A Novel Approach for the Formation of Carbon−Nitrogen Bonds: Azidation of Alkyl Radicals with Sulfonyl Azides

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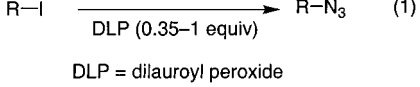
Abstract: Two preparatively attractive methods for the azidation of alkyl radicals are described. Secondary and tertiary alkyl iodides and dithiocarbonates are easily converted into the corresponding azides, either by reaction with ethanesulfonyl azide in the presence of dilauroyl peroxide, or by treatment with benzenesulfonyl azide and hexabutylditin in the presence of a radical initiator. Interestingly, intramolecular tandem radical cyclization−azidation processes can be performed in high yields.

Introduction

Owing to their compatibility with a large number of functional groups and their high potential to perform sequential transformation under mild conditions, the use of free radical reactions in multistep synthesis has steadily increased during these last years. The majority of the work concerns the formation of carbon−carbon and carbon−hydrogen bonds. The formation of carbon−heteroatom bonds from carbon-centered radicals is also well-documented when the heteroatom is sulfur, halogen, and oxygen.[1] On the other hand, radical aminations are far less explored despite their importance for the preparation of biologically active compounds.[2] Since azides are very versatile precursors of amines, we decided to develop an azidation procedure based on the observation that traces of alkyl azides were built during Curtius-type rearrangements of sulfonyl azides. Their formation was rationalized from the reaction of alkyl radicals with sulfonyl azides.[3] We report here two efficient and practical approaches for the azidation of alkyl radicals using sulfonyl azides as radical traps.[4]

Results and Discussion

Tin Free Radical Azidation with Ethanesulfonyl Azide. Recently, Zard,[5] Fuchs,[6] and Kim[7] have reported the formation of carbon−carbon bonds involving the fragmentation of ethane-, methane- and trifluoromethanesulfonyl radicals as the key step. These procedures are either based on iodine and xanthate transfers from ethyl and methyl radicals or hydrogen atom transfers from trifluoromethyl radicals. On the basis of similar concepts, we envisaged to develop an intermolecular radical azidation process of iodides and dithiocarbonates using ethanesulfonyl azide as reagent (Scheme 1, eq 1). Ethanesulfonyl azide,



easily prepared from ethanesulfonyl chloride and sodium azide, is a stable liquid that can be heated at 100 °C without decomposition. However, since sulfonyl azides are capable of exploding, it is strongly recommended to apply standard safety rules and to use a safety shield. The crucial step of this process is the addition of the alkyl radical in the α or γ position of the azido moiety to give a 1,3- and/or a 3,3-triazenyl radical (Scheme 1).[8,9] These radical intermediates should fragment to liberate the corresponding alkyl azide and the ethanesulfonyl radical. After sulfur dioxide extrusion, the ethyl radical can propagate the chain by an atom or group transfer process. The initiation step is a crucial point for the success of the reaction.

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(1) For a general review on radical reactions, see: *Radicals in Organic Synthesis*; Renaud P., Sibi M., Eds; Wiley-VCH: Weinheim, 2001. Giese, B. *Radicals in Organic Synthesis: Formation of Carbon−Carbon Bonds*; Pergamon: Oxford, 1988. Curran, D. P. In *Comprehensive Organic Synthesis*; Trost, B. M., Fleming I., Eds; Pergamon: Oxford, 1991; Vol. 4, p 715. Motherwell, W. B.; Crich, D. *Free Radical Chain Reactions in Organic Synthesis*; Academic Press: London, 1992. Fossey, J.; Lefort, D.; Sorba, J. *Free Radicals in Organic Synthesis*; Wiley: Chichester, 1995. Chatgilialoglu, C.; Renaud, P. In *General Aspects of the Chemistry of Radicals*; Alfassi, Z. B., Ed.; Wiley: Chichester, 1999; p 501.

(2) For early examples of intermolecular radical aminations, see: Patel, V. F.; Pattenden, G. *Tetrahedron Lett.* **1987**, *28*, 1451. Ghosez, A.; Göbel, T.; Giese, B. *Chem. Ber.* **1988**, *121*, 1807. Veit, A.; Giese, B. *Synlett* **1990**, 166. Barton, D. H. R.; Jaszberenyi, J. Cs.; Theodorakis, E. A.; Reibenspies, J. H. *J. Am. Chem. Soc.* **1993**, *115*, 8050. For an exhaustive review, see: Ollivier, C.; Renaud, P. In *Radicals in Organic Synthesis*; Renaud, P., Sibi, M. P., Eds; Wiley-VCH: Weinheim, 2001; Vol. 2, p 93.

(3) Abramovitch, R. A.; Holcomb, W. D. *Chem. Commun.* **1969**, 1298. Breslow, D. S.; Martin, F. S.; Newburg, N. R.; Renfrow, W. B. *J. Am. Chem. Soc.* **1969**, *91*, 2273.

(4) For a preliminary communication, see: Ollivier, C.; Renaud, P. *J. Am. Chem. Soc.* **2000**, *122*, 6496.

(5) The use of allyl and alkenyl ethyl sulfones for tin free radical allylation and alkenylation has been recently reported: Le Guyader, F.; Quiclet-Sire, B.; Seguin, S.; Zard, S. Z. *J. Am. Chem. Soc.* **1997**, *119*, 7410. Quiclet-Sire, B.; Seguin, S; Zard, S. Z. *Angew. Chem., Int. Ed.* **1998**, *37*, 2864. Bertrand, F.; Quiclet-Sire, B.; Zard, S. Z. *Angew. Chem., Int. Ed.* **1999**, *38*, 1943.

(6) Gong, J.; Fuchs, P. L. *J. Am. Chem. Soc.* **1996**, *118*, 4486. Xiang, J.; Fuchs, P. L. *J. Am. Chem. Soc.* **1996**, *118*, 11986. Xiang, J.; Jiang, W.; Fuchs, P. L. *Tetrahedron Lett.* **1997**, 38, 6635. Xiang, J.; Jiang, W.; Gong, J.; Fuchs, P. L. *J. Am. Chem. Soc.* **1997**, *119*, 4123. Xiang, J.; Evarts, J.; Rivkin, A.; Curran, D. P.; Fuchs, P. L. *Tetrahedron Lett.* **1998**, *39*, 4163.

(7) Kim, S.; Yoon, J.-Y. *J. Am. Chem. Soc.* **1997**, *119*, 5982. Kim, S.; Kim, N.; Yoon, J.-Y.; Oh, D. H. *Synlett* **2000**, 1148.

(8) For a mechanistic investigation of the radical addition to sulfonyl azides, see: Dang, H.-S.; Roberts, B. P. *J. Chem. Soc., Perkin Trans. 1* **1996**, 1493.

(9) Intramolecular additions to alkyl azides: Kim, S.; Joe, G. H.; Do, J. Y. *J. Am. Chem. Soc.* **1994**, *116*, 5521. Kizil, M.; Murphy, J. A. *J. Chem. Soc., Chem. Commun.* **1995**, 1409.

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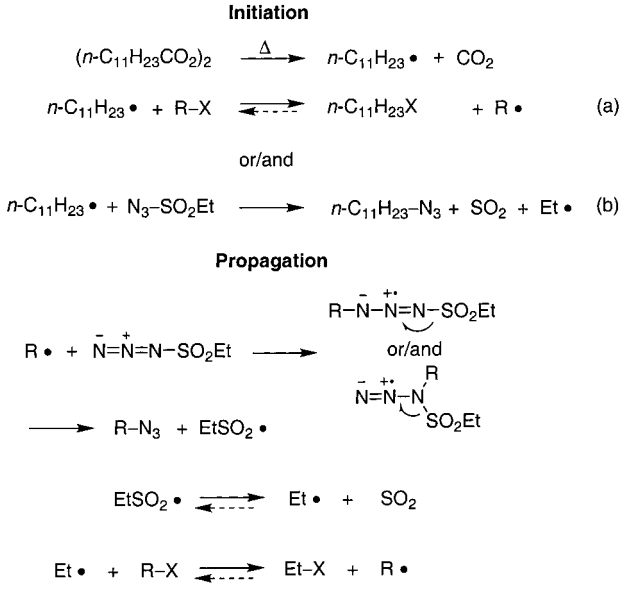
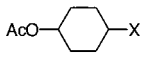
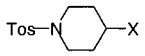
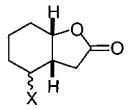
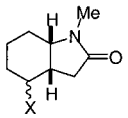
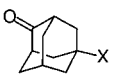
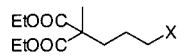
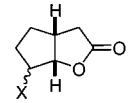
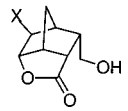
Scheme 1. Radical Azidation with Ethanesulfonyl Azide



Early studies using cyclohexyl iodide with AIBN failed to give the desired azidation products, presumably due to the stability (no iodine atom transfer with cyclohexyl iodide) and the lack of nucleophilicity (no reaction with ethanesulfonyl azide) of the 2-cyanoprop-2-yl radical generated from AIBN. Therefore, an initiator that gives nucleophilic radicals such as dilauroyl peroxide (DLP), which has been used with much success by Zard in reactions involving iodides and dithiocarbonates[10] and more recently by us for iodine atom transfers,[11] is a perfect candidate to perform such transformations. The undecyl radical delivered by DLP is expected to react with the radical precursor to initiate the chain reaction (Scheme 1, pathway a). Reaction of the undecyl radical with ethanesulfonyl azide is also possible (Scheme 1, pathway b). Small amounts of undecyl azide were isolated at several occasions confirming this hypothesis.

Reaction of alkyl iodides with ethanesulfonyl azide and DLP affords the corresponding alkyl azides (eq 1, Table 1). The azidation of cyclic secondary iodides (**1** and **3)** was carried out with 3 equiv of ethanesulfonyl azide and a substoichiometric amount of DLP in a refluxing mixture of chlorobenzene and heptane (method A, entries 1 and 2). In most cases, a high level of conversion was observed with less than 0.5 equiv of DLP. However, the use of 0.6−1.0 equiv of DLP is sometimes necessary to reach a complete conversion. Sterically more hindered secondary cyclic iodides such as **5** and **7** are efficiently converted into azides by treatment with 5 equiv of ethanesulfonyl azide in chlorobenzene at 100 °C (method B, entries 3 and 4). For these substrates and for the iodolactones **13** and **15**, the use of heptane as cosolvent is not judicious because it favors the formation of reduction products. With tertiary iodides, a rapid and total conversion of **9** was reached by using only 0.35 equiv of initiator (method A, entry 5) and led to the tertiary azide **10** in high yield (87% yield according to ^{1}H NMR, 77% isolated yield). The primary alkyl iodide **11** was converted into the azide **12** in only 24% yield (method B, entry 6). The inefficiency of this reaction is caused by the nearly thermoneutral iodine atom transfer between the ethyl radical and the primary alkyl iodide as well as by the lower nucleophilicity of primary alkyl radicals relative to secondary and tertiary ones. Iodides resulting from iodolactonization processes represent interesting synthetic intermediates and perfect candidates for the azidation process. Under optimized conditions, the iodolactones **13** and **15** gave the azides **14** and **16** in 60% and 56% yield, respectively. For these two substrates, the presence of β-acyloxy groups reduces the nucleophilic character of the intermediate radicals and as a consequence makes the reaction with the ethanesulfonyl azide less efficient.[12] For the substrate

Table 1. Radical Azidation of Alkyl Iodides According to Eq 1

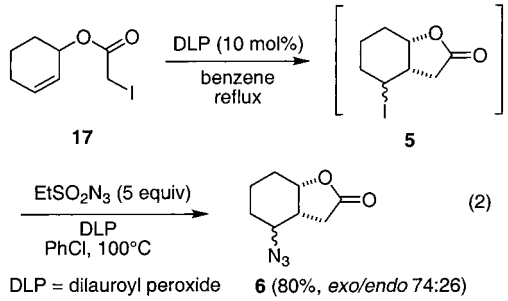
Entry	R–I/ R–N_3	Method[a]	Yield [%]
1	 **1**: X = I (*cis*/*trans* 59:41) **2**: X = N_3 (*cis*/*trans* 54:46)	A	84
2	 **3**: X = I **4**: X = N_3	A	81
3	 **5**: X = I (*exo*) **6**: X = N_3 (*exo*/*endo* 74:26)	B	80
4	 **7**: X = I (*exo*) **8**: X = N_3 (*exo*/*endo* 80:20)	B	77
5	 **9**: X = I **10**: X = N_3	A	77 (87)[b]
6	 **11**: X = I **12**: X = N_3	B	24
7	 **13**: X = I **14**: X = N_3 (*exo*/*endo* 84:16)	B	60
8	 **15**: X = I (*exo*) **16**: X = N_3 (*exo*)	B	56

[a] Method A: $EtSO_2N_3$ (3 equiv) in refluxing chlorobenzene/heptane (1:1), DLP (0.35−1 equiv) as initiator. Method B: $EtSO_2N_3$ (5 equiv) in chlorobenzene at 100 °C, DLP (0.35−1 equiv) as initiator. [b] Yield according to ^{1}H NMR.

(10) Zard, S. Z. *Angew. Chem. Int. Ed.* **1997**, *36*, 672.
(11) Ollivier, C.; Bark, T.; Renaud, P. *Synthesis* **2000**, 1598.

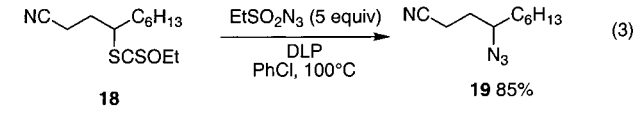
15, it is of interest to mention that the classical ionic substitution reaction with sodium azide failed to give the corresponding azide. Indeed, after 8 h in DMF at 70 °C, no trace of the azide **16** was detected and only partial recovery (69%) of the starting material was possible.

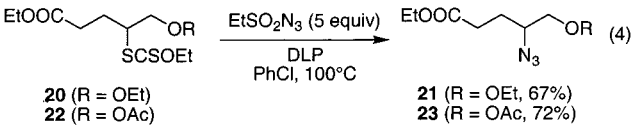
As we have shown recently, carbon−carbon bond formation under iodine atom-transfer conditions can be efficiently promoted by a substoichiometric amount of dilauroyl peroxide.[11] As a consequence, sequential reactions involving a radical cyclization followed by an azidation process should be feasible. The allylic iodoacetate **17** gave upon treatment with DLP (10% mol) in benzene under dilute conditions the bicyclic iodide **5**. Without isolation, the crude iodide **5** was immediately treated with 5 equivs of ethanesulfonyl azide in chlorobenzene at 100 °C and the desired bicyclic secondary azide **6** was isolated in 80% yield from **17** as a 74:26 mixture of two diastereoisomers (eq 2).

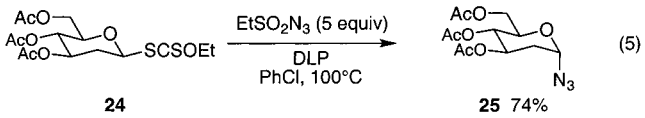


As reported by Zard,[10] dithiocarbonates are also suitable precursors for radical group transfer reactions. Therefore, we expected them to be also suitable substrates for the azidation process. This hypothesis was tested first with the dithiocarbonate **18**, prepared by radical addition of *S*-(cyanomethyl) *O*-ethyl carbonodithioate to 1-octene.[12] Treatment of **18** with ethanesulfonyl azide under classical conditions affords the azide **19** in 85% isolated yield (eq 3). Other dithiocarbonates such as **20** and **22** react with ethanesulfonyl azide to give **21** and **23** in 67% and 72% yield, respectively (eq 4). In a similar way, the anomeric dithiocarbonate **24**, easily obtained by the nucleophilic substitution of α-bromo-2-desoxyglucose derivative with the commercially available potassium *O*-ethyl xanthate,[12] gives the anomeric azide **25** as a single α-anomer in 74% yield (eq 5).[13] Interestingly, the preparation of such α-anomeric azides is much more difficult than that of the *β*-isomers when classical nucleophilic substitution approaches are employed.[14] Moreover, such anomeric azides are useful intermediates for the preparation of biologically important *N*-linked glycoconjugates.

This first approach for the azidation of carbon-centered radicals is complementary to the well-established electrophilic and nucleophilic azidation procedures. Secondary and tertiary iodides and dithiocarbonates are easily converted to the corresponding azides under tin free conditions. However, we notice that the purification of the final azides may be problematic when they are apolar. Indeed, they are contaminated with other apolar

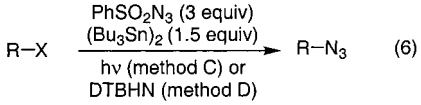






side products derived from DLP such as undecyl azide. Long reaction times (≥12 h) are often necessary for completion of the azidation. This is due to the relative inefficiency of the chain process. Finally, different attempts to achieve cascade reactions involving radical cyclization and azidation processes in a one-pot procedure failed. Therefore, we decided to look for an alternative azidation procedure that could solve some of these drawbacks.

Ditin-Mediated Radical Azidation with Benzenesulfonyl Azide. The reaction of ditin derivatives with sulfonyl radicals affords stannyl radicals that could ideally sustain a chain reaction.[15] This reaction is far more promising that the common use of tin hydride,[16] allylstannane,[17] silanes,[18] or Barton thiohydroxamic esters[19] to sustain a chain reaction. Indeed, ditin derivatives are inert toward alkyl radicals and no competing reaction such as the direct reduction of the intermediate alkyl radical is expected. Therefore, we decided to replace ethanesulfonyl azide by benzenesulfonyl azide and to use hexabutylditin as chain transfer reagent. Because of the instability of the phenyl radical, the intermediate benzenesulfonyl radical does not lose SO_2. The proposed chain reaction is described in Scheme 2 (eq 6). The initiation of this process is critical: when



alkyl iodides are used as radical precursors, the reaction can be initiated by irradiation with a 300 W sun lamp (method C). However, thermal initiation (80 °C) with di-*tert*-butylhypo-

(12) The 2-alkoxy (or *β*-alkoxy) effect is well-known in radical reactions. Indeed, the nucleophilicity of alkyl radicals is altered by the presence of a vicinal alkoxy substituent. Quiclet-Sire, B.; Zard, S. Z. *J. Am. Chem. Soc.* **1996**, *118*, 9190 and references cited therein. As suggested by a referee, the *β*-oxygen effect retards reactions when the alkyl radical acquires a δ^+ charge at the transition state. This is clearly the case for the radical azidation with sulfonyl azides.

(13) The stereochemistry is in accordance with related radical reactions involving anomeric radicals: Giese, B.; Dupuis, J. *Angew. Chem., Int. Ed.* **1983**, *22*, 622.

(14) Soli, E. D.; DeShong, P. *J. Org. Chem.* **1999**, *64*, 9724 and references cited therein.

(15) Radical allylation of alkyl halides with allyl sulfones in the presence of a ditin derivatives: Keck, G. E.; Tafesh, A. M. *J. Org. Chem.* **1989**, *54*, 5845. Ward, D. E.; Gai, Y.; Kaller, B. F. *J. Org. Chem.* **1995**, *60*, 7830. Pontén, F.; Magnusson, G. *J. Org. Chem.* **1996**, *61*, 7463. For free radical acylations with benzenesulfonyl oxime ethers and nitroalkylations with benzenesulfonyl silyl nitronates, see: Kim, S.; Lee, I. Y.; Yoon, J.-Y.; Oh, D. H. *J. Am. Chem. Soc.* **1996**, *118*, 5138. Kim, S.; Yoon, J.-Y.; Lee I. Y. *Synlett* **1997**, 475. Jeon, G.-H.; Yoon, J.-Y.; Kim, S.; Kim, S. S. *Synlett* **2000**, 128. Kim, S.; Yoon, J.-Y.; Lim, C. J. *Synlett* **2000**, 1151.

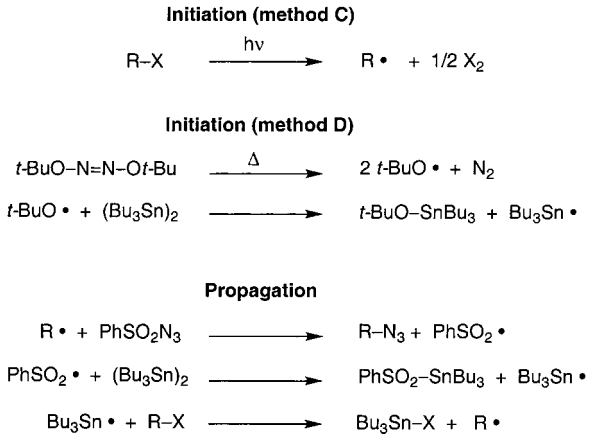
(16) Padwa, A.; Kline, D. N.; Murphree, S. S.; Yeske, P. E. *J. Org. Chem.* **1992**, *57*, 298. Ward, D. E.; Gai, Y.; Kaller, B. F. *J. Org. Chem.* **1995**, *60*, 7830.

(17) Ryu, I.; Kuriyama, H.; Minakata, S.; Komatsu, M.; Yoon, J.-Y.; Kim, S. *J. Am. Chem. Soc.* **1999**, *121*, 12190.

(18) Chatgilialoglu, C.; Alberti, A.; Ballestri, M.; Macciantelli, D.; Curran, D. P. *Tetrahedron Lett.* **1996**, *37*, 6391.

(19) (a) Barton, D. H. R.; Crich, D. *J. Chem. Soc., Perkin Trans. 1* **1986**, 1613. (b) Padwa, A.; Murphree, S. S.; Yeske, P. E. *Tetrahedron Lett.* **1990**, *31*, 2983. (c) Padwa, A.; Kline, D. N.; Murphree, S. S.; Yeske, P. E. *J. Org. Chem.* **1992**, *57*, 298.

Scheme 2. Radical Azidation with Benzenesulfonyl Azide

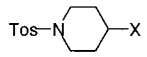
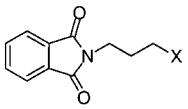
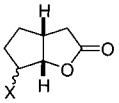
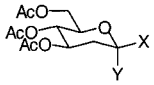
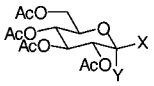


nitrite[20] (DTBHN) (method D) proved to be more effective. The efficacy of this approach is due to the well-documented reaction of *tert*-butoxyl radicals with hexabutylditin.[21]

The scope and limitation of this approach has been studied for different radical precursors according to eq 6 and the results are summarized in Table 2. The two initiation procedures were tested first with a precursor of a secondary alkyl radical. The cyclic iodide **3** was converted into the corresponding azide **4** by treatment with 3 equiv of benzenesulfonyl azide and 1.5 equiv of hexabutylditin in benzene. Under irradiation with a sun lamp (Method C), a yield of 77% was obtained. Under thermal initiation with DTBHN, the yield was enhanced to 89%. This difference could result from the partial decomposition of benzenesulfonyl azide during the irradiation.[22] Interestingly, under thermal conditions, the reaction is clean and fast (≤4 h) and the purification of the product is easier than in the tin free procedure described previously (vide supra). As expected, the cyclic secondary alkyl bromide **26** failed to react under irradiation. However, with DTBHN, the azidation product **4** was obtained in 32% yield (60% after correction for recovered starting material). This yield was determined from ^{1}H NMR of an unseparable 58:42 mixture of unreacted starting bromide **26** and azide **4**. The low conversion is attributed to a side reaction of the stannyl radical with benzenesulfonyl azide leading to consumption of the azidation reagent. The use of primary alkyl iodides such as **27** was also investigated by using both the irradiation and DTBHN initiation techniques. Similar yields of 30% and 34% were obtained, respectively. These results support our hypothesis that the addition of primary alkyl radicals to sulfonyl azides is slower than the reaction of the more nucleophilic secondary and tertiary alkyl radicals.

The iodolactonization product **13** was converted to the azide **14** in a yield similar to the one obtained with ethanesulfonyl azide (55% yield). The β-anomeric dithiocarbonates **24** and **29** afforded the α-azide **25** and **30** in 70% and 37% yield, respectively. This again demonstrates the detrimental steric and electronic β-alkoxy effect.[12]

Table 2. Radical Azidation of Alkyl Halides and Dithiocarbonates with $PhSO_2N_3$ According to Eq 6

R–I/ R–N_3	Method[a]	Yield [%]
	C	77 (from **3**)
	D	89 (from **3**)
3: X = I	C	– (from **26**)
26: X = Br **4**: X = N_3	D	32 (60)[b] (from **26**)
	C	30
	D	34
27: X = I **28**: X = N_3		
	D	55
13: X = I **14**: X = N_3 (*exo*/*endo* 84:16)		
	D	70
24: X = SCSOEt, Y = H **25**: X = H, Y = N_3		
	D	37
29: X = SCSOEt, Y = H **30**: X = H, Y = N_3		

[a] Method C: $PhSO_2N_3$ (3 equiv) and $(Bu_3Sn)_2$ (1.5 equiv) in benzene at room temperature, *hν* as initiator. Method D: $PhSO_2N_3$ (3 equiv) and $(Bu_3Sn)_2$ (1.5 equiv) in benzene at 80 °C, DTBHN (catalyst) as initiator. [b] Yield according to ^{1}H NMR.

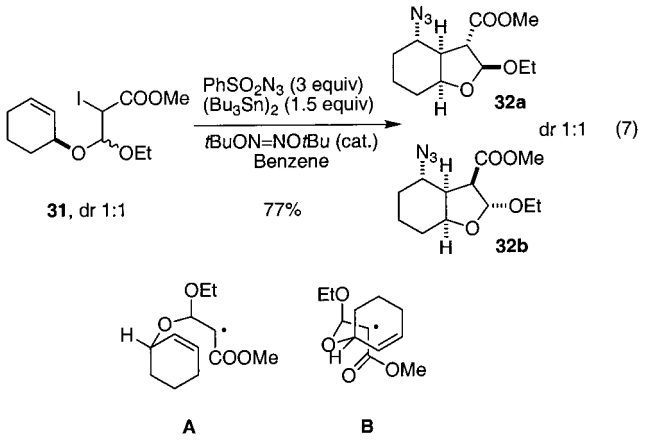
Tandem Radical Cyclization−Aazidation Processes. One of the most attractive applications of the radical azidation process is to combine intramolecular carbon−carbon formation with the azidation in a one-pot procedure. For instance, the α-iodoacetate **31** (dr 1:1) was treated in a one-pot procedure with benzenesulfonyl azide (3 equiv) and hexabutylditin (1.5 equiv) with DTBHN as radical initiator (Method D) and the bicyclic azide **32** was obtained in 77% yield (eq 7). Remarkably, each diastereomer of **31** gives a completely diastereoselective reaction and the azidation product **32** consists of a 1:1 mixture of **32a** and **32b** (the reaction were not conducted with single diastereomers of **31** because they could not be separated by column chromatography). The relative stereochemistry of the two isomers was determined by NOE experiments. The stereochemical outcome of the reaction can be explained with the two transition states model **A** and **B** where the conformation of the acetal maximizes the anomeric effect.[23] A *trans*-diaxial disposition between the ethoxy and the methoxycarbonyl groups also characterizes both transition states. The cyclohexene ring adopts a conformation that allows the cyclization via a boatlike transition state (model **A**) and via a chairlike transition state (model **B**).

(20) Kiefer, H.; Traylor, T. G. *Tetrahedron Lett.* **1966**, *49*, 6163. DTBHN decomposes with a half-life time of 29 min at 65 °C to give *tert*-butoxyl radicals and nitrogen. It is a stable solid, easily prepared from *tert*-butyl bromide and commercially available sodium hyponitrite (Aldrich): Mendenhall, G. D. *Tetrahedron Lett.* **1983**, *24*, 451. For further preparation details, see: Banks, J. T.; Scaiano, J. C.; Adam, W.; Oestrich R. S. *J. Am. Chem. Soc.* **1993**, *115*, 2473.

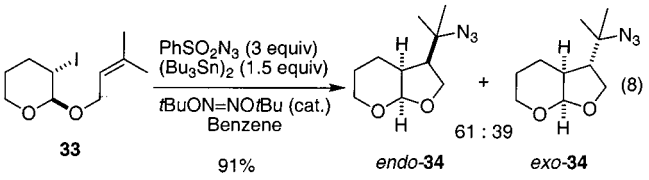
(21) The reaction of hexaalkylditin with *tert*-butoxyl radicals generated thermally or photochemically from di-*tert*-butyl peroxide is known: Neumann, W. P.; Rübsamen, K.; Sommer, R. *Chem. Ber.* **1967**, *100*, 1063. Watts, G. B.; Ingold, K. U. *J. Am. Chem. Soc.* **1972**, *94*, 491.

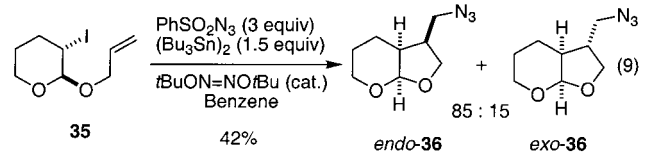
(22) Reagan, M. T.; Nickon, A. *J. Am. Chem. Soc.* **1968**, *90*, 4096.

(23) Beckwith, A. L. J.; Page, D. M. *J. Org. Chem.* **1998**, *63*, 5144. Villar, F.; Renaud, P. *Tetrahedron Lett.* **1998**, *39*, 8655. Villar, F.; Equey, O.; Renaud, P. *Org. Lett.* **2000**, *2*, 1061.

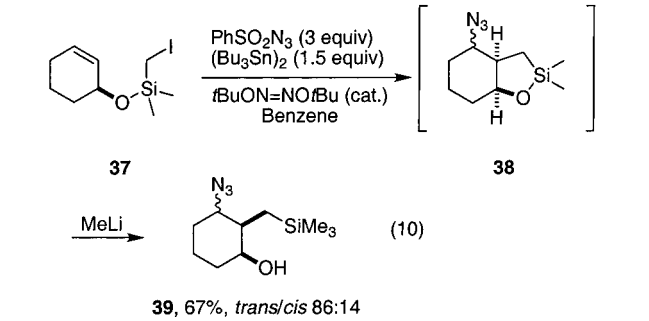


The iodoacetal **33** provides the corresponding tertiary azide **34** in high yield as an *endo*/*exo* 61:39 mixture of diastereoisomers (eq 8). Under similar conditions, the iodoacetal **35** gave the primary azide **36** (endo/exo 85:15) in 42% yield (eq 9).[24] This result (moderate yield of primary azide) supports further the low reactivity of primary alkyl radicals with sulfonyl azides.





Finally, we have shown that the primary (iodomethyl)-dimethylsilyl ether **37** is also a suitable precursor for such cyclization−azidation process. Under Method D, the iodide **37** gave the unstable cyclic silyl ether **38** that is immediately converted by treatment with MeLi into the cylohexanol derivative **39** in 67% overall yield (trans/cis 86:14) (eq 10).



Conclusion

We have reported here two efficient methods for the azidation of secondary and tertiary alkyl radicals generated from iodide and dithiocarbonates. The first method using ethanesulfonyl azide possesses the great advantage of being a tin free procedure but is somewhat limited by long reaction times and formation of apolar side products (particularly undecyl azide) that are difficult to remove from the products when apolar substrates are used. The second approach uses ditin to sustain the chain reaction. It is rapid and extremely efficient to run sequential reactions involving a cyclization process immediately followed by an azidation step. Interestingly, sulfonyl azides are slow radical traps and the cylization reactions are easily achieved in a one-pot procedure where all the reagents are mixed together at the beginning of the reaction. This novel type of radical chain reactions is expected to find applications for the synthesis of alkaloids and other nitrogen-containing compounds.

(24) For the stereochemical outcome of closely related reactions, see: Torii, S.; Inokuchi, T.; Yukawa, T. *J. Org. Chem.* **1985**, *50*, 5875. Hackmann, C.; Schäfer, H. J. *Tetrahedron* **1993**, *49*, 4559. Cossy, J.; Ranaivosata, J.-L.; Bellosta, V. *Tetrahedron Lett* **1994**, *35*, 8161. Engman, L.; Gupta, V. *J. Org. Chem.* **1997**, *62*, 157. Terstiege, I.; Maleczka, R. E., Jr. *J. Org. Chem.* **1999**, *64*, 342. Beckwith, A. L. J.; Page, D. M. *Tetrahedron* **1999**, *55*, 3245.

Experimental Section

General Techniques. THF was freshly distilled from K under N_2; Et_2O from sodium-benzophenone; and CH_2Cl_2, 1,2-dichloroethane, benzene, and Et_3N from CaH_2 under N_2. Other reagents were obtained from commercial sources and used as received. Flash column chromatography (FC): Macherey-Nagel silica gel (0.063−0.200 mm) and Lobar column Fluka silica gel (0.04−0.063 mm). Filtration: Macherey-Nagel silica gel (0.063−0.200 mm); AcOEt, Et_2O, and hexane as eluents. Thin-layer chromatography (TLC): Baker silica gel 25 UV_{254} analytical plates; detection either with UV or by spraying or dipping in a solution of $KMnO_4$ (3 g), K_2CO_3 (20 g), and NaOH 5% (3 mL) in H_2O (300 mL) and subsequent heating. Mp: not corrected; Reichert Thermovar Kofler hot stage apparatus. IR spectroscopy: Perkin-Elmer 16PC. FT-IR spectroscopy: Mattson Unicam 5000. NMR spectroscopy: Varian Gemini 200 (^1H = 200 MHz, ^{13}C = 50.3 MHz), Bruker AM 360 (^1H = 360 MHz, ^{13}C = 90.5 MHz), Bruker advance DRX 500 (^1H = 500.13 MHz, ^{13}C = 125.8 MHz); chemical shift δ in ppm relative to tetramethylsilane (δ = 0 ppm) or $CHCl_3$ for ^1H (δ = 7.26 ppm) and $CDCl_3$ for ^{13}C (δ = 77.0 ppm). MS: Vacuum Generators Micromass VG 70/70E and DS 11-250; CI (CH_4), EI (70 eV); *m*/*z* (%), FAB: in 2-nitrobenzyl alcohol with Ar at 8 KV. High-resolution mass spectra (HRMS) were recorded on a FTICR mass spectrometer Bruker 4.7T BioApex II. Optical rotation: Perkin-Elmer 241 MC. Elementary analysis: Ilse Beetz, Microanalytisches Laboratorium, D-8640 Kronach (Germany).

Caution: Sulfonyl azides are capable of exploding, it is strongly recommended to apply standard safety rules and to use a safety shield.

Procedure A. DLP (20 mg, 0.05 mmol) was added every 1 h to a refluxing solution of the iodide (1.0 mmol) and ethanesulfonyl azide (0.31 mL, 3.0 mmol) in heptane/chlorobenzene (1:1, 4 mL) under N_2. The reaction was monitored by GC or TLC. Upon completion, the solvent was removed under reduced pressure and the residue was purified by FC (hexane/AcOEt).

Procedure B. DLP (20 mg, 0.05 mmol) was added every 1 h to a solution of the iodide or the dithiocarbonate (1.0 mmol) and ethanesulfonyl azide (0.52 mL, 5.0 mmol) in chlorobenzene (2 mL) at 100 °C under N_2. The reaction was monitored by GC or TLC. Upon completion, the solvent was removed under reduced pressure and the residue was purified by FC (hexane/AcOEt).

Procedure C. A solution of iodide (1.0 mmol), benzenesulfonyl azide (550 mg, 3.0 mmol), and $(Bu_3Sn)_2$ (0.76 mL, 1.5 mmol) in benzene (2 mL) was irradiated at room temperature with a 300 W sun lamp placed 10 cm from the reaction vessel. The reaction was monitored by TLC. Upon completion, the solvent was removed under reduced pressure, the crude product was filtered through silica gel (hexane, then hexane/AcOEt), and the combined fractions were concentrated in vacuo. The residue was purified by FC (hexane/AcOEt).

Procedure D. DTBHN[20] (5 mg, 0.03 mmol) was added every 2 h to a solution of the iodide or the dithiocarbonate (1.0 mmol), benzenesulfonyl azide (550 mg, 3.0 mmol), and $(Bu_3Sn)_2$ (0.76 mL, 1.5 mmol) in benzene (2 mL) at reflux under N_2. The reaction was monitored by TLC. Upon completion, the solvent was removed under reduced pressure, the crude product was filtered through silica gel

(hexane, then hexane/AcOEt), and the combined fractions were concentrated in vacuo. The residue was purified by FC (hexane/AcOEt).

Procedure E. DLP (20 mg, 0.05 mmol) was added every 2 h to a refluxing solution of the iodide (1.0 mmol) in dry benzene (40 mL) under N_2. The reaction was monitored by TLC. Upon completion, the solvent was removed under reduced pressure and the residue was dissolved in chlorobenzene (2 mL). Ethanesulfonyl azide was added (0.52 mL, 5.0 mmol) and the reaction mixture was heated at 100 °C. Further portions of DLP (20 mg, 0.05 mmol) were added every 1 h. Upon completion, the solvent was removed under reduced pressure and the residue was purified by FC (hexane/AcOEt).

Procedure F.[11] DLP (20 mg, 0.05 mmol) was added every 2 h to a refluxing solution of the iodide (1.0 mmol) in dry benzene (40 mL) under N_2. The reaction was monitored by TLC. Upon completion, the solvent was removed under reduced pressure and the residue was purified by FC (hexane/AcOEt).

Procedure G.[12] DLP (8 mg, 0.02 mmol) was added every 2 h to a refluxing solution of the dithiocarbonate (1.0 mmol) and the olefin (2.0 mmol) in dry 1,2-dichloroethane (1 mL) under N_2. The reaction was monitored by TLC or ^{1}H NMR. Upon completion, the solvent was removed under reduced pressure and the residue was purified by FC (hexane/AcOEt).

1-Ethanesulfonyl Azide. A solution of NaN_3 (9.48 g, 0.146 mol) in H_2O (60 mL) was added dropwise at 0 °C to a solution of ethanesulfonyl chloride (8.9 mL, 94.0 mmol) in acetone (200 mL). The mixture was stirred overnight at room temperature. The acetone was removed under reduced pressure and the resulting aqueous phase was extracted with AcOEt (200 mL), washed with H_2O (2 × 100 mL), 5% Na_2CO_3 (2 × 100 mL), and water (2 × 100 mL), dried over $MgSO_4$, and concentrated in vacuo. The residue was purified by distillation under reduced pressure (0.8 mbar) and gave 1-ethanesulfonyl azide (11.08 g, 87%) as a colorless liquid. Bp 61 °C (0.8 mbar). d^{20} 1.29. IR (neat) 2987, 2947, 2887, 2137, 1458, 1359, 1288, 1157, 1049, 781 cm^{-1}. ^{1}H NMR (360 MHz, $CDCl_3$) δ 3.35 (*q*, $J = 7.3$ Hz, 2H), 1.51 (*t*, $J = 7.3$ Hz, 3H). ^{13}C NMR (50 MHz, $CDCl_3$) 50.5, 8.0. MS (CI, CH_4) *m*/*z* (%) 136 (MH^+, 100), 93 ($M - N_3$, 20). Anal. Calcd for $C_2H_5N_3O_2S$ (135.14): C, 17.78; H, 3.73; N, 31.09. Found: C, 17.83; H, 3.81; N, 31.00.

Benzenesulfonyl Azide. *Caution: Pure benzenesulfonyl azide decomposes rapidly but quietly upon warming to approximately 105 °C but crude product detonates violently upon heating.*[25] Benzenesulfonyl azide was prepared according to previous procedure from benzenesulfonyl chloride (12.05 mL, 94.0 mmol) and NaN_3 (9.48 g, 0.146 mmol). The residue was purified by precipitation in hexane/Et_2O 10:1 at −78 °C and gave benzenesulfonyl azide (15.9 g, 92%) as a colorless liquid. Physical and spectral data were in accordance with literature data.[8] IR (neat) 2347, 2129, 1583, 1477, 1450, 1369, 1313, 1298, 1171, 1087, 1024, 999, 750, 684 cm^{-1}. ^{1}H NMR (360 MHz, $CDCl_3$) δ 7.96 (*d*, $J = 7.3$ Hz, 2H), 7.74 (*t*, $J = 7.3$ Hz, 1H), 7.63 (*t*, $J = 7.3$ Hz, 2H).

4-Iodocyclohexyl Acetate (1). 1 was prepared according to a literature procedure[26] from 4-hydroxycyclohexyl acetate.[27] Triphenylphosphine (7.08 g, 27.0 mmol) and imidazole (1.84 g, 27.0 mmol) were successively dissolved in CH_2Cl_2 (72 mL). The resulting mixture was cooled to 0 °C and I_2 (6.85 g, 27.0 mmol) was added portionwise. The solution was stirred 10 min at room temperature. A solution of 4-hydroxycyclohexyl acetate (2.36 g, 18.0 mmol) in CH_2Cl_2 (18 mL) was cannuled to the yellow resulting suspension. After the solution was stirred for 1 h at room temperature, H_2O (50 mL) was added. The aqueous layer was extracted with CH_2Cl_2 (50 mL). The combined extracts were washed with 10% $Na_2S_2O_3$ (50 mL), dried over $MgSO_4$, and concentrated in vacuo. The solid residue was condensed on silica gel and purified by FC (hexane/AcOEt 9:1) to afford an yellow oil as a 83:17 mixture of the iodide **1** and the 4-acetoxycyclohexene. Elimination of the alkene was achieved by bulb-to-bulb distillation (80−90 °C, 1 mbar) to afford **1** (2.59 g, 54%) as a 59:41 mixture of two isomers (^{1}H NMR).

1 (major, more polar): colorless crystals. Mp 41 °C. ^{1}H NMR (500 MHz, $CDCl_3$) δ 4.93−4.89 (*m*, 1H), 4.51−4.43 (*m*, 1H), 2.22−2.16 (*m*, 2H), 2.07 (*s*, 3H), 1.98−1.82 (*m*, 4H), 1.76−1.70 (*m*, 2H). ^{13}C NMR (50 MHz) δ 170.0, 69.9, 34.5 ($2CH_2$), 30.1, 29.8 ($2CH_2$), 21.1.

1 (minor, less polar): colorless oil. ^{1}H NMR (500 MHz) δ 4.84−4.79 (*m*, 1H), 4.34−4.26 (*m*, 1H), 2.28−2.19 (*m*, 2H), 2.03−1.90 (*m*, 4H), 2.02 (*s*, 3H), 1.57−1.50 (*m*, 2H). ^{13}C NMR (50 MHz) δ 169.9, 69.4, 35.6 ($2CH_2$), 31.1 ($2CH_2$), 28.8, 21.1.

1 (mixture of diastereomers): IR (neat) 2949, 2864, 1734, 1442, 1363, 1244, 1037 cm^{-1}. MS (EI, 70 eV) *m*/*z* (%) 268 (M^+, 12), 141 ($M - I$, 86), 127 (24), 99 (91), 81 (100), 53 (18). Anal. Calcd for $C_8H_{13}IO_2$ (268.09): C, 35.84; H, 4.89. Found: C, 35.86; H, 4.93.

4-Azidocyclohexyl Acetate (2). 2 was prepared according to procedure A from **1** (268 mg, 1.0 mmol) and DLP (278 mg, 0.7 mmol). Two successive FC (hexane/AcOEt 90:10) gave **2** (154 mg, 84%) as a 54:46 mixture of two isomers (^{1}H NMR). Colorless oil.

2 (major, less polar): ^{1}H NMR (500 MHz, $CDCl_3$) δ 4.87−4.83 (*m*, 1H), 3.56−3.51 (*m*, 1H), 2.05 (*s*, 3H), 1.88−1.81 (*m*, 2H), 1.78−1.73 (*m*, 4H), 1.68−1.62 (*m*, 2H). ^{13}C NMR (125 MHz) δ 170.5, 69.4, 57.9, 27.6 ($2CH_2$), 27.1 ($2CH_2$), 21.3.

2 (minor, more polar): ^{1}H NMR (500 MHz) δ 4.78−4.72 (*m*, 1H), 3.47−3.41 (m, 1H), 2.05−1.97 (*m*, 4H), 2.03 (*s*, 3H), 1.53−1.44 (*m*, 4H). ^{13}C NMR (125 MHz) δ 170.4, 70.9, 58.5, 28.6 ($2CH_2$), 28.4 ($2CH_2$), 21.3.

2 (mixture of diastereomers): IR (neat) 2947, 2868, 2096, 1734, 1448, 1369, 1244, 1043, 908 cm^{-1}. MS (CI, CH_4) *m*/*z* (%) 184 (MH^+, 42), 156 ($M - N_2$, 14), 141 (19), 124 (17), 114 (9), 96 (100), 81 (67), 68 (26). Anal. Calcd for $C_8H_{13}N_3O_2$ (183.21): C, 52.45; H, 7.15; N, 22.94. Found: C, 52.37; H, 7.12; N, 22.89.

4-Iodo-1-[(4-methylphenyl)sulfonyl]piperidine (3). A solution of 1-[(4-methylphenyl)sulfonyl]-4-piperidinyl 4-methylbenzenesulfonate (2.04 g, 5.0 mmol), prepared from 3-hydroxypiperidine according to a literature procedure,[28] NaI (971 mg, 6.5 mmol), and HMPA (3.8 mL, 21.7 mmol) in benzene (13 mL) was stirred for 5 h at 70 °C under N_2. The crude mixture was dissolved in Et_2O (50 mL), washed with brine (2 × 30 mL), 5% $Na_2S_2O_3$ (20 mL), and brine (20 mL), dried over $MgSO_4$, filtered, and concentrated under reduced pressure. The crude material was purified by FC (hexane/AcOEt 80:20, then 70:30) followed by recrystallization (CH_2Cl_2/hexane) to afford **3** (1.06 g, 58%) as white needles. Mp 148−149 °C (from CH_2Cl_2/hexane). IR (KBr) 2972, 2920, 2868, 1597, 1475, 1442, 1342, 1307, 1244, 1184, 1163, 1082, 1047, 1006, 925, 852, 814, 738, 678, 650, 574, 549 cm^{-1}. ^{1}H NMR (360 MHz, $CDCl_3$) δ 7.64 (*d*, $J = 8.2$ Hz, 2H), 7.34 (*d*, $J = 8.2$ Hz, 2H), 4.29 (*quint*, $J = 6.4$ Hz, 1H), 3.17 (*dt*, $J = 11.6$, 5.2 Hz, 2H), 2.98 (*dt*, $J = 11.3$, 5.2 Hz, 2H), 2.44 (*s*, 3H), 2.19−2.07 (*m*, 4H). ^{13}C NMR (50 MHz, $CDCl_3$) δ 143.7, 133.2, 129.7 (2CH), 127.6 (2CH), 45.6, 36.4 ($2CH_2$), 25.5 ($2CH_2$), 21.5. MS (CI, CH_4) *m*/*z* (%) 365 (M, 12), 238 ($M - I$, 100), 184 (71), 155 (95), 139 (11), 91 (99), 65 (45). Anal. Calcd for $C_{12}H_{16}INO_2S$ (365.23): C, 39.46; H, 4.42; N, 3.84. Found: C, 39.57; H, 4.45; N, 3.88.

4-Azido-1-[(4-methylphenyl)sulfonyl]piperidine (4). (a) Prepared according to procedure A from **3** (365 mg, 1.0 mmol) and DLP (239 mg, 0.6 mmol): Two successive FC (hexane/AcOEt 85:15) gave **4** (227 mg, 81%) as a white solid. Mp 63−65 °C (from CH_2Cl_2/hexane). IR (KBr) 2955, 2924, 2843, 2090, 1595, 1332, 1257, 1165, 1093, 1024, 939, 819, 729, 677, 650, 590, 549 cm^{-1}. ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.64 (*d*, $J = 8.2$ Hz, 2H), 7.33 (*d*, $J = 8.2$ Hz, 2H), 3.53−3.48 (*m*, 1H), 3.28−3.23 (*m*, 2H), 2.92−2.86 (*m*, 2H), 2.44 (*s*, 3H), 1.97−1.92 (*m*, 2H), 1.76−1.69 (*m*, 2H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 143.7, 133.1, 129.7 (2CH), 127.6 (2CH), 56.1, 43.3 ($2CH_2$), 29.9 ($2CH_2$), 21.5. MS (CI, CH_4) *m*/*z* (%) 281 (MH^+, 100), 253 ($M - N_2$, 83), 238 (70), 97 (31). Anal. Calcd for $C_{12}H_{16}N_4O_2S$ (280.34): C, 51.41; H, 5.75; N, 19.98. Found: C, 51.37; H, 5.71; N, 20.04.

(b) Prepared according to procedure C from **3** (183 mg, 0.5 mmol), $PhSO_2N_3$ (275 mg, 1.5 mmol), and $(Bu_3Sn)_2$ (0.38 mL, 0.75 mmol): The reaction was completed after 2 h. Filtration (hexane then hexane/AcOEt 85:15) and FC (hexane/AcOEt 85:15) gave **4** (108 mg, 77%).

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(26) Lange, G. L.; Gottardo, C. *Synth. Commun.* **1990**, *20*, 1473.
(27) Endo, K.; Seya, K.; Hikino, H. *Tetrahedron* **1987**, *43*, 2681.
(28) Shanklin, J. R., Jr.; Johnson, I. C. P.; Proakis, A. G.; Barrett, R. J. *J. Med. Chem.* **1991**, *34*, 3011.

(c) Prepared according to procedure D from **3** (365 mg, 1.0 mmol), $PhSO_2N_3$ (550 mg, 3.0 mmol), $(Bu_3Sn)_2$ (0.76 mL, 1.5 mmol), and DTBHN (10 mg, 0.06 mmol): Filtration (hexane then hexane/AcOEt 85:15) and FC (hexane/AcOEt 85:15) gave **4** (249 mg, 89%).

(d) Prepared according to procedure D from **26** (365 mg, 1.0 mmol), $PhSO_2N_3$ (550 mg, 3.0 mmol), $(Bu_3Sn)_2$ (0.76 mL, 1.5 mmol), and DTBHN (87 mg, 0.50 mmol) added 5% every 1 h: Filtration (hexane then hexane/AcOEt 85:15) and FC (hexane/AcOEt 85:15) gave a 58:42 nonseparable mixture of **26** and **4** containing **4** (89 mg, 32% according to ^{1}H NMR).

4-Iodohexahydrobenzofuran 2(3*H*)-one (5). 5 was prepared according to procedure F from 2-cyclohexen-1-yl 2-iodoacetate **17** (266 mg, 1.0 mmol) and DLP (40 mg, 0.1 mmol). FC (hexane/AcOEt 3:1) gave **5** (236 mg, 89%) as a 5.4:1 mixture of two isomers (^{1}H NMR). Physical and spectral data were in accordance with literature data.[29]

exo-**5** (major, less polar): ^{1}H NMR (360 MHz, $CDCl_3$) δ 4.47 (*q*, J = 3.7 Hz, 1H), 3.85 (*ddd*, J = 12.2, 10.6, 4.0 Hz, 1H), 2.87 (*m*, 1H), 2.70 (*dd*, J = 17.4, 6.7 Hz, 1H), 2.54 (*d*, J = 17.1 Hz, 1H), 2.43−2.36 (*m*, 1H), 2.32−2.22 (*m*, 1H), 2.04−1.92 (*m*, 1H), 1.75−1.61 (*m*, 1H), 1.59−1.49 (*m*, 2H).

endo-**5** (minor, more polar): ^{1}H NMR (360 MHz, $CDCl_3$) δ 4.51 (*dt*, J = 10.4, 6.4 Hz, 1H), 4.29 (*dt*, J = 12.8, 4.9 Hz, 1H), 3.18 (*m*, 1H), 2.67 (*dd*, J = 17.3, 13.1 Hz, 1H), 2.55 (*dd*, J = 17.3, 8.2 Hz, 1H), 2.43−2.36 (*m*, 1H), 2.32−2.22 (*m*, 1H), 2.04−1.92 (*m*, 1H), 1.75−1.61 (*m*, 1H), 1.59−1.49 (*m*, 2H).

4-Azidohexahydrobenzofuran 2(3*H*)-one (6). (a) Prepared according to procedure B from **5** (266 mg, 1.0 mmol) and DLP (339 mg, 0.85 mmol). Filtration (hexane/AcOEt 80:20 then 70:30) and FC (hexane/AcOEt 75:25 for the first isomer and hexane/AcOEt 70:30 for the second isomer) gave **6** (145 mg, 80%) as a 74:26 mixture of two isomers (GC and ^{1}H NMR).

exo-**6** (major, less polar): colorless oil. ^{1}H NMR (360 MHz, $CDCl_3$) δ 4.62 (*dt*, J = 3.4, 3.7 Hz, 1H), 3.16 (*ddd*, J = 10.2, 11.3, 4.0 Hz, 1H), 2.69 (*dd*, J = 17.0, 6.4 Hz, 1H), 2.59 (*d*, J = 17.4 Hz, 1H), 2.24−2.17 (*m*, 2H), 2.12−2.04 (*m*, 1H), 1.81−1.72 (*m*, 1H), 1.66−1.50 (*m*, 2H), 1.47−1.35 (*m*, 1H). ^{13}C NMR (125 MHz) δ 175.9, 79.1, 60.6, 41.2, 36.0, 28.7, 26.8, 18.5.

endo-**6** (minor, more polar): colorless oil. ^{1}H NMR (360 MHz) δ 4.54 (*dt*, J = 8.2, 5.5 Hz, 1H), 3.81 (*ddd*, J = 9.1, 5.8, 4.0 Hz, 1H), 2.87−2.78 (*m*, 1H), 2.50 (*d*, J = 8.1 Hz, 2H), 2.01−1.78 (*m*, 3H), 1.74−1.57 (*m*, 2H), 1.47−1.25 (*m*, 1H). ^{13}C NMR (125 MHz) δ 175.8, 77.6, 58.4, 38.7, 30.5, 27.5, 25.8, 17.3.

exo-**6** and *endo*-**6** (mixture of diastereomers): IR (neat) 2941, 2870, 2106, 1778, 1452, 1423, 1346, 1257, 1153, 1091, 1006, 945 cm^{-1}. MS (CI, CH_4) *m*/*z* 182 (MH^+, 65), 154 (23), 139 (100), 123 (38), 108 (56), 94 (55), 81 (31), 69 (11), 61 (16). Anal. Calcd for $C_8H_{11}N_3O_2$ (181.19): C, 53.03; H, 6.12; N, 23.19. Found: C, 53.10; H, 6.19; N, 23.12.

(b) Prepared according to procedure E from 2-cyclohexen-1-yl 2-iodoacetate **17** (266 mg, 1.0 mmol) and DLP (40 mg, 0.1 mmol). In presence of $EtSO_2N_3$, DLP (339 mg, 0.85 mmol) was added portionwise over 17 h. Filtration (hexane/AcOEt 80:20 then 70:30) and two successive FCs (hexane/Et_2O 50:50) gave **6** (144 mg, 80%) as a 74:26 mixture of two isomers (GC and isolated).

4-Iodo-1-methyloctahydro-2*H*-indol-2-one (7). 7 was prepared according to procedure F from *N*-(2-cyclohexen-1-yl)-2-iodo-*N*-methylacetamide (837 mg, 3.0 mmol) and DLP (180 mg, 0.3 mmol). FC (Et_2O/AcOEt 9:1) gave **7** (640 mg, 76%) as a 3.2:1 mixture of two isomers (^{1}H NMR). Physical and spectral data were in accordance with literature data.[29]

exo-**7** (major): ^{1}H NMR (360 MHz, $CDCl_3$) δ 4.06 (*ddd*, J = 10.7, 8.9, 4.0 Hz, 1H), 3.55 (*dt*, J = 4.9, 4.6 Hz, 1H), 2.80−2.73 (*m*, 1H), 2.77 (*s*, 3H), 2.53−2.34 (*m*, 2H), 2.30−1.09 (*m*, 6H).

endo-**7** (minor): ^{1}H NMR (360 MHz, $CDCl_3$) δ 4.33 (*dt*, J = 13.1, 5.0 Hz, 1H), 3.43 (*dt*, J = 10.7, 6.4 Hz, 1H), 2.96−2.85 (*m*, 1H), 2.80 (*s*, 3H), 2.53−2.34 (*m*, 2H), 2.30−1.09 (*m*, 6H).

4-Azido-1-methyloctahydro-2*H*-indol-2-one (8). 8 was prepared according to procedure B from **7** (279 mg, 1.0 mmol) and DLP (358 mg, 0.90 mmol). Filtration (Et_2O/AcOEt 50:50 then 5:95) and FC (Et_2O/AcOEt 5:95) gave **8** (150 mg, 77%) as a 80:20 mixture of two isomers (^{1}H NMR). Brown oil.

exo-**8** (major): ^{1}H NMR (500 MHz, $CDCl_3$) δ 3.63 (*dt*, J = 13.1, 6.4 Hz, 1H), 3.24 (*ddd*, J = 13.9, 14, 5.9 Hz, 1H), 2.76 (*s*, 3H), 2.43−2.39 (*m*, 2H), 2.17−1.79 (*m*, 3H), 1.74−1.62 (*m*, 2H), 1.52−1.08 (*m*, 2H). ^{13}C NMR (125 MHz) δ 174.8, 60.8, 58.1, 38.2, 36.3, 28.5, 26.9, 25.6, 18.4.

endo-**8** (minor): ^{1}H NMR (500 MHz) δ 3.70 (*dt*, J = 19.1, 6.8 Hz, 1H), 3.45 (*dt*, J = 14.4, 8.9 Hz, 1H), 2.82 (*s*, 3H), 2.35−2.29 (*m*, 2H), 2.17−1.79 (*m*, 3H), 1.74−1.62 (*m*, 2H), 1.52−1.08 (*m*, 2H). ^{13}C NMR (125 MHz) δ 173.3, 59.4, 59.0, 36.9, 30.5, 27.8, 26.8, 25.9, 20.0.

exo-**8** and *endo*-**8** (mixture of diastereomers): IR (neat) 2939, 2866, 2096, 1691, 1425, 1398, 1253, 1107, 976, 950 cm^{-1}. MS (CI, CH_4) *m*/*z* 195 (MH^+, 100), 182 (3), 167 (6), 152 (71), 124 (7), 110 (5), 89 (16), 70 (11), 61 (19). Anal. Calcd for $C_9H_{14}N_4O$ (194.23): C, 55.65; H, 7.27; N, 28.84. Found: C, 55.61; H, 7.23; N, 28.75.

5-Iodo-2-adamantanone (9). 9 was prepared in two steps from 2-adamantanone according to a literature procedure.[30,31] Physical and spectral data were in accordance with literature data: Mp 82−85 °C (lit.[31] mp 83−85 °C). ^{1}H NMR (360 MHz, $CDCl_3$) δ 2.88−2.73 (*m*, 6H), 2.52−2.47 (*m*, 2H), 2.19−2.06 (*m*, 5H). ^{13}C NMR (50 MHz, $CDCl_3$) δ 214.2, 52.4 ($2CH_2$), 50.6, 50.1 (2CH), 41.2, 37.4 ($2CH_2$), 31.6.

5-Azido-2-adamantanone (10). 10 was prepared according to procedure A from **9** (276 mg, 1.0 mmol) and DLP (140 mg, 0.35 mmol). Two successive FCs (hexane/AcOEt 85:15) gave a mixture of **10** and $EtSO_2N_3$ (47:53) containing **10** (166 mg, 87%) according to ^{1}H NMR. Ethanesulfonyl azide was eliminated upon standing for one night under vacuum (6×10^{-2} bar) and **10** was isolated (147 mg, 77%) as colorless crystals. Mp 73−76 °C. IR (KBr) 2932, 2862, 2093, 1722, 1452, 1356, 1252, 1061, 887, 663 cm^{-1}. ^{1}H NMR (500 MHz, $CDCl_3$) δ 2.68−2.64 (*m*, 2H), 2.37−2.34 (*m*, 1H), 2.15−1.95 (*m*, 10H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 215.0, 57.3, 46.4 (2CH), 41.8 ($2CH_2$), 40.4, 37.9 ($2CH_2$), 29.0. MS (CI, CH_4) *m*/*z* 192 (MH^+, 100), 164 (17), 149 (70). Anal. Calcd for $C_{10}H_{13}N_3O$ (191.23): C, 62.81; H, 6.85; N, 21.97. Found: C, 62.91; H, 6.79; N, 21.83.

Diethyl 2-(3-Iodopropyl)-2-methylmalonate (11). A suspension of diethyl 2-(3-bromopropyl)-2-methylmalonate (2.74 g, 9.27 mmol), prepared from dimethyl methylmalonate and 1,3-dibromopropane according to a literature procedure[32] and NaI (2.78 g, 18.5 mmol) in acetone (30 mL), was heated at reflux for 24 h. The reaction mixture was evaporated and the resulting oil was dissolved in Et_2O (100 mL) and washed with H_2O (50 mL). The organic layer was separated and washed with H_2O (20 mL), 10% $Na_2S_2O_3$ (30 mL), and brine, dried over $MgSO_4$, and concentrated in vacuo. The residue was purified by FC (hexane/AcOEt 95:5) to afford **11** (2.8 g, 88%) as a colorless oil. IR (neat) 2982, 1730, 1464, 1379, 1302, 1253, 1157, 1105, 1022, 862 cm^{-1}. ^{1}H NMR (360 MHz, $CDCl_3$) δ 4.18 (*q*, J = 7.15 Hz, 4H), 3.29 (*t*, J = 6.7 Hz, 2H), 1.98−1.93 (*m*, 2H), 1.84−1.77 (*m*, 2H), 1.41 (*s*, 3H), 1.25 (*t*, J = 7.15 Hz, 6H). ^{13}C NMR (50 MHz, $CDCl_3$) δ 171.8 (2C), 61.2 ($2CH_2$), 52.9, 36.4, 28.5, 19.9, 13.9 ($2CH_3$), 5.7. MS (EI, 70 eV) *m*/*z* 343 (M + 1, 36), 297 (23), 269 (14), 215 (100), 187 (16), 141 (38), 113 (20), 85 (30), 69 (38). Anal. Calcd for $C_{11}H_{19}IO_4$ (342.17): C, 38.61; H, 5.60. Found: C, 38.55; H, 5.49.

Diethyl 2-(3-Azidopropyl)-2-methylmalonate (12). 12 was prepared according to procedure B from **11** (342 mg, 1.0 mmol) and DLP (995 mg, 2.5 mmol). Two successive FCs (hexane/AcOEt 90:10) followed by Lobar (hexane/AcOEt 95:5) gave **12** (63 mg, 24%) as a colorless oil. IR (neat) 2984, 2941, 2098, 1732, 1452, 1381, 1255, 1188, 1116, 1022, 860 cm^{-1}. ^{1}H NMR (500 MHz, $CDCl_3$) δ 4.19 (*q*, J = 7.15 Hz, 4H), 3.29 (*t*, J = 6.75 Hz, 2H), 1.92 (*dt*, J = 8.05, 4.5 Hz, 2H), 1.60−1.52 (*m*, 2H), 1.42 (*s*, 3H), 1.25 (*t*, J = 7.15 Hz, 6H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 172.0 (2C), 61.3 ($2CH_2$), 53.3, 51.4, 32.8, 24.0, 19.9, 14.0 ($2CH_3$). MS (CI, CH_4) *m*/*z* 258 (MH^+, 100), 230 (10), 215 (60), 201 (19), 184 (35), 174 (25), 156 (37), 110 (10), 84 (10), 56 (35).

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Anal. Calcd for $C_{11}H_{19}N_3O_4$ (257.29): C, 51.35; H, 7.44; N, 16.33. Found: C, 51.46; H, 7.42; N, 16.22.

6-Iodohexahydro-2*H*-cyclopenta[b]furan-2-one (13). 13 was prepared in one step from 2-(2-cyclopenten-1-yl)acetic acid according to a literature procedure.[33] Physical and spectral data were in accordance with literature data:[33,34] Mp 34−35 °C (lit.[33] mp 35−36 °C). ^{1}H NMR (360 MHz, $CDCl_3$) δ 5.20 (*d*, J = 6.1 Hz, 1H), 4.47 (*d*, J = 4.9 Hz, 1H), 3.21−3.12 (*m*, 1H), 2.89 (*dd*, J = 18.6, 9.75 Hz, 1H), 2.52−2.40 (*m*, 1H), 2.38 (*dd*, J = 18.6, 2.1 Hz, 1H), 2.21−2.01 (*m*, 2H), 1.63−1.56 (*m*, 1H).

6-Azidohexahydro-2*H*-cyclopenta[b]furan-2-one (14). (a) Prepared according to procedure B from **13** (252 mg, 1.0 mmol) and DLP (338 mg, 0.85 mmol). Filtration (hexane/AcOEt 80:20 then 70:30) and FC (hexane/Et_2O 50:50) gave **14** (101 mg, 60%) as a 84:16 mixture of two isomers (^{1}H NMR). Colorless oil.

exo-**14** (major): ^{1}H NMR (500 MHz, $CDCl_3$) δ 4.73 (*d*, J = 6.9 Hz, 1H), 4.14 (*s(br)*, 1H), 3.07−3.00 (*m*, 1H), 2.84 (*dd*, J = 18.6, 10.4 Hz, 1H), 2.31 (*dd*, J = 18.6, 2.9 Hz, 1H), 2.21−2.13 (*m*, 1H), 2.07−1.95 (*m*, 1H), 1.89−1.83 (*m*, 1H), 1.78−1.51 (*m*, 1H). ^{13}C NMR (125 MHz) δ 175.8, 77.6, 58.4, 38.7, 30.5, 27.5, 25.8.

endo-**14** (minor):^{1}H NMR (500 MHz) δ 5.00 (*t*, J = 3.6 Hz, 1H), 2.29 (*dd*, J = 17.7, 2.1 Hz, 1H) characteristic signals.

e*xo*-**14** and *endo*-**14** (mixture of diastereomers): IR (neat) 2962, 2876, 2102, 1780, 1462, 1359, 1255, 1161, 1031, 931, 889 cm^{-1}. MS (CI, CH_4) *m*/*z* 168 (MH^+, 32), 127 (100), 109 (79), 94 (36), 81 (26), 67 (23). HRMS for $C_7H_9N_3NaO_2$ [MNa^+]: calcd 190.0592; found 190.0586.

(b) Prepared according to procedure D from **13** (126 mg, 0.5 mmol), $PhSO_2N_3$ (275 mg, 1.5 mmol), Bu_6Sn_2 (0.38 mL, 0.75 mmol), and DTBHN (32 mg, 0.18 mmol). Filtration (hexane then hexane/AcOEt 85:15) and FC (hexane/Et_2O 85:15) gave **14** (46 mg, 55%) as a 84:16 mixture of two isomers (^{1}H NMR).

9-(Hydroxymethyl)-2-iodo-4-oxatricyclo[4.2.1.0^{3,7}]nonan-5-one (15). 15 was prepared in two steps from *cis*-*endo*-bicyclo[2,2,1]hept-5-ene-2,3-dicarboxylic anhydride according to a literature procedure.[35,36] Physical and spectral data were in accordance with literature data: Mp 127−129 °C (lit.[36] mp 125−127 °C). ^{1}H NMR (360 MHz, $CDCl_3$) δ 5.18 (*d*, J = 5.2 Hz, 1H), 4.16 (*d*, J = 2.7 Hz, 1H), 3.83 (*dd*, J = 11.6, 8.2 Hz, 1H), 3.76−3.71 (*m*, 1H), 3.27 (*td*, J = 4.8, 1.2 Hz, 1H), 2.76−2.71 (*m*, 2H), 2.52−2.46 (m, 1H), 2.43 (*d*, J = 11.6 Hz, 1H), 2.11 (*s(br)*, 1H), 1.90 (*d(br)*, J = 11.6 Hz, 1H).

9-(Hydroxymethyl)-2-azido-4-oxatricyclo[4.2.1.0^{3,7}]nonan-5-one (16). 16 was prepared according to procedure B from **15** (294 mg, 1.0 mmol) and DLP (219 mg, 0.55 mmol). Two successive FCs (hexane/AcOEt 50:50, then 40:60) gave **16** (118 mg, 56%). Colorless oil, contaminated by traces of unseparable byproducts (≤5 wt %). IR (neat) 3429, 2978, 2889, 2102, 1780, 1466, 1359, 1251, 1161, 1030, 970 cm^{-1}. ^{1}H NMR (500 MHz, $CDCl_3$) δ 4.55 (*d*, J = 5.05 Hz, 1H), 3.84 (*d*, J = 1.75 Hz, 1H), 3.82 (*dd*, J = 11.6, 8.1 Hz, 1H), 3.72 (*dd*, J = 11.45, 7.35 Hz, 1H), 3.31−3.39 (*m*, 1H), 2.73 (*ddd*, J = 10.7, 4.9, 0.85 Hz, 1H), 2.57 (*s*, 1H), 2.53−2.47 (*m*, 1H), 2.21 (*s (br)*, 1H), 2.03 (*dt*, J = 11.45, 1.6 Hz, 1H), 1.66 (*d*, J = 11.5 Hz, 1H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 178.7, 85.0, 63.5, 60.2, 46.6, 45.5, 43.3, 40.8, 34.6. MS (CI, CH_4) *m*/*z* 210 (MH^+, 100), 192 (28), 167 (28), 154 (4), 137 (5), 123 (17), 110 (59), 93 (17), 81 (20), 74 (31), 56 (6). HRMS for $C_9H_{12}N_3O_3$ [MH^+]: calcd 210.0878; found 210.0876.

***S*-[1-(2-Cyanoethyl)heptyl] *O*-Ethyl Carbonodithioate (18). 18** was prepared according to procedure G from *S*-(cyanomethyl) *O*-ethyl carbonodithioate[37] (1.61 g, 10.0 mmol), 1-octene (3.14 mL, 20.0 mmol), and DLP (160 mg, 0.4 mmol) in 1,2-dichloroethane (10 mL). FC (hexane/AcOEt 94:6) gave **18** (2.48 g, 91%) as a yellow oil. IR (neat) 2930, 2858, 2249, 1452, 1219, 1112, 1051, 856 cm^{-1}. ^{1}H NMR (360 MHz, $CDCl_3$) δ 4.66 (*q*, J = 7.3 Hz, 2H), 3.85−3.77 (m, 1H), 2.50 (*t*, J = 7.3 Hz, 2H), 2.17−2.08 (*m*, 1H), 2.03−1.92 (*m*, 1H), 1.71−1.64 (*m*, 2H), 1.51−1.22 (*m*, 8H), 1.44 (*t*, J = 7.3 Hz, 3H), 0.88 (*t*, J = 7.3 Hz, 3H). ^{13}C NMR (50 MHz, $CDCl_3$) δ 212.9, 118.8, 69.8, 49.6, 33.4, 31.2, 30.2, 28.6, 26.4, 22.2, 14.6, 13.7, 13.4. MS (EI, 70 eV) *m*/*z* 273 (M, 15), 240 (16), 184 (10), 152 (95), 123 (100), 110 (17), 89 (74), 69 (63), 55 (52). Anal. Calcd for $C_{13}H_{23}NOS_2$ (273.45): C, 57.10; H, 8.48; N, 5.12. Found: C, 57.24; H, 8.49; N, 5.03.

4-Azidodecanenitrile (19). Prepared according to procedure B from **18** (273 mg, 1.0 mmol) and DLP (319 mg, 0.80 mmol). Two successive FCs (hexane/AcOEt 95:5) gave **19** (164 mg, 85%) as a colorless oil. IR (neat) 2931, 2858, 2247, 2100, 1460, 1346, 1267 cm^{-1}. ^{1}H NMR (500 MHz, $CDCl_3$) δ 3.46−3.41 (*m*, 1H), 2.49−2.46 (*m*, 1H), 1.91−1.84 (*m*, 1H), 1.75−1.53 (*m*, 3H), 1.48−1.24 (*m*, 8H), 0.89 (*t*, J = 6.95 Hz, 3H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 118.9, 61.1, 34.1, 31.6, 30.1, 28.9, 25.8, 22.5, 14.2, 14.0. MS (CI, CH_4) *m*/*z* 195 (MH^+, 100), 167 (15), 152 (34), 123 (5), 97 (4), 83 (15), 69 (4), 54 (3). Anal. Calcd for $C_{10}H_{18}N_4$ (194.28): C, 61.82; H, 9.34; N, 28.84. Found: C, 61.75; H, 9.45; N, 28.76.

Ethyl 5-Ethoxy-4-[(ethoxycarbothioyl)sulfanyl]pentanoate (20). 20 was prepared according to procedure G from ethyl 2-[(ethoxycarbothioyl)sulfanyl]acetate (2.08 g, 10.0 mmol, easily prepared from ethyl iodoacetate and potassium ethyl xanthogenate), allyl ethyl ether (5.69 mL, 50.0 mmol) and DLP (1.19 g, 3.0 mmol) in 1,2-dichloroethane (10 mL). FC (hexane/AcOEt 92:8) gave **20** (1.52 mg, 52%) as a yellow oil. IR (neat) 2980, 2870, 1736, 1446, 1375, 1228, 1111, 1047, 856 cm^{-1}. ^{1}H NMR (360 MHz, $CDCl_3$) δ 4.64 (*q*, J = 7.3 Hz, 2H), 4.13 (*q*, J = 7.3 Hz, 2H), 3.99−3.92 (*m*, 1H), 3.68 (*dd*, J = 10.0, 4.25 Hz, 1H), 3.57−3.44 (*m*, 3H), 2.56−2.42 (*m*, 2H), 2.29−2.20 (*m*, 1H), 1.99−1.88 (*m*, 1H), 1.42 (*t*, J = 7.3 Hz, 3H), 1.25 (*t*, J = 7.3 Hz, 3H), 1.19 (*t*, J = 7.3 Hz, 3H). ^{13}C NMR (50 MHz, $CDCl_3$) δ 213.8, 172.8, 71.9, 69.9, 66.5, 60.3, 49.8, 31.6, 26.3, 14.9, 14.1, 13.7. MS (EI, 70 eV) *m*/*z* 295 (M + 1, 20), 250 (11), 249 (94), 172 (94), 161 (16), 143 (12), 127 (22), 98 (100), 85 (86), 59 (14). Anal. Calcd for $C_{12}H_{22}O_4S_2$ (294.42): C, 48.95; H, 7.53. Found: C, 48.89; H, 7.42.

Ethyl 4-Azido-5-ethoxypentanoate (21). 21 was prepared according to procedure B from **20** (295 mg, 1.0 mmol) and DLP (339 mg, 0.85 mmol). Filtration (hexane/AcOEt 90:10) and two successive FCs (hexane/AcOEt 95:5) gave **21** (144 mg, 67%) as a colorless oil. IR (neat) 2978, 2931, 2874, 2102, 1736, 1446, 1377, 1271, 1178, 1120, 1031, 860 cm^{-1}. ^{1}H NMR (500 MHz, $CDCl_3$) δ 4.14 (*q*, J = 7.15 Hz, 2H), 3.59−3.45 (*m*, 5H), 2.49−2.38 (*m*, 2H), 1.89−1.82 (*m*, 1H), 1.74−1.66 (*m*, 1H), 1.26 (*t*, J = 7.15 Hz, 3H), 1.21 (*t*, J = 7.05 Hz, 3H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 172.8, 73.0, 66.8, 60.8, 60.5, 30.6, 26.1, 15.0, 14.1. MS (CI, CH_4) *m*/*z* 216 (20), 188 (17), 173 (37), 142 (30), 129 (60), 114 (20), 100 (100), 85 (23), 70 (10), 59 (29). Anal. Calcd for $C_9H_{17}N_3O_3$ (215.25): C, 50.22; H, 7.96; N, 19.52. Found: C, 50.34; H, 7.93; N, 19.51.

Ethyl 5-(Acetyloxy)-4-[(ethoxycarbothioyl)sulfanyl]pentanoate (22). 22 was prepared according to procedure G from ethyl 2-[(ethoxycarbothioyl)sulfanyl]acetate (1.47 g, 7.0 mmol), allyl acetate (1.52 mL, 14.0 mmol), and DLP (80 mg, 0.20 mmol) in 1,2-dichloroethane (5 mL). FC (hexane/AcOEt 85:15) gave **22** (1.60 g, 74%) as a yellow oil. IR (neat) 2982, 1739, 1446, 1379, 1222, 1112, 1037, 854 cm^{-1}. ^{1}H NMR (360 MHz, $CDCl_3$) δ 4.64 (*q*, J = 7.3 Hz, 2H), 4.31 (*dd*, J = 11.3, 4.9 Hz, 1H), 4.23 (*dd*, J = 11.3, 6.0 Hz, 1H), 4.14 (*q*, J = 7.3 Hz, 2H), 4.05−3.98 (*m*, 1H), 2.57−2.41 (*m*, 1H), 2.21−2.12 (*m*, 1H), 2.08 (*s*, 3H), 1.98−1.87 (*m*, 1H), 1.42 (*t*, J = 7.3 Hz, 3H), 1.26 (*t*, J = 7.3 Hz, 3H). ^{13}C NMR (50 MHz, $CDCl_3$) δ 212.6, 172.4, 170.4, 70.2, 65.4, 60.5, 48.7, 31.4, 25.9, 20.6, 14.1, 13.6. MS (EI, 70 eV) *m*/*z* 309 (M + 1, 8), 249 (100), 187 (35), 161 (22), 145 (15), 127 (25), 99 (19), 85 (12), 55 (8). Anal. Calcd for $C_{12}H_{20}O_5S_2$ (308.41): C, 46.73; H, 6.54. Found: C, 46.84; H, 6.47.

Ethyl 4-Azido-5-acetyloxypentanoate (23). 23 was prepared according to procedure B from **22** (308 mg, 1.0 mmol) and DLP (339 mg, 0.85 mmol). Filtration (hexane/Et_2O 85:15) afforded a mixture of **23** and $EtSO_2N_3$. Removal of $EtSO_2N_3$ at 55−60 °C by a stream of nitrogen and FC (hexane/Et_2O 85:15) gave **23** (165 mg, 72%) as a colorless oil. IR (neat) 2984, 2941, 2112, 1739, 1450, 1369, 1228, 1180, 1045, 862 cm^{-1}. ^{1}H NMR (500 MHz, $CDCl_3$) δ 4.23 (*dd*, J = 11.5, 3.9 Hz, 1H), 4.15 (*q*, J = 7.15 Hz, 2H), 4.08 (*dd*, J = 11.5, 7.65 Hz, 1H), 3.70−3.65 (*m*, 1H), 2.51−2.41 (*m*, 2H), 2.11 (*s*, 3H), 1.91−1.84 (*m*, 1H), 1.76−1.68 (*m*, 1H), 1.27 (*t*, J = 7.15 Hz, 3H). ^{13}C NMR (125

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MHz, $CDCl_3$) δ 172.5, 170.5, 66.3, 60.7, 59.8, 30.3, 26.0, 20.6, 14.1. MS (CI, CH_4) *m*/*z* 230 (37), 202 (13), 187 (24), 170 (41), 160 (65), 142 (23), 128 (13), 114 (100), 96 (33), 72 (16). Anal. Calcd for $C_9H_{15}N_3O_4$ (229.23): C, 47.16; H, 6.60; N, 18.33. Found: C, 47.27; H, 6.54; N, 18.30.

3-(Acetyloxy)-2-[(acetyloxy)methyl]-6-[(ethoxycarbothioyl)sulfanyl]tetrahydro-2*H*-pyran-4-yl-acetate (24). A solution of HBr (33% in AcOH, 16 mL) was added dropwise to a solution of 3,6-bis-(acetyloxy)-2-[(acetyloxy)methyl] tetrahydro-2*H*-pyran-4-yl acetate (3.32 g, 10.0 mmol) in CH_2Cl_2 and the mixture was stirred at 0 °C for 90 min under N_2. The reaction mixture was poured onto ice and extracted with CH_2Cl_2 (2 × 20 mL). The organic layer was washed with saturated $NaHCO_3$ (2 × 30 mL) and brine, dried over $MgSO_4$, and concentrated in vacuo. The residue was immediately treated by potassium ethyl xanthogenate (2.4 g, 15.0 mmol) in acetonitrile (52 mL) at room temperature. After 6 h, H_2O (30 mL) was added and the aqueous phase was extracted with CH_2Cl_2 (2 × 30 mL). The organic layer was dried over $MgSO_4$ and concentrated in vacuo. The residue was purified by FC (hexane/AcOEt 70:30) to afford **8** (2.4 mg, 62%) as a white solid. For analytical purposes, a sample was recrystallized from EtOH at 4 °C. Mp 98−99 °C (lit.[38] mp 99−100 °C). $[\alpha]_D^{22}$ −34.8 (*c* 0.615, $CHCl_3$) [lit.[38] $[\alpha]_D^{20}$ −32 ($CHCl_2CHCl_2$)]. IR (neat) 3016, 2959, 2885, 1730, 1458, 1369, 1309, 1242, 1041, 964, 916, 812, 605 cm^{-1}. ^1H NMR (360 MHz, $CDCl_3$) δ 5.47 (*dd*, *J* = 12.5, 2.1 Hz, 1H), 5.12 (*ddd*, *J* = 9.5, 10.7, 5.2 Hz, 1H), 5.02 (*t*, *J* = 9.4 Hz, 1H), 4.65 (*q*, *J* = 7.3 Hz, 1H), 4.27 (*dd*, *J* = 12.5, 5.2 Hz, 1H), 4.10 (*dd*, *J* = 12.5, 2.1 Hz, 1H), 3.75 (*ddd*, *J* = 9.7, 4.9, 2.1 Hz, 1H), 2.47 (*ddd*, *J* = 12.5, 5.2, 2.1 Hz, 1H), 2.07 (*s*, 3H), 2.05 (*s*, 3H), 2.04 (*s*, 3H), 1.98 (*dd*, *J* = 23.3, 12.5 Hz, 1H), 1.42 (*t*, *J* = 7.3 Hz, 3H). ^{13}C NMR (50 MHz, $CDCl_3$) δ 210.0, 170.6, 170.1, 169.6, 82.0, 76.3, 71.6, 70.3, 68.3, 62.2, 34.6, 20.8, 20.7, 20.6, 13.6. MS (EI, 70 eV) *m*/*z* 273 (M − SCSOEt, 35), 213 (100), 171 (11), 153 (95), 111 (87), 97 (9), 61 (4). Anal. Calcd for $C_{15}H_{22}O_8S_2$ (394.45): C, 45.67; H, 5.62. Found: C, 45.67; H, 5.54.

3-(Acetyloxy)-2-[(acetyloxy)methyl]-6-azidotetrahydro-2*H*-pyran-4-yl-acetate (25). (a) Prepared according to procedure B from **24** (394 mg, 1.0 mmol) and DLP (358 mg, 0.9 mmol): Two successive FCs (hexane/AcOEt 75:25) gave **25** (232 mg, 74%) as a white solid. For analytical purposes, a sample was recrystallized from EtOH at 4 °C. Colorless crystals. Mp 91−93 °C. $[\alpha]_D^{20}$ + 249.3 (*c* 0.355, $CHCl_3$). IR (neat) 2982, 2960, 2112, 1743, 1454, 1383, 1230, 1101, 1076, 1053, 972, 918 cm^{-1}. ^1H NMR (500 MHz, $CDCl_3$) δ 5.53 (*dd*, *J* = 4.2, 1.35 Hz, 1H), 5.21 (*dddd*, *J* = 11.3, 9.4, 5.1, 0.4 Hz, 1H), 5.00 (*t*, *J* = 9.6 Hz, 1H), 4.32 (*dd*, *J* = 12.6, 5.1 Hz, 1H), 4.14−4.10 (*m*, 2H), 2.17 (*ddd*, *J* = 13.2, 5.4, 1.5 Hz, 1H), 2.10 (*s*, 3H), 2.05 (*s*, 3H), 2.01 (*s*, 3H), 1.85 (*ddd*, *J* = 13.2, 11.4, 4.7 Hz, 1H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 170.6, 170.0, 169.7, 86.6, 70.1, 68.7, 68.3, 62.0, 34.2, 20.8, 20.7, 20.6. MS (CI, CH_4) *m*/*z* 316 (MH^+, 1), 273 (23), 256 (25), 228 (12), 213 (100), 186 (15), 168 (8), 153 (49), 126 (5), 111 (5). Anal. Calcd for $C_{12}H_{17}N_3O_7$ (315.28): C, 45.72; H, 5.43; N, 13.33. Found: C, 45.75; H, 5.32; N, 13.21.

(b) Prepared according to procedure D from **24** (395 mg, 1.0 mmol), $PhSO_2N_3$ (550 mg, 3.0 mmol), $(Bu_3Sn)_2$ (0.76 mL, 1.5 mmol), and DTBHN (26 mg, 0.15 mmol) added by (5.2 mg, 0.03 mmol) portions every 90 min. Filtration (hexane then hexane/AcOEt 75:25) and FC (hexane/AcOEt 75:25) gave **25** (219 mg, 70%).

4-Bromo-1-[(4-methylphenyl)sulfonyl]piperidine (26). A solution of 1-[(4-methylphenyl)sulfonyl]-4-piperidinyl 4-methylbenzenesulfonate (2.04 g, 5.0 mmol) and LiBr (1.08 mg, 12.5 mmol) in DMF (20 mL) was stirred for 36 h at 50 °C under N_2. The crude mixture was dissolved in Et_2O (50 mL), washed with water (6 × 30 mL) and brine (20 mL), dried over $MgSO_4$, filtered, and concentrated under reduced pressure. The crude material was purifed by FC (hexane/AcOEt 85:15) to afford **26** (1.19 g, 75%) as white needles. Mp 141−143 °C. IR (KBr) 2964, 2924, 2874, 1597, 1477, 1444, 1344, 1309, 1244, 1207, 1161, 1091, 1051, 1008, 927, 858, 812, 744, 713, 696, 651, 578, 551 cm^{-1}. ^1H NMR (500 MHz, $CDCl_3$) δ 7.65 (*d*, *J* = 8.3 Hz, 2H), 7.34 (*d*, *J* = 8.2 Hz, 2H), 4.26−4.22 (*m*, 1H), 3.19 (*ddd*, *J* = 12, 8.1, 3.5 Hz, 2H), 3.10 (*ddd*, *J* = 12, 7.0, 3.8 Hz, 2H), 2.44 (*s*, 3H), 2.22−2.16 (*m*, 2H), 2.08−2.02 (*m*, 2H). ^{13}C NMR (90 MHz, $CDCl_3$) δ 143.7, 133.2, 129.7 (2CH), 127.6 (2CH), 47.8, 43.7 ($2CH_2$), 34.6 ($2CH_2$), 21.5. MS (CI, CH_4) *m*/*z* (%) 318 (MH^+, 77), 320 (MH^+, 78), 238 (100). Anal. Calcd for $C_{12}H_{16}BrNO_2S$ (318.23): C, 45.29; H, 5.07. Found: C, 45.22; H, 5.11.

2-(3-Iodopropyl)-1*H*-isoindolone-1,3(2*H*)-dione (27). A suspension of 2-(3-bromopropyl)-1*H*-isoindolone-1,3(2*H*)-dione (2.67 g, 10.0 mmol), prepared from phthalimide potassium salt and 1,3-dibromopropane according to a literature procedure,[39] and NaI (3.38 g, 22.5 mmol) in acetone (30 mL) was heated at reflux for 24 h. The reaction mixture was concentrated and the resulting oil was dissolved in Et_2O (100 mL) and washed with H_2O (50 mL). The organic layer was separated and washed with H_2O (20 mL), 10% $Na_2S_2O_3$ (30 mL), and brine, dried over $MgSO_4$, and concentrated in vacuo. The residue was purified by FC (hexane/AcOEt 85:15) to afford **27** (2.27 g, 73%), as a white solid. Mp 87−89 °C. IR (KBr) 2978, 2924, 1763, 1703, 1612, 1462, 1435, 1402, 1371, 1330, 1305, 1197, 1170, 1085, 1055, 993, 958, 868, 723, 530 cm^{-1}. ^1H NMR (360 MHz, $CDCl_3$) δ 7.86 (*dd*, *J* = 5.5, 3.2 Hz, 2H), 7.73 (*dd*, *J* = 5.5, 3.2 Hz, 2H), 3.78 (*t*, *J* = 6.8 Hz, 2H), 3.17 (*t*, *J* = 6.8 Hz, 2H), 2.25 (*quint*, *J* = 6.8 Hz, 2H). ^{13}C NMR (90 MHz, $CDCl_3$) δ 168.1 (2C), 134.0 (2CH), 131.9 (2C), 123.2 (2CH), 38.5, 32.5, 1.16. MS (CI,CH_4) *m*/*z* 316 (MH^+, 100), 188 (96), 160 (18). HRMS for $C_{11}H_{11}NO_2I$ [MH^+] 315.9836, found 315.9828.

2-(3-Azidopropyl)-1*H*-isoindolone-1,3(2*H*)-dione (28). Prepared according to procedure C from **27** (158 mg, 0.5 mmol), $PhSO_2N_3$ (275 mg, 1.5 mmol), and $(Bu_3Sn)_2$ (0.38 mL, 0.75 mmol): The reaction was completed after 8 h. Filtration (hexane then hexane/AcOEt 85:15) and FC (hexane/AcOEt 85:15) gave **28** (35 mg, 30%). Colorless oil. IR (neat) 2941, 2874, 2102, 1772, 1712, 1614, 1468, 1437, 1396, 1375, 1261, 1138, 1039, 899, 721 cm^{-1}. ^1H NMR (500 MHz, $CDCl_3$) δ 7.86 (*dd*, *J* = 5.5, 3.0 Hz, 2H), 7.73 (*dd*, *J* = 5.5, 3.0 Hz, 2H), 3.79 (*t*, *J* = 6.8 Hz, 2H), 3.38 (*t*, *J* = 6.8 Hz, 2H), 1.96 (*quint*, *J* = 6.8 Hz, 2H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 168.3 (2C), 134.1 (2CH), 132.0 (2C), 123.3 (2CH), 49.1, 35.4, 28.1. MS (CI,CH_4) *m*/*z* 231 (MH^+, 2), 199 (10), 188 (15), 174 (40), 160 (19), 148 (7), 57 (100). Anal. Calcd for $C_{11}H_{10}N_4O_2$ (230.22): C, 57.39; H, 4.38; N, 24.34. Found: C, 57.43; H, 4.31; N, 24.35.

(b) Prepared according to procedure D from **27** (158 mg, 0.5 mmol), $PhSO_2N_3$ (275 mg, 1.5 mmol), $(Bu_3Sn)_2$ (0.38 mL, 0.75 mmol), and DTBHN (104 mg, 0.6 mmol) added by (17 mg, 0.1 mmol) portions every 1 h: Filtration (hexane then hexane/AcOEt 85:15) and FC (hexane/AcOEt 85:15) gave **28** (39 mg, 34%).

3,5-Bis(Acetyloxy)-2-[(acetyloxy)methyl]-6-[(ethoxycarbothioyl)-sulfanyl] tetrahydro-2*H*-pyran-4-yl-acetate (29). Acetobromo-α-D-glucose (2.5 g, 6.0 mmol) was treated by potassium ethyl xanthogenate (1.44 g, 9.0 mmol) in acetonitrile (30 mL) at room temperature under N_2. After 3 h, H_2O (30 mL) was added and the aqueous phase was extracted with CH_2Cl_2 (2 × 30 mL). The organic layer was dried over $MgSO_4$ and concentrated in vacuo. The residue was purified by FC (hexane/AcOEt 70:30 then 60:40) to afford **29** (2.34 g, 86%) as a syrup. The residue was recrystallized from EtOH at 4 °C. White solid. Mp 78−80 °C (lit.[40] mp 75−76 °C). $[\alpha]_D^{20}$ +33.6 (*c* 0.530, $CHCl_3$) [lit.[40] $[\alpha]_D^{18}$ +30 ($CHCl_3$)]. IR (neat) 2995, 2951, 1755, 1730, 1433, 1367, 1298, 1280, 1236, 1215, 1085, 1043, 913, 895, 814 cm^{-1}. ^1H NMR (500 MHz, $CDCl_3$) δ 5.47 (*d*, *J* = 10.6 Hz, 1H), 5.32 (*t*, *J* = 9.3 Hz, 1H), 5.18 (*dd*, *J* = 10.6, 9.2 Hz, 1H), 5.12 (*dd*, *J* = 10.2, 9.4 Hz, 1H), 4.65 (*q*, *J* = 7.1 Hz, 1H), 4.25 (*dd*, *J* = 12.5, 4.9 Hz, 1H), 4.13 (*dd*, *J* = 12.5, 2.2 Hz, 1H), 3.84 (*ddd*, *J* = 10.2, 4.9, 2.3 Hz, 1H), 2.07 (*s*, 3H), 2.04 (*s*, 3H), 2.03 (*s*, 3H), 2.01 (*s*, 3H), 1.42 (*t*, *J* = 7.1 Hz, 3H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 210.0, 170.6, 170.1, 169.4, 169.3, 85.8, 76.5, 74.0, 70.7, 68.5, 68.3, 61.7, 20.7 ($2CH_3$), 20.6 ($2CH_3$), 13.6. MS (CI, CH_4) *m*/*z* 331 (MH^+ − HSCSOEt, 100), 271 (14), 169 (56), 109 (13), 61 (16). Anal. Calcd for $C_{17}H_{24}O_{10}S_2$ (452.49): C, 45.13; H, 5.35. Found: C, 45.13; H, 5.43.

3,5-Bis(Acetyloxy)-2-[(acetyloxy)methyl]-6-azidotetrahydro-2*H*-pyran-4-yl-acetate (30). 30 was prepared according to procedure D from **29** (453 mg, 1.0 mmol), $PhSO_2N_3$ (550 mg, 3.0 mmol), $(Bu_3Sn)_2$ (0.76 mL, 1.5 mmol), and DTBHN (31 mg, 0.18 mmol) added by (5

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mg, 0.03 mmol) portions every 90 min. Filtration (hexane, hexane/AcOEt 70:30 then 60:40) and FC (hexane/AcOEt 70:30) gave **30** (139 mg, 37%) as a white solid. For analytical purpose, a sample was recrystallized from EtOH at 4 °C. Colorless crystals. Mp 102−103 °C. $[\alpha]_D^{22}$ +172.1 (*c* 0.380, $CHCl_3$). IR (neat) 2966, 2118, 1753, 1431, 1369, 1236, 1111, 1066, 1043, 918 cm^{-1}. ^1H NMR (500 MHz, $CDCl_3$) δ 5.60 (*d*, *J* = 4.3 Hz, 1H), 5.39 (*t*, *J* = 9.7 Hz, 1H), 5.05 (*t*, *J* = 10.1 Hz, 1H), 4.95 (*dd*, *J* = 10.1, 4.4 Hz, 1H), 4.27 (*dd*, *J* = 12.5, 4.6 Hz, 1H), 4.18−4.12 (*m*, 2H), 2.11 (*s*, 3H), 2.10 (*s*, 3H), 2.03 (*s*, 3H), 2.02 (*s*, 3H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 170.5, 169.9 (2C), 169.4, 86.1, 70.1, 69.6, 69.5, 67.8, 61.5, 20.7, 20.6, 20.5 ($2CH_3$). MS (CI, CH_4) *m*/*z* 331 ($MH^+ - HN_3$, 100), 314 (14), 271 (27), 169 (52), 139 (14). Anal. Calcd for $C_{14}H_{19}N_3O_9$ (373.32): C, 45.04; H, 5.13; N, 11.26. Found: C, 45.13; H, 5.06; N, 11.16.

Methyl 3-(2-Cyclohexen-1-yloxy)-3-(ethyloxy)-2-iodopropanoate (31). To a solution of 2-cyclohexen-1-ol (1.1 mL, 11.0 mmol) and methyl (*E*)-3-ethoxy-2-propenoate[41] (1.69 g, 13.0 mmol) in dry CH_2Cl_2 (10 mL) was added *N*-iodosuccinimide (2.92 g, 13.0 mmol) portionwise at 0 °C under N_2. After 30 h at room temperature, the reaction mixture was diluted with CH_2Cl_2 (20 mL), washed with water (20 mL), 10% $Na_2S_2O_3$ (20 mL), and brine, dried over $MgSO_4$, and concentrated in vacuo. The residue was purified by FC (hexane/AcOEt 95:5 then 90:10) to afford **31** (2.94 g, 86%) as a 50:50 mixture of two isomers (^1H NMR). Orange oil. IR (neat) 3028, 2934, 1740, 1437, 1373, 1346, 1304, 1253, 1203, 1103, 1039, 941, 727 cm^{-1}. ^1H NMR (360 MHz, $CDCl_3$) δ 5.90−5.82 (*m*, 2H, two diastereomers), 5.71−5.62 (*m*, 2H, two diastereomers), 5.07 (*d*, *J* = 2.7 Hz, 1H, one diast.), 5.04 (*d*, *J* = 2.7 Hz, 1H, one diastereomer), 4.44 (*s*, 1H, one diastereomer), 4.42 (*s*, 1H, one diastereomer), 4.20−4.13 (*m*, 2H, two diastereomers), 3.74 (*s*, 6H, two diastereomers), 3.71−3.57 (*m*, 4H, two diastereomers), 2.08−1.47 (*m*, 12H, two diastereomers), 1.25 (*t*, 6H, two diastereomers). ^{13}C NMR (90 MHz, $CDCl_3$) δ 169.6 (two diastereomers), 131.5 (one diastereomer), 131.1 (one diastereomer), 127.1 (one diastereomer), 126.7 (one diastereomer), 101.4 (one diastereomer), 100.5 (one diastereomer), 72.1 (one diastereomer), 71.1 (one diastereomer), 60.6 (one diastereomer), 60.1 (one diastereomer), 52.7 (one diastereomer), 52.6 (one diastereomer), 29.6 (one diastereomer), 27.9 (one diastereomer), 24.9 (one diastereomer), 24.8 (one diastereomer), 21.3 (one diastereomer), 21.0 (one diastereomer), 18.9 (one diastereomer), 18.4 (one diastereomer), 15.0 (one diastereomer), 14.9 (one diastereomer). MS (CI, CH_4) *m*/*z* 257 (50), 225 (39), 207 (10), 131 (33), 103 (20), 97 (82), 82 (100), 69 (9). HRMS for $C_{12}H_{20}IO_4$ [MH^+]: calcd 355.0408; found 355.0402.

Methyl 4-Azido-2-(ethyloxy)octahydro-1-benzofuran-3-carboxylate (32). 32 was prepared according to procedure D from **31** (354 mg, 1.0 mmol), $PhSO_2N_3$ (550 mg, 3.0 mmol), $(Bu_3Sn)_2$ (0.76 mL, 1.5 mmol), and DTBHN (11 mg, 0.06 mmol). Filtration (hexane then hexane/AcOEt 80:20) and three successive FCs (hexane/AcOEt 95:5, 90:10 then 80:20) gave **32** (207 mg, 77%) as a 53:47 mixture of two diastereomers (^1H NMR). Colorless oil. **32a** (less polar):^1H NMR (500 MHz, $CDCl_3$) δ 5.48 (*d*, *J* = 4.9 Hz, 1H), 4.32−4.29 (*m*, 1H), 3.76 (*qd*, *J* = 9.5, 7.1 Hz, 1H), 3.75 (*s*, 1H), 3.50 (*qd*, *J* = 9.5, 7.1 Hz, 1H), 3.31 (*ddd*, *J* = 12.1, 10.6, 4.3 Hz, 1H), 3.12 (*dd*, *J* = 6.6, 4.9 Hz, 1H), 2.20 (*ddd*, *J* = 10.5, 6.6, 3.5 Hz, 1H), 2.08−2.00 (*m*, 2H), 1.68−1.45 (*m*, 3H), 1.36−1.27 (*m*, 3H), 1.19 (*t*, *J* = 7.1 Hz, 3H). NOE difference spectra for **32a** (less polar) (500 MHz): 5.49−5.47 (EtOC*H*) → 3.74−3.76 (5.27%), 3.36−3.29 (3.55%); 4.32−4.29 (EtOCHOC*H*) → 3.14−3.11 (4.08%), 2.22−2.17 (6.53%); 3.36−3.29 (N_3CH) → 5.49−5.47 (3.52%); 3.14−3.11 (MeOOCC*H*) → 5.49−5.47 (1.56%), 4.32−4.29 (3.24%); 2.22−2.17 (6.17%); 2.22−2.17 (MeOOCHC*H*CHN_3) → 4.32−4.29 (5.78%); 3.14−3.11 (7.60%). ^{13}C NMR (125 MHz) δ 171.5, 104.8, 77.1, 64.3, 58.0, 55.2, 52.1, 47.6, 30.2, 26.8, 18.8, 15.2.

32b (more polar): ^1H NMR (500 MHz, $CDCl_3$) δ 5.28 (*d*, *J* = 1.9 Hz, 1H), 4.25−4.22 (*m*, 1H), 3.78 (*qd*, *J* = 9.5, 7.1 Hz, 1H), 3.74 (*s*, 1H), 3.68 (*ddd*, *J* = 10.9, 9.5, 4.3 Hz, 1H), 3.52 (*qd*, *J* = 9.5, 7.1 Hz, 1H), 3.06 (*t*, *J* = 2.2 Hz, 1H), 2.18 (*ddd*, *J* = 9.3, 4.8, 2.5 Hz, 1H), 2.06−1.95 (*m*, 2H), 1.67−1.53 (*m*, 3H), 1.43−1.36 (*m*, 3H), 1.22 (*t*, *J* = 7.1 Hz, 3H). NOE difference spectra for **32b** (more polar) (500 MHz): 5.28−5.27 (EtOC*H*) → 4.25−4.22 (1.34%), 3.55−3.48 (4.70%), 3.08−3.04 (2.35%); 4.25−4.22 (EtOCHOC*H*) → 5.28−5.27 (1.59%), 2.20−2.14 (6.58%); 3.55−3.48 ($CH_3CHHOCH$) → 5.28−5.27 (4.38%), 3.81−3.74 (9.60%); 3.08−3.04 (MeOOCC*H*) → 5.28−5.27 (2.52%), 3.71−3.66 (4.89%); 2.20−2.14 (2.40%); 2.20−2.14 (MeOOCH-C*H*CHN_3) → 4.25−4.22 (5.64%), 3.08−3.04 (2.42%). ^{13}C NMR (125 MHz) δ 172.1, 105.4, 77.4, 64.3, 60.0, 55.1, 52.3, 45.8, 29.1, 27.5, 18.8, 15.3.**32** (mixture of diastereomers): IR (neat) 2941, 2870, 2100, 1738, 1439, 1377, 1201, 1095, 1010 cm^{-1}. MS (CI, CH_4) *m*/*z* 270 (MH^+, 4), 224 (100), 195 (12), 181 (13), 153 (17), 136 (8). Anal. Calcd for $C_{12}H_{19}N_3O_4$ (269.30): C, 53.52; H, 7.11; N, 15.60. Found: C, 53.62; H, 7.10; N, 15.69.

3-Iodo-2-[(3-methyl-2-butenyl)oxy]tetrahydro-2*H*-pyran (33). To a solution of 3-methyl 2-buten-1-ol (1.0 mL, 10.0 mmol) and 3,4-dihydropyran (1.1 mL, 12.0 mmol) in dry CH_2Cl_2 (10 mL) was added *N*-iodosuccinimide (2.25 g, 10.0 mmol) portionwise at −30 °C under N_2. After 3 h, the reaction mixture was diluted with CH_2Cl_2 (20 mL), washed with water (20 mL), 10% $Na_2S_2O_3$ (20 mL), and brine, dried over $MgSO_4$, and concentrated in vacuo.The residue was purified by FC (hexane/Et_2O 90:10) to afford **33** (2.76 g, 93%). Colorless oil. IR (neat) 2945, 2853, 1439, 1377, 1354, 1201, 1122, 1068, 1018, 941, 868 cm^{-1}. ^1H NMR (360 MHz, $CDCl_3$) δ 5.36 (*t*, *J* = 6.8 Hz, 1H), 4.66 (*d*, *J* = 5.4 Hz, 1H), 4.21 (*dd*, *J* = 11.7, 6.8 Hz, 1H), 4.12−3.96 (*m*, 3H), 3.58 (*ddd*, *J* = 11.8, 7.3, 3.2 Hz, 1H), 2.42−2.34 (*m*, 1H), 2.06−1.97 (*m*, 1H), 1.81−1.71 (*m*, 1H), 1.76 (*s*, 3H), 1.69 (*s*, 3H), 1.63−1.52 (*m*, 1H). ^{13}C NMR (90 MHz, $CDCl_3$) δ 137.9, 120.0, 101.3, 64.4, 63.4, 32.7, 29.5, 25.7, 25.5, 18.0. MS (CI, CH_4) *m*/*z* 297 (MH^+, 1), 211 (18), 70 (100). Anal. Calcd for $C_{10}H_{17}IO_2$ (296.15): C, 40.56; H, 5.79. Found: C, 40.63; H, 5.74.

3-(1-Azido-1-methylethyl)hexahydro-4*H*-furo[2,3-b]pyran (34). **34** was prepared according to procedure D from **33** (296 mg, 1.0 mmol), $PhSO_2N_3$ (550 mg, 3.0 mmol), $(Bu_3Sn)_2$ (0.76 mL, 1.5 mmol), and DTBHN (11 mg, 0.06 mmol). Filtration (hexane then hexane/AcOEt 70:30) and FC (hexane/AcOEt 80:20) gave **34** (193 mg, 91%) as a 61:39 mixture of two isomers (^1H NMR). Colorless oil. IR (neat) 2939, 2887, 2100, 1450, 1371, 1263, 1149, 1037, 953, 897 cm^{-1}. ^1H NMR (500 MHz, $CDCl_3$) δ 5.23 (*d*, *J* = 3.5 Hz, 1H, one diastereomer), 5.02 (*d*, *J* = 3.8 Hz, 1H, one diastereomer), 4.16 (*t*, *J* = 8.9 Hz, 1H, one diastereomer), 4.00 (*dd*, *J* = 11.0, 7.9 Hz, 1H, one diastereomer), 3.92−3.87 (*m*, 1H, one diastereomer), 3.90 (*t*, *J* = 7.9 Hz, 1H, one diastereomer), 3.80−3.75 (*m*, 2H, two diastereomers), 3.67−3.63 (*m*, 1H, one diastereomer), 3.44 (*ddd*, *J* = 11.5, 10.7, 2.6 Hz, 1H, one diastereomer), 2.33−2.28 (*m*, 2H, two diastereomers), 2.10−1.38 (*m*, 10H, two diastereomers), 1.39 (*s*, 3H, one diastereomer), 1.31 (s, 3H, one diastereomer), 1.30 (*s*, 3H, one diastereomer), 1.27 (s, 3H, one diastereomer). ^{13}C NMR (90 MHz, $CDCl_3$) δ 102.2, 101.2, 69.0, 64.6, 64.2, 62.7, 60.9, 60.3, 50.4, 47.9, 39.6, 36.3, 26.7, 25.5, 24.8, 24.5, 23.9, 23.2, 20.8, 20.1. MS (CI, CH_4) *m*/*z* 212 (MH^+, 21), 184 (44), 169 (62), 154 (28), 139 (100), 100 (50), 71 (17), 98 (29), 58 (18). Anal. Calcd for $C_{10}H_{17}N_3O_2$ (211.26): C, 56.85; H, 8.11; N, 19.89. Found: C, 56.83; H, 8.20; N, 19.94.

3-Iodo-2-(2-propenyloxy)tetrahydro-2*H*-pyran (35). To a solution. of allylic alcohol (0.68 mL, 10.0 mmol) and 3,4-dihydropyran (1.1 mL, 12 mmol) in dry CH_2Cl_2 (10 mL) was added *N*-iodosuccinimide (2.25 g, 10.0 mmol) portionwise at −30 °C under N_2. After 3 h, the reaction mixture was diluted with CH_2Cl_2 (20 mL), washed with water (20 mL), 10% $Na_2S_2O_3$ (20 mL), and brine, dried over $MgSO_4$, and concentrated in vacuo. The residue was purified by FC (hexane/Et_2O 90:10) to afford **35** (2.56 g, 95%). Colorless oil. IR (neat) 2945, 2851, 1435, 1377, 1352, 1201, 1122, 1068, 1026, 943, 866, 696 cm^{-1}. ^1H NMR (360 MHz, $CDCl_3$) δ 5.99−5.88 (*m*, 1H), 5.33 (*d*, *J* = 17.2 Hz, 1H), 5.21 (*d*, *J* = 10.4 Hz, 1H), 4.68 (*d*, *J* = 5.4 Hz, 1H), 4.26 (*dd*, *J* = 12.7, 5.4 Hz, 1H), 4.14−3.96 (*m*, 3H), 3.59 (*ddd*, *J* = 11.3, 7.7, 3.6 Hz, 1H), 2.43−2.34 (*m*, 1H), 2.07−1.97 (*m*, 1H), 1.82−1.73 (*m*, 1H), 1.63−1.53 (*m*, 1H). ^{13}C NMR (90 MHz, $CDCl_3$) δ 133.9, 117.3, 101.4, 68.8, 63.3, 32.6, 29.2, 25.5. MS (CI, CH_4) *m*/*z* 269 (MH^+, 1), 211 (100), 141 (90), 101 (22), 85 (21), 72 (14), 56 (6). Anal. Calcd for $C_8H_{13}IO_2$ (268.09): C, 35.84; H, 4.89. Found: C, 35.95; H, 4.84.

3-(Azidomethyl)hexahydro-4*H*-furo[2,3-*b*]pyran (36). **36** was prepared according to procedure D from **35** (268 mg, 1.0 mmol), $PhSO_2N_3$ (550 mg, 3.0 mmol), $(Bu_3Sn)_2$ (0.76 mL, 1.5 mmol), and DTBHN (70 mg, 0.40 mmol) added by (5.2 mg, 0.03 mmol) portions

(41) Tietze, L.-F.; Meier, H.; Voss, E. *Synthesis* **1988**, 274. Weiguny, J.; Schäfer, H. J. *Liebigs Ann. Chem.* **1994**, 225.

every 1.5 h. Filtration (hexane then hexane/AcOEt 70:30) and FC (hexane/AcOEt 80:20) gave **36** (77 mg, 42%) as a 85:15 mixture of two isomers, respectively (GC). Yellow oil. *endo*-**36 (**major): ^{1}H NMR (500 MHz, $CDCl_3$) δ 5.23 (*d*, J = 3.5 Hz, 1H), 4.01 (*t*, J = 8.3 Hz, 1H), 3.83−3.74 (*m*, 2H), 3.64−3.59 (*m*, 1H), 3.45 (*dd*, J = 7.7 Hz, 1H), 3.36 (*dd*, J = 8.0 Hz, 1H), 2.64−2.56 (*m*, 1H), 2.15−2.09 (*m*, 1H), 1.92−1.82 (*m*, 1H), 1.77−1.67 (*m*, 1H), 1.60−1.49 (*m*, 2H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 101.7, 68.3, 61.5, 50.2, 40.6, 36.3, 22.8, 19.6. *exo*-**36** (minor): ^{1}H NMR (500 MHz, $CDCl_3$) δ 5.02 (*d*, J = 3.3 Hz, 1H), 4.29 (*t*, J = 8.7 Hz, 1H), 3.69 (*dd*, J = 8.6, 7.2 Hz, 1H) characteristic signals. ^{13}C NMR (125 MHz, $CDCl_3$) δ 101.8, 71.3, 64.4, 53.5, 41.7, 38.3, 22.6, 20.5. *endo*-**36** and *exo*-**36** (mixture of diastereomers): IR (neat) 2939, 2876, 2098, 1452, 1275, 1149, 1026, 952, 898 cm^{-1}. MS (CI,CH_4) *m*/*z* 184 (MH^+, 21), 156 (100), 141 (35), 125 (35), 111 (24), 95 (55), 82 (43), 56 (8). Anal. Calcd for $C_8H_{13}N_3O_2$ (183.21): C, 52.45; H, 7.15; N, 22.94. Found: C, 52.29; H, 7.10; N, 22.76.

(2-Cyclohexen-1-yloxy)(iodomethyl)dimethylsilane (37). Under N_2, (bromomethyl)chlorodimethylsilane (1.36 mL, 10.0 mmol) was added dropwise to a solution of 2-cyclohexen-1-ol (1 mL, 10.0 mmol), triethylamine (1.55 mL, 11.0 mmol), and DMAP (122 mg, 1.0 mmol) in CH_2Cl_2 (20 mL) at 0 °C and stirred at room temperature for 1 h. The crude mixture was dissolved in CH_2Cl_2 (50 mL), washed with saturated NH_4Cl (30 mL) and brine (2 × 30 mL), dried over Na_2SO_4, filtered, and concentrated under reduced pressure. The crude material was purified by FC (hexane/Et_2O 95:5) to afford the intermediate bromide (2.35 g, 94%). A suspension of the bromide (1.24 g, 5.0 mmol) and NaI (7.49 g, 50.0 mmol) in acetone (25 mL) was heated at reflux for 24 h. The reaction mixture was dissolved in Et_2O (100 mL) and washed with H_2O (50 mL). The organic layer was separated and washed with H_2O (20 mL), 10% $Na_2S_2O_3$ (30 mL), and brine, dried over $MgSO_4$, and concentrated in vacuo. The residue was purified by FC (hexane/Et_2O 95:5) to afford **37** (1.45 g, 98%). Colorless oil. IR (neat) 3026, 2939, 2865, 1457, 1369, 1392, 1253, 1074, 1020, 885, 837, 804, 721 cm^{-1}. ^{1}H NMR (500 MHz, $CDCl_3$) δ 5.80 (*dtd*, J = 10.0,3.5, 1.3 Hz, 1H), 5.66−5.63 (*m*, 1H), 4.32−4.27 (*m*, 1H), 2.06−1.99 (*m*, 1H), 2.05 (*s*, 2H), 1.97−1.89 (*m*, 1H), 1.87−1.82 (*m*, 1H), 1.81−1.73 (*m*, 1H), 1.64−1.50 (*m*, 2H), 0.31 (*s*, 6H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 130.2, 130.0, 67.1, 32.3, 24.9, 19.4, −1.9 ($2CH_3$), −13.9. MS (CI, CH_4) *m*/*z* 297 (MH^+, 10), 296 (M, 27), 281 (7), 199 (4), 169 (32), 161 (35), 97 (7), 81 (100). Anal. Calcd for $C_9H_{17}IOSi$ (296.25): C, 36.49; H, 5.78. Found: C, 36.42; H, 5.71.

3-Azido-2-[(trimethylsilyl)methyl]cyclohexanol (39). 39 was prepared according to procedure D from **37** (282 mg, 0.95 mmol), $PhSO_2N_3$ (550 mg, 3.0 mmol), $(Bu_3Sn)_2$ (0.76 mL, 1.5 mmol), and DTBHN (16 mg, 0.09 mmol). The reaction mixture was diluted in benzene (15 mL), treated with MeLi 1.6 M in Et_2O (3.2 mL, 5.0 mmol) at 0 °C and stirred 30 min at room temperature under N_2. The resulting solution was dissolved in Et_2O (50 mL) and washed with saturated NH_4Cl (30 mL). The organic layer was separated and washed with brine, dried over $MgSO_4$, and concentrated in vacuo. Filtration (hexane then hexane/AcOEt 80:20) and FC (hexane/AcOEt 80:20) gave **39** (144 mg, 67%) as a 86:14 mixture of two isomers (^{1}H NMR). Colorless oil.

39 (major): ^{1}H NMR (360 MHz, $CDCl_3$) δ 3.96 (*br s*, 1H), 3.34 (*td*, J = 10.4, 4.0 Hz, 1H), 2.06−2.01 (*m*, 1H), 1.91−1.25 (*m*, 7H), 0.89 (*dd*, J = 14.9, 4.5 Hz, 1H), 0.70 (*dd*, J = 14.9, 9.9 Hz, 1H), 0.05 (*br s*, 9H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 69.7, 63.3, 42.9, 32.3, 18.8 (3 CH_2), −0.7 (3 CH_3).

39 (minor): ^{1}H NMR (500 MHz, $CDCl_3$) δ 3.64−3.73 (*m*, 1H) characteristic signal. ^{13}C NMR (125 MHz, $CDCl_3$) δ 71.2, 64.5, 39.8, 30.6, 15.7 (3 CH_2), −0.7 (3 CH_3).

39 (mixture of diastereomers): IR (neat) 3427, 2943, 2098, 1448, 1415, 1357, 1249, 1151, 1064, 991, 854, 760, 690 cm^{-1}. MS (CI, CH_4) *m*/*z* 228 (MH^+, 5), 212 (10), 200 (20), 184 (24), 110 (38), 96 (100), 81 (10), 56 (10). Anal. Calcd for $C_{10}H_{21}N_3OSi$ (227.38): C, 52.82; H, 9.31; N, 18.48. Found: C, 52.88; H, 9.23; N, 18.47.

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