Ring Closure Reactions of Disubstituted 4-Penten-1-oxyl Radicals − Towards a Stereoselective Synthesis of *allo*-Muscarine

Jens Hartung,*[a] and Rainer Kneuer[a]

Dedicated to Professor Dr. Bernd Giese on the occasion of his 60th birthday

Keywords: Radicals / Cyclizations / Pyridinethione / Tetrahydrofurans / Asymmetric synthesis / Thiazolethione

The trisubstituted functionalized tetrahydrofurans **10**, **11**, **16**, **18**, and **19** were photochemically prepared from 2,3-*syn*- and 2,3-*anti*-configured *N*-(3-benzoyloxy-5-hexen-2-oxy)thiazole-2(3*H*)-thione *anti*-**6**, pyridinethiones **7**, *anti*-**8**, and $BrCCl_3$. The formation of tetrahydrofurans was achieved by an efficient and highly regioselective alkoxyl radical cyclization (5-*exo*-trig). The 2,3-*anti* substituted intermediates **9** and **12** cyclize stereoselectively whereas a 2,3-*syn*-configured *O*-radical affords both possible diastereomeric addition products in equal amounts. The cyclized tetrahydrofuryl methyl radicals were trapped with the bromine atom donor $BrCCl_3$ to afford the bromomethyl-substituted cyclic ethers **10**, **11**, **18**, and **19** in excellent yields. The utility of this reaction was stressed by conversion of one of the newly prepared tetrahydrofurans in a two-step synthesis into (+)-*allo*-muscarine (+)-**20**.

Introduction

The discovery of *N*-alkoxythiazole-2(3*H*)-thiones[1] and their corresponding pyridine-2(1*H*)-thiones[2] as efficient precursors of free alkoxyl radicals has enabled us to study tetrahydrofuran syntheses from substituted 4-penten-1-oxyl radicals.[3−5] We have observed that 2,5-*trans*-, 2,4-*cis*-, and 2,3-*trans*-dialkyl-substituted tetrahydrofurans are accessible from monosubstituted pentenoxyl radicals in spite of their high reactivities (rate constants of 5-*exo*-trig cyclizations: $k^{cycl} \approx 10^8\ s^{-1}$). The efficiency of these transformations has raised the question whether *O*-radical reactions could be usefully applied in stereoselective syntheses of multiply substituted tetrahydrofurans, such as the muscarine alkaloids which, according to the best of our knowledge, have never been prepared using free radical chemistry. The feasibility of such reactions, however, is dependent on a precise stereocontrol of the central *O*-radical reaction by substituent effects. If, for instance, cyclizations of disubstituted 4-pentenoxyl radicals would follow similar guidelines as those of monosubstituted 4-penten-1-oxyl radicals with regard to stereoselectivity, tetrahydrofuran syntheses using alkoxyl radical chemistry should become of notable synthetic utility. These considerations initiated the present investigation on substituent effects in alkoxyl radical ring closures of 3-substituted 5-hexen-2-oxyl radicals.

Results and Discussion

The 2,3-*syn*- and 2,3-*anti*-configured hexenols **2** were chosen as starting materials for our studies (Scheme 1). These compounds are readily available from methyl lactate by adapting the method of Chan and Li.[6] Since the major aim of the present work was an elucidation of the general scope of hitherto unknown cyclizations of 3-substituted 5-hexen-2-oxyl radicals we could have started with racemic methyl lactate. For economic reasons, however, we used methyl *S*-(−)-lactate (**1**) as substrate. The α-hydroxy ester **1** was converted into the *p*-methoxybenzyl-protected[7] 2-(*p*-methoxybenzyloxy)propanal, which was reacted with allyl magnesium bromide at −78 °C in diethyl ether in a one-pot reaction to afford a 14:86 mixture of *anti*- and *syn*-**2**. The diastereomers **2** were separated by column chromatography to afford pure *syn*-**2** and *anti*-**2**. Reaction of *syn*-**2** with benzoyl chloride and 1,4-diazabicyclo[2.2.2]octane (DABCO) was followed by removal of the *p*-methoxybenzyl protecting group with DDQ[7] and tosylation[8] of the free hydroxyl group in position 2 to afford *syn*-**3** (Scheme 1).

A similar procedure which uses the reaction of alcohol *syn*-**2** with TBDMSCl and imidazole in DMF in the first step was applied for the synthesis of tosylate *syn*-**4** from *syn*-**2**. The alcohol *anti*-**2** was converted into *anti*-**3** in 87% overall yield as described for its diastereomer *syn*-**2**. Based on our experience, the *N*-alkoxy derivatives of pyridine-2(1*H*)-thione and of 4-methylthiazole-2(3*H*)-thione[9,10] were selected as *O*-radical precursors. To the best of our knowledge there is no report in the literature on the utility of *N*-alkoxy-4-methylthiazole-2(3*H*)-thiones as sources of *O*-radicals. Synthesis of a 4-methylthiazolethione-derived radical precursor *anti*-**6** was achieved by treatment of the *N*-hydroxy-4-methylthiazole-2(3*H*)-thione tetraethylammo-

[a] Institut für Organische Chemie, Universität Würzburg,
Am Hubland, D-97074 Würzburg, Germany
Fax: (internat.) + 49-931/888-4606
E-mail: hartung@chemie.uni-wuerzburg.de

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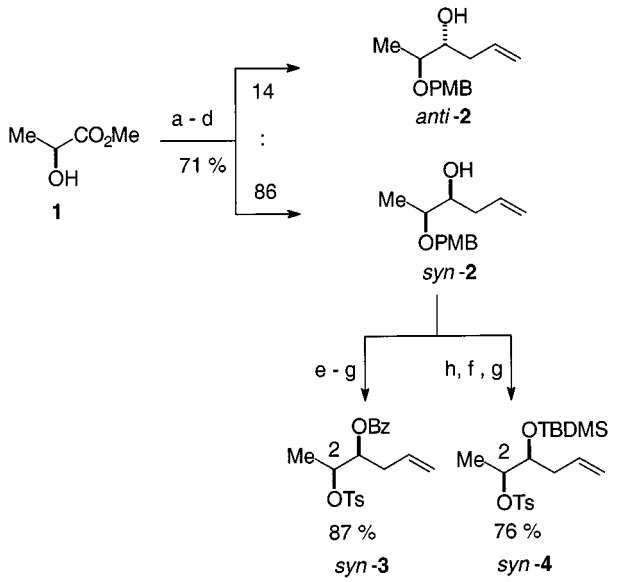
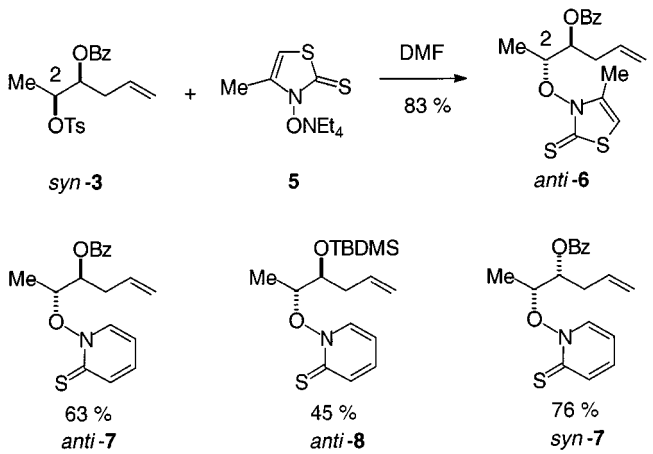
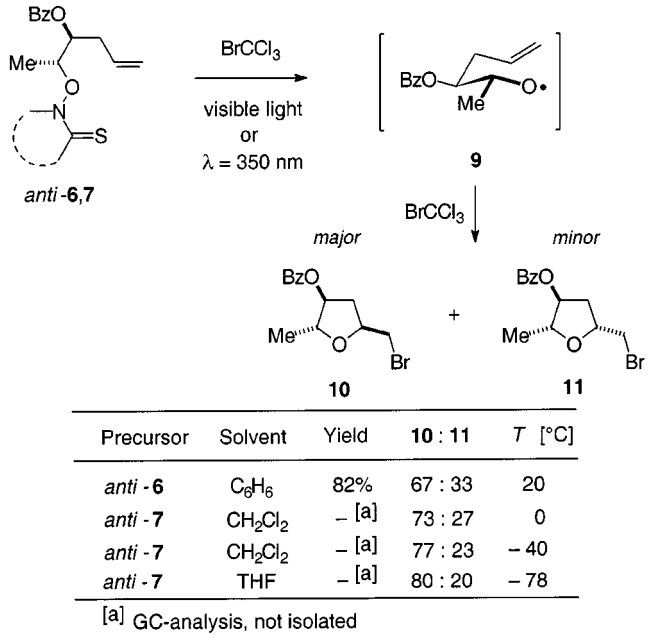


Scheme 1. Synthesis of tosylates *syn*-**3**−**4**; reagents and conditions: (a) NaH, *p*-methoxybenzyl chloride (PMBCl), DMF (75%); (b) DIBAH, Et_2O, −78 °C; (c) allyl magnesium bromide, Et_2O, −78 °C (94% step b and c); (d) column chromatography, SiO_2, petroleum ether/CH_2Cl_2/MeOH, 10/4/1(v/v/v); (e) PhCOCl, DABCO, CH_2Cl_2 (99%); (f) DDQ, H_2O/CH_2Cl_2 (94%) [84%]; (g) TosCl, DABCO, CH_2Cl_2 (94%) [96%]; (h) (*tert*-butyl)dimethylsilyl chloride, imidazole, DMF (94%); yields in square brackets refer to the synthesis of *syn*-**4**



Scheme 2. Preparation of alkoxyl radical precursors **6**−**8**



Precursor	Solvent	Yield	**10** : **11**	*T* [°C]
anti-**6**	C_6H_6	82%	67 : 33	20
anti-**7**	CH_2Cl_2	– [a]	73 : 27	0
anti-**7**	CH_2Cl_2	– [a]	77 : 23	−40
anti-**7**	THF	– [a]	80 : 20	−78

[a] GC-analysis, not isolated

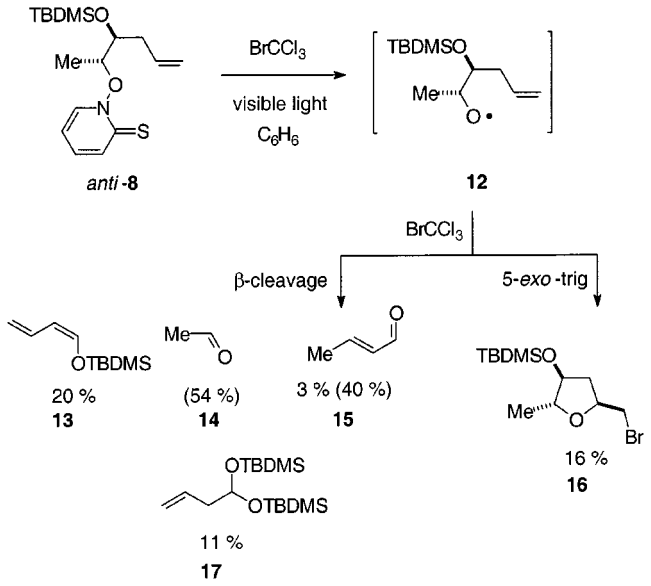
Scheme 3. Photoreaction of *anti*-**6**−**7** and $BrCCl_3$

nium salt (**5**)[9] with *syn*-**3**. The reaction proceeded with a clean inversion of configuration at carbon C-2 (Scheme 2) and afforded the 2,3-*anti*-configured alkoxyl radical precursor *anti*-**6** (83% yield, tan oil). The respective 5-hexen-2-oxypyridinethione *anti*-**7** was obtained in 63% yield as a yellow oil. Reaction of the TBDMS-substituted tosylate *syn*-**4** and *N*-hydroxypyridine-2(1*H*)-thione tetrabutylammonium salt[9] gave the alkoxyl radical precursor *anti*-**8** in 45% yield (yellow oil). The tosylate *anti*-**3** was treated with *N*-hydroxypyridine-2(1*H*)-thione tetrabutylammonium salt to afford the 2,3-*syn*-configured *N*-alkoxypyridinethione *syn*-**7** (76% yield, yellow oil). The pyridinethiones **7** and **8** were only moderately stable and had to be kept in the dark, while thiazolethione *anti*-**6** was stable towards visible light and did not deteriorate upon storage at room temperature.

The photochemical reaction (λ = 350 nm, T = 20 °C) of *N*-(3-benzoyloxy-5-hexen-2-oxy)thiazole-2(3*H*)-thione *anti*-**6** (c_o = 0.18 M) and $BrCCl_3$ (c_o = 1.4 M) in C_6H_6 gave, upon workup of the colourless solution, the trisubstituted tetrahydrofuran **10** (55%) as major and **11** (27%) as minor product (Scheme 3). The heterocycles **10** and **11** originated from a homolysis of the N,O bond in ester *anti*-**6** to afford the alkoxyl radical **9**. The intermediate **9** cyclized stereoselectively to give carbon centred tetrahydrofurylmethyl radicals (not shown in Scheme 3) which were trapped by $BrCCl_3$ to afford heterocycles **10** and **11** (Scheme 3). The tetrahydrofurans **10** and **11** were isolated as pure diastereomers by column chromatography. In order to increase the selectivity for the formation of tetrahydrofuran **10** the photoreactions were carried out at lower temperatures. This, however, was more conveniently achieved using pyridinethione *anti*-**7** as source of *O*-radical **9**, since the *N*-alkoxypyridine-2(1*H*)-thiones are highly sensitive to visible light. Thus, solutions of *anti*-**7** and $BrCCl_3$ were thermostated in a mirrored Dewar vessel at −40 °C or at −78 °C and were irradiated using incandescent light. The results of this study (Scheme 3) indicated that the selectivity for the formation of the desired product **10** increased from **10**:**11** = 67:33 at 20 °C to 80:20 at −78 °C. Quantification of our results using *n*-$C_{14}H_{30}$ as internal standard for GC analysis showed that yields of **10** and **11** at −40 °C corresponded to the isolated yields given in Scheme 3 for the photoreaction of thiazolethione *anti*-**6** and $BrCCl_3$ at room temperature. A further decrease of the reaction temperature to −78 °C can, however, not be recommended for synthetic purposes. Although the selectivity for the formation of **10** increased, yields of **10** and **11** dropped and became hard to quantify in a reproducible manner. Furthermore, photochemical conversion of *anti*-**7** at −78 °C became sluggish and stopped without complete consumption of starting mat-

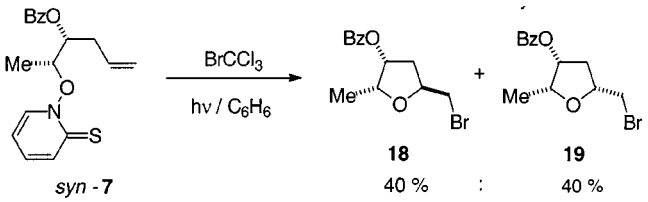
erial. In addition, new side products were formed in minor amounts which have not yet been characterized.

Increasing the steric bulk of the β-oxy substituent was thought to be a straightforward approach to further improve the stereoselectivity of the *O*-radical cyclization of 2,3-*anti*-substituted alkoxyl radicals (Scheme 4). Thus, the TBDMS-substituted *N*-hexenoxypyridinethione *anti*-**8** (c_o = 0.18 M) was subjected to photolysis in the presence of $BrCCl_3$ (c_o = 1.4 M). The starting material was consumed within one minute. Upon workup of the reaction mixture, only a single stereoisomer of tetrahydrofuran **16** was isolated. Its yield, however, was poor (16%). Besides heterocycle **16**, four additional products were identified from this experiment which pointed to a β-cleavage of radical **12**. One major product of this fragmentation was acetaldehyde (**14**) (54%); it was only identified when the reaction was run in an NMR tube. Upon extrusion of the C−2 unit of the parent alkoxyl radical **12** a carbon centred butenyl radical (not shown in Scheme 4) should originate which is thought to give rise to products **13**, **15**, and **17**. Fragmentation of the β-silyloxy-substituted *O*-radicals are known processes in bicyclic systems.[11] However it was surprising to note from the present example that such fissions can get more efficient than the 5-*exo*-trig cyclization of *O*-radical **12**.



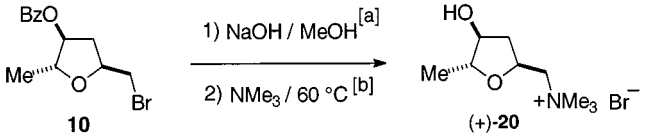
Scheme 4. Photolysis of TBDMS-protected alkoxyl radical precursor *anti*-**8** in the presence of $BrCCl_3$; Figures in parentheses denote yields of volatile aldehydes as derived from a separate NMR experiment in C_6D_6

If the 2,3-*syn*-substituted pyridinethione *syn*-**7** was photoreacted at room temperature with $BrCCl_3$ (incandescent light) the (bromomethyl)tetrahydrofurans **18** and **19** were isolated in 80% yield. However, no stereoselectivity for the formation of either product was observed (Scheme 5). In earlier work we have studied 4-penten-1-oxyl radical cyclizations by ab initio theoretical methods.[12] According to these data the lowest energy transition state for 5-*exo*-trig ring closure of alkoxyl radicals is reminiscent of a flattened chair-like conformer, which is similar to the Beckwith transition structure of 5-hexenyl radical cyclizations.[13] If such a transition state is of significance for *O*-radical cyclizations which have been described in this work, both substituents in the 2,3-*anti*-substituted radical **9** (derived from *anti*-**6** and *anti*-**7**) would be located preferentially in *pseudo*-equatorial positions (this corresponds to a *trans*-configuration in cyclic systems, Scheme 3) and will favour formation of trisubstituted tetrahydrofuran **10**. If radicals derived from 2,3-*syn* substituted pyridinethione *syn*-**7** would cyclize via a chair-like transition state, either the methyl or the benzoyloxy group has to be situated in a *pseudo*-axial arrangement. Therefore, we refer to the 2,3-*anti* configuration in *anti*-**6** and *anti*-**7** as matched for the stereoselective synthesis of trisubstituted tetrahydrofurans via alkoxyl radical 5-*exo*-trig ring closures. In the same manner, the 2,3-*syn* arrangement in *syn*-**7** appears to be the mismatched case.



Scheme 5. Preparation of tetrahydrofurans **18** and **19** from *syn*-**7**

In order to underline the utility of the new stereoselective tetrahydrofuran synthesis described in this work, the benzoyl ester **10** was saponified to afford a 3-hydroxyl-substituted 2-methyl-5-bromomethyltetrahydrofuran which was reacted with NMe_3 in ethanol at 60 °C in a sealed tube (no elevated pressure).[14] According to our results, substitution of trimethylamine for bromine stopped at 38% conversion of the starting material and afforded (+)-*allo*-muscarine (+)-**20** as colourless crystals as well as 60% of starting material (Scheme 6). The NMR spectroscopic data of (+)-**20** are in agreement with the published values for the enantiomer (−)-*allo*-muscarine (−)-**20**.[14]–[18]



Scheme 6. Synthesis of (+)-*allo*-muscarine (+)-**20**: (a) 76% yield; (b) 38% yield and 60% of recovered starting material

Conclusion

The 5-*exo*-trig ring closures of 2,3-*syn*- and 2,3-*anti* 5-hexen-2-oxyl radicals have been studied for the first time. The stereochemical course of these radical cyclizations point to matched (2,3-*anti* substituted 5-hexen-2-oxyl radicals **9**, **12**) and mismatched (2,3-*syn* substitution) cases in *O*-radical cyclizations. Based on these findings we were able to complete the first synthesis of a muscarine alkaloid whose central ring was built by an *O*-radical reaction. These findings should be of significant importance for an application of alkoxyl radical chemistry in synthetic organic chemistry.

Experimental Section

General Remarks: Methyl *S*-(−)-lactate (**1**) was purchased from Aldrich and used as received. Petroleum ether refers to the fraction boiling between 55−60 °C. Unless otherwise noted, NMR spectra were recorded in $CDCl_3$. IR spectra were measured in CCl_4 in NaCl cuvettes (0.5 mm). C,H,N,S analyses were carried out in the Microanalytical Laboratory in the department of Inorganic Chemistry at the Universität Würzburg. Combustion analyses of compounds **2**, **3**, **7**, **10**, **11**, **18**, and **19** (diastereomers) were obtained from samples which contained both possible diastereomers. All solvents were distilled prior to use and were purified according to standard procedures.[19]

Preparation of Tosylates 3 and 4

Methyl 2-(4-Methoxybenzyloxy)propionate: Methyl 2*S*-(−)-lactate (**1**) (2.95 g, 28.3 mmol) was added dropwise at 0 °C to a mixture of *p*-methoxybenzyl chloride (4.44 g, 28.3 mmol) and sodium hydride (0.608 g, 28.3 mmol) under argon in anhydrous DMF (35 mL). The suspension was stirred for 18 h at room temp. and was poured into a mixture of H_2O and diethyl ether (30 mL each). The aqueous phase was separated and extracted with diethyl ether (2 × 20 mL) The combined organic phases were washed with water (2 × 20 mL) and with brine (20 mL) and dried ($MgSO_4$). The solvent was removed in vacuo and the remaining oil was distilled to afford methyl 2-(4-methoxybenzyloxy)propionate (4.76 g, 75%). − Colourless liquid, bp 98 °C/1.6 × 10^{-2} mbar. − MS (70 eV, EI): *m*/*z* (%) = 224 (5), 137 (63), 121 (100). − IR (NaCl): $\tilde{\nu}$ = 2920 cm^{-1}, 1730, 1590, 1490, 1440, 1230, 1130, 1100, 1020, 810. − ^{1}H NMR (250 MHz): δ = 1.42 (d, *J* = 6.7 Hz, 3 H), 3.75 (s, 3 H), 3.80 (s, 3 H), 4.05 (q, *J* = 6.7 Hz, 1 H), 4.39 (d, *J* = 11.3 Hz, 1 H), 4.62 (d, *J* = 11.3 Hz, 1 H), 6.88 (d, *J* = 8.9 Hz, 2 H), 7.29 (d, *J* = 8.9 Hz, 2 H). − ^{13}C NMR (63 MHz): δ = 18.7, 51.9, 55.2, 71.6, 73.6, 113.7, 129.5, 129.6, 159.3, 173.8. − $C_{12}H_{16}O_4$ (224.3): calcd. C 64.27, H 7.19; found C 64.06, H 7.06.

***syn*- and *anti* 2-(4-Methoxybenzyloxy)-5-hexen-3-ol (2):** A solution of methyl 2-(4-methoxybenzyloxy)propionate (3.05 g, 13.6 mmol) in anhydrous diethyl ether (70 mL) was treated at −78 °C under nitrogen atmosphere dropwise with a solution of diisobutylaluminum hydride (1 M in *n*-hexane, 17.7 mL). The reaction mixture was stirred for 30 min at −78 °C and was reacted at this temperature dropwise with a solution of allyl magnesium bromide in diethyl ether (prepared from 0.727 g, 29.9 mmol of magnesium turnings and 3.29 g, 27.2 mmol of allyl bromide in 14 mL of anhydrous diethyl ether). The reaction mixture was stirred for 6 h at −78 °C and was allowed to warm to 0 °C. 2 N HCl (25 mL) was added and the aqueous phase was separated and was extracted with diethyl ether (2 × 20 mL). The combined ethereal phases were washed with a satd. solution of $NaHCO_3$ (20 mL) and H_2O (20 mL), and then dried ($MgSO_4$). The solvent was removed in vacuo and the remaining oil was purified by column chromatography [(SiO_2, petroleum ether/CH_2Cl_2/ MeOH, 10:4:1 (v/v/v)]. Mixture of isomers: $C_{14}H_{20}O_3$ (236.3): calcd. C 71.16, H 8.53; found C 70.82, H 8.50.

***syn*-2:** Yield 2.60 g (81%), colourless oil, R_f = 0.48. − IR (NaCl): $\tilde{\nu}$ = 3420 cm^{-1}, 3040, 2920, 2900, 1600, 1500, 1240, 1120, 1060, 900, 810. − ^{1}H NMR (250 MHz): δ = 1.19 (d, *J* = 6.0 Hz, 3 H), 2.11−2.41 (m, 3 H), 3.41 (qd, J_q = 6.0 Hz, J_d = 6.1 Hz, 1 H), 3.46−3.55 (m, 1 H), 3.81 (s, 3 H), 4.37 (d, *J* = 11.0 Hz, 1 H), 4.60 (d, *J* = 11.0 Hz, 1 H), 5.08 (d, *J* = 10.7 Hz, 1 H), 5.10 (d, *J* = 16.0 Hz, 1 H), 5.87 (m_c, 1 H), 6.88 (d, *J* = 8.7 Hz, 2 H), 7.26 (d, *J* = 8.9 Hz, 2 H). − ^{13}C NMR (63 MHz): δ = 15.4, 37.5, 55.2, 70.7, 74.2, 77.2, 113.8, 117.1, 129.4, 130.4, 134.8, 159.2. − MS (70 eV, EI): *m*/*z* (%) = 236 (1), 135 (28), 121 (100), 77 (27).

***anti*-2:** Yield 0.42 g (13%), colourless oil, R_f = 0.44. − ^{1}H NMR (250 MHz): δ = 1.18 (d, *J* = 6.3 Hz, 3 H), 1.92 (br. s, 1 H), 2.24 (m_c, 2 H), 3.50 (dq, J_d = 4.0 Hz, J_q = 6.3 Hz, 1 H), 3.76 (m_c, 1 H), 3.81 (s, 3 H), 4.43 (d, *J* = 11.2 Hz, 1 H), 4.56 (d, *J* = 11.2 Hz, 1 H), 5.11 (d, *J* = 11.5 Hz, 1 H), 5.12 (d, *J* = 17.0 Hz, 1 H), 5.84 (m_c, 1 H), 6.88 (d, *J* = 8.7 Hz, 2 H), 7.26 (d, *J* = 8.7 Hz, 2 H). − ^{13}C NMR (63 MHz): δ = 14.0, 37.2, 55.5, 70.6, 72.7, 77.2, 114.0, 117.7, 129.4, 130.7, 135.2, 159.4.

***syn*-2-(4-Methoxybenzyl)-5-hexen-3-yl Benzoate:** Alcohol *syn*-**2** (552 mg, 2.34 mmol) and DABCO (536 mg, 4.78 mmol) were dissolved at 0 °C in reagent grade CH_2Cl_2 (2.4 mL) and treated dropwise with neat benzoyl chloride (493 mg, 3.51 mmol). The mixture was stirred for 30 min at 0 °C. Methyl *tert*-butyl ether (MTB, 10 mL) was added and the precipitate was dissolved by acidification of the reaction mixture with 2 N aqueous HCl (10 mL). The organic phase was separated and the aqueous layer was extracted with MTB (2 × 5 mL). The combined organic solutions were successively washed with 2 N HCl, satd. aqueous $NaHCO_3$, brine (10 mL each), and then dried ($MgSO_4$). The solvent was removed in vacuo to afford pure *syn*-2-(4-methoxybenzyl)-5-hexen-3-yl benzoate: yield 791 mg (99%), colourless oil. − $C_{21}H_{24}O_4$ (340.4): calcd. C 74.09, H 7.11; found C 73.88, H 6.82. − ^{1}H NMR (250 MHz): δ = 1.22 (d, *J* = 6.4 Hz, 3 H), 2.40−2.58 (m, 2 H), 3.76 (m_c, 1 H), 3.80 (s, 3 H), 4.47 (d, *J* = 11.2 Hz, 1 H), 4.60 (d, *J* = 11.6 Hz, 1 H), 5.04 (d, *J* = 10.1 Hz, 1 H), 5.09 (d, *J* = 17.4 Hz, 1 H), 5.25 (ddd, *J* = 4.6, 4.9, 7.9 Hz, 1 H), 5.79 (m_c, 1 H), 6.84 (d, *J* = 8.9 Hz, 2 H), 7.27 (d, *J* = 8.9 Hz, 2 H), 7.44 (m_c, 2 H), 7.55 (m_c, 1 H), 8.05 (m_c, 2 H). − ^{13}C NMR (63 MHz): δ = 15.4, 34.2, 55.2, 70.8, 74.2, 75.4, 113.7, 117.7, 128.3, 128.9, 129.3, 129.6, 130.6, 132.9, 133.8, 159.1, 166.1.

***anti*-2-(4-Methoxybenzyl)-5-hexen-3-yl Benzoate:** This compound was obtained in the same manner as described for its *syn* isomer: yield 790 mg (99%), colourless oil. − ^{1}H NMR (250 MHz): δ = 1.26 (d, *J* = 6.4 Hz, 3 H), 2.51−2.57 (m, 2 H), 3.74 (dq, J_d = 4.6 Hz, J_q = 6.4 Hz, 1 H), 3.78 (s, 3 H), 4.52 (s, 2 H), 5.04 (d, *J* = 10.1 Hz, 1 H), 5.11 (d, *J* = 17.1 Hz, 1 H), 5.26 (ddd, *J* = 4.6, 5.5, 7.3 Hz, 1 H), 5.81 (m_c, 1 H), 6.83 (d, *J* = 8.5 Hz, 2 H), 7.26 (d, *J* = 8.5 Hz, 2 H), 7.44 (m_c, 2 H), 7.56 (m_c, 1 H), 8.05 (m_c, 2 H). − ^{13}C NMR (63 MHz): δ = 15.9, 34.5, 55.2, 70.7, 74.9, 75.4, 113.7, 117.7, 128.3, 128.9, 129.2, 129.6, 130.5, 132.8, 133.8, 159.1, 166.0.

***syn*-3-Benzoyloxy-5-hexen-2-ol:** *syn*-2-(4-Methoxybenzyl)-5-hexen-3-yl benzoate (699 mg, 2.03 mmol) was dissolved in CH_2Cl_2 (22 mL). Water (1.1 mL) and DDQ (658 mg, 2.90 mmol) were added. The resulting slurry was stirred for 30 min at 20 °C. The precipitate was filtered off and was thoroughly washed with CH_2Cl_2. The combined liquid phases were extracted with satd. aqueous $NaHCO_3$ and with brine (10 mL each), and then dried ($MgSO_4$). The solvent was removed in vacuo and the remaining residue was purified by column chromatography [SiO_2, petroleum ether/diethyl ether, 2:1 (v/v)]: yield 419 mg (94%) colourless oil. − MS (70 eV, EI): *m*/*z* (%) = 179 (2), 176 (2), 105 (100), 77 (44). − $C_{13}H_{16}O_3$ (220.3): calcd. C 70.89, H 7.32; found C 70.59, H 7.15. − ^{1}H NMR (250 MHz): δ = 1.26 (d, *J* = 6.4 Hz, 3 H), 2.00 (s br., 1 H), 2.43−2.64 (m, 2 H), 3.99 (dq, J_d = 4.9 Hz, J_q = 6.4 Hz, 1 H), 5.06 (d, *J* = 10.1 Hz, 1 H), 5.08 (d, *J* = 17.1, 1 H), 5.83 (m_c, 1 H), 7.44 (m_c, 2 H), 7.57 (m_c, 1 H), 8.06 (m_c, 2 H). − ^{13}C NMR (63 MHz): δ = 19.5, 35.2, 68.4, 77.4, 118.2, 128.4, 129.6, 130.1, 133.1, 133.2, 166.3.

***anti*-3-Benzoyloxy-5-hexen-2-ol:** yield 371 mg (83%), colourless oil. − ^{1}H NMR (250 MHz): δ = 1.26 (d, *J* = 6.4 Hz, 3 H), 2.17 (s br., 1 H), 2.42-−2.62 (m, 2 H), 4.05 (dq, J_d = 4.9 Hz, J_q = 6.4 Hz, 1

H), 5.07 (d, J = 10.1 Hz, 1 H), 5.15 (m_c, 1 H), 5.84 (ddt, J_d = 10.1, 17.1 Hz, J_t = 7.0 Hz, 1 H), 7.45 (m_c, 2 H), 7.57 (m_c, 1 H), 8.05 (m_c, 2 H). − ^{13}C NMR (63 MHz): δ = 18.1, 34.4, 69.0, 77.6, 117.9, 128.4, 129.6, 130.2, 133.1, 133.6, 166.5.

***syn*-3-(Benzoyloxy)-5-hexen-2-yl *p*-Toluenesulfonate [*syn*-(3)]:** A solution of *syn*-3-(benzoyloxy)-5-hexen-2-ol (399 mg, 1.81 mmol) and DABCO (406 mg, 3.62 mmol) in reagent grade CH_2Cl_2 (2 mL) was treated with *p*-toluenesulfonyl chloride (517 mg, 2.17 mmol) at 0 °C. The slurry was stirred for 1 h at 0 °C, diluted with MTB (5 mL), and treated with aqueous 2N HCl (5 mL) to dissolve the precipitate. The organic layer was separated and the aqueous phase was washed with MTB (2 × 5 mL). The combined organic phases were extracted with 2N aqueous HCl, satd. aqueous $NaHCO_3$, and brine (10 mL each), and then dried ($MgSO_4$). The solvent was removed in vacuo to afford pure *syn*-**3** as a colourless oil. Yield 636 mg (94%). − ^{1}H NMR (250 MHz): δ = 1.33 (d, J = 6.6 Hz, 3 H), 2.37 (s, 3 H), 2.28−2.46 (m, 2 H), 4.86 (dq, J_d = 5.0 Hz, J_q = 6.6 Hz, 1 H), 5.05 (d, J = 10.1 Hz, 1 H), 5.07 (d, J = 17.2 Hz, 1 H), 5.18 (dt, J_d = 5.0 Hz, J_t = 6.9 Hz, 1 H), 5.71 (ddt, J_d = 10.1, 17.2 Hz, J_t = 6.9 Hz, 1 H), 7.22 (d, J = 8.4 Hz, 2 H), 7.42 (m_c, 2 H), 7.57 (m_c, 1 H), 7.75 (d, J = 8.4 Hz, 2 H), 7.96 (m_c, 2 H). − ^{13}C NMR (100 MHz): δ = 17.4, 21.6, 34.9, 74.0, 78.7, 118.9, 127.6, 128.3, 129.6, 129.8, 132.2, 133.1, 134.2, 144.6, 165.6. − MS (70 eV, EI); *m*/*z* (%): 200 (23), 172 (14), 155 (43), 91 (100), 77 (24).

***anti*-3-(Benzoyloxy)-5-hexen-2-yl *p*-Toluenesulfonate [*anti*-(3)]:** This compound was obtained from *anti*-3-(benzoyloxy)-5-hexen-2-ol as described above for the *syn*-isomer. Yield 636 mg (94%). − ^{1}H NMR (250 MHz): δ = 1.42 (d, J = 6.6 Hz, 3 H), 2.29 (s, 3 H), 2.37−2.60 (m, 2 H), 4.83 (dq, J_d = 3.2 Hz, J_q = 6.6 Hz, 1 H), 5.04 (d, J = 10.1 Hz, 1 H), 5.04−5.08 (m, 1 H), 5.08 (d, J = 17.3 Hz, 1 H), 5.69 (ddt, J_d = 10.1, 17.3 Hz, J_t = 6.9 Hz, 1 H), 7.16 (d, J = 8.3 Hz, 2 H), 7.41 (m_c, 2 H), 7.56 (m_c, 1 H), 7.74 (d, J = 8.4 Hz, 2 H), 7.90 (m_c, 2 H). − ^{13}C NMR (100 MHz): δ = 16.8, 21.6, 32.3, 74.5, 78.7, 118.5, 127.8, 128.3, 129.6, 129.7, 130.2, 132.7, 133.1, 133.7, 144.6, 165.6. − Mixture of *syn*-**3** and *anti*-**3**: $C_{20}H_{22}O_5S$ (374.5): calcd. C 64.15, H 5.92, S 8.56; found C 63.86, H 5.80, S 8.50.

***syn*-3-[(*tert*-Butyl)dimethylsilyloxy]-2-(4-methoxybenzyloxy)-5-hexene:** Small portions of *tert*-butyldimethylsilyl chloride (573 mg, 3.79 mmol) were added at 20 °C to a solution of imidazole (462 mg, 6.78 mmol) and alcohol *syn*-**2** (641 mg, 2.71 mmol) in DMF. The solution was stirred for 18 h at 20 °C and diluted afterwards with H_2O (20 mL). The solution was extracted with diethyl ether (3 × 15 mL). The combined organic washings were dried ($MgSO_4$) and concentrated in vacuo to afford a colourless oil which was purified by column chromatography [SiO_2, petroleum ether/diethyl ether, 2:1, (v/v)]. Yield 899 mg (94%), colourless oil. − ^{1}H NMR (250 MHz): δ = 0.00 (s, 3 H), 0.03 (s, 3 H), 0.88 (s, 9 H), 1.14 (d, J = 6.4 Hz, 3 H), 2.13 (m_c, 1 H), 2.35−2.44 (m, 1 H), 3.49 (dq, J_d = 4.9 Hz, J_q = 6.4 Hz, 1 H), 3.74 (m_c, 1 H), 3.82 (s, 3 H), 4.46 (d, J = 11.6 Hz, 1 H), 4.54 (d, J = 11.6 Hz, 1 H), 5.03 (d, J = 10.1 Hz, 1 H), 5.06 (d, J = 17.1 Hz, 1 H), 5.84 (m_c, 1 H), 6.89 (d, J = 8.6 Hz, 2 H), 7.28 (d, J = 8.6 Hz, 2 H). − ^{13}C NMR (63 MHz): δ = −4.5, −3.0, 14.0, 18.1, 25.9, 36.3, 55.3, 70.7, 73.8, 113.7, 116.5, 129.1, 131.1, 136.2, 159.0. − MS (70 eV, EI): *m*/*z* (%) = 121 (100), 73 (86), 57 (20), 41 (9). − $C_{20}H_{34}O_3Si$ (350.6): C 68.52, H 9.78; found C 69.09, H 9.90.

***syn*-3-[(*tert*-Butyl)dimethylsilyloxy]-5-hexen-2-ol:** A mixture of *syn*-3-[(*tert*-butyl)dimethylsilyloxy]-2-(4-methoxybenzyloxy)-5-hexene (880 mg, 2.51 mmol) in CH_2Cl_2 (12 mL) and H_2O (0.6 mL) was treated for 15 min at 20 °C with DDQ (639 mg, 2.82 mmol). The reddish precipitate was filtered off and washed thoroughly with CH_2Cl_2 (3 × 10 mL). The combined organic phases were washed with satd. aqueous $NaHCO_3$, brine (15 mL each), and then dried ($MgSO_4$). The solvent was distilled off in vacuo to afford a colourless oil which was purified by column chromatography [SiO_2, petroleum ether/diethyl ether, 2:1 (v/v)]. Yield 485 mg (84%), colourless oil. − ^{1}H NMR (250 MHz): δ = 0.09 (s, 3 H), 0.09 (s, 3 H), 0.91 (s, 9 H), 1.13 (d, J = 6.4 Hz, 3 H), 2.10 (br. s, 1 H), 2.14−2.25 (m, 1 H), 2.40 (m_c, 1 H), 3.48 (dt, J_d = 4.6 Hz, J_t = 6.7 Hz, 1 H), 3.65 (dq, J_d = 4.6 Hz, J_q = 6.4 Hz, 1 H), 5.06 (d, J = 10.4 Hz, 1 H), 5.07 (d, J = 17.1 Hz, 1 H), 5.81 (m_c, 1 H). − ^{13}C NMR (63 MHz): δ = −4.7, −4.2, 18.1, 19.4, 25.8, 38.4, 68.8, 76.1, 117.4, 134.2. − MS (70 eV, EI): *m*/*z* (%) = 185 (13), 75 (100), 41 (8). − $C_{12}H_{26}O_2Si$ (230.4): C 62.55, H 11.37; found C 62.26, H 11.19.

***syn*-3-[(*tert*-Butyl)dimethylsilyloxy]-5-hexen-2-yl *p*-Toluenesulfonate [*syn*-(4)]:** *syn*-3-[(*tert*-Butyl)dimethylsilyloxy]-5-hexen-2-ol (484 mg, 2.10 mmol) and DABCO (472 mg, 4.21 mmol) were dissolved in anhydrous CH_2Cl_2 and were treated with *p*-toluenesulfonyl chloride (601 mg, 3.16 mmol) as described for the synthesis of *syn*-**3** to afford *p*-toluenesulfonic acid ester *syn*-**4**. Crude *syn*-**4** was purified by column chromatography [SiO_2, petroleum ether/ethyl acetate, 3:1 (v/v)]. Yield 773 mg (96%), colourless oil. − ^{1}H NMR (250 MHz): δ = −0.06 (s, 3 H), −0.03 (s, 3 H), 0.82 (s, 9 H), 1.17 (d, J = 6.4 Hz, 3 H), 2.03−2.15 (m, 1 H), 2.25−2.35 (m, 1 H), 2.44 (s, 3 H), 3.66 (dt, J = 4.3, 8.2 Hz, 1 H), 4.46 (dq, J_d = 4.3 Hz, J_q = 6.4 Hz, 1 H), 5.03 (d, J = 11.6 Hz, 1 H), 5.04 (d, J = 15.6 Hz, 1 H), 5.72 (m_c, 1 H), 7.34 (d, J = 7.9 Hz, 2 H), 7.79 (d, J = 8.2 Hz, 2 H). − ^{13}C NMR (63 MHz): δ = −4.8, −4.7, 14.3, 17.9, 21.6, 25.7, 35.6, 72.6, 80.4, 117.5, 127.8, 129.8, 134.4, 134.7, 144.6. − MS (70 eV, EI): *m*/*z* (%) = 343 (8), 229 (100), 155 (10), 91 (37), 73 (63), 41 (18). − $C_{19}H_{32}O_4SSi$ (384.6): calcd. C 59.33, H 8.39, S 8.34; found C 59.66, H 8.41, S 8.14.

Preparation of Alkoxyl Radical Precursors 6−8

***N*-(2,3-*anti*-3-Benzoyloxy-5-hexen-2-oxy)-4-methylthiazole-2(3*H*)-thione [*anti*-(6)]:** A flame-dried round-bottomed flask was charged with *N*-hydroxy-4-methylthiazole-2(3*H*)-thione tetraethylammonium salt (**5**)[9] (1.42 g, 5.15 mmol), anhydrous DMF (20 mL) and tosylate *syn*-**3** (1.78 g, 4.78 mmol). The reaction mixture was stirred for 5 d at 20 °C and was then poured into a mixture of H_2O and MTB (100 mL each). The organic phase was separated and the aqueous layer was washed with MTB (3 × 50 mL). The combined organic phases were extracted with 2 N NaOH and brine (50 mL each), and then dried ($MgSO_4$). The solvent was removed in vacuo to afford a tan oil which was purified by column chromatography [SiO_2, petroleum ether/diethyl ether, 1:1 (v/v)] to afford *anti*-**6** (tan oil) (1.00 g, 83%, based on a conversion of 72% of *syn*-**3**) and tosylate *syn*-**3** (0.50 g, 28%). − ^{1}H NMR (250 MHz): δ = 1.41 (d, J = 6.4 Hz, 3 H), 2.12 (d, J = 1.2 Hz, 3 H), 2.49−2.71 (m, 2 H), 5.09 (d, J = 10.1 Hz, 1 H), 5.15 (d, J = 17.1 Hz, 1 H), 5.50 (ddd, J = 3.4, 6.1, 7.6 Hz, 1 H), 5.77 (dq, J_d = 3.4 Hz, J_q = 6.4 Hz, 1 H), 5.86 (ddt, J_d = 10.1, 17.1 Hz, J_t = 7.0 Hz, 1 H), 6.13 (q, J = 1.2 Hz, 1 H), 7.46 (m_c, 2 H), 7.59 (m_c, 1 H), 8.06 (m_c, 2 H). − ^{13}C NMR (100 MHz): δ = 13.2, 13.8, 35.5, 73.3, 81.1, 102.7, 118.6, 128.5, 129.7, 130.2, 132.6, 133.2, 138.9, 165.7, 181.0. − MS (70 eV, EI): *m*/*z* (%) = 349 (2), 131 (14), 105 (100), 77 (41). − $C_{17}H_{19}NO_3S_2$ (349.5): calcd. C 58.43, H 5.48, N 4.01, S 18.35; found C 58.53, H 5.76, N 3.97, S 18.07.

***N*-(2,3-*anti*-3-Benzoyloxy-5-hexen-2-oxy)pyridine-2(1*H*)-thione [*anti*-(7)]:** Compound *anti*-**7** (210 mg, 63% based on a conversion of *syn*-**5** of 64%) was obtained from the reaction of tosylate *syn*-**3** (594 mg, 1.59 mmol) and *N*-hydroxypyridine-2(1*H*)-thione tetrabutylammonium salt[9] (643 mg, 1.74 mmol) after 5 d at 20 °C in anhydrous DMF (8 mL) in the dark.[4] The crude product was ob-

tained in pure form after column chromatography [SiO_2, petroleum ether/diethyl ether, 1:2 (v/v)] as yellow oil as well as unreacted *syn*-**3** (216 mg, 36%). − ^{1}H NMR (250 MHz): δ = 1.59 (d, J = 6.1 Hz, 3 H), 2.33−2.61 (m, 2 H), 5.05 (d, J = 10.1 Hz, 1 H), 5.12 (d, J = 17.2 Hz, 1 H), 5.27 (dq, J_d = 2.2 Hz, J_q = 6.1 Hz, 1 H), 5.57 (ddd, J = 2.2, 5.5, 7.7 Hz, 1 H), 5.74 (ddt, J_d = 10.1, 17.2 Hz, J_t = 6.9 Hz, 1 H), 6.59 (dt, J_d = 1.8 Hz, J_t = 6.9 Hz, 1 H), 7.14 (ddd, J = 1.7, 6.8, 8.7 Hz, 1 H), 7.47 (m_c, 2 H), 7.61 (m_c, 1 H), 7.67 (dd, J = 1.8, 8.7 Hz, 1 H), 7.96 (dd, J = 1.7, 6.9 Hz, 1 H), 8.07 (m_c, 2 H). − ^{13}C NMR (100 MHz): δ = 12.7, 35.7, 72.0, 81.9, 112.4, 118.7, 128.5, 129.7, 129.9, 132.4, 132.8, 133.3, 138.0, 139.9, 166.1, 176.0. − MS (70 eV, EI): *m*/*z* (%) = 105 (100) 77 (42).

***N*-(*syn*-3-Benzoyloxy-5-hexen-2-oxy)pyridine-2(1*H*)-thione [*syn*-(7)]:** The radical precursor *syn*-**7** (176 mg, 76%) was obtained by treatment of tosylate *anti*-**3** (262 mg, 0.70 mmol) and *N*-hydroxypyridine-2(1*H*)-thione tetrabutylammonium salt[9] (284 mg, 0.77 mmol) for 5 d at 20 °C in anhydrous DMF (4 mL) in the dark.[4] Column chromatography [SiO_2, petroleum ether/diethyl ether, 1:2 (v/v)] afforded *syn*-**7** as a yellow oil. − ^{1}H NMR (250 MHz): δ = 1.36 (d, J = 6.6 Hz, 3 H), 2.61−2.68 (m, 1 H), 2.79−2.86 (m, 1 H), 5.08 (d, J = 9.9 Hz, 1 H), 5.15 (d, J = 17.3 Hz, 1 H), 5.47 (ddd, J = 4.4, 4.8, 8.8 Hz, 1 H), 5.63 (dq, J_d = 4.8 Hz, J_q = 6.6 Hz, 1 H), 5.87 (m_c, 1 H), 6.43 (dt, J_d = 1.8 Hz, J_t = 7.0 Hz, 1 H), 7.04, (ddd, J = 1.8, 6.6, 8.5 Hz, 1 H), 7.43 (m_c, 2 H), 7.57 (m_c, 1 H), 7.61−7.64 (m, 2 H), 8.01 (m_c, 2 H). − ^{13}C NMR (100 MHz): δ = 14.5, 35.3, 76.6, 79.9, 112.2, 118.5, 128.4, 129.7, 129.9, 132.4, 132.9, 133.2, 138.2, 139.4, 165.9, 176.5. − Mixture of *syn*- and *anti*-**7**: $C_{18}H_{19}NO_3S$ (329.4): calcd. C 65.63, H 5.81, N 4.25, S 9.37; found C 65.42, H 5.52, N 4.25, S 9.54.

***N*-{[*anti*-3-(*tert*-Butyl)dimethylsilyloxy]-5-hexen-2-oxy}pyridine-2(1*H*)-thione [*anti*-(8)]:** Pyridinethione *anti*-**8** (89 mg, 45%) was obtained from the reaction of tosylate *syn*-**4** (226 mg, 0.59 mmol) and *N*-hydroxypyridine-2(1*H*)-thione tetrabutylammonium salt[9] (326 mg, 0.88 mmol) for 2 d at 20 °C in anhydrous DMF (4 mL) in the dark.[4] Column chromatography [SiO_2, petroleum ether/diethyl ether, 1:1 (v/v)] afforded analytically pure *anti*-**8** as a yellow oil. − ^{1}H NMR (250 MHz): δ = 0.05 (s, 3 H), 0.06 (s, 3 H), 0.87 (s, 9 H), 1.23 (d, J = 6.4 Hz, 3 H), 2.28 (m_c, 2 H), 4.24 (dt, J_d = 1.8 Hz, J_t = 6.6 Hz, 1 H), 5.01−5.11 (m, 3 H), 5.82 (m_c, 1 H), 6.52 (dt, J_d = 2.0 Hz, J_t = 6.8 Hz, 1 H), 7.09 (dt, J_d = 1.7 Hz, J_t = 6.8 Hz, 1 H), 7.64 (m, 2 H). − ^{13}C NMR (100 MHz): δ = −4.4, −4.3, 11.7, 18.1, 25.8, 38.9, 72.7, 83.5, 112.0, 117.5, 132.4, 134.3, 137.8, 139.9, 176.0. − MS (70 eV, EI): *m*/*z* (%) = 282 (2), 212 (8), 127 (19), 73 (100). − $C_{17}H_{29}NO_2SSi$ (339.6): calcd. C 60.13, H 8.61, N 4.13, S 9.44; found C 60.54, H 8.46, N 3.92, S 9.16.

Preparation of Bromomethyltetrahydrofurans 10 and 11: Thiazolethione *anti*-**6** (560 mg, 1.60 mmol) and $BrCCl_3$ (2.54 g, 12.8 mmol) were dissolved in C_6H_6 (9 mL). The solution was flushed for 5 min at 20 °C with a gentle stream of argon and then photolyzed for 25 min at 20 °C in a Rayonet® chamber reactor equipped with 350 nm light bulbs. The reaction mixture was concentrated in vacuo to afford a tan oil which was purified by column chromatography (SiO_2, petroleum ether/diethyl ether, 5:1, v/v) to afford **10** (263 mg, 55% yield, colourless oil, R_f = 0.39) and **11** (130 mg, 27% yield, colourless oil, R_f = 0.42).

***cis*-3-Benzoyloxy-5-bromomethyl-*trans*-2-methyltetrahydrofuran (10):** ^{1}H NMR (250 MHz): δ = 1.30 (d, J = 6.7 Hz, 3 H), 2.16 (ddd, J = 3.7, 4.9, 14.3 Hz, 1 H), 2.63 (ddd, J = 6.7, 7.9, 14.3 Hz, 1 H), 3.47 (dd, J = 7.3, 10.1 Hz, 1 H), 3.55 (dd, J = 5.8, 10.1 Hz, 1 H), 4.39 (dq, J_d = 2.8 Hz, J_q = 6.7 Hz, 1 H), 4.44−4.51 (m, 1 H), 5.17 (dt, J_d = 6.7 Hz, J_t = 2.8 Hz, 1 H), 7.46 (m_c, 2 H), 7.59 (m_c, 1 H), 8.02 (m_c, 2 H). − ^{13}C NMR (100 MHz): δ = 19.0, 35.1, 35.7, 77.5, 79.7, 80.5, 128.5, 129.6, 129.9, 133.2, 166.1. − MS (70 eV, EI): *m*/*z* (%) = 205 (2), 176 (14), 178 (14), 105 (100), 77 (62).

***trans*-3-Benzoyloxy-5-bromomethyl-*cis*-2-methyltetrahydrofuran (11):** ^{1}H NMR (250 MHz): δ = 1.36 (d, J = 6.7 Hz, 3 H), 2.10−2.32 (m, 2 H), 3.48 (dd, J = 5.2, 10.7 Hz, 1 H), 3.55 (dd, J = 4.9, 10.1 Hz, 1 H), 4.26 (dq, J_d = 2.8 Hz, J_q = 6.7 Hz, 1 H), 4.36−4.46 Hz, (m, 1 H), 5.16 (m_c, 1 H), 7.45 (m_c, 2 H), 7.58 (m_c, 1 H), 8.03 (m_c, 2 H). − ^{13}C NMR (100 MHz): δ = 19.9, 34.9, 36.9, 77.7, 80.1, 81.2, 128.4, 129.6, 130.0, 133.2, 166.1. − Mixture of **10** and **11**: $C_{13}H_{15}BrO_3$ (299.2): calcd. C 52.19, H 5.05; found C 51.92, H 5.23.

Synthesis of 2,3-*cis*-Configured Tetrahydrofurans 18 and 19: Pyridinethione *syn*-**7** (36.1 mg, 0.110 mmol) and $BrCCl_3$ (174 mg, 0.877 mmol) were dissolved in degassed (Ar) C_6H_6 (0.6 mL). The yellow reaction mixture was photolyzed with incandescent light (2 min) and was worked up as described for isomers **10** and **11** [chromatography: SiO_2, petroleum ether/diethyl ether, 2:1 (v/v)]. Tetrahydrofurans **18** and **19** were isolated as a 50:50 mixture of isomers. Yield 26.1 mg, (80%).

***trans*-3-Benzoyloxy-5-bromomethyl-*trans*-2-methyltetrahydrofuran (18):** ^{1}H NMR (250 MHz): δ = 1.29 (d, J = 6.4 Hz, 3 H), 2.19−2.42 (m, 2 H), 3.51 (d, J = 5.2 Hz, 2 H), 4.38 (dq, J_d = 3.4 Hz, J_q = 6.4 Hz, 1 H), 4.55 (m_c, 1 H), 5.57 (m_c, 1 H), 7.46 (m_c, 2 H), 7.59 (m_c, 1 H), 8.06 (m_c, 2 H). − ^{13}C NMR (63 MHz): δ = 14.8, 36.1, 38.3, 76.4, 76.5, 78.2, 128.5, 129.6, 129.9, 133.2, 165.8.

***cis*-3-Benzoyloxy-5-bromomethyl-*cis*-2-methyltetrahydrofuran (19):** ^{1}H NMR (250 MHz) δ = 1.32 (d, J = 6.4 Hz, 3 H), 2.07 (ddd, J = 5.2, 5.5, 14.7 Hz, 1 H), 2.62 (ddd, J = 6.4, 8.2, 14.7 Hz, 1 H), 3.45 (dd, J = 6.7, 10.1 Hz, 1 H), 3.54 (dd, J = 5.8, 10.1 Hz, 1 H), 4.15 (dq, J_d = 3.7 Hz, J_q = 6.4 Hz, 1 H), 4.25 (m_c, 1 H), 5.50 (ddd, J = 3.7, 5.5, 8.2 Hz, 1 H), 7.46 (m_c, 2 H), 7.59 (m_c, 1 H), 8.05 (m_c, 2 H). − ^{13}C NMR (63 MHz): δ = 14.6, 35.0, 38.0, 75.5, 77.1, 78.8, 128.5, 129.6, 130.2, 133.3, 165.9. − Mixture of isomers **18** and **19**: $C_{13}H_{15}BrO_3$ (299.2): calcd. C 52.19, H 5.05; found C 52.36, H 4.85.

Photoreaction of TBDMS-substituted Pyridinethione *anti*-8 and $BrCCl_3$: Pyridinethione *anti*-**8** (205 mg, 0.604 mmol) and $BrCCl_3$ (1.03 g, 5.18 mmol) were dissolved in benzene (3.5 mL). The yellow solution was irradiated with incandescent light (*Philips* 150 W Spotline® R80) until the yellow colour of the radical precursor had faded (1 min). The reaction mixture was then purified by column chromatography [SiO_2, petroleum ether/diethyl ether, 5:1 (v/v), R_f = 0.62].

5-bromomethyl-*cis*-3-[(*tert*-butyl)dimethylsilyloxy)]-*trans*-2-methyltetrahydrofuran (16). Yield 30.2 mg (16%), colourless liquid. − IR (NaCl): $\tilde{\nu}$ = 2920 cm^{-1}, 2900, 2820, 1240, 1080, 1020. − ^{1}H NMR (250 MHz): δ = 0.06 (s, 6 H), 0.88 (s, 9 H), 1.16 (d, J = 6.1 Hz, 3 H), 1.87 (m_c, 1 H), 2.31 (m_c, 1 H), 3.47 (m_c, 2 H), 3.82−3.97 (m, 2 H), 4.30 (m_c, 1 H). − ^{13}C NMR (100 MHz): δ = −4.9, −4.7, 18.9, 25.7, 36.1, 38.9, 77.4, 77.8, 81.9. − MS (70 eV, EI): *m*/*z* (%) = 253 (5), 131 (79), 97 (22), 75 (55), 57 (76), 43 (100). − All samples which eluted faster than heterocycle **16** on chromatographic purification (vide supra) were collected and concentrated in vacuo (T = 20 °C, p = 20 mbar) to afford a colourless volatile liquid (44.7 mg). According to NMR analysis the isolated product was a mixture of compounds **13**, **15**, and **17**.

***cis*-1-(*tert*-Butyl)dimethylsilyloxy-1,3-butadiene (13):**[20] yield 20%. − ^{1}H NMR (250 MHz): δ = 0.15 (s, 6 H), 0.89 (s, 9 H), 4.89 (d, J = 10.4 Hz, 1 H, 4-H), 5.06 (d, J = 17.4 Hz, 1 H, 4-H), 5.20 (dd, J = 5.8, 10.7 Hz, 1 H, 2-H), 6.19 (d, J = 5.8 Hz, 1 H, 1-H), 6.75 (ddd, J = 10.4, 10.7, 17.4 Hz, 1 H, 3-H).

1,1-bis[(*tert*-Butyl)dimethylsilyloxy]-3-butene (17):[21] yield 11%. − ^{1}H NMR (250 MHz): δ = 0.08 (s, 6 H), 0.11 (s, 6 H), 0.94 (s, 18 H), 2.31 (m_c, 2 H, 2-H), 5.02−5.08 (m, 2 H, 4-H), 5.13 (t, 1 H, J = 5.2 Hz, 1-H), 5.82 (m_c, 1 H, 3-H). − ^{13}C NMR (63 MHz): δ = −5.4, −4.2, −3.7, −3.6, 18.0, 18.3, 25.5, 25.6, 45.6, 93.3, 111.2, 113.0, 117.2, 129.8, 140.5.

2-Butenal (15): yield 3%.

On repetition of the photoreaction of *anti*-**8** and $BrCCl_3$ in C_6D_6 using 2,2-dichloro-5,5-dimethylcyclohexane-1,2-dione as internal standard, yields of volatile aldehydes were quantified more precisely.

Acetaldehyde (14): yield 54%. − ^{1}H NMR (400 MHz, C_6D_6): δ = 1.52 (d, J = 3.0 Hz, 3 H), 9.20 (q, J = 3.0 Hz, 1 H).

2-Butenal (15): yield 40%. − ^{1}H NMR (400 MHz, C_6D_6): δ = 1.39 (d, J = 6.6 Hz, 3 H), 5.81 (dd, J = 7.7, 15.4 Hz, 1 H), 6.07 (dq, J_d = 15.7, J_q = 6.6 Hz, 1 H), 9.17 (d, J = 7.7 Hz, 1 H).

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[16] The observed optical rotation of our sample of (+)-**20** {$[\alpha]_D^{20}$ = + 22.4 (*c* = 0.41, EtOH)} was lower than the reference value for (+)-**20** {$[\alpha]_D^{25}$ = +39.1 (*c* = 0.38, EtOH)}.[15] The non-stereorigidity is probably due to the first step in the synthesis[17] of methyl *p*-methoxybenzyl lactate. In order to verify that the stereochemical leak is not related to the central radical reactions of this work, the benzoate groups in the radical precursor *anti*-**6** and in the trisubstituted tetrahydrofuran **10** were removed by NaOH in MeOH and the respective alcohols were converted into their *S*-Mosher esters.[18] ^{1}H NMR investigation of these products indicated an *ee* value of 34% for both compounds and therefore, presumably, for *anti*-**6** and **10**.
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