solution of 29 mg of the crude hydroxy ester in 5 mL of MeOH was added dropwise 10 μL of concentrated $H_2SO_4$. The resulting solution was refluxed for 40 min under Ar. The reaction was quenched with $H_2O$, and the product was extracted with $CH_2Cl_2$ (3×). The combined extracts were dried over $MgSO_4$. Flash column chromatography on silica gel using 15% EtOAc in hexane as eluent afforded 15 mg (54% based on the keto ester) of the indenecarboxylate **35a** as yellowish needles: mp 91-92 °C; $R_f$ = 0.54 (30% EtOAc in hexane); IR (KBr) $\nu$ 3090, 2982, 2940, 2911, 2836, 1701, 1599, 1559, 1480, 1427, 1285, 1248, 1209, 1132, 1090, 1018, 930, 851, 822, 737, 548 $cm^{-1}$; $^1H$ NMR ($CDCl_3$, 300 MHz) δ 7.92 (d, $J$ = 8.5 Hz, 1 H), 7.32 (t, $J$ = 2.0 Hz, 1 H), 7.05 (d, $J$ = 2.1 Hz, 1 H), 6.91 (dd, $J$ = 2.3, 8.4 Hz, 1 H), 3.90 (s, 3 H), 3.84 (s, 3 H), 3.49 (d, $J$ = 1.6 Hz, 2 H); $^{13}C$ NMR ($CDCl_3$, 75.46 MHz) δ 164.7, 158.4, 145.3, 142.3, 135.7, 133.8, 122.9, 112.4, 110.1, 55.5, 51.6, 38.4; MS (70 eV) $m/z$ 204 ($M^+$), 189, 173, 161, 145, 130, 115, 102, 76, 59, 51; HRMS calcd for $C_{12}H_{12}O_3$ 204.0786, found 204.0786.

**7-Methoxy-3-oxoindan-1-carboxylic Acid Methyl Ester (34b).** The same procedure as employed in the preparation of **34a** afforded 160 mg (70% based on 6-methoxy-1-indanone) of the keto ester **34b** as a yellowish oil: $R_f$ = 0.68 (50% EtOAc in hexane); IR (neat) $\nu$ 3004, 2943, 2835, 1733, 1708, 1592, 1475, 1430, 1392, 1324, 1272, 1261, 1191, 1151, 1074, 1025, 888, 784, 757 $cm^{-1}$; $^1H$ NMR ($CDCl_3$, 300 MHz) δ 7.46-7.36 (m, 2 H), 7.08 (d, $J$ = 7.7 Hz, 1 H), 4.22 (dd, $J$ = 3.5, 8.2 Hz, 1 H), 3.89 (s, 3 H), 3.72 (s, 3 H), 2.99 (dd, $J$ = 8.3, 18.9 Hz, 1 H), 2.77 (dd, $J$ = 3.5, 18.9 Hz, 1 H); $^{13}C$ NMR ($CDCl_3$, 75.46 MHz) δ 203.9, 173.3, 156.9, 140.4, 138.2, 130.5, 115.6, 115.3, 55.7, 52.3, 41.0, 40.9; MS (70 eV) $m/z$ 220 ($M^+$), 161, 131, 118, 99, 95, 89, 84; HRMS calcd for $C_{12}H_{12}O_4$ 220.0736, found 220.0736.

**Acknowledgment.** We are indebted to the National Institute on Drug Abuse for support of these studies (DA 05587). Dr. Yuan-Ping Pang acknowledges the Ben Franklin Foundation for a Ben Franklin Fellowship and the Andrew Mellon Foundation for an Andrew Mellon Predoctoral Fellowship.

**Supplementary Material Available:** $^1H$ spectral data for all new compounds (38 pages). Ordering information is given on any current masthead page.

# Synthesis of 2(*E*),4(*E*)-Dienamides and 2(*E*),4(*E*)-Dienoates from 1,3-Dienes via 2-Phenylsulfonyl 1,3-Dienes

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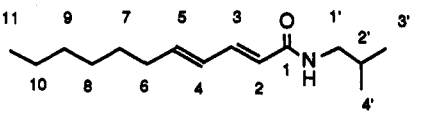
A procedure for the preparation of 2*E*,4*E* unsaturated carboxylic acid derivatives from dienes was developed. Transformation of terminal 1,3-dienes to (*E*)-2-phenylsulfonyl 1,3-dienes and subsequent addition of a carboxy anion equivalent and elimination of benzenesulfinic acid led to 2,4-dienoic amides and esters. In this way the natural products *N*-isobutyl-2(*E*),4(*E*)-undecadienamide (**1a**), *N*-isobutyl-2(*E*),4(*E*)-decadienamide (pellitorine, **1b**), and methyl 2(*E*),4(*E*)-decadienoate (**1c**) were obtained in high isomeric purity.

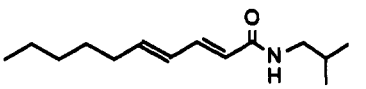
## Introduction

2,4-Diunsaturated carboxylic acid derivatives belong to a group of naturally occurring compounds that show some interesting biological activity.[1] *N*-Isobutyl-2(*E*),4(*E*)-undecadienamide (**1a**) has been identified in extracts from the plant *Leucocyclus formosus*.[2] The analogous *N*-isobutyl-2(*E*),4(*E*)-decadienamide, pellitorine (**1b**), was isolated from roots of the plant *Anacyclus pyrethrum*[3] and has insecticidal activity.[1a] Methyl 2(*E*),4(*E*)-decadienoate (**1c**) is a flavor substance in pears.[4]

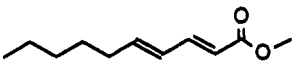
The essential synthetic problem has been to prepare the functionalized diene system in a highly stereoselective manner, and a wide variety of synthetic approaches has been used.[5-15] We have recently developed procedures for the preparation of 2-phenylsulfonyl 1,3-dienes and demonstrated the use of these compounds in organic synthe-




**1a**




**1b**




**1c**

(1) (a) Miyakado, M.; Nakayama, I.; Yoshioka, H.; Nakatani, N. *Agric. Biol. Chem.* **1979**, *43*, 1609. (b) Bohlmann, F.; Ganzer, M.; Kruger, M.; Nordhoff, E. *Tetrahedron* **1983**, *39*, 123. (c) Crombie, L.; Fisher, D. *Tetrahedron Lett.* **1985**, *26*, 2477 and 2481 and references cited therein. (d) Elliot, M.; Farnham, A. W.; Janes, N. F.; Johnson, D. M.; Pulman, D. A. *Pestic. Sci.* **1987**, *18*, 191. (e) Byers, J. A.; Högberg, H. E.; Unelius, C. R.; Birgersson G.; Löfqvist, J. *J. Chem. Ecol.* **1989**, *15*, 685. (f) Horsham, M. A.; Class, T. J.; Johnston, J. J.; Casida, J. E. *J. Agric. Food Chem.* **1989**, *37*, 777. (g) Norin, T. *Pure Appl. Chem.* **1989**, *61*, 547.

(2) Greger, H.; Grenz, M.; Bohlmann, F. *Phytochemistry* **1981**, *20*, 2579.

(3) Crombie, L. *J. Chem. Soc.* **1955**, 999.

(4) Heinz, D. E.; Jennings, W. G. *J. Food Science* **1966**, *31*, 69.

(5) These approaches include Wittig-type reactions,[6] palladium-catalyzed couplings[7] and eliminations,[8,6a] oxidative removal of selenium[9b,c] or sulfur groups,[9c-f] base-catalyzed elimination of sulfinic acid,[10] double elimination of sulfinic and acetic acid,[11] thermal extrusion of sulfur dioxide from sulfolenes,[12] rearrangements,[13] haloboration,[14] or the Knoevenagel condensation.[15]

(6) (a) Vig, O. P.; Ahuja, V. D.; Sharma, M. L.; Sharma, S. D. *Indian J. Chem.* **1975**, *13*, 1358. (b) Sakai, T.; Seko, K.; Tsuji, A.; Utaka, M.; Takeda, A. *J. Org. Chem.* **1982**, *47*, 1101. (c) Crombie, L.; Fisher, D. *Tetrahedron Lett.* **1985**, *26*, 2477 and 2481. (d) Shi, L.; Yang, J.; Li, M.; Huang, Y.-Z. *Liebigs Ann. Chem.* **1988**, 377. (e) Baeckström, P.; Jacobsson, U.; Norin, T.; Unelius, C. R. *Tetrahedron* **1988**, *44*, 2541. (f) Kann, N.; Rein, T.; Åkermark, B.; Helquist, P. *J. Org. Chem.* **1990**, *55*, 5312.

(7) (a) Kim, J. I.; Lee, J. T.; Yeo, K. D. *Bull. Korean Chem. Soc.* **1985**, *6*, 366. (b) Stille, J. K.; Groh, B. L. *J. Am. Chem. Soc.* **1987**, *109*, 813. (c) Crombie, L.; Hobbs, A. J. W.; Horsham, M. A.; Blade, R. J. *Tetrahedron Lett.* **1987**, *28*, 4875. (d) Jeffery, T. *Synth. Commun.* **1988**, *18*, 77. (e) Yanagi, T.; Ohe, T.; Miyaura, N.; Suzuki, A. *Bull. Chem. Soc. Jpn.* **1989**, *62*, 3892. (f) Yamashina, N.; Hyuga, S.; Hara, S.; Suzuki, A. *Tetrahedron Lett.* **1989**, *30*, 6555.

0022-3263/91/1956-4508$02.50/0 

**Scheme I**

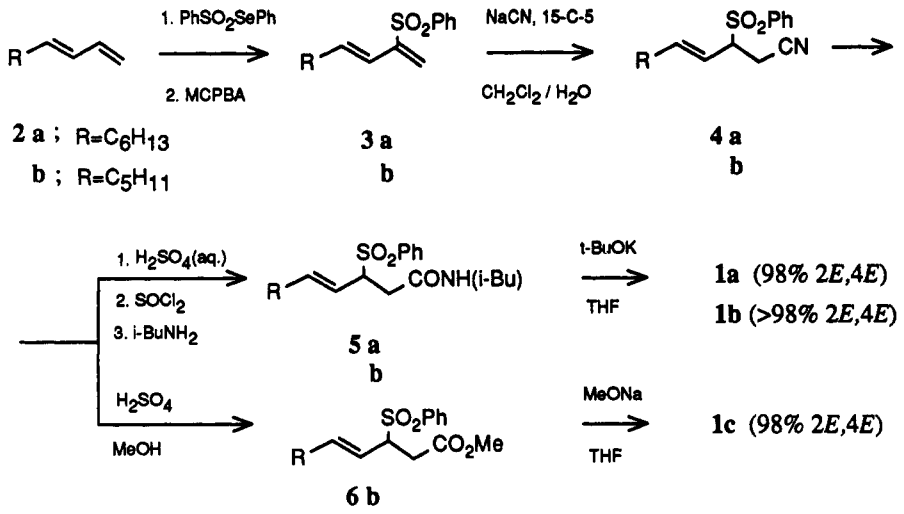
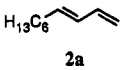
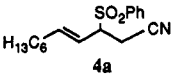
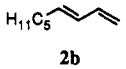
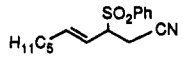
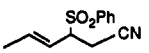



**Table I. Formation of Cyanide Adducts from 1,3-Dienes via 2-Phenylsulfonyl 1,3-Dienes**

| entry | diene | product | yield (%) method A[a] | yield (%) method B[b] |
|---|---|---|---|---|
| 1 |  2a |  4a | 66 | 42 |
| 2 |  2b |  4b | 60 | |
| 3 |  |  | | 76 |

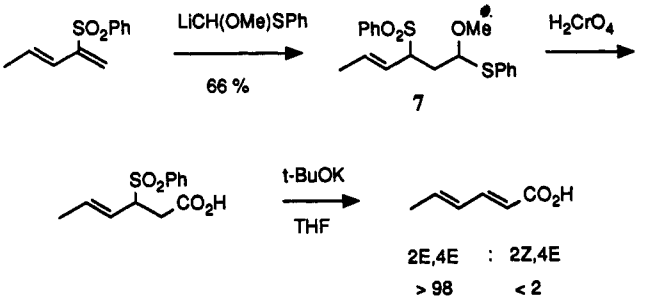
[a] Via selenosulfonation. [b] Via mercuriosulfonation.

sis.[16,17] In this paper we report a highly stereoselective procedure for the preparation of 2(*E*),4(*E*)-dienamides and 2(*E*),4(*E*)-dienoates via (*E*)-2-phenylsulfonyl 1,3-dienes.

## Results and Discussion

The present procedure starts from a terminal diene,

**Scheme II**




which is transformed to an (*E*)-2-phenylsulfonyl 1,3-diene via the tandem selenosulfonation–oxidation[17a,b] or the mercuriosulfonation–elimination procedure.[16a,b] The vinylic sulfone moiety is susceptible to Michael addition by various nucleophiles,[16b] and one may introduce a carboxyl group in the 1-position by the use of a carboxy anion equivalent, a number of which are known in the literature.[18-20] Cyanide ion[19] and methoxymethyl phenyl sulfide

(8) Mandai, T.; Gotoh, J.; Otera, J.; Kawada, M. *Chem. Lett.* **1980**, 313.
(9) (a) Tsuji, J.; Nagashima, T.; Takahashi, T.; Masaoka, K. *Tetrahedron Lett.* **1977**, *22*, 1917. (b) Tanikaga, R.; Nishida, M.; Ono, N.; Kaji, A. *Chem. Lett.* **1980**, *7*, 781. (c) Nokami, J.; Nishiuchi, K.; Wakabayashi, S.; Okawara, R. *Tetrahedron Lett.* **1980**, *21*, 4455. (d) Tamura, Y.; Choi, H. D.; Maeda, H.; Ishibashi, H. *Ibid.* **1981**, *22*, 1343. (e) Tanikaga, R.; Nozaki, Y.; Tanaka, K.; Kaji, A. *Chem. Lett.* **1982**, *11*, 1703. (f) Matui, S.; Tanaka, K.; Kaji, A. *Synthesis* **1983**, 127.
(10) Lorne, R.; Julia, S. A. *Bull. Soc. Chim. Fr.* **1986**, *2*, 317.
(11) (a) Trost, B. M.; Lautens, M.; Peterson, B. *Tetrahedron Lett.* **1983**, *24*, 4525. (b) Mandai, T.; Moriyama, T.; Tsujimoto, K.; Kawada, K.; Otera, J. *Ibid.* **1986**, *27*, 603. (c) Moriyama, T.; Mandai, T.; Kawada, K.; Otera, J.; Trost, B. M. *J. Org. Chem.* **1986**, *51*, 3896.
(12) (a) Bloch, R.; Hassan-Gonzales, D. *Tetrahedron* **1986**, *42*, 4975. (b) Sagio, K.; Kudo, K.; Hashimoto, Y.; Kihara, N.; Hasegawa, M. *Chem. Lett.* **1989**, *7*, 1203.
(13) (a) Tsuboi, S.; Nooda, Y.; Takeda, A. *J. Org. Chem.* **1984**, *49*, 1204. (b) Ma, D.; Lu, X. *Tetrahedron* **1990**, *46*, 3189.
(14) Satoh, Y.; Tayano, T.; Hara, S.; Suzuki, A. *Tetrahedron Lett.* **1989**, *30*, 5153.
(15) Jacobson, M. *J. Am. Chem. Soc.* **1953**, *75*, 2584.
(16) (a) Andell, O. S.; Bäckvall, J. E. *Tetrahedron Lett.* **1985**, *26*, 4555. (b) Bäckvall, J. E.; Juntunen, S. K. *J. Am. Chem. Soc.* **1987**, *109*, 6396. (c) Bäckvall, J. E.; Junteunen, S. K. *J. Org. Chem.* **1988**, *53*, 2398. (d) Bäckvall, J. E.; Plobeck, N. A.; Juntunen, S. K. *Tetrahedron Lett.* **1989**, *30*, 2589. (e) Bäckvall, J. E.; Rise, F. *Ibid.* **1989**, *30*, 5347. (f) Bäckvall, J. E.; Plobeck, N. A. *J. Org. Chem.* **1990**, *55*, 4528.
(17) (a) Bäckvall, J. E.; Najera, C.; Yus, M. *Tetrahedron Lett.* **1988**, *29*, 1445. (b) Back, T. G.; Collins, S. *J. Org. Chem.* **1981**, *46*, 3249. For some recent applications on 2-arylsulfonyl 1,3-dienes from other laboratories see: (c) Chou, T. S.; Hueng, S. C. *J. Org. Chem.* **1988**, *53*, 3020. (d) Padwa, A.; Harrison, B.; Murphree, S. S.; Yeske, P. E. *Ibid.* **1989**, *54*, 4232. (e) Back, T. G.; Lai, E. K. Y.; Muralidharan, K. R. *Tetrahedron Lett.* **1989**, *30*, 6481. (f) Hoffman, H. M. R.; Weichert, A.; Slawin, A. M. Z.; Williams, D. J. *Tetrahedron*, **1990**, *46*, 5591.

(18) (a) Hase, T. A. *Umpoled Synthons*; Wiley-Interscience, John Wiley and Sons: New York, 1987. (b) Seebach, D. *Synthesis* **1969**, 17. (c) Lever, O. W., Jr. *Tetrahedron* **1976**, *32*, 1943. (d) Gröbel, B. T.; Seebach, D. *Synthesis* **1977**, 357. (e) Seebach, D. *Angew. Chem., Int. Ed. Engl.* **1979**, *18*, 239. (f) Wade, P. A.; Hinney, H. R.; Amin, N. V.; Vail, P.-D.; Morrow, S. D.; Hardinger, S. A.; Saft, M. S. *J. Org. Chem.* **1981**, *46*, 765. (g) Albright, J. D. *Tetrahedron* **1983**, *39*, 3207. (h) Trost, B. M.; Quayle, P. *J. Am. Chem. Soc.* **1984**, *106*, 2469. (i) Mori, K.; Uematsu, T.; Yanagi, K.; Minobe, M. *Tetrahedron* **1985**, *41*, 2751. (j) Nemoto, H.; Kubota, Y.; Yamamoto, Y. *J. Org. Chem.* **1990**, *55*, 4515. (k) Sengupta, S.; Snieckus, V. *Ibid.* **1990**, *55*, 5680.
(19) (a) For a review see: Nagata, W.; Yoshioka, M. *Org. React.* **1977**, *25*, 255. (b) Taber, D. F.; Saleh, S. A. *J. Org. Chem.* **1981**, *46*, 4817.
(20) (a) de Groot, A.; Jansen, B. J. M. *Tetrahedron Lett.* **1981**, *22*, 887. (b) Mandai, T.; Hara, K.; Nakajima, T.; Kawada, M.; Otera, J. *Ibid.* **1983**, *24*, 4993. (c) Otera, J.; Niibo, Y.; Nozaki, H. *J. Org. Chem.* **1989**, *54*, 5003.

anion[20] were found to be useful for this transformation and several 2*E*,4*E*-diunsaturated carboxylic acid derivatives were prepared in this way.

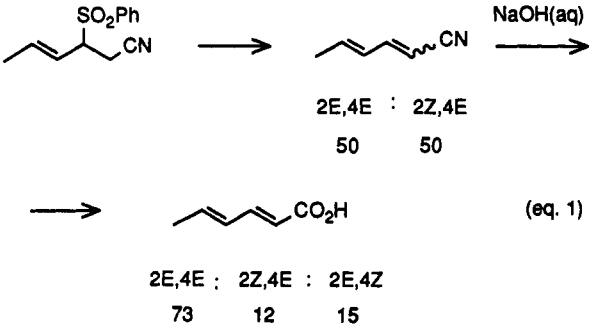
The reaction sequence is outlined in Scheme I. Selenosulfonation of (*E*)-1,3-decadiene (**2a**) followed by oxidation of the intermediate adduct gave **3a** in a one-pot procedure. Subsequent treatment of sulfonyl diene **3a** with NaCN and 15-crown-5 in a two-phase system consisting of $CH_2Cl_2$–water afforded cyano adduct **4a** in 66% overall yield from **2a** (Table I). The choice of solvent was critical for this reaction. For example, benzene–water or ether–water gave a slower and less selective reaction while in a homogeneous solvent mixture of ether and methanol rapid elimination of benzenesulfinic acid took place from the adduct to produce 2,4-undecadienenitrile. This elimination was nonselective and afforded a 1:1 mixture of the 2*E*,4*E* and the 2*Z*,4*E* isomers (vide infra).

Because of the low 2*E*/2*Z* selectivity in the elimination of benzenesulfinic acid from nitriles, the cyano group was transformed into a sterically more demanding group prior to the elimination. Aqueous acid hydrolysis of the nitrile **4a** to the acid and subsequent treatment with thionyl chloride and isobutyl amine afforded the amide **5a** in 70% overall yield. Elimination of benzenesulfinic acid from the amide **5a** with potassium *tert*-butoxide in tetrahydrofuran (THF) was highly stereoselective and the 2*E*,4*E* isomer of **1a** was obtained in 80% yield with an isomeric purity of 98% according to $^1H$ NMR spectroscopy, the remaining 2% being the 2*Z*,4*E* isomer. The overall yield from diene **2a** to the dienamide **1a** was 36%. The same procedure was applied to (*E*)-1,3-nonadiene, which gave pellitorine (**1b**) in 34% overall yield with an isomeric purity of >98% 2*E*,4*E*. Methyl 2(*E*),4(*E*)-decadienoate (**1c**) was synthesized by the same method from **2b**. Nitrile **4b** was hydrolyzed with acid in methanol to give the ester **6b**. Subsequent elimination of benzenesulfinic acid from ester **6b** with sodium methoxide[21] in THF yielded **1c** in 98% isomeric purity. The overall yield from 1,3-nonadiene (**2b**) was 30%.

α-Lithiomethoxymethyl phenyl sulfide was also investigated as a carboxy anion equivalent in the reaction with **3**. When methoxymethyl phenyl sulfide was lithiated with *n*-butyllithium at −40 °C[20] and a 50 mM ether solution of (*E*)-2-(phenylsulfonyl)-1,3-pentadiene was added during 1 h at −40 °C the adduct **7** was formed (Scheme II). The mixed thioketal was oxidized to the acid, and subsequent treatment of the acid with potassium *tert*-butoxide in THF resulted in elimination of benzenesulfinic acid. Again, the elimination which now took place from the carboxylate was highly stereoselective to give 2(*E*),4(*E*)-hexadienoic acid (sorbic acid), which according to the $^1H$ NMR spectrum was >98% 2*E*,4*E* isomer.

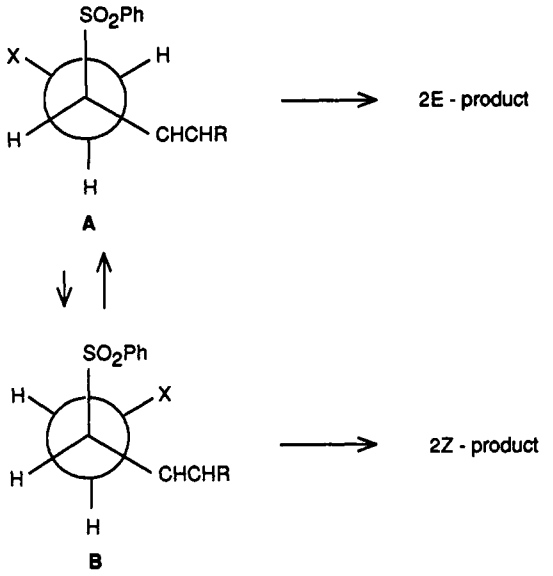
Two other base–solvent systems, 1,8-diazabicyclo[5.4.0]undec-7-ene (DBU)/$CH_2Cl_2$ and $Na_2CO_3$/EtOH, for the elimination of benzenesulfinic acid from substrates like **6b** have been described in the literature.[22] We investigated these systems for the elimination of benzenesulfinic acid from **6b** and found that they gave a 2*E*,4*E* selectivity of 96 and 93%, respectively, in the formation of the dienoic ester. This should be compared with the 2*E*,4*E* selectivity of 98% obtained when alkoxide/THF was employed (Scheme I).

Attempts to obtain good 2*E*,4*E* selectivity in the elimination of benzenesulfinic acid from the cyano adduct were unsuccessful. Spontaneous elimination during its preparation (NaCN, methanol–ether) afforded the 2*E*,4*E* and 2*Z*,4*E* isomers in a 1:1 ratio.[23] When this diene nitrile mixture was hydrolyzed with aqueous NaOH a 73:12:15 ratio of isomers of hexadienoic acid was obtained (eq 1).




The high selectivity for the 2*E*,4*E* product observed in the elimination in Schemes I and II is remarkable and can be explained by considering the conformations leading to elimination. The two conformations (A and B) for a base-induced anti elimination of benzenesulfinic acid are given in Scheme III. For steric reasons conformation A would be expected to be strongly favored over B if X is a large group. The observed high selectivity for the 2*E* porduct when X = $COO^-$, COOR, or CONHR but an essentially nonselective reaction when X = CN is in line with this picture. The same conclusion is obtained by considering the elimination to take place via an enolate anion.[24]

**Scheme III**




(21) The use of potassium *tert*-butoxide in the elimination step gave 10% of the *tert*-butyl ester as a side product.

(22) (a) Julia, M.; Badet, B. *Bull. Soc. Chim. Fr.* **1976**, 525. (b) Auvray, P.; Knochel, P.; Normant, J. F. *Tetrahedron Lett.* **1985**, *26*, 2329.

(23) Elimination of the cyano adduct using *t*-BuOK/THF gave a 67:29:4 ratio between the 2*E*,4*E*:2*Z*,4*E*:2*E*,4*Z* isomers of the dienenitrile.

(24) Elimination from an enolate is an alternative explanation. In this case the double bond of the enolate has to be perpendicular to the carbon–sulfur bond in order to give the required orbital overlap (enolate π-system parallel to the carbon–sulfur σ-bond). Thus the conformation A′ and B′ would be the two possible conformations leading to elimination. For steric reasons conformation A′ is strongly favored over B′, which would lead to the observed 2*E* product.

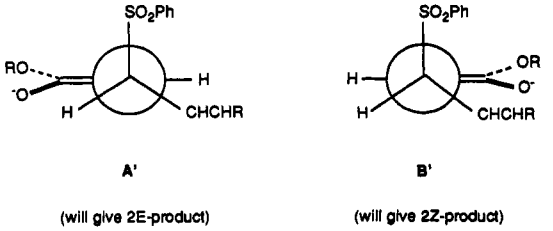
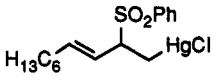


**Table II. $^{13}C$ NMR Assignments of Compounds 1a and 1b**

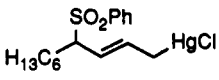
| carbon | 1a | 1b | carbon | 1a | 1b |
|---|---|---|---|---|---|
| 1 | 166.5 | 166.4 | 8 | 28.8 | 31.3 |
| 2 | 121.8 | 121.7 | 9 | 31.6 | 22.4 |
| 3 | 141.1 | 141.2 | 10 | 22.5 | 14.0 |
| 4 | 128.2 | 128.2 | 11 | 14.0 | – |
| 5 | 143.0 | 143.1 | 1′ | 46.9 | 46.9 |
| 6 | 32.9 | 32.9 | 2′ | 28.5 | 28.6 |
| 7 | 28.7 | 28.4 | 3′,4′ | 20.1 | 20.1 |

Evidently, the 2E,4E-selective reaction cannot be under thermodynamic product control since hydrolysis of a mixture of 2(E),4(E)- and 2(Z),4(E)-dienenitriles under strongly basic conditions afforded a 73:12:15 mixture between the 2E,4E, 2Z,4E, and 2E,4Z isomers of the acid (eq 1).

The 2-phenylsulfonyl 1,3-dienes were also prepared via the sulfonylmercuration–elimination sequence.[16a,b] The sulfonylmercuration went smoothly for 1,3-pentadiene (95%, 5 h) (cf. Table I), but was sluggish and less selective for the long-chain dienes. Thus, reaction of diene **2a** with a mercuric chloride–benzenesulfinate complex[16a] in DMSO/water, 1:1, afforded a 3:1 ratio of 1,2-adduct **8** and 1,4-adduct **9** in 60% yield. In DMSO/water, 90:10, the reaction improved and a 62% yield of product **8** was obtained after 48 h. Elimination of mercury with base gave **3a** in high yield.




**8**




**9**

Previously reported syntheses of the 2(E),4(E)-dienoates and -dienamides typically give 85–95% isomeric purity in the diene-forming step.[5-15] For example, the recently reported palladium-catalyzed coupling of (E)-octenyl iodide with methyl acrylate to give the dienoate **1c** is reported to subsequently give isomerically pure pellitorine.[7d] We have repeated the latter synthesis and when examining the crude ester **1c** formed in the actual coupling step, we found it to be an isomeric mixture of 2E,4E:2Z,4E:2E,4Z dienoic ester in a ratio 90:5:5.

The new procedure described herein is relatively simple and a variety of 2E,4E-diunsaturated carboxylic acid derivatives can be obtained in high isomeric purity, making further purification easy or unnecessary. In addition, the present procedure gives access to intermediate structures containing the sulfonyl and the cyano group which allow further functionalization.

**$^{13}C$ NMR Spectral Assignments.** The $^{13}C$ NMR spectral assignments[25] of the products **1a–c** were determined with constant time HETCOR[26] and selective INEPT[27] experiments. It was possible to make unambiguous assignments of all carbons in **1a–c**, and the earlier assignment[28] of **1b** had to be revised (Table II).

## Experimental Section

**General Methods.** $^1H$ and $^{13}C$ NMR spectra were recorded at 300 and 75.4 MHz, respectively, with $CDCl_3$ as solvent. IR spectra were recorded using a 0.1-mm KBr cell with $CDCl_3$ as solvent. Ether and THF was distilled from sodium benzophenone under nitrogen. $CH_2Cl_2$ and toluene were distilled from $CaH_2$. Flash chromatography was performed on silica gel 60, 230–400 ASTM obtained from Merck.

**3-(Phenylsulfonyl)-4(E)-undecenenitrile (4a). Method A.** (E)-1,3-Decadiene[29] (300 mg, 2.17 mmol) was added to a solution of $PhSeSO_2Ph$[17a,b] (644 mg, 2.17 mmol) in $CH_2Cl_2$ (20 mL). Boron trifluoride etherate (60 μL) was added and the solution was stirred at room temperature for 20 h. A solution of *m*-chloroperoxybenzoic acid (1.1 g, 5.4 mmol, 85%) in $CH_2Cl_2$ was added dropwise, and the reaction mixture was stirred for 30 min. The solution was filtered through a plug of silica and then washed with 10% $Na_2SO_3$(aq), 5% $K_2CO_3$(aq), and brine. The solution of (E)-2-(phenylsulfonyl)-1,3-decadiene (**3a**) was diluted to approximately 50 mM (40 mL) in $CH_2Cl_2$ and added to a solution of NaCN (2.0 g, 40 mmol), acetic acid (140 μL, 2.4 mmol), and 15-crown-5 (90 mg, 0.4 mmol) in water (10 mL). After the mixture was stirred for 10 h at room temperature, the phases were separated and the organic phase was washed with water and brine, dried ($MgSO_4$), and evaporated. Flash chromatography (EtOAc/hexane, 20:80) gave 440 mg (66%) of **4a** as a colorless oil that crystallized in the freezer: IR 2258, 1309, 1151 $cm^{-1}$; $^1H$ NMR δ 7.87–7.54 (m, 5 H, Ar-H), 5.59 (dt, J = 15, 6 Hz, 1 H, H-5), 5.33 (ddt, J = 15, 9, 1 Hz, 1 H, H-4), 3.77 (ddd, J = 10, 9, 4 Hz, 1 H, H-3), 3.14 (dd, J = 16, 4 Hz, 1 H, H-2), 2.83 (dd, J = 16, 10 Hz, 1 H, H-2), 2.00 (m, 2 H, H-6), 1.32–1.13 (m, 8 H, alkyl-H), 0.88 (t, 3 H, Me-H); $^{13}C$ NMR δ 143.4, 135.8, 134.4, 129.3, 129.2, 118.6, 115.8, 64.5, 32.5, 31.5, 28.6, 28.3, 22.5, 17.6, 14.0. Anal. Calcd for $C_{17}H_{23}NO_2S$: C, 66.85; H, 7.59. Found: C, 66.79; H, 7.50.

**Method B.** Sodium benzenesulfinate (2.0 g, 12 mmol) and $HgCl_2$ (3.3 g, 12 mmol) was dissolved in degassed DMSO/water, 90:10 (80 mL). The solution was stirred for 2 h before (E)-1,3-decadiene (550 mg, 4.0 mmol) was added, and stirring was continued for 48 h at 25 °C. Water was added, and the reaction mixture was extracted with EtOAc/hexane, 1:1. The organic phase was washed with water and brine and dried ($MgSO_4$). Evaporation of the solvent and flash chromatography (EtOAc/hexane, 10:90 then 20:80) of the crude product gave the mercury adduct **8** as a colorless oil (1.3 g, 2.5 mmol, 62%). Compound **8** was dissolved in ether (50 mL), and 2 M NaOH(aq) (3.3 mL, 7.5 mmol) was added. The solution was stirred vigorously for 30 min. The ether phase was then decanted off the precipitated mercury, dried ($MgSO_4$), and filtered through a short plug of silica. The ether was then rapidly evaporated under reduced pressure without heating and immediately[30] replaced with $CH_2Cl_2$ (50 mL) to give an approximately 50 mM solution of the sulfonyl diene **3a**. The following procedure was the same as in method A and gave the nitrile **4a** (520 mg, 42%) after flash chromatography. A comparison between the methods is given in Table I.

***N*-Isobutyl-3-(phenylsulfonyl)-4(E)-undecenamide (5a).** The nitrile **4a** (310 mg, 1.0 mmol) was heated to 100 °C in a mixture of HOAc, $H_2SO_4$, and water (6 mL, 1:1:1) for 10 h. The reaction mixture was diluted with water and extracted with ether. The ether phase was washed with water and brine, dried ($MgSO_4$), and evaporated. The crude acid (330 mg, 100%) was essentially pure by TLC and NMR, and it was refluxed in $SOCl_2$ (5 mL) for 30 min. The excess $SOCl_2$ was then evaporated under reduced pressure, and toluene (2 mL) was added followed by isobutylamine (0.3 mL, 3.0 mmol) in toluene (2 mL) at 0 °C. The solution was stirred at room temperature for 30 min, washed with water, dried ($MgSO_4$), and evaporated. Flash chromatography (30:70 EtOAc/hexane) afforded the amide **5a**, 140 mg (70%) as a colorless oil: IR 3388, 1666, 1525, 1304, 1146 $cm^{-1}$; $^1H$ NMR δ 7.85–7.48 (m, 5 H, Ar-H), 6.10 (m, 1 H, N-H), 5.43 (dt, J = 15, 6.5 Hz, 1 H, H-5), 5.27 (dd, J = 15, 9 Hz, 1 H, H-4), 4.12 (ddd, J = 10, 9, 4 Hz, 1 H, H-3), 3.12–2.90 (m, 3 H, H-1′,1′,2), 2.52 (dd, J = 14.5, 10 Hz, 1 H, H-2), 1.90 (m, 2 H, H-6), 1.69 (septet, J = 6.5 Hz, 1 H, H, H-2′), (1.28–1.08 (m, 8 H, alkyl-H), 0.88–0.80 (m, 9 H, Me-11,3′,4′); $^{13}C$ NMR δ 168.3, 141.3, 137.0, 133.7, 129.0, 128.8,

(25) For a recent and detailed example using selective INEPT and other techniques in assignment, see: Gogoll, A.; Plobeck, N. A. *Magn. Reson. Chem.* **1990**, *28*, 635.
(26) Reynolds, W. F.; McLean, S.; Perpick-Dumont, M.; Enriquez, R. G. *Magn. Reson. Chem.* **1988**, *26*, 1068.
(27) Bax, A. J. *Magn. Reson.* **1984**, *57*, 314.
(28) Banerji, A.; Sarkar, M.; Ghosal, R.; Pal, S. C. *Org. Magn. Reson.* **1984**, *22*, 734.
(29) (a) Zweifel, G.; Miller, J. A. *Org. React. (N.Y.)* **1984**, *32*, 430. (b) Negishi, E.; Takahashi, T.; Baba, S.; van Horn, D. E.; Okukado, N. *J. Am. Chem. Soc.* **1987**, *109*, 2393.
(30) The dimerization of the neat 2-phenylsulfonyl 1,3-diene is rapid and the dimer can be detected within a few minutes. To avoid this concentration and change of solvent the elimination of mercury can alternatively be done directly in methylene chloride–aqueous NaOH.[16b]

120.2, 65.5, 47.0, 34.4, 32.4, 31.5, 28.6, 28.5, 28.3, 22.4, 20.0, 14.0. Anal. Calcd for $C_{21}H_{33}NO_3S$: C, 66.45; H, 8.76. Found: C, 66.24; H, 8.62.

***N*-Isobutyl-2(*E*),4(*E*)-undecadienamide (1a).** Potassium *tert*-butoxide[31] (42 mg, 0.37 mmol) was added to a stirred solution of the amide **5a** (140 mg, 0.37 mmol) in THF (5 mL) at 25 °C. A precipitate formed immediately, and stirring was continued for 30 min. Water (5 mL) was added, and the mixture was extracted with ether. The organic phase was washed with water and brine, dried ($MgSO_4$), and concentrated in vacuo to yield 70 mg (80%) of yellow–white crystals. The isomeric purity was 98% 2*E*,4*E* according to $^1H$ NMR; 2% of the 2*Z*,4*E* isomer was present as determined by integration of H-2 (5.51 ppm, d, $J$ = 11 Hz). No isomerization was observed after flash chromatography on silica (EtOAc/hexane, 20:80). Spectral data were identical with those reported for pellitorine (**1b**). $^{13}C$ NMR shifts and assignments are given in Table II.

***N*-Isobutyl-2(*E*),4(*E*)-decadienamide (Pellitorine, 1b).** Prepared analogously to **1a** from (*E*)-1,3-nonadiene. The isomeric purity was >98%. Spectral data are in accord with those reported for **1b**.[7d,27] A reassignment of the $^{13}C$ NMR spectrum was made (Table II).

**Methyl 3-(Phenylsulfonyl)-4(*E*)-decenoate (6b).** The nitrile **4b** (150 mg, 0.51 mmol) was treated with $H_2SO_4$ (1 mL) in methanol (2.5 mL) at 80 °C for 12 h. The solution was allowed to cool, diluted with water, and extracted with ether. The ether phase was washed with water and brine, dried ($MgSO_4$), and evaporated. Flash chromatography (EtOAc/hexane, 10:90) of the crude product gave 133 mg (80%) of pure **6b** as a colorless oil: IR 1738, 1306, 1231, 1148 $cm^{-1}$; $^1H$ NMR $\delta$ 7.87–7.50 (m, 5 H, Ar-H), 5.47 (dt, $J$ = 15, 6.5 Hz, 1 H, H-5), 5.28 (ddt, $J$ = 15, 9, 1 Hz, 1 H, H-4), 4.06 (ddd, $J$ = 10, 9, 4 Hz, 1 H, H-3), 3.65 (s, 3 H, MeO), 3.13 (dd, $J$ = 16, 4 Hz, 1 H, H-2), 2.65 (dd, $J$ = 16, 10 Hz, 1 H, H-2), 1.94 (m, 2 H, H-6), 1.30–1.08 (m, 6 H, alkyl-H), 0.86 (t, 3 H, Me-10); $^{13}C$ NMR $\delta$ 170.0, 141.0, 136.5, 133.7, 129.1, 128.7, 120.1, 64.8, 52.0, 32.7, 32.2, 30.9, 28.0, 22.2, 13.8. Anal. Calcd for $C_{17}H_{24}O_4S$: C, 62.93; H, 7.46. Found: C, 62.87; H, 7.40.

**Methyl 2(*E*),4(*E*)-Decadienoate (1c).** In a procedure analogous to that for **1a** and **1b**, the ester **6b** (130 mg, 0.40 mmol) was treated with sodium methoxide (44 mg, 0.80 mmol) to yield 50 mg (68%) of **1c** after flash chromatography (EtOAc/hexane, 10:90). No isomerization was observed upon flash chromatography. The isomeric purity was 98%. $^1H$ NMR and $^{13}C$ NMR data and assignment were identical with published data.[32]

**Phenyl 1-Methoxy-1-(phenylthio)-4(*E*)hexen-3-yl Sulfone (7).** To a stirred solution of methoxymethyl phenyl sulfide (0.15 mL, 1.0 mmol) in THF (5 mL) at −78 °C was added dropwise *n*-butyllithium (0.46 mL, 2.2 M in hexanes, 1.0 mmol). The temperature was raised to −40 °C, and the mixture was stirred for 30 min.[20c] Then a dry dilute solution of (*E*)-2-(phenylsulfonyl)-1,3-pentadiene[33] (10 mL, 0.42 mmol) in ether was added dropwise during 1 h. The reaction mixture was then stirred for another 30 min before being quenched at −40 °C by addition of water and benzene. The organic phase was washed with water and brine and dried ($MgSO_4$). After evaporation of the solvent and flash chromatography (EtOAc/hexane, 20:80) of the crude product, 100 mg (66%) of **7** was obtained as a 1:1 mixture of diastereomers: IR 1305, 1147, 1085 $cm^{-1}$; $^1H$ NMR (isomer 1) $\delta$ 7.80–7.20 (m, 10 H, Ar-H), 5.56 (dq, $J$ = 15, 6 Hz, 1 H, H-5), 5.25 (ddq, $J$ = 15, 9, 1.5 Hz, 1 H, H-4), 4.61 (dd, $J$ = 8, 5 Hz, 1 H, H-1), 3.88 (ddd, $J$ = 10, 9, 5 Hz, 1 H, H-3), 3.48 (s, 3 H, MeO), 2.29 (ddd, $J$ = 14, 8, 5 Hz, 1 H, H-2), 2.01 (ddd, $J$ = 14, 10, 5 Hz, 1 H, H-2), 1.66 (dd, $J$ = 6, 1.5 Hz, 3 H, Me-6); $^{13}C$ NMR (isomer 1) 137.2, 136.1, 134.1, 133.5, 131.1, 129.1, 128.9, 128.8, 128.0, 121.8, 87.8, 66.1, 55.9, 33.5, 18.2; $^1H$ NMR (isomer 2) 7.80–7.20 (m, 10 H, Ar-H), 5.49 (dq, $J$ = 15, 6 Hz, 1 H, H-5), 5.28 (ddq, $J$ = 15, 9, 1 Hz, 1 H, H-4), 4.53 (dd, $J$ = 10.5, 3.5 Hz, 1 H, H-1), 3.70 (ddd, $J$ = 11, 9, 3.5 Hz, 1 H, H-3), 3.39 (s, 3 H, MeO), 2.35 (ddd, $J$ = 14, 10.5, 3.5 Hz, 1 H, H-2), 2.04 (ddd, $J$ = 14, 11, 3.5 Hz, 1 H, H-2), 1.66 (dd, $J$ = 6, 1 Hz, 3 H, Me-6); $^{13}C$ NMR (isomer 2) $\delta$ 137.4, 136.1, 134.3, 133.5, 131.4, 129.0, 128.8, 128.7, 128.1, 121.7, 86.1, 66.1, 55.5, 34.0, 18.2. Anal. Calcd for $C_{19}H_{22}O_3S_2$: C, 62.95; H, 6.12. Found: C, 62.77; H, 6.06.

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(31) Julia, M.; Arnould, D. *Bull. Soc. Chim. Fr.* **1973**, 743.

(32) Spectra for all four diastereoisomers of **1c** are given in ref 6e.

(33) The solution was prepared as described in ref 17b and dried first with $MgSO_4$ then with 4-Å molecular sieves in the freezer overnight.