carried out are summarized in Table I.

It should be noted that under these reaction conditions allylic C–H insertion, to produce **9**, competes effectively with the usually efficient[7a] intramolecular cyclopropanation.[8] Methylene C–H insertion is substantially more rapid than methyl C–H insertion,[9] allowing clean formation of **10**. While it might be extrapolated that methine should be more efficient than methylene insertion, ring-size effects predominate, so that **7** is formed from **2**.

The functionalized cyclopentanes produced by this cyclization should be versatile intermediates for elaboration to complex natural products. Keto ester **10**, for example, prepared by Tsuji,[10] has been converted by him to methyl dihydrojasmonate[10] and 18-hydroxyestrone.[11]

Experimental Section

General Methods. ^{1}H NMR spectra were determined on a JEOLCO MH-100 spectrometer as solutions in $CDCl_3$. Chemical shifts are reported in parts per million downfield from the internal reference tetramethylsilane. Couplings (J) are in hertz. The infrared spectra (IR) were recorded on a Perkin-Elmer 257 spectrometer as solutions in CCl_4 and are reported in reciprocal centimeters. Mass spectra were determined at 70 eV on an LKB 9000 gas chromatograph–mass spectrometer interfaced with a PDP-12 computer system and are reported as mass per unit charge, with intensities as a percentage of the peak of greatest ion current having $m/z \geq 100$ in parentheses. High-resolution mass spectroscopy was carried out on a VG 7070f double-focusing mass spectrometer. Organic chemicals were purchased from Aldrich Chemical Co. Organometallics were purchased from Alfa Inorganics and were titrated prior to use. Solvent mixtures (e.g., 5% ethyl acetate/hexane) are volume/volume mixtures. The R_f values indicated refer to thin-layer chromatography on Analtech 2.5 × 10 cm, 250-μm analytical plates coated with silica gel GF. Column chromatography was carried out by using TLC-mesh silica gel, following the procedure we have described.[12]

Preparation of 6.[13] Diazo ester **1** (1.55 g, 5.50 mmol), prepared by alkylation of the dianion of methyl acetoacetate[4] followed by diazo transfer,[5,6] was diluted with 30 mL of CH_2Cl_2 (dried by filtration through K_2CO_3) under N_2. Rhodium(II) acetate[7] (0.040 g) was added, and the mixture stirred at room temperature for 30 min. Vigorous gas evolution was observed, and the solution turned a bright emerald green. The reaction mixture was diluted with 4% aqueous HCl and extracted with CH_2Cl_2. The combined organic extracts were dried over Na_2SO_4 and concentrated in vacuo. The residue was chromatographed on 50 g of silica gel with 4% EtOAc/petroleum ether. The first 950 mL was discarded. The next 350 mL was concentrated in vacuo to give **6** as a colorless oil: 0.948 g (68%); TLC (10% EtOAc/hexane) R_f 0.40; ^{1}H NMR 0.90 (t, J = 7, 3 H), 1.2–1.8 (m, 16 H), 2.20 (m, 1 H), 2.40 (t, J = 7, 2 H), 2.90 (d, J = 11, 1 H), 3.80 (s, 3 H); IR 2920, 2850, 1750, 1725, 1430, 1115; MS, 254 (4.6), 233 (15), 199 (33), 184 (27), 141 (100), 109 (56); exact mass calcd for $C_{15}H_{26}O_3$ 254.1882, obsd 254.1863.

7: TLC (10% EtOAc/hexane) R_f 0.27; ^{1}H NMR 0.94 (d, J = 8, 3 H), (0.98, d, J = 8, 3 H); 1.44 – 1.90, (m, 2 H); 2.04 – 2.26, (m, 1 H); 2.28 – 2.58, (m, 2 H); 2.96, (d, J = 11, 1 H); 3.80, (s, 3 H). IR: 2955, 1750, 1725, 1430, 1245, 1110, 970. MS, 184 (12), 152 (34), 141 (93), 109 (100); exact mass calcd for $C_{10}H_{16}O_3$ 184.1100, obsd 184.1085.

8: TLC (10% EtOAc/hexane) R_f 0.29; ^{1}H NMR 1.12 (s, 3 H), 1.24 (s, 3 H), 1.70–2.25 (m, 2 H), 2.35–2.60 (m, 2 H), 2.97 (s, 1 H), 3.80 (s, 3 H); IR 2940, 1715, 1645, 1605, 1430, 1315, 1200, 1030; MS, 170 (15), 155 (17), 138 (41), 123 (100), 115 (36); exact mass calcd for $C_9H_{14}O_3$ 170.0943, obsd 170.0942.

9: TLC (10% EtOAc/hexane) R_f 0.23; ^{1}H NMR 1.68 (m, 1 H), 2.1–2.6 (m, 3 H), 3.10 (d, J = 11, 1 H), 3.24 (m, 1 H), 3.78 (s, 3 H), 5.12 (d, J = 10, 1 H), 5.20 (d, J = 16, 1 H), 5.91 (ddd, J = 16, 10, 7, 1 H); IR 2950, 1755, 1725, 1650, 1430, 1265, 985, 910; MS, 168 (36), 136 (54), 112 (78), 108 (79), 81 (100); exact mass calcd for $C_9H_{12}O_3$ 168.0786, obsd 168.0769.

10: TLC (10% EtOAc/hexane) R_f 0.35; ^{1}H NMR 0.99 (s, 3 H), 1.28 (s, 3 H), 1.69 (s, 3 H), 1.72 (s, 3 H), 1.9–2.7 (m, 5 H), 3.05 (d, J = 11, 1 H), 3.78 (s, 3 H), 5.14 (m, 1 H); IR 1720, 1430, 1365, 1345, 1330, 1295, 1210, 1140, 1020; MS, 238 (6.2), 207 (4.9), 206 (4.6), 191 (3.8), 179 (9.1), 137 (16), 123 (100). Exact mass calcd for $C_{14}H_{22}O_3$ 238.1569 obsd 238.1580.

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Registry No. **1**, 83221-08-3; **2**, 83221-09-4; **3**, 83221-10-7; **4**, 83221-11-8; **5**, 83221-12-9; (±)-**6**, 83221-13-0; (±)-**7**, 83221-14-1; (±)-**8**, 83221-15-2; (±)-**9**, 83221-16-3; (±)-**10**, 83221-17-4; rhodium(II) acetate, 15956-28-2.

(7) (a) For use of Rh_2OAc_4 to catalyze intramolecular cyclopropanations, see Anciaux, A. J.; Hubert, A. J.; Noels, A. F.; Petinot, N.; Teyssie, P. *J. Org. Chem.* **1980**, *45*, 695. (b) For studies of other carbenoid reactions mediated by rhodium catalysts, see: Doyle, M. P.; Tamblyn, W. H.; Bagheri, V. *Ibid.* **1981**, *46*, 5094. (c) For an earlier study of copper-catalyzed C–H insertion to form cyclopentanes, see: Kuwajima, I.; Higuchi, Y.; Iwasawa, H.; Sato, T. *Chem. Lett.* **1976**, 1271.

(8) The cyclopropane is also formed in the cyclization of **4**, in about 10% yield. We have not investigated the other products of these cyclizations.

(9) For a study of intermolecular C–H insertion using rhodium catalysts, see: Demonceau, A.; Noels, A. F.; Hubert, A. J.; Teyssie, P. *J. Chem. Soc., Chem. Commun.* **1981**, 688.

(10) Tsuji, J.; Kobayashi, Y.; Kataoka, H.; Takahashi, T. *Tetrahedron Lett.* **1980**, *21*, 1475.

(11) Tsuji, J.; Okumoto, H.; Kobayashi, Y.; Takahashi, T. *Tetrahedron Lett.* **1981**, *22*, 1357.

(12) Taber, D. F. *J. Org. Chem.* **1982**, *47*, 1351.

(13) Cyclizations of **2–5** were carried out in the same way.

Acyl–Oxygen Cleavage in the Alkaline Hydrolysis of Activated Vinyl Esters

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The only observed route known for the basic hydrolysis of vinyl esters[2,3] is the $B_{Ac}2$ mechanism, which involves acyl–oxygen fission.[4] Nucleophilic catalysis in such hydrolysis also involves initial nucleophilic attack on the acyl group.[5] An earlier determination of the site of bond cleavage in the hydrolysis of vinyl acetate with $H_2{}^{18}O$ suggested simultaneous cleavage of the vinyl–oxygen and acyl–oxygen bonds,[6] but later work which used a similar technique showed that acyl–oxygen cleavage is the only route involved.[7]

In view of the facile nucleophilic substitution of electrophilic olefins substituted by a leaving group on the β

(1) On sabbatical leave from the Department of Chemistry, University of Vermont, Burlington, Vermont.

(2) For a review, see Rekasheva, A. F. *Usp. Khim.* **1968**, *37*, 2272–2299.

(3) For a recent review, see Euranto, E. K. *Pure Appl. Chem.* **1977**, *49*, 1009–1020.

(4) Ingold, C. K., "Structure and Mechanism in Organic Chemistry", 2nd ed.; Cornell University Press: Ithaca, NY, 1969; Chapter 15, pp 1128–1163.

(5) Reddy, G. S.; Gehring, D. G. *J. Org. Chem.* **1967**, *32*, 2291–2293. Briody, J. M.; Satchell, D. P. N. *J. Chem. Soc.* **1965**, 3778–3785. Kirby, A. J.; Meyer, G. *J. Chem. Soc., Perkin Trans. 2* **1972**, 1446–1451.

(6) Kiprianova, L. A.; Rekasheva, A. F. *Dokl. Akad. Nauk SSSR* **1962**, *144*, 386–389. *Ibid.* **1963**, *153*, 642–645.

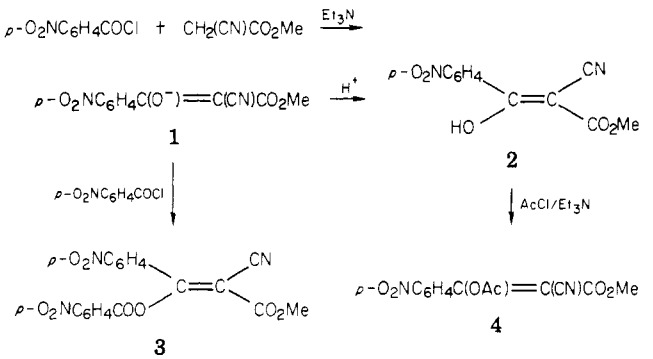
(7) Euranto, E. K.; Alhoniemi, A. *Acta Chem. Scand.* **1972**, *26*, 855–856.

0022-3263/82/1947-4809$01.25/0

carbon,[8] it was of interest to discern whether attack on a vinylic ester activated by electron-withdrawing groups will follow the usual $B_{Ac}2$ route or if attack might occur on vinylic carbon, resulting in the as yet unobserved vinylic analogue of the $B_{Al}2$ route involving vinyl–oxygen fission. A priori predictions concerning the site of bond cleavage are difficult, since both vinylic $B_{Ac}2$[9] and nucleophilic vinylic substitution[8] are accelerated by electron-withdrawing substituents on the vinylic carbon. Although the substituents are closer to the reaction site in the latter route, it does not necessarily follow that this route will prevail.

To further investigate these mechanistic routes, we synthesized the two activated esters **3** and **4** and determined the site of basic hydrolysis by conducting the reaction in basic $H_2{}^{18}O$–THF media.

Reaction of excess of *p*-nitrobenzoyl chloride with methyl cyanoacetate in benzene in the presence of triethylamine gave directly a low yield of *p*-nitrobenzoate ester **3** (eq 1), apparently by esterification of initially

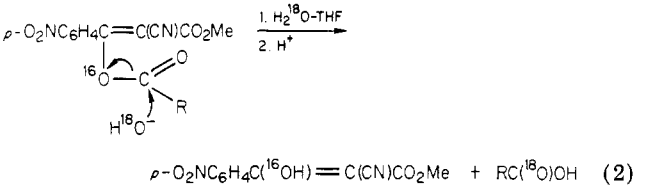


(1)

formed enolate ion **1**. The main product was *p*-nitrobenzoic acid anhydride.[10] The ester **3** was shown (by ^1H NMR) to be the main product of the reaction of the enol **2** with *p*-nitrobenzoyl chloride and triethylamine. X-ray crystallography showed that the product is the Z isomer with *cis*-*p*-nitrobenzoyloxy and carbomethoxy groups. The crystallographic parameters are given in Table I. When a 1:1 mixture of the two reagents with excess Et_3N was used, **2** was obtained.[11] Acetylation of **2** with acetyl chloride in the presence of triethylamine gave the vinylic acetate **4**. It is noteworthy that direct vinylic substitution of methyl 3-chloro-3-(*p*-nitrophenyl)-2-cyanopropenoate (**5**) by acetate ion gave enol **2** directly rather than acetate ester **4**,[11] apparently as a result of attack at the carbonyl group of **4** by the acetate ion.[12]

$$p\text{-}O_2NC_6H_4C(Cl){=}C(CN)CO_2Me$$
5

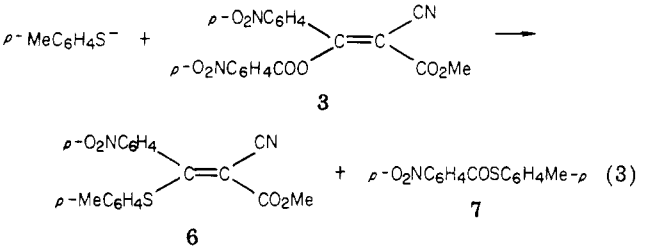
The esters **3** and **4** were hydrolyzed in a 40:1 mixture (v/v) of THF and H_2O–HO^- (with ^{18}O enrichment of 22.5%) for a period of 21 h at room temperature. At the end of the reaction, the solvent was removed, and the remaining solid was dried, dissolved in cold dry methanol and acidified (with concentrated H_2SO_4 in the hydrolysis of **3** and with gaseous HCl in the case of **4**). The enol **2** which crystallized was analyzed by mass spectrometry. In both cases the spectrum was identical with that of the unlabeled enol **2** (prepared from *p*-nitrobenzoyl chloride and methyl cyanoacetate) with a molecular peak at *m/e* 248 and an M + 2 peak of <2% intensity at *m/e* 250. Consequently, cleavage of both esters takes place at the carbonyl group (eq 2). This was additionally verified by



(2)

mass spectral analysis of the *p*-nitrobenzoic acid isolated from the hydrolysis of **3**. Molecular peaks at both *m/e* 169 (^{18}O-labeled acid) and 167 (^{16}O-labeled acid) were observed in a ratio of ca. 1:5, indicating that ^{18}O incorporation in the acid part of the ester is almost complete.

Since competition between attack on vinylic carbon and carbonyl carbon might be associated with the difference in softness of the two reaction centers, it was of interest to study the position of attack with a much softer nucleophile. Reaction of **3** with sodium *p*-toluenethiolate in acetonitrile gave two products in nearly equal amounts. The (*Z*)-thioether **6**[10] results from attack on vinylic carbon with vinyl–oxygen cleavage, and thioester **7** results from attack on the carbonyl group with acyl–oxygen cleavage (eq 3).



(3)

Consequently, use of the softer nucleophile indeed results in partitioning of attack to both centers, with about half occurring at the softer vinyl carbon site, suggesting that exclusive attack of hydroxide ion on the carbonyl group results from a favorable hard–hard interaction. Hence, the probability of finding a vinylic analogue of the $B_{Al}2$ route should be enhanced with vinylic esters containing a much harder vinylic carbon and a much softer carbonyl ester group than in **3** and **4**.

It is noteworthy that cyrstallographic data on both **3** and **6** show unequivocally that both have the *Z* configuration. The vinylic substitution therefore proceeds with apparent retention of configuration. Retention is the usual stereochemical outcome of vinylic substitution of good leaving groups, e.g., Cl,[8] but the present case is one of the few in which the stereochemistry of substitution of the much poorer ester leaving group was determined.[13] The complete stereoconvergence in the substitution of both the (*E*)- and the (*Z*)-chloro analogues of **3** by *p*-toluenethiolate ion

(8) Rappoport, Z. *Adv. Phys. Org. Chem.* **1969**, *7*, 1–114. *Acc. Chem. Res.* **1981**, *14*, 7–15.

(9) Novak, M.; Loudon, G. M. *J. Am. Chem. Soc.* **1976**, *98*, 3591–3597.

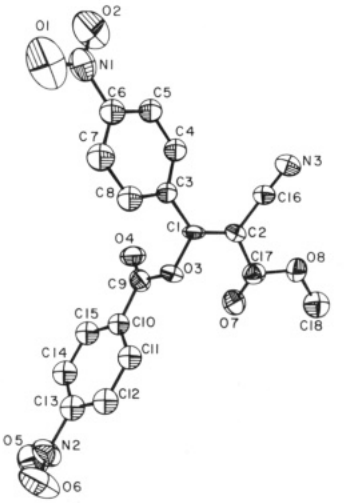
(10) Formation of the anhydride is conceivable if part of the acid chloride is converted to the *p*-nitrobenzoate salt in the presence of adventitious water, but even careful drying of solvents and reactants does not completely eliminate this reaction. The fact that triethylamine reacts with **3** to give a complex mixture of products suggests the formation of *p*-nitrobenzoate ion from vinylic substitution by Et_3N and its further reaction with *p*-nitrobenzoyl chloride to form the anhydride.

(11) Rappoport, Z.; Avramovitch, B. *J. Org. Chem.*, **1982**, *47*, 1357–1408.

(12) The other expected product is acetic anhydride. For an example of a related process that accompanies vinylic solvolysis, see Stang, P. J.; Rappoport, Z.; Hanack, M.; Subramanian, L. R. "Vinyl Cations"; Academic Press: New York, 1979.

(13) For example, stereoconvergence was observed in the substitution of an activated vinyl fluoride (Marchese, G.; Modena, G.; Naso, F. *J. Chem. Soc. B* **1969**, 290–293) or an activated ether (van der Sluijs, M. J.; Stirling, C. J. M. *J. Chem. Soc., Perkin Trans 2* **1974**, 1268–1274).

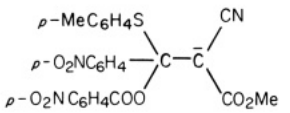
Table I. Crystallographic Parameters for Compound 3[a]



bond	length,[b] Å	bond	length,[b] Å	angle	degrees[c]
N_1-O_1	1.2159	C_{17}-O_8	1.3356	$O_{17}O_8C_{18}$	115.4638
N_1-O_2	1.2044	O_8-C_{18}	1.4599	$O_7C_{17}O_8$	124.2786
C_6-N_1	1.4489	C_1-O_3	1.3825	$C_{17}C_2C_{16}$	116.6057
C_5-C_6	1.3545[d]	O_3-C_9	1.3715	$C_{16}C_2C_1$	122.2631
C_1-C_3	1.4622	O_4-C_9	1.1793	$C_1C_2C_{17}$	121.0782
C_1-C_2	1.3421	C_9-C_{10}	1.4798	$C_2C_1C_3$	128.3440
C_2-C_{16}	1.4374	C_{13}-N_2	1.4412	$O_3C_1C_3$	113.9823
C_{16}-N_3	1.1287	N_2-O_5	1.2217	$O_3C_1C_2$	117.3316
C_2-C_{17}	1.5078	N_2-O_6	1.2223	*e*	
C_{17}-O_7	1.1900				

[a] Comoound 3 crystallized in space group $P2_1/c$. Its unit cell constants are a = 15.183, b = 8.581, c = 14.39 Å and β = 102.53°. [b] Error ±0.01 Å. [c] Error ±0.5°. [d] All aromatic C-C bond lengths are between 1.394 and 1.396 Å. [e] Dihedral angles: between planes $C_1C_2C_3$ and $C_3C_4C_8$, 30°; between planes $C_1C_2C_3$ and $C_{11}C_{10}C_{15}$, 108°; between planes $C_3C_4C_8$ and $C_{11}C_{10}C_{15}$, 90°.

and the general theory of nucleophilic vinylic substitution[8b] indicate that the reaction intermediate in the present case is the carbanion 8, which is long lived enough to undergo



8

internal rotation before leaving-group expulsion. However, in the absence of the *E* isomer of **3**, it is impossible to distinguish between retention and stereoconvergence routes. Inspection of the ^{1}H NMR of reaction mixtures in the preparation of **3** and **4** did not reveal any evidence for the formation of *E* isomers, and the *Z* isomers **3** and **6** are probably thermodynamically favored.

Experimental Section

Melting points are uncorrected. ^{1}H NMR spectra were determined on Varian T-60 or Brucker 300-MHz spectrometers and are given as δ values downfield from internal Me_4Si.

Methyl 3-(*p*-Nitrophenyl)-3-[(*p*-nitrobenzoyl)oxy]-2-cyanopropenoate (3). A solution of 75 g (0.4 mol) of *p*-nitrobenzoyl chloride (Aldrich Chemical Co.) and methyl cyanoacetate (20 g, 0.2 mol) (Aldrich Chemical Co.) in dry benzene (300 mL) was cooled to 10 °C. The mixture was rapidly stirred, and 40 g (0.4 mol) of distilled triethylamine (Aldrich Chemical Co.) was added in small portions over a period of 60 min. After the addition was complete, the orange mixture was refluxed for an additional 1 h and then cooled to room temperature. The Et_3N·HCl was filtered off, and the filtrate upon standing yielded a yellow-white crystalline solid, which after filtering and recrystallizing from ethyl acetate melted at 186–189 °C. Its ^{1}H NMR showed only a singlet at δ 8.4, and the IR (ν_{max} 1750, 1819 cm^{-1}) confirmed it as *p*-nitrobenzoic acid anhydride (lit.[14] mp 189 °C). When the benzene filtrate was concentrated, it yielded a red oil, which was added to refluxing ethanol. This resulted in 7 g (5%) of an insoluble white crystalline solid, which analyzed correctly for the ester **3**: mp 156–157 °C; ^{1}H NMR ($CDCl_3$) δ 3.81 (3 H, s, Me), 8.2 (4 H, q, J = 7 Hz, Ar), 8.3 (4 H, br s, Ar); mass spectrum, *m/e* 150 ($O_2NC_6H_4CO^+$, 100%), 120 ($OC_6H_4CO^+$, 25%), no M^+ observed. Anal. Calcd for $C_{18}H_{11}N_3O_8$: C, 54.50; H, 2.79; N, 10.58. Found: C, 54.62; H, 2.98; N, 10.82. When the ethanol solution was cooled to room temperature, it yielded additional white solid: a mixture of **2** and **3** according to ^{1}H NMR. When this solid was treated with boiling methanol, it gave an additional 2.9 g (2.1%) of **3**. A crystal X-ray analysis showed that **3** has a *Z* configuration.

Methyl 3-(*p*-Nitrophenyl)-3-acetoxy-2-cyanopropenoate (4). A mixture of **2** (0.76 g, 3 mmol) and acetyl chloride (1 g, 12.7 mmol) was added to triethylamine (0.31 g, 3 mmol) in dry benzene, and the resulting yellow solution was refluxed for 12 h until the color diminished in intensity and accumulating Et_3N·HCl was clearly apparent. The mixture was then cooled to room temperature and filtered, and excess solvent was removed under vacuum. Recrystallization of the resulting solid from 1:1 chloroform–petroleum ether yielded white plates of **4**: mp 124–126 °C; ^{1}H NMR ($CDCl_3$) δ 2.32 (3 H, s, AcO), 3.79 (3 H, s, CO_2Me), 8.15 (4 H, q, J = 7 Hz, Ar); mass spectrum, *m/e* 290 (M^+, 23%), 248 ($M - CH_2CO$, 100%). Anal. Calcd for $C_{13}H_{10}N_2O_6$: C, 53.81; H, 3.45; N, 9.65. Found: C, 53.81; H, 3.60; N, 10.01.

Reaction of 3 with Sodium *p*-Toluenethiolate. Addition of sodium *p*-toluenethiolate (0.72 g, 5 mmol) to a solution of **3** (2.0 g, 5 mmol) in dry acetonitrile (15 mL) resulted in formation of a dark yellow-orange mixture, which after a few minutes yielded a heavy precipitate. The mixture was refluxed for an additional 10 min and then cooled to room temperature and allowed to stand for 12 h. Filtering off the white sodium *p*-nitrobenzoate gave orange filtrate. Removal of the acetonitrile under reduced pressure

(14) Rappoport, Z. "Handbook of Tables of Organic Compound Identification", 3rd ed.; The Chemical Rubber Co.: Cleveland, OH, 1967; p 226.

yielded a yellow-orange solid, which was shown by ^1H NMR to be a ca. 1:1 mixture of the thioether **6** and the thioester **7** (vide infra). Recrystallization from methanol yielded white needles of **7** (0.2 g, 14%): mp 102–104 °C; ^1H NMR ($CDCl_3$) δ 2.35 (3 H, s, Me), 7.25 (4 H, br s, Ar), 8.2 (4 H, q, J = 7 Hz, Ar). Anal. Calcd for $C_{14}H_{11}NO_3S$: C, 61.54; H, 4.03; N, 5.12. Found: C, 61.44; H, 4.16; N, 5.45.

The methanol filtrate, when allowed to stand for a few hours (with concomittant concentration of dissolved material), followed by cooling, deposited 0.1 g (6%) of white crystals, mp 178–180 °C, which are identical by mmp, IR, and ^1H NMR with the *Z* thioether **6** obtained previously from the reaction of **5** with sodium *p*-toluenethiolate.[11]

Hydrolysis of 3 with $H_2{}^{18}O/Na^{18}OH$. ^{18}O-enriched water (22.51%) (0.25 mL, 13 mmol) was added to 8 mL of dry THF. Sodium (11.6 mg, 0.5 mmol) was added, and after its dissolution, **3** (200 mg, 0.5 mmol) in dry THF (2 mL) was added. After the mixture was warmed to 35–40 °C for a few min, the characteristic yellow color of **1** began to develop. The mixture was stirred at room temperature for 21 h, the solvent was then removed under reduced pressure, and the resulting yellow powder was dried at 70 °C over P_2O_5 at 1 mmHg. The dried material was dissolved in anhydrous methanol and cooled to 0 °C, and one drop of concentrated sulfuric acid was added. The small amount of white solid formed (mainly **2**) was filtered, and the filtrate was slowly concentrated to yield two types of readily separable crystals: plates, mp 235–237 °C, of *p*-nitrobenzoic acid (identified by mass spectra and mmp) and needles, mp 156–157 °C, of enol **2**. The mass spectrum of this enol shows a parent peak at m/e 248 with M + 1 and M + 2 peaks with intensities predicted by the ^{13}C natural abundance but with no appreciable ^{18}O incorporation. The complete spectrum is identical with that of **2** previously prepared from *p*-nitrobenzoyl chloride and methyl cyanoacetate.[11] The *p*-nitrobenzoic acid isolated by this procedure shows a m/e 169 (M^+ for ^{18}O acid) with an intensity of ca. 20% of that of the peak at m/e 167 (M^+ for the ^{16}O acid), indicating that incorporation of ^{18}O into the acid from the 22.5% ^{18}O-enriched water is complete within the accuracy of determination of relative peak intensities.

Hydrolysis of 4 with $H_2{}^{18}O/Na^{18}OH$. This reaction was run in a fashion similar to that for the hydrolysis of **3**, except that the cooled solution of **1** in methanol was acidified with dry HCl gas instead of concentrated sulfuric acid. The enol **2** that precipitated from this acid treatment was filtered off, and its mass spectrum showed only M^+ at 248, with no ^{18}O enrichment.

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Registry No. (*Z*)-**3**, 83291-80-9; (*Z*)-**4**, 83291-81-0; (*Z*)-**6**, 80641-26-5; **7**, 28122-84-1; *p*-$O_2NC_6H_4COCl$, 122-04-3; $CH_2(CN)CO_2Me$, 105-34-0; sodium *p*-toluenethiolate, 10486-08-5.

Neutral Regioselective Copper-Catalyzed Hydration of Some Nitriles to Amides†

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A variety of methods exist for the hydration of nitriles to amides.[1] While acidic and basic catalysts have long been employed, the importance of catalytic hydration especially under neutral conditions is being increasingly recognized.[2,3] The hydration of nitriles like acrylonitrile to give acrylamide,[4-6] an important industrial chemical, dictates regioselectivity as a further criterion in the hydration reaction.

Considerable patent literature[7] exists on the use of "reduced copper" for the hydration of acrylonitrile to acrylamide, but there is a paucity of published information on the generality of the reaction, experimental conditions, yield data, properties of the catalyst, etc. We have examined in detail the use of copper(0) as a catalyst for the hydration of various nitriles to the corresponding amides (eq 1).

$$RCN \xrightarrow[H_2O]{Cu(0)} RC(O)NH_2 \qquad (1)$$

The catalyst was prepared by reducing copper(II) sulfate with sodium borohydride. The resulting black powder, essentially copper(0) (X-ray) had a surface area of ~8 m^2/g (BET). This catalyst was very effective in the re-

Table I. Conversion of Nitriles to Amides[a]

nitrile	amide	crude yield % [b]	mp, °C found [c]	mp, °C reported
acetonitrile	acetamide	50	81	82.3 [d]
acrylonitrile	acrylamide	89	83.6	84-85 [d]
2-chloro-acrylonitrile	2-chloro-acrylamide	65	91.2	94 [e]
benzonitrile	benzamide	83	129	132.5-133.5 [d]
phenyl-acetonitrile	phenyl-acetamide	76	159.3	156-160 [f]
malononitrile	2-cyano-acetamide [g,h]	96	112	121

[a] All amides gave satisfactory NMR (^1H and ^{13}C) and IR data; ^{13}C chemical shift data (δ) when not available in literature are mentioned here. 2-Chloroacrylamide (solvent D_2O): 167.65 ($CONH_2$), 133.42 (=CCl), 125.42 ($=CH_2$). Malonamide (solvent D_2O): 173.06 ($CONH_2$), 43.17 (CH_2). 2-Cyanoacetamide (solvent Me_2SO): 164.59 ($CONH_2$), 116.24 (C≡N), 25.29 (CH_2). [b] Yields are not necessarily optimized. Crude products were spectroscopically pure. [c] Melting pints of crude products. [d] Weast, R. C., Ed. "Handbook of Chemistry and Physics", 52nd ed.; CRC Press: Cleveland, OH, 1971-1972. [e] Ivanov, S. S.; Koton, M M. *Zh. Obshch. Khim.* **1958**, *28*, 139; *Chem. Abstr.* **1958**, *52*, 12757*d*. [f] "The Condensed Chemical Dictionary", 8th ed.; Van Nostrand-Reinhold: New York, 1971; p 678. [g] Contains ~10% of the diamide. [h] A product mixture containing monoamide and diamide in the ratio of 1:3 was obtained when the time of reaction was 4 h and the substrate catalyst ratio was 0.5.

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(1) Beckwith, A. L. J. "The Chemistry of Amides"; Zabicky, J.; Ed.; Interscience: New York, 1970; pp 119–125.
(2) Matsuda, F. *CHEMTECH* **1977**, 308 and references cited therein.
(3) Cook, M. G.; Forbes, E. J.; Khan, G. M. *J. Chem. Soc., Chem. Commun.* **1966**, 121.
(4) Gaset, A.; Constant, G.; Kalack, P.; Villain, G. *J. Mol. Catal.* **1980**, *7*, 355. Villain, G.; Kalak, P.; Gaset, A. *Tetrahedron Lett.* **1980**, *21*, 2901.
(5) Hayashi, H.; Nishi, H.; Watanabe, Y.; Okazaki, T. *J. Catal.* **1981**, *69*, 44.
(6) *Chem. Eng.* **1973**, *80*, 69.
(7) (a) Svarz, J. J.; Goretta, L. A.; Seale, V. L. German Offen. 2401 142; *Chem. Abstr.* **1975**, *83*, 44014. (b) Matsuda, F.; Takahashi, T.; Horiuchi, M. Japanese Kokai Tokkyo Koho 75 14 621; *Chem. Abstr.* **1975**, *83*, 11136. (c) Kurata, T.; et. al. Japanese Kokai Tokkyo Koho 74 135 912; *Chem. Abstr.* **1974**, *80*, 27640. Japanese Kokai Tokkyo Koho 73 68519; *Chem. Abstr.* **1974**, *80*, 59522. German Offen. 2 265 238; *Chem. Abstr.* **1973**, *79*, 67032. (d) Habermann, C. E.; Tefertiller, B. A. U.S. Patent 3 758 578; *Chem. Abstr.* **1973**, *79*, 146986. (e) Barber, W. A.; Fetchin, J. A. German Offen. 2 303 648; *Chem. Abstr.* **1973**, *79*, 1365492. (f) Nakamura, T.; Ogawa, Y. Japanese Kokai Tokkyo Koho 77 19616; *Chem. Abstr.* **1977**, *87*, 38936. (g) Takagi, K.; Matsuda, T. Japanese Kokai Tokkyo Koho 74 42609; *Chem. Abstr.* **1975**, *82*, 17451.

0022-3263/82/1947-4812$01.25/0