Synthesis of 4,6-Dimethyldibenzothiophene and 1,2,3,4-Tetrahydro-4,6-dimethyldibenzothiophene *via Tilak* Annulation

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1,2,3,4-Tetrahydro-4,6-dimethyldibenzothiophene was prepared by coupling 2-bromo-3-methylcyclohexanone with 2-methylbenzenethiol and annulating the product with the aid of polyphosphoric acid. A mixture of 1,2,3,4-tetrahydro-4,6-dimethyldibenzothiophene and 4,6-dimethyldibenzothiophene was prepared by coupling 2-bromo-3-methylcyclohex-2-en-1-one with 2-methylbenzenethiol and annulating the product with the aid of polyphosphoric acid. 2-Bromo-3-methylcyclohexanone was synthesized by conjugate addition of Me_3Al to 2-bromocyclohex-2-en-1-one with CuBr as catalyst and 2-bromo-3-methylcyclohex-2-en-1-one by bromination–elimination of 3-methylcyclohex-2-en-1-one. 1,2,3,4,4a,9b-Hexahydro-4,6-dimethyldibenzothiophene was prepared by reduction of 1,2,3,4-tetrahydro-4,6-dimethyldibenzothiophene with Zn and CF_3COOH.

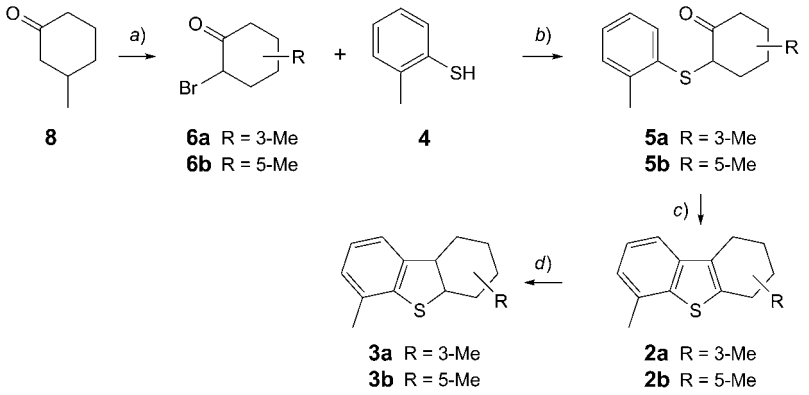
Introduction. – Many countries have introduced or will soon introduce stringent legislation regarding the maximum permitted level of sulfur in gasoline and diesel fuels. Polyaromatic sulfur compounds and their substituted derivatives, such as dibenzothiophene and 4,6-dialkyldibenzothiophene, with the alkyl groups adjacent to the S-atom, are the most refractory compounds in the hydrodesulfurization (HDS) process that is industrially used to remove sulfur from fuel. Therefore, 4,6-dimethyldibenzothiophene (4,6-DMDBT; **1**) is often used as a model compound in hydrodesulfurization studies [1]. 1,2,3,4-Tetrahydro-4,6-dimethyldibenzothiophene (TH-4,6-DMDBT; **2a**) and 1,2,3,4,4a,9b-hexahydro-4,6-dimethyldibenzothiophene (HH-4,6-DMDBT; **3a**) are crucial intermediates in the complex reaction network of the removal of sulfur from 4,6-DMDBT [2].

To achieve a low level of sulfur in fuels, a detailed knowledge of the mechanism of the HDS reaction and of the behavior of the reaction intermediates is required. Compounds **2a** and **3a** have been synthesized by hydrogenation of **1** [3], but this method is inefficient, because the conversion of **1** must be kept low to avoid further reaction of the hydrogenated intermediates to desulfurized hydrocarbons. As a consequence, laborious column-chromatographic separations of the product mixture and recycling of unreacted **1** have to be performed. In addition, commercial 4,6-

DMDBT is expensive. It can be prepared in two steps from dibenzothiophene (DBT) by lithiation at C(4) and C(6) of DBT and subsequent reaction with MeI [4], but this reaction gives not only a mixture of mono- and dimethyl-dibenzothiophene, but is also difficult to apply on a multi-gram scale. However, one needs *ca.* 40 g of **1** to synthesize 10 g of **2a** as well as 10 g of **3a**, as needed to study HDS [2]. 4,6-DMDBT (**1**) has also been synthesized from 2-bromo-3-nitrotoluene and 2-methylbenzenethiol (**4**) by reduction of the NO_2 group, followed by diazotation and ring closure by the *Pschorr* reaction, in which the diazonium group attacks the *ortho*-C-atom on the other phenyl ring [5]. The yield of this cyclization step was, however, low (26%). A future method for synthesizing **1** could be a Pd-catalyzed domino cyclization reaction of 2-chloro-6-methylbenzenethiol with 2-bromotoluene, analogous to the domino reaction of anilines and 1,2-dihaloarenes to carbazoles [6].

The reaction of benzenethiol with 2-halocyclohexanone to 2-(phenylsulfanyl)cyclohexanone, followed by the *Tilak* annulation, is an established reaction scheme that leads in two simple steps to tetrahydrodibenzothiophene (TH-DBT) [7]. Analogously, one can react **4** with 2-halo-3-methylcyclohexanone to give 3-methyl-2-[(2-methylphenyl)sulfanyl]cyclohexanone (**5a**) and let this molecule undergo *Tilak* annulation to form **2a** (*Scheme 1*), as shown by some of us in a preliminary communication [8]. *Aoyama et al.* demonstrated that one could even combine the base-catalyzed coupling of the α-halo ketone with the arenethiol and the subsequent acid-catalyzed *Tilak* cyclization, when the base and acid are supported on separate supports, *e.g.*, Na_2CO_3/SiO_2 and PPA/SiO_2 [9].

Scheme 1



a) Br_2, AcOH, H_2O, 0° to r.t.; 87%. *b*) NaOH, EtOH, H_2O, reflux, 2.5 h; 75%. *c*) Polyphosphoric acid (PPA), 165°, 3 h; 69%. *d*) Zn, CF_3COOH (TFA), r.t., 4 d; 80%.

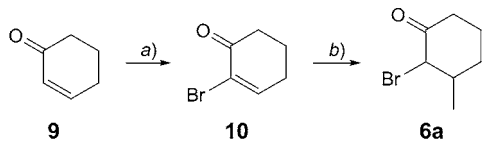
Here, we describe an approach to synthesize **2a** and **2b** (TH-2,6-DMDBT) based on the classic *Tilak* annulation, the coupling of 2-bromo-3-methylcyclohexanone (**6a**) and 2-bromo-5-methylcyclohexanone (**6b**), respectively, with **4**. Then, **3a** and **3b** (HH-2,6-DMDBT) were prepared by reduction of the corresponding compounds **2a** and **2b** with Zn and trifluoroacetic acid (TFA). In a second approach, we synthesized **2a** and **1** simultaneously by means of vinylic substitution (S_NV) of 2-bromo-3-methylcyclohex-

en-1-one (**7**; *cf. Scheme 3*) with the thiophenol **4**, followed by an unconventional *Tilak* annulation.

Results and Discussion. – A crucial intermediate in the synthesis of **2a** is **6a**. We first tried to synthesize **6a** by bromination and iodination of 3-methylcyclohexanone (**8**) to 2-halo-3-methylcyclohexanone. This reaction is easy to perform, and the literature even indicated that 2-iodo-3-methylcyclohexanone would be formed preferentially [10]. Unfortunately, but not surprisingly, this turned out not to be the case, and the reaction led to a mixture of four isomers, *cis*- and *trans*-2-iodo-3-methyl-, and *cis*- and *trans*-2-iodo-5-methylcyclohexanone, which were too difficult to separate. Although the analogous four Br isomers could not be separated either, reaction of the mixture with **4** and cyclization of the resulting products 3-methyl-2-[(2-methylphenyl)sulfanyl]cyclohexanone (**5a**) and 5-methyl-2-[(2-methylphenyl)sulfanyl]cyclohexanone (**5b**) led to a crystalline mixture of **2a** and **2b** (main product; *Scheme 1*). Crystallization led to pure **2b** but to impure **2a**. To synthesize pure **2a**, we, therefore, turned our attention to cyclohexenones.

We investigated the use of cyclohex-2-en-1-one (**9**), because it could give **6a** in only two steps (*Scheme 2* [8]). The first step, the bromination of **9**, and the final step, the hydrolysis of the Al–O bond, proved to be easy. However, the conjugate addition of Me_3Al to 2-bromocyclohex-2-en-1-one (**10**) [11] required safety precautions, and, therefore, only small batches (2 g) at a time could be prepared [8]. With the thus obtained **6a** (*cis*/*trans*-mixture) and **4**, the synthesis of **2a** presented no problem (*Scheme 1*). We tried to synthesize **3a** in a similar way by reducing **6a** with $NaBH_4$ to 2-bromo-3-methylcyclohexanol and then react the latter with **4** in the presence of polyphosphoric acid (PPA). While the reduction of the ketone and the subsequent coupling of the thiol with 2-bromo-3-methylcyclohexan-1-ol to 3-methyl-2-[(2-methylphenyl)sulfanyl]cyclohexanol proceeded smoothly, the final ring closure by the reaction of the OH group with the *ortho*-C-atom of the phenyl ring was not successful. As an alternative, we transformed 3-methyl-2-[(2-methylphenyl)sulfanyl]cyclohexanol to 1-chloro-3-methyl-2-[(2-methylphenyl)sulfanyl]cyclohexane and tried to cyclize the latter with the aid of $AlCl_3$ or $ZnCl_2$. However, also this last step was not successful. Apparently, *Friedel–Crafts* reactions are not only difficult for phenols, but also for benzenethiols. We successfully synthesized **3a**, instead, by the reduction of **2a** with the Zn and TFA couple [12]. Similarly, **3b** was synthesized by reduction of **2b** with Zn and TFA (*Scheme 1*).

Scheme 2

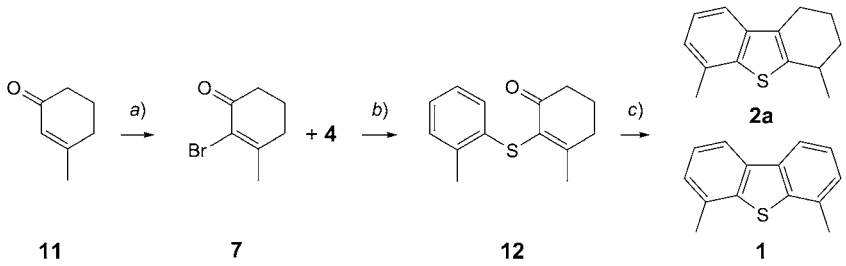


a) Br_2, CH_2Cl_2, Et_3N, 0° to r.t.; 60%. *b*) CuBr, PPh_3, toluene, Me_3Al, −60° to r.t.; 75%.

Instead of using 2-bromo-3-methylcyclohexanone in the synthesis of hydrogenated intermediates of 4,6-dimethyldibenzothiophene, one could try to use 2-bromo-3-

methylcyclohex-2-en-1-one (**7**). We prepared **7** by bromination of 3-methylcyclohex-2-en-1-one (**11**; *Scheme 3*), extraction with Et_2O, and chromatographic purification on a silica gel column. Hydrogenation of **7** might, in principle, give **6a**, which could be used for the synthesis of **2a** [8]. However, when halogen atoms are present in α,β-unsaturated aldehydes and ketones, the hydrogenolysis of the C–X bond is faster than the hydrogenation of the C=C bond. Thus, it was impossible to selectively hydrogenate **7** to **6a**. We, therefore, attempted to couple **7** directly with **4** by vinylic substitution (S_NV). The coupling was successful and 3-methyl-2-[(2-methylphenyl)sulfanyl]cyclohex-2-en-1-one (**12**) formed. The resulting **12** (*Fig.*) was used to close the thiophene ring with the aid of PPA to give **2a** and **1** (*Scheme 3*). After separation by silica-gel column chromatography, **1** was obtained as white needle-like crystals and **2a** as a colorless liquid.

Scheme 3



a) Tetrabutylammonium tribromide (TBATB), CH_2Cl_2, K_2CO_3, r.t., 56 h; 67%. *b*) NaOH, EtOH, H_2O, reflux, 2.5 h; 65%. *c*) PPA, 150°, in the absence of O_2, 3 h; **2a** (21%) and **1** (44%).

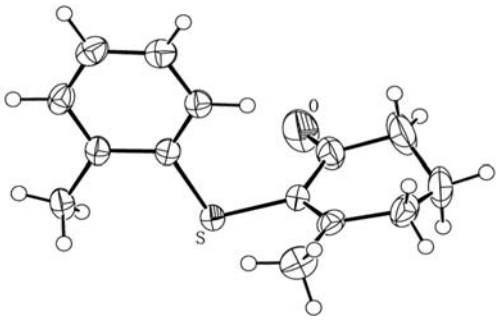


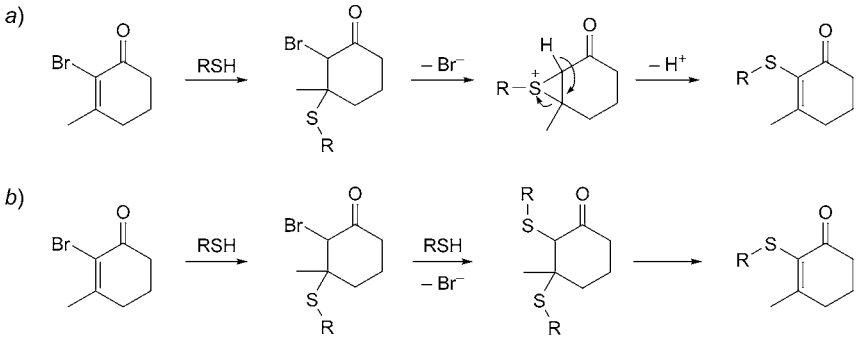
Figure. *Crystal structure of 3-methyl-2-[(2-methylphenyl)sulfanyl]cyclohex-2-en-1-one* (**12**). The ADP ellipsoids are drawn at the 50% probability level.

In general, S_NV reactions of vinyl halides do not proceed as well as S_N2 reactions of alkyl halides. Only when an electron-withdrawing group is present in the β-position relative to the leaving group (in our study Br) is the rate of vinylic substitution fast [13]. In particular, the keto group in the β-position has been studied in depth [13c], but the influence of a C=O group in the α-position has not been studied systematically. To the best of our knowledge, this reaction has been described only once, as the first step in the

synthesis of tetracycline [14]. Another example of vinylic substitution with an electron-withdrawing group in the α-position relative to the leaving group is the recent synthesis of phenyl(1-styryl)sulfide from 1-styryl bromide and benzenethiol [15].

The replacement of the Br-atom of **7** by the RS group of the 2-methylbenzenethiol may take place by the conjugate addition of the RS group in β-position to form aryl 3-vinyl sulfide, which then forms aryl 2-vinyl sulfide by substitution of the Br-atom by the RS group, *i.e.*, an α,β shift (*Scheme 4*, *a*). This substitution reaction may be supported by the neighboring group effect of the S-atom. Another possible explanation is that the conjugate addition of the RS group is followed by nucleophilic substitution of the Br-atom by another RS group. Elimination of the RS group in β-position would then give cyclohexenone with the RS group in the α-position (*Scheme 4*, *b*).

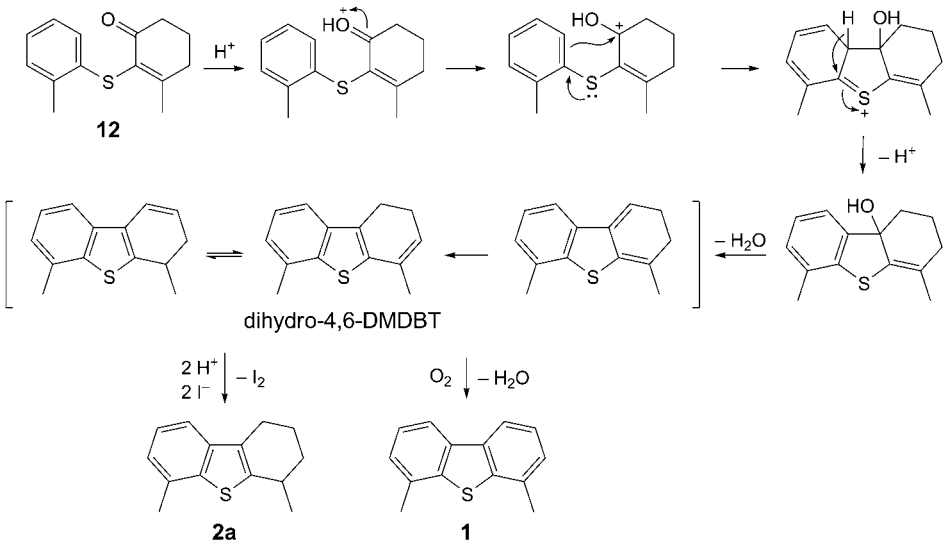
Scheme 4. *Possible Mechanisms for the Replacement of the Br-Atom by the Thiol Group*



The final cyclization of **12** gave **2a** and **1**. However, heating 2-(arylsulfanyl)cyclohexanone in the presence of a strong acid leads to cyclization by C,C coupling and the formation of a C=C bond [7] to give **2a** in our case. If the same reaction were to proceed with our aryl vinyl sulfide, then an additional double bond would be formed in the cyclohexene ring, and the product would probably have been dihydro-4,6-DMDBT. Instead, a mixture of **2a** and **1** was obtained. When the reaction time was reduced from 3 to 2 h, two new peaks were observed in the GC, and their mass spectrum revealed that both correspond to *m*/*z* 214. The peaks might belong to the isomers 1,2-dihydro-4,6-DMDBT and 3,4-dihydro-4,6-DMDBT (*Scheme 5*). Unfortunately, a pure intermediate was not obtained, and the accurate structure of the intermediate could not be determined.

Dihydro-4,6-DMDBT will be unstable under the reaction conditions and disproportionate to **2a** and **1**, but this reaction should have led to a 1:1 mixture, whereas a *ca.* 1:3 mixture was obtained. This suggests that dihydro-4,6-DMDBT can react to **1** by dehydrogenation. Dehydrogenation in the absence of a metal catalyst seems unlikely, but oxidation by air might explain the *ca.* 1:3 ratio of compounds **2a** and **1**. Indeed, when the cyclization of the aryl vinyl sulfide with PPA was carried out under N_2, the **2a**/**1** ratio became *ca.* 1:1, as expected for the stoichiometric reaction from dihydro-4,6-DMDBT. To improve the yield of **2a**, we used HI as the reducing agent, knowing that I_2 improves the reverse reaction, *i.e.*, the dehydrogenation of a dihydrothiophene ring

Scheme 5. *Mechanism of the* Tilak *cyclization of* **12** *to* **2a** *and* **1**



[16][17]. To prepare HI *in situ*, the cyclization of the aryl vinyl sulfide was carried out with PPA in the presence of KI. The product contained a *ca.* 2 : 1 mixture **2a**/**1**, but at the cost of a substantial amount of by-products. This result was obtained when the reaction was carried out in daylight, but not in the dark. Therefore, iodine radicals and HI, formed from KI and PPA, may be responsible for the reduction of the dihydro-4,6-DMDBT to **2a**. Oxidizing or reducing agents are thus able to influence the ratio **2a**/**1** (*Scheme 5*).

Conclusions. – The *Tilak* annulation is a convenient way to synthesize **2a** and **2b**. The synthesis of **6a** can be achieved by the conjugate addition of Me_3Al to **10** with a Cu salt as the catalyst. Coupling **7** with **4** and closing the ring with PPA led to a mixture **2a**/**1**. The ratio of the two products was steered by adding oxidants or reductants. This synthesis can be carried out under mild conditions, consists of only few steps, and leads to the simultaneous preparation of **2a** and **1**. Compounds **3a** and **3b** can be prepared by the reduction of **2a** and **2b**, respectively, with Zn and TFA at room temperature. This demonstrates that *Tilak* annulation can also be used for alkylbenzenethiols and β-alkyl α,β-enones, providing easy access to hydrogenated intermediates of derivatives of dibenzothiophene with alkyl substituents, which are used as model molecules in hydrodesulfurization studies [2].

This work was supported by the *Natural Science Foundation of China* (20503003, 20773020, 20973030, and 21073022), the *Ministry of Education of China*, the *Fundamental Research Funds for the Central Universities*, and *Project 111*. The authors are grateful to Prof. *D. Seebach*, the late Prof. *L. Lu*, and Mr. *L. Bertschi* for helpful discussions.

Experimental Part

General. All reactions were carried out in air, unless mentioned otherwise. Commercially available reagents and solvents were used without further purification, and were purchased from *Acros* or *Sinopharm Chemical Reagent Co., Ltd*. The progress of all reactions was monitored by TLC using glass plates pre-coated with silica gel *60 F_{254}* of a thickness of 0.5 mm (*Merck*). All samples were analyzed on an *Agilent GC* (*6890N*) instrument equipped with *HP-5* column (30 m × 0.25 mm × 0.25 μm). Column chromatography (CC): silica gel (SiO_2; 200–300 mesh) with petroleum ether (PE; b.p. 60–90°) and AcOEt as the eluents. M.p.: *Electrothermal CN66 M/X-6* apparatus. IR Spectra: *Thermo-Nicolet NEXUS 670* FT-IR spectrophotometer. ^{1}H- and ^{13}C-NMR spectra: in $CDCl_3$ with a *Varian INVA 400* MHz or a *Bruker Avance 200* MHz spectrometer, with TMS as an internal standard. MS: *HP6890 GC/5973 MSD* GC-MS instrument. HR-EI-MS: *Waters-Micromass-Autospec-Ultima* spectrometer.

Bromination of 3-Methylcyclohexanone (**8**). Br_2 (15.1 g, 90 mmol) was added dropwise to a vigorously stirred mixture of 10.6 g (90 mmol) of **8** and 1 ml glacial AcOH in 38 ml of H_2O. The reaction vessel was cooled in an ice bath throughout the addition. The mixture was then saturated with NaCl, and the org. layer was separated. The aq. layer was extracted with Et_2O, and the combined org. phase was washed three times with sat. $NaHCO_3$ sol. and once with brine, dried ($MgSO_4$), and concentrated to give 17.4 g of a yellow oil (87%). GC showed that it contained 30% of **6a** and 59% of **6b**.

Data of 2-Bromo-3-methylcyclohexanone (**6a**). EI-MS: 192 (14, $[M+2]^+$), 190 (13, M^+), 148 (21), 147 (26), 146 (20), 111 (62), 83 (14), 69 (52), 55 (100), 41 (36).

Data of 2-Bromo-5-methylcyclohexanone (**6b**). EI-MS: 192 (13, $[M+2]^+$), 190 (14, M^+), 148 (7), 146 (7), 111 (30), 84 (7), 69 (100), 55 (21), 41 (23) [18].

3-Methyl-2-[(2-methylphenyl)sulfanyl]cyclohexanone (**5a**). *2-Methylbenzenethiol* (**4**; 7.4 g) and NaOH (2.4 g) were dissolved in a mixture of 15 ml of EtOH and 15 ml of H_2O. Compound **6a** (12 g) dissolved in EtOH (20 ml) was added dropwise to this soln., kept under a stream of N_2. The mixture was stirred at r.t. for 30 min and then heated to reflux for 4 h. After cooling, 60 ml of H_2O were added. The lower oily layer was removed, and the aq. phase was extracted with $CHCl_3$. The combined oily layer and extract were dried (Na_2SO_4). After evaporation, 11 g (75%) of the *cis*/*trans*-product was obtained. EI-MS: 234 (M^+, 100), 190 (8), 163 (5), 149 (5), 124 (78), 110 (7), 91 (25), 77 (8), 55 (29), 41 (12) [8].

*1,2,3,4-Tetrahydro-4,6-dimethyldibenzo[*b,d*]thiophene* (**2a**). Compound **5a** (11 g) was added to a round-bottom flask containing 100 g of PPA, and the mixture was slowly heated in an oil bath with continuous stirring for 3 h at 165°. After cooling, the mixture was poured onto ice. The oily layer was separated, and the aq. phase was extracted with $CHCl_3$. The oily layer and the extracts were combined, dried (Na_2SO_4), and the $CHCl_3$ was distilled off to yield 8 g (69%) of **2a**. Yellow oil. ^{1}H-NMR (400 MHz, $CDCl_3$): 7.41 (*d*, *J* = 7.2, 1 H); 7.26 (*t*, *J* = 7.6, 1 H); 7.07 (*d*, *J* = 7.2, 1 H); 3.06–3.08 (*m*, 1 H); 2.68–2.76 (*m*, 1 H); 2.64–2.67 (*m*, 1 H); 2.52 (*s*, 3 H); 2.03–2.09 (*m*, 2 H); 1.76–1.85 (*m*, 1 H); 1.52–1.55 (*m*, 1 H); 1.37 (*d*, *J* = 7.2, 3 H). ^{13}C-NMR (100 MHz, $CDCl_3$): 143.2; 139.8; 138.6; 131.9; 130.1; 124.4; 124.1; 118.6; 32.9; 31.8; 24.2; 23.1; 21.6; 20.5. EI-MS: 216 (62, M^+), 201 (100), 188 (29), 186 (14), 171 (13), 149 (15) [3][8].

*1,2,3,4-Tetrahydro-2,6-dimethyldibenzo[*b,d*]thiophene* (**2b**). The mixture **6a**/**6b** obtained in the bromination of **8** was reacted with **4** to a mixture **5a**/**5b** in the same way as **6a** was reacted with **4** to **5a**. The resulting mixture **5a**/**5b** was reacted with PPA, as **5a** was reacted with PPA to **2a**. The crude product mixture **2a**/**2b** was purified by CC on SiO_2 with PE (b.p. 60–90°). The separated compounds were stored in a refrigerator overnight, after which **2b** was obtained as a white solid. The solid was washed with PE (b.p. 30–60°), recrystallized from AcOEt, and 2.3 g (32%) white needle-like crystals were obtained. The fraction that contained **2a** could not be crystallized to a pure product. ^{1}H-NMR (400 MHz, $CDCl_3$): 7.41 (*d*, *J* = 8, 1 H); 7.24 (*m*, 1 H); 7.06 (*d*, *J* = 8, 1 H); 2.86–2.91 (*m*, 3 H); 2.50 (*s*, 3 H); 2.24–2.29 (*m*, 1 H); 1.96–2.01 (*m*, 2 H); 1.51–1.59 (*m*, 1 H); 1.14 (*d*, *J* = 8, 3 H). ^{13}C-NMR (100 MHz, $CDCl_3$): 139.5; 138.8; 136.3; 131.7; 130.2; 124.2; 123.9; 118.1; 32.3; 31.9; 28.7; 25.5; 21.7; 20.3. EI-MS: 216 (66, M^+), 201 (14), 174 (100) [19].

*1,2,3,4,4a,9b-Hexahydro-4,6-dimethyldibenzo[*b,d*]thiophene* (**3a**). Compound **2a** (0.06 g, 0.3 mmol), TFA (10 ml), and 1.2 g of Zn powder were added to a round-bottom flask, and the mixture was stirred with a magnetic stirrer at r.t. for 4 d. The mixture was extracted three times with AcOEt. The combined

org. layer was washed with sat. $NaHCO_3$ soln., H_2O, and brine, and then dried (Na_2SO_4) and concentrated *in vacuo* to remove the solvent. Twofold purification of the crude product by CC (SiO_2; PE/AcOEt 10:1) gave 0.03 g (50%) **3a** as yellow needle-like crystals. The NOE results show that H–C(9b) is close to H–C(4a) in space, that H–C(4a) is close to H–C(9b) and Me–C(4), and that H–C(4a), H–C(9b), and Me–C(4) are on the same side of the molecule. Thus, product **3a** has the (4*R*,4a*S*,9b*S*)- or (4*S*,4a*R*,9b*R*)-configuration. Comparison of the NMR results of our product **3a** with those published by *Kukula et al.* of the stereoisomers of HH-4,6-DMDBT [3] confirmed this assignment. ^{1}H-NMR (400 MHz, $CDCl_3$): 6.98 (*t*, *J* = 8, 1 H); 6.87 (*d*, *J* = 8, 1 H); 6.82 (*d*, *J* = 8, 1 H); 3.32 (br. *s*, 1 H); 2.79 (*dd*, *J* = 8, 4, 1 H); 2.23 (*s*, 3 H); 2.04–2.08 (*m*, 1 H); 1.28–1.44 (*m*, 3 H); 1.12–1.21 (*m*, 2 H); 0.92 (*d*, *J* = 4, 3 H); 0.64–0.73 (*m*, 1 H). ^{13}C-NMR (100 MHz, $CDCl_3$): 142.3; 141.0; 132.7; 128.2; 124.7; 121.0; 59.5; 48.8; 35.3; 33.8; 26.2; 21.6; 21.5; 20.6. ^{1}H-NMR (NOE): H–C(9b)/H–C(4a); H–C(4a)/H–C(9b); H–C(4a)/Me–C(4). EI-MS: 218 (100, M^+), 175 (39), 162 (48), 161 (68), 149 (34), 147 (24), 128 (7), 115 (8).

*1,2,3,4,4a,9b-Hexahydro-2,6-dimethyldibenzo[*b,d*]thiophene* (**3b**). Purification of the crude product mixture **3a**/**3b**, obtained from the reaction of the mixture **2a**/**2b** with Zn and TFA, by CC (SiO_2; PE/AcOEt 10:1) gave **3b** as a yellow oil; yield (80%). GC/MS analysis of this oil showed at least five peaks, and GC/MS indicated that all peaks belonged to **3b**. The peak with the lowest retention time represented *ca.* 90% of the intensity. From the yellow oil, we were able to isolate 10% of stereoisomerically pure **3b**. From a comparison of the NMR results of this product with those published by *Kukula et al.* for the stereoisomers of the HH-2,6-DMDBT product, obtained in the *Birch* reduction of 4,6-DMDBT with Na in liquid NH_3 [19], we concluded that our product **3b** had the (*2*S,*4a*S,*9b*S)-configuration. ^{1}H-NMR (400 MHz, $CDCl_3$): 7.02–7.06 (*m*, 1 H); 6.97–7.01 (*m*, 1 H); 6.94–6.96 (*m*, 1 H); 3.46–3.57 (*m*, 2 H); 2.29–2.37 (*m*, 1 H); 2.26 (*s*, 3 H); 1.77–1.91 (*m*, 1 H); 1.53–1.57 (*m*, 2 H); 1.31–1.47 (*m*, 2 H); 0.96–1.05 (*m*, 1 H); 0.93 (*d*, *J* = 8, 3 H). ^{13}C-NMR (100 MHz, $CDCl_3$): 141.4; 140.5; 132.7; 127.7; 124.4; 120.9; 50.4; 48.5; 34.8; 33.7; 31.4; 26.8; 22.2; 20.5. EI-MS: 218 (100, M^+), 175 (23), 162 (56), 161 (87), 149 (30), 147 (26), 128 (9), 115 (9).

2-Bromocyclohex-2-en-1-one (**10**). A soln. of Br_2 (157.5 mmol, 9 ml) in 150 ml of CH_2Cl_2 was added dropwise over a period of 3 h to a stirred soln. of **9** (150 mmol, 15 ml) in 400 ml of CH_2Cl_2 at 0°. The soln. was stirred at 0° for 3 h, then Et_3N (250 mmol, 35 ml) was added dropwise, and the mixture was stirred at r.t. for another 3 h. It was washed with 3% HCl and brine, and dried ($MgSO_4$). Recrystallization from hexane/Et_2O gave pure **10** (15 g, 60% yield). ^{1}H-NMR (200 MHz, $CDCl_3$): 7.47 (*t*, 1 H); 2.67 (*t*, 2 H); 2.48–2.52 (*m*, 2 H); 2.10–2.15 (*m*, 2 H). ^{13}C-NMR (50 MHz, $CDCl_3$): 191.3; 151.2; 123.9; 38.4; 28.4; 22.7 [8].

2-Bromo-3-methylcyclohexanone (**6a**). To a mixture of CuBr (100 mg) and PPh_3 (300 mg) were added 50 ml of dry toluene under N_2. The soln. was stirred at r.t. for 30 min and then cooled to −60° (acetone and dry ice). Me_3Al (12 ml, 2M in toluene) was added dropwise, maintaining the temp. below −60°. The soln. was stirred for 5 min, and 3 g of **10** in 50 ml of toluene were added dropwise. The mixture was stirred below −60° for 2 h and then allowed to warm to r.t., until all starting material was consumed. The soln. was diluted with Me_2O, the reaction was quenched with MeOH, and the mixture was successively washed with 2N HCl and brine. The org. layer was dried (Na_2SO_4). After evaporation, **6a** (2.4 g, 75%; *cis*/*trans*-mixture) was obtained. This procedure was repeated five times to obtain 12 g of product [8].

2-Bromo-3-methylcyclohex-2-en-1-one (**7**). A soln. of **11** (1.1 g, 10 mmol) in CH_2Cl_2 (100 ml) was cooled in a ice-water bath, and tetrabutylammonium tribromide (TBATB; 24.1 g, 50 mmol) was added at 0–5°. After 20 min, K_2CO_3 (8.3 g, 60 mmol) was added, and after another 30 min, the mixture was brought slowly to r.t. under continuous stirring. After 24 h, more K_2CO_3 (4.2 g, 30 mmol) was added. The reaction was complete in 56 h, as shown by the GC spectrum. The mixture was filtered, and the white solid was washed with CH_2Cl_2. The combined filtrate was concentrated *in vacuo* to remove the CH_2Cl_2, and the product was extracted from the resulting oil with Et_2O. The Et_2O was distilled off in vacuum, and 1.5 g of yellow/orange oil was obtained. Purification of the crude product by CC (SiO_2; PE/AcOEt 4:1) gave 1.3 g (67%) of **7**. Colorless liquid. IR (neat): 2922, 2851, 1733, 1683, 1605, 1456, 1426, 1374, 1270, 1172, 1134, 793, 570, 508. ^{1}H-NMR (400 MHz, $CDCl_3$): 2.58 (*t*, *J* = 6.8, 2 H); 2.51–2.54 (*m*, 2 H); 2.18 (*s*, 3 H); 1.98–2.04 (*m*, 2 H) [20].

3-Methyl-2-[(2-methylphenyl)sulfanyl]cyclohex-2-en-1-one (**12**). Compound **4** (0.5 g, 4 mmol), NaOH (0.2 g, 4 mmol), deionized H_2O (5 ml), and EtOH (5 ml) were added to a three-neck flask, and the temp. of the H_2O bath was increased to reflux temp. A soln. of **7** (0.8 g, 4 mmol) in EtOH (5 ml) was added to the refluxed soln. by means of a dropping funnel, after which the soln. was refluxed for 2.5 h. After cooling, 40 ml of H_2O were added, and the mixture was extracted three times with Et_2O. The combined oil layer was washed with H_2O and brine, dried (Na_2SO_4), and concentrated *in vacuo* to remove the solvent. Purification of the crude product by CC (SiO_2; PE/AcOEt 1:1) gave 0.6 g (65%) of **12**. White solid. When the chromatographic purification was omitted, a substantial amount of bis(2-methylphenyl) disulfide was also obtained. Apparently, the ether extract still contained TBATB, the bromination agent. This tribromide oxidized the thiol **4** to the disulfide. To determine the structure of **12**, and especially the position of the (2-methylphenyl)sulfanyl group, not only ^{1}H- and ^{13}C-NMR data, but also HR-MS data were collected. The structure was ultimately established by an X-ray structure determination[1]). The unit cell contains two molecules with very similar conformation. The angle between the best planes through the aryl and cyclohexenone rings is 75° in one molecule and 81° in the other. M.p. 93.8–95.9°. ^{1}H-NMR (400 MHz, $CDCl_3$): 7.10–7.12 (*m*, 1 H); 7.00–7.02 (*m*, 2 H); 6.78–6.80 (*m*, 1 H); 2.62 (*t*, $J = 6$, 2 H); 2.57 (*t*, $J = 6.8$, 2 H); 2.41 (*s*, 3 H); 2.23 (*s*, 3 H); 2.03–2.10 (*m*, 2 H). ^{13}C-NMR (100 MHz, $CDCl_3$): 194.7; 169.6; 135.9; 135.8; 130.3; 129.6; 126.4; 125.9; 125.1; 38.5; 34.5; 24.6; 21.9; 20.4. EI-MS: 232.0921 (100, M^+), 217.0686 (14), 199.1126 (9), 199.0582 (6), 171.1171 (30), 162.0490 (16), 161.0416 (16), 147.0259 (11), 143.0851 (11), 135.0256 (11), 129.0694 (12), 119.0492 (12), 105.0701 (11), 91.0549 (42), 85.0111 (15), 79.0546 (12), 77.0391 (10), 65.0386(11), 44.9769 (14), 41.0358 (14), 39.0197 (12).

X-Ray Crystal-Structure Determination of **12**. Colorless single crystals were obtained by recrystallization from AcOEt. All diagrams and calculations were performed using the *maXus* computer program [21]. Data reduction was performed with the *Denzo* and *Scalepak* programs [22], and cell refinement with HKL Scalepack [22], refined using SHELXS-97 [23] (*Table*).

Table 1. *Crystal Data and Details of Structure Refinement of 3-Methyl-2-[(2-methylphenyl)sulfanyl]cyclohex-2-en-1-one* (**12**)

Crystallized from	AcOEt	γ [°]	105.3195 (9)
Empirical formula	$C_{14}H_{16}OS$	V [Å^3]	1221.19 (4)
Formula weight	232.345	D_x [g m^{-3}]	1.264
Crystal color, habit	colorless, cube	2θ Range [°]	5.82–54.97
Crystal dimensions [mm]	$0.42 \times 0.39 \times 0.195$	μ(MoK$_\alpha$) [mm^{-1}]	0.241
Temp. [K]	173	$2\theta_{max}$ [°]	55
Crystal system,	triclinic	Measured reflections	9779
Space group	$P\bar{1}$	Independent reflections	5590
Z	4	Observed reflections	4693
a [Å]	7.96950 (10)	Final $R(gt)(I > 2\sigma I)$	0.0418
b [Å]	10.4833 (2)	$\omega R(gt)(F^2)$	0.1313
c [Å]	15.5639 (3)	Calculated weights	$1/[\sigma^2(I_o) + (I_o + I_c)^2/900]$
α [°]	90.9897 (9)	Δ/σ_{max}	0.006
β [°]	102.3762 (9)	$\Delta\rho$ (max; min) [eÅ^3]	0.453; −0.307

*4,6-Dimethyldibenzo[*b,d*]thiophene* (**1**). Compound **12** (2.0 g, 8.6 mmol) and PPA (40 g) were added to a round-bottom flask in the absence of O_2, and the mixture was slowly heated to 150° in an oil bath

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[1]) File CCDC-800163 at the *Cambridge Crystallograpic Data Centre* (*CCDC*) contains the supplementary crystallographic information. These data can be obtained free of charge at www.ccdc.cam.ac.uk/data_request/cif, by sending an e-mail to data_request@ccdc.cam.ac.uk or by contacting The Cambridge Crystallographic Data Centre, 12, Union Road, Cambridge CB21EZ, UK; fax: +44 1223 336033.

under continuous stirring for 3 h. After cooling, ice-H_2O was added, and the mixture was extracted three times with Et_2O. The combined org. layer was washed with sat. $NaHCO_3$ soln., H_2O, and brine, dried (Na_2SO_4), concentrated *in vacuo* to remove the solvent, and analyzed by GC. The product consisted of 45% **2a**, 49% **1**, and 6% by-products when the reaction was carried out in the absence of O_2, of 24% **2a** and 76% **1** under air, and of 55% **2a**, 31% **1**, and 14% by-products in the presence of KI. The crude product was further purified by CC (SiO_2; PE (b.p. 60–90°)). The final yields were 21% (**2a**) and 44% (**1**) in the absence of O_2, 19% (**2a**) and 60% (**1**) when exposed to air, and 29% (**2a**) and 19% (**1**) in the presence of KI. Compound **1** was obtained as white needle-like crystals. M.p. 152.8–154.2°. ^{1}H-NMR (400 MHz, $CDCl_3$): 7.99 (*d*, *J* = 8, 2 H); 7.39 (*t*, *J* = 7.6, 2 H); 7.25–7.28 (*m*, 2 H); 2.61 (*s*, 6 H). ^{13}C-NMR (100 MHz, $CDCl_3$): 139.5; 136.3; 132.4; 127.1; 124.9; 119.5; 20.7. EI-MS: 212 (100, M^+), 197 (16), 178 (6), 105 (12) [3–5].

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Received May 5, 2011