Photoreactions of Phenyl-Substituted *N*-(Pent-4-enyl-1-oxy)pyridine-2(1*H*)-thiones

Jens Hartung,* Margit Hiller, and Philipp Schmidt

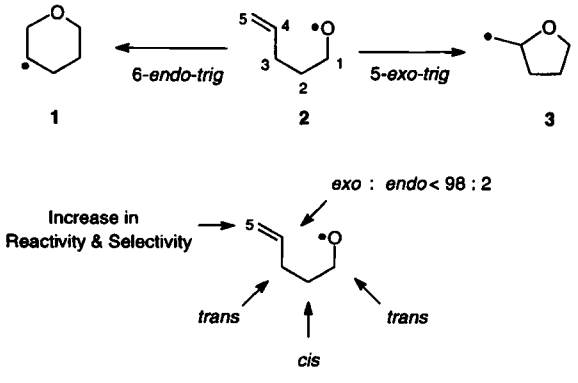
Abstract: A series of hitherto unknown *N*-(pent-4-enyl-1-oxy)pyridine-2(1*H*)-thiones (**6**) were prepared from substituted pent-4-enyl tosylates or benzylic chlorides. On irradiation with incandescent light heterocycles **6** liberated alkoxy radicals **2**, which were studied for rearrangement reactions. Surprisingly, all transformations involving the 1-phenylpent-4-enyl-1-oxy radical (**2a**), for example, to give the substituted thioether **8**, 2-bromomethyl-5-phenyltetrahydrofuran (**11**), or the tetrahydrofuran **14a**, were not stereoselective. On the other hand 2-, 3-mono-, and 1,5-disubstituted pent-4-enyl-1-oxy radicals **2d–e** and **2g** cyclized in good yields and with good to excellent stereoselectivities to give the corresponding 2,4-*cis*- and 2,3-*trans*-phenyltetrahydrofurfuryl radicals **3d–e**, and the *trans*-2-benzyl-5-methyl substituted intermediate **3g**. The major reaction mode of the 4-phenylpent-4-enyl-1-oxy radical (**2f**) was the 6-*endo* cyclization, which afforded 3-phenyltetrahydropyran (**13f**) as the major product (*endo*:*exo* = 93:7) after trapping with hydrogen donors. According to the experimental data of the present study, the unusual reactivity of the 1-phenylpent-4-enyl-1-oxy radical (**2a**) in 5-*exo*-*trig* ring closures could be caused by a coplanar arrangement of the benzyloxy moiety in the transition state of the cyclization. This interaction would lock the radical center in **2a** in a preferred conformation, which would result in similar steric effects for both *cis*- and *trans*-cyclizations.

Keywords
alkoxy radicals · cyclizations · pyridinethiones · radicals · tetrahydrofurans

Introduction

The fascinating role of small molecules such as substituted tetrahydrofurans in physiology,[1] as building blocks in organic synthesis, for example, for polyether toxins,[2] or as ligands in coordination chemistry[3] stimulated our interest in developing new, stereoselective routes to substituted oxolanes, starting from open-chain precursors such as substituted pentenols or the corresponding oxygen-centered radicals generated under the mild, yet largely unexplored reaction conditions of *free* alkoxy radical chemistry.[4] This methodology takes advantage of the electrophilic nature of oxygen-centered radicals, which add readily to C–C double bonds even when the latter are not activated.[5]

In a recent study[6] we investigated the scope of the 5-*exo*-*trig* reaction of alkyl-substituted pent-4-enyl-1-oxy radicals in stereoselective tetrahydrofuran syntheses (Scheme 1). Using Beckwith's findings that alkoxy radicals can be generated from *N*-alkyloxypyridinethiones,[7] we were able to show that these precursors offer several advantages over classical alkoxy radical progenitors, such as peroxides, nitrous acid esters, or alkyl hypohalites, for studying the basic principles of heterocycle formation from pent-4-enyloxy radicals. Our competition experiments have demonstrated that ring closures of *O*-centered radicals are exceedingly fast reactions with rate constants between 10^8 and $10^9\ s^{-1}$. In spite of this high reactivity, the cyclizations proved to be regio- and stereoselective. We were able to derive general guidelines for ring closures which state that 1- and 3-alkyl-substituted pent-4-enyl-1-oxy radicals preferably yield the *trans*-alkyltetrahydrofurfuryl radicals, whereas 2-substituted pent-4-enyloxy radicals rearrange preferentially to *cis*-4-alkyl-2-tetrahydrofurfuryl radicals. All reactions studied so far strongly favor the thermodynamically less stable primary tetrahydrofurylmethyl radical (**3**). The products derived from the 6-*endo* intermediate, the tetrahydropyranyl radical (**1**), are always obtained along with the substituted tetrahydrofurans, but can be separated on a preparative scale.



Scheme 1. Top: modes of ring closure of the pent-4-enyl-1-oxy radical (**2**). Bottom: the major effects of alkyl substituents on the stereo- and regioselectivity of pent-4-enyl-1-oxy radical cyclization

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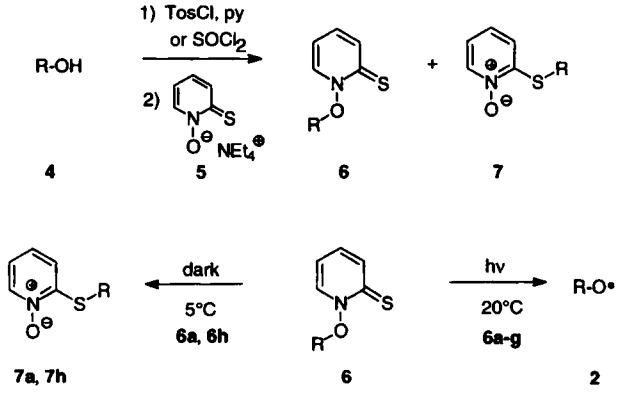
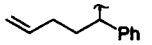
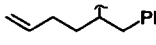
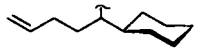
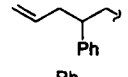
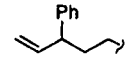
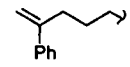
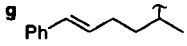
The enormous significance of phenyl groups in radical chemistry,[8] in stabilization and hence selectivity control, led us to extend our mechanistic studies to phenyl-substituted pent-4-enyl-1-oxy radicals. Besides exploring the effects of phenyl substituents on the stereo- and regioselectivity of alkoxy radical ring closures, we aimed to introduce useful functionalities into the synthesized tetrahydrofurans. The aryl groups could be further converted, for example, to carbonyl compounds by a Birch reduction[9] and subsequent ozonolysis of the cyclohexadienes,[10] to carboxylic acids by RuO_4 oxidation,[11] or to *cis*-diols by enzymatic arene oxidation,[12] to afford building blocks of further use in synthetic tetrahydrofuran chemistry.

Results

Substituted pent-4-en-1-ols **4** were prepared by standard procedures using reagents such as Grignard, ethyl malonate, or ethyl acetoacetate. The benzylic alcohols **4a** and **4h** were transformed into the corresponding chlorides with thionyl chloride,[13] while all other alcohols **4** were converted to the respective tosylates (Scheme 2).[14] The cyclic thiohydroxamic acid esters **6** were obtained in 31–63% yield by treating the alkylating agents with 2-mercaptopyridine *N*-oxide tetraethylammonium salt (**5**) in DMF.[6, 7] The ambident anion **5** also reacted at sulfur to give **7** as a by-product. All precursors **6** were yellow oils, except for crystalline **6a** and **6h**. They proved to be fairly stable when stored in amber-colored flasks, except for the 1-phenyl-substituted esters **6a** and **6h**, which rearranged in the dark, sometimes within days, to give the corresponding pyridine *N*-oxides **7a** and **7h** in quantitative yields.

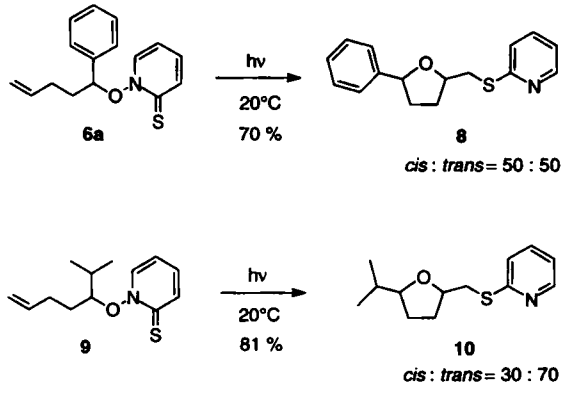


	R	Yield (%) 6	7
a		48	49
b		50	48
c		49	45
d		31	[a]
e		37	[a]
f		38	30
g		50	[a]
h		63	14

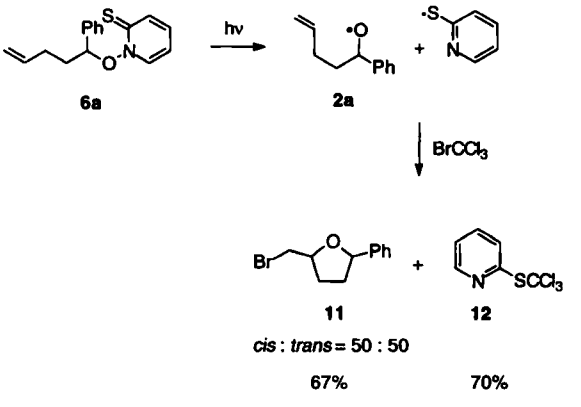
[a] Not isolated.

Scheme 2. Synthesis and transformations of *N*-alkoxypyridinethiones **6**.

A yellow solution of **6a** in benzene ($T = 20\,^{\circ}C$) quickly decolorized upon irradiation and afforded the thioether **8** (*cis*:*trans* = 50:50) in 70% yield after workup (Scheme 3). Likewise, anaerobic photolysis of pyridinethione **6a** in benzene in the presence of the radical trap $BrCCl_3$ ($c_0 = 1.5\,M$) afforded, after workup of the colorless solution, **11** as a pleasant smelling liquid in 67% yield (Scheme 4). The *cis*–*trans* ratio of **11** was 50:50. In con-



Scheme 3. Photolysis of **6a** and **9** in the absence of a radical trap.

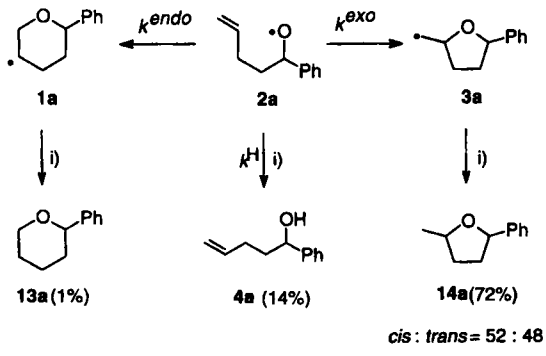


Scheme 4. Photolysis of **6a** in the presence of the radical trap $BrCCl_3$.

Authentic samples of the substituted tetrahydropyrans **13**[15] and oxolanes **14**[16] (Scheme 6) were needed for NMR, GC, and GC/MS analysis of the reaction mixtures of the alkoxy radical reactions. The 5-*exo* products **14** were synthesized from pentenols **4** by iodocyclization[17] and subsequent reduction of the phenyl-2-iodomethyltetrahydrofurans with $LiAlH_4/LiH$[18] mixtures. The assignments of the NMR spectroscopic data for both the *cis*- and the *trans*-disubstituted tetrahydrofurans **14** are based on H,H and H,C COSY and NOE experiments (**14a–c,g**). In two cases (**14d,e**), the stereochemical assignments could be directly deduced from differences in proton chemical shifts of *cis* and *trans* products due to the proximity of protons to the magnetic anisotropy caused by the phenyl groups. Where the data has not previously been reported, the proton and carbon chemical shifts of substituted tetrahydropyrans **13** are included in the Experimental Section.

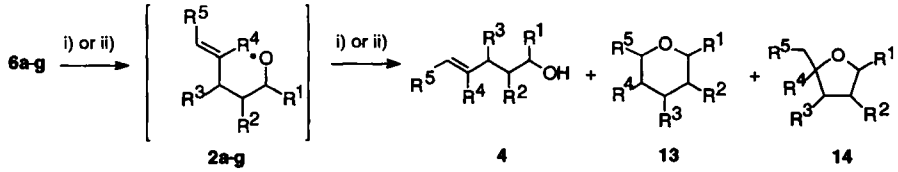
trast to the lack of stereoselectivity observed in photoreactions of the phenyl-substituted pyridinethione **6a**, anaerobic photolysis of the 1-isopropyl-substituted ester **9** in benzene ($T = 20\,^{\circ}C$) afforded the *trans*-2,5-disubstituted heterocycle **10** as the major product (*cis*:*trans* = 30:70, Scheme 3).

Addition of the hydrogen donor tri-*n*-butylstannane to the photolyzed solution of **6a** in benzene ($c_0 = 1.8$ M, 2.5 equiv) afforded almost equivalent amounts of *cis*- and *trans*-**14a** (*cis*:*trans* = 52:48) in a total yield of 72%, in addition to 14% of phenylpentenol **4a** and 1% of 2-phenyltetrahydropyran (**13a**) (Scheme 5). The *exo*:*endo* ratio of cyclized products



Scheme 5. Photolysis of **6a** in the presence of a hydrogen donor: i) 2.5 equiv Bu_3SnH ($c_0 = 1.8$ M), C_6H_6, 20 °C.

(**14a**:**13a** = 98:2) clearly points to the intermediacy of alkoxy radical **2a**.[19] The phenylpentenol **4a** was formed by the reaction of **2a** and Bu_3SnH prior to 5-*exo*–*trig* cyclization, and the amount of this product was dependent on the concentration of tin hydride in solution.[20] In order to obtain more information on the effect of the phenyl substituent on the ring closures of substituted pent-4-enyl-1-oxy radicals **2** to give substituted tetrahydrofurfuryl radicals **3**, we examined the reactions of a number of radicals **2** (Scheme 6, Table 1).



2, 4, 13, 14	R¹	R²	R³	R⁴	R⁵
a	C_6H_5	H	H	H	H
b	$C_6H_5CH_2$	H	H	H	H
c	c-C_6H_{11}	H	H	H	H
d	H	C_6H_5	H	H	H
e	H	H	C_6H_5	H	H
f	H	H	H	C_6H_5	H
g	CH_3	H	H	H	C_6H_5

Scheme 6. For conditions i) and ii) used in the ring closure, see footnotes [a] and [b] of Table 1.

Alkoxy radicals **2** were generated from the parent pyridinethiones **6** according to two different protocols: In a first group of experiments (conditions i), thiones **6** were photolyzed for 5 min at 15 °C with 2-napthalenethiol (NpSH) ($c_0 = 1.2$ M, 1.2 equiv) in deaerated C_6D_6 solutions. The yellow mixtures of the reaction products were immediately analyzed by GC and ^1H NMR spectroscopy. Almost all samples showed a clean conversion of **6** to the *cis*–*trans* mixtures of the corresponding tetrahydrofurans **14**, varying amounts of pentenols **4**, and 2-pyridyl-2′-naphthalenedisulfide.[6] Only the photoreactions of pyridinethiones **6a** and **6e** yielded significant amounts of phenylpent-4-enols [13% (**4a**) and 23% (**4e**)]. The parent radical **2a** rearranged in an unselective 5-*exo* reaction to yield, after hydrogen trapping by the thiol, a mixture of *cis*- and *trans*-**14a** containing a slight excess of the *cis* isomer (*cis*:*trans* = 52:48). The presence of the 6-*endo* product **13a** was confirmed by GC analysis of the reaction mixture (*exo*:*endo* = 98:2).

Table 1. Ring-closure reactions of substituted pent-4-enyl-1-oxy radicals **2**.

	Reaction Conditions i) [a]		Reaction Conditions ii) [b]			
	14 [c] *cis*:*trans*	**14**:**13** [d] *exo*:*endo*	**14** Yield/% [e] (*cis*:*trans*)	**14**:**13** [d,f] *exo*:*endo*	**13** Yield/% [e] (*cis*:*trans*)	**4** [e] Yield/%
2a	52:48	98:2	72 (52:48)	98:2	1	14
2b	38:62	99:1	66 (38:62)	99:1	1	1
2c	32:68	99:1	64 (32:68)	99:1	1	3
2d	88:12	97:3	70 (88:12)	96:4	3	–
2e	>5:<95	91:9	72 (2:98)	91:9	7	20
2f	–	7:93	5	5:95	89/82 [g]	5
2g	33:67	– [h]	95 (34:66) [g]	<99:>1	>1 (84:16) [i]	4

[a] Conditions i): hv, 15 °C, 1.2 equiv NpSH, C_6D_6. [b] Conditions ii): hv, 30 °C, 2.5 equiv Bu_3SnH, TBB or C_6H_6. [c] ^1H NMR spectroscopy used to determine *cis*–*trans* ratios; stereochemical assignments of the products derived from NOE and H,H and H,C COSY experiments; yields of cyclized products >95%, except for photoreactions of **6a** and **6e**: **4a**, 13%; **4e**, 32%; experimental error of *cis*–*trans* ratios: ±3%. [d] GC/MS analysis based on comparison with samples of independently synthesized **14** and **13**; the *exo*–*endo* ratios vary within ±0.2% in absolute values. [e] Photoreactions of **6a–g** performed in TBB or C_6H_6; yields determined vs. *n*-$C_{14}H_{30}$ as internal standard (experimental error: ±5%). [f] The *exo*–*endo* ratios vary within ±0.2% in the absolute values. [g] Isolated yield of 3-deuterio-3-phenyltetrahydropyran (**15**) from photoreaction of **6f** and Bu_3SnD. [h] Not determined. [i] The tetrahydropyrans **13g** formed in trace amounts only.

The 1-benzyloxy radical **2b**, generated by anaerobic photolysis of its parent pyridinethione **6b**, closed preferentially to the *trans* intermediate **3b** and afforded, after reaction with NpSH, the *trans* ether **14b** as the major product (*cis*:*trans* = 38:62). The 1-cyclohexyloxy radical **2c** gave rise to *trans* tetrahydrofuran **14c** (*cis*:*trans* = 32:68) as the main product. The 2-phenyl isomer of **2a**, **2d**, was found to close very selectively to the *cis*-4-phenyl-2-tetrahydrofurfuryl radical (**3d**). Thus, the photoreaction of **6d** and NpSH led preferentially to *cis*-**14d** (*cis*:*trans* = 88:12). The next isomer of **2a** to be examined was the 3-phenyloxy radical **2e** with the olefinic π-system adjacent to the large phenyl substituent. The exceptionally high stereoselectivity of the 5-*exo*–*trig* ring closure of **2e** (*cis*:*trans* = 2:98) is likely to reflect the steric interactions between the neighboring groups arising along the reaction coordinate of the C–O bond formation. Irradiation of the 4-phenyl isomer **6f** and NpSH in perdeuteriobenzene afforded **13f** and only traces of **14f**. The exact *exo*–*endo* ratio of 7:93 was taken from the integration of the gas chromatogram of the sample. Thus, the cyclization of radical **2f** is the first example of a regioselective 6-*endo* closure of substituted pent-4-enyloxy radicals **2**. The last alkoxy radical studied in this series was generated from (*E*)-phenylhexene **6g**. Ring closure of the corresponding radical **2g** and subsequent trapping of

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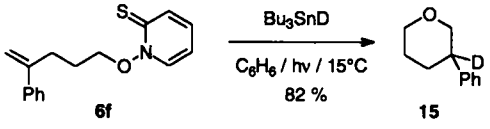
the carbon-centered cyclized radicals led to a 33:67 mixture of *cis*- and *trans*-**14g**.

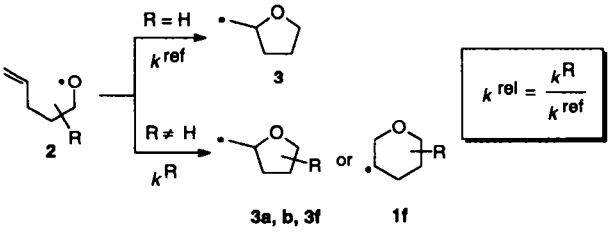
A second series of experiments were performed in which precursors **6** were irradiated in the presence of Bu_3SnH ($c_0 = 1.8$ M, 2.5 equiv) in benzene or in *tert*-butylbenzene (TBB) at 30 °C (conditions ii) in order to determine the yields of the alkoxy radical products versus an internal standard. All samples were immediately analyzed by GC and GC/MS. The minor reaction products **4** and **13** (or **14f**) were identified by addition of authentic samples of alkenols **4** and tetrahydropyrans **13** (or tetrahydrofuran **14f**) to the reaction mixtures of previously analyzed samples. In general, the values for *cis*–*trans* and for *exo*–*endo* selectivities of all radical reactions matched well with the first set of results (conditions i). The clean conversion of **6f** to **13f** was further explored by treating **6f** with tri-*n*-butyltin deuteride on a larger scale. 3-Deuterio-3-phenyltetrahydrohydropyran (**15**) was isolated in 82% yield from the reaction mixture (Scheme 7).



Scheme 7. Synthesis of the deuterio analogue of **13f**, **15**.

According to our NMR experiments, no detectable amounts of hydrogen were incorporated from competitive hydrogen donors such as the α-hydrogens of the reaction product **15**; thus, the tin deuteride, and presumably the tin hydride in the reactions studied above, are the only significant sources of reactive hydrogen.

In order to further rationalize the reactivities of phenyl-substituted pent-4-enyl-1-oxy radicals **2**, three sets of competition experiments were carried out. Deaerated samples of radical precursors **6** were thermostated ($T = 30$ °C) in the dark with an at least tenfold excess of Bu_3SnH. Three sets of experiments, each consisting of five runs, were performed with varying concentrations of the hydrogen donor from 0.07 to 1.65 M. The unsubstituted radical **2** was taken as the reference (Scheme 8), and the



Scheme 8. Competition experiments for the ring closure of phenyl-substituted pent-4-enyl-1-oxy radicals **2** with the unsubstituted radical as the reference.

individual relative rate constants were obtained as described previously ($k^{ref}(\mathbf{2}) \equiv 1.00 \pm 0.05$).[6, 21] The results of the competition experiments are summarized in Table 2 and discussed in the following section.

Table 2. Relative rate constants for ring closures of alkoxy radicals [6,21].

Reaction **2** → **3**	k^{rel} ($k^{ref} \equiv 1.00 \pm 0.05$)	
2a → *cis*-**3a** + *trans*-**3a**	$k^{rel}_{cis} = 0.86 \pm 0.08$	$k^{rel}_{trans} = 0.77 \pm 0.07$
2b → *cis*-**3b** + *trans*-**3b**	$k^{rel}_{cis} = 0.87 \pm 0.08$	$k^{rel}_{trans} = 1.3 \pm 0.1$
2f → **1f** + **3f**	$k^{rel}_{endo} = 8.0 \pm 0.7$	$k^{rel}_{exo} = 0.48 \pm 0.04$

Discussion

Phenyl-substituted *N*-(pent-4-enyl-1-oxy)pyridine-2(1*H*)-thiones **6** were easily synthesized and could, much as expected from a previous study,[6] be readily photodecomposed with incandescent light to yield *free* alkoxy radicals **2**. We were surprised to find that a second decomposition pathway of **6** occurred when the esters **6** were kept in the dark at 20 °C or lower. Besides the N–O homolysis, which occurred upon irradiation of **6** or as an elementary reaction in a radical chain process, the secondary benzylic-substituted heterocycles **6a** and **6h** underwent alkyl shifts that exclusively led to the *S*-alkylated pyridine *N*-oxides **7a** and **7h** (Scheme 2).[22]

The second reaction channel of **6a**, the alkoxy radical reaction, was no less surprising. The photoreaction of **6a** in the absence of additional radical traps afforded the tetrahydrofurylthioether **8** (*cis*:*trans* = 50:50, Scheme 3) via the intermediate alkoxy radical **2a**. On the other hand, the photorearrangement of the 2-propyl-substituted ester **9** furnished the *trans*-**10** in 40% d.e. This value demonstrates that an isopropyl group in the intermediate 2-(2-propyl)-pent-4-enyl-1-oxy radical is able to control the stereoselectivity of the 5-*exo*–*trig* reaction. The lack of the preference for *trans* cyclization of **2a** was also observed in the photoreactions of **6a** either with $BrCCl_3$ (Scheme 4), which afforded the bromide **11** (67% yield, *cis*:*trans* = 50:50), or with Bu_3SnH, which led to the ethers **14a** (*cis*:*trans* = 52:48, *exo*:*endo* = 98:2, Scheme 5) in 72% yield, in addition to the pyran **13a** and the pentenol **4a**. Usually 1-alkyl-substituted pent-4-enyl-1-oxy radicals show a preference for the *trans* cyclization, because this transformation is speeded up by the presence of the alkyl group ($k^{rel}_{trans} = 1.2 \pm 0.1 - 2.0 \pm 0.2$), whereas the *cis* reaction rates remain constant or are slowed to $k^{rel}_{cis} = 0.73 \pm 0.07$.[6] However, the kinetic data that describe the rearrangement **2a** → **3a** indicate that the *trans* reaction **2a** → *trans*-**3a** proceeds more slowly than expected ($k^{rel}_{trans} = 0.77 \pm 0.07$), whereas the value for *cis* isomerization **2a** → *cis*-**3a** ($k^{rel}_{cis} = 0.86 \pm 0.08$) is in line with our previous study. The rate-retarding factor of the *trans* reaction is, we think, related to the proximity of the phenyl group to the radical center in the alkenyl-substituted benzyloxy radical **2a**. This proximity of the phenyl ring and an unpaired, oxygen-centered electron separated by only one sp^3 carbon in the intermediate **2a** is reminiscent of the situation in neophyl-type radicals[23] or in *para*-substituted cumyloxy radicals, which have recently been studied by Ingold et al.[24] In these intermediates the unpaired electron tends to align itself orthogonal to the plane of the aryl group. If this is also true for radical **2a**, the interaction between the aromatic π-system would stabilize the radical center and lock the system into a preferred conformation where the unpaired electron is situated orthogonal to the plane O-C1-Ca-Cb (Fig. 1). This favorable arrange-

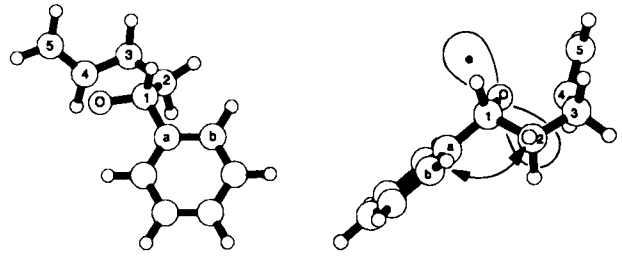
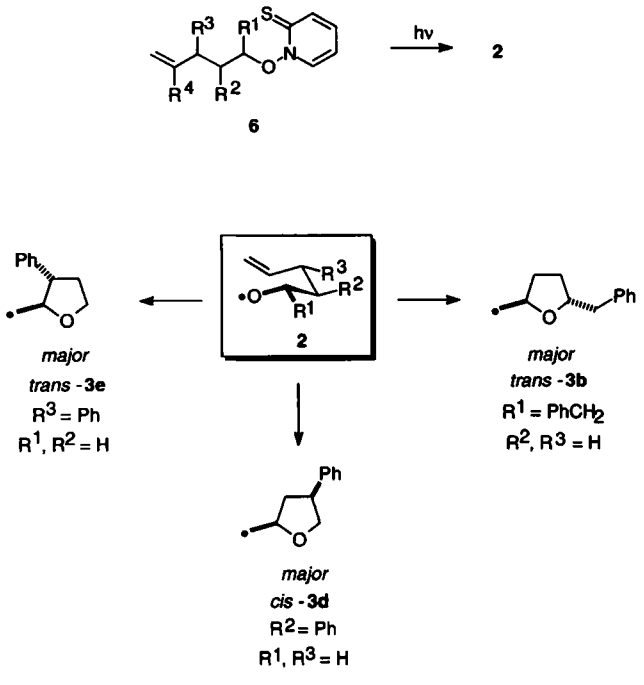


Fig. 1. Right: Schematic presentation of the 5-*exo*–*trig* transition-state model for the *trans* cyclization of **2a**; the phenyl substituent is situated in the pseudoequatorial position. Left: View onto the plane of the phenyl group showing the coplanar alignment of the aryl nucleus and the unpaired electron. The arrow indicates steric interactions between the proximal *ortho*-hydrogen and the pseudoequatorial hydrogen 2-H [25].

ment would impose additional torsional strain in the course of the *trans* ring closure **2a** → *trans*-**3a** due to a close contact between the pseudoequatorial 2-H and the proximal *ortho*-hydrogen. The distance between these neighbors and therefore the energetic contribution to the reactivity of **2a** should be similar to effects found for the eclipsing hydrogens in ethane.[25] Thus, the overall effect would be that the rate constant of the *trans* cyclization is reduced compared to that of the reference radical **2**. The *cis* reaction would suffer no more steric congestion than in the corresponding reaction of simple 1-alkyl-substituted pent-4-enyloxy radicals.

In order to confirm our transition-state model, a derivative of **2a**, **2c**, lacking the aromatic π system, was chosen as a mechanistic probe. Photolysis of **6c** and NpSH or Bu_3SnH in an inert solvent gave *trans*-**14c** as the major product. The *cis*:*trans* ratio of 32:68 is in line with the value found for similar alkyl-substituted pent-4-enyloxy radicals.[6] However, the cyclohexyl substituent in **2c** also increases the steric bulk in the vicinity of the radical center, as in **2a**. Therefore the phenyl and the radical center in **2a** were separated in the next experiments by one more CH_2 group in order to disrupt the interactions outlined in Figure 1: the ring closure of the 1-benzyloxy radical **2b** proceeded stereoselectively and afforded *trans*-**14b** as the major product (*cis*:*trans* = 38:62). Similarly, the results of competition kinetics for the ring closure **2b** → **3b** indicate that—much as expected from the alkyl case—the *trans* cyclization is faster than the reference reaction **2** → **3** ($k^{rel}_{trans} = 1.3 \pm 0.1$), whereas the minor product *cis*-**14b** is derived from the slower cyclization ($k^{rel}_{cis} = 0.87 \pm 0.08$). According to these results the 1-ethyl- and the 1-benzylpent-4-enyl-1-oxy radical (**2b**) show comparable reactivities and selectivities.

The photoreaction of the 4-phenyl derivative **6f** and reactive hydrogen donors afforded 3-phenyltetrahydropyran (**13f**) in 89–82% yield. The reversal of the *endo*–*exo* selectivity, which is commonly observed in alkenyloxy radical ring closures, is not simply due to the reduction of the rate constant k_{exo} caused by a steric shielding of C-4 by the phenyl group in position 4 ($k^{rel}_{exo} = 0.48 \pm 0.04$), but rather to a significant increase in the rate of 6-*endo* ring closure ($k^{rel}_{endo} = 8.0 \pm 0.7$). Considering α-methylstyrene as an appropriate model for the description of the frontier molecular orbitals of the olefinic π bond, it seems obvious that the phenyl group in position 4 of the radical **1f** increases the coefficient at carbon 5 in the orbital describing the bonding interaction of the olefinic π system.[26] Besides the favorable arrangement for frontier molecular orbital overlap in the transition state of the 6-*endo* ring closure, the rearrangement **2f** → **1f** also leads to a secondary benzylic radical, which should profit from the stabilizing effects of the phenyl ring.



Scheme 9. Transition-state model for the cyclization of **2**.

The remaining alkoxy radical cyclizations listed in Table 1 all follow our guidelines for stereoselective tetrahydrofuran synthesis from intermediates **2** and can be rationalized with the transition-state model in Scheme 9. This model favors products derived from the pseudoequatorial arrangement of the substituents R. The efficiency of the groups R in controlling the stereochemical course of the 5-*exo*–*trig* reactions is governed by their steric influence. Bearing in mind the enormous rate constants for these unimolecular reactions ($k_{exo} = 10^8 - 10^9\ s^{-1}$), the stereoselectivies *cis*:*trans* of 88:12 for **2d** → **3d** and even 2:98 for **2e** → **3e** are high enough to allow these transformations to replace the classical iodine cyclization, which is less selective in these two cases.[17]

Conclusions

Phenyl-substituted *N*-(pent-4-enyl-1-oxy)pyridine-2(1*H*)-thiones **6** are interesting mechanistic tools, which allow us to uncover new reaction pathways of the as yet little investigated class of *N*-alkyloxypyridinethiones. Irradiation of **6** affords a series of new, substituted pent-4-enyl-1-oxy radicals **2**, which give stereoselective 5-*exo*–*trig* reactions **2** → **3**, except for one example. A phenyl group in position 2 directs the 5-*exo*–*trig* cyclization to give the *cis*-disubstituted intermediate **3d** as the major product, whereas a 3-phenyl group favors the *trans* product **3e**. These carbon-centered radicals are trapped by hydrogen donors to give the tetrahydrofurans **14d** and **14e**, respectively, in good to excellent yields. This pattern of stereoselectivity is in accord with our transition-state model for alkoxy radical rearrangements and illustrates the steric contributions of phenyl groups on the stereochemical outcome of these reactions. Favorable stereoelectronic effects in the transition state of the 6-*endo* ring closure reverse the common *exo*–*endo* selectivity of intermediates **2** and lead to the pyranyl radical **1f** as major intermediate from the cyclization reaction. The present study also shows that transformations involving radical **2a** proceed without stereoselectivity. The special reactivity of intermediate **2a** is presumably due to a coplanar arrangement of the benzyloxy moiety in the transition state of the C–O bond formation, which imposes additional torsional strain in the course of the *trans* ring closure.

Experimental Procedure

The following abbreviations have been used throughout the paper: naphthalene-2-thiol (NpSH), methyl *tert*-butyl ether (MTB), lithium aluminum hydride (LAH). All compounds used in this study are racemic. Tri-*n*-butyltin hydride was purchased from Fluka (purum, 98%) and used as obtained. The purity of the reagent was checked by ^1H NMR.

NMR spectra were recorded unless otherwise noted at 20 °C in $CDCl_3$ on Bruker WM 400, AC 200, or AC 250 instruments. UV spectra were measured in ethanol in 1 cm quarz cuvettes on a Perkin-Elmer spectrophotometer 330, and IR spectra in CCl_4 in NaCl cuvettes (0.5 mm) on a Perkin-Elmer 1600 FTIR machine. GC analysis: Carlo Erba GC 6000 (Vega Series), FID, connected to Spectra Physics integrator 4290. Helium at a flow rate of 3 mL min^{-1} (≡80 kPa pressure) was used as carrier gas; injector and detector temperature 250 °C; DB-225 column from J & W

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Scientific. Preparative thin-layer chromatography: 1 mm silica gel plates on glass (Merck). All solvents were distilled prior to use and purified according to standard procedures [27]. Boiling points are given for the indicated pressure in Torr.

Preparation of the alcohols 4: 1-Phenylpent-4-en-1-ol (**4a**) [28a], 1-phenylhex-5-en-2-ol (**4b**) [28b] and 1-cyclohexylpent-4-en-1-ol (**4c**) were prepared by reaction of 3-buten-1-ylmagnesium bromide (0.06 mol) in anhydrous THF (25 mL) with the respective aldehydes (0.06 mol in equivalent volumes of THF). 2-Phenylpent-4-en-1-ol (**4d**) was obtained from styrene oxide and allylmagnesium bromide [17a]. 3-Phenylpent-4-en-1-ol (**4e**) was synthesized by LAH reduction of 3-phenylpent-4-en-1-al [29]. 4-Phenylpent-4-en-1-ol (**4f**) was obtained by treating 3-benzoyl-1-propanol with methylentriphenylphosphonium ylide [30]. (*E*)-6-phenyl-5-hexen-2-ol (**4g**) [31] was obtained from cinnamyl chloride and ethyl acetoacetate [32] and subsequent LAH reduction of 6-phenyl-5-hexen-2-one.

1-Phenylhex-5-en-2-ol (4b) [28b]: Yield 3.70 g (35%), $b.p._{0.01}$ 85–88 °C; colorless oil; ^1H NMR (250 MHz): δ = 1.56–1.67 (m, 3H; CH_2, OH), 2.10–2.35 (m, 2H; CH_2), 2.67 (dd, $^3J(H,H)$ = 9, 14 Hz, 1H; CH_2), 2.84 (dd, $^3J(H,H)$ = 9, 14 Hz, 1H; CH_2), 3.85 (m_c, 1H; CH), 4.95–5.10 (m, 2H; CH_2), 5.85 (ddt, $^3J(H,H)$ = 7, 10, 17 Hz, 1H; CH), 7.20–7.38 (m, 5H; CH); ^{13}C NMR (63 MHz): δ = 30.1, 35.8, 44.1, 72.1, 114.9, 126.5, 128.6, 129.4, 138.4, 144.4; MS (70 eV, EI): *m/z* (%): 92 (100) [$C_7H_8^+$], 85 (6) [$M^+ - C_7H_7$]; $C_{12}H_{16}O$ (176.3): calcd C 81.77, H 9.15; found C 81.44, H 9.44.

1-Cyclohexylpent-4-en-1-ol (4c): Yield 7.67 g (76%), $b.p._{0.01}$ 65–67 °C; colorless liquid; ^1H NMR (250 MHz): δ = 1.14–1.96 (m, 14H; CH_2, OH), 2.35 (m_c, 2H; CH_2), 3.55 (m_c, 1H; CH_2), 5.14 (m_c, 1H; CH_2), 5.22 (m_c, 1H; CH_2), 6.02 (ddt, $^3J(H,H)$ = 7, 10, 17 Hz, 1H; CH); ^{13}C NMR (63 MHz): δ = 26.2, 26.3, 26.5, 27.8, 29.2, 30.33, 33.2, 43.7, 75.7, 114.6, 138.8; MS (70 eV, EI): *m/z* (%): 135 (8) [$M^+ - H_2O - CH_3$], 128 (18) [$M^+ - C_3H_6$], 95 (100) [$C_7H_{11}^+$], 63 (82) [$M^+ - H_2O - C_6H_{11}$]; $C_{11}H_{20}O$ (168.3): calcd C 78.51, H 11.98; found C 78.22, H 11.92.

3-Phenylpent-4-en-1-ol (4e): Yield 7.69 g (79%), $b.p._{15}$ 130–133 °C; colorless liquid; ^1H NMR (250 MHz): δ = 1.56 (s, 1H; OH), 1.99 (m_c, 2H; CH_2), 3.48 (q, $^3J(H,H)$ = 8 Hz, 1H; CH), 3.62 (dt, $J(H,H)$ = 3, 6 Hz, 2H; CH_2), 5.04–5.13 (m, 2H; CH_2), 5.99 (ddt, 8, 10, 17 Hz, 1H; CH), 7.18–7.38 (m, 5H; CH); ^{13}C NMR (63 MHz): δ = 37.9, 46.2, 60.8, 114.4, 126,4, 127.5, 128.5, 141.8, 143.6; MS (70 eV, EI): *m/z* (%): 162 (17) [M^+], 144 (24) [$M^+ - H_2O$], 117 (100) [$C_3H_4C_6H_5^+$], 77 (14) [$C_6H_5^+$]; $C_{11}H_{14}O$ (162.2): calcd C 81.44, H 8.70; found C 81.23, H 8.74.

Preparation of the tosylates and chlorides: The tosylates of the alcohols **4b–g** were prepared by reaction of pentenols **4** (0.012 mol) with *p*-toluenesulfonic acid chloride (2.10 g, 0.012 mol) in anhydrous chloroform (15 mL) and pyridine (2 mL) at 0 °C for 14 h. The crude products were purified by column chromatography on silica gel with toluene as eluent [14]. 1-Chloro-1-phenylpent-4-ene and 1-phenylethyl chloride were prepared from the parent alcohols **4** (0.01 mol) and thionyl chloride (2.5 mL, 0.03 mol) at 20 °C [13]. 1-Chloro-1-phenylpent-4-ene proved to be unstable towards HCl elimination and was used as obtained from bulb to bulb distillation.

1-Chloro-1-phenylpent-4-ene: Yield 1.36 g (75%), $b.p._{0.01}$ 120 °C; colorless liquid; ^1H NMR (250 MHz): δ = 2.10–2.28 (m, 3H; CH_2), 2.35–2.46 (m, 1H; CH_2), 4.98 (dd, $^3J(H,H)$ = 6, 8 Hz, 1H; CH), 5.03–5.16 (m, 2H; CH_2), 5.79 (ddt, $^3J(H,H)$ = 7, 10, 17 Hz, 1H; CH), 7.28–7.42 (m, 5H; C_6H_5).

1-Phenyl-5-hexen-2-yl *p*-toluenesulfonate: Yield 3.17 g (80%); colorless oil; ^1H NMR (250 MHz): δ = 1.69 (m_c, 2H; CH_2), 2.03 (m_c, 2H; CH_2), 2.42 (s, 3H; CH_3), 2.90 (m_c, 2H; CH_2), 4.77 (quint, $^3J(H,H)$ = 7 Hz, 1H; CH) 4.78–4.95 (m, 2H; CH_2), 5.65 (m_c, 1H; CH), 7.07 (d, $^3J(H,H)$ = 8 Hz, 2H; CH), 7.19–7.23 (m, 5H; C_6H_5), 7.67 (d, $^3J(H,H)$ = 8 Hz, 2H; CH); ^{13}C NMR (63 MHz): δ = 21.6, 29.0, 32.8, 40.8, 83.6, 115.3, 126.7, 127.7, 128.5, 129.5, 129.6, 134.2, 136.2, 137.0, 144.4; MS (70 eV, EI): *m/z* (%): 155 (100) [$C_7H_7SO_3^+$], 91 (100) [$C_7H_7^+$]; $C_{19}H_{22}SO_3$ (330.4): calcd C 69.06, H 6.71 S 9.70; found C 69.18, H 6.57 S 9.40.

1-Cyclohexylpent-4-en-1-yl *p*-toluenesulfonate: Yield 2.67 g (69%); colorless oil; ^1H NMR (250 MHz): δ = 0.87–1.21 (m, 5H; CH, CH_2), 1.57–1.70 (m, 8H; CH_2), 1.92–2.04 (m_c, 2H; CH_2), 2.44 (s, 3H; CH_3), 4.46 (m_c, 1H; CH_2), 4.90–4.97 (m, 2H; CH_2), 5.68 (ddt, $^3J(H,H)$ = 7, 10, 18 Hz, 1H; CH), 7.32 (d, $^3J(H,H)$ = 8 Hz, 2H; CH), 7.79 (d, $^3J(H,H)$ = 8 Hz, 2H; CH); ^{13}C NMR (63 MHz): δ = 21.9, 26.2, 26.5, 28.3, 29.2, 30.3, 41.2, 88.1, 115.4, 127.9, 129.9, 135.1, 137.7, 144.6; MS (70 eV, EI): *m/z* (%): 155 (60) [$C_7H_7SO_3^+$], 91 (100) [$C_7H_7^+$]; $C_{18}H_{26}SO_3$ (322.5): calcd C 67.05, H 8.13, S 9.94; found C 66.65, H 8.03, S 9.87.

2-Phenylpent-4-en-1-yl *p*-toluenesulfonate: Yield 3.15 g (83%); m.p. 39–42 °C, colorless crystals; ^1H NMR (250 MHz): δ = 2.29–2.57 (m, 2H; CH_2); 2.43 (s, 3H; CH_3), 3.00 (tt, $^3J(H,H)$ = 6, 9 Hz, 1H; CH), 4.13 (dd, $^3J(H,H)$ = 4, 8 Hz, 2H; CH_2), 4.92–5.02 (m, 2H; CH_2), 5.59 (ddt, $^3J(H,H)$ = 6, 10, 17 Hz, 1H; CH), 7.08 (d, $^3J(H,H)$ = 8 Hz, 2H; CH), 7.24–7.29 (m, 5H; C_6H_5), 7.65 (d, $^3J(H,H)$ = 8 Hz, 2H; CH); ^{13}C NMR (63 MHz): δ = 21.6, 36.1, 44.7, 73.0, 117.2, 127.0, 127.8 (2C), 128.5, 129.7, 132.9, 134.9, 139.9, 144.6; MS (70 eV, EI): *m/z* (%): 275 (12) [$M^+ - C_3H_5$], 155 (83) [$C_7H_7SO_3^+$], 91 (100) [$C_7H_7^+$]; $C_{18}H_{20}SO_3$ (316.4): calcd C 68.33, H 6.37, S 10.13; found C 68.48, H 6.48, S 9.84.

3-Phenylpent-4-en-1-yl *p*-toluenesulfonate: Yield 2.62 g (69%); colorless oil; ^1H NMR (250 MHz): δ = 2.04 (m_c, 2H; CH_2); 2.45 (s, 3H; CH_3), 3.38 (q, $^3J(H,H)$ = 8 Hz, 1H; CH), 3.97 (m_c, 2H; CH_2), 4.94–5.04 (m, 2H; CH_2), 5.85 (ddd, $^3J(H,H)$ = 8, 10, 17 Hz, 1H; CH), 7.03 (d, $^3J(H,H)$ = 8 Hz, 2H; CH), 5.15–7.34 (m, 5H; C_6H_5), 7.76 (d, $^3J(H,H)$ = 8 Hz, 2H; CH); ^{13}C NMR (63 MHz): δ = 21.6, 24.1, 45.4, 68.4, 115.2, 126.6, 127.5, 127.9, 128.6, 130.1, 133.4, 140.4, 142.4, 145.0; MS (70 eV, EI): *m/z* (%): 155 (89) [$C_7H_7SO_3^+$], 91 (100) [$C_7H_7^+$]; $C_{18}H_{20}SO_3$ (316.4): calcd C 68.33, H 6.37, S 10.13; found C 68.31, H 6.48, S 9.94.

4-Phenylpent-4-en-1-yl *p*-toluenesulfonate: Yield 3.04 g (80%); colorless oil; ^1H NMR (250 MHz): δ = 1.74–1.85 (m, 2H; CH_2), 2.46 (s, 3H; CH_3), 2.56 (td, $^3J(H,H)$ = 1, 7 Hz, 2H; CH_2), 4.05 (t, $^3J(H,H)$ = 6 Hz, 2H; CH_2), 5.00 (q, $^4J(H,H)$ = 1 Hz, 1H; CH_2), 5.27 (d, $^4J(H,H)$ = 1 Hz, 1H; CH_2) 7.14–7.37 (m, 7H; CH), 7.79 (d, $^3J(H,H)$ = 8 Hz, 2H; CH); ^{13}C NMR (63 MHz): δ = 21.7, 27.27, 31.07, 69.9, 113.4, 126.11, 127,6, 127.9, 128.5, 129.9, 133.2, 140.4, 144.8, 146.6; MS (70 eV, EI): *m/z* (%): 144 (15) [$C_7H_7SO_3^+$], 91 (100) [$C_7H_7^+$]; $C_{18}H_{20}SO_3$ (316.4): calcd C 68.33, H 6.37, S 10.13; found C 68.27, H 6.41, S 10.07.

(*E*)-6-Phenyl-5-hexen-2-yl *p*-toluenesulfonate: Yield 76%; colorless oil; ^1H NMR (250 MHz): δ = 1.31 (d, $^3J(H,H)$ = 6 Hz, 3H; CH_3), 1.59–1.89 (m, 2H; CH_2) 2.17 (m_c, 2H; CH_2), 2.43 (s, 3H; CH_3), 4.67 (q, $^3J(H,H)$ = 6 Hz, 1H; CH), 6.02 (dt, $^3J(H,H)$ = 7, 16 Hz, 1H; CH), 6.29 (d, $^3J(H,H)$ = 16 Hz, 1H; CH), 7.16–7.33 (m, 7H; C_6H_5), 7.81 (d, $^3J(H,H)$ = 8 Hz, 2H; CH); ^{13}C NMR (63 MHz): δ = 20.9, 21.6, 28.3, 36.1, 79.7, 125.9, 127.1, 127.7, 128.4, 128.8, 129.8, 130.7 134.7, 137.4, 144.2; MS (70 eV, EI): *m/z* (%): 129 (100) [$C_{10}H_9^+$], 91 (40) [$C_7H_7^+$]; $C_{19}H_{22}SO_3$ (330.4): calcd C 69.06, H 6.71, S 9.70; found C 69.18, H 6.99, S 9.46.

Preparation of the tetrahydrofurans: The tetrahydrofurans **14** were prepared from the parent pentenols **4** in two steps by iodocyclization and subsequent reduction of the tetrahydrofurylmethyl iodides with LAH/LiH mixtures [17,18].

Iodocyclization: Iodine (2.25 g, 1.10 mmol) was dissolved in a mixture of acetonitrile (10 mL) and saturated aqueous sodium hydrogencarbonate (2.5 mL) at 0 °C. Pentenol **4** (2.25 g, 1.10 mmol) was added in small portions, and the mixture was stirred for 3 h at 20 °C. The solvent was removed in vacuo, and the residue taken up in diethyl ether (40 mL) and washed with aq. sodium thiosulfate solution [10 mL, 10% (w/w)] and with water (2 × 10 mL). The organic phase was separated, dried ($MgSO_4$), and the solvent removed in vacuo to afford an oil, which was purified by column chromatography [silica gel, petroleum ether/diethyl ether, 50/50 (v/v)].

***cis*- and *trans*-2-Iodomethyl-5-phenyltetrahydrofuran**: Yield: 1.32 g (92%), colorless liquid, *cis*:*trans* = 30:70, $C_{11}H_{13}IO$ (288.1): calcd C 45.86, H 4.55; found C 45.65, H 4.32; MS (70 eV, EI): *m/z* (%): 288 (37) [M^+], 147 (100) [$M^+ - CH_2I$], 77 (32) [$C_6H_5^+$].

cis-2-Iodomethyl-5-phenyltetrahydrofuran: ^1H NMR (250 MHz): δ = 1.82–1.98 (m, 2H; CH_2), 2.14–2.37 (m, 2H; CH_2), 3.33 (dd, $^3J(H,H)$ = 7, 10 Hz, 1H; CH_2I), 3.39 (dd, $^3J(H,H)$ = 5, 10 Hz, 1H; CH_2I), 4.16 (m_c, 1H; CH), 4.95 (dd, $^3J(H,H)$ = 6, 8 Hz, 1H; CH), 7.23–7.41 (m, 5H; CH); ^{13}C NMR (63 MHz): δ = 10.5, 31.8, 34.3, 78.6, 82.2, 125.8, 127.4, 128.3, 142.3.

trans-2-Iodomethyl-5-phenyltetrahydrofuran: ^1H NMR (250 MHz): δ = 1.76–2.00 (m, 2H; CH_2), 2.24–2.35 (m, 1H; CH_2), 2.37–2.48 (m, 1H; CH_2), 3.28 (dd, $^3J(H,H)$ = 7, 10 Hz, 1H; CH_2I), 3.38 (dd, $^3J(H,H)$ = 5, 10 Hz, 1H; CH_2I), 4.32 (m_c, 1H; CH), 5.12 (dd, $^3J(H,H)$ = 6, 8 Hz, 1H; CH), 7.21–7.37; ^{13}C NMR (63 MHz): δ = 10.9, 32.8, 35.4, 78.9, 81.5, 125.5, 127.3, 128.3, 142.7.

***cis*- and *trans*-2-Iodomethyl-5-benzyltetrahydrofuran**: Yield: 1.06 g (70%), colorless oil, *cis*:*trans* = 26:74, $C_{12}H_{15}IO$ (302.2): calcd C 47.70, H 5.00; found C 47.55, H 4.91; MS (70 eV, EI): *m/z* (%): 212 (6) [$M^+ - C_7H_6$], 211 (100) [$M^+ - C_7H_7$], 174 (16) [$M^+ - HI$].

cis-2-Iodomethyl-5-cyclohexyltetrahydrofuran: ^1H NMR (250 MHz): δ = 1.61–1.77 (m, 2H; CH_2), 1.86–2.07 (m, 1H; CH_2), 2.08–2.23 (m, 1H; CH_2), 2.77 (dd, $^3J(H,H)$ = 7, 14 Hz, 1H; CH_2), 2.98 (dd, $^3J(H,H)$ = 5, 13 Hz, 1H; CH_2), 3.14 (dd, $^3J(H,H)$ = 7, 10 Hz, 1H; CH_2I), 3.25 (dd, $^3J(H,H)$ = 5, 10 Hz, 1H; CH_2I), 4.14 (m_c, 1H; CH), 4.10–4.24 (m, 1H; CH), 7.18–7.32 (m, 5H; CH); ^{13}C NMR (63 MHz): δ = 10.8, 30.4, 31.4, 42.2, 78.6, 81.4, 126.3, 128.3, 129.4, 138.3.

trans-2-Iodomethyl-5-benzyltetrahydrofuran: ^1H NMR (250 MHz): δ = 1.61–1.77 (m, 2H; CH_2), 1.86–2.07 (m, 1H; CH_2), 2.08–2.23 (m, 1H; CH_2), 2.72 (dd, $^3J(H,H)$ = 7, 14 Hz, 1H; CH_2), 2.96 (dd, $^3J(H,H)$ = 5, 13 Hz, 1H; CH_2), 3.17 (dd, $^3J(H,H)$ = 7, 10 Hz, 1H; CH_2I), 3.27 (dd, $^3J(H,H)$ = 5, 10 Hz, 1H; CH_2I), 4.06–4.16 (m, 1H; CH), 4.33 (tt, $^3J(H,H)$ = 6, 8 Hz, 1H; CH), 7.18–7.32 (m, 5H; CH); ^{13}C NMR (63 MHz): δ = 11.0, 31.6, 32.4, 41.9, 78.3, 80.8, 126.3, 128.2, 129.3, 138.3.

***cis*- and *trans*-2-Iodomethyl-5-cyclohexyltetrahydrofuran**: Yield: 1.33 g (90%), colorless oil, *cis*:*trans* = 17:83, $C_{11}H_{19}IO$ (294.18): calcd C 44.91, H 6.51; found C 44.82, H 6.74; MS (70 eV, EI): *m/z* (%): 294 (2) [M^+], 211 (100.0) [$M^+ - C_6H_{11}$], 153 (67) [$M^+ - CH_2I$].

cis-2-Iodomethyl-5-cyclohexyltetrahydrofuran: ^1H NMR (250 MHz): δ = 0.85–2.09 (m, 15H; CH_2), 3.11 (dd, $^3J(H,H)$ = 7, 10 Hz, 1H; CH_2), 3.22 (dd, $^3J(H,H)$ = 5, 10 Hz, 1H; CH_2), 3.61 (m_c, 1H; CH), 3.94 (m_c, 1H; CH); ^{13}C NMR (63 MHz): δ = 10.8, 25.9, 26.0, 26.5, 28.3, 29.0, 29.7, 31.4, 43.0, 78.0, 85.3.

trans-2-Iodomethyl-5-cyclohexyltetrahydrofuran: ^{1}H NMR (250 MHz): δ = 0.83–2.17 (m, 15H; CH_2), 3.13 (dd, ^3J(H,H) = 7, 10 Hz, 1H; CH_2), 3.25 (dd, ^3J(H,H) = 5, 10 Hz, 1H; CH_2), 3.73 (q, ^3J(H,H) = 7 Hz, 1H; CH), 4.00 (m_c, 1H; CH); ^{13}C NMR (63 MHz): δ = 11.2, 25.8, 26.0, 26.4, 28.6, 29.8, 30.9, 32.7, 43.0, 78.0, 84.6.

***cis*- and *trans*-2-Iodomethyl-4-phenyltetrahydrofuran** [16a]: Yield: 1.13 g (78%), colorless oil, *cis*:*trans* = 83:17.

cis-2-Iodomethyl-4-cyclohexyltetrahydrofuran: ^{1}H NMR (250 MHz): δ = 1.82 (ddd, ^3J(H,H) = 10, 11, 13 Hz, 1H; CH_2), 2.58 (ddd, ^3J(H,H) = 6, 7, 13 Hz, 1H; CH_2), 3.35 (m, 2H; CH_2I), 3.54 (m_c, 1H; CH), 3.90 (dd, ^3J(H,H) = 7, 9 Hz, 1H; CH_2), 4.15 (ddt, ^3J(H,H) = 6, 10 Hz, 1H; CH), 4.25 (dd, ^3J(H,H) = 6, 8 Hz, 1H; CH_2), 7.20–7.35 (m, 5H; CH); ^{13}C NMR (63 MHz): δ = 10.2, 41.1, 45.8, 74.8, 79.1, 126.8, 127.2, 128.6, 140.7.

trans-2-Iodomethyl-4-phenyltetrahydrofuran: ^{1}H NMR (250 MHz): δ = 1.82 (ddd, ^3J(H,H) = 10, 11, 13 Hz, 1H; CH_2), 2.58 (ddd, ^3J(H,H) = 6, 7, 13 Hz, 1H; CH_2), 3.28 (m, 2H; CH_2I), 3.50 (m_c, 2H; CH_2), 3.80 (dd, ^3J(H,H) = 8, 9 Hz, 1H; CH_2), 4.26 (quint, ^3J(H,H) = 6 Hz, 1H; CH), 4.31 (dd, ^3J(H,H) = 7, 9 Hz, 1H; CH_2), 7.18–7.33 (m, 5H; CH). ^{13}C NMR (63 MHz): δ = 9.5, 38.8, 43.6, 74.2, 77.5, 125.7, 126.1, 127.6, 140.6.

***cis*- and *trans*-2-Iodomethyl-3-phenyltetrahydrofuran**: Yield: 0.81 g (56%), colorless oil, *cis*:*trans* = 16:84, $C_{11}H_{13}IO$ (288.1): calcd C 45.86, H 4.55; found C 45.93, H 4.44; MS (70 eV, EI): *m/z* (%): 288 (9) [M^+], 161 (100.0) [$M^+ - I$], 117 (70) [$C_3H_4C_6H_5$].

cis-2-Iodomethyl-4-phenyltetrahydrofuran: ^{1}H NMR (250 MHz): δ = 2.16–2.29 (m, 1H; CH_2), 2.41–2.55 (m, 1H; CH_2), 2.69 (dd, ^3J(H,H) = 5, 10 Hz, 1H; CH_2I), 2.89 (dd, ^3J(H,H) = 8, 10 Hz, 1H; CH_2I), 3.52 (dt, ^3J(H,H) = 5, 8 Hz, 1H; CH), 3.98 (ddd, ^3J(H,H) = 7, 9, 16 Hz, 1H; CH), 4.26 (m_c, 2H; CH_2), 7.19–7.35 (m, 5H; CH).

trans-2-Iodomethyl-3-phenyltetrahydrofuran: ^{1}H NMR (250 MHz): δ = 2.20–2.32 (m, 1H; CH_2), 2.38–2.50 (m, 1H; CH_2), 3.10 (q, ^3J(H,H) = 8 Hz, 1H; CH), 3.19 (dd, ^3J(H,H) = 6, 11 Hz, 1H; CH_2I), 3.38 (dd, ^3J(H,H) = 4, 11 Hz, 1H; CH_2I), 3.70 (ddd, ^3J(H,H) = 4, 5, 9 Hz, 1H; CH), 4.09 (m_c, 2H; CH_2), 7.21–7.35 (m, 5H; C_6H_5); ^{13}C NMR (63 MHz): δ = 9.6, 35.3, 51.0, 68.1, 84.3, 127.0, 127.5, 128.8, 140.4.

***cis*-3-iodo-6-methyl-2-phenyltetrahydropyran**: Yield: 1.19 g (79%), colorless oil, ^{1}H NMR (250 MHz): δ = 1.20 (d, ^3J(H,H) = 6 Hz, 3H; CH_3), 1.53–1.67 (m, 2H; CH_2), 2.25–2.46 (m, 1H; CH_2), 2.66 (dq, ^3J(H,H) = 4.13 Hz, 1H; CH), 3.77 (m_c, 1H; CH), 4.16 (ddd, ^3J(H,H) = 4, 10, 12 Hz, 1H; CH), 4.49 (d, ^3J(H,H) = 10 Hz, 1H; CH), 7.29–7.39 (m, 5H; C_6H_5); ^{13}C NMR (63 MHz): δ = 21.8, 33.2, 36.8, 28.6, 74.8, 86.1, 127.6, 128.1, 128.3, 140.6; $C_{12}H_{15}IO$ (302.2): calcd C 47.70, H 5.00; found C 48.08, H 4.70.

Reduction of tetrahydrofurylmethyl iodides: Tetrahydrofurylmethyl iodide (1.74 mmol) was added in small portions to a mixture of LiH (30.0 mg, 3.80 mmol) and LAH (70.0 mg, 1.80 mmol) in anhydrous THF (15 mL). The reaction mixture was refluxed for 3 h and stirred for another hour at 20 °C. The slurry was cooled to 0 °C, and water was added until no further hydrogen was evolved. The salts were dissolved with aq. sulfuric acid [10% (v/v)], the organic phase was separated, and the aqueous phase was washed with diethyl ether (4 × 20 mL). The combined organic phases were washed with saturated aq. sodium thiosulfate solution (20 mL) and brine (20 mL), and dried ($MgSO_4$). The solvent was removed in vacuo to yield products **14**.

***cis*- and *trans*-2-Phenyl-5-methyltetrahydrofuran (14a)** [16a]: Yield: 130 mg (46%), colorless liquid, *cis*:*trans* = 26:74.

cis-**14a**: ^{1}H NMR (250 MHz): δ = 1.37 (d, ^3J(H,H) = 6 Hz, 3H; CH_3), 1.55–1.70 (m, 1H; CH_2), 1.78–1.95 (m, 1H; CH_2), 2.02–2.24 (m, 1H; CH_2), 2.27–2.45 (m, 1H; CH_2), 4.17 (m_c, 1H; CH), 4.88 (dd, ^3J(H,H) = 6, 7 Hz, 1H; CH), 7.32–7.35 (m, 5H; CH); ^{13}C NMR (63 MHz): δ = 21.3, 33.1, 34.6, 75.9, 81.0, 125.8, 127.1, 128.3, 144.0.

trans-**14a**: ^{1}H NMR (250 MHz): δ = 1.32 (d, ^3J(H,H) = 6 Hz, 3H; CH_3), 1.55–1.70 (m, 1H; CH_2), 1.78–1.95 (m, 1H; CH_2), 2.02–2.24 (m, 1H; CH_2), 2.27–2.45 (m, 1H; CH_2), 4.36 (m_c, 1H; CH), 5.04 (dd, ^3J(H,H) = 6, 8 Hz, 1H; CH), 7.32–7.35 (m, 5H; CH). ^{13}C NMR (63 MHz): δ = 21.5, 34.3, 35.6, 75.9, 80.2, 125.6, 127.0, 128.3, 144.0.

***cis*- and *trans*-2-Benzyl-5-methyltetrahydrofuran (14b)**: Yield: 274 mg (89%), colorless liquid, *cis*:*trans* = 26:74; $C_{12}H_{16}O$ (176.26): calcd C 81.77, H 9.15; found C 81.52, H 9.07; MS (70 eV, EI): *m/z* (%): 117 (3) [$C_3H_4Ph^+$], 91 (26) [$C_7H_7^+$], 85 (100.0) [$M^+ - C_7H_7$].

cis-**14b**: ^{1}H NMR (250 MHz): δ = 1.25 (d, ^3J(H,H) = 7 Hz, 3H; CH_3), 1.30–1.71 (m, 2H; CH_2), 1.81–2.08 (m, 2H; CH_2), 2.66–2.77 (m, 1H; CH_2), 2.93–3.03 (m, 1H; CH_2), 3.92–4.31 (m, 2H; CH), 7.17–7.33 (m, 5H; CH); ^{13}C NMR (63 MHz): δ = 21.4, 30.7, 32.7, 42.5, 75.4, 80.1, 126.1, 128.2, 129.3, 138.9.

trans-**14b**: ^{1}H NMR (250 MHz): δ = 1.22 (d, ^3J(H,H) = 6 Hz, 3H; CH_3), 1.30–1.71 (m, 2H; CH_2), 1.81–2.08 (m, 2H; CH_2), 2.66–2.77 (m, 1H; CH_2), 2.93–3.03 (m, 1H; CH_2), 3.92–4.31 (m, 2H; CH), 7.17–7.33 (m, 5H; CH); ^{13}C NMR (63 MHz): δ = 21.4, 31.7, 33.7, 42.3, 74.8, 79.4, 126.1, 128.2, 129.3, 138.8.

***cis*- and *trans*-2-cyclohexyl-5-methyltetrahydrofuran (14c)**: Yield: 151 mg (52%), colorless liquid, *cis*:*trans* = 17:83; $C_{11}H_{20}O$ (168.3): calcd 78.51, H 11.98; found C 78.23, H 12.04; MS (70 eV, EI): *m/z* (%): 168 (1) [M^+], 86 (5) [$M^+ - C_6H_{10}$], 85 (100) [$M^+ - C_6H_{11}$].

cis-**14c**: ^{1}H NMR (250 MHz): δ = 0.85–2.04 (m, 15H; CH_2, CH), 1.21 (d, ^3J(H,H) = 6 Hz, 3H; CH_3), 3.51 (q, ^3J(H,H) = 7 Hz, 1H; CH), 3.85–4.05 (m, 1H; CH); ^{13}C NMR (63 MHz): δ = 21.3, 25.8, 26.1, 29.0, 29.6, 32.8, 43.2, 74.9, 84.1.

trans-**14c**: ^{1}H NMR (250 MHz): δ = 0.85–2.04 (m, 15H; CH, CH_2), 1.20 (d, ^3J(H,H) = 6 Hz, 3H; CH_3), 3.67 (dt, ^3J(H,H) = 6, 8 Hz, 1H; CH), 3.85–4.05 (m, 1H; CH); ^{13}C NMR (63 MHz): δ = 21.3, 26.0, 26.6, 28.8, 29.9, 34.2, 43.4, 74.6, 83.3.

***cis*- and *trans*-4-Phenyl-2-methyltetrahydrofuran (14d)**: Yield: 153 mg (54%), colorless liquid, *cis*:*trans* = 83:17.

cis-**14d**: ^{1}H NMR (250 MHz): δ = 1.36 (d, ^3J(H,H) = 6 Hz, 3H; CH_3), 1.62 (ddd, ^3J(H,H) = 10, 12 Hz, 1H; CH_2), 2.45 (ddd, ^3J(H,H) = 6, 8, 13 Hz, 1H; CH_2), 3.47 (quint, ^3J(H,H) = 8 Hz, 1H; CH), 3.84 (dd, ^3J(H,H) = 6, 8 Hz, 1H; CH_2), 4.11–4.19 (m, 2H; CH, CH_2), 7.19–7.33 (m, 5H; CH); ^{13}C NMR (63 MHz): δ = 20.8, 42.8, 45.9, 74.3, 76.3, 126.4, 127.1, 128.5, 142.8.

trans-**14d**: ^{1}H NMR (250 MHz): δ = 1.31 (d, ^3J(H,H) = 6 Hz, 3H; CH_3), 1.99 (ddd, ^3J(H,H) = 9, 13, 19 Hz, 1H; CH_2), 2.15 (ddd, ^3J(H,H) = 7, 13 Hz, 1H; CH_2), 3.47 (quint, ^3J(H,H) = 8 Hz, 1H; CH), 3.71 (dd, ^3J(H,H) = 7, 9 Hz, 1H; CH_2), 4.24–4.33 (m, 2H; CH, CH_2), 7.19–7.33 (m, 5H; CH); ^{13}C NMR (63 MHz): δ = 21.6, 41.3, 44.7, 74.7, 75.4, 126.7, 127.2, 128.5, 142.6.

Synthesis of Tetrahydropyrans: 2-Phenyl- and 2-benzyltetrahydropyran (**13a,b**) were prepared according to the procedure of Kim et al. [15a]. 2-Cyclohexyltetrahydropyran (**13b**) [15c], 3-phenyltetrahydropyran (**13d**) [15d], and 4-phenyltetrahydropyran [15e] (**13e**) were obtained by literature procedures. *cis*-2-phenyl-6-methyltetrahydropyran (**13g**) [15f] was prepared by iodocyclization of (*E*)-6-phenylhex-5-en-2-ol (**4g**) and subsequent reduction of the 3-iodo-2-phenyl-6-methyltetrahydropyran as described above.

2-Benzyltetrahydropyran (13b) [15b]: ^{1}H NMR (250 MHz): δ = 1.52–1.94 (m, 6H; CH_2), 3.51–3.62 (m, 1H; CH_2), 3.94 (ddd, ^3J(H,H) = 4, 8, 12 Hz, 1H; CH_2), 4.52 (d, ^3J(H,H) = 1 Hz, 1H; CH_2), 4.73 (t, ^3J(H,H) = 3 Hz, 1H; CH), 4.82 (d, ^3J(H,H) = 12 Hz, 1H; CH_2), 7.20–7.41 (m, 5H; C_6H_5); ^{13}C NMR (63 MHz): δ = 19.4, 25.5, 31.5, 62.1, 68.9, 97.8, 127.5, 127.9, 128.4, 138.4.

2-Cyclohexyltetrahydropyran (13c) [15f]: ^{1}H NMR (250 MHz): δ = 0.82–1.90 (m, 17H; CH_2, CH), 2.97 (ddd, ^3J(H,H) = 2, 6, 11 Hz, 1H; CH), 3.38 (dt, ^3J(H,H) = 3, 11 Hz, 1H; CH_2), 3.96 (m_c, 1H; CH_2); ^{13}C NMR (63 MHz): δ = 23.8, 26.2, 26.3, 26.4, 26.6, 28.6, 28.7, 29.1, 43.3, 68.7, 82.4.

***cis*-2-phenyl-6-methyltetrahydropyran (13g)** [15b]: ^{1}H NMR (250 MHz): δ = 1.26 (d, ^3J(H,H) = 6 Hz, 3H; CH_3), 1.20–1.97 (m, 6H; CH_2), 3.64 (m, 1H; CH_2) 4.38 (dd, ^3J(H,H) = 2, 11 Hz, 1H; CH), 7.21–7.40 (m, 5H; C_6H_5); ^{13}C NMR (63 MHz): δ = 22.3, 24.11, 33.1, 33.5, 74.4, 79.9, 125.9, 127.1, 128.3, 143.5.

1. Preparation of *N*-(Alkyloxy)pyridine-2(1*H*)-thiones 6: A flame-dried round-bottom flask was charged with 2-mercaptopyridine *N*-oxide tetraethylammonium salt (**5**) [7] (1.36 g, 5.30 mmol) and pentenyl tosylate or chloride (5.30 mmol) dissolved in anhydrous DMF (25 mL) under argon at 0 °C. The reaction mixture was stirred for 1 h with ice cooling and 14 h in the dark at 20 °C. The yellow solution was poured into a separatory funnel, which had been charged with 0.1 N sodium hydroxide solution (40 mL) and methyl *tert*-butyl ether (MTB) (40 mL). The organic layer was separated and the aqueous phase extracted with MTB (3 × 25 mL). The combined ethereal extracts were washed with saturated sodium hydrogencarbonate (25 mL) and brine (25 mL), and dried ($MgSO_4$) to afford a yellow solution. The solvent was removed in vacuo. The residual yellow oil was purified by column chromatography (SiO_2, MTB) in the dark. After the yellow bands of **6** had been isolated, the pyridine *N*-oxides **7** were eluted with acetone.

***N*-(1-Phenylpent-4-enyl-1-oxy)pyridine-2(1*H*)-thione (6a)**: Yield: 0.69 g (48%), yellow crystals, m.p. 86 °C; ^{1}H NMR (200 MHz): δ = 1.95–2.12 (m, 3H; CH_2), 2.37–2.49 (m, 1H; CH_2), 4.87–4.99 (m, 2H; CH_2), 5.67–5.87 (m, 2H; CH), 6.10 (dd, ^3J(H,H) = 7, 9 Hz, 1H; CH), 6.86–6.97 (m, 2H; CH), 7.21–7.31 (m, 5H; CH), 7.55 (dd, ^3J(H,H) = 2, 9 Hz, 1H; CH); ^{13}C NMR (50 MHz): δ = 29.3, 32.2, 86.0, 111.6, 115.1, 128.6, 128.8, 129.4, 132.6, 136.6, 137.3, 137.5, 139.3, 175.6; IR: $\tilde{\nu}$ = 3066, 1958, 1642, 1609, 1525, 1447, 1408, 1276, 1175 cm^{-1}; UV/Vis: λ_{max} (ε) = 362 (5700), 288 (11700), 235 nm (6000); MS (70 eV), *m/z* (%): 271 (10) [M^+], 127 (32) [$M^+ - C_{11}H_{12}$], 91 (100) [$C_7H_7^+$]; $C_{16}H_{17}NOS$ (271.4): calcd C 70.82, H 6.31, N 5.16, S 11.81; found: C 70.74, H 6.35, N 4.94, S 12.00.

***N*-(1-Phenyl-5-hexenyl-2-oxy)pyridine-2(1*H*)-thione (6b)**: Yield: 0.76 g (50%), yellow oil; ^{1}H NMR (200 MHz): δ = 1.75 (m_c, 2H; CH_2), 2.27 (m_c, 2H; CH_2), 2.97 (dd, ^3J(H,H) = 8, 14 Hz, 1H; CH_2), 3.17 (dd, ^3J(H,H) = 5, 14 Hz, 1H; CH_2),

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4.92–5.03 (m, 2H; CH_2), 5.35 (m_c, 1H; CH), 5.76 (ddt, ^3J(H,H) = 6, 10, 17 Hz, 1H; CH), 6.49 (dt, ^3J(H,H) = 7 Hz, ^4J(H,H) = 2 Hz, 1H; CH), 7.08 (ddd, ^3J(H,H) = 7, 9 Hz, ^4J(H,H) = 2 Hz, 1H; CH), 7.17–7.31 (m, 5H; CH), 7.54 (dd, ^3J(H,H) = 7 Hz, ^4J(H,H) = 2 Hz, 1H; CH), 7.66 (dd, ^3J(H,H) = 9 Hz, ^4J(H,H) = 2 Hz, 1H; CH); ^{13}C NMR (50 MHz): δ = 28.8, 30.2, 37.9, 84.9, 112.3, 115.1, 126.7, 128.6, 129.3, 132.3, 136.5, 137.6, 138.1, 139.4, 176.6; IR: $\tilde{\nu}$ = 2926, 1609, 1525, 1447, 1408, 1224, 1176, 1132 cm^{-1}; UV/Vis: λ_{max} (ε) = 364 (5100), 291 nm (11200); MS (70 eV), *m/z* (%): 285 (2) [M^+], 128 (100) [$C_5H_6NOS^+$], 127 (85) [$C_5H_5NOS^+$], 91 (89) [$C_7H_7^+$]; $C_{17}H_{19}NOS$ (285.4): calcd C 71.54, H 6.71 N 4.91, S 11.23; found: C 70.95, H 6.70, N 4.86, S 11.05.

***N*-(1-Cyclohexylpent-4-enyl-1-oxy)pyridine-2(1*H*)-thione (6c)**: Yield: 0.49 g (50%), yellow oil; ^{1}H NMR (200 MHz): δ = 1.17–1.38 (m, 5H; CH, CH_2), 1.58–1.91 (m, 8H; CH_2), 2.28 (m_c, 2H; CH_2), 4.92–5.06 (m, 3H; CH_2, CH), 5.79 (ddt, ^3J(H,H) = 7, 10, 17 Hz, 1H; CH), 6.55 (dt, ^3J(H,H) = 7 Hz, ^4J(H,H) = 2 Hz, 1H; CH), 7.09 (ddd, ^3J(H,H) = 7 Hz, ^4J(H,H) = 2 Hz, 1H; CH), 7.61 (ddd, ^3J(H,H) = 10 Hz, ^3J(H,H) = 2 Hz, 2H; CH); ^{13}C NMR (50 MHz): δ = 26.1, 26.4 (2C), 27.7, 28.0, 28.2, 29.8, 39.0, 87.7, 112.3, 115.0, 132.1, 138.0, 138.4, 139.5, 176.8; IR: $\tilde{\nu}$ = 2931, 1610, 1525, 1446, 1407, 1276, 1176, 1130 cm^{-1}; UV/Vis: λ_{max} (ε) = 364 (5100), 291 nm (11100); MS (70 eV), *m/z* (%): 277 (2) [M^+], 150 (5) [$M^+ - C_5H_5NOS$], 128 (100) [$C_5H_6NOS^+$], 127 (54) [$C_5H_5NOS^+$]; $C_{16}H_{23}NOS$ (277.42): calcd C 69.27, H 8.36 N 5.05, S 11.56; found: C 68.85, H 8.12, N 5.14, S 11.76.

***N*-(2-Phenylpent-4-enyl-1-oxy)pyridine-2(1*H*)-thione (6d)**: Yield: 0.45 g (31%), yellow oil; ^{1}H NMR (200 MHz): δ = 2.50 (td, ^3J(H,H) = 7, 15 Hz, 1H; CH_2), 2.66 (td, ^3J(H,H) = 7, 14 Hz, 1H; CH_2), 3.26 (m_c, 1H; CH), 4.44 (dd, ^3J(H,H) = 5, 8 Hz, 1H; CH_2), 4.79 (dd, ^3J(H,H) = 7, 8 Hz, 1H; CH_2), 5.02 (m_c, 2H; CH_2), 5.72 (ddt, ^3J(H,H) = 7, 10, 17 Hz, 1H; CH), 6.47 (dt, ^3J(H,H) = 7 Hz, ^4J(H,H) = 2 Hz, 1H; CH), 7.08 (ddd, ^3J(H,H) = 7, 9 Hz, ^3J(H,H) = 2 Hz, 1H; CH), 7.15–7.36 (m, 6H; CH), 7.61 (dd, ^3J(H,H) = 9 Hz, ^4J(H,H) = 2 Hz, 1H; CH); ^{13}C NMR (50 MHz): δ = 36.8, 44.2, 79.8, 112.9, 117.0, 127.0, 128.0, 128.6, 132.6, 135.3, 137.7, 138.0, 140.9, 176.6; IR: $\tilde{\nu}$ = 3030, 2361, 1609, 1525, 1446, 1410, 1277, 1176, 1135 cm^{-1}; UV/Vis: λ_{max} (ε) = 362 (5100), 290 nm (11200); MS (70 eV), *m/z* (%): 271 (1) [M^+], 131 (59) [$C_4H_6Ph^+$], 127 (35) [$C_5H_5NOS^+$], 91 (100) [$C_7H_7^+$]; $C_{16}H_{17}NOS$ (271.4): calcd C 70.82, H 6.31, N 5.16, S 11.81; found: C 71.06, H 6.46, N 4.85, S 11.85.

***N*-(3-Phenylpent-4-enyl-1-oxy)pyridine-2(1*H*)-thione (6e)**: Yield: 0.53 g (37%), yellow oil; ^{1}H NMR (200 MHz): δ = 2.26 (m_c, 2H; CH_2), 3.60 (q, ^3J(H,H) = 8 Hz, 1H; CH), 4.35 (m_c, 2H; CH_2), 5.07–5.17 (m, 2H; CH_2), 5.99 (ddd, ^3J(H,H) = 8, 10, 17 Hz, 1H; CH), 6.55 (dt, ^3J(H,H) = 7 Hz, ^4J(H,H) = 2 Hz, 1H; CH), 7.12 (ddd, ^3J(H,H) = 7, 8 Hz, ^3J(H,H) = 2 Hz, 1H; CH), 7.19–7.38 (m, 5H; CH), 7.57 (dd, ^3J(H,H) = 7 Hz, ^4J(H,H) = 2 Hz, 1H; CH), 7.63 (dd, ^3J(H,H) = 9 Hz, ^3J(H,H) = 1 Hz, 1H; CH); ^{13}C NMR (50 MHz): δ = 32.6, 45.9, 74.5, 113.1, 115.0, 126.7, 127.6, 128.7, 132.7, 137.7, 138.0, 141.0, 142.8, 176.8; IR: $\tilde{\nu}$ = 2978, 1609, 1524, 1446, 1410, 1177, 1134 cm^{-1}; UV/Vis: λ_{max} (ε) = 364 (5200), 292 nm (11700); MS (70 eV), *m/z* (%): 271 (2) [M^+], 161 (28) [$M^+ - C_5H_4NS$], 117 (100) [$C_3H_4Ph^+$], 91 (85) [$C_7H_7^+$]; $C_{16}H_{17}NOS$ (271.4): calcd C 70.82, H 6.31, N 5.16, S 11.81; found: C 70.58, H 6.06, N 4.97, S 11.84.

***N*-(4-Phenylpent-4-enyl-1-oxy)pyridine-2(1*H*)-thione (6f)**: Yield: 0.54 g (38%), yellow oil; ^{1}H NMR (400 MHz): δ = 1.96 (quint, ^3J(H,H) = 8 Hz, 2H; CH_2), 2.74 (t, ^3J(H,H) = 7 Hz, 2H; CH_2), 4.39 (t, ^3J(H,H) = 7 Hz, 2H; CH_2), 5.13 (brs, 1H; CH), 5.35 (brs, 1H; CH), 6.56 (td, ^3J(H,H) = 7 Hz, ^4J(H,H) = 1 Hz, 1H; CH), 7.11 (ddd, ^3J(H,H) = 7, 8 Hz, ^4J(H,H) = 1 Hz, 1H; CH), 7.24–7.34 (m, 5H; C_6H_5), 7.38–7.41 (m, 1H; CH), 7.60–7.63 (m, 1H; CH); ^{13}C NMR (100 MHz): δ = 26.3, 31.3, 75.7, 112.9, 113.1, 126.1, 127.5, 128.3, 132.6, 137.7, 138.0, 140.8, 147.3, 175.8; IR: $\tilde{\nu}$ = 2973, 1610, 1524, 1446, 1410, 1277, 1134 cm^{-1}; UV/Vis (EtOH): λ_{max} (ε) = 361 (5400), 290 (11900), 245 nm (9100, sh); MS (70 eV), *m/z* (%): 118 (100) [$C_9H_{10}^+$], 77 (14) [$C_6H_5^+$]; $C_{16}H_{17}NOS$ (271.4): calcd C 70.82, H 5.90, N 6.31, S 11.81; found: C 70.63, H 6.08, N 5.60, S 11.90.

***N*-(6-Phenyl-5-hexen-2-oxy)pyridine-2(1*H*)-thione (6g)**: Yield: 0.76 g (50%), yellow oil; ^{1}H NMR (200 MHz): δ = 1.33 (d, ^3J(H,H) = 6 Hz, 3H; CH_3), 1.70–2.12 (m, 2H; CH_2), 2.85 (m_c, 2H; CH_2), 5.27 (m_c, 1H; CH), 6.25 (dt, ^3J(H,H) = 7, 16 Hz, 1H; CH), 6.45 (d, ^3J(H,H) = 16 Hz, 1H; CH), 6.56 (dt, ^3J(H,H) = 7 Hz, ^4J(H,H) = 2 Hz, 1H; CH), 7.13 (ddd, ^3J(H,H) = 8 Hz, ^3J(H,H) = 2 Hz, 1H; CH), 7.19–7.38 (m, 5H; CH), 7.64 (dd, ^3J(H,H) = 7 Hz, ^4J(H,H) = 1 Hz, 1H; CH), 7.68 (dd, ^3J(H,H) = 9 Hz, ^4J(H,H) = 2 Hz, 1H; CH); ^{13}C NMR (50 MHz): δ = 27.0, 28.4, 33.9, 80.5, 112.1, 126.0, 127.0, 128.4, 129.5, 130.6, 132.3, 137.6, 138.2, 139.7, 176.6; IR: $\tilde{\nu}$ = 2975, 1610, 1525, 1447, 1408, 1176, 1132 cm^{-1}; UV/Vis: λ_{max} = 364, 292, 251 nm; MS (70 eV), *m/z* (%): 285 (2) [M^+], 201 (30) [$M^+ - C_4H_4S$], 129 (71) [$C_4H_4C_6H_5^+$], 85 (100) [$C_4H_5S^+$]; $C_{17}H_{19}NOS$ (285.4): calcd C 71.54, H 6.71, N 4.91, S 11.23; found: C 70.95, H 6.70, N 4.86, S 11.05.

***N*-(1-Phenylethyl-1-oxy)pyridine-2(1*H*)-thione (6h)**: Yield: 0.78 g (63%), m.p. 45 °C; ^{1}H NMR (200 MHz): δ = 1.76 (d, ^3J(H,H) = 7 Hz, 3H; CH_3), 6.00 (q, ^3J(H,H) = 7 Hz, 1H; CH), 6.19 (td, ^3J(H,H) = 7 Hz, ^4J(H,H) = 2 Hz, 1H; CH), 6.94–6.99 (m, 1H; CH), 7.01 (td, ^3J(H,H) = 7, 9 Hz, ^4J(H,H) = 2 Hz, 1H; CH), 7.33 (m, 5H; C_6H_5), 7.62 (ddd, ^3J(H,H) = 9 Hz, ^4J(H,H) = 1, 2 Hz, 1H; CH); ^{13}C NMR (50 MHz): δ = 19.1, 82.6, 111.7, 128.1, 128.8, 129.3, 132.7, 137.6, 138.0, 139.3, 175.7; IR: $\tilde{\nu}$ = 2981, 1608, 1528, 1449, 1410, 1274, 1131 cm^{-1}; UV/Vis: λ_{max} (ε) = 361 (5700), 290 nm (11400); MS (70 eV), *m/z* (%): 127 (19) [$M^+ - C_8H_8$], 105 (100) [$M^+ - C_5H_4NOS$], 77 (37) [$C_6H_5^+$]; $C_{13}H_{13}NOS$ (231.3): calcd C 67.50, H 5.66, N 6.06, S 13.87; found: C 67.19, H 6.04, N 6.00, S 13.87.

***S*-(1-Phenylpent-4-en-1-yl)-2-thiopyridine *N*-oxide (7a)**: Yield: 0.70 g (49%), colorless crystals, m.p. 107–108 °C; ^{1}H NMR (250 MHz): δ = 1.91–2.12 (m, 4H; CH_2), 4.26 (m_c, 1H; CH), 4.91–4.98 (m, 2H; CH_2), 5.61–5.77 (m, 1H; CH), 6.82–6.97 (m, 3H, CH), 7.11–7.26 (m, 3H; CH), 7.34–7.39 (m, 2H; CH), 8.07–8.11 (m, 1H; CH); ^{13}C NMR (63 MHz): δ = 30.1, 35.2, 47.2, 115.0, 119.6, 121.9, 124.4, 126.7 (2C), 127.8, 135.9, 137.6, 139.5, 150.2; IR: $\tilde{\nu}$ = 3071, 1641, 1587, 1425, 1248 cm^{-1}; UV/Vis: λ_{max} (ε) = 308 (850), 271 (3100), 245 nm (8900); MS (70 eV), *m/z* (%): 271 (6) [M^+], 254 [M^+ – OH], 127 (32) [$M^+ - C_{11}H_{12}$], 91 (100) [$C_7H_7^+$]; $C_{16}H_{17}NOS$ (271.4): calcd C 70.82, H 6.31, N 5.16, S 11.81; found: C 70.66, H 6.27, N 5.15, S 11.75.

***S*-(1-Phenyl-5-hexen-2-yl)-2-thiopyridine *N*-oxide (7b)**: Yield: 0.73 g (48%), colorless crystals, m.p. 112–113 °C; ^{1}H NMR (250 MHz): δ = 1.65–1.93 (m, 2H; CH_2), 2.28 (dt, ^3J(H,H) = 7, 14 Hz, 2H; CH_2), 2.99 (d, ^3J(H,H) = 7 Hz, 2H; CH_2), 3.48 (dq, ^3J(H,H) = 5, 7 Hz, 1H; CH), 4.95–5.03 (m, 2H; CH_2), 5.72 (ddt, ^3J(H,H) = 6, 10, 17 Hz, 1H; CH), 6.97 (td, ^3J(H,H) = 7 Hz, ^4J(H,H) = 2 Hz, 1H; CH), 7.06 (dd, ^3J(H,H) = 8 Hz, ^4J(H,H) = 2 Hz, 1H; CH), 7.13 (ddd, ^3J(H,H) = 7, 8 Hz, ^4J(H,H) = 2 Hz, 1H; CH), 7.18–7.99 (m, 5H; C_6H_5), 8.20 (d, ^3J(H,H) = 7 Hz, 1H; CH); ^{13}C NMR (63 MHz): δ = 30.8, 32.7, 41.3, 45.4, 115.8, 120.4, 122.3, 125.4, 126.8, 128.6, 129.3, 137.2, 138.3, 139.1, 151.6; IR (KBr): $\tilde{\nu}$ = 3026, 1639, 1584, 1417, 1238 cm^{-1}; MS (70 eV, EI), *m/z* (%): 268 (33) [M^+ – OH], 128 (84) [$C_5H_6NOS^+$], 127 (100) [$C_5H_5NOS^+$]; $C_{17}H_{19}NOS$ (285.4): calcd C 71.54, H 6.71, N 4.91, S 11.23; found: C 71.22, H 6.71, N 4.80, S 11.09.

***S*-(1-Cyclohexylpent-4-en-1-yl)-2-thiopyridine *N*-oxide (7c)**: Yield: 0.66 g (45%), colorless crystals, m.p. 106–107 °C; ^{1}H NMR (250 MHz): δ = 1.03–1.28 (m, 5H; CH_2), 1.59–2.01 (m, 8H; CH, CH_2), 2.15–2.30 (m, 2H; CH_2), 3.09 (quint, ^3J(H,H) = Hz, 1H; CH), 4.94–5.02 (m, 2H; CH_2), 5.75 (ddt, ^3J(H,H) = 6, 10, 17 Hz, 1H; CH), 6.95–7.04 (m, 1H; CH), 7.09 (ddd, ^3J(H,H) = 6, 8 Hz, ^4J(H,H) = 2 Hz, 1H; CH), 7.15–7.22 (m, 1H; CH), 8.23 (d, ^3J(H,H) = 6 Hz, 1H; CH); ^{13}C NMR (63 MHz): δ = 26.0, 26.4, 26.5, 29.5, 29.8, 31.4, 33.0, 41.8, 50.0, 115.7, 119.9, 121.8, 125.5, 137.6, 139.1, 152.8; IR (KBr): $\tilde{\nu}$ = 2924, 1637, 1586, 1410, 1251 cm^{-1}; MS (70 eV, EI), *m/z* (%): 260 (25) [M^+ – OH], 128 (71) [$C_5H_6NOS^+$], 127 (100) [$C_5H_5NOS^+$]; $C_{16}H_{23}NOS$ (277.4): calcd C 69.27, H 8.36, N 5.05, S 11.56; found: C 69.33, H 8.21, N 5.18, S 11.47.

***S*-(4-Phenylpent-4-en-1-yl)-2-thiopyridine *N*-oxide (7f)**: Yield: 0.43 g (30%), colorless crystals, m.p. 75–76 °C; ^{1}H NMR (250 MHz): δ = 1.89 (quint, ^3J(H,H) = 7 Hz, 2H; CH_2), 2.73 (t, ^3J(H,H) = 7 Hz, 2H; CH_2), 2.85 (t, ^3J(H,H) = 7 Hz, 1H; CH_2), 5.12 (brs, 1H; CH_2), 5.33 (brs, 1H; CH_2), 6.88 (dd, ^3J(H,H) = 8, ^4J(H,H) = 1 Hz, 1H; CH), 6.97 (td, ^3J(H,H) = 7 Hz, ^4J(H,H) = 1 Hz, 1H; CH), 7.09 (td, ^3J(H,H) = 8 Hz, ^4J(H,H) = 1 Hz, 1H; CH), 7.24–7.42 (m, 5H; C_6H_5), 8.20 (d, ^3J(H,H) = 6 Hz, 1H; CH); ^{13}C NMR (63 MHz): δ = 26.2, 29.5, 34.3, 113.7, 120.1, 121.1, 125.6, 126.2, 127.7, 128.5, 138.8, 140.3, 146.8, 152.4; IR (KBr): $\tilde{\nu}$ = 2935, 1623, 1571, 1414, 1255 cm^{-1}; MS (70 eV, EI), *m/z* (%): 271 (3) [M^+], 254 (23) [M^+ – OH], 127 (100) [$C_5H_5NOS^+$]; $C_{16}H_{17}NOS$ (271.4): calcd C 70.82, H 6.31, N 5.90, S 11.81; found: C 70.64, H 6.32, N 5.63, S 11.73.

***S*-(1-Phenylethyl)-2-thiopyridine *N*-oxide (7h)** [33]: Yield: 0.17 g (14%), colorless crystals, m.p. 118-119 °C; ^{1}H NMR (250 MHz): δ = 1.64 (d, ^3J(H,H) = 7 Hz, 3H; CH_3), 4.43 (q, ^3J(H,H) = 7 Hz, 1H; CH), 6.83–6.92 (m, 1H; CH), 6.93–7.06 (m, 2H; CH), 7.12–7.30 (m, 3H; CH), 7.47 (m_c, 2H; CH), 8.19 (dt, ^3J(H,H) = 6 Hz, ^4J(H,H) = 1 Hz, 1H; CH); ^{13}C NMR (63 MHz): δ = 23.4, 44.0, 120.7, 123.2, 125.4, 127.0, 127.7, 128.9, 138.8, 142.1, 151.3; IR (KBr): $\tilde{\nu}$ = 2972, 1588, 1472, 1425, 1250 cm^{-1}; MS (70 eV, EI), *m/z* (%): 231 (9) [M^+], 214 (42) [M^+ – OH], 127 (43) [$C_5H_5NOS^+$], 105 (100) [$C_8H_9^+$]; $C_{13}H_{13}NOS$ (231.3): calcd C 67.50, H 5.66, N 6.06, S 13.86; found: C 67.36, H 5.83, N 6.03, S 13.42.

2.1. Photolysis of thiohydroxamic acid ester 6 in C_6D_6/NpSH: In a typical run the ester **6** (0.10 mmol) and NpSH (19.2 mg, 0.12 mmol) were dissolved in C_6D_6 (1.0 mL) in a small Schlenk flask (standard glassware). The reaction vessel was closed with a rubber septum, wrapped in aluminum foil, and frozen to liquid-nitrogen temperature. After thorough evacuation the flask was flushed with argon, thermostated in a water bath at T = 15 °C, and photolyzed with incandescent light (Philips 150 W Spotline® R 80) for 5 min. The yellow reaction mixture was transferred into an NMR tube.

2.2. Photolysis of thiohydroxamic acid ester 6 in C_6H_6 or TBB with Bu_3SnH: In a typical run the ester **6** (0.10 mmol) was dissolved in C_6H_6 or TBB (2.0 mL) in a small Schlenk flask. A standard amount of olefin free *n*-tetradecane (Fluka, standard for GC) was added and the reaction vessel was closed with a rubber septum, wrapped in aluminum foil, and frozen to liquid-nitrogen temperature. After thorough evacuation the flask was flushed with argon and thermostated in a water bath at T = 30 °C. Addition of tri-*n*-butylstannane (0.1 mL, 0.11 g, 0.37 mmol) under argon to the reaction mixture was followed by photolysis of the reaction mixture with incandescent light (Philips 150 W Spotline® R 80) for 1 min. The decolorized solution was immediately subjected to GC analysis.

3-Phenyltetrahydropyran (13f) [8b]: ^{1}H NMR (400 MHz): δ = 1.35–1.71 (m, 3H; CH_2), 1.82–1.92 (m, 1H; CH_2), 2.82 (tt, ^3J(H,H) = 4, 11 Hz, 1H; CH), 3.31 (td, ^3J(H,H) = 3, 11 Hz, 1H; CH_2) 3.47 (t, ^3J(H,H) = 11 Hz, 1H; CH_2), 3.97 (dquint, ^3J(H,H) = 2, 11 Hz, 1H; CH_2), 4.12 (ddd, ^3J(H,H) = 2, 4, 11 Hz, 1H; CH_2), 6.96–7.21 (m, 5H; C_6H_5).

3-Deuterio-3-phenyltetrahydropyran (15): Yield 71.2 mg (82%), b.p.$_{15}$ 100 °C (Kugelrohr); colorless liquid; ^{1}H NMR (250 MHz): δ = 1.25–1.32 (m, 1H; CH_2), 1.36–1.63 (m, 2H; CH_2), 1.71–1.78 (m, 1H; CH_2), 3.15 (td, ^3J(H,H) = 3, 11 Hz, 1H; CH_2), 3.24 (dt, ^3J(H,H) = 2, 10 Hz, 1H; CH_2) 3.86 (dquint, ^3J(H,H) = 2, 11 Hz, 1H; CH_2), 3.99 (dd, ^3J(H,H) = 2, 11 Hz, 1H; CH_2), 6.95–7.19 (m, 5H; C_6H_5); ^{13}C NMR (63 MHz): δ = 26.3, 30.3, 42.6 [^2J(D,^{13}C) = 19 Hz], 68.2, 73.8, 126.7, 127.4, 128.6, 142.7; MS (70 eV, EI): *m/z* (%): 163 (27) [M^+], 119 (23) [$M^+ - C_3H_8$], 105 (100) [$M^+ - C_5H_{10}$]; $C_{11}H_{13}DO$ (163.2): calcd C 80.94, H 9.26; found C 81.07, H 8.98.

3. Competition kinetics: A Schlenk flask (standard glassware) was charged with the ester **6** (1.0 mL of a 0.02 M solution in TBB) in the dark. The flask was closed with a rubber septum, wrapped in aluminum foil, and frozen to liquid-nitrogen temperature. After thorough evacuation the reactor was flushed with argon and thermostated in a water bath at $T = 30 \pm 0.2$ °C. After 15 min tri-*n*-butylstannane (0.20–0.80 mL, 1.3 M in TBB or 0.20–1.00 mL of neat Bu_3SnH), which had been thermostated in the same water bath at $T = 30 \pm 0.2$ °C, was added. The aluminum foil was removed 10 min later, and the yellow reaction mixture photolyzed for 1 min with incandescent light (Philips 150 W Spotline® R 80). The decolorized solution was immediately subjected to GC analysis. Five data points composed of three single runs each were recorded for each radical precursor **6**.

4. *cis*- and *trans*-2-Bromomethyl-5-phenyltetrahydrofuran (11): $BrCCl_3$ (1.5 mL, 3.02 g, 15.2 mmol) was added to a solution of thiohydroxamic acid ester **6a** (0.50 g, 1.84 mmol) in benzene (10 mL), and treated as described in Section 2.1 without addition of NpSH. The reaction mixture was purified by column chromatography [SiO_2, hexanes/diethyl ether, 9/1 (v/v)] to afford the bromide **11** (0.34 g, 67%, *cis*:*trans* = 50:50) as a colorless liquid. The *cis*-bromide **11** eluted faster than the *trans* isomer; samples containing the *cis* isomer in 80% excess were thus prepared for the mechanistic studies. $C_{11}H_{13}BrO$ (241.1): calcd C 54.79, H 5.43; found C 54.54, H 5.45; MS (70 eV, EI): *m/z* (%): 242, 240 (50, 53) [M^+], 147 (100) [$M^+ - CH_2Br$], 105 (99) [$C_7H_5O^+$].

cis-**11**: ^{1}H NMR (250 MHz): δ = 1.86–2.01 (m, 2H; CH_2), 2.17–2.35 (m, 2H; CH_2), 3.50 (dd, ^3J(H,H) = 6, 10 Hz, 1H; CH_2), 3.58 (dd, ^3J(H,H) = 5, 10 Hz, 1H; CH_2), 4.35 (m_c, 1H; CH), 4.96 (dd, ^3J(H,H) = 6, 8 Hz, 1H; CH), 7.27–7.41 (m, 5H; C_6H_5); ^{13}C NMR (63 MHz): δ = 30.5, 35.8, 41.4, 78.6, 82.1, 125.8, 127.5, 128.4, 142.3.

trans-**11**: ^{1}H NMR (250 MHz): δ = 1.86–2.01 (m, 2H; CH_2), 2.17–2.35 (m, 1H; CH_2), 2.38–2.56 (m, 1H; CH_2), 3.46 (dd, ^3J(H,H) = 7, 10 Hz, 1H; CH_2), 3.55 (dd, ^3J(H,H) = 4, 10 Hz, 1H; CH_2), 4.49 (m_c, 1H; CH), 5.10 (dd, ^3J(H,H) = 6, 8 Hz, 1H; CH), 7.27–7.41 (m, 5H; C_6H_5); ^{13}C NMR (63 MHz): δ = 31.2, 35.2, 36.1, 78.8, 81.6, 125.6, 127.4, 128.4, 142.7.

5. *cis*- and *trans*-5-Phenyl-2-tetrahydrofurylmethyl 2′-pyridyl sulfide (8): A solution of ester **6a** (101.53 mg, 0.37 mmol) in anhydrous benzene (6 mL) was treated as described in Section 2.1, except that no radical trap was added. The reaction mixture was purified by preparative thin-layer chromatography [hexane/ethyl acetate, 3/1, (v/v)] to afford the thioether **8** (70.55 mg, 70%, *cis*:*trans* = 50:50). $C_{16}H_{17}NOS$ (271.4): calcd C 70.82, H 6.31, N 5.16, S 11.81; found C 70.69, H 6.40, N 5.13, S 11.62; MS (70 eV, EI): *m/z* (%): 120 (29) [$C_8H_{10}O^+$], 105 (100) [$C_7H_7O^+$].

cis-**8**: ^{1}H NMR (250 MHz): δ = 1.88–2.06 (m, 2H; CH_2), 2.17–2.5 (m, 2H; CH_2), 3.46–3.70 (m, 2H; CH_2), 4.46 (quint, ^3J(H,H) = 6 Hz, 1H; CH), 5.00 (t, ^3J(H,H) = 7 Hz, 1H; CH), 7.05 (ddd, ^3J(H,H) = 5, 7 Hz, ^4J(H,H) = 2 Hz, 1H; CH), 7.28–7.48 (m, 6H; CH), 7.54 (ddd, ^3J(H,H) = 8, 10 Hz, ^4J(H,H) = 2 Hz, 1H; CH), 8.51 (ddd, ^3J(H,H) = 5 Hz, ^4J(H,H) = 1, 2 Hz, 1H; CH); ^{13}C NMR (63 MHz): δ = 31.0, 34.8, 54.1, 78.8, 81.2, 119.7, 122.6, 125.9, 127.5, 143.4, 149.6, 158.9.

trans-**8**: ^{1}H NMR (250 MHz): δ = 1.88–2.06 (m, 2H; CH_2), 2.17–2.5 (m, 2H; CH_2), 3.46–3.70 (m, 2H; CH_2), 4.62 (quint, ^3J(H,H) = 6 Hz, 1H; CH), 5.17 (dd, ^3J(H,H) = 7, 8 Hz, 1H; CH), 7.05 (ddd, ^3J(H,H) = 5, 7 Hz, ^4J(H,H) = 2 Hz, 1H; CH), 7.28–7.48 (m, 6H; CH), 7.54 (ddd, ^3J(H,H) = 8, 10 Hz, ^4J(H,H) = 2 Hz, 1H; CH), 8.51 (ddd, ^3J(H,H) = 5 Hz, ^4J(H,H) = 1, 2 Hz, 1H; CH); ^{13}C NMR (63 MHz): δ = 32.0, 35.5, 54.1, 78.9, 81.8, 119.7, 122.6, 126.2, 127.5, 128.5, 143.6, 149.6, 158.9.

***cis*- and *trans*-5-(2-Propyl)-2-tetrahydrofurylmethyl 2′-pyridyl sulfide (10)**: *N*-[(2-Methylhept-6-enyl)-3-oxy]pyridine-2(1*H*)-thione (**9**) [6] (87.82 mg, 0.37 mmol) was isomerized as described in Section 5 to afford thioether **10** (71.14 mg, 81%, *cis*:*trans* = 30:70). $C_{13}H_{19}NOS$ (271.4): calcd C 65.78, H 8.07, N 5.90, S 13.51; found C 65.87, H 8.05, N 5.61, S 13.28; MS (70 eV, EI): *m/z* (%): 194 (12) [$M^+ - C_3H_7$], 95 (100).

cis-**10**: ^{1}H NMR (250 MHz): δ = 0.82 (d, ^3J(H,H) = 7 Hz, 3H; CH_3), 0.89 (d, ^3J(H,H) = 7 Hz, 3H;CH_3), 1.45–1.72 (m, 3H; CH_2), 1.84–2.02 (m, 2H; CH_2), 3.26 (dd, ^3J(H,H) = 6, 13 Hz, 1H; CH_2), 3.34 (dd, ^3J(H,H) = 6, 13 Hz, 1H; CH_2), 3.52 (q, ^3J(H,H) = 8 Hz, 1H; CH), 4.11 (quint, ^3J(H,H) = 6 Hz, 1H; CH), 6.86–6.91 (m, 1H; CH), 7.10–7.15 (m, 1H; CH), 7.35–7.42 (m, 1H; CH), 8.33 (ddd, ^3J(H,H) = 5 Hz, ^4J(H,H) = 1, 2 Hz, 1H; CH); ^{13}C NMR (63 MHz): δ = 17.3, 18.3, 27.2, 29.6, 32.1, 33.9, 75.5, 84.5, 118.3, 121.2, 134.8, 148.3, 157.9.

trans-**10**: ^{1}H NMR (250 MHz): δ = 0.74 (d, ^3J(H,H) = 7 Hz, 3H; CH_3), 0.84 (d, ^3J(H,H) = 7 Hz, 3H; CH_3), 1.45–1.72 (m, 3H; CH_2), 1.84–2.02 (m, 2H; CH_2), 3.24 (dd, ^3J(H,H) = 6, 13 Hz, 1H; CH_2), 3.37 (dd, ^3J(H,H) = 6, 13 Hz, 1H; CH_2), 3.63 (m_c, 1H; CH), 4.18 (quint, ^3J(H,H) = 6 Hz, 1H; CH), 6.86–6.91 (m, 1H; CH), 7.10–7.15 (m, 1H; CH), 7.35–7.42 (m, 1H; CH), 8.33 (ddd, ^3J(H,H) = 5 Hz, ^4J(H,H) = 1, 2 Hz, 1H; CH); ^{13}C NMR (63 MHz): δ = 17.2, 18.3, 28.7, 30.5, 32.1, 33.9, 76.7, 83.8, 118.3, 121.2, 134.8, 148.3, 157.9.

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[19] A 1.8 M solution (2.5 equiv) of Bu_3SnH was found to be optimum for the synthesis of cyclic ethers **13** and **14**. A decrease of the tin hydride concentration below 0.07 M gave rise to detectable amounts (GC) of 1-phenylpent-4-en-1-one. Control experiments indicated that the 5-*exo*–*trig* reaction of the 1-phenylpent-4-enyl-1-oxy radical (**2a**) is irreversible under the chosen reaction conditions. The reduction of 2-bromomethyl-5-phenyltetrahydrofuran (*cis*:*trans* = 90:10) in refluxing benzene (three individual runs) by tri-*n*-butyltin hydride (c_o = 1.8 M, 1.2 equiv) with AiBN as initiator yielded the product **14a** in (96 ± 1)% yield (*cis*:*trans* = 89:11). In the same manner **14a** (*cis*:*trans* = 30:70) was obtained from 2-iodomethyl-5-phenyltetrahydrofuran

in quantitative yield (three individual runs). Each of the probes investigated showed no signals of the alcohol **4a** in the gas chromatogram of the crude reaction mixture, thus ruling out a radical-induced ether cleavage **3a** → **2a** under the chosen reaction conditions.

[20] It was assumed that the reactive hydrogen donors delivered their hydrogen with equivalent rate constants to all intermediate carbon radicals. Therefore the analyzed product ratios should immediately reflect the stereo- and the regioselectivities of the alkoxy radicals **2** in ring closure reactions. The rate constant k^H of hydrogen abstraction of alkoxy radicals from Bu_3SnH was shown to be independent of the nature of the alkyl subsituent. k^H was measured for the *tert*-butoxy radical by J. A. Lusztyk [$k^H = (5 \pm 2) \times 10^8$ L mol^{-1} s^{-1} at $T = 30$ °C (unpublished results cited in A. L. J. Beckwith, B. P. Hay, G. M. Williams, *J. Chem. Soc. Chem. Commun.* **1989**, 1202–1203)]. NpSH reacts 1.4 times faster ($T = 30$ °C) than Bu_3SnH with the pent-4-enyl-1-oxy radical (**2**) to afford pent-4-en-1-ol (**4**) [6].

[21] The relative rate constants k^{rel} were calculated from the rate constant k^{ref} of the reference radical **2** and the values k_{cis} and k_{trans} of the reactions **2a** → *cis*-**3a** and **2a** → *trans*-**3a** [Eq. (1)]. The individual rate constants for each series were

$$\frac{[4]}{[14]} = \frac{k^H}{k^{ref}}[Bu_3SnH] \quad (1)$$

calculated from the slope of a linear correlation of a series of experiments (5 data points consisting of 3 individual experiments) at different Bu_3SnH concentrations. The corresponding ratios of pentenol **4** and substituted tetrahydrofuran **14** were monitored by GC. The equation is derived from a kinetic model which is based on an irreversible rearrangement **2** → **3** [19]. k^{exo} refers to the rate constant of the 5-*exo*-*trig* rearrangement [(**4**)]:[(**14**)] = $(1.37 \pm 0.06)[Bu_3SnH] - 0.02$ ($R2 = 0.999$) for the parent pent-4-en-1-yl-oxy radical (**2**) ($T = 30$ °C). The k^{rel} values in Table 2 are based on the assumption that Bu_3SnH delivers its reactive hydrogen atom to all alkoxy radicals **2** with the same rate constant k^H [Eq. (2)].

$$k^{rel} = \frac{k_X^X}{k_X^H} \Big/ \frac{k_{ref}^{ref}}{k_{ref}^H} = \frac{k^X}{k^{ref}} \frac{k_{ref}^H}{k_X^H} = \frac{k^X}{k^{ref}} \quad (2)$$

[22] The driving force of the rearrangements **6a,h** → **7a,h** obviously is the formation of the heteroaromatic pyridine *N*-oxides **7a,h** from the cross-conjugated cyclic olefins **6a,h**.

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