	–	8.2
4	8.0	n.o.	7.3	–	–	–	1.2	–	–	8.2
7	7.8	0.9	7.1	1.2	7.7	8.2	0.7	7.8	–	–
15	8.1	n.o.	7.9	–	–	8.2	n.o.	7.4	1.0	7.7
16	–	1.9	–	–	8.8	–	1.8	–	–	8.7
18	7.7	0.8	7.6	0.9	7.4	n.d[b]	n.d.	n.d.	n.d.	n.d.
19	7.3	1.0	7.6	1.1	7.4	–	1.9	–	–	8.7
20	n.d.	n.d.	n.d.	n.d.	n.d.	8.2	n.o.	8.1	–	–
21	7.3	1.1	7.5	1.2	7.3	–	2.0	–	–	8.7
22[c]	–	1.7	–	–	8.3	–	n.o.	–	–	8.6
23	8.3	n.o.	7.1	n.o.	7.7	–	1.7	–	–	8.2
24	n.d.	n.d.	n.d.	n.d.	n.d.	–	2.2	–	–	8.8
25	–	–	7.7	n.o.	7.9	–	–	7.6	n.o.	7.5
26	8.1	n.o.	7.2	n.o.	7.8	–	–	7.7	n.o.	7.8
27	–	–	7.6	n.o.	7.8	8.1	n.o.	7.4	1.3	7.3
28	7.7	n.o.	7.4	–	–	7.8	n.o.	7.4	n.o.	8.0

[a] Not observed; [b] Not determined; [c] Measured in DMSO-d_6.

TABLE III
^{13}C NMR data of derivatives of [1]benzothieno[3,2-*b*][1]benzofuran derivatives

Compound	C-1	C-2	C-3	C-4	C-4a	C-4b	C-5a	C-6	C-7	C-8	C-9	C-9a	C-9b	C-1-a
1	120.4	125.6[a]	125.6[c]	125.0	125.9	153.7	159.5	113.2	125.6[c]	124.0	120.3	124.8	119.3	142.7
2	127.6	119.6[c]	129.3	121.4	124.3	153.4	159.7	116.8	119.0[c]	127.6	121.1	123.6	119.4[c]	144.0
3[b]	125.9	135.1	126.0	120.9	128.3[c]	155.5	159.7	113.6	135.6	124.8	120.5	128.3[c]	122.9	143.4
4[c]	129.1	125.5	127.3	134.4	127.9	155.8	159.1	144.2	135.4	124.2	120.1	127.9	122.2	144.9
7[d]	124.8	125.9	124.9	120.5	124.3	155.9	160.0	117.8	125.3	126.3	129.2	124.3[c]	121.0	144.4
15	130.9[e]	124.3	123.1[e]	145.0	119.5	150.7	159.7	114.0	127.6	124.3	120.7	123.4	125.1	143.0
16	121.6[c]	146.2	121.6[c]	121.6[c]	128.5	156.0	158.5	110.1	146.8	120.4	121.0	129.0	124.4	142.5
17	123.0	131.6	134.0	120.9	125.7	159.7[c]	159.9[c]	113.6	127.3	126.3	121.2	121.2[c]	121.0[c]	146.1
18	128.8	130.5	132.8	121.3	128.2	161.5	159.8	113.5	126.7	125.8	121.1	124.6	121.2	152.2
19	128.8	1332.0	133.3	122.4	127.3	166.0	158.4	110.0	146.4	121.6	121.0	130.2	125.6	152.7
20	128.8	132.2	132.9	122.1	127.0	165.5	160.0	119.6	126.0	121.8	140.7	121.7	125.1	152.8
21	123.4	133.1	134.4	121.9	124.6	164.2	158.3	110.1	147.0	122.0	121.2	126.7	120.5	146.4
22[f]	118.6	145.3	130.0	122.9	128.3	161.4	157.7	110.1	146.3	121.5	121.0	1124.9	12.1	149.7
25[g]	134.2	126.1	125.9	118.1	125.5	154.3	158.5	123.6	1126.7	124.7	117.7	124.5	119.2	142.7
26[h]	125.1	126.1	125.8	121.1	125.7	154.8	158.1	117.0	127.9	123.8	125.1	126.4	229.0	143.0
27	127.0	127.7	125.9	124.7	125.8	153.3	159.6	113.2	125.2	124.0	120.6	124.5	122.3	143.4

[a] Interchangeable chemical shifts; [b] Other signals: 27.5 (CH_3); (C=O) was not detected; [c] Other signals: 27.5 (CH_3), (CH_3), 197.1 (C=O), 199.6 (C=O); [d] Other signals: 27.5 (CH_3), 199.0 (C=O); [e] Detection of ^3J(N,H) between nitro group and H-3 allowed the assignment; [f] Measured in DMSO-d_6; [g] Other signals: 15.8 (6-CH_3) and 20.1 (1-CH_3); [h] Other signals: 53.0 (OCH_3), 166.0 (C=O); [i] Other signals: 53.1 (OCH_3), 167.1 (C=O).

The structure of 9b-butyl-4b,9b-dihydro[1]benzothieno[3,2-*b*][1]benzofuran-4b-ol (**29**) could only be confirmed after total assignment of NMR data. Signals of aromatic protons in ^{1}H NMR spectrum of compound **29** are shifted upfield in comparison with **1**. More significant changes occurred in the ^{13}C NMR spectrum where one signal with chemical shift around 155 ppm was missing. Signals of quaternary carbons C-5a and C-10a were determined in analogy with compound **1**. Signals of tertiary carbons were assigned after identification of protons H-4 and H-9, which exhibit two ^3J(C,H) interactions in HMBC spectrum (with C-4b and C-10a, and C-5a and C-9b, respectively). The last two quaternary carbons were assigned from ^3J(C,H) interactions with corresponding protons. Two signals of quaternary carbons with chemical shift below 100 ppm were detected. The changes prove the addition to the double bond C_{4b}=C_{9b}. Regioselectivity of the addition to the central double bond was confirmed using NOE experiment. Surprisingly, no interaction between methylene group bonded to the heterocycle and proton H-9 was observed. On the other hand, an interaction with proton H-1 was detected. The presence of hydroxy group in the molecule of **29** was proved by a characteristic absorption band in IR spectrum, by absence of ^1J(C,H) interaction of the proton resonating in HMQC spectrum at 6.93 ppm, and by a shift of the hydroxy group signal in ^{1}H NMR spectrum measured in DMSO-d_6 in a temperature experiment.

Mass spectra of derivatives of compound **1** are characterized by intensive molecular ions (often with 100% relative intensity) and fragments corresponding to elimination of functional groups (*m/z* 223 or 222). In particular, spectra of monosubstituted derivatives exhibit consecutive fragmentation of heterocyclic skeleton (*m/z* 195, 194 or 193). On the other hand, the mass spectrum of dimethyl derivative **25** contains, besides the molecular, ion only the fragment $[M^+ - H]$.

The fragmentation pattern of sulfone **17** is quite similar to the fragmentation of [1]benzothiophene 1,1-dioxide[31] and dibenzothiophene 5,5-dioxide[32,33] and is based on a primary rearrangement of the molecular ion to an internal sulfinyl ester. The spectrum contains molecular ion of [1]benzofuro[3,2-*b*][1]benzofuran (*m/z* 208) which is formed by extrusion of SO fragment from the rearranged molecular ion. The dominant ion of the spectrum, $[C_7H_4OS]^+$ (*m/z* 136), splits subsequently carbon monoxide off giving (*m/z* 108).

On the other hand, the molecular ion of sulfoxide **18** after losing an oxygen atom, undergoes further fragmentation analogous to the fragmentation mode of compound **1** (ref.[4]).

A series of electrophilic substitution reactions of heterocycle **1** was studied. It is evident that ring system **1** possesses two activated sites, positions 2 and 7, the latter being slightly preferred. The reactivity of the other positions to electrophilic attack is lower by an order of magnitude. These facts are in agreement with our theoretical calculations. However, reactivity of positions 2 and 7 is relatively comparable and monosubstitution leads to a mixture of nonseparable products. Substitutions with excess of reagents can be used for the synthesis of 2,7-disubstituted derivatives of **1**. Reactivity pattern can be changed by oxidation of sulfur atom in **1**. Electrophilic substitution of the respective sulfone or sulfoxide proceeds selectively in positions 7. Their deoxygenation proceeds, however, successfully only with the sulfoxide. Metallation of **1** confirmed the preferred activation of positions 1 and 6 to the attack of a base. Two unexpected products **28** and **29** were also isolated.

EXPERIMENTAL

Melting points were determined on a Boetius block and are uncorrected. NMR spectra were taken on spectrometers Varian-Gemini 300 HC (300 MHz for ^{1}H and 100 MHz for ^{13}C) and Bruker DRX 500 (500 MHz for ^{1}H and 100 MHz for ^{13}C). Deuteriochloroform was used as the solvent except for compound **22**, which was measured in DMSO-d_6, and the signals of the solvent served as internal standards. Chemical shifts are given in the δ-scale (ppm), coupling constants ^{3}J(H,H) in Hz. Signal multiplicities in the ^{13}C NMR were determined in the APT experiment. NOE effects were observed using the DPFGSE-NOE experiment. The 2D experiments, COSY, HMBC, HMQC, were carried out using pulse sequence and program provided by the manufacturer. ^{3}J(N,H) interaction in compound **15** was detected in hsqs1d-lr-h, N-H experiment. IR spectra were recorded on a Nicolet FTIR 740 spectrometer in chloroform or KBr (compounds **10**, **22**, **23**). Mass spectra of positive ions obtained by electron impact (70 eV) were measured on a GC-MS instrument Finnigan MAT. UV spectra were measured on a Specord 40 instrument in ethanol.

2,7-Dibromo[1]benzothieno[3,2-*b*][1]benzofuran (**2**)

To a solution of compound **1** (32 mg, 0.143 mmol) in dry chloroform (2 ml), a solution of bromine (50 mg, 0.313 mmol) in dry chloroform (0.5 ml) was added dropwise at 0 °C. The reaction mixture was allowed to warm up to room temperature and stirred for 15 h. The solution was diluted with chloroform (30 ml) and subsequently washed with water (2 × 10 ml), 10% solution of sodium thiosulfate (2 × 10 ml), saturated sodium hydrogencarbonate solution (2 × 10 ml) and brine (2 × 10 ml), dried with anhydrous magnesium sulfate and evaporated to dryness. The residue was twice crystallized from a mixture of ethyl acetate– ethanol to afford 31 mg (56%) of compound **2**, m.p. 178–180 °C. For $C_{14}H_6Br_2OS$ (382.1) calculated: 44.01% C, 1.58% H, 8.39% S; found: 43.88% C, 1.94% H, 8.28% S. IR: 3 095, 3 067, 1 571, 1 557, 1 457, 1 414, 1 392, 1 351, 1 284, 1 251, 1 144, 1 130, 1 100, 1 068, 1 004. MS (EI, *m/z* (rel.%)): 384 (40) [M^+], 382 (100) [M^+], 380 (30) [M^+], 194 (20) [M^+ – 2 Br – CO], 193 (10) [M^+ – 2 Br – CHO], 152 (15), 150 (20).

2,7-Diacetyl- (**3**) and 4,7-Diacetyl[1]benzothieno[3,2-*b*][1]benzofuran (**4**)

To a slurry of aluminum chloride (507 mg, 3.80 mmol) in dry dichloromethane (4 ml), freshly distilled acetyl chloride (0.3 ml, 4.22 mmol) was added under stirring at 0 °C and, after 30 min, a solution of compound **1** (149 mg, 0.664 mmol) in dry dichloromethane (1 ml) was added. The resulting mixture was stirred under nitrogen at 0 °C for 45 min, poured into cold dilute hydrochloric acid and washed with dichloromethane (4 × 30 ml). Combined organic solutions were subsequently washed with water (2 × 20 ml), saturated sodium hydrogencarbonate solution (2 × 20 ml) and brine (2 × 20 ml), and dried with anhydrous magnesium sulfate. The residue after evaporation was purified by column chromatography (silica gel, chloroform–methanol, 99 : 1). A mixture of diacetyl derivatives **3** and **4** in the ratio 3 : 1 (172 mg, 84%) was obtained. The mixture was three times separated by chromatography (silica gel, chloroform–toluene, 3 : 2) (compound **3** was followed by **4**) and twice crystallized to afford pure **3** (81 mg, 40%) and **4** (16 mg, 8%).

2,7-Diacetyl[1]benzothieno[3,2-b][1]benzofuran (**3**). M.p. 246–248 °C (chloroform–methanol). For $C_{18}H_{12}O_3S$ (308.4) calculated: 70.11% C, 3.92% H, 10.40% S; found: 69.74% C, 3.88% H, 10.17% S. IR: 3 022, 1 680 (C=O), 1 618, 1 593, 1 469, 1 420, 1 356, 1 272, 1 097. MS (EI, *m/z* (rel.%)): 308 (30) [M^+], 294 (30), 293 (80) [$M^+ - CH_3$], 266 (10), 265 (50) [$M^+ - CH_3CO$], 251 (20), 250 (100) [$M^+ - CH_3CO - CH_3$], 222 (70) [$M^+ - 2\ CH_3CO$], 209 (20), 207 (30), 149 (15), 126 (15), 97 (15), 75 (20), 44 (50).

4,7-Diacetyl[1]benzothieno[3,2-b][1]benzofuran (**4**). M.p. 192–195 °C (toluene). IR: 3 021, 1 682 (C=O), 1 617, 1 562, 1 432, 1 406, 1 370, 1 356, 1 286, 1 271, 1 240. MS (EI, *m/z* (rel.%)): 308 (60) [M^+], 294 (30), 293 (85) [$M^+ - CH_3$], 265 (80) [$M^+ - CH_3CO$], 251 (30), 250 (100) [$M^+ - CH_3CO - CH_3$], 246 (15), 225 (30), 223 (20), 222 (65) [$M^+ - 2\ CH_3CO$], 209 (20), 208 (35), 195 (15), 193 (35), 174 (10), 163 (20), 161 (10), 150 (35), 139 (15), 137 (20), 69 (20), 44 (80).

Acetylation of Compound **1**

A) To a cooled (–78 °C) slurry of aluminum chloride (610 mg, 4.57 mmol) in dry dichloromethane (8 ml), freshly distilled acetyl chloride (0.24 ml, 3.38 mmol) was added and after 60 min a solution of compound **1** (255 mg, 1.14 mmol) in dry dichloromethane (8 ml) was added dropwise. The resulting mixture was stirred for 90 min at –78 °C and worked up as above. Column chromatography (silica gel, toluene) of the residue afforded a mixture of 7-acetyl- (**5**), and 2-acetyl[1]benzothieno[3,2-*b*][1]benzofuran (**6**) (267 mg, 88%) in the ratio 2 : 1. For **5** + **6** $C_{16}H_{10}O_2S$ (266.3) calculated: 72.16% C, 3.78% H, 12.04% S; found: 72.02% C, 3.62% H, 11.89% S.

B) An analogous experiment with **1** (149 mg, 0.664 mmol), acetyl chloride (0.15 ml, 2.11 mmol), and titanium tetrachloride (0.52 g, 2.74 mmol) at room temperature for 15 h gave, after two column chromatographic purifications, 9-acetyl[1]benzothieno[3,2-*b*][1]benzofuran (**7**) (4 mg, 1%) that was followed by a mixture of compounds **5** and **6** (150 mg, 85%) in the ratio 3 : 2.

C) Reaction of compound **1** (150 mg, 0.669 mmol) with acetyl chloride (0.15 ml, 2.11 mmol) in the presence of boron tribromide (675 mg, 2.69 mmol) at room temperature for 15 h afforded 2 mg (1%) of **7** and 140 mg (79%) of a mixture of **5** and **6** in the ratio 3 : 2.

9-Acetyl[1]benzothieno[3,2-b][1]benzofuran (**7**). M.p. 189–191 °C (toluene). IR: 3 015, 1 672 (C=O), 1 574, 1 428, 1 396, 1 370, 1 267, 1 240, 1 179, 1 130, 1 087, 1 057, 1 018. MS (EI,

m/z (rel.%)): 266 (32) [M^+], 251 (50) [$M^+ - CH_3$], 223 (55) [$M^+ - CH_3CO$], 195 (100) [$M^+ - CH_3CO - CO$], 169 (15), 151 (40), 150 (20), 125 (15), 97 (15).

Benzoylation of Compound **1**

To a cold (0 °C) and stirred slurry of aluminum chloride (90 mg, 0.675 mmol) in dry dichloromethane (2 ml), freshly distilled benzoyl chloride (0.1 ml, 0.861 mmol) was added, followed, after 20 min, by a solution of compound **1** (51 mg, 0.227 mmol) in dry dichloromethane (0.5 ml). The resulting mixture was stirred under cooling for 15 min and worked up similarly as the experiments above. Column chromatography (silica gel, toluene) of the residue afforded 65 mg (87%) of an inseparable mixture of 7-benzoyl[1]benzothieno-[3,2-*b*][1]benzofuran (**8**) and 2-benzoyl[1]benzothieno[3,2-*b*][1]benzofuran (**9**) in the ratio 3 : 2. For **8** + **9** $C_{21}H_{12}O_2S$ (328.4) calculated: 76.81% C, 3.68% H, 9.76% S; found: 76.67% C, 3.69% H, 9.55% S.

2,7-Dibenzoyl[1]benzothieno[3,2-*b*][1]benzofuran (**10**)

A mixture of aluminum chloride (188 mg, 1.41 mmol) and freshly distilled benzoyl chloride (0.2 ml, 1.72 mmol) in dry dichloromethane was treated with a solution of compound **1** (55 mg, 0.245 mmol) in dry dichloromethane (0.5 ml). The resulting mixture was refluxed for 12 h and worked up as above. Column chromatography (silica gel, toluene) of the residue gave 78 mg (74%) of 2,7-dibenzoyl derivative **10**, m.p. 241–243 °C (ethyl acetate–ethanol). For $C_{28}H_{16}O_3S$ (432.5) calculated: 77.76% C, 3.73% H, 7.41% S; found: 77.49% C, 3.85% H, 7.55% S. IR (KBr): 3 050, 1 646 (C=O), 1 615, 1 589, 1 461, 1 444, 1 417, 1 319, 1 300, 1 279, 1 251, 1 043.

Formylation of Compound **1**

To a solution of compound **1** (98 mg, 0.437 mmol) in dry dichloromethane (10 ml), titanium tetrachloride (0.2 ml, 1.82 mmol) and subsequently butyl dichloromethyl ether (0.17 ml, 1.20 mmol) were added dropwise at 0 °C. The mixture was stirred at 0 °C for 2 h and then at room temperature for 18 h. The solution was poured into cold water and extracted with dichloromethane (2 × 30 ml). Combined organic solutions were washed with water (2 × 10 ml), saturated sodium hydrogencarbonate solution (2 × 10 ml) and brine (2 × 10 ml), and dried with anhydrous magnesium sulfate. The residue after evaporation was purified by column chromatography (silica gel, hexane–ethyl acetate, 7 : 1) affording 82 mg (75%) of an inseparable mixture of [1]benzothieno[3,2-*b*][1]benzofuran-7-carbaldehyde (**11**) and [1]benzothieno[3,2-*b*][1]benzofuran-2-carbaldehyde (**12**) in the ratio 2 : 1. For **11** + **12** $C_{15}H_8O_2S$ (252.3) calculated: 71.41% C, 3.20% H, 12.71% S; found: 71.18% C, 3.07% H, 12.44% S.

Nitration of Compound **1**

A solution of compound **1** (701 mg, 3.13 mmol) in dichloromethane (50 ml) was treated with 100% nitric acid (0.24 ml, 5.79 mmol) in dry dichloromethane (15 ml) at –60 °C. After 15 min of stirring, solid sodium hydrogencarbonate (300 mg) was added, the mixture was warmed up to 0 °C, water (50 ml) was added. The organic layer was washed with water (2 × 15 ml) and brine (2 × 15 ml), and dried with anhydrous magnesium sulfate. The residue

after evaporation was purified four times by column chromatography (silica gel, hexane–toluene, 3 : 1) and the minor product was isolated by preparative thin-layer chromatography. Thus, 777 mg (92%) of inseparable mixture of equimolar amounts of 7-nitro- (**13**) and 2-nitro[1]benzothieno[3,2-*b*][1]benzofuran (**14**) followed by 30 mg (4%) of pure 4-nitro-[1]benzothieno[3,2-*b*][1]benzofuran (**15**) was obtained. For **13** + **14** $C_{14}H_7NO_3S$ (269.3) calculated: 62.44% C, 2.62% H, 5.20% N, 11.91% S; found: 62.28% C, 2.71% H, 5.01% N, 11.64% S.

4-Nitro[1]benzothieno[3,2-b][1]benzofuran (**15**). M.p. 199 °C (hexane–toluene). IR: 3 029, 2 926, 2 856, 1 605, 1 556, 1 529 (NO_2), 1 506, 1 472, 1 445, 1 349 (NO_2), 1 322, 1 296, 1 267, 1 196, 1 125, 1 112, 1 097, 1 065, 1 013. MS (EI, *m/z* (rel.%)): 270 (10), 269 (75) [M^+], 239 (50) [M^+ – NO], 224 (20), 223 (100) [M^+ – NO_2], 211 (35), 195 (55) [M^+ – NO_2 – CO], 179 (10), 151 (45), 150 (25), 139 (15).

2,7-Dinitro[1]benzothieno[3,2-*b*][1]benzofuran (**16**)

To a solution of an equimolar mixture of compounds **13** and **14** (50 mg, 0.186 mmol) in dry dichloromethane (5 ml), 100% nitric acid (0.05 ml, 1.21 mmol) was added dropwise and the solution was stirred at room temperature for 15 min. Water (30 ml) was added and the mixture was extracted with dichloromethane (3 × 15 ml). Combined organic solutions were washed with water (2 × 15 ml) and brine (2 × 15 ml), and dried with anhydrous magnesium sulfate. The residue after evaporation was purified by column chromatography (silica gel, toluene) affording 55 mg (94%) of 2,7-dinitro derivative **16**, m.p. 303–305 °C subl. (ethyl acetate). For $C_{14}H_6N_2O_5S$ (314.3) calculated: 53.51% C, 1.92% H, 8.91% N, 10.20% S; found: 53.42% C, 2.31% H, 8.55% N, 9.90% S. IR: 3 024, 1 607, 1 534 (NO_2), 1 499, 1 466, 1 338 (NO_2), 1 306, 1 123.

[1]Benzothieno[3,2-*b*][1]benzofuran 10,10-Dioxide (**17**)

A mixture of **1** (125 mg, 0.557 mmol), the urea–hydrogen peroxide adduct (570 mg, 6.06 mmol) and phthalic anhydride (421 mg, 2.84 mmol) in dry acetonitrile (10 ml) was stirred at room temperature for 24 h, then diluted with dichloromethane (50 ml), and washed subsequently with water (3 × 20 ml), saturated sodium hydrogencarbonate solution (2 × 15 ml), and brine (2 × 15 ml). The organic layer was dried with anhydrous magnesium sulfate. The residue after evaporation was crystallized from ethanol to afford sulfone **17** (128 mg, 90%), m.p. 205–207 °C. For $C_{14}H_8O_3S$ (256.3) calculated: 65.61% C, 3.15% H, 12.51% S; found: 65.46% C, 3.52% H, 12.53% S. IR: 3 028, 1 612, 1 545, 1 477, 1 439, 1 392, 1 316 (SO_2), 1 271, 1 186, 1 162 (SO_2), 1 126, 1 108, 1 045. UV (λ (log ε)): 243 (4.60), 249 (4.58), 297 (4.03), 309 (4.07), 334 (4.02). MS (EI, *m/z* (rel.%)): 256 (45) [M^+], 208 (15) [M^+ – SO], 163 (30), 152 (25), 137 (15), 136 (100) [[C_7H_4OS]$^+$], 120 (20), 108 (30) [[C_7H_6OS]$^+$ – CO], 92 (15), 63 (10).

[1]Benzothieno[3,2-*b*][1]benzofuran 10-Oxide (**18**)

A solution of **1** (51 mg, 0.227 mmol) in acetic acid (2 ml) was treated with 30% aqueous hydrogen peroxide (333 mg, 2.94 mmol) and stirred at 40 °C for 4 h. The work-up of the reaction mixture as for **17** was followed by column chromatography (silica gel, gradient elution from toluene–chloroform 2 : 1 to chloroform–methanol 99 : 1). In addition to a small amount of sulfone **17** (12% yield), sulfoxide **18** was obtained (39 mg; 71%), m.p. 174– 176 °C (etha-

nol). For $C_{14}H_8O_2S$ (240.3) calculated: 69.98% C, 3.36% H, 13.34% S; found: 69.74% C, 3.18% H, 13.09% S. IR: 3 009, 1 606, 1 539, 1 475, 1 447, 1 393, 1 315, 1 267, 1 185, 1 129, 1 108, 1 094, 1 061, 1 030 (SO). UV (λ (log ε)): 237 (4.40), 251 (4.45), 299 (3.97), 323 (3.95), 347 (3.89). MS (EI, *m/z* (rel.%)): 240 (10) [M^+], 225 (20), 224 (100) [M^+ – O], 195 (25) [M^+ – O – CHO], 152 (40).

Nitration of Sulfone **17**

To a mixture of nitronium tetrafluoroborate (173 mg, 1.30 mmol) in dry nitromethane (8 ml), a solution of compound **17** (167 mg, 0.652 mmol) in dry nitromethane (4 ml) was added dropwise at –30 °C and then the mixture was stirred for 30 min. The reaction mixture was allowed to warm up to room temperature, stirred for 1 h, poured into ice water (100 ml) and washed with dichloromethane (3 × 30 ml). Combined organic layers were washed with water (2 × 20 ml), saturated sodium hydrogencarbonate solution (2 × 20 ml) and brine (2 × 20 ml). The organic layer was then dried with anhydrous magnesium sulfate. The residue after evaporation was separated by column chromatography (silica gel, hexane–ethyl acetate, 1 : 1) to afford 7-nitro 10,10-dioxide **21** (104 mg, 53%) followed by 2,7-dinitro 10,10-dioxide **22** (32 mg, 14%).

7-Nitro[1]benzothieno[3,2-b][1]benzofuran 10,10-dioxide (**21**). M.p. 305–306 °C (hexane–ethyl acetate). For $C_{14}H_7NO_5S$ (301.3) calculated: 55.81% C, 2.34% H, 4.65% N, 10.64% S; found: 55.58% C, 2.41% H, 4.44% N, 10.71% S. IR: 3 017, 1 615, 1 526 (NO_2), 1 468, 1 390, 1 345 (NO_2), 1 323 (SO_2), 1 192, 1 161 (SO_2), 1 123, 1 046. MS (EI, *m/z* (rel.%)): 302 (10), 301 (85) [M^+], 271 (20) [M^+ – NO], 207 (15), 179 (10), 172 (10), 171 (40), 170 (25), 163 (40), 150 (20), 137 (30), 136 (100) [$[C_7H_4OS]^+$], 120 (15), 108 (20) [$[C_7H_4OS]^+$ – CO], 75 (15), 63 (10).

2,7-Dinitro[1]benzothieno[3,2-b][1]benzofuran 10,10-dioxide (**22**). M.p. 266–268 °C (hexane–toluene). IR (KBr): 3 101, 2 924, 1 593, 1 544 (NO_2), 1 531 (NO_2), 1 467, 1 343 (NO_2), 1 332 (SO_2), 1 261, 1 164 (SO_2), 1 099.

Nitration of Sulfoxide **18**

A) 100% Nitric acid (0.03 ml, 0.724 mmol) in dry dichloromethane (1 ml) was added dropwise to a solution of compound **18** (63 mg, 0.262 mmol) in dry dichloromethane (4 ml) at 0 °C. The reaction mixture was allowed to warm up to room temperature, stirred for 1 h, poured into ice water (100 ml) and worked up as for nitration of **17**. The residue after evaporation was separated by column chromatography (silica gel, hexane–ethyl acetate, 1 : 1). 7-Nitro sulfoxide **19** (29 mg, 39%) was followed by 9-nitro sulfoxide **20** (3 mg, 4%).

B) To a cooled (–30 °C) slurry of nitronium tetrafluoroborate (69 mg, 0.520 mmol) in dry nitromethane (3 ml), a solution of compound **18** (61 mg, 0.254 mmol) in dry nitromethane (2 ml) was added dropwise under nitrogen. The reaction mixture was stirred for 2 h and then decomposed with water (2 ml). After the workup as in *A*) 7-nitro sulfoxide **19** (47 mg, 65%) and 9-nitro sulfoxide **20** (5 mg, 7%) were obtained.

7-Nitro[1]benzothieno[3,2-b][1]benzofuran 10-oxide (**19**), m.p. 228–230 °C (chloroform–ethyl acetate). For $C_{14}H_7NO_4S$ (285.3) calculated: 58.94% C, 2.47% H, 4.91% N, 11.24% S; found: 58.75% C, 2.56% H, 4.81% N, 11.26% S. IR: 3 011, 1 614, 1 526 (NO_2), 1 466, 1 383, 1 344 (NO_2), 1 286, 1 085, 1 035 (SO).

9-Nitro[1]benzothieno[3,2-b][1]benzofuran 10-oxide (**20**), m.p. 184–187 °C (chloroform–ethyl acetate). IR: 3 016, 2 957, 2 927, 1 629, 1 581, 1 525 (NO_2), 1 466, 1 396, 1 347 (NO_2), 1 317, 1 278, 1 063, 1 036 (SO).

[1]Benzothieno[3,2-*b*][1]benzofuran-7-amine (**23**)

36% Aqueous hydrochloric acid (0.4 ml) was added dropwise to a mixture of 7-nitro sulfoxide **19** (65 mg, 0.228 mmol), zinc dust (300 mg, 4.59 mmol), and acetic acid (3 ml). The reaction mixture was stirred for 1 h, diluted with chloroform (30 ml) and brought to pH 12 by addittion ofa 15% aqueous sodium hydroxide. The precipitate was filtered off, washed with chloroform (3 × 10 ml) and the aqueous layer was also washed with chloroform (2 × 10 ml). Combined organic solutions were washed with water (2 × 20 ml) and brine (2 × 20 ml), and dried with anhydrous magnesium sulfate. Evaporation of the filtrate afforded 53 mg (97%) of **23**, m.p. 164–167 °C (methanol–water). For $C_{14}H_9NOS$ (239.3) calculated: 70.27% C, 3.79% H, 5.85% N, 13.40% S; found: 70.01% C, 3.85% H, 5.59% N, 13.14% S. IR (KBr): 3 442 (NH_2), 3 361 (NH_2), 3 059, 1 627 (NH_2), 1 499, 1 443, 1 393, 1 361, 1 302, 1 129, 1 085. ^{13}C NMR: 99.4 (C-H), 112.9 (C-H), 116.7, 119.7 (C-H), 120.8 (C-H), 124.7 (C-H), 125.0 (C-H), 125.6 (C-H), 126.2, 141.8, 145.8, 152.2, 161.3 (the signal of one quaternary carbon was not detected).

[1]Benzothieno[3,2-*b*][1]benzofuran-7-amine 10,10-Dioxide (**24**)

36% Aqueous hydrochloric acid (1 ml) was added dropwise to a mixture of 7-nitro sulfone **21** (124 mg, 0.412 mmol), zinc dust (342 mg, 5.23 mmol) and acetic acid (5 ml). The resulting mixture was stirred for 4 h and worked up similarly as in the experiment above. The crude product was purified by column chromatography (silica gel, chloroform–methanol, 99 : 1) to give 108 mg (97%) of compound **24**, m.p. 257–259 °C (toluene). For $C_{14}H_9NO_3S$ (271.3) calculated: 61.98% C, 3.34% H, 5.16% N, 11.82% S; found: 61.70% C, 3.88% H, 5.18% N, 12.08% S. IR: 3 406 (NH_2), 3 031, 1 634 (NH_2), 1 546, 1 501, 1 395, 1 312 (SO_2), 1 161 (SO_2), 1 114. ^{13}C NMR: 98.8 (C-H), 101.3, 112.7, 115.0 (C-H), 120.1 (C-H), 121.6 (C-H), 122.9 (C-H), 126.4, 130.6 (C-H), 133.9 (C-H), 145.8, 147.2, 157.7, 161.6.

1,6-Dimethyl[1]benzothieno[3,2-*b*][1]benzofuran (**25**)

To a solution of compound **1** (208 mg, 0.927 mmol) in dry THF (15 ml), butyllithium in hexanes (2.03 mol/l, 2 ml, 4.06 mmol) was dropwise added at –78 °C under nitrogen. The mixture was brought to room temperature, stirred for 1.5 h, cooled down to –78 °C and then iodomethane (0.5 ml, 8.01 mmol) was added. The mixture was allowed to warm up to room temperature and stirred for additional 1.5 h. After decomposition with saturated ammonium chloride solution (10 ml), the resulting mixture was extracted with ether (3 × 20 ml). Combined organic extracts were washed with water (2 × 15 ml) and brine (2 × 15 ml), and dried with anhydrous magnesium sulfate. The residue after evaporation was purified by double crystallization to give 150 mg (64%) of 1,6-dimethyl derivative **25**, m.p. 126–129 °C (hexane). For $C_{16}H_{12}OS$ (252.3) calculated: 76.16% C, 4.79% H, 12.71% S; found: 75.84% C, 4.87% H, 12.59% S. IR: 3 062, 3 012, 2 927, 1 618, 1 598, 1 574, 1 532, 1 491, 1 452, 1 411, 1 381, 1 359, 1 299, 1 207, 1 192, 1 147, 1 051. MS (EI, *m/z* (rel.%)): 253 (20), 252 (100) [M^+], 251 (40) [$M^+ - H$], 208 (15), 125 (10).

Lithiation of Compound **1**. General Procedure

A solution of butyllithium in hexanes (2.03 mol/l, 1 ml, 2.03 mmol) was added dropwise to a mixture of compound **1** (199 mg, 0.887 mmol) in dry THF (10 ml) at –70 °C under nitrogen. The solution was stirred and kept at –30 °C for 4 h and poured onto crushed solid carbon dioxide (≈10 g). The solution was allowed to warm up to room temperature, acidified with dilute hydrochloric acid (1 : 10; 20 ml) and extracted with ether (3 × 10 ml). Combined organic solutions were washed with water (2 × 10 ml) and brine (2 × 10 ml), and dried with anhydrous magnesium sulfate. The residue after evaporation was treated with an excess of ethereal solution of diazomethane. The solution was after 5 min evaporated to dryness and subjected to column chromatography (silica gel, gradient elution, hexane–toluene) to obtain a small portion of starting compound **1** (17 mg, 9%), followed by hydroxy compound **29** (17 mg, 6%), a mixture of esters **27** and **28** (53 mg, 21%) in the ratio 3 : 1, and ester **26** (134 mg, 53%). The mixture of esters **27** and **28** was subsequently separated by several crystallizations from methanol and a hexane–toluene mixture to afford 28 mg (11%) of **27** and 10 mg (4%) of **28**.

Methyl [1]benzothieno[3,2-b][1]benzofuran-6-carboxylate (**26**), m.p. 118–119 °C (methanol). For $C_{16}H_{10}O_3S$ (282.3) calculated: 68.07% C, 3.57% H, 11.36% S; found: 68.32% C, 3.75% H, 11.25% S. IR: 3 025, 2 954, 1 718 ($COOCH_3$), 1 427, 1 411, 1 393, 1 296, 1 262, 1 192, 1 149, 1 097. MS (EI, *m/z* (rel.%)): 283 (20), 282 (100) [M^+], 252 (10), 251 (50) [$M^+ - OCH_3$], 223 (40) [$M^+ - COOCH_3$], 195 (40) [$M^+ - CO - COOCH_3$], 151 (25), 150 (15), 98 (10).

Methyl [1]benzothieno[3,2-b][1]benzofuran-1-carboxylate (**27**), m.p. 166–168 °C (methanol). For $C_{16}H_{10}O_3S$ (282.3) calculated: 68.07% C, 3.57% H, 11.36% S; found: 67.88% C, 3.75% H, 11.40% S. IR: 3 020, 2 954, 1 709 ($COOCH_3$), 1 442, 1 416, 1 381, 1 203, 1 153, 1 023. MS (EI, *m/z* (rel.%)): 283 (20), 282 (100) [M^+], 251 (30) [$M^+ - OCH_3$], 224 (15), 223 (50) [$M^+ - COOCH_3$], 195 (30) [$M^+ - CO - COOCH_3$], 151 (30), 150 (15), 98 (10).

Methyl [1]benzothieno[3,2-b][1]benzofuran-4-carboxylate (**28**), m.p. 195–198 °C (hexane–toluene). For $C_{16}H_{10}O_3S$ (282.3) calculated: 68.07% C, 3.57% H, 11.36% S; found: 68.21% C, 3.66% H, 11.50% S. IR: 3 021, 2 955, 1 709 ($COOCH_3$), 1 438, 1 425, 1 331, 1 284, 1 151, 1 075. ^{13}C NMR: 53.1 (OCH_3), 122.6 (C-H), 124.7 (C-H), 125.3 (C-H), 125.7 (C-H), 125.8, 126.0 (C-H), 126.7 (C-H), 127.9 (C-H), 133.6, 133.9, 135.1, 137.6, 143.3, 144.0, 167.3 (C=O). MS (EI, *m/z* (rel.%)): 283 (15), 282 (100) [M^+], 252 (15), 251 (45) [$M^+ - OCH_3$], 223 (45) [$M^+ - COOCH_3$], 195 (40) [$M^+ - CO - COOCH_3$], 169 (10), 151 (30), 150 (20), 97 (15).

9b-Butyl-4b,9b-dihydro[1]benzothieno[3,2-b][1]benzofuran-4b-ol (**29**). Oil. IR: 3 465 (OH), 3 013, 2 960, 2 930, 2 858, 1 574, 1 487, 1 464, 1 435, 1 344, 1 290, 1 241, 1 197. ^{1}H NMR: 0.93 t, 3 H, J = 7.2 (CH_3); 1.48 m, 2 H (CH_2); 1.68 m, 2 H (CH_2); 3.00 t, 2 H, J = 7.6 (CH_2); 6.91 ddd, 1 H, J(7,8) = 7.4, J(6,8) = 0.5 (H-8); 6.93 s, 1 H (OH); 7.04 d, 1 H, J(6,7) = 8.2 (H-6); 7.21 ddd, 1 H, J(2,3) = 7.4, J(1,3) = 0.7 (H-3); 7.26 ddd, 1 H (H-7); 7.31 ddd, 1 H (H-2); 7.39 d, 1 H, J(1,2) = 7.9 (H-1); 7.43 dd, 1 H, J(8,9) = 7.7, J(7,9) = 1.5 (H-9); 7.53 dd, 1 H, J(3,4) = 7.7, J(2,4) = 1.2 (H-4). ^{1}H NMR (DMSO-d_6): 0.89 t, 3 H, J = 7.1 (CH_3); 1.45 m, 2 H (CH_2); 1.60 m, 2 H (CH_2); 3.01 t, 2 H, J = 7.1 (CH_2); 6.83 dd, 1 H, $J_1 = J_2$ = 7.1; 6.92 d, 1 H, J = 7.7; 7.20 m, 2 H; 7.35 m, 3 H; 7.47 d, 1 H, J = 7.1; 10.00 s, 1 H (OH). ^{13}C NMR: 14.3 (CH_3), 22.7 (CH_2), 31.8 (CH_2), 34.1 (CH_2), 90.6 (C-9b), 95.4 (C-4b), 110.1 (C-9a), 115.5 (C-6), 120.8 (C-8), 124.1 (C-4a), 126.5 (C-3), 129.1 (C-1), 129.5 (C-2), 131.3 (C-7), 131.5 (C-9), 132.2 (C-4), 139.5 (C-10a), 158.4 (C-5a).

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