An Efficient Preparation of β-Dimethylaminovinyl Sulfone and Sulfoximide, and Investigation of Their Reactivity as Dipolarophiles

Nela Peša*, Chris J. Welch and Andrew N. Boa

Department of Chemistry, University of Hull, Cottingham Road, Hull, HU6 7RX, U.K.

Received October 25, 2004

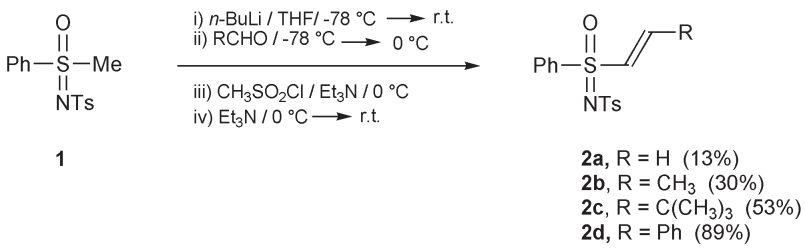
A simple reaction affording (*E*)-1-dimethylamino-2-phenylsulfonylethylene, and *S*-((*E*)-2-(*N'*,*N'*-dimethylamino)ethenyl)-*S*-phenyl-*N*-(*p*-tolylsulfonyl) sulfoximide in high yields is described. A reversal in regioselectivity was observed when the β-dimethylaminovinyl sulfone was employed as a dipolarophile in cycloadditions with nitrile oxides. The sulfone gives rise mainly to 4-substituted isoxazoles, after elimination of dimethyl amine. In comparison, phenyl vinyl sulfone cycloadds to give 5-substituted isoxazolines. Although not showing comparable dipolarophilic activity in reactions with nitrile oxides and nitrile imides, the β-dimethylaminovinyl sulfoximide was easily converted to *S*-((*E*)-(3-ethoxycarbonyl)prop-2-enyl)-*S*-phenyl-*N*-(*p*-tolylsulfonyl) sulfoximide. This allylic sulfoximide cycloadds in good yield to both benzonitrile oxide and diphenylnitrile imide, but no stereoselectivity was observed in the process; and only modest regioselectivity was detected in the case of benzonitrile oxide.

J. Heterocyclic Chem., **42**, 599 (2005).

1,3-Dipolar cycloaddition reactions provide powerful synthetic methodology for the preparation of a wide range of useful heterocycles, as well as advanced synthetic intermediates [1]. The great scope of 1,3-dipolar cycloadditions in organic synthesis stems from the large number of available 1,3-dipoles and the possibility of any double or triple bond, including heteromultiple bonds, to react as dipolarophiles. As part of a program investigating novel dipolarophiles we decided to investigate methods for simple preparation of new sulfur-containing alkenes, such as substituted vinyl sulfones and sulfoximides (sulfoximines according to CAS). Barzaghi *et al*. reported the effect of the sulfinyl and sulfonyl group on the reactivity of alkene dipolarophiles and regioselectivity in 1,3-dipolar cycloadditions with diphenylnitrile imide and 3,5-dichloromesitylnitrile oxide [2]. Although similar results were obtained by Shimizu *et al*. [3], their interpretations were different, suggesting that the combination of both electron-withdrawing effect of the sulfonyl group and the effect of other substituents on the double bond influence the regioselectivity in cycloadditions. Thus, we were interested in investigating further such effects. Moreover, 1,3-dipolar cycloaddition reactions of sulfoximides has only briefly been reported by Pyne *et al*. [4]. Reactants involving chiral moieties in either dipole or dipolarophile are additionally useful and can in many cases be used to make products with high degrees of asymmetric induction [5]. Considering the versatility of sulfonimidoyl functional group, and the possibility for obtaining chiral compounds with this moiety, it was suggested that there should be more investigation of dipolarophilic activity of vinylic sulfoximides [6].

Herein, we report a facile synthesis of (*E*)-1-dimethylamino-2-phenylsulfonylethylene (**4**) and its sulfoximide analogue, *S*-((*E*)-2-(*N'*,*N'*-dimethylamino)ethenyl)-*S*-phenyl-*N*-(*p*-tolylsulfonyl) sulfoximide (**5**). In a previous report, the sulfone **4** was prepared in moderate yield (60%) by Peterson-type olefination reaction [7]. Although the Peterson reaction is most often employed in olefin-synthesis, this method involving multiple steps is quite difficult, especially when applied to preparation of vinyl sulfoximides. Amongst several alternatives to the Peterson olefination, we found the method of Jackson [8] to work the best, and by this method we prepared from *S*-methyl-*S*-phenyl-*N*-(*p*-tolylsulfonyl)sulfoximide (**1**) several different vinyl sulfoximides (**2a-d**), ranging from poor to good yields (Scheme 1). Reaction of phenyl methyl sulfone (**3**) with *N*,*N*-dimethylformamide dimethyl acetal in refluxing dry DMF, however, gave dimethylamino vinyl sulfone **4** in excellent yield, with high selectivity and only the *E*-isomer was isolated. The reaction was equally successful with

Scheme 1

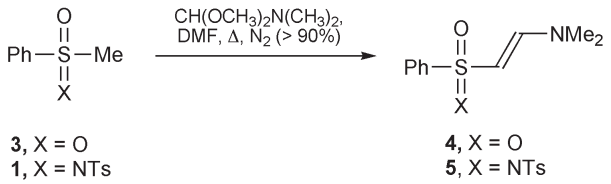


1

2a, R = H (13%)
2b, R = CH_3 (30%)
2c, R = $C(CH_3)_3$ (53%)
2d, R = Ph (89%)

S-methyl-*S*-phenyl-*N*-(*p*-tolylsulfonyl)sulfoximide (**1**), affording the corresponding dimethylamino vinyl sulfoximide **5** (Scheme 2).

Scheme 2



When the same method was applied to the corresponding sulfoxide there was unfortunately no reaction, not even when catalytic *p*-TsOH was added. Paley and Snow have prepared a variety of unsaturated sulfoximides from β-tosyloxy-(*E*)-vinyl sulfoximide, which undergoes an addition-elimination process with higher-order cuprate nucleophiles [9]. We hoped that the enamines **4** and **5** would behave in a similar fashion so we investigated briefly the possibility of preparing other unsaturated sulfones and sulfoximides from these compounds. However, reaction of **4** and **5** with simple nucleophiles (*e.g.* malonate salts and simple organometallic reagents) under a wide variety of conditions were unsuccessful, but copper(I) catalysed methods *as per* Paley and Snow have not yet been investigated. Modest success in preparing new vinyl sulfoximides was achieved with simple amine-exchange reactions. The lack of reactivity of either the enamine or sulfonyl/sulfonimidoyl functions is most likely due to resonance stabilisation of **4** and **5** (Figure 1); a similar example can be found in the work of Hyatt and Krutak [10].

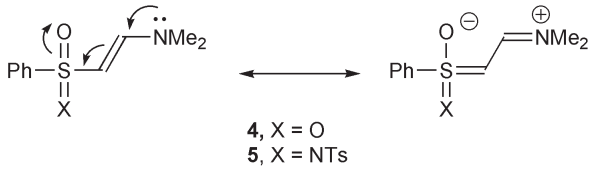


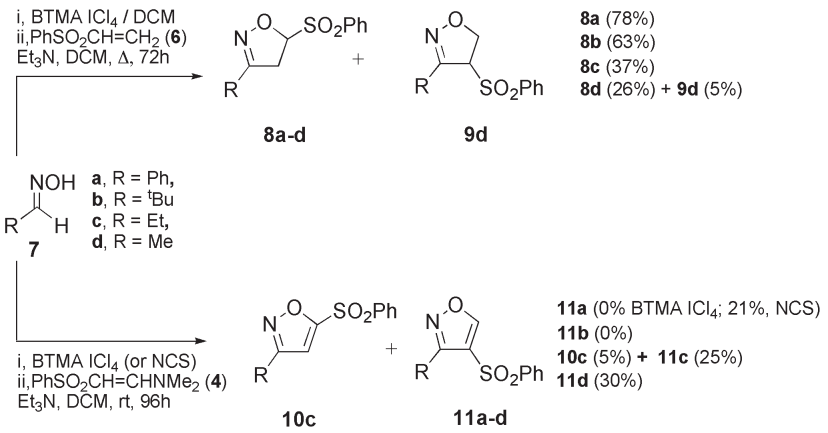
Figure 1

To investigate the dipolarophilic activity of the enamine **4**, and the possible effect of dimethylamino group on reactivity and regioselectivity of cycloadditions, we decided to carry out 1,3-dipolar cycloadditions of **4** with nitrile oxides, and compare these results to the corresponding reactions using unfunctionalised phenyl vinyl sulfone (**6**). α-Chloroximes, precursors to the desired nitrile oxides, were conveniently generated using benzyl trimethylammonium tetrachloroiodate (BTMA ICl_4) [11]. To a solution of aldoxime **7a-d** in DCM was added BTMA ICl_4 and the green suspension was stirred at room temperature for ten minutes. In this period the hydroximoyl chloride formed as indicated by the clear yellow solution, due to formation of soluble BTMA ICl_2. The dipolarophile was then added, followed by two equivalents of triethylamine. In the reactions of nitrile oxides with phenyl vinyl sulfone (**6**), 5-phenylsulfonyl-2-substituted isoxazolines **8a-d** were obtained almost exclusively, while the opposite regioisomer 4-phenylsulfonyl-2-substituted isoxazoline was isolated only in one case (**9d**, R = CH_3). Barzaghi *et al*. reported that 1,3-dipolar cycloaddition of 3,5-dichloromesitylnitrile oxide with phenyl vinyl sulfone gave mostly 5-phenylsulfonyl-2-isoxazoline (73%), with a small amount of opposite regioisomer, 4-phenylsulfonyl-2-isoxazoline (7%) [2]. Our results with different nitrile oxides are therefore generally in agreement with the 5-phenylsulfonyl-2 isoxazoles being isolated as the major or sole cycloadduct (Scheme 3).

In reactions with enamine **4** isoxazolines were not detected, rather the corresponding isoxazoles **10** and **11** resulting from elimination of dimethylamine were obtained. A reversal in regioselectivity was also observed and the 4-phenylsulfonyl isoxazoles were obtained in these cases. The 5-phenylsulfonylisoxazole was only detected in one case (**10c**). The yields however were at best modest, one possible reason being the aforementioned stability of **4**, and the reaction with pivaladoxime and benzaldoxime were unsuccessful with BTMA ICl_4; many more by-products formed and the desired adducts could not be conclusively identified amongst them. An alternative procedure was investigated to generate the dipole in the case of benzonitrile oxide. Following the method described previously [12], benzaldehyde oxime was pre-chlorinated using *N*-chlorosuccinimide (NCS). Without further purification, the benzohydroximoyl chloride was dissolved in chloroform with enamine **4**, followed by addition of triethylamine. In this case the reaction was cleaner, and after heating at reflux for two days isoxazole **11a** was isolated, along with the furoxan dimer [13] of the dipole (Scheme 3).

Similarly, Zong *et al*. reported on reversed regioselectivity achieved by the cycloaddition of methyl 3-(*p*-nitrobenzoyloxy)acrylate to a variety of substituted benzonitrile oxides [14]. Also, only 4-substituted isoxazole was isolated from the reaction of 2-methoxyvinyl phenyl ketone with benzonitrile oxide [15]. Both dipolarophiles, 2-methoxyvinyl phenyl ketone and enamine **4**, have one electron-donating (EDG) and one electron-withdrawing (EWG) group attached on the opposite sides of the double bond. It is believed that such dipolarophiles have a HOMO more polarised on the carbon adjacent to EWG, and the LUMO has larger coefficient on the carbon where the EDG is attached. In this case, both dipole LUMO-dipolarophile

Scheme 3



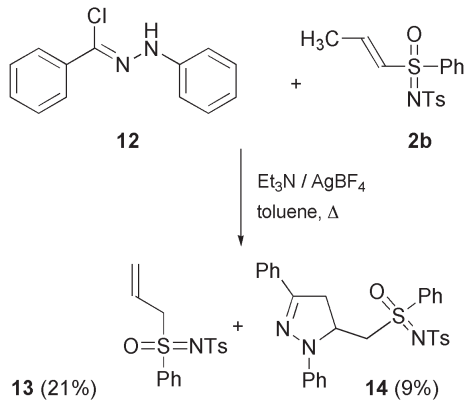
HOMO and dipole HOMO-dipolarophile LUMO interactions lead to isoxazolines/isoxazoles with the EWG in 4-position. In our case, therefore, 4-phenylsulfonyl isoxazoles **11** were isolated. It may be noticed that there is an effect, possibly steric, of the substituent R on nitrile oxide, on the reactivity and regioselectivity of the dipole in cycloaddition. The best yield of the product was obtained with methyl group as substituent. In the case of phenyl substituent, it was more difficult to achieve cycloaddition and an alternative route had to be found, affording lower yield of the product. With ethyl, also a small amount of the opposite regioisomer **10c** was isolated, and for R = *t*-butyl product could not be isolated.

Although slightly detrimental on the yield, the dimethylamino group of the enamine **4** showed the effect of the reversed regioselectivity in 1,3-dipolar cycloaddition reactions with nitrile oxides. The sulfoximide analogue **5**, on the other hand, showed no dipolarophilic activity in the same reactions. In fact, other vinyl sulfoximides, which we prepared to the method of Jackson [8] as previously mentioned, were also unreactive using same nitrile oxides as 1,3-dipoles. Attempted cycloadditions of these vinyl sulfoximides with diarylnitrile imides were unsuccessful as well. These reactions were extensively investigated under a range of conditions, and usually dipole dimerisations/self condensation reactions appeared to take place and the vinyl sulfoximide was recovered intact. Thus, we can only confirm that vinyl sulfoximides are poor dipolarophiles, with only one example of their dipolarophilic activity in the reactions with nitrones [4]. Apart from attempting to use different type of dipoles, molecular orbital calculations might be needed to understand better how vinyl sulfoximides could be useful in 1,3-dipolar cycloaddition reactions in the future.

Interestingly, to our knowledge, there are no reports on dipolarophilic activity of allylic sulfoximides. An unexpected result of one of the attempted cycloaddition reactions using vinylic sulfoximide led us to believe that allylic sulfoximides actually might be interesting dipolarophiles to study. This attempted cycloaddition undertaken was between α-chlorobenzaldehyde phenylhydrazone (**12**) [16] and *S*-((*E*)-prop-1-enyl)-*S*-phenyl-*N*-(*p*-tolylsulfonyl) sulfoximide (**2b**) [8] in toluene. To enhance the dehydrohalogenation process silver tetrafluoroborate was added and the mixture heated at reflux for 24 h. None of the expected cycloadducts were identified; however *S*-(prop-2-enyl)-*S*-phenyl-*N*-(*p*-tolylsulfonyl) sulfoximide (**13**) was recovered along with a small amount of 1,3-diphenyl-5-([*S*-phenyl-*N*-toluene-4-sulfonyl]sulfoximinylmethyl)-4,5-dihydro-1*H* pyrazoline (**14**) as a 1:1 mixture of diastereoisomers. The allylic sulfoximide **13**, formed presumably as the result of base-catalyzed isomerization [17] of vinyl sulfoximide **2b**, which then gave rise to the pyrazoline **14** by cycloaddition (Scheme 4). We decided therefore to look further at allylic sulfoximides.

There are only a few methods describing general preparations of allylic sulfoximides [6], but we envisaged a

Scheme 4

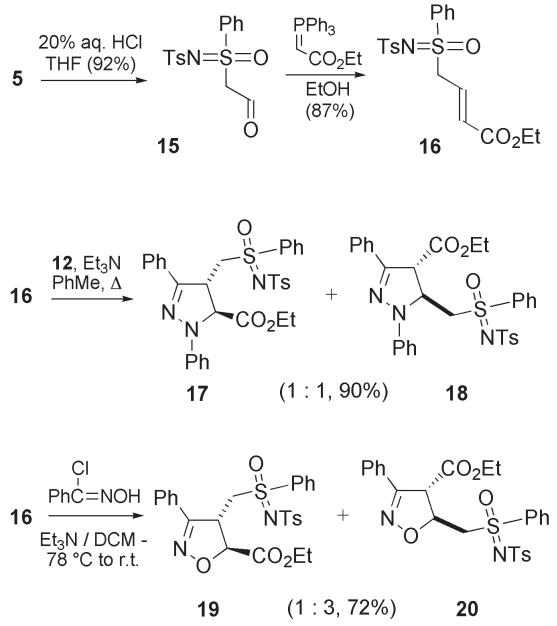


straightforward route to such sulfoximides using enamine **5**. This was hydrolysed to *S*-(2-oxoethyl)-*S*-phenyl-*N*-(*p*-tolylsulfonyl) sulfoximide (**15**). Although aldehyde **15** seemed to be obtained in very good yield, it was found to be unstable and without further purification was then condensed with ethoxycarbonylmethylene triphenylphosphorane [18] to give *S*-((*E*)-(3-ethoxycarbonyl)prop-2-enyl)-*S*-phenyl-*N*-(*p*-tolylsulfonyl) sulfoximide (**16**). Although not further investigated, the aldehyde **15** should react in principle with a range of Wittig reagents, thus providing a general stereospecific route to allylic sulfoximides. The corresponding aldehyde from sulfone enamine **4** was found to be quite water soluble and also volatile, so obtaining reasonable yields proved very difficult using this approach.

Allylic sulfoximide **16** reacted with diphenylnitrile imide at room temperature to give a cycloadduct in excellent yield (90%). However an inseparable 1:1 mixture of two regioisomeric pyrazolines **17** and **18** was obtained. From the proton nmr we could also deduce that each regioisomer was present as a 1:1 mixture of diastereoisomers due to the chirality at sulfur (Scheme 5).

To study nitrile oxide cycloaddition reactions benzaldoxime and acetaldoxime were first chlorinated with BTMA ICl_4 and then allylic sulfoximide **16** was added. After a short period, starting materials were consumed but many by-products formed. In a test reaction there was no evidence that BTMA ICl_4 reacted with the sulfoximide directly, so the reactions with aldoximes were repeated using low temperature conditions. The allylic sulfoximide **16** was added to the chlorinated aldoximes at -78 ˚C. The temperature of the mixture was then slowly brought to room temperature but the same results were obtained as before. Next, benzohydroximoyl chloride, preformed by reaction of benzaldehyde oxime (**7a**) with NCS [12], was dissolved in dichloromethane and at -78 ˚C was added allylic sulfoximide **16**, followed by triethylamine to generate the dipole. The mixture was warmed to room temperature slowly overnight with stirring, to afford cycloadducts **19** and **20** in good yield (72%). It proved impossible to separate each of the isomers cleanly by column chromatography, but we determined that a slight excess of regioisomer **20** was obtained. This deduction was based on chemical shift information from the proton nmr spectrum, and also the expected electronic factor favouring addition of the oxygen of the dipole to the β-carbon of the eneoate group. Again, each regioisomer was present as a 1:1 mixture of diastereoisomers (Scheme 5).

Scheme 5



In conclusion, a simple reaction afforded (*E*)-1-dimethylamino-2-phenylsulfonylethylene and *S*-((*E*)-2-(*N'*,*N'*-dimethylamino)ethenyl)-*S*-phenyl-*N*-(*p*-tolylsulfonyl) sulfoximide. These compounds might be employed to prepare other functionalised vinyl sulfones/sulfoximides, thus avoiding the potentially more difficult Peterson olefination. The dimethylamino group of the sulfone seems to have an effect leading to reversed regioselectivity in cycloadditions with nitrile oxides. The sulfoximide analogue showed no dipolarophilic activity, just as many other vinyl sulfoximides have proved to be poor reaction partners in cycloadditions. On the other hand, during an attempted cycloaddition, unexpected isomerisation of the vinyl sulfoximide took place and the resulting allylic isomer gave rise to a cycloadduct, indicating that allylic sulfoximides could be better chiral dipolarophiles. β-Dimethylaminovinyl sulfoximide was easily converted to *S*-((*E*)-(3-ethoxycarbonyl)prop-2-enyl)-*S*-phenyl-*N*-(*p*-tolylsulfonyl) sulfoximide, offering a route for the preparation of other allylic sulfoximides through the aldehyde intermediate. The allylic sulfoximide we prepared reacts with both benzonitrile oxide and diphenylnitrile imide to give rise to cycloadducts in high yield. Unfortunately, no stereoselectivity and only modest regioselectivity in the case of benzonitrile oxide was observed. Nevertheless, this preliminary investigation indicates that allylic sulfoximides are more interesting dipolarophiles, therefore, it might be worth investigating further reaction conditions, the effects of the substituents and which 1,3-dipoles to employ to achieve better regio- and stereoselectivity in the future.

EXPERIMENTAL

Melting points were measured in glass capillary tubes using a Gallenkamp melting point apparatus and are uncorrected. The ir

spectra were recorded on a Perkin Elmer 882 IR spectrophotometer. The ^1H and ^{13}C nmr spectra were recorded on a JEOL JNM-LA 400 or JEOL JNM-GX 270 at 400 MHz (^1H) and 100 or 67.8 MHz (^{13}C). All chemical shifts are reported in ppm (δ) downfield from internal tetramethylsilane and coupling constants are given in Hertz (Hz). The mass spectra were recorded on a Finnigan MAT 1020 GC/MS mass spectrometer. Chromatographic separations were carried out on silica gel column (Prolabo silica gel 60, 35-75 μm, 230-400 mesh). Reactions were monitored by tlc on silica plates (Merck Kieselgel 60 F_{254}). Elemental analyses were performed by staff at the Chemistry Department at the University of Hull. Tetrahydrofuran was dried over and distilled from sodium benzophenone ketal. Toluene was dried over sodium wire. *N*,*N*-Dimethylformamide (DMF) and ethanol were dried over 4 Å molecular sieves. Dichloromethane and triethylamine were dried over calcium hydride powder.

S-Methyl-*S*-phenyl-*N*-(*p*-tolylsulfonyl)sulfoximide (**1**).

S-Methyl-*S*-phenyl-*N*-(*p*-tolylsulfonyl)sulfoximide (**1**) was previously prepared and described by Johnson *et al.* [19]. However, as part of our synthesis of this compound, we applied much simpler method for the preparation of sulfilimines, recently reported by Marzinzik and Sharpless [20]. Our simplified method for the preparation of **1** is described here: To a stirred mixture of 2 g (0.016 mole) of thioanisole dissolved in 50 ml of acetonitrile was added 5.63 g (0.02 mole) of chloramine-T trihydrate. This mixture was stirred overnight at room temperature. The reaction was quenched with 60 ml of dichloromethane and the white precipitate formed was removed by filtration and discarded. The solvent was removed under reduced pressure to leave a viscous amber oil, which was recrystallised from ethanol to yield 3.75 g (80%) of pale yellow crystals (*S*-methyl-*S*-phenyl-*N*-(*p*-tolylsulfonyl)sulfilimine). Sulfilimine (1.56 g, 5.4 mmole) and 6 ml (0.144 mole) of acetonitrile were dissolved in 120 ml of methanol. To this was added a solution of 0.8 g (58 mmole) of potassium carbonate and 6 ml (60 mmole) of hydrogen peroxide in 120 ml of methanol. The mixture was stirred at room temperature overnight, then the solvent removed *in vacuo* to leave a cloudy white liquid. 80 ml of dichloromethane and 80 ml of water were added and the organic layer separated, washed with water and dried over magnesium sulfate. The solvent was removed under reduced pressure leaving an off white solid which was recrystallised from ethanol to yield 1.38 g (80%) of **1** as white crystals, mp 91-100 °C (from ethanol); ir (potassium bromide): 3021, 2922, 1598, 1480, 1450, 1315 (SO), 1231 (SO), 1147 (SO), 1090, 1067 cm^{-1}; ^1H nmr (400 MHz, deuteriochloroform): δ 2.40 (s, 3H, C_6H_4-CH_3), 3.43 (s, 3H, $SOCH_3$), 7.23-7.29 (m, 2H, SO_2ArH, *m*), 7.59-7.63 (m, 2H, SOPhH, *m*), 7.68-7.72 (m, 1H, SOPhH, *p*), 7.85-7.87 (m, 2H, SOPhH, *o*), 8.01-8.03 (m, 2H, SO_2ArH, *o*); ^{13}C nmr (100 MHz, deuteriochloroform): δ 21.52, 46.65, 126.66, 127.49, 129.29, 129.72, 134.39, 138.38, 140.64, 142.90; ms: m/z 309 (M^+, 4%), 294 (84), 139 (60), 91 (100), 77 (53), 65 (64).

Anal. Calcd. for $C_{14}H_{15}NO_3S_2$: C, 54.3; H, 4.9; N, 4.5; S, 20.7. Found: C, 54.1; H, 5.0; N, 4.5; S, 21.8.

General Procedure for the Olefination of *S*-methyl-*S*-phenyl-*N*-(*p*-tolylsulfonyl)sulfoximide (**1**).

To a solution of 1 g (3.2 mmole) of *S*-methyl-*S*-phenyl-*N*-(*p*-tolylsulfonyl)sulfoximide (**1**) dissolved in 15 ml of dry tetrahydrofuran, 2 ml (3.2 mmole) of *n*-butyllithium was added dropwise at -78 ºC under nitrogen. The mixture was warmed to room temperature and stirred for ten minutes, then cooled back to -78 ºC. At that temperature, aldehyde (4.8 mmole) was added to the mixture. The mixture was warmed to 0 ºC and stirred for 45 minutes. Then, 0.5 ml (3.5 mmole) of dry triethylamine was added, followed by 0.27 ml (3.5 mmole) of methanesulfonyl chloride added dropwise at 0 ºC. After stirring at 0 ºC for 20 minutes, a second equivalent of dry triethylamine (0.5 ml, 3.5 mmole) was added to the mixture. The mixture was warmed to room temperature and stirred for another 20 minutes, then quenched with 2 ml of diluted aqueous ammonium chloride solution (10% NH_4Cl) and extracted with dichloromethane. After the solvent was dried over magnesium sulfate, and removed by evaporation, the resulting yellow oil was purified by column chromatography on silica gel (hexane/ethyl acetate = 1:1) as eluent to give the product.

S-Phenyl-*N*-(*p*-tolylsulfonyl)-vinylsulfoximide (**2a**).

This compound was obtained as white crystals (13%), mp 127 ºC; ir (potassium bromide): 3061, 1597, 1449 (CH=CH), 1314 (SO), 1289, 1232 (SO), 1152 (SO), 1087, 1059 cm^{-1}; ^1H nmr (400 MHz, deuteriochloroform): δ 2.43 (s, 3H, C_6H_4-CH_3), 6.19 (dd, 1H, J = 9.6 Hz, J = 1.5 Hz, C=CH), 6.48 (dd, 1H, J = 16.3 Hz, J = 1.5 Hz, C=CH), 6.83 (dd, 1H, J = 16.3 Hz, J = 9.6 Hz, SOCH=C), 7.24-7.26 (m, 2H, SO_2ArH, *m*), 7.56-7.60 (m, 2H, SOPhH, *m*,), 7.66-7.70 (m, 1H, SOPhH, *p*), 7.85-7.87 (m, 2H, SOPhH, *o*), 7.96-7.99 (m, 2H, SO_2ArH, *o*); ^{13}C nmr (100 MHz, deuteriochloroform): δ 21.61, 126.76, 128.11, 128.33, 129.36, 129.76, 130.13, 134.37, 137.40, 137.69, 142.99, ms: m/z 321 (M^+, 6%), 139 (100), 125 (65), 91 (66), 77 (37), 65 (39).

Anal. Calcd. for $C_{15}H_{15}NO_3S_2$: C, 56.1; H, 4.7; N, 4.4; S, 20.0. Found: C, 56.5; H, 4.7; N, 4.3; S, 19.8.

S-((*E*)-Prop-1-enyl)-*S*-phenyl-*N*-(*p*-tolylsulfonyl)sulfoximide (**2b**).

This compound was obtained as white crystals (30%), mp 126-128 ºC (from ethanol); ir (potassium bromide): 3056, 1641 (CH=CH trans), 1596, 1450 (CH=CH trans), 1319 (SO), 1229 (SO), 1150 (SO), 1087, 1059 cm^{-1}; ^1H nmr (400 MHz, deuteriochloroform): δ 1.95 (dd, 3H, J = 7.1 Hz, J = 1.7 Hz, CH-CH_3), 2.39 (s, 3H, C_6H_4-CH_3), 6.45 (dq, 1H, J = 14.8 Hz, J = 1.7 Hz, CH=C), 6.99 (dq, 1H, J = 14.8 Hz, J = 7.1 Hz, CH=C), 7.24-7.26 (m, 2H, SO_2ArH, *m*), 7.54-7.67 (m, 3H, SOPhH, *m*, *p*), 7.83-7.96 (m, 4H, SOPhH, *o* + SO_2ArH, *o*); ^{13}C nmr (100 MHz, deuteriochloroform): δ 17.61, 21.60, 126.75, 127.78, 129.29, 129.62, 130.27, 133.96, 138.69, 140.96, 142.82, 144.53; ms: m/z 335 (M^+, 3%), 278 (27), 139 (100), 125 (53), 91 (83), 77 (28).

Anal. Calcd. for $C_{16}H_{17}NO_3S_2$: C, 57.3; H, 5.1; N, 4.1; S, 19.1. Found: C, 57.6; H, 5.2; N, 3.9; S, 19.3.

S-((*E*)-3,3-Dimethyl-but-1-enyl)-*S*-phenyl-*N*-(*p*-tolylsulfonyl)-sulfoximide (**2c**).

This compound was obtained as pale yellow crystals (53%), mp 166-168 ºC (from ethanol); ir (potassium bromide): 3043, 2964, 1621 (CH=CH trans), 1448 (CH=CH trans), 1317 (SO), 1252, 1216 (SO), 1152 (SO), 1101, 1070 cm^{-1}; ^1H nmr (400 MHz, deuteriochloroform): δ 1.08 (s, 9H, $C(CH_3)_3$), 2.39 (s, 3H, C_6H_4-CH_3), 6.29 (d, 1H, J = 15.1 Hz, CH=C), 6.96 (d, 1H, J = 15.1 Hz, CH=C), 7.23-7.26 (m, 2H, SO_2ArH, *m*), 7.54-7.68 (m, 3H, SOPhH, *m*, *p*), 7.82-7.95 (m, 4H, SOPhH, *o* + SO_2ArH, *o*); ^{13}C nmr (100 MHz, deuteriochloroform): δ 21.60, 28.26, 34.78, 125.45, 126.78, 127.74, 128.29, 129.29, 129.62, 133.91, 138.88, 141.00, 142.79; ms: m/z 378 (M^+, 1%), 155 (28), 139 (100), 125 (33), 91 (63), 77 (27).

Anal. Calcd. for $C_{19}H_{23}NO_3S_2$: C, 60.5; H, 6.1; N, 3.7; S, 17.0. Found: C, 60.8; H, 6.3; N, 3.5; S, 17.2.

S-2-((*E*)-2-Phenylethenyl)-*S*-phenyl-*N*-(*p*-tolylsulfonyl)sulfoximide (**2d**).

This compound was obtained as white crystals (89%), mp 130-132 ºC (from ethanol); ir (potassium bromide): 3058, 1608 (CH=CH trans), 1448 (CH=CH trans), 1319 (SO), 1235 (SO), 1223, 1152 (SO), 1086, 1058 cm^{-1}; ^1H nmr (400 MHz, deuteriochloroform): δ 2.38 (s, 3H, C_6H_4-CH_3), 6.90 (d, 1H, J = 15.1 Hz, CH=C), 7.23-7.26 (m, 3H, 2 ArH + CH=C), 7.37-7.47 (m, 4H, ArH), 7.55-7.67 (m, 4H, ArH), 7.85-7.87 (m, 2H, SOPhH, *o*), 8.01-8.03 (m, 2H, SO_2ArH, *o*); ^{13}C nmr (100 MHz, deuteriochloroform): δ 21.59, 125.61, 126.84, 127.81, 128.97, 129.24, 129.35, 129.73, 131.82, 131.90, 134.08, 138.82, 140.88, 142.92, 144.02; ms: m/z 398 (M^+, 4%), 368 (32), 139 (100), 125 (29), 91 (98), 77 (43).

Anal. Calcd. for $C_{21}H_{19}NO_3S_2$: C, 63.5; H, 4.8; N, 3.5; S, 16.1. Found: C, 63.8; H, 5.0; N, 3.5; S, 16.4.

(*E*)- 1-Dimethylamino-2-phenylsulfonylethylene (**4**).

To a solution of 1.0 g (6.40 mole) of methyl phenyl sulfone (**3**) dissolved in 30 ml of dry *N*,*N*-dimethylformamide was added 4.4 ml (32 mole) of *N*,*N*-dimethylformamide dimethyl acetal under nitrogen, and the solution was heated at reflux overnight. The solvent and the excess of acetal were then removed by evaporation *in vacuo*. The resulting solid was recrystallised from ethanol to give 1.1 g (94%) of **4** as pale yellow crystals, mp 119-120 ºC (from ethanol); ir (potassium bromide): 3073, 2915, 2817, 1623 (CH=CH), 1478, 1449 (CN), 1433, 1396, 1318 (SO), 1267 (SO), 1132 (SO), 1080, 969, 898, 844, 754, 720, 690 cm^{-1}; ^1H nmr (400 MHz, deuteriochloroform): δ 2.74 (s, 3H, NCH_3), 3.06 (s, 3H, NCH_3), 4.87 (d, 1H, J = 12.7 Hz, C=CH), 7.32 (d, 1H, J = 12.7 Hz, C=CH), 7.44-7.52 (m, 3H, PhH, *m*, *p*), 7.85-7.88 (m, 2H, PhH, *o*); ^{13}C nmr (100 MHz, deuteriochloroform): δ 37.11, 44.48, 92.31, 126.11, 128.78, 131.52, 145.12, 151.01; ms: m/z 211 (M^+, 100%), 146 (35), 134 (15), 91 (29), 77 (62), 69 (94).

Anal. Calcd. for $C_{10}H_{13}NO_2S$: C, 56.9; H, 6.2; N, 6.6; S, 15.2. Found: C, 56.8; H, 6.2; N, 6.3; S, 14.9.

S-((*E*)-2-(*N'*,*N'*-Dimethylamino)ethenyl)-*S*-phenyl-*N*-(*p*-tolylsulfonyl) Sulfoximide (**5**).

To a solution of 1.0 g (3.20 mole) of *S*-methyl-*S*-phenyl-*N*-(*p*-tolylsulfonyl)sulfoximide (**1**) dissolved in 20 ml of dry *N*,*N*-dimethylformamide was added 2.2 ml (16.5 mole) of *N*,*N*-dimethylformamide dimethyl acetal under nitrogen, and the solution was heated at reflux overnight. The solvent and the excess of acetal were then removed by evaporation *in vacuo*. The resulting solid was recrystallised from ethyl acetate to give 1.1 g (94%) of **5** as yellow solid, mp 108-110 ºC (from ethyl acetate); ir (potassium bromide): 3078, 2920, 1627 (CH=CH), 1446 (CN), 1319 (SO), 1212 (SO), 1154 (SO), 1098, 1050 cm^{-1}; ^1H nmr (400 MHz, deuteriochloroform): δ 2.38 (s, 3H, C_6H_4-CH_3), 2.74 (s, 3H, NCH_3), 3.08 (s, 3H, NCH_3), 4.79 (d, 1H, J = 12.2 Hz, C=CH), 7.20-7.22 (m, 2H, SO_2ArH, *m*), 7.34 (d, 1H, J = 12.2 Hz, C=CH), 7.44-7.54 (m, 3H, SOPhH, *m*, *p*), 7.81-7.91 (m, 4H, SOPhH, *o* + SO_2ArH, *o*); ^{13}C nmr (100 MHz, deuteriochloroform): δ 21.55, 37.50, 45.06, 88.60, 126.46, 126.76, 128.81, 129.08, 132.36, 141.62, 142.17, 143.62, 151.77; ms: m/z 364 (M^+, 1%), 194 (5), 161 (26), 91 (32), 86 (100), 69 (44).

Anal. Calcd. for $C_{17}H_{20}N_2O_3S_2$: C, 56.0; H, 5.5; N, 7.7; S, 17.6. Found: C, 56.0; H, 5.6; N, 7.6; S, 17.6.

General Procedure for the Reaction of Aldoximes **7a-d** with Phenyl vinyl sulfone (**6**).

All aldoximes (**7a-d**) were prepared according to the method of Bashiardes *et al*. [21]. Benzyl trimethylammonium tetrachloroiodate (BTMA ICl_4) was prepared as previously described [11]. To a solution of aldoxime (3.1 mmole) was added 1.3 g (3.1 mmole) of BTMA ICl_4 in 15 ml of dry dichloromethane under nitrogen. The green suspension was stirred at room temperature for ten minutes, during which period it became a clear yellow solution. Then, 0.504 g (3 mmole) of phenyl vinyl sulfone was added followed by 0.47 ml (3.3 mmole) of triethylamine added dropwise. The mixture was then heated at reflux for three days. Diethyl ether was added and the precipitate of BTMA ICl_2 was removed by filtration. The solvent was removed *in vacuo* and the resulting oil was purified by column chromatography on silica gel (hexane/ethyl acetate = 1:1) as eluent to give the product as an oil or a solid.

5-Benzenesulfonyl-3-phenyl-4,5-dihydro-isoxazole (**8a**).

This compound was obtained as white crystals (78%), mp 136-138 ºC (from ethanol); ir (potassium bromide): 2977, 1447, 1356, 1311 (SO), 1145 (SO) cm^{-1}; ^1H nmr (400 MHz, deuteriochloroform): δ 3.79 (dd, 1H, J_{AB} = 18.3 Hz, J_{AX} = 10.9 Hz), 4.06 (dd, 1H, J_{AB} = 18.3 Hz, J_{BX} = 4.5 Hz), 5.55 (dd, 1H, J_{AX} = 10.9 Hz, J_{BX} = 4.5 Hz), 7.36-7.68 (m, 8H, PhH), 7.98-8.00 (m, 2H, SO_2ArH, *o*); ^{13}C nmr (67.8 MHz, deuteriochloroform): δ 36.84, 93.27, 127.06, 127.27, 128.86, 129.23, 129.74, 131.10, 134.57, 135.19, 156.88; ms: m/z 288 (MH^+, 2%), 146 (M^+-SO_2Ar, 100), 144 (6), 118 (49), 91 (19), 77 (77).

Anal. Calcd. for $C_{15}H_{13}NO_3S$: C, 62.7; H, 4.6; N, 4.9; S, 11.2. Found: C, 62.4; H, 4.6; N, 5.0; S, 10.8.

5-Benzenesulfonyl-3-*tert*-butyl-4,5-dihydro-isoxazole (**8b**).

This compound was obtained as white crystals (63%), mp 120-121 ºC (from ethanol); ir (potassium bromide): 3852, 3440, 3075, 2970, 2935 ($(CH_3)_3$), 2906, 2871, 2359, 2340, 1909, 1825, 1700 (C=N), 1616, 1585, 1477, 1452 ($(CH_3)_3$), 1436, 1396, 1370 ($C(CH_3)_3$), 1321, 1312 (SO), 1276 (SO), 1260, 1145 (SO), 1086, 1015, 962, 855, 792, 766, 740, 689 cm^{-1}; ^1H nmr (400 MHz, deuteriochloroform): δ 1.13 (s, 3H, $(CH_3)_3$), 3.43 (dd, 1H, J_{AB} = 18.6 Hz, J_{AX} = 10.7 Hz), 3.62 (dd, 1H, J_{AB} = 18.6 Hz, J_{BX} = 4.2 Hz), 5.40 (dd, 1H, J_{AX} = 10.7 Hz, J_{BX} = 4.2 Hz), 7.57-7.61 (m, 2H, PhH, *m*), 7.68-7.72 (m, 1H, PhH, *p*), 7.98-8.00 (m, 2H, PhH, *o*); ^{13}C nmr (100 MHz, deuteriochloroform): δ 27.97, 33.21, 36.62, 93.20, 129.28, 130.03, 134.55, 135.28, 166.18; ms: m/z 268 (MH^+, 1%), 149 (7), 126 (100), 97 (5), 77 (64), 70 (10).

Anal. Calcd. for $C_{13}H_{17}NO_3S$: C, 58.4; H, 6.4; N, 5.2; S, 12.0 Found: C, 58.5; H, 6.3; N, 5.5; S, 12.1.

5-Benzenesulfonyl-3-ethyl-4,5-dihydro-isoxazole (**8c**).

This compound was obtained as yellow oil (37%); ir (neat): 3630, 3066, 2978, 2942 (CH_2CH_3), 2883, 2361, 2342, 1981, 1908, 1743, 1696 (C=N), 1631, 1585, 1478, 1462, 1448 (CH_2CH_3), 1429, 1378, 1348, 1309 (SO), 1213 (SO), 1178, 1151 (SO), 1086, 1024, 999, 956, 878, 837, 801, 765, 735, 691, 633 cm^{-1}; ^1H nmr (400 MHz, deuteriochloroform): δ 1.08 (t, 3H, J = 7.6 Hz, CH_3), 2.28-2.35 (m, 2H, CH_2), 3.43 (dd, 1H, J_{AB} = 18.8 Hz, J_{AX} = 10.7 Hz), 3.59 (dd, 1H, J_{AB} = 18.8 Hz, J_{BX} = 4.2 Hz), 5.41 (1 H, dd, J_{AX} = 10.7 Hz, J_{BX} = 4.2 Hz), 7.56-7.61 (m, 2H, PhH, *m*), 7.68-7.72 (m, 1H, PhH, *p*), 7.95-7.98 (m, 2H, PhH, *o*); ^{13}C nmr (67.8 MHz, deuteriochloroform): δ 10.52, 20.53, 38.70,

92.57, 129.18, 129.73, 134.46, 135.21, 160.33; ms: m/z 240 (MH^+, 1%), 125 (7), 104 (10), 98 (100), 77 (75), 70 (89).

5-Benzenesulfonyl-3-methyl-4,5-dihydro-isoxazole (**8d**).

This compound was obtained as white crystals (26%), mp 83-85 ºC; ir (potassium bromide): 2976, 2927, 1450, 1432, 1304 (SO), 1146 (SO) cm^{-1}; ^1H nmr (400 MHz, deuteriochloroform): δ 1.96 (s, 3H, CH_3), 3.43 (dd, 1H, J_{AB} = 18.8 Hz, J_{AX} = 10.7 Hz), 3.60 (dd, 1H, J_{AB} = 18.8 Hz, J_{BX} = 4.4 Hz), 5.40 (dd, 1H, J_{AX} = 10.7 Hz, J_{BX} = 4.4 Hz), 7.57-7.61 (m, 2H, PhH, *m*), 7.68-7.72 (m, 1H, PhH, *p*), 7.95-7.97 (m, 2H, PhH, *o*); ^{13}C nmr (67.8 MHz, dimethylsulfoxide-d_6): δ 12.34, 40.18, 92.67, 129.25, 129.74, 134.57, 135.29 and 155.92; ms: m/z 226 (MH^+, 1%), 125 (13), 104 (16), 97 (13), 84 (100), 65 (14).

Anal. Calcd. for $C_{10}H_{11}NO_3S$: C, 53.3; H, 4.9; N, 6.2; S, 14.2 Found: C, 53.4; H, 4.9; N, 6.5; S, 14.0.

4-Benzenesulfonyl-3-methyl-4,5-dihydro-isoxazole (**9d**).

This compound was obtained as yellow oil (5%); ^1H nmr (400 MHz, deuteriochloroform): δ 2.26 (s, 3H, CH_3), 4.40 (dd, 1H, J_{AX} = 10.7 Hz, J_{AB} = 10.5 Hz), 4.61 (dq, 1H, J_{AB} = 10.5 Hz, J_{BX} = 4.4 Hz), 4.73 (dd, 1H, J_{AX} = 10.7 Hz, J_{BX} = 4.4 Hz), 7.58-7.62 (m, 2H, PhH, *m*), 7.69-7.74 (m, 1H, PhH, *p*), 7.86-7.89 (m, 2H, PhH, *o*); ^{13}C nmr (67.8 MHz, deuteriochloroform): δ 12.88, 70.51, 75.40, 128.91, 129.27, 129.54, 134.95, 149.47; ms: m/z 226 (MH^+, 8%), 168 (14), 125 (82), 97 (28), 84 (100), 65 (34).

General Procedure for the Reaction of Aldoximes **7a-d** with (*E*)-1-Dimethylamino-2-phenylsulfonylethylene (**4**).

The procedure is the same as for the reaction of aldoximes **7a-d** with Phenyl vinyl sulfone (**6**), only the reaction mixture was heated at reflux for four days.

5-Benzenesulfonyl-3-ethyl-isoxazole (**10c**) and 4-Benzenesulfonyl-3-ethyl-isoxazole (**11c**).

The compound **11c** was obtained as yellow oil (27%) and a mixture containing some of the other regioisomer **10c**, as shown by ^1H and ^{13}C nmr, which could not be separated. The ratio of regioisomers **11c** and **10c** is estimated from ^1H nmr to be 5:1, thus, the yield can be calculated as 25% for **11c** and 5% for **10c**; the following data in ^1H nmr refer to the regioisomer **11c** except where assigned to the minor regioisomer **10c** - ^1H nmr (400 MHz, deuteriochloroform): δ 1.24 (t, 3H, J 7.6 Hz, CH_3), 1.35 (t, J 7.3 Hz, CH_3, **10c**), 2.56 (q, J 7.3 Hz, CH_2, **10c**), 2.75 (q, 2H, J 7.6 Hz, CH_2), 6.42 (s, C=CH, **10c**), 7.57-7.82 (m, 3H, PhH, *m*, *p*), 7.95-8.06 (m, 2H, PhH, *o*), 8.90 (s, 1H, C=CH); ^{13}C nmr (100 MHz, deuteriochloroform): δ 9.87, 11.04, 11.35, 16.01, 18.48, 19.34, 127.50, 129.13, 129.30, 129.59, 130.88, 131.22, 134.11, 135.26, 135.59, 140.62, 160.71, 162.35; ms: m/z 237 (M^+, 14%), 141 (44), 125 (17), 96 (21), 77 (100), 68 (9).

4-Benzenesulfonyl-3-methyl-isoxazole (**11d**).

This compound was obtained as white crystals (30%), mp 85-86 ºC; ir (potassium bromide): 3139, 3110, 1566, 1449, 1400, 1318 (SO), 1168 (SO), 1138 (SO), 1119, 1072 cm^{-1}; ^1H nmr (400 MHz, deuteriochloroform): δ 2.35 (s, 3H, CH_3), 7.56-7.61 (m, 2H, PhH, *m*), 7.65-7.70 (m, 1H, PhH, *p*), 7.96-7.99 (m, 2H, PhH, *o*), 8.92 (s, 1H, C=CH); ^{13}C nmr (67.8 MHz, deuteriochloroform): δ 9.92, 127.54, 129.63, 134.14, 134.17, 140.50, 156.24, 162.19; ms: m/z 223 (M^+, 100%), 130 (44), 116 (12), 102 (11), 77 (83), 65 (13).

Anal. Calcd. for $C_{10}H_9NO_3S$: C, 53.8; H, 4.1; N, 6.3; S, 14.4 Found: C, 53.8; H, 4.0; N, 6.3; S, 14.3.

Modified Method for the Preparation of 4-Benzenesulfonyl-3-phenyl-isoxazole (**11a**).

To a solution of 0.266 g (2.2 mmole) of benzaldehyde oxime (**7a**) dissolved in 10 ml of dry *N*,*N*-dimethylformamide was added 0.297 g (2.2 mmole) of solid *N*-chlorosuccinimide with stirring. The solution was stirred at room temperature for one hour before it was poured into cold water and extracted with diethyl ether. The combined extracts were washed with cold water and dried over magnesium sulfate, then the solvent was removed by evaporation. The resulting yellow oil of benzohydroximoyl chloride was dissolved in 12 ml of chloroform and 0.422 g (2 mmole) of enamine **4** was added at room temperature. Then, 0.32 ml (2.2 mmole) of triethylamine was added dropwise over 15 minutes, and the mixture was then heated at reflux for two days. The solvent was removed *in vacuo*, and the resulting oil was purified by column chromatography on silica gel (hexane/ethyl acetate = 2:1) as eluent to give the product **11a** as white solid (0.12 g, 21%); ir (potassium bromide): 3108, 3064, 1447, 1366, 1328 (SO), 1146 (SO), 1135 (SO) cm^{-1}; ^1H nmr (400 MHz, deuteriochloroform): δ 7.22-7.53 (m, 8H, PhH), 8.08-8.11 (m, 2H, SO_2PhH, *o*), 8.96 (s, 1H, C=CH); ms: m/z 285 (M^+, 24%), 220 (7), 143 (84), 90 (21), 77 (100), 63 (14). Another product was obtained as the first fraction, dimer of the dipole, furoxan, as white crystals (0.06 g, 13%); ir (potassium bromide): 3062, 1598, 1575 (C=N), 1444 (N-O), 1422 (N-O) cm^{-1}; ^1H nmr (400 MHz, deuteriochloroform): δ 7.41-7.64 (m, 8H, PhH), 8.16-8.24 (m, 2H, PhH); ms: m/z 238 (M^+, 6%), 222 (M^+-O, 29), 178 (100), 119 (46), 91 (11), 77 (14).

1,3-Dipolar Cycloaddition Reaction of δ-Chlorobenzaldehyde Phenylhydrazone (**12**) and *S*-((*E*)-Prop-1-enyl)-*S*-phenyl-*N*-(*p*-tolylsulfonyl) Sulfoximide **2b**; an Unexpected Isomerisation and Cycloaddition of Allylic Sulfoximide: *S*-(Prop-2-enyl)-*S*-phenyl-*N*-(*p*-tolylsulfonyl) Sulfoximide (**13**) and (*R*,*S*/*S*,*R*)- and (*S*,*S*/*R*,*R*)-1,3-Diphenyl-5-([*S*-phenyl-*N*-toluene-4-sulfonyl]sulfoximinylmethyl)-4,5-dihydro-1*H*-pyrazole (**14**).

To a solution of 0.078 g (0.34 mmole) of α-chlorobenzaldehyde phenylhydrazone (**12**) [16] and 0.11 g (0.33 mmole) of vinyl sulfoximide **2b** in 10 ml of dry toluene, 0.19 ml (1.36 mmole) of dry triethylamine was added dropwise, followed by 0.066 g (0.34 mmole) of silver tetrafluoroborate. The mixture was kept in the dark, under nitrogen and heated at reflux for one day. The solid formed was removed by filtration, and then the solvent removed *in vacuo*. The crude product was purified by column chromatography on silica gel (hexane/ethyl acetate = 3:1) as eluent to give **13**, which was formed by isomerisation of vinyl sulfoximide **2b**. The isomer was obtained as brown oil (0.023 g, 21%); ^1H nmr (400 MHz, deuteriochloroform): δ 2.39 (s, 3H, C_6H_4-CH_3), 4.23-4.34 (m, 2H, J = 7.6 Hz, $SOCH_2$), 5.13 (dd, 1H, J_{AB} = 18.2 Hz, $J_{AA'}$ = 1.0 Hz, H_A), 5.36 (dd, 1H, $J_{A'B}$ = 10.4 Hz, $J_{AA'}$ = 1.0 Hz, $H_{A'}$), 5.73 (ddt, 1H, J_{AB} = 18.2 Hz, $J_{A'B}$ = 10.4 Hz, J = 7.6 Hz H_B), 7.24-7.27 (m, 2H, ArH), 7.55-7.59 (m, 2H, ArH), 7.66-7.70 (m, 1H, ArH, *p*), 7.86-7.93 (m, 4H, SO_2ArH, *o* + SOPhH, *o*); ^{13}C nmr (67.8 MHz, deuteriochloroform): δ 21.54, 62.55, 123.57, 126.68, 126.72, 128.78, 129.02, 129.28, 129.29, 134.41, 135.36, 142.85; ms: m/z 335 (M^+, 1%), 180 (16), 155 (68), 117 (37), 91 (100), 77 (39). Another product was obtained as a first fraction, cycloadduct of allylic sulfoximide **13** and hydrazone **12**. The cycloadduct **14** was obtained as a mixture of

diastereoisomers (due to chirality at sulphur) in the ratio 1:1, as brown oil (0.016 g, 9%); ^{1}H nmr (400 MHz, deuteriochloroform)*: δ 2.41 (s, 3H, C_6H_4-CH_3), 3.28-3.84 (m, 4H, $SOCH_2$, $H_AH_{A'}$), 4.65-4.72 (tdd, 1/2H, J = 10.1 Hz, J = 4.5 Hz, J = 1.7 Hz, H_B), 4.96-5.02 (tdd, 1/2H, J = 10.1 Hz, J = 4.5 Hz, J = 1.7 Hz, $H_{B'}$), 6.75-8.07 (m, 19H, ArH); ^{13}C nmr (100 MHz, deuteriochloroform)**: δ 21.63, 38.41, 39.10, 54.03, 54.47, 57.30, 57.54, 113.58, 125.96, 126.36, 126.74, 128.24, 128.41, 128.48, 128.72, 129.32, 129.44, 129.52, 129.61, 129.93, 130.03, 149.02, 155.73; ms: m/z 529 (M^+, 5%), 234 (100), 221 (53), 105 (29), 91 (71), 77 (58).

* Some signals were overlapping, so it was not possible to calculate all coupling constants.

** The aromatic region appears to be too complicated to assign signals accurately to all carbons and it seems that many signals are overlapping.

S-(2-Oxoethyl)-*S*-phenyl-*N*-(*p*-tolylsulfonyl) Sulfoximide (**15**).

To a solution of 0.5 g (1.35 mmole) of *S*-((*E*)-2-(*N*′,*N*′-Dimethylamino)ethenyl)-*S*-phenyl-*N*-(*p*-tolylsulfonyl) sulfoximide (**5**) in 20 ml of tetrahydrofuran, hydrochloric acid (20%) was added until the pH was 1. The two-phase system was stirred at room temperature overnight. Then, a saturated solution of sodium bicarbonate was added until the pH was 7, followed by extraction with dichloromethane. The organic layer was dried over magnesium sulfate and the solvent removed by evaporation, to give **15** as white crystals (0.42 g, 92%), mp 55-57 ºC; ir (potassium bromide): 3063, 2927, 1726 (CO), 1598, 1448, 1316 (SO), 1241 (SO), 1152 (SO), 1088, 1060 cm^{-1}; ^{1}H nmr (400 MHz, deuteriochloroform): δ 2.41 (s, 3H, C_6H_4-CH_3), 4.64 (d, 2H, J = 2.6 Hz, CH_2), 7.21-7.30 (m, 2H, SO_2ArH, *m*), 7.50-7.66 (m, 2H, SOPhH, *m*), 7.71-7.83 (m, 1H, SOPhH, *p*), 7.89 (d, 2H, J = 8.4 Hz, SOPhH, *o*), 7.96 (d, 2H, J = 7.8 Hz, SO_2ArH, *o*), 9.83 (br s, 1H, CHO); ^{13}C nmr (100 MHz, deuteriochloroform): δ 21.64, 66.75, 126.78, 128.14, 129.43, 129.55, 130.02, 135.28, 136.17, 143.57, 188.48; ms: m/z 338(MH^+, 3%), 139 (48), 105 (55), 91 (100), 77 (51), 65 (49).

* This aldehyde was not stable enough to obtain good elemental analysis.

S-((*E*)-(3-Ethoxycarbonyl)prop-2-enyl)-*S*-phenyl-*N*-(*p*-tolylsulfonyl) Sulfoximide (**16**).

To a solution of 0.4 g (1.19 mmole) of *S*-(2-oxoethyl)-*S*-phenyl-*N*-(*p*-tolylsulfonyl)sulfoximide (**15**) in 20 ml of ethanol, 0.42 g (1.19 mmole) of ethoxycarbonylmethylene(triphenyl)-phosphorane [18] was added, and the mixture was stirred at room temperature for half an hour. The product was extracted with dichloromethane, and the organic extracts dried over magnesium sulfate, before the solvent was removed *in vacuo*. The resulting oil was purified by column chromatography on silica gel (hexane/ethyl acetate = 1:1) as eluent to give **16** as white crystals (0.42 g, 87%), mp 95-97 ºC; ir (potassium bromide): 3422, 3069, 2982, 2924, 1719 (C=O), 1654 (CH=CH *trans*), 1600, 1495, 1473, 1445 (CH=CH *trans*), 1408, 1367, 1320 (SO), 1299, 1266 (CO), 1234 (SO), 1200 (CO), 1152 (SO), 1090, 1053, 1014, 996, 980, 809, 783, 767, 742, 718, 685, 665 cm^{-1}; ^{1}H nmr (400 MHz, deuteriochloroform): δ 1.26 (t, 3H J = 7.2 Hz, CH_2CH_3), 1.40 (s, 3H, C_6H_4-CH_3), 4.17 (q, 2H, J = 7.2 Hz, CH_2CH_3), 4.46 (m, 2H, CH_2CH=C), 5.85 (d, 1H, J = 15.7 Hz, C=$CHCO_2$), 6.66 (dt, 1H, J = 15.7 Hz, J = 7.8 Hz, CH_2CH=C), 7.26-7.28 (m, 2H, SO_2ArH, *m*), 7.56-7.73 (m, 3H, SOPhH, *m*, *p*), 7.86-7.94 (m, 4H, SOPhH, *o* + SO_2ArH, *o*); ^{13}C nmr (100 MHz, deuteriochloroform): δ 14.19, 21.61, 60.74, 61.10, 126.75, 128.60, 129.41, 129.68, 131.17, 131.44, 134.92, 135.27, 140.63, 143.15, 164.53; ms: m/z 407 (M^+, 1%), 294 (64), 155 (78), 91 (100), 77 (28), 65 (22).

Anal. Calcd. for $C_{19}H_{21}NO_5S_2$: C, 56.0; H, 5.2; N, 3.4; S, 15.7. Found: C, 56.3; H, 5.5; N, 3.6; S, 15.8.

1,3-Dipolar Cycloaddition Reaction of α-Chlorobenzaldehyde Phenylhydrazone (**12**) and *S*-((*E*)-(3-Ethoxycarbonyl)prop-2-enyl)-*S*-phenyl-*N*-(*p*-tolylsulfonyl) sulfoximide (**16**): Ethyl (4*S*,5*R*,*R*/*S*)- and (4*R*,5*S*,*R*/*S*)-1,3-diphenyl-4-([*S*-phenyl-*N*-toluene-4-sulfonyl]sulfoximidylmethyl)-4,5-dihydro-1*H*-pyrazole-5-carboxylate (**17**) and Ethyl (4*R*, 5*S*, *R*/*S*)- and (4*S*, 5*R*, *R*/*S*)-1,3-diphenyl-5-([*S*-phenyl-*N*-toluene-4-sulfonyl]sulfoximidylmethyl)-4,5-dihydro-1*H*-pyrazole-4-carboxylate (**18**).

To a solution of 0.169 g (0.736 mmole) of α-chlorobenzaldehyde phenylhydrazone (**12**) and 0.3 g (0.736 mmole) of allylic sulfoximide **16** in 15 ml of dry toluene, 0.41 ml (2.944 mmole) of dry triethylamine was added dropwise over 15 minutes. The mixture was stirred under nitrogen at room temperature for two days. The solvent was removed *in vacuo*, and the crude product was purified by column chromatography on silica gel (hexane/ethyl acetate = 3:1) as eluent to give a mixture of regioisomers **17** and **18** and their diastereoisomers (due to chirality at sulphur) in the ratio 1:1:1:1. The isomers could not be separated and the mixture was obtained as a yellow solid (0.4 g, 90%), mp 57-62 ºC; ir (potassium bromide): 3061, 2980, 2927, 1735 (C=O), 1598 (C=N), 1559, 1496 (C-N), 1447, 1388, 1320 (SO), 1235 (SO), 1196 (C-O), 1152 (SO), 1089, 1061, 1018, 997, 904, 843, 815, 749, 692, 670 cm^{-1}; ^{1}H nmr (400 MHz, deuteriochloroform): δ 1.11-1.17 (m, 3H, CH_2CH_3), 2.40 (s, 3H, C_6H_4-CH_3), 3.43-3.87 (many doublets overlapping, 2H, CH_2SO), 4.03 (dt, 1/4H, H_B), 4.06-4.16 (m, 2H, CH_2CH_3), 4.41 (dt, 1/4H, H_B), 4.73 (d, 1/4H, J = 2.7 Hz, H_A), 4.78 (d, 1/4H, J = 2.7 Hz, H_A), 5.05 (dt, 1/4H, H_B), 5.11 (d, 1/4H, J = 2.0 Hz, H_A), 5.19 (d, 1/4H, J = 2.0 Hz, H_A), 5.30 (dt, 1/4H, H_B), 6.82-8.12 (m, 19H, ArH); ^{13}C nmr (100 MHz, deuteriochloroform): δ 14.02, 14.21, 21.07, 21.55, 44.01, 44.18, 55.23, 55.63, 55.75, 56.18, 56.39, 56.69, 58.15, 58.66, 61.99, 62.14, 65.40, 65.66, 113.56, 113.62, 113.66, 120.42, 120.58, 125.69, 125.84, 126.73, 128.42, 128.59, 128.82, 128.99, 129.15, 129.33, 129.48, 129.98, 131.21, 134.92, 135.06, 136.04, 136.34, 136.88, 140.46, 141.70, 143.01, 143.09, 143.72, 145.32, 168.33, 168.39, 168.87, 169.05; ms: m/z 601 (M^+, 4%), 306 (42), 293 (100), 233 (87), 91 (32), 77 (30).

Anal. Calcd. for $C_{32}H_{31}N_3O_5S_2$: C, 63.9; H, 5.2; N, 7.0; S, 10.7. Found: C, 63.6; H, 5.4; N, 6.8; S, 10.4.

* Many signals were overlapping in both ^{1}H and ^{13}C nmr, so it was not possible to calculate some coupling constants and assign the signals to all atoms.

1,3-Dipolar Cycloaddition Reaction of Benzohydroximoyl Chloride and *S*-((*E*)-(3-Ethoxycarbonyl)prop-2-enyl)-*S*-phenyl-*N*-(*p*-tolylsulfonyl) Sulfoximide (**16**): Ethyl (4*S*,5*S*,*R*/*S*)- and (4*R*,5*R*,*R*/*S*)-3-phenyl-4-([*S*-phenyl-*N*-toluene-4-sulfonyl]sulfoximidylmethyl)-4,5-dihydroisoxazole-5-carboxylate (**19**) and Ethyl (4*S*,5*S*,*R*/*S*)- and (4*R*,5*R*,*R*/*S*)-3-phenyl-5-([*S*-phenyl-*N*-toluene-4-sulfonyl]sulfoximidylmethyl)-4,5-dihydroisoxazole-4-carboxylate (**20**).

To a solution of 0.067 g (0.55 mmole) of benzaldehyde oxime (**7a**) in 5 ml of dry *N*,*N*-dimethylformamide, 0.149 g (1.1 mmole) of solid *N*-chlorosuccinimide was added with stirring. The solution was stirred at room temperature for one hour before it was

poured into cold water and extracted with diethyl ether. The combined extracts were washed with cold water and dried over magnesium sulfate, then the solvent was removed by evaporation. The resulting yellow oil of benzohydroximoyl chloride was dissolved in 8 ml of dichloromethane and 0.18 g (0.42 mmole) of allylic sulfoximide **16** was added at -78 ºC, followed by 0.08 ml (0.55 mmole) of dry triethylamine, added dropwise. The mixture was left to warm to room temperature and stir overnight. The solvent was removed *in vacuo*, and the crude product was purified by column chromatography on silica gel (hexane/ethyl acetate = 2:1) as eluent to give a mixture of regioisomers **19** and **20** in the ratio ~ 1:3, with each regioisomer obtained as a pair of diastereoisomers (due to chirality at sulphur) in the ratio 1:1. The isomers could not be separated and the mixture was obtained as a yellow solid (0.16 g, 72%), mp 41-43 ºC; ir (potassium bromide): 3854, 3463, 3062, 2981, 2928, 2361, 2339, 1734 (C=O), 1700, 1653, 1602, 1559, 1498, 1448, 1374, 1319 (SO), 1235 (SO), 1153 (SO), 1090, 1061, 1018, 998, 886, 816, 749, 684, 667 cm^{-1}; ^1H nmr (400 MHz, deuteriochloroform): δ 1.11-1.31 (m, 3H, CH_2CH_3), 2.36 and 2.37 (2 s, 3H, 2 _ C_6H_4-CH_3), 3.44-4.29 (many peaks overlapping, 4H, CH_2SO, CH_2CH_3), 4.36-4.39 (m, $J_{A'B'}$ = 2.8 Hz, $H_{B'}$), 4.62 (d, $J_{C'D'}$ = 4.8 Hz, $H_{C'}$), 4.66-4.68 (m, J_{AB} = 3.1 Hz, H_B), 4.71 (d, J_{CD} = 5.3 Hz, H_C), 5.11 (d, $J_{A'B'}$ = 2.8 Hz, $H_{A'}$), 5.28 (d, J_{AB} = 3.1 Hz, H_A), 5.35-5.40 (dt, $J_{C'D'}$ = 4.8 Hz, $H_{D'}$), 5.46-5.50 (dt, J_{CD} = 5.3 Hz, H_D), 7.21-8.06 (m, 14H, ArH); ^{13}C nmr (67.8 MHz, deuteriochloroform): δ 13.80, 14.01, 21.49, 45.03, 45.35, 56.21, 56.80, 58.13, 58.18, 58.40, 58.45, 60.18, 60.50, 60.59, 60.95, 62.33, 62.39, 62.44, 62.51, 78.52, 79.28, 82.10, 82.15, 82.44, 125.96, 126.00, 126.61, 126.88, 127.02, 127.33, 127.45, 128.30, 128.44, 128.64, 129.27, 129.54, 129.68, 129.97, 130.69, 130.76, 131.01, 131.07, 131.30, 134.80, 135.04, 135.34, 136.22, 136.35, 140.30, 140.36, 143.03, 143.12, 154.48, 154.62, 155.61, 164.38, 167.49, 168.30, 168.51; ms: m/z No M^+, 294 (57%), 155 (91), 125 (41), 91 (100), 77 (61), 65 (39).

Anal. Calcd. for $C_{26}H_{26}N_2O_6S_2$: C, 59.3; H, 5.0; N, 5.3; S, 12.2. Found: C, 58.7; H, 5.0; N, 5.3; S, 10.5.

* Many signals were overlapping in both ^1H and ^{13}C nmr, so it was not possible to calculate some coupling constants and assign the signals to all atoms.

Acknowledgment.

We wish to thank the Ministry of Science and Technology of Republic of Croatia for financial support.

REFERENCES AND NOTES

[1] 1,3-Dipolar Cycloaddition Chemistry, A. Padwa, ed, Wiley & Sons, New York, 1984; R. P. Litvinovskaya and V. A. Khripach, *Usp. Khim.*, **70**, 464 (2001); C. P. Dell, *J. Chem. Soc., Perkin Trans. I*, 3873 (1998); C. P. Dell, *Contemp. Org. Synth.*, **4**, 87 (1997); D. P. Curran, *Adv. Cycloaddition*, **1**, 129 (1988); K. B. G. Torsell, in Nitrile Oxides, Nitrones and Nitronates in Organic Synthesis, VCH publishers, Weinheim, 1988.

[2] M. Barzaghi, P. L. Beltrame, P. Dalla Croce, P. Del Buttero, E. Licandro, S. Maiorana and G. Zecchi, *J. Org. Chem.*, **48**, 3807 (1983).

[3] T. Shimizu, Y. Hayashi, M. Miki and K. Teramura, *J. Org. Chem*., **50**, 904, (1985).

[4] D. M. David, M. Bakavoli, S. G. Pyne, B. W. Skelton and A. H. White, *Tetrahedron*, **51**, 12393 (1995).

[5] K. V. Gothelf and K. A. Jørgensen, *Chem. Rev*., **98**, 863 (1998).

[6] M. Reggelin and C. Zur, *Synthesis*, 1 (2000).

[7] T. Agawa, M. Ishikawa, M. Komatsu and Y. Ohshiro, *Bull. Chem. Soc. Jpn*., **55**, 1205 (1982).

[8] P. L. Bailey, W. Clegg, R. F. W. Jackson and O. Meth-Cohn, *J. Chem. Soc., Perkin Trans. I*, 343 (1993).

[9] R. S. Paley and S. R. Snow, *Tetrahedron Lett.*, **31**, 5853 (1990).

[10] J. A. Hyatt and J. J. Krutak, *J. Org. Chem*., **42**, 169 (1977).

[11] S. Kanemasa, H. Matsuda, A. Kamimura and T. Kakinami, *Tetrahedron*, **56**, 1057 (2000).

[12] J. E. Johnson, D. Nwoko, M. Hotema, N. Sanchez, R. Alderman and V. Lynch, *J. Heterocyclic Chem*., **33**, 1583 (1996).

[13] P. Caramella and P. Grünanger, in 1,3-Dipolar Cycloaddition Chemistry, Vol. **1**, A. Padwa, ed, Wiley & Sons, New York, 1984, p 291; N. Arai, M. Iwakoshi, K. Tanabe and K. Narasaka, *Bull. Soc. Chem. Jpn*., **72**, 2277 (1999).

[14] K. Zong, S. I. Shin, D. J. Jeon, J. N. Lee and E. K. Ryu, *J. Heterocyclic Chem*., **37**, 75, (2000).

[15] E. C. Argyropoulou and E. Thessalonikeos, *J. Heterocyclic Chem*., **28**, 429, (1991).

[16] E. E. v. Tamelen and D. Carty, *J. Am. Chem. Soc*., **93**, 6102 (1971).

[17] S. G. Pyne, and Z. Dong, *J. Org. Chem*., **61**, 5517 (1996).

[18] J. R. Anderson, R. L. Edwards and A. J. S. Whalley, *J. Chem. Soc., Perkin Trans. I*, 1481 (1985).

[19] C. R. Johnson, R. A. Kirchhoff, R. J. Reischer and G. F. Katekar, *J. Am. Chem. Soc*., **95**, 4287 (1973).

[20] A. L. Marzinzik and B. K. Sharpless, *J. Org. Chem*., **66**, 594 (2001).

[21] G. Bashiardes, G. J. Bodwell and S. G. Davies, *J. Chem. Soc., Perkin Trans. I*, 459 (1993).