calcd for $C_{10}H_{14}N_2O_2$, 194.1055.

Acknowledgment. This work has been financially supported by the Consiglio Nazionale delle Ricerche, Progetto Finalizzato "Chimica Fine e Secondaria".

Registry No. **1ay**, 31882-35-6; **1by**, 39716-23-9; **1bz**, 4147-00-6; **1cx**, 670-80-4; **1dx**, 98945-50-7; **1ex**, 10468-26-5; **2ay**, 98945-51-8; **2by**, 98945-52-9; **2bz**, 98945-54-1; **2cx**, 98945-55-2; **3a**, 4663-84-7; **3b**, 83487-79-0; **3c**, 98945-58-5; **3d**, 98945-56-3; **3e**, 40887-55-6; **4ex**, 98945-57-4; **5x**, 13640-77-2; **5y**, 98945-53-0; **5z**, 86296-10-8; NBSU, 2955-74-0; cyclohexanone, 108-94-1; *cis*-2,5-dimethylpyrrolidine, 39713-71-8; (ethoxycarbonyl)nitrene, 2655-26-7.

Synthesis and Reactivity of *N*-Mesitylcyclopropylideneazomethine

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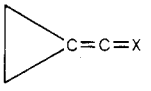
Allenylidenecyclopropanes **1** are quite stable compounds whose chemistry has been widely investigated.[1] For instance they have been reported to react with very electrophilic partners, such as chlorosulfonyl isocyanate and 4-phenyl-4*H*-1,2,4-triazolin-3,5-dione to give bis(alkylidene)cyclopentane derivatives, through addition across the cumulative double bond and the ring opening of the cyclopropane moiety. On the other hand, the heteroanalogues of **1**, such as the ketenes **2** and ketene imines **3** have not been reported to date.

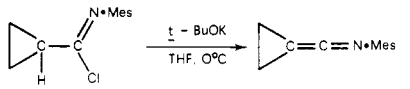


X = CR_2 (**1**); X = O (**2**); X = NR (**3**)

Compounds **2** have been characterized as 2 + 2 cyclodimers[2] only, while their behavior toward other cycloaddition partners has not been reported.

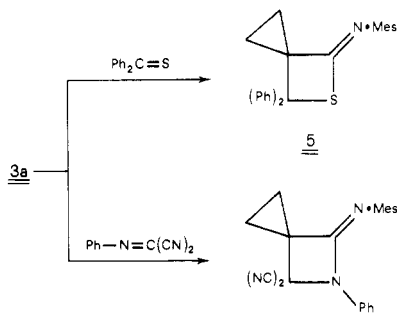
We have undertaken the synthesis of the ketene imines **3**, which are expected to be more resistant to dimerization, owing to their lower electrophilicity,[3] and endowed with a substantially greater reactivity with respect to the allenylidenecyclopropanes.

Treatment of *N*-mesitylcyclopropylformimidoyl chloride (**4**) with potassium *tert*-butoxide in THF at 0 °C gives the *N*-mesitylcyclopropylideneazomethine (**3a**), as indicated by a strong IR band at 2080 cm^{-1} (see Experimental Section). Quite remarkably, the cyclopropylidene moiety



4 **3a**

Mes = 2, 4, 6 - Me_3 - C_6H_2 -



5

6

moves the cumulene absorption to consistently higher frequencies ($\Delta\nu$ = 80–30 cm^{-1}) with respect to that usually observed for the C=C=N (2000–2050 cm^{-1}) group.[4] While **3a** appeared sufficiently stable, when in solution, attempts to isolate it as a pure material failed, due to a rapid decomposition. Reactions of **3a**, generated in situ, were carried out with appropriate reactants. In particular thiobenzophenone and *N*-(dicyanomethylene)aniline added in a 2 + 2 fashion to the C–C double bond of **3a** to give the corresponding spiro derivatives **5** and **6**, respectively. The structure of compound **5** was established by an X-ray crystal structure analysis (Figure 1). Spectroscopic data for **5** and **6** (see Experimental Section) are consistent with the assigned structure. It is worthy of note the relatively upfield ^{13}C NMR resonance (47.03 ppm) of C_3 of the spiro

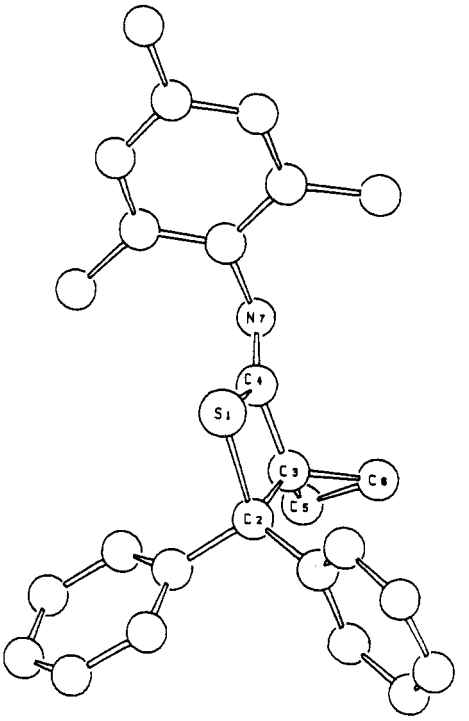


Figure 1. Structure of the spiro[2.3]hexane **5** in the solid state from a single-crystal X-ray analysis.

(1) Pasto, D. J.; Borchardt, J. K. *J. Am. Chem. Soc.* **1974**, *96*, 6944 and references therein.

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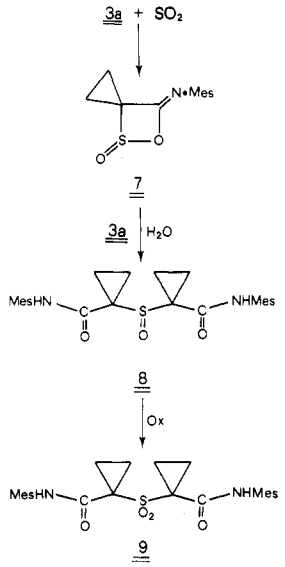
(3) Ghosez, L.; O'Donnell, M. J. In "Pericyclic Reactions"; Marchand, A. P., Lehr, E. R., Eds.; Academic Press, New York, 1977; Vol. II, Chapter 2.

(4) Krow, G. R. *Angew. Chem., Int. Ed. Engl.* **1971**, *10*, 435–448.

0022-3263/85/1950-5368$01.50/0

compound **5** with respect to that of 2-(mesitylimino)-3,3-dimethyl-4,4-diphenylthietane[5] (65.5 ppm). This can be accounted by the ring-current model used to explain the anomalous shielding of the cyclopropane moiety.[6] The same NMR feature is shown by the cycloadduct **6**. In addition, this showed a high frequency value (1730 cm^{-1}) for the IR absorption of the N=C—N group, as previously observed in strained diazetidinimines[7] and 3-imino-oxazetidine.[4]

Addition of liquid sulfur dioxide into a THF solution of **3a**[8] at 0 °C and evaporation of the solvent gave, after workup, an oily residue, which was characterized as the open-chain sulfoxide **8**. Oxidation of **8** with *m*-chloro-



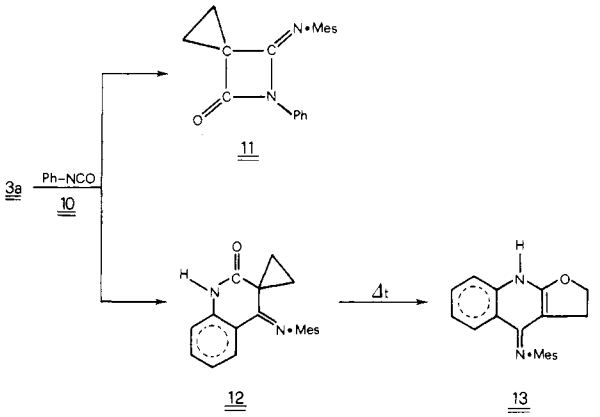
perbenzoic acid afforded the sulfone **9**. The formation of **8** can be rationalized by an initial 2 + 2 cycloaddition between **3a** and sulfur dioxide to give the β-sultinimine[8] **7** which undergoes sulfur–oxygen bond fission and addition of a molecule of **3a** and water.

Finally ketene imine **3a** reacted with phenyl isocyanate (**10**) to give a 1:1 mixture of the two cycloadducts **11** and **12**, the former deriving from a 2 + 2 addition between the C=C of **3a** and the N=C of **10**, the latter from a 4 + 2 addition involving the N=C and the *N*-phenyl ring of **10**. Precedents of the 1,4-heterodiene behavior of **10** have been already reported.[9] In solution of $CHCl_3$, at room temperature for several days, compound **12** converted into **13** by ring expansion of the cyclopropyl moiety.

From the above results it appears that ketene imine **3a**, unlike the allenylidenecyclopropanes,[1] cycloadds as a 2π system using the C=C bond, while the cyclopropyl group is mantained unaltered.

Experimental Section

^1H and ^{13}C NMR spectra were recorded, in the indicated solvent, on a 90-MHz Varian EM 390 and 80-MHz Varian CFT-80 spectrometers, respectively, and chemical shifts are given as δ values (in parts per million) from Me_4Si. IR spectra were determined on a Perkin-Elmer 257 grating spectrometer. Low-resolution mass spectra were recorded at an ionizing voltage of



70 eV on a Varian spectrometer. Analytical TLC was done on 2 mm thick layer of silica gel 60 plates, whereas column chromatography used E. Merck silica gel 60 (70–230 mesh).

Materials. All solvents were purified by standard methods before use.[10] Thiobenzophenone[11] and (dicyanomethylene)-aniline[12] were prepared by the literature procedure.

Reactions of *N*-Mesitylcyclopropylideneazomethine (3a). General Procedure. Compound **3a** was prepared as follows. To a stirred solution of potassium *tert*-butoxide in THF was added an equimolar amount of *N*-mesitylcyclopropylformimidoyl chloride.[13] The solvent was quickly concentrated at −15 °C (10^{-2} torr) to a few milliliters and redissolved with cold CCl_4. IR inspection of the crude material revealed a consistent peak at 2080 cm^{-1}, which disappeared into 24 h. Reactions in situ were done by adding the selected reagent to a solution of **3a** 5 min after its generation. The reaction mixture was allowed to stand at room temperature for 1 day, KCl removed by filtration, and the solvent distilled in vacuo, and the products were isolated. Details on each reaction are given below.

Reaction of Thiobenzophenone and Ketene Imine 3a. Ketene imine **3a** (0.47 g, 2.54 mmol) was reacted with thione (0.5 g, 2.53 mmol) in THF (100 mL) at room temperature for 3 h. After evaporation of the solvent, column chromatography of the residue (SiO_2, 12:3 *n*-pentane–ethyl acetate) yielded 0.82 g (2.20 mmol, 85%) of **6,6-diphenyl-4-(mesitylimino)-5-thiaspiro[2.3]hexane (5)**: mp 130–132 °C (from ethyl ether–*n*-pentane); IR (CCl_4, C_2Cl_4, CS_2) 1700 (S—C=N) cm^{-1}; ^1H NMR ($CDCl_3$) δ 0.93–1.13 (m, 2 H), 1.58–1.87 (m, 2 H), 2.13 (s, 6 H, 2 ortho CH_3), 2.23 (s, 3 H, 1 para CH_3), 6.73–6.80 (br, 2 H, a), 7.20–7.45 (m, 10 H, a); ^{13}C NMR ($CDCl_3$) δ 17.67 (2 ortho CH_3), 17.9 (2 CH_2), 20.7 (para CH_3), 47.0 (C_3), 61.4 (C_6), 127.34 (2 CH, a), 127.47 (2 C, a), 128.3 (8 CH, a), 128.7 (2 CH, a), 133.05 (2 CH, a), 143.18 (C, a), 143.64 (2 C, a), 166.64 (C of SC=N); mass spectrum, *m/e* 383 (M^+), 382, 206, 205, 177. Anal. Calcd for $C_{26}H_{25}NS$: C, 81.42; H, 6.57; N, 3.65. Found: C, 81.66; H, 6.49; N, 3.71.

Reaction of *N*-(Dicyanomethylene)aniline and Ketene Imine 3a. Ketene imine **3a** (0.188 g, 1.0 mmol) was reacted with DCMA (0.158 g, 1.02 mmol) in THF (60 mL) at room temperature for 2 days. Evaporation of the solvent and column chromatography of the residue (SiO_2, 4:10 ethyl ether–*n*-pentane) afforded, in order, 0.07 g of unreacted DCMA and 0.141 g (0.415 mmol, 75% with respect to reacted DCMA) of **6,6-dicyano-4-(mesitylimino)-5-phenyl-5-azaspiro[2.3]hexane (6)**: mp 203–206 °C (from ethyl ether); IR (CCl_4, C_2Cl_4, CS_2) 2255 vw C≡N), 1730 (NC=N) cm^{-1}; ^1H NMR ($CDCl_3$) δ 1.03–1.23 (m, 2 H), 1.23–1.53 (m, 2 H), 2.15 (s, 6 H, 2 ortho CH_3), 2.23 (s, 3 H, 2 ortho CH_3), 6.73–6.77 (br, 2 H, a), 7.1–7.80 (m, 5 H, a); ^{13}C NMR ($CDCl_3$) δ 11.59 (2 CH_3), 18.36 (2 CH_3), 20.70 (1 CH_3), 42.59 (C_3), 51.58 (C of $C(CN)_2$), 111.46 (2 C of C≡N), 116.43 (2 CH, a), 124.87 (CH, a), 127.78 (2 C, a),

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(10) Weissberger, "Techniques of Organic Chemistry"; Interscience: New York, 1955; Vol. VII.
(11) Lunazzi, L.; Maccagnani, G.; Mazzanti, G.; Placucci, G.; *J. Chem. Soc. B* **1971**, 162.
(12) Camaggi, C. M.; Leardini, R.; Chatgilialoglu, C.; *J. Org. Chem.* **1977**, *42*, 2611.
(13) The title compound was prepared according standard procedures, from equimolar amount of the corresponding amide and PCl_5 C. L.; (Stevens, J. C. French, *J. Am. Chem. Soc.* **1954**, *76*, 4938), bp 92 °C (0.02 mmHg).

128.52 (2 CH, a), 129.69 (2 CH, a), 133.21 (C, a), 136.86 (C, a), 139.29 (C, a), 151.06 (C of NC=N); mass spectrum, m/e 340 (M^+), 325, 236, 185, 104. Anal. Calcd for $C_{22}H_{20}N_4$: C, 77.62; H, 5.92; N, 16.46. Found: C, 78.01; H, 5.87; N, 16.51.

Reaction of Sulfur Dioxide and Ketene Imine 3a. Liquid sulfur dioxide (ca. 5 mL) was added to a freshly prepared solution (THF, 80 mL) of ketene imine **3a** (0.59 g, 3.17 mmol) at -40 °C. After warmup at room temperature and evaporation of the excess of sulfur dioxide, the residue was chromatographed (SiO_2, ethyl ether), yielding 0.50 g (1.106 mmol, 70%) of **bis[(*N*-mesitylcarbamoyl)cyclopropyl] sulfoxide (8)**: mp 225-226 °C (from methanol); IR (CCl_4, C_2Cl_4, CS_2) 3200-3100 (NH), 1670-1640 (*CO*NH), 1540-1515, 1470-1440, 1080 and 1070 (SO) cm^{-1}; ^1H NMR ($CDCl_3$) δ 1.33-1.60 (br, 8 H, 4 CH_2), 2.02-2.10 (br, 12 H, 4 CH_3), 2.27 (s, 6 H, 2 CH_3), 6.8-6.9 (br, 4 H, a), 8.4-8.53 (2 H of NH); ^{13}C NMR ($CDCl_3$) δ 11.39 (2 CH_2), 12.95 (2 CH_2), 18.32 (4 CH_3), 20.87 (2 CH_3), 40.22 (2 C), 129.00 (4 CH), 130.71 (2 C), 134.60 (4 C), 137.00 (2 C), 166.47 (2 C of CONH); mass spectrum, m/e 452 (M^+), 437, 250, 202. Anal. Calcd for $C_{26}H_{32}N_2O_3S$: C, 68.99; H, 7.13; N, 6.19; S, 7.08. Found: C, 68.46; H, 7.19; N, 6.10; S, 7.01.

The sulfoxide **8** (0.25 g, 0.553 mmol) was reacted with *m*-chloroperbenzoic acid (85%) (0.112 g, 0.553 mmol) at room temperature for 24 h. Removal of the solvent and chromatography on a preparative plate (SiO_2, 4:1 *n*-pentane-ethyl acetate) yielded 0.25 g of the corresponding **bis[(*N*-mesitylcarbamoyl)cyclopropyl]sulfone (9)**: mp 190-192 °C (from ethyl ether); IR (CCl_4, C_2Cl_4, CS_2) 3300-3100 (NH), 1680-1650, 1470-1450, 1380, 1330, 1122 cm^{-1} ^1H NMR ($CDCl_3$) δ 1.73-1.87 (br, 4 H, 2 CH_2), 1.86-2.00 (br, 4 H, 2 CH_2), 2.17-2.27 (br, 12 H, 4 CH_3), 2.27-2.40 (br, 6 H, 2 CH_3), 6.87-7.00 (br, 4 H, a), 8.60-8.73 (br, 2 H of NH); mass spectrum, m/e 468 (M^+), 334.

Reaction of Phenyl Isocyanate (10) and Ketene Imine 3a. Keteneimine **3a** (0.663 g, 3.58 mmol) was reacted with **10** (1.096 g, 9.20 mmol) in THF (100 mL) at room temperature for 24 h. After evaporation of the solvent and of the excess of **10** in vacuo, chromatographic workup of the residue (SiO_2, 10:1 *n*-pentane-ethyl acetate) gave the following.

(a) 4-(Mesitylimino)-5-phenyl-5-azaspiro[2.3]hexan-6-one (11): 0.44 g (1.445 mmol, 40%); oil; IR (CCl_4, C_2Cl_4, CS_2) 3080-2930, 1735 (N-C=O), 1715 (N-C=N) cm^{-1}; ^1H NMR ($CDCl_3$) δ 0.8-1.0 (m, 2 H), 1.22- 1.40 (m, 2 H), 2.15 (s, 6 H, 2 CH_3), 2.25 (s, 3 H, 1 CH_3), 6.73-6.80 (br, 2 H, a), 7.03-7.53 (m, 3 H, a), 8.0-8.23 (m, 2 H, a); ^{13}C NMR ($CDCl_3$) δ 10.30 (2 CH_2), 18.25 (2 CH_3), 20.71 (CH_3), 39.37 (C_3), 118.85 (2 CH), 125.32 (CH), 127.38 (2 C), 128.47 (2 CH), 129.02 (2 CH), 132.96 (C), 136.44 (C), 140.98 (C), 154.06 (C of NC=N), 170.9 (C of NC=O); mass spectrum, m/e 304 (M^+), 185, 119. Anal. Calcd for $C_{20}H_{20}N_2O$: C, 78.92; H, 6.62; N, 9.20. Found: C, 79.10; H, 6.66; N, 9.16.

(b) 4-(Mesitylimino)-1,2,3,4-tetrahydrospiro[2-quinolone-3,1′-cyclopropane] (12): 0.50 g (1.645 mmol, 45%); mp 226-230 °C (from CH_2Cl_2); IR (Nujol) 3350-3300 (NH), 1683, 1635 cm^{-1}; ^1H NMR ($CDCl_3$) δ 1.84-1.91 (br, 6 H, 2 CH_3), 1.92-2.07 (br, 4 H), 2.24-2.31 (br, 3 H, 1 CH_3), 6.60-7.40 (m, 4 H, a), 6.80-6.90 (br, 2 H, a), 10.0-10.20 (br, 1 H of NH); ^{13}C NMR ($CDCl_3$) δ 17.84 (2 CH_3), 20.73 (1 CH_3), 26.57 (2 CH_2), 30.89 (C), 116.99 (CH), 122.89 (CH), 123.53 (2 C), 126.51 (CH), 129.02 (2 CH), 131.31 (C), 132.50 (CH), 138.73 (C), 145.75 (C), 157.56 (C), 173.21 (C of NC=O); mass spectrum, m/e 304 (M^+), 289, 275, 185. Anal. Calcd for $C_{20}H_{20}N_2O$: C, 78.92; H, 6.62; N, 9.20. Found C, 78.51; H, 6.65; N, 9.24.

Compound **12** (0.35 g, 1.15 mmol) was dissolved in $CHCl_3$ (25 mL) and thermostated at 20 °C for 1 week. Evaporation of the solvent and chromatography on preparative plate (SiO_2, 1:1 CH_2Cl_2-ethyl acetate) afforded, in order, 0.07 g (0.23 mmol, 20%) of unreacted **12** and 0.21 g (0.69 mmol, 75%) of **4-(mesitylimino)-2,3,4,9-tetrahydrofuro[2,3-*b*]quinoline (13)**: mp >230 °C dec (slowly; from ethyl ether); IR (Nujol) 3400-3100 (NH), 1628, 1580, 1520 cm^{-1}; ^1H NMR ($CDCl_3$) δ 2.14-2.20 (br, 6 H, 2 CH_3), 2.20-2.28 (br, 2 H), 2.30-2.36 (br, 3 H, 1 CH_3), 4.20-4.43 (t, 2 H, OCH_2), 6.30-6.50 (br, 1 H of NH), 6.89-6.98 (br, 2 H, a), 7.20-8.00 (m, 4 H, a); ^{13}C NMR ($CDCl_3$) δ 18.25 (2 CH_3), 20.96 (1 CH_3), 26.53 (1 CH_2), 68.65 (OCH_2), 97.67 (C), 117.28 (C), 119.65 (CH), 122.71 (CH), 128.02 (CH), 128.49 (2 CH), 129.02 (CH), 134.2 (C), 137.02 (2 C), 144.86 (C), 147.68 (C), 169.18 (C); mass spectrum, m/e 304 (M^+), 60. Anal. Calcd for $C_{20}H_{20}N_2O$: C, 78.92; H, 6.62; N, 9.20. Found: C, 79.03; H, 6.56; N, 9.25.

Crystal Data of 6,6-Diphenyl-4-(mesitylimino)-5-thiaspiro[2.3]hexane (5): $C_{26}H_{25}NS$, M_r = 383.6, monoclinic, space group $P2_1/n$, a = 9.210 (4) Å, b = 12.716 (5) Å, c = 18.102 (7) Å, β = 99.52 (3)°; Z = 4, d_c = 1.22 g cm^{-3}, V = 2090 Å^3, Mo K radiation, λ = 0.7107 Å. Of 3340 independent reflections, 2517 having $I > 2.5\ \sigma(I)$ were considered observed. Structure determination by direct methods and refined anisotropically. (SHELX program.) The most relevant interatomic distances (standard deviations) (in Å) within the three- and four-membered rings are as follows: S_1-C_2 = 1.887 (3); S_1-C_4 = 1.780 (4); C_2-C_3 = 1.548 (5); C_3-C_4 = 1.472 (4); C_3-C_{17} = 1.499 (5); C_3-C_{18} = 1.512 (5); C_{17}-C_{18} = 1.484 (6); C_4-N_{19} = 1.254. The dihedral angle between the three-membered ring and the least-squares mean plane through the four-membered ring is 86.5°. Within the four-membered ring the dihedral angle between the two planes formed by C_2-S_1-C_4 and C_2-C_3-C_4 respectively, is 11.6°. See paragraph at the end of the paper about supplementary material.

Acknowledgment. We thank Giovanni Bragaglia and Paolo Bonetti, Ozzano E., for technical assistance.

Registry No. 3a, 98875-59-3; **5**, 98875-60-6; **6**, 98875-61-7; **8**, 98875-62-8; **9**, 98875-63-9; **10**, 103-71-9; **11**, 98875-64-0; **12**, 98900-98-2; **13**, 98875-65-1; *N*-mesitylcyclopropylformimidoyl chloride, 98875-66-2; thiobenzophenone, 1450-31-3; *N*-(dicyanomethylene)aniline, 19769-98-3; sulfur dioxide, 7446-09-5.

Supplementary Material Available: Full X-ray data for compound **5** (4 pages). Ordering information is given on any current masthead page.

Nickel-Catalyzed Markovnikov Addition of Hydrogen Cyanide to Olefins. Application to Nonsteroidal Antiinflammatories†

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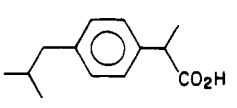
The two antiinflammatory drugs ibuprofen[1] (1) and



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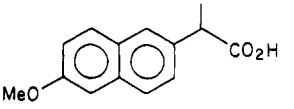
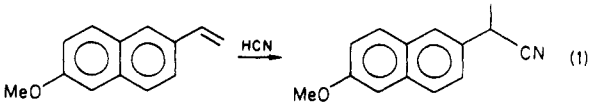


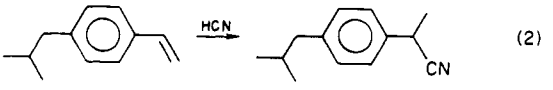
2

naproxen[2] (2) are members of the class of 2-arylpropionic acids toward which extensive synthesis research has been directed.[3] This reflects both the economic importance of these pharmaceuticals and the fact that none of the existing routes are fully satisfactory.[4]

An attractive approach to these compounds involves hydrocyanation of the corresponding vinylarenes (eq 1 and 2) followed by hydrolysis.



3 4 (1)



5 6 (2)

The anti-Markovnikov addition of HCN to butadiene is practiced on a large scale for the manufacture of adi-

† Contribution no. 3749.

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