Direct Nucleophilic Addition versus a Single-Electron Transfer Pathway of σ^H Adduct Formation in Vicarious Nucleophilic Substitution of Hydrogen

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Two mechanistic pathways of formation of σ^H adducts, which are key intermediates in the vicarious nucleophilic substitution of hydrogen, namely direct nucleophilic addition of carbanions to nitroarenes and a two-step mechanism involving an electron-transfer process, are discussed on the basis of the existing data and results of the VNS reactions in which a radical probe — chloromethyl aryl sulfone bearing a 2,2-dimethylcyclopropyl substituent — was used as the carbanion precursor.

Introduction

Vicarious Nucleophilic Substitution of hydrogen (VNS) is presently a well-established, general method for the introduction of substituents into electron-deficient aromatic rings, particularly those containing nitro groups.[1−4] The reaction is general with respect to the electron-deficient arenes and nucleophiles used, and practically all carbo- and heterocyclic nitroarenes undergo this reaction provided there are hydrogen atoms in the positions *ortho* or *para* to the nitro group. On the other hand, carbanions containing leaving groups such as halogens, ArO, RO, ArS, etc. can undergo this reaction, without limitations, provided they are sufficiently stable and active nucleophiles. Besides carbanions, anions of alkyl hydroperoxides[5−8] — *tert*-butyl and cumyl in particular — and a plethora of aminating agents such as derivatives of hydrazine,[9,10] hydroxylamine[11,12] and sulfenamide[13,14] undergo the VNS, introducing OH and NH_2 or NHR substituents, respectively, into nitroaromatic rings.

In spite of such a large field of applications the mechanistic features of this process are not well known and are essentially based on qualitative studies and observations. Since the VNS reaction is a multistep process embracing formation of the σ^H adducts and their transformation into products, a few mechanistic questions should be addressed, the most important concerning the formation of the σ^H intermediate adducts and how they are transformed into the products. The second point has been discussed in a few mechanistic papers and there is no doubt that the transformation of the σ^H adducts into the products proceeds as a base-induced β-elimination of HX.[15−19] Recently, more detailed semi-quantitative studies have disclosed an effect of base concentration on the rate of β-elimination and the relative rates of the addition and elimination steps.[18] Much less attention has been paid to the question of how the σ^H adducts are formed. Formation of the anionic σ adducts of carbanions to nitroarenes is a common initial step for the VNS reaction, the S_NAr reaction of halogens or other leaving groups in nitroaromatic rings and some other processes.[20−22] In general, two pathways are considered for this process: direct nucleophilic addition and a two-step process initiated by single-electron transfer (SET), resulting in the formation of radicals and anion radicals, followed by coupling of these paramagnetic species. The latter pathway was recently often favoured for the formation of σ^X adducts, which are intermediates in the S_NAr of halogens.[23−26] It appears, however, that the occurrence of this pathway has been overestimated and the concept often abused.[27] The possible intervention of a radical intermediate in the fluoride-promoted addition of silyl enol ethers to nitroarenes resulting in σ^H adduct formation has been investigated by RajanBabu et al.[28] They found that the reaction with *p*-nitrocumyl chloride or 4-(cyclopropyl)nitrobenzene gave normal products, and those expected from the radical-ion intermediates were not observed.

In this paper we attempt to clarify whether the anionic σ^H adducts of carbanions and nitroarenes — intermediates in the VNS reaction — are formed by direct addition or by a two-step process involving SET.

When analysing this problem, it should be taken into account that formation of the σ^H adducts by addition of carbanions to nitroarenes is a reversible process. A frequently observed influence of the reaction conditions, particularly the strength and concentration of a base on the orientation of VNS, as well as on its rate, estimated on the basis of a competition between VNS and the substitution of halogens, can only be explained by assuming the reversibility of the

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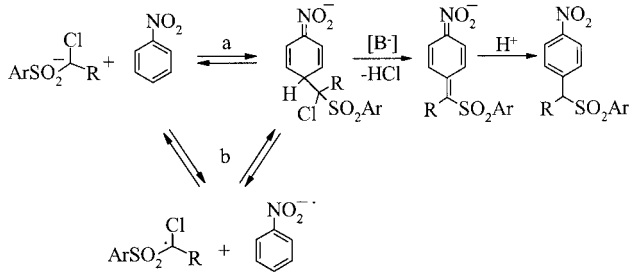
σ^H adduct formation.[15−19,29] The addition of various nucleophiles to more electrophilic polynitroarenes was also found to be a reversible process and in many cases corresponding thermodynamic data were obtained.[30,31]

A general scheme for alternative pathways of the VNS with a model α-chloroalkyl phenyl sulfone carbanion with nitrobenzene derivatives is presented in Scheme 1.



Scheme 1

According to the microreoversibility principle, formation of the σ^H adduct by a two-step SET mechanism requires that its dissociation should also occur by homolytic C−C bond cleavage, producing the nitroarene anion-radical $ArNO_2^-$ and a free radical of the chlorosulfone. The latter is poorly stabilized,[32] so this dissociation pathway seems unlikely as an alternative to the ionic process. Moreover, this dissociation should be followed by a single-electron transfer from the nitroarene radical anion to the sulfone-free radical, so the starting reactants are recovered. Thus, reversibility of the σ^H adduct formation suggests that they are formed rather by direct addition (Scheme 1, path a).

Additional arguments against SET as a step in the formation of the σ^H adducts came from the observation that the ratio of *o*- and *p*-substitution in nitrobenzene and its derivatives is strongly affected by the reaction conditions, particularly the base-solvent system. While reactions of chloromethyl aryl sulfone carbanion promoted by NaOH, *t*BuOK etc. in DMSO, DMF or liquid ammonia give *o*- and *p*-nitrobenzyl sulfones in ratios ranging from 1:2 to 2:1, depending on the kind of base and its concentration,[1−4,15,16] substitution in the presence of *t*BuOK in a less-polar solvent (THF) often proceeds selectively *ortho* to the nitro group.[15,33] It was assumed that the interaction of potassium cations of the tight ion-pairs existing in THF with the oxygen atoms of the nitro group attracts the ion pair, leading to the *ortho* addition of the carbanion to the nitroaromatic ring. Addition of 18-crown-6 to the reaction medium eliminates this effect as it binds the K^+ cations efficiently.

According to Bartoli,[34] addition of MeMgBr or EtMgBr to nitroarenes in THF gives the respective σ^H adducts *ortho* and *para* to the nitro group in ratios close to statistical in spite of the partially covalent character of C−Mg bonding and the expected efficient interactions between the magnesium cation and oxygen atoms of the nitro group. The absence of such an effect is apparently due to the mechanism of addition, which, as shown by Bartoli, proceeds by SET, hence polar effects are negligible in the σ^H adduct formation.[35]

The differences between the orientation of the addition of the Grignard reagents and halocarbanions in the VNS reaction suggest strongly that in the latter case formation of the new C−C bond in the addition is an ionic process.

The participation of radical intermediates in a formally polar reaction can be detected when the starting materials contain fragments able to enter rapid free-radical reactions. These compounds are considered as radical probes or so-called radical clocks.[37] When free radicals are real intermediates in the process the course of the reaction and the nature of the final products should change with the use of such substrates. Thus, in our attempts to clarify whether the intermediate σ^H adducts are formed by a two-step process including SET, we used aryl α-chloroalkyl sulfones, which can behave as radical clocks.

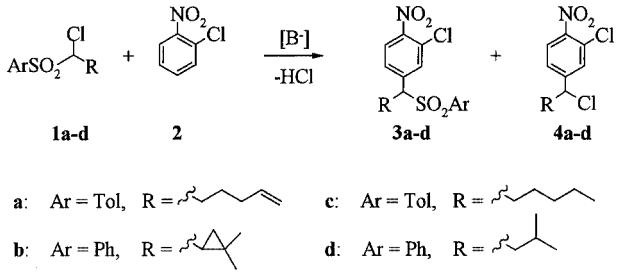
Results and Discussion

The most common and widely used radical probes are those possessing a 4-pentenyl chain attached to the carbon atom that is the potential radical centre.[36,37] When formed the 5-hexenyl radicals undergo cyclization, giving products different from those expected for processes that do not involve free radicals. Although intramolecular addition of the carbon radical to the terminal double bond is not a very fast reaction — its rate determined for unsubstituted and alkyl-substituted 5-hexenyl radicals is around 10^5 s^{-1} — there are numerous examples of the successful application of this class of radical probes. However, radicals stabilized with a sulfonyl group, when generated by tin hydride reduction of the appropriate α-halosulfone, do not cyclize efficiently,[38] whereas the corresponding α-chloro-α-sulfonyl radicals, which are of interest to us, have not yet been studied. In our hands the reaction of tributyltin hydride with 1,1-dichloro-5-hexenyl phenyl sulfone did not provide reliable data concerning the rate of cyclization of such radicals.

Nevertheless, the VNS reaction of chlorosulfone **1a** was examined and the results have been included in this work. However, for the above-mentioned reasons we turned to another type of α-chlorosulfone-derived radical probe, namely chloro(2,2-dimethylcyclopropyl)methyl phenyl sulfone (**1b**). It is well-known that the rearrangement of cyclopropylmethyl radicals into homoallylic radicals by opening of the cyclopropane ring is one of the fastest known processes among alkyl-radical transformations.[36,37,39,40] We have previously used an analogous compound for studies of the halophilic reaction, the halogen exchange between carbanions and dimerization of carbanions.[41] In those studies we found that the ring-opening reaction of chloro(2,2-dimethylcyclopropyl)methyl tolyl sulfone radical, generated by Bu_3SnH/AIBN reduction of the corresponding dichloro derivative, proceeds with a very high rate constant (approx. 10^9 s^{-1}). A radical probe of a similar structure — cyclopropylmethyl phenyl sulfone — was later used by Chanon in studies on radical intermediates in reactions of α-sulfonyl carbanions with polyhalomethanes.[42] However, the rate

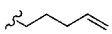
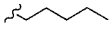
constant of the free-radical rearrangement of this cyclopropylmethyl derivative was estimated to be 10^7 s^{-1}.

To clarify whether radical species participate in the formation of σ^H adducts, selected α-chlorosulfones **1a** and **1b**, which could play the role of the radical probes, were submitted to the reaction with 2-chloronitrobenzene (**2**). The reactions of their structural analogues, 1-chlorohexyl tolyl sulfone (**1c**) and 1-chloro-3-methylbutyl phenyl sulfone (**1d**) with the same nitroarene were used as reference processes (Scheme 2). The reactions were carried out under various conditions typical for the VNS reaction. Yields of the VNS products and observed side products were compared. The results of these studies are summarised in Table 1.



Scheme 2

Table 1. Reactions of chloroalkyl phenyl sulfones **1a**–**d** with 2-chloronitrobenzene as in Scheme 2

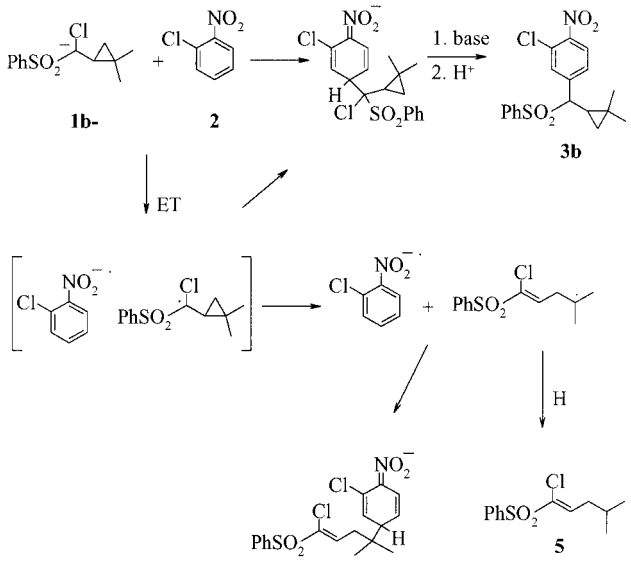
Entry	Sulfone	R	Reaction conditions	Product, GC yield (%) VNS		other	
1	**1a**		KOH/DMSO room temp., 30 min	**3a**	70	**4a**	12
2	**1b**		KOH/DMSO room temp., 30 min	**3b**	77	[b]	
3			KOH/DMSO room temp. + 4-ClNB[a]	**3b**	83	[b]	
4			*tert*-BuOK/DMSO room temp., 3 min	**3b**	68	[b]	
5			*tert*-BuOK/DMF −40 °C	**3b**	80	[b]	
6	**1c**		KOH/DMSO room temp., 40 min	**3c**	65	**4c**	6
7	**1d**		KOH/DMSO room temp., 30 min	**3d**	52	**4d**	10
8			*tert*-BuOK/DMSO room temp., 2 min	**3d**	67	**4d**	7
9			*tert*-BuOK/DMF −40 °C, 3 min	**3d**	56	**4d**	12

[a] 4-Chloronitrobenzene (1 equiv.) was added. [b] Not detected.

The reference sulfones **1c** and **1d** react with 2-chloronitrobenzene (**2**) according to the VNS scheme giving products **3c** and **3d**, respectively, with good yields. Similar results were also obtained for radical clocks **1a** and **1b**. In fact, in all reactions of the chlorosulfones used, unidentified by-products were detected only in very small amounts (< 1% each). The only identified side products formed in noteworthy amounts were nitrobenzylic chlorides **4**, and sometimes also products of their transformations into the corresponding nitrophenones. These compounds are apparently products of the VNS reaction proceeding by β-elimination of toluenesulfinic acid rather than HCl from the intermediate σ^H adducts. The unexpected formation of products of this type in VNS reactions will be presented and discussed elsewhere.

The data collected in Table 1 show that starting materials that are able enter fast reactions via free radicals (radical clocks) react with nitroarenes along the VNS reaction course without the formation of side products. Particularly diagnostic are experiments with **1b**, which is a very fast radical clock.

Chlorosulfone **1b**, which differs from **1d** only by the type of alkyl substituent, was expected to behave very similarly to **1d**, provided the formation of the σ^H adduct is a one-step, ionic process. On the other hand, if the reaction proceeds by initial formation of the radical intermediate, it should, at least partially, undergo a ring-opening process, with formation of the tertiary alkyl radical (Scheme 3). The latter, being nucleophilic in character, is expected to exhibit lower reactivity towards the nitroarene radical-anion, and therefore other reactions, for example hydrogen abstraction from the solvent or from another source, rather than addition to the nitroarene, are more plausible. However, the open-chain chlorosulfone **5** was not found in the reaction mixture (by comparison with an authentic sample). Moreover, the σ^H adduct formed by addition of the rearranged free radical to the nitroarene radical anion would be unable to eliminate the HCl molecule by a base-induced β-elimination process. Conversion of such σ^H adducts into stable products could eventually proceed by an oxidative pathway giving products of different structure than **3b**.



Scheme 3

It seems clear that participation of an electron transfer in the σ^H adduct formation step should change the reaction course considerably, preventing the VNS process to a sub-

stantial degree. Similar considerations can also be made for the possible SET reaction pathways in the reaction of **1a**. Reactions carried out at room temperature in the KOH/DMSO system in which the only operating bases, soluble in the reaction medium, are the chlorosulfone carbanions, seem to be particularly diagnostic. Due to a relatively low rate of β-elimination of HCl from the σ^H adducts promoted by this weak base, these conditions favour equilibration of the addition process. The concentration of σ^H adducts is therefore relatively high, and reversibility of their formation gives the biggest chance for possible electron transfer and further, irreversible radical processes to occur. In fact, under these conditions **1b** reacts even more readily than **1d**.

An additional argument against the SET pathway for the VNS reaction came from the experiment in which **1b** was treated with **2** and 4-chloronitrobenzene in equimolar amounts. The latter nitroarene has a similar electron affinity to that of **2**, as can be seen from their reduction potentials,[43] while its reactivity in the VNS reactions with tertiary carbanions of α-chlorosulfones is very low in the KOH/DMSO system.[1−4] The results in Table 1 (Entry 3) show that this additive does not affect the VNS reaction with **2** and the yield of **3b** did not decrease, which would be expected if the added nitroarene competed with **2** in the SET process.

Conclusion

On the basis of the observations that the VNS reaction of typical radical probes — sulfones **1a** and **1b** — with *o*-chloronitrobenzene gave similar results as the reaction of analogous sulfones **1c** and **1d**, we believe that addition of these carbanions to nitroarenes with formation of the intermediate σ^H adducts proceeds as a one-step ionic process rather than by SET. Even if some electron-transfer processes do take place in the carbanion/nitroarene system under investigation, which cannot be altogether excluded, they do not seem to interfere with the main reaction course of the VNS, particularly the σ^H adduct formation. Our recent observations that the ^{1}H NMR spectrum of the σ^H adduct of the carbanion of chloromethyl phenyl sulfone to *p*-nitroanisole does not show paramagnetic broadening, supports the above supposition.[19]

Experimental Section

General Remarks: Melting points are uncorrected. ^{1}H NMR spectra were recorded on a Varian Mercury 400 (400 MHz) or a Bruker DRX 500 (500 MHz) instrument at 30 °C. Chemical shifts are expressed in ppm referred to TMS, with coupling constants in hertz. Mass spectra were obtained on an AMD-604 spectrometer. GC analyses were performed on an HP 6890 chromatograph with HP-5 capillary column. Silica gel Merck 60 (230−400 mesh) was used for column chromatography.

Starting Materials and Reagents: 1-Chloro-3-methylbutyl phenyl sulfone (**1d**), 1-chlorohexyl tolyl sulfone (**1c**) and 1-chlorohex-5-enyl tolyl sulfone (**1a**) were prepared by alkylation of the corresponding chloromethyl aryl sulfones with appropriate alkyl bromides under PTC conditions according to the procedure described earlier for an analogous alkylation.[44]

1-Chloro-3-methylbutyl Phenyl Sulfone (1d): M.p. 73−74 °C (EtOH/hexane). ^{1}H NMR (400 MHz, $CDCl_3$): δ = 0.92 (d, *J* = 6.4 Hz, 3 H), 1.01 (d, *J* = 6.6 Hz, 3 H), 1.78−1.88 (m, 1 H), 1.89−1.99 (m, 1 H), 2.08−2.17 (m, 1 H), 4.68 (dd, *J* = 11.5, 2.7 Hz, 1 H), 7.57−7.63 (m, 2 H), 7.70−7.45 (m, 1 H), 7.95−7.99 (m, 2 H) ppm. MS (EI): *m*/*z* (%) = 246 (1), 143 (100), 142 (32), 125 (7), 78 (26), 77 (26), 69 (69), 51 (13). HRMS (LSIMS, NBA): Calcd. for $C_{11}H_{16}{}^{35}ClO_2S$ 247.0559; found $[M + H]^+$ 247.0558.

1-Chlorohex-5-enyl 4-Methylphenyl Sulfone (1a): M.p. 49−50 °C (EtOH/hexane). ^{1}H NMR (400 MHz, $CDCl_3$): δ = 1.50−1.62 (m, 1 H), 1.70−1.89 (m, 2 H), 2.05−2.18 (m, 2 H), 2.37−2.46 (m, 1 H), 2.47 (s, 3 H), 4.63 (dd, *J* = 10.8, 2.8 Hz, 1 H), 4.95−5.07 (m, 2 H), 5.70−5.82 (m, 1 H), 7.35−7.40 (m, 2 H), 7.80−7.85 (m, 2 H) ppm. MS (EI): *m*/*z* (%) = 157 (97), 139 (21), 116 (19), 92 (67), 91 (57), 81 (100), 65 (30). HRMS (LSIMS, NBA): Calcd. for $C_{13}H_{18}{}^{35}ClO_2S$ 273.0716; found $[M + H]^+$ 273.0718.

1-Chlorohexyl 4-Methylphenyl Sulfone (1c): M.p. 39 °C (EtOH/hexane). ^{1}H NMR (500 MHz, $CDCl_3$): δ = 0.87−0.93 (m, 3 H), 1.25−1.37 (m, 4 H), 1.39−1.50 (m, 1 H), 1.59−1.70 (m, 1 H), 1.75−1.85 (m, 1 H), 2.34−2.43 (m, 1 H), 2.47 (s, 3 H), 4.61 (dd, *J* = 10.9, 2.9 Hz, 1 H) 7.38 (d, *J* = 8.0 Hz, 2 H), 7.83 (d, *J* = 8.0 Hz, 2 H) ppm. MS (EI): *m*/*z* (%) = 274 (4), 157 (100), 139 (18), 92 (55), 83 (23), 55 (41). HRMS (EI): Calcd. for $C_{13}H_{19}{}^{35}ClO_2S$ 274.0794; found 274.0799.

Chloro(2,2-dimethylcyclopropyl)methyl Phenyl Sulfone (1b): (2,2-Dimethylcyclopropyl)methyl phenyl sulfone and then dichloro(2,2-dimethylcyclopropyl)methyl phenyl sulfone were obtained according to the procedures published previously for the tolyl analogues.[41] Monohydrodechlorination of the latter was accomplished by the following procedure:

$P(NMe_2)_3$ (547 mg, 0.61 mL, 3.35 mmol) was added in one portion to a solution of dichloro(2,2-dimethylcyclopropyl)methyl phenyl sulfone (651 mg, 2.23 mmol) in a mixture of DMF (5 mL) and EtOH (0.5 mL) cooled in a water bath. The mixture was stirred for 15 min then poured into acidified water and extracted with CH_2Cl_2. The extract was washed thoroughly with water and dried with Na_2SO_4. The solvent was evaporated and the crude solid recrystallized from MeOH. Yield 490 mg (85%), 1:1 mixture of stereoisomers. **1b:** M.p. 89−109 °C (MeOH). ^{1}H NMR (200 MHz, $CDCl_3$) 1:1 mixture of stereoisomers: δ = 0.40 (dd, *J* = 5.2, 5.6 Hz, 1 H), 0.55 (dd, *J* = 5.1, 5.3 Hz, 1 H), 0.83 (dd, *J* = 8.5, 5.6 Hz, 1 H), 0.85 (dd, *J* = 9.0, 5.1, 1 H), 0.96 (s, 3 H), 1.06 (s, 3 H), 1.10 (s, 3 H), 1.13 (s, 3 H), 1.0−1.3 (m, 2 × 1 H), 4.28 (d, *J* = 11.2 Hz, 1 H), 4.39 (d, *J* = 11.2 Hz, 1 H), 7.5−7.8 (m, 2 × 3 H), 7.95−8.05 (m, 2 × 2 H) ppm. MS (EI): *m*/*z* (%) = 153 (12), 119 (27), 117 (85), 116 (100), 91 (21), 89 (62), 81 (86), 79 (26), 77 (29), 75 (34). HRMS (LSIMS, NBA): Calcd. for $C_{12}H_{15}{}^{35}ClO_2SNa$ 281.0379; found $[M + Na]^+$ 281.0388.

(2,2-Dimethylcyclopropyl)methyl Phenyl Sulfone: Oil. ^{1}H NMR (500 MHz, $CDCl_3$): δ = 0.01 (t, *J* = 5.2 Hz, 1 H), 0.51 (dd, *J* = 8.7, 4.9 Hz, 1 H), 0.78 (s, 3 H), 0.83−0.91 (m, 1 H), 0.98 (s, 3 H), 3.04 (dd, *J* = 7.2, 14.6 Hz, 1 H), 3.21 (dd, *J* = 7.2, 14.6 Hz, 1 H), 7.54−7.59 (m, 2 H), 7.63−7.68 (m, 1 H), 7.91−7.94 (m, 2 H) ppm. ^{13}C NMR (125 MHz, $CDCl_3$): δ = 16.1, 17.6, 19.3, 19.9, 26.4, 57.6, 128.5, 129.0, 133.6, 139.3 ppm. MS (EI): *m*/*z* (%) = 143 (5), 125 (2), 83 (50), 82 (60), 77 (18), 67 (22), 55 (100). HRMS (ESI): Calcd. for $C_{12}H_{16}O_2SNa$ 247.0763; found $[M + Na]^+$ 247.0777.

Dichloro(2,2-dimethylcyclopropyl)methyl Phenyl Sulfone: Oil. ^{1}H NMR (500 MHz, $CDCl_3$): δ = 0.87 (dd, *J* = 8.4, 5.3 Hz, 1 H), 0.92 (t, *J* = 5.6 Hz, 1 H), 1.16 (s, 1 H), 1.33 (s, 1 H), 1.88 (dd, *J* = 8.4, 5.6 Hz, 1 H), 7.56−7.62 (m, 2 H), 7.71−7.76 (m, 1 H), 8.06−8.09 (m, 2 H) ppm. MS (EI): *m*/*z* (%) = 256 (15) [M^+ − HCl], 216 (13), 151 (95), 150 (88), 109 (82), 79 (91), 77 (100), 51 (46). HRMS (EI): Calcd. for $C_{12}H_{13}{}^{35}ClO_2S$ [M^+ − HCl] 256.0325; found 256.0314.

1-Chloro-4-methylpentenyl Phenyl Sulfone (5): Bu_3SnH (44.8 mg, 0.15 mmol) and a few crystals of AIBN were added to a deoxygenated solution of dichloro(2,2-dimethylcyclopropyl)methyl phenyl sulfone (18 mg, 0.062 mmol) in benzene (2 mL) under reflux. The mixture was refluxed for 2 h, then the solvent was evaporated, the residue dissolved in hexane and passed through a SiO_2 pad, eluting first with hexane and then with hexane/EtOAc (5:1). The latter eluate was collected and the solvents evaporated to obtain a chromatographically pure sample of **5**, 8.5 mg, 53%; oil. ^{1}H NMR (500 MHz, $CDCl_3$): δ = 0.95 (d, *J* = 6.7 Hz, 6 H), 1.87 (sept, *J* = 6.7 Hz, 1 H), 2.20−2.25 (m, 2 H), 7.26 (q, *J* = 7.45 Hz, 1 H), 7.54−7.59 (m, 2 H), 7.64−7.68 (m, 1 H), 7.92−7.95 (m, 2 H) ppm. MS (EI): *m*/*z* (%) = 258 (5), 216 (100), 203 (28), 181 (24), 125 (36), 77 (28). HRMS (EI): Calcd. for $C_{12}H_{15}{}^{35}ClSO_2$258.0481; found [$M^+$] 258.0479.

All other reagents are commercially available.

General Procedure for the Reactions of Chlorosulfones 1a−d with 2-Chloronitrobenzene (2):

KOH/DMSO System: Powdered KOH (0.2 g) was stirred magnetically in DMSO (1 mL) under Ar for 15 min. A solution of **2** (76 mg, 0.5 mmol) and the appropriate chlorosulfone **1a−d** (0.5 mmol) in DMSO (1 mL, deoxygenated with Ar) was then added dropwise during about 30 s. The reaction mixture was stirred for 60 min at ambient temperature, then poured into acidified water and extracted with dichloromethane. The extract was washed with water, dried with $MgSO_4$ and analysed by GC. Pure samples of the products were obtained by column chromatography of the crude product mixtures (SiO_2, hexane/EtOAc).

***t*BuOK/DMSO System:** According to the above procedure, but with *t*BuOK (246 mg, 2.2 mmol) instead of KOH. Reaction time 2 min.

***t*BuOK/DMF System:** Procedure as above, with DMF instead of DMSO and temperature maintained at −40 °C. Reaction time 5 min.

2-Chloro-4-{1-[(4-methylphenyl)sulfonyl]hex-5-enyl}-1-nitrobenzene (3a): M.p. 88 °C (EtOH). ^{1}H NMR (200 MHz, $CDCl_3$): δ = 1.15−1.4 (m, 2 H), 1.95−2.2 (m, 3 H), 2.3−2.45 (m, 1 H), 2.44 (s, 3 H), 4.05 (dd, *J* = 11.5, 3.8 Hz, 1 H), 4.9−5.02 (m, 2 H), 5.55−5.80 (m, 1 H), 7.20 (d, *J* = 8.3 Hz, 1 H) ppm. MS (EI): *m*/*z* (%) = 240 (32), 238 (100), 221 (21), 196 (11), 194 (12), 192 (38), 184 (21),157 (44), 150 (27), 140 (17),115 (20), (1 (31), 67 (18). HRMS (LSIMS, NBA): Calcd. for $C_{19}H_{21}{}^{35}ClNO_4S$ 394.0880; found [M + H]$^+$ 394.0867.

(3-Chloro-4-nitrophenyl)(2,2-dimethylcyclopropyl)methyl Phenyl Sulfone (3b). Isomer I: M.p. 180−182 °C (EtOH). ^{1}H NMR (200 MHz, $CDCl_3$): δ = −0.16 (dd, *J* = 5.7, 4.9 Hz, 1 H), 0.65 (dd, *J* = 4.9, 9.0 Hz, 1 H), 0.69 (s, 3 H), 1.0 (s, 3 H), 1.42 (ddd, *J* = 10.9, 9.0, 5.7 Hz, 1 H), 3.75 (d, *J* = 10.9 Hz, 1 H), 7.41 (dd, *J* = 8.5, 1.9 Hz, 1 H), 7.5−7.9 (m, 7 H) ppm. **Isomer II:** M.p. 161−162 °C (EtOH). ^{1}H NMR (200 MHz, $CDCl_3$): δ = 0.12 (dd, *J* = 5.4, 5.2 Hz, 1 H), 0.66 (dd, *J* = 5.2, 8.2 Hz, 1 H), 0.77 (s, 3 H), 1.05 (s, 3 H), 1.33 (ddd, *J* = 11.3, 8.2, 5.2 Hz, 1 H), 3.68 (d, *J* = 11.3 Hz, 1 H), 7.38 (dd, *J* = 8.5, 1.9 Hz, 1 H), 7.47−7.9 (m, 7 H) ppm. MS (EI): *m*/*z* (%) = 238 (100), 221 (27), 192 (45), 177 (59), 157 (28), 142 (20), 141 (19), 115 (27), 77 (16). HRMS (LSIMS, NBA): Calcd. for $C_{18}H_{18}{}^{35}ClNO_4SNa$ 402.0543; found [M + Na]$^+$ 402.0547.

1-(3-Chloro-4-nitrophenyl)hexyl 4-Methylphenyl Sulfone (3c): M.p. 107−109 °C (EtOH). ^{1}H NMR (400 MHz, $CDCl_3$): δ = 0.8−0.9 (m, 3 H), 1.1−1.32 (m, 6 H), 2.0−2.13 (m, 1 H), 2.31−2.47 (m, 1 H), 2.43 (s, 1 H), 4.04 (dd, *J* = 11.6, 3.8 Hz, 1 H), 7.20 (dd, *J* = 8.4, 1.8 1 H), 7.24−7.30 (m, 3 H), 7.44−7.50 (m, 2 H), 7.79 (d, *J* = 8.4 Hz, 1 H) ppm. MS (EI): *m*/*z* (%) = 277 (5), 275 [M^+ + 8], 240 (18), 205 (19), 198 (13), 194 (15), 183 (100), 175 (11), 153 (15), 43 (70). HRMS (LSIMS, NBA): Calcd. for $C_{19}H_{22}{}^{35}ClNO_4SNa$ 418.0856; found [M + Na]$^+$ 418.0869.

1-(3-Chloro-4-nitrophenyl)-3-methylbutyl Phenyl Sulfone (3d): M.p. 122−123 °C (EtOH). ^{1}H NMR (200 MHz, $CDCl_3$): δ = 0.80 (d, *J* = 6.6 Hz, 3 H), 0.92 (d, *J* = 6.6 Hz, 3 H), 1.24−1.48 (m, 1 H), 2.04−2.21 (m, 2 H), 4.06−4.23 (m, 1 H), 7.19 (dd, *J* = 8.4, 1.9 Hz, 1 H), 7.25−7.30 (m, 1 H), 7.43−7.70 (m, 5 H), 7.78 (d, *J* = 8.4 Hz, 1 H) ppm. MS (EI): *m*/*z* (%) = 226 (54), 184 (100), 165 (24), 140 (20), 125 (16), 102 (16), 77 (68). HRMS (LSIMS, NBA): Calcd. for $C_{17}H_{19}{}^{35}ClNO_4S$ 368.0723; found [M + H]$^+$ 368.0690.

2-Chloro-4-(1-chlorohex-5-enyl)-1-nitrobenzene (4a): Oil. ^{1}H NMR (200 MHz, $CDCl_3$): δ = 1.1−2.2 (m, 6 H), 4.77−4.89 (m, 1 H), 4.92−5.15 (m, 2 H), 5.65−5.9 (m, 1 H), 7.42 (dd, *J* = 8.3, 1.9 Hz, 1 H), 7.58 (d, *J* = 1.9 Hz, 1 H), 7.88 (d, *J* = 8.3 Hz, 1 H) ppm. MS (EI): *m*/*z* (%) = 275 (9), 273 (14), 256 (3), 238 (22), 217 (15), 183 (100), 153 (45), 115 (53). HRMS (EI): Calcd. for $C_{12}H_{13}{}^{35}Cl_2NO_2$ 273.0323; found [M^+] 273.0348.

2-Chloro-4-(1-chlorohexyl)-1-nitrobenzene (4c): Oil. ^{1}H NMR (400 MHz, $CDCl_3$): δ = 0.85−0.93 (m, 3 H), 1.26 −1.60 (m, 6 H), 1.93−2.14 (m, 2 H), 4.82, (dd, *J* = 6.2, 8.2 Hz, 1 H), 7.42 (dd, *J* = 8.4, 2.0 Hz, 1 H), 7.57 (d, *J* = 2.0 Hz, 1 H), 7.88 (d, *J* = 8.4 Hz, 1 H) ppm. MS (EI): *m*/*z* (%) = 277 (5), 275 [M^+ + 8], 240 (18), 205 (19), 194 (15), 183 (100), 170 (13), 153 (15), 43 (70). HRMS (EI): Calcd. for $C_{12}H_{15}{}^{35}Cl_2NO_2$ 275.0480; found [M^+] 275.0482.

2-Chloro-4-(1-chloro-3-methylbutyl)-1-nitrobenzene (4d): Oil. ^{1}H NMR (500 MHz, $CDCl_3$): δ = 0.96 (d, *J* = 6.4 Hz, 3 H), 0.97 (d, *J* = 6.4 Hz, 3 H), 1.74−1.82 (m, 2 H), 1.98−2.08 (m, 1 H), 4.88 (dd, *J* = 9.2, 5.5 Hz, 1 H), 7.42 (dd, *J* = 8.4, 1.9 Hz, 1 H), 7.57 (d, *J* = 1.9 Hz, 1 H), 7.88 (d, *J* = 8.4 Hz, 1 H) ppm. MS (EI): *m*/*z* (%) = 261 (24), 226 (21), 205 (86), 184 (28), 170 (13), 123 (11), 75 (13), 57 (100). HRMS (EI): Calcd. for $C_{11}H_{13}{}^{35}Cl_2O_2N$ 261.0323; found [M^+] 261.0321.

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