Research Article

Reactions of (1-nitroethenyl)sulfonylbenzene, a nitroethene derivative geminally substituted by a second W-group

Peter A. Wade[a]*, James K. Murray[a], Alma Pipic[a], Robert J. Arbaugh[a] and Amutha Jeyarajasingam[a]

Nitroaldol reaction of phenylsulfonylnitromethane with formaldehyde affords a mixture of 2,4-dinitro-2,4-bis(phenylsulfonyl)butan-1-ol and 2,4-dinitro-2,4- bis(phenylsulfonyl)pentane-1,5-diol. Treatment of this mixture with base followed by reacidification affords 1,1'-[(1,3-dinitro-1,3-propanediyl)bis(sulfonyl)]bis(benzene) as a mixture of (R*, R*) and (R*, S*)-diastereomers from which the (R*, S*)-diastereomer can be obtained pure. The intermediate in the nitroaldol reaction is (1-nitroethenyl)sulfonylbenzene and, if dienes are present, additional products are also obtained. If either (E)-2-methyl-1,3-pentadiene or 1-(1-methylethenyl)cyclohexene are present, typical Diels-Alder adducts are obtained with the major isomers explainable by assuming a transition state in which the nitro group is endo. If furan is present, its formal conjugate addition product, 2-[2-nitro-2-(phenylsulfonyl)ethyl]furan, is formed. If cyclooctatetraene is present, it first dimerizes and then affords isomeric Diels-Alder cycloadducts of the dimer. Semiempirical calculations comparing the LUMO energies of (1-nitroethenyl)sulfonylbenzene to the corresponding *trans*-1,2 isomer are presented to explain relative reactivity of 1,1- and 1,2-disubstituted dienophiles. Copyright © 2009 John Wiley & Sons, Ltd.

Keywords: Diels–Alder reaction; nitroalkene; nitroaldol; semibullvalene; nitrosulfone

INTRODUCTION

Nitroethene is a useful, reactive dienophile suitable for Diels–Alder reactions[1] and also a useful Michael acceptor for use in conjugate addition reactions.[2] It is sufficiently stable for isolation and short-term storage[3] although not highly amenable to commercialization. Geminal substitution with a second W-group would be expected to enhance the reactivity of nitroethene in Diels–Alder reactions. In accordance, we have shown that (1-nitroethenyl)sulfonylbenzene (**3**), a nitroethene derivative possessing a geminal phenylsulfonyl group, is both a powerful dienophile and a powerful Michael acceptor.[4,5] It has not been possible to isolate the highly reactive nitroalkene **3**, but methods for its generation and *in situ* use have been previously described. The ^{1}H NMR spectrum of **3**, taken immediately after generation, has confirmed its existence in solution.[4]

Here we present a number of new reactions involving nitroalkene **3** as an intermediate, further mechanistic information on the simplest method of generating **3**, and calculations rationalizing the reactivity of **3**. The Diels–Alder cycloadducts formed from nitroalkene **3**, secondary α-nitrosulfones, have potential as substrates in $S_{RN}1$ reactions as was previously demonstrated.[4]

RESULTS AND DISCUSSION

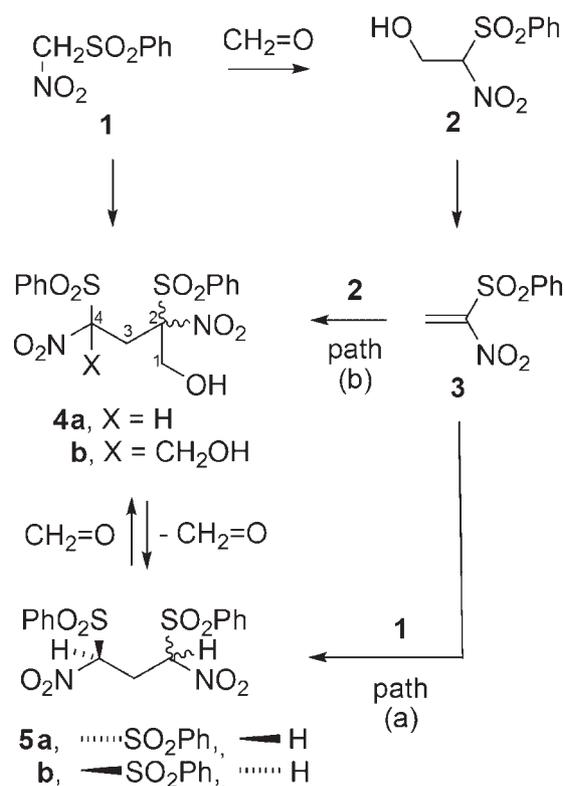### The nitroaldol route to nitroalkene 3

The simpler of two reported methods for obtaining nitroalkene **3** involves nitroaldol reaction of phenylsulfonylnitromethane (**1**)

with formaldehyde followed by *in situ* dehydration of the resulting nitroaldol **2** (Scheme 1). To generate **3**, one simply warms a solution of **1** containing formalin and acetic acid.

When generation of **3** is carried out in the absence of dienes, a gummy residue containing polar products not previously identified, is obtained. The polar products have now been identified as the bis(nitrosulfone) formaldehyde nitroaldol adducts **4a–b**. Indeed, these are universal side products in reactions involving generation of nitroalkene **3** from **1** using excess formaldehyde: they are also formed in the presence of dienes. In a definitive run, the mono nitroaldol adduct **4a** was present as a 60:40 mixture of diastereomers readily identifiable by the presence of two ^{1}H NMR signals (two dd) at δ 5.84 and 6.31, respectively, attributable to H_4 of the individual diastereomers. The presence of bis(nitroaldol) adduct **4b** is predicated on the relative intensity of the complex NMR multiplets at δ 3.6–3.8 and 4.1–4.7. The δ 3.6–3.8 signal is attributable to C_3 protons in both **4a** and **4b**. The δ 4.1–4.7 signal is attributable to C_4 protons in both **4a** and **4b** and also C_5 protons of **4b**. The signal intensities in these regions were consistent with a 1:1 mixture of **4a** and **4b** under typical reaction conditions. The aryl signal intensity relative to the δ 3.6–3.8 and 4.1–4.7 signals was also consistent with a 1:1

* Correspondence to: P. A. Wade, Chemistry Department, Drexel University, 3141 Chestnut Street, Philadelphia, PA 19104, USA.
E-mail: wadepa@drexel.edu

a   P. A. Wade, J. K. Murray, A. Pipic, R. J. Arbaugh, A. Jeyarajasingam
Chemistry Department, Drexel University, 3141 Chestnut Street, Philadelphia, PA 19104, USA
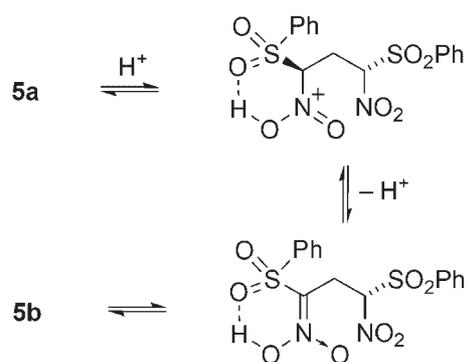
Scheme 1. Formation of bis(nitrosulfones)

Scheme 2. Isomerization of **5a–b**

analyses of isomer pairs have been reported as, for example, with isomers of 2,4-diphenylpentanedinitrile.[9,10]

The racemic diastereomer **5a** interconverts with **5b** in the presence of acid. Trifluoroacetic acid catalyzed conversion of pure **5a** to an equilibrium 50:50 mixture of **5a–b**. When a sample of pure **5a** was subjected to preparative TLC, a 50:50 mixture of **5a–b** also resulted. These acid-catalyzed isomerizations are thought to proceed through the aci-nitro isomer (Scheme 2). Most nitro compounds do not protonate as readily as **5a–b**. A likely explanation is that protonation of the nitro group is enhanced by internal H-bonding with a sulfone O-atom. Deprotonation from carbon would then afford the planar aci-nitro isomer which could be protonated on either face. Similar internal H-bonding was used to explain the ready interconversion of isomers of 2,5-dinitro-1,6-hexanediol.[11]

The formation of bis(nitrosulfone) **5a–b** from reaction of formaldehyde with nitrosulfone **1** prompted us to reinvestigate the synthesis of **1** from nitromethane and sodium benzenesulfinate.[8] Variable amounts of bis(nitrosulfone) **5a–b** are formed as a co-crystallizable side product in this synthesis, but the preparation does not involve formaldehyde as a starting material. However, formaldehyde might be expected to form during the synthesis. Work-up involves acidification with mineral acid which could generate formaldehyde by Nef reaction of the residual nitromethane anion present. It seems, then, that condensation of **1** with a limited amount of formaldehyde might be responsible for formation of **5a–b** as the side product [Scheme 1, path (a)]. We now isolate **1** during its preparation by controlled acidification using saturated aqueous ammonium chloride. Under these conditions, **5a–b** does not form.

$$CH_3NO_2 \xrightarrow[\substack{2)\ NaO_2SPh, \\ I_2 \\ 3)\ aq\ HCl}]{1)\ NaOMe} \mathbf{1} + \mathbf{5a\text{-}b}$$
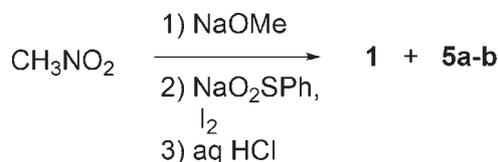
Generation of nitroalkene *3* in the presence of dienes

Generation of nitroalkene **3** in the presence of reactive dienes typically affords the Diels–Alder adduct. We have previously reported[4] formation of cycloadducts from cyclopentadiene, spiro[2.4]hepta-4,6-diene, 2,3-dimethyl-1,3-butadiene, isoprene, and 1-methoxy-1,3-butadiene using the nitroaldol method to generate **3**. Here we report Diels–Alder reactions of **3** with (*E*)-2-methyl-1,3-pentadiene, 1-(1-methylethenyl)cyclohexene,

ratio of **4a** and **4b**. Presumably more than one stereoisomer of **4b** was present but this was not confirmed.

Two possible pathways for formation of **4a–b** present themselves [paths (a) and (b)]. The anion of **1** could undergo Michael addition to nitroalkene **3** affording **5a–b** subsequently converted to **4a–b** via nitoaldol reactions with formaldehyde [path (a)]. Alternatively, the anion of nitroaldol **2** could add to **3** giving **4a** directly followed by subsequent partial conversion to **4b** [path (b)]. Approximately 10% of anions present would be derived from **1** (pK_a[6] 5.69) in solutions containing acetic acid (pK_a[7] 4.74). Nitroaldol **2** should have a similar thermodynamic acidity to **1** but would be very slow to deprotonate. Other primary nitrosulfones typically require several minutes for a significant concentration of anion to build up in the presence of hydroxide ion, far greater basicity than present here.[8] As build-up of **2** has never been observed in these reactions, it seems unlikely that a significant concentration of the anion of **2** could form and react further to give **4a–b**. Therefore, the first alternative [path (a)] involving the anion of **1** is presumably the main one followed.

Treatment of crude **4a–b** with aqueous base followed by acidification gave the bis(nitrosulfone) **5a–b** which was isolated in 82% overall yield from **1**. Typically a 50:50 mixture of racemic and meso diastereomers **5a–b** was obtained. However, isomer **5a** crystallizes more readily than **5b** so that rapid acidification led to exclusive deposition of crystalline **5a** in some instances. The racemic diastereomer **5a** has been obtained pure whereas the meso diastereomer **5b** was obtained in mixtures containing **5a**.
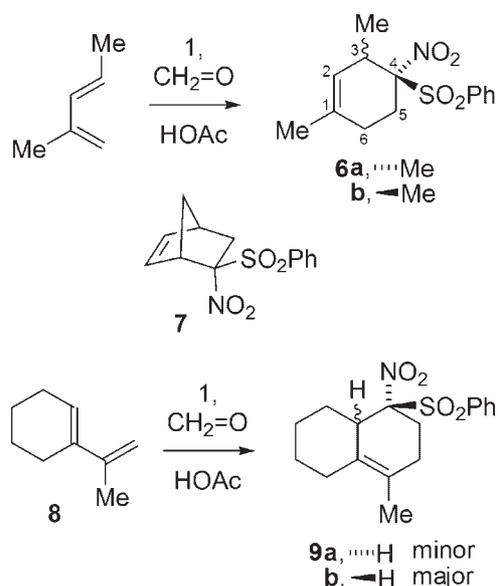
The racemic diastereomer, isomer **5a**, is readily identifiable based on the homotopic methylene protons present on C$_2$. A single signal (apparent triplet) was observed for the methylene protons. Conversely, these protons in the meso diastereomer **5b** are diastereotopic and exhibited separate signals. Similar

Scheme 3. Diels–Alder reactions

furan, and cyclooctatetraene (COT). The first two of these reactions proceeded in straightforward fashion. The third and fourth reactions took alternate pathways.

Reaction of nitroalkene **3** with (*E*)-2-methyl-1,3-pentadiene gave diastereomeric cycloadducts **6a–b** in 61% yield as an 80:20 isomeric mixture (Scheme 3). It was anticipated that the major isomer was the R^*, R^* diastereomer **6a**. This was by analogy with previously obtained results for cyclopentadiene.[4] Only adduct **7** was obtained, requiring a transition state with *endo*-placement of the nitro group. Similar preferred *endo*-placement of the nitro group in reaction with (*E*)-2-methyl-1,3-pentadiene would afford the R^*, R^* diastereomer **6a** as the major product.

Verification of the major product identity was obtained by analysis of the ^1H NMR spectra of **6a** and **6b**. The $J_{a,x}$ coupling constants for **6a–b** provide clear evidence for formation of the R^*, R^* diastereomer **6a** as the major product (Scheme 4). The major isomer exhibited a small (1.5 Hz maximum) coupling constant while the minor isomer exhibited a 5.8 Hz coupling constant. From the Karplus equation, the 1.5 Hz coupling constant in the major product would be consistent with one heavily preferred conformation having a H_a, H_x dihedral angle in the range of 65–105°.
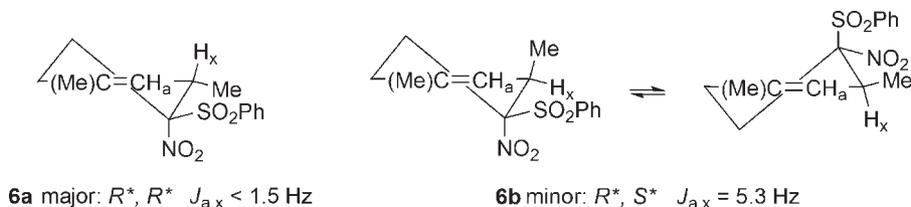
The R^*, R^* isomer should exist as a single conformation with a H_a, H_x dihedral angle of approximately 75°. This conclusion assumes a C_1, C_4 dihedral angle of 15°, similar to the angle present in cyclohexene.[12] Conformational preference can then be estimated in the following way. From the literature, there is a 0.97 kcal mol^{-1} preference for pseudo-equatorial placement of
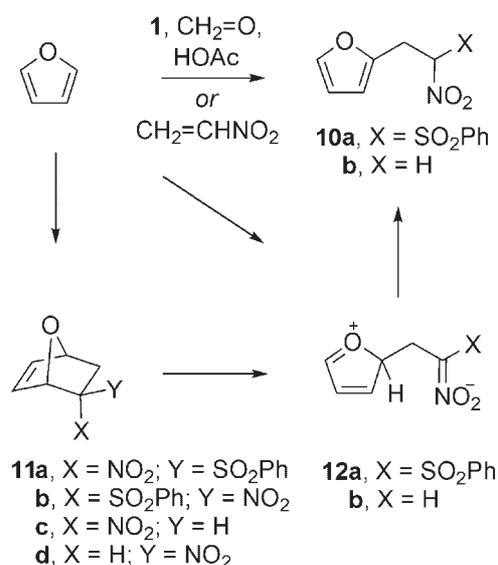
the methyl group in 3-methylcyclohexene.[13] Also known is the equatorial preference of the nitro group in 4-nitrocyclohexene ($-\Delta G^\circ = 0.25$ kcal mol^{-1}).[14] Equatorial preference for the phenylsulfonyl group was indirectly estimated because no conformational preference has been reported for sulfonyl groups at the 4-position of cyclohexene. The conformational preference has been determined for the phenylsulfonyl group on cyclohexane ($-\Delta G^\circ = 2.7$ kcal mol^{-1}).[15] Eliel[12] has noted that $-\Delta G^\circ$ for equatorial preference at the 4-position of cyclohexenes is approximately half $-\Delta G^\circ$ in cyclohexanes (there is only a single 1,3-diaxial interaction). Halving the known value for the phenylsulfonyl group allows a straightforward estimation of conformational preference.[16] Thus, placing the sulfonyl group equatorial at the 4-position and the methyl pseudo-equatorial at the 3-position should then be favored by roughly 2.1 kcal mol^{-1} ($0.97 + 1.35 - 0.25 = 2.1$ kcal mol^{-1}) over the ring-flip conformation, a strong preference.

For the R^*, S^* diastereomer by contrast, two significantly populated conformations should exist. The difference in energy between these two conformations is estimated to be 0.2 kcal mol^{-1} ($0.97 - 1.35 + 0.25 = -0.2$ kcal mol^{-1}). Contributions from the conformation with the pseudo-axial methyl group would result in a large coupling constant owing to the roughly 45° dihedral angle between H_a and H_x.
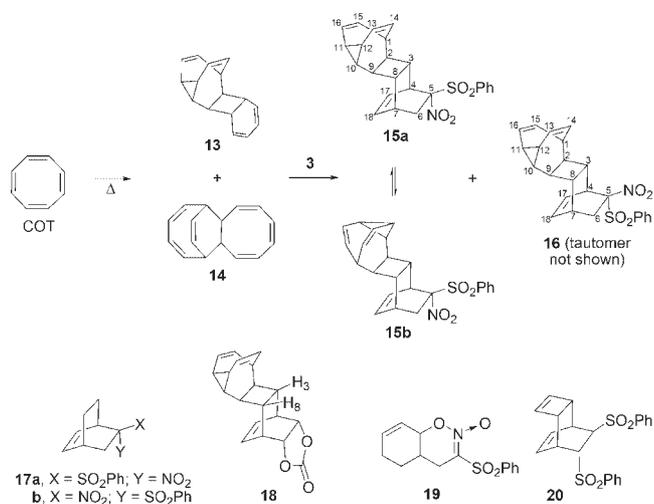
Reaction of nitroalkene **3** with 1-(1-methylethenyl)cyclohexene (**8**) gave diastereomeric cycloadducts **9a–b** in 64% yield as an 85:15 isomeric mixture. Based on the assumption of a preferred transition state with *endo*-placement of the nitro group, the major isomer of the reaction should be the R^*, S^* diastereomer **9b**. However, here it was not possible to confirm the assignment. The bridgehead proton of the major isomer did exhibit the higher-field chemical shift, consistent with structure **9b** where it is *cis* to the sulfone rather than the nitro group. A similar chemical shift pattern for the proton adjacent to the nitro and sulfone groups was observed for cycloadducts **6a** and **6b**.

Generation of nitroalkene **3** in the presence of furan, a well-recognized diene for Diels–Alder reactions, gave no detectable cycloadduct. Instead, the furan adduct **10a** was obtained in 51% yield (Scheme 5). This adduct had limited stability, undergoing substantial decomposition within a day of preparation. Adduct **10a** is formally the conjugate addition product of **3** and furan. A similar addition product, nitro compound **10b**, has been reported as the sole product from the reaction of nitroethene with furan.[3] Under very similar conditions, the cycloadduct isomers **11c–d** (mainly **11c**) were also reported as the reaction products of nitroethene with furan.[17] It was proposed that **10b** was formed from the cycloadduct **11c** via the zwitterion **12b**.[3] The analogous zwitterion **12a** would be expected to be more stable than **12b** owing to the second W-group. Thus, formation of cycloadduct **11a**, ring-opening to the zwitterion **12a**, and

6a major: R^*, R^* $J_{a,x} < 1.5$ Hz

6b minor: R^*, S^* $J_{a,x} = 5.3$ Hz

Scheme 4. Conformations of cycloadducts **6a** and **6b**

Scheme 5. Reactions of furan

**Scheme 6.** COT cycloadducts and structurally related compounds

As before, a major material and a minor material were present in a 90:10 ratio: these proved to be isomers. From the spectra of the major isomer, clear evidence for a semibullvalene structure was apparent. Proton absorptions at δ 3.7–4.0 were assigned to the four equilibrating cyclopropyl/alkenyl protons. Of the several possible isomeric structures, only the equilibrating valence bond tautomers **15a–b** are consistent with the spectral data. The structure of COT dimer **13** has been well established, although assignment of the *trans*-stereochemistry relies on two indirect observations. Moore[19] originally proposed the *trans*-structure on the basis of the inability of dimer **13** to undergo an intramolecular Diels–Alder reaction. Crystallographic data presented by Stezowski[20] on cycloadduct **18**, obtained[21] from reaction of COT with ethylidene carbonate at elevated temperature, require *trans*-COT dimer **13** as the precursor. The COT dimer **14** is known to be unreactive in typical Diels–Alder reactions.[18]

The ^{1}H NMR spectrum of the major isomer **15** exhibited signals for the H_{17},H_{18} ethenyl bridge protons similar to the signals for corresponding protons in the 1,3-cyclohexadiene adduct **17a**[5] (δ 6.1 *vs.* 6.0 and δ 6.44 *vs.* 6.36, respectively). Proton H_3 in **15** (δ 3.07) is in resonance at substantially *lower* field than the corresponding protons H_3,H_8 (δ 2.2) in adduct **18** and in reasonable agreement with the corresponding proton in adduct **17a** (δ 2.42). This presumably arises from the proximity of H_3 to the phenylsulfonyl group at C_5. The *endo*-placement of the nitro group in **17a** was firmly based on the observation that **17a** as opposed to **17b** is produced from [3,3]-sigmatropic rearrangement of nitronic ester **19**.[5] The signal attributed to H_4 in isomer **15** (δ 3.68) also exhibited a similar chemical shift to the corresponding signal for cyclohexadiene adduct **17a** (δ 3.6).

Assignment of the minor isomer **16** is based on comparison to cyclohexadiene adduct **17b**. The ^{1}H NMR signals for the H_{17},H_{18} ethenyl bridge protons have similar chemical shifts to the signals of corresponding protons in the adduct **17b** (δ 6.35 *vs.* 6.28 and δ 6.61 *vs.* 6.47, respectively) and are at lower field than the H_{17},H_{18} signals of major isomer **15** or the corresponding signals of adduct **17a**. The signal attributed to H_4 in isomer **16** (δ 3.4) also exhibited a similar chemical shift to the corresponding signal for adduct **17b** (δ 3.27).

De Lucchi and coworkers[22] have reported that (*E*)-1,2-bis(phenylsulfonyl)ethene, undergoes reaction with COT monomer to produce cycloadduct **20** in competition with cycloaddition to the COT dimer. Although less powerfully substituted (nitro is a stronger W-group than phenylsulfonyl), (*E*)-1,2-bis(phenylsulfonyl)ethene was more reactive with COT than nitroalkene **3**. However, (*Z*)-1,2-bis(phenylsulfonyl)ethene behaved similar to nitroalkene **3** failing to react with monomeric COT and giving uncharacterized cycloadducts of COT dimer. Based on these observations, it would seem that 1,1-disubstitution of W-groups in the dienophile may be generally less efficient than *trans*-1,2 disubstitution at activating Diels–Alder cycloaddition reactions. This would be expected if the LUMO of the 1,2-disubstituted dienophile were lower in energy than the LUMO of the corresponding 1,1-disubstituted isomer. Semiempirical calculations at the PM3 level were performed on nitroalkene **3** and the known[23] *trans*-1,2-disubstituted isomer **21** with the result that, indeed, the 1,2-isomer had the lower LUMO energy. The calculated LUMO energy levels for **3** and **21** were −1.22 eV and −1.68 eV, respectively. Thus, **21** should be a more powerful dienophile than **3**. Conversely, 1,1-disubstituted dienophiles such as

tautomerization is a likely pathway for the formation of adduct **10a**. In the present case, it is not possible to rule out an alternate route: conjugate addition of furan to the highly reactive double bond of **3** to give **12a** directly. Either route would involve tautomerization of **12a** to afford adduct **10a**.

Reaction of COT, a less reactive Diels–Alder diene component, was also investigated with nitroalkene **3** (Scheme 6). Generation of **3** from **1**, formalin, and acetic acid under moderate heating in the presence of COT provided a very low yield of cycloadduct, two materials in a 90:10 ratio being formed. From NMR spectra, the major cycloadduct consisted of two COT units and one dienophile unit. It was thought that COT might have dimerized prior to reaction with **3** to give the known[18] dimer **13** and that dimer **13** subsequently reacted with **3** to give the observed cycloadduct. To confirm this conjecture, COT was dimerized at 100°C by the method of Schröder[18] and the dimeric material, used as a mixture of **13** and **14**, was then subjected to cycloaddition. A 47% yield (96% conversion) of the same cycloadduct obtained from monomeric COT was now obtained.

nitroalkene **3** are significantly more regioselective than 1,2-disubstituted dienophiles.

$$O_2N \diagdown \diagup SO_2Ph$$
21
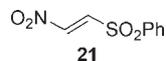
EXPERIMENTAL

General

Commercially available reagents were used without further purification unless otherwise noted. Tetrahydrofuran was distilled from sodium benzophenone ketyl. NMR spectra were recorded on a Varian 500 Innova spectrometer at 500 MHz (^{1}H NMR) or 126 MHz (^{13}C NMR). The three aryl absorptions for PhSO$_2$ are recorded as apparent d, t and t, respectively, although the AA'MXX' pattern is non-first order, and does show additional complexity. Mass spectra were determined on a VG Analytical 70SE magnetic sector instrument. Reactions were routinely run under a nitrogen atmosphere. 1-(1-Methylethyl)cylohexene was prepared from 1-acetylcyclohexene by a published procedure[24] except that THF at room temperature was employed rather than refluxing ether. Phenylsulfonylnitromethane (**1**) was prepared by the published procedure,[8] except that acidification during work-up was carried out first with saturated ammonium chloride to pH 5 followed by aqueous 5% HCl to pH 1–3. PM3 Semiempirical calculations were performed using Hyperchem release 7.1.

General procedure—generation of (1-nitroethenyl) sulfonylbenzene 3 in the presence of dienes

A mixture of diene (4.7 mmol), phenylsulfonylnitromethane (2.83 g, 14 mmol), formalin (3.81 g of a 37% solution, 47 mmol of CH$_2$=O), acetic acid (2.8 g, 47 mmol), and THF (20 ml) was heated at 40–50°C for 16 h. Volatiles were removed at reduced pressure and the residue partitioned between water (50 ml) and CH$_2$Cl$_2$ (extraction with three 40-mL portions). The combined extracts were washed with water (50 ml), dried over anhydrous Na$_2$SO$_4$, and concentrated at reduced pressure. Flash chromatography (various eluents) gave purified product followed by more polar side products **4a–b** which were not routinely isolated. All reagent quantities were scaled according to the amount of diene employed.

Preparation of COT dimers 13 and 14

A 2.01 g (19 mmol) portion of freshly distilled COT was heated in a closed N$_2$-flushed flask at 95–105°C for 69 h. Volatiles were removed from the crude product at reduced pressure (20–100°C, 15 mm Hg). The residue was subjected to Kugelrohr distillation to separate tetramers from the dimers. A 23% yield (0.45 g, 2.2 mmol) of distillate (bp 110–120°C, 0.09 mm Hg) consisting of a 1:1 mixture (based on the ^{1}H NMR spectrum) of **13** and **14** was obtained.

New products formed from nitroalkene 3

(2,4-Dimethyl-1-nitro-3-cyclohexenen-1-yl)sulfonylbenzene 6

From 0.5 g (6.1 mmol) of (*E*)-2-methyl-1,3-pentadiene was obtained 1.09 g (3.7 mmol, 61% yield) of an oil (elution with 50:50 hexanes/CH$_2$Cl$_2$). This purified product was an 80:20 mixture of **6a** and **6b** (found: MH$^+$, 296.0958; C$_{14}$H$_{17}$NO$_4$S+H requires 296.0957); ν_{max} (film)/cm^{-1} 1550 (NO$_2$), 1331 (NO$_2$, SO$_2$), 1146 (SO$_2$) cm^{-1}. ^{13}C NMR (CDCl$_3$) δ 135.1, 134.9, 134.6, 133.5, 132.7, 131, 130.3, 129.2, 128.9, 123.6, 121.5, 110.6 (CNO$_2$, **6b**), 108.9 (CNO$_2$, **6a**), 34.3, 29.7, 27.9, 27.4, 25.3, 22.7, 22.6, 21.6 18.9, 18.3.

A portion of the mixture was enriched in the separate isomers by cutting the single preparative TLC band (eluted with 60:40 CH$_2$Cl$_2$/hexanes) into three fractions. The minor isomer was somewhat enriched in the top third fraction (67:33, **6a/6b**) and the major isomer was enriched in the bottom third fraction (90:10, **6a/6b**). ^{1}H NMR (CDCl$_3$) obtained for two mixtures of different concentration δ 7.90 (d, 2H of **6a**, $J = 7.3$ Hz), 7.83 (d, 2H of **6b**, $J = 7.3$ Hz), 7.74 (m, 1H of **6a–b**), 7.59 (m, 2H of **6a–b**), 5.36 (d, 1H of **6b**, $J = 5.8$ Hz, H$_A$), 5.25 (m, 1H of **6a**, all $J < 1.5$ Hz, H$_A$), 3.67 (quint, 1H of **6b**, $J = 6.8$ Hz, H$_X$), 3.18 (broad s, 1H of **6a**, H$_X$), 2.55–2.7 (m), 2.3–2.45 (m), and 2.05–2.25 (m, 4H total), 1.69 (s, 3H of **6a**), 1.57 (s, 3H of **6b**), 1.44 (d, 3H of **6b**, $J = 6.8$ Hz), and 1.15 (d, 3H of **6a**, $J = 6.8$ Hz).

1,2,3,4,6,7,8,8a-Octahydro-5-methyl-8-nitro-8- (phenylsulfonyl) naphthalene 9

From 0.68 g (5.6 mmol) of 1-(1-methylethyl)cyclohexene was obtained 1.19 g (3.6 mmol, 64% yield) of a semi-solid (50:50 hexanes/CH$_2$Cl$_2$ eluent). This purified product consisted of an 85:15 mixture of **9b** and **9a**, respectively. Iterative flash and thin-layer chromatography (elution with 50:50 hexanes/CH$_2$Cl$_2$) effected separation of the two isomers. Major isomer **9b** was the less mobile fraction and was recrystallized three times from benzene-hexanes (found: MH$^+$, 336.1264; C$_{17}$H$_{21}$NO$_4$S+H requires 336.1270); mp 106–108°C; ν_{max} (KBr)/cm^{-1} 1553 (NO$_2$), 1330 (NO$_2$, SO$_2$), 1151 (SO$_2$); ^{1}H NMR (CDCl$_3$) δ 7.88 (d, 2H, $J = 7.8$ Hz), 7.73 (t, 1H, $J = 7.3$ Hz), 7.59 (t, 2H, $J = 7.3$ Hz), 2.7–2.8 (m, 2H), 2.65–2.7 (m, 1H), 2.61 (m, 1H), 2.38 (dt, 1H, $J = 8.7$, 14.2 Hz), 2.23 (dd, 1H, $J = 8.1$, 17.6 Hz), 1.79 (m, 2H), 1.69 (s, 3H), 1.45–1.6 (m, 2H), 1.41 (qt, 1H, $J = 3.9$, 13.2 Hz), 1.2–1.28 (m, 2H); ^{13}C NMR (CDCl$_3$) δ 134.8, 134.6, 130.9, 128.8, 128.6, 123.3, 109.6 (CNO$_2$), 43.0, 31.8, 31.2, 29.6, 27.8, 26.5, 23.8, 18.2.

Minor isomer **9a** was the more mobile fraction and, after three recrystallizations from benzene-hexanes, was obtained as a solid (found: MH$^+$, 336.1263; C$_{17}$H$_{21}$NO$_4$S+H requires 336.1270); mp 178–81°C; ν_{max} (KBr)/cm^{-1} 1553 (NO$_2$), 1323 (NO$_2$, SO$_2$), 1147 (SO$_2$); ^{1}H NMR (CDCl$_3$) δ 7.81 (d, 2H, $J = 7.8$ Hz), 7.72 (t, 1H, $J = 7.8$ Hz), 7.56 (t, 2H, $J = 7.8$ Hz), 3.52 (d, 1H, $J = 11.7$ Hz), 2.71 (d, 1H, $J = 11.7$ Hz), 2.63 (dd, 1H, $J = 1.5$, 12.8 Hz), 2.51 (m, 2H), 2.12 (m, 2H), 1.95 (d, 1H, $J = 13.7$ Hz), 1.86 (dd, 1H, $J = 1.5$, 12.2 Hz), 1.70 (m, 2H), 1.53 (s) overlapping 1.2–1.6 (m) [6H total]; ^{13}C NMR (CDCl$_3$) δ 135.1, 133.3, 131.6, 130.2, 129.2, 121.5, 110.5 (CNO$_2$), 43.6, 32.4, 31.7, 28.8, 28.4, 26.8, 23.0, 18.0.

2-[2-Nitro-2-(phenylsulfonyl)ethyl]furan 10a

The general procedure was followed but the reaction temperature was kept at 20-25°c. A 0.41 g (6 mmol) portion of furan was used as diene. Rapidly performed flash chromatography (CH$_2$Cl$_2$ followed by 98:2 CH$_2$Cl$_2$/MeOH eluents) gave 0.86 g (3.1 mmol, 51% yield) of pure **10a** as a solid having limited stability (found: MNa$^+$, 304.0252; C$_{12}$H$_{11}$NO$_5$S+Na requires 304.0256); ν_{max} (KBr)/cm^{-1} 1561 (NO$_2$), 1339 (NO$_2$, SO$_2$), 1151 (SO$_2$); ^{1}H NMR (CDCl$_3$) δ 7.92 (d, 2H, $J = 7.8$ Hz), 7.80 (t, 1H, $J = 7.6$ Hz), 7.65 (t, 2H,

$J = 7.8$ Hz), 7.31 (m, 1H), 6.28 (dd, 1H, $J = 2.9$, 2.0 Hz), 6.16 (d, 1H, $J = 2.9$ Hz), 5.81 (dd, 1H, $J = 9.8$, 3.9 Hz, X portion of ABX), 3.68 (dd, $J = 3.9$, 15.6 Hz) on 3.65 (dd, $J = 9.8$, 15.6 Hz, total 2H, AB portion of ABX); ^{13}C NMR (CDCl$_3$) δ 145.9, 143.0, 135.6, 134.1, 129.9, 129.6, 110.8, 109.1, 100.1, 26.9.

COT dimer cycloadducts **15** and **16**

The crude product was obtained from a mixture of COT dimers (0.13 g, 0.62 mmol) by the general procedure (elution with 50:50 hexanes/CH$_2$Cl$_2$ followed by CH$_2$Cl$_2$). COT dimeric material (70 mg, 54% recovery, 1:7 mixture of **13** and **14**, respectively) was obtained from the least polar chromatography fractions followed by cycloadduct (0.12 g, 0.29 mmol, 47% yield, 96% conversion) and side products **4a–b**. The cycloadduct was a 90:10 mixture of two isomers that overlapped on a TLC plate. Preparative TLC (three fractions were taken) provided pure **15** and an enriched sample of **16**. The fastest moving fraction was the major isomer **15**: it was recrystallized from ethanol, mp 210–212°C. ν_{max} (KBr): 1544 (NO$_2$), 1328 (NO$_2$, SO$_2$), 1150 (SO$_2$) cm^{-1}. ^{1}H NMR (CDCl$_3$) δ 7.81 (d, 2H, $J = 7.8$ Hz), 7.72 (t, 1H, $J = 7.4$ Hz), 7.57 (t, 2H, $J = 7.8$ Hz), 6.44 (t, 1H, $J = 7.3$ Hz, H$_{18}$), 6.1 (t, 1H, $J = 7.3$ Hz, H$_{17}$), 6.03 (t, 1H, $J = 9.6$ Hz, H$_{13 \text{ or } 16}$), 5.69 (t, 1H, $J = 9.8$ Hz, H$_{13 \text{ or } 16}$), 3.68 (dd, $J = 3.6$, 6.1 Hz, H$_4$) overlapping 3.35–4.05 (m, H$_{11,12,14,15}$, 5H total), 3.07 (quint, 1H, $J = 4.4$ Hz, H$_3$), 2.91 (m, 1H, H$_7$), 2.76 (dd, 1H, $J = 3.9$, 15.1 Hz, H$_6$), 2.44 (dd, $J = 1.5$, 15.1 Hz, H$_{6'}$) overlapping 2.45–2.5 (m, H$_8$, total 2H), 2.17 (m, 2H, H$_{2,9}$), and 1.9 (m, 2H, H$_{1,10}$); ^{13}C NMR (CDCl$_3$) δ 136.5, 135.0, 134.4, 130.1, 129.4, 129.1, 126.7, 126.5, 111.6 (C$_5$), 41.5, 39.6, 36.8, 36.2, 35.4, 33.2, 29.7, 27.9, 27.5. Anal. Calcd. for C$_{24}$H$_{23}$NO$_4$S: C 68.39, H 5.50, N 3.32. Found: C 68.25, H 5.49, N 3.22.

The slowest moving fraction from preparative TLC was a partially purified mixture, containing 76% of the minor isomer **16** with 24% of the major isomer **15** remaining. ^{1}H NMR (CDCl$_3$) bands attributable to the minor isomer δ 7.84 (d, 2H, $J = 7.8$ Hz), 7.74 (t, 1H, $J = 7.3$ Hz), 7.60 (t, 2H, $J = 7.8$ Hz), 6.61 (t, 1H, $J = 7.3$ Hz, H$_{18}$), 6.35 (t, 1H, $J = 7.3$ Hz, H$_{17}$), 5.84 (t, 1H, $J = 9.3$ Hz, H$_{13 \text{ or } 16}$), 5.64 (t, 1H, $J = 9.7$ Hz, H$_{13 \text{ or } 16}$), 3.3–4.1, (m, 4H, H$_{11,12,14,15}$), 3.29 (dd, 1H, $J = 3.4$, 10.3 Hz, H$_4$), 2.93 (m, 1H, H$_7$), 2.79 (dd, 1H, $J = 2.4$, 15.6 Hz, H$_6$), 2.60 (dd, 1H, $J = 3.4$, 15.6 Hz, H$_{6'}$), 2.25 (m, 1H), 2.07 (m, 2H), and 1.88 (m, 2H).

2,4-Dinitro-2,4-bis(phenylsulfonyl)butan-1-ol **4a**, 2,4-dinitro-2,4-bis(phenylsulfonyl)-pentane-1,5-diol **4b**, and 1,1'-[(1,3-dinitro-1,3-propanediyl)bis(sulfonyl)]bis(benzene) **5a–b**

A mixture of phenylsulfonylnitromethane (1.0 g, 5 mmol), formalin (4.07 g of a 37% solution, 50 mmol of CH$_2$=O), acetic acid (3 g, 50 mmol), and DMSO (50 ml) was heated at 35–40°C for 24 h. The crude reaction solution was added to ice water (500 ml) and the resultant was extracted with CH$_2$Cl$_2$ (three 100 ml portions). The combined extracts were washed with water (three 75 ml portions), dried over anhydrous Na$_2$SO$_4$, and concentrated at reduced pressure. The gummy solid crude product (1.12 g) consisted mainly of **4a–b**. ν_{max} (film) 3250–3600 (broad, OH), 1563 (NO$_2$), 1338 (NO$_2$, SO$_2$), 1155 (SO$_2$) cm^{-1}. ^{1}H NMR (CDCl$_3$) δ 7.75–8 (m, 3H all aryl), 7.55–7.7 (m, 2H all aryl), 6.31 (dd, 1H 1st isomer of **4a**, $J = 2.9$, 6.8 Hz), 5.84 (dd, 1H 2nd isomer of **4a**, $J = 2.9$, 7.8 Hz), 4.2–4.7 (m, 2H of **4a–b**, all CH$_2$ between CNO$_2$), 3.6–3.8 (m, 2H of **4a** and 4H of **4b**, CH$_2$O).

The crude **4a–b** (1.12 g) was taken up in CH$_2$Cl$_2$ (125 ml) and was extracted into aqueous 5% NaOH (150 ml). The separated aqueous layer was acidified to pH 2 with saturated aqueous ammonium chloride followed by 10% aqueous HCl. The product was extracted with CH$_2$Cl$_2$ (three 50 ml portions). The combined organic layers were washed with water (20 ml), dried over anhydrous Na$_2$SO$_4$, and concentrated at reduced pressure. The resulting 0.86 g (82% yield) portion of off-white solids consisted of a 1:1 mixture of **5a** and **5b** in definitive runs, although considerable variation in the isomer ratio was noted in other runs. ^{1}H NMR (CDCl$_3$) δ 7.9–7.95 (m, 4H of **5a** and **5b**), 7.83 (t, 2H of **5a** and **5b**, $J = 7.8$ Hz), 7.67 (t, 4H of **5a** and **5b**, $J = 7.8$ Hz), 5.84 (dd, 2H of **5b**, $J = 6.3$, 7.3 Hz), 5.78 (t, 2H of **5a**, $J = 6.8$ Hz), 3.53 (dt, 1H of **5b**, $J = 6.3$, 16.1 Hz), 3.45 (t, 2H of **5a**, $J = 6.8$ Hz), 3.33 (dt, 1H of **5b**, $J = 7.3$, 16.1 Hz).

The less soluble isomer could be readily crystallized from an ethanol mixture of the isomers to afford pure **5a** as a white solid: mp 165–66°C (lit[8] mp 165–66°C). ^{1}H NMR (CDCl$_3$) δ 7.93 (d, 4H, $J = 7.8$ Hz), 7.83 (t, 2H, $J = 7.4$ Hz), 7.67 (t, 4H, $J = 7.4$ Hz), 5.77 (t, 2H, $J = 6.8$ Hz), 3.45 (t, 2H, $J = 6.8$ Hz).

Thin layer chromatography (CH$_2$Cl$_2$ eluent) of pure **5a** led to formation of a 1:1 mixture of **5a** and **5b**. Stirring a CH$_2$Cl$_2$ solution of **5a** containing 1 molar equivalent of trifluoroacetic acid for 4 h led to formation of a 1:1 mixture of **5a** and **5b**.

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