

hexane (50 mL). The extract was washed with an aqueous NH_4Cl solution (2×100 mL) and dried over MgSO_4 . The solvent was evaporated in vacuum, and the crude mixture was analyzed by ^1H NMR spectroscopy in order to determine the ratio of 4/5. These ratios were the following: 84/16 starting from **3a**, 98/2 starting from **3b**, and 88/12 starting from **3c**. Optical rotations were measured after purification of the crude allenenes¹³ by column chromatography ($\text{Al}_2\text{O}_3 + 5\% \text{H}_2\text{O}$; eluent, hexane). The following specific rotations, $[\alpha]_D^{20}$, were measured (chemical yields of the allenenes after purification are given in parentheses): -192° (51%) starting from **3a**, -270° (50%) starting from **3b**, -211° (80%) starting from **3c**.

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Registry No. **1a**, 84681-19-6; **1b**, 84681-20-9; **1c**, 70000-50-9; (*R*)-**2**, 49768-13-0; (*S*)-**2**, 3780-00-5; **3a**, 84681-21-0; **3b**, 36022-00-1; **3c**, 76685-96-6; **4**, 74055-34-8; **5**, 84693-98-1; (*R*)-1-phenyl-2-propyn-1-ol, 61317-73-5; mestranol, 72-33-3; PhZnCl , 28557-00-8; $\text{Pd}[\text{PPh}_3]_4$, 14221-01-3.

(13) The crude product contained ca. 10–20 mol % of mestranol from which the allene was purified by column chromatography.

Catalyzed Addition of Furan with Acrylic Monomers¹

J. A. Moore* and Emmett M. Partain, III

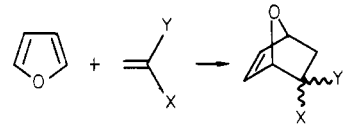
Department of Chemistry, Rensselaer Polytechnic Institute,
Troy, New York 12181

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The 7-oxabicyclo[2.2.1]heptane system has been used in the synthesis of prostaglandins,² C-nucleosides,³ muscarine analogues,^{4,5} and antibiotics.⁶ The most direct method to prepare these systems would be the Diels–Alder reaction of furan with various dienophiles. However, ring strain in the 7-oxabicyclo[2.2.1]heptane system and the aromatic character of the furan molecules combine to slow the rate of most of these reactions (Table I).

Strongly activated dienophiles such as acryloyl chloride and nitroethylene react readily with furan but are potent lachrymators and polymerize easily. The Diels–Alder reaction of furan and certain dienophiles may be accelerated by increasing the pressure on the reaction mixture. Dauben¹¹ has shown that at 15 000 atm, yields of about 50% are obtained after 4 h, and recently Kotsuki and Nishizawa⁵ similarly prepared the adduct of furan and 2-

Table I. Some Diels–Alder Reactions with Furan

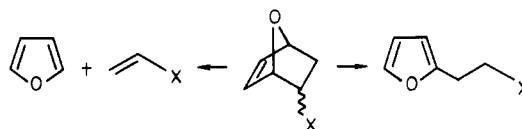


X	Y	time	yield, %
CO_2H	H	75 days	45 ⁶
		9 days	48 ^a
CO_2Et	H	"several weeks" ^b	19 ⁷
CO_2Me	H	2–3 months	50 ⁸
		14 days	33 ^a
CN	H	35 days	39 ⁹
		9 days	48 ^a
CN	Cl	6 days	54
COCl	H	24 h	"high" ¹⁰
NO_2	H	24 h	"high" ¹⁰

^a This work. Yields were determined by NMR. The reactions were conducted with a cupric fluoroborate concentration of 4.2 mol % and a hydroquinone concentration of 0.45 mol %, based on the concentration of dienophile.

^b Reaction temperature of 34°C .

chloroacrylonitrile. Unfortunately, 15 kbar equipment is not normally accessible for routine synthetic chemistry and is limited in reaction scale. Heating is often an ineffective expedient to increase the reaction rate, because the adducts of furan are thermally unstable and either decompose to furan and dienophile or are cleaved to a Michael-type product.



As part of our continuing interest in the synthesis of oxygenated bicyclic monomers¹² we sought to catalyze these reactions. Our attempts to use Lewis acids such as ferric chloride, stannic chloride, and zinc chloride with furan and different dienophiles yielded resinous products. Corey and co-workers¹³ reported that cupric fluoroborate catalyzed the Diels–Alder reaction of cyclopentadiene derivatives and 2-chloroacrylonitrile. When we tried using cupric fluoroborate with furan and different, freshly distilled, acrylic monomers, no catalysis was observed. However, if hydroquinone (a polymerization inhibitor) was added, the rate of the Diels–Alder reaction¹⁴ was greatly enhanced without changing the product stereochemistry. Thus, cupric fluoroborate alone does not catalyze the Diels–Alder reaction, but cupric fluoroborate and hydroquinone together catalyzed the reaction of furan with some acrylic monomers (Table I).

Dienophiles such as methacrylonitrile, methacrylic acid, methyl acrylate, vinylidene chloride, acrylamide, vinyl acetate, and styrene do not add to furan and could not be induced to react in the presence of copper(II)/hydroquinone either. A few dienophiles such as 2-chloroacrylic acid, maleic anhydride, and fumaronitrile react rapidly with furan, and the addition of copper(II)/hydroquinone causes no catalysis.

The reduction of Cu(II) to Cu(I) by hydroquinone was demonstrated spectroscopically by following the appearance of the characteristic quinone UV absorption at 243

(1) Presented in part at the 183rd National Meeting of the American Chemical Society, Las Vegas, NV, April 1982; Abstract ORGN 205.

(2) T. A. Eggelte, H. de Koning, and H. O. Huisman, *J. Chem. Soc., Perkin Trans. 1* 980 (1978); *Tetrahedron*, **29**, 2445, 2491 (1973).

(3) G. Just and M. I. Lim, *Can. J. Chem.*, **55**, 427, 2993 (1977); *Tetrahedron Lett.*, 1063 (1976).

(4) W. L. Nelson, D. R. Allen, and F. F. Vincenzi, *J. Med. Chem.*, **14**, 698 (1971).

(5) H. Kotsuki and H. Nishizawa, *Heterocycles*, **16**, 1287 (1981).

(6) T. Suami, S. Ogawa, K. Nakamoto, and I. Kasahara, *Carbohydr. Res.*, **58**, 240 (1977); S. Ogawa, I. Kasahara, and T. Suami, *Bull. Chem. Soc. Jpn.*, **52**, 118 (1979).

(7) M. P. Kunstman, D. S. Tarbell, and R. L. Autrey, *J. Am. Chem. Soc.*, **84**, 4115 (1962).

(8) W. L. Nelson, and D. R. Allen, *J. Heterocycl. Chem.*, **9**, 561 (1972).

(9) F. Kienzle, *Helv. Chim. Acta*, **58**, 1180 (1975).

(10) T. A. Eggelte, H. de Koning, and H. O. Huisman, *Heterocycles*, **4**, 19 (1976).

(11) W. G. Dauben and H. O. Krabbenhoft, *J. Am. Chem. Soc.*, **98**, 1992 (1976).

(12) J. A. Moore and J. E. Kelly, *J. Polym. Sci., Polym. Lett. Ed.*, **13**, 333 (1975); J. A. Moore and E. M. Partain, III, *ibid.*, **20**, 521 (1982).

(13) E. J. Corey, N. M. Weinshenker, T. K. Schaaf, and W. Huber, *J. Am. Chem. Soc.*, **91**, 5675 (1969).

(14) We recognize the possibility that the actual path may prove to be stepwise.

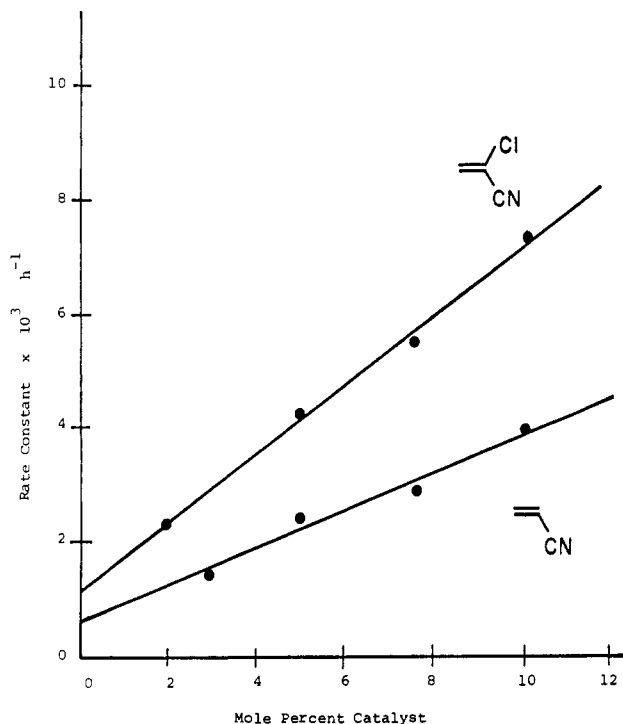


Figure 1. Rate of Diels-Alder reaction vs. catalyst concentration.

nm. Attempts to use quinone, or copper(II) fluoroborate and quinone, to catalyze the Diels-Alder reactions failed. Tetrakis(acetonitrile)copper(I) fluoroborate was prepared¹⁵ and was found to catalyze the Diels-Alder reaction with furan. Preliminary kinetic measurements were obtained by NMR spectroscopy under pseudo-first-order conditions (furan in 5-fold excess). A plot of rate constants vs. the mole percent of $\text{Cu}(\text{CH}_3\text{CN})_4\text{BF}_4$ (based on the dienophile concentration) is shown in Figure 1 for acrylonitrile and chloroacrylonitrile. The experimental evidence indicates that copper(I) is the catalytic species.

Experimental Section

General Methods. Infrared spectra were obtained with a Perkin-Elmer Model 298 infrared spectrophotometer. Nuclear magnetic resonance (NMR) spectra were measured with a Varian T-60A spectrophotometer at 60 MHz. Fourier transform nuclear magnetic resonance spectra were obtained with a Hitachi Perkin-Elmer R-600 high-resolution NMR spectrophotometer at 60 MHz. ¹³C and 200-MHz proton nuclear magnetic resonance spectra were obtained with a Varian XL-200 spectrophotometer. Spectra were obtained in chloroform-*d* with either tetramethylsilane or hexamethyldisiloxane as an internal standard.

Representative Example: 2-Carbomethoxy-7-oxabicyclo[2.2.1]hept-5-ene. Methyl acrylate (9.0 mL, 100 mmol), furan (15 mL), cupric fluoroborate (1.0 g, 4.2 mol%, based on methyl acrylate), and hydroquinone (0.10 g, 0.91 mol%) were placed in a 50-mL round-bottomed flask. The flask was flushed with nitrogen and stirred for 2 weeks at room temperature. The mixture was poured into 25 mL of aqueous EDTA and extracted with diethyl ether (3 × 50 mL). The ether extracts were dried over magnesium sulfate, and removal of the solvent gave crude ester as a brown liquid, 5.08 g (33%). Vacuum distillation afforded pure ester as a colorless liquid: bp 66–69 °C (0.2 torr) [lit.⁸ bp 60 °C (0.15 torr)]; 4.00 g (26% isolated). Spectra data are completely in accord with literature values for the compounds prepared in this work (Table I).

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Registry No. $\text{Cu}(\text{I})(\text{CH}_3\text{CN})_4\text{BF}_4$, 15418-29-8; 2-carbomethoxy-7-oxabicyclo[2.2.1]hept-5-ene, 21987-33-7; 7-oxabicyclo[2.2.1]hept-5-ene-2-carboxylic acid, 24363-23-3; 2-carboethoxy-7-oxabicyclo[2.2.1]hept-5-ene, 84752-03-4; 7-oxabicyclo[2.2.1]hept-5-ene-2-carbonitrile, 53750-68-8; 2-chloro-7-oxabicyclo[2.2.1]hept-5-ene-2-carbonitrile, 84752-04-5; 7-oxabicyclo[2.2.1]hept-5-ene-2-carboxyl chloride, 84752-05-6; 2-nitro-7-oxabicyclo[2.2.1]hept-5-ene, 84752-06-7; methyl acrylate, 96-33-3; acrylic acid, 79-10-7; ethyl acrylate, 140-88-5; acrylonitrile, 107-13-1; 2-chloroacrylonitrile, 920-37-6; acryloyl chloride, 814-68-6; nitroethene, 3638-64-0; cupric fluoroborate, 38465-60-0; hydroquinone, 123-31-9; furan, 110-00-9.

A Convenient Synthesis for 3-Alkyl- and 3-Alkenylfurans, Including Perillene

Robert A. Wiley,* Hea-Young Choo, and David McClellan

Department of Medicinal Chemistry, The University of Kansas, Lawrence, Kansas 66045

Received June 7, 1982

Furans substituted at the 3-position with alkyl or alkenyl groups are of interest because of their pronounced toxicity¹ and because they form the basis for the structures of several natural products.^{2,3} Although a reasonably efficient synthesis for 3-methylfuran has been reported,⁴ procedures described in the literature for synthesis of 3-alkylfurans are lengthy, or they require highly specialized reagents.⁵⁻⁷ We now report an efficient synthesis of two alkylfurans by alkylation of dialkylcuprates with methyl 3-furantiosylate.

It has been reported² that 3-furanmethanol reacts with methanesulfonyl chloride to produce an unstable mesylate that in turn reacts with enolates such as the sodium salt of diethyl malonate. We confirmed this finding but were unable to produce the required alkylfurans by modifying the side chain. We also found that by using NaOH instead of pyridine as the basic catalyst,⁸ a tosylate could be produced by reaction of 3-furanmethanol with *p*-toluenesulfonyl chloride, which appeared more stable than the mesylate, although it could not be isolated. Thus, we were able to generate the tosylate and allow it to react in situ with lithium dimethylcuprate and lithium dibutylcuprate to afford the required 3-ethyl- and 3-pentylfurans, respectively, in good yield.

The natural product perillene (4) has been of recent synthetic interest,⁹⁻¹³ and it was also necessary to obtain other 3-alkenylfurans for toxicity testing. It was therefore of interest to determine whether the new procedure could

(1) R. J. McMurtry and J. R. Mitchell, *Toxicol. Appl. Pharmacol.*, **42**, 285 (1977).

(2) O. P. Vig, O. P. Chugh, V. K. Handa, and A. K. Vig, *J. Indian Chem. Soc.*, **52**, 199 (1975).

(3) W. C. Still, *J. Am. Chem. Soc.*, **100**, 1481 (1978).

(4) J. W. Cornforth, *J. Chem. Soc. C*, 1310 (1957).

(5) Y. Kojima, S. Wakita, and N. Kato, *Tetrahedron Lett.* 4577 (1979).

(6) A. Yasuda, M. Takahashi, and H. Takaya, *Tetrahedron Lett.*, **22**, 2413 (1981).

(7) K. Inomata, S. Aoyama, and H. Kotake, *Bull. Chem. Soc. Jpn.*, **51**, 930 (1978).

(8) R. V. Sendega, *Zh. Org. Khim.*, **4**, 1907 (1968).

(9) K. Kondo and M. Matsumoto, *Tetrahedron Lett.* 391, 4363 (1976).

(10) S. Takahashi, *Synth. Commun.*, **331** (1976).

(11) J. E. McMurry and S. F. Donovan, *Tetrahedron Lett.*, 2869 (1977).

(12) P. Gosselin, S. Masson, and A. Thuillier, *J. Org. Chem.*, **44**, 2807 (1979).

(13) S. P. Tanis, *Tetrahedron Lett.* **23**, 3115 (1982).

(15) B. J. Hathaway, D. G. Holah, and J. D. Postlethwaite, *J. Chem. Soc.*, 3215 (1961).