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A Dihydro-α-furoic Ester Synthesis by the Catalyzed Reactions of Ethyl Diazopyruvate with Enol Ethers

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The synthesis of ethyl dihydrofuroates by the decomposition of ethyl diazopyruvate in the presence of enol ethers and under the influence of bis(acetonato)copper(II) or dirhodium tetraacetate is described. The vinyl ethers are variously alkylated and include oxygenated styrenes, dienol ethers, and enediol ethers. Elimination of alcohol from the products by a variety of means is shown to yield α-furoic acid derivatives.

For some time the two-reaction sequence of a transition-metal-catalyzed thermal decomposition of α-diazocarbonyl compounds in the presence of enol derivatives and the acid hydrolysis of the resultant β-oxycyclopropyl keto substances has served as facile access to γ-dicarbonyl systems (Scheme I) in route to a variety of natural products.[2] In a recent study of the thermal decomposition of the α-diazo ketone—ethyl diazopyruvate (1)—under the aforementioned circumstances, it was shown, however, that the reaction led to no cyclopropane formation but instead to a dihydrofuran system, from which an α-furoic ester could be obtained (Scheme I).[3] In order to ensure the generality of the new scheme of furan synthesis, a broader investigation of the reaction between ethyl diazopyruvate (1) and enol ethers was undertaken.

The thermolyses of ethyl diazopyruvate (1, Chart I) were carried out in refluxing benzene solutions over bis(acetoacetonato)copper(II) catalyst in the presence of enol ethers **2** and **4a–f** and produced dihydro-α-furoates **3** and **5a–f**, respectively, in 36–79% yields. It was noteworthy that all products were 5-alkoxy compounds, indicative of the power of the enol ether oxygen in governing the reaction regiochemistry. As in the previous study[3] it was possible to eliminate the alkoxy group and thereby prepare α-furoic acid derivatives. Thus, for example, dihydrofuroate **5e** was converted into 4-phenylfuroic acid (**6a**) on being refluxed in aqueous alkali and pyrolysis of ester **3** led to α-furoate **7**.

Utilization of dihydrofuran **8**, itself a product derived from the interaction of a vinyl ether and an α-diazocarbonyl compound[3], as the enol ether starting material in the bis(acetoacetonato)copper(II) catalyzed thermolysis of ethyl diazopyruvate (**1**) led to the aflatoxin-like adduct **9** (Chart II). The sole stereoisomer obtained was considered to possess the depicted cis-anti-cis configuration on the basis of the known propensity of the cycloaddition to proceed in a cis manner and the revelation of the close proximity of the adduct's methoxy group and olefinic π bond by the strong shielding (3.13 ppm) of the methoxy hydrogens in the product's ^{1}H NMR spectrum.

Scheme I

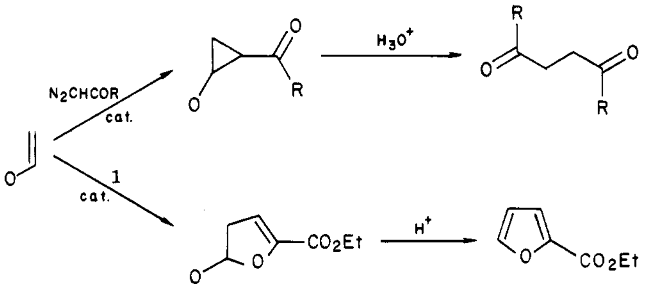
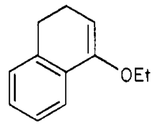


Chart I

$N_2CHCOCO_2Et$

1



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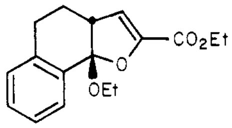

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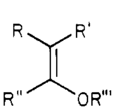

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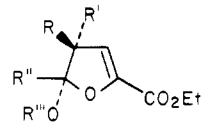
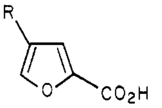
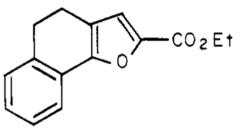


5

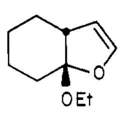
a, R = R′ = R″ = H; R‴ = *n*-Bu
b, R = Et; R′ = R″ = H; R‴ = Me; *E*/*Z* mixture
c, R = R′ = Me; R″ = H; R‴ = Et
d, R + R′ = $(CH_2)_5$; R″ = H; R‴ = Me
e, R = C_6H_5; R′ = R″ = H; R‴ = Me; *E*/*Z* mixture
f, R = R′ = H; R″ = C_6H_5; R‴ = Me



6a, R = C_6H_5
b, R = OMe



7



8

It next became of interest to test the reactivity of dialkoxyolefins, both 1,1- (i.e., ketene acetals) and 1,2-dioxygenated hydrocarbons, toward the diazopyruvic ester 1. However, in the case of the ketene acetals it was necessary first to undertake a related reaction, cyclopropanation by a catalyzed thermolysis of diazoacetic ester, in order to make certain of their normal behavior toward diazocarbonyl compounds, two previous experiments having led to conflicting results. The reaction of ethyl diazoacetate and ketene diethyl acetal (**10a**) over copper powder or cuprous bromide has been claimed to yield ethyl 4,4-diethoxy-3-butenoate (**10b**),[5,6] whereas the reaction of

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(1) (a) Gran Mariscal de Ayacucho fellowship holder, 1975–1977. (b) Gran Mariscal de Ayacucho fellowship holder, 1976–1978.

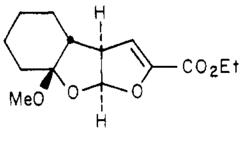
(2) Wenkert, E. *Acc. Chem. Res.* **1980**, *13*, 27.

(3) Wenkert, E.; Alonso, M. E.; Buckwalter, B. L.; Sanchez, E. L. *J. Am. Chem. Soc.* **1983**, *105*, 2021.[4]

(4) For other metal-catalyzed reactions between diazopyruvic esters and olefins, see: (a) Gallucci, R. R.; Jones, M., Jr. *J. Am. Chem. Soc.* **1976**, *98*, 7704. (b) Bien, S.; Segal, Y. *J. Org. Chem.* **1977**, *42*, 1685, 3983. (c) Mueller, L. G.; Lawton, R. G. *Ibid.* **1979**, *44*, 4741. (d) Alonso, M. E.; Jano, S. P.; Hernandez, M. I *Ibid* **1980**, *45*, 5299. (e) Wenkert, E.; Halls, T. D. J.; Kwart, L. D.; Magnusson, G.; Showalter, H. D. H. *Tetrahedron* **1981**, *37*, 4017.

0022-3263/83/1948-3047$01.50/0

Chart II



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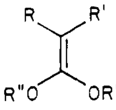
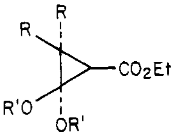
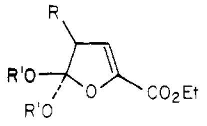


10a, R = R' = H; R'' = Et
b, R = H; R' = CH_2CO_2Et; R'' = Et
c, R = R' = R'' = Me
d, R = R' = H; R'' = Me
e, R = H; R' = Me; R'' = Et



11a, R = R' = Me
b, R = H; R' = Me

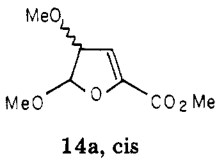
diazoacetic ester with dimethylketene dimethyl acetal (**10c**) over copper bronze has been reported to afford ester **11a**.[7] A bis(acetoacetonato)copper(II) assisted reaction between ethyl diazoacetate and ketene dimethyl acetal (**10d**) now gave ester **11b**, indicating that the acetal exhibits normal behavior. When, as a consequence, ethyl diazopyruvate (**1**) was exposed to catalyzed reactions with the latter acetal as well as methylketene diethyl acetal (**10e**), there were formed the expected dihydrofuroates **12a**,**b**, respectively.



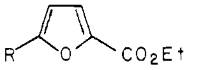
12a, R = H; R' = Me
b, R = Me; R' = Et

$MeOCH{=}CHOMe$

13a, cis
b, trans



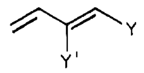
14a, cis
b, trans



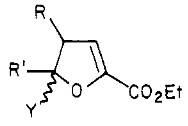
15a, R = OMe
b, R = $CH{=}CH_2$

Decomposition of ethyl diazopyruvate (**1**) over dirhodium tetraacetate in (*Z*)- and (*E*)-1,2-dimethoxyethylene (**13a** and **13b**, respectively)[8] led to the dimethoxydihydrofuroates (**14a** and **14b**, respectively). Distillation of the cis product (**14a**) over ethyldiisopropylammonium *p*-toluenesulfonate converted it into the trans isomer (**14b**), while exposure to the solid acid catalyst for a longer time transformed the latter into ethyl 5-methoxyfuroate (**15a**). Treatment of ester **14a** with potassium hydride and subsequently with water led to 4-methoxyfuroic acid (**6b**). Thus the use of 1,2-dimethoxyethylene in the two-step furan synthesis has yielded access to α- or β-alkoxyfurans, from which, in principle, furanones can be prepared.[9]

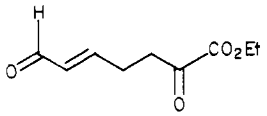
The final olefins to come under scrutiny with regard to their behavior toward diazopyruvic ester (**1**) were conjugated dienol ethers 1- and 2-methoxy-1,3-butadiene (**16a** and **16b**, respectively). In the cyclopropanation reaction with diazoacetic ester or α-diazo ketones, the terminally oxygenated dienes had been shown to exhibit strong regiochemical preference for the unoxygenated double bond, albeit giving product mixtures.[10] This trend was maintained in the reaction between ethyl diazopyruvate (**1**) and 1-methoxy-1,3-butadiene (**16a**) over dirhodium tetraacetate, as the formation of dihydrofuroates **17a** and **17b** in ca. 9:1 ratio revealed. It was noteworthy also that despite the greater complexity of this reaction the carbon–carbon bond-forming site has been dictated once again by the oxygen of the enol ether starting material. Expectedly, ester **17a** was exceedingly unstable, especially toward acid, and underwent ready hydrolysis to yield ester **18**.



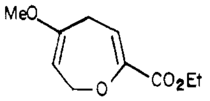
16a, Y = OMe; Y' = H
b, Y = H; Y' = OMe



17a, R = Y = H; R' = CH=CHOMe (*E*)
b, R = $CH{=}CH_2$; R' = H; Y = OMe
c, R = H; R' = $CH{=}CH_2$; Y = OMe



18



19

Decomposition of ethyl diazopyruvate (**1**) in 2-methoxy-1,3-butadiene (**16b**) yielded dihydrofuroate **17c**, accompanied by a small quantity of the highly unstable dehydrooxepin ester **19**, whose exposure to silica gel isomerized it into the major product (**17c**). Pyrolysis of the latter led to exceedingly metastable ethyl 5-vinylfuroate (**15b**).[11]

Experimental Section

Melting points were taken on a Reichert micro hotstage and are uncorrected. Infrared spectra on neat liquids and KBr pellets of solids were measured on Perkin-Elmer 137 and Pye Unicam 3-200 spectrophotometers. ^{1}H NMR spectra of deuteriochloroform solutions with Me_4Si as internal standard (δ = 0 ppm) were recorded on Varian A-60 and EM-390 spectrometers and ^{13}C NMR spectra on a Varian XL-100-15 spectrometer operating at 25.2 MHz in the Fourier transform mode. The carbon shifts are for deuteriochloroform solutions in ppm downfield from Me_4Si; $\delta(Me_4Si) = \delta(CDCl_3) + 76.9$ ppm. Mass spectra were obtained by the use of DuPont 21-492 and A.E.I.-Kratos MS-30 mass spectrometers.

General Procedure for the Reactions of Ethyl Diazopyruvate (1) with Enol Ethers. A solution of 3.5–7.0 mmol of freshly sublimed ethyl diazopyruvate (**1**) and 10–25 mmol of enol ether **3**, **4**, **10d**, or **10e** in 15–30 mL of dry benzene was added dropwise over a 4–5-h period to a stirring suspension of 5–10 mg, of bis(acetoacetonato)copper(II) in 2–3 mL of refluxing, dry benzene (containing a few drops of enol ether). Heating was continued for 0.5 h, and the mixture was then passed through a short column of neutral alumina (activity IV). The column was washed with benzene, and the combined filtrates and excess enol ether were evaporated under vacuum. The residual oil was distilled under vacuum. On the occasion of the distillate being colored, it was dissolved in warm hexane and treated with active charcoal. The mixture was filtered, the filtrate evaporated, and the resultant residue distilled under vacuum.

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(5) Dull, M. F.; Abend, P. G. *J. Am. Chem. Soc.* **1959**, *81*, 2588.

(6) For a previous discussion of this reaction, see footnote 40 of ref 7.

(7) Wenkert, E.; Mueller, R. A.; Reardon, E. J., Jr.; Sathe, S. S.; Scharf, D. J.; Tosi, G. *J. Am. Chem. Soc.* **1970**, *92*, 7428.

(8) O'Connor, B. R. *J. Org. Chem.* **1968**, *33*, 1991.

(9) Hofmann, A.; von Philipsborn, W.; Eugster, C. H. *Helv. Chim. Acta* **1965**, *48*, 1322.

(10) Wenkert, E.; Goodwin, T. E.; Ranu, B. C. *J. Org. Chem.* **1977**, *42*, 2137.

(11) Dihydrofurans **16a** and **16c** are allyl vinyl ethers. Whereas they thus should be transformable into cyclopentene derivatives on thermal Claisen rearrangement, their tendency to unravel and eliminate alcohol, respectively, made this conversion unrealizable.

A solution of 7.0 mmol of crystalline ethyl diazopyruvate (1) and 4.0 mmol of enol ether 13 or 16 in 30 mL of methylene chloride was added dropwise over a 4-h period to a stirring solution of 10 mg of dirhodium tetraacetate and 4 mmol of enol ether in 50 mL of methylene chloride at room temperature. The stirring was continued until the analysis showed the disappearance of the diazo compound. Concentration of the mixture under vacuum to a volume of 3 mL was followed by filtration through a Florisil pad and washing of the pad with dichloromethane. The combined filtrates were evaporated under vacuum and then chromatographed.

1-Ethoxy-3,4-dihydronaphthalene (2). A mixture of 35.0 g of freshly distilled α-tetralone, 3 g of Amberlite IR 120 H ion exchange resin (previously washed with absolute ethanol), and 115 mL of triethyl orthoformate in 250 mL of absolute ethanol was stirred at 45 °C for 16 h and then refluxed for 72 h. It was filtered, and the filtrate was distilled for the removal of solvent and excess formate. Distillation of the residue gave 30.9 g (70%) of liquid ether 2: bp 124–125 °C (3.5 torr), IR C=C 1650 (s) cm^{-1}; ^{1}H NMR δ 1.33 (t, 3, J = 7 Hz, Me), 2.1–2.9 (m, 4, methylene), 3.78 (q, 2, J = 7 Hz, OCH_2), 4.90 (t, 1, J = 7 Hz, olefinic H), 7.0–7.7 (m, 4, aromatic H).

Anal. Calcd for $C_{12}H_{14}O$: C, 82.71; H, 8.11; O, 9.19. Found: C, 82.49; H, 8.15; O, 9.16.

Ethyl 6,7-Benzo-4,5-dihydrobenzofuran-2-carboxylate (7). Chromatography of crude product, derived from a reaction of 1.50 g (11 mmol) of ethyl diazopyruvate (1) and 3.5 g (20 mmol) of ether 2 in 35 mL of benzene, on basic alumina (activity III) and elution with hexane led to the recovery of 1.30 g of α-tetralone. Elution with 1:1 hexane–ether yielded 2.14 g (37%) of colorless, liquid ester 3: IR C=O 1740 (s), C=C 1650 (s) cm^{-1}; ^{1}H NMR δ 1.18 (t, 3, J = 8 Hz, Me), 1.30 (t, 3, J = 7 Hz, ester Me), 1.9–3.0 (m, 4, methylene), 3.32 (m, 1, allyl H), 3.56 (q, 2, J = 8 Hz, OCH_2), 4.23 (q, 2, J = 7 Hz, ester OCH_2), 5.98 (d, 1, J = 3 Hz, furan H), 7.1–7.9 (m, 4, aromatic H).

The ester 3, 2.00 g, was heated for a 5-h period at 135 °C, while ethanol was being removed by distillation. Chromatography of the residue on neutral alumina (activity III) and elution with 20:1 hexane–ether gave a product, whose crystallization from hexane–ether yielded 1.51 g of colorless crystals of ester 7: mp 68–69 °C (lit.[12] mp 68–69 °C); spectral data were identical with reported values.

Ethyl 5-*n*-Butoxy-4,5-dihydrofuroate (5a). A reaction of 500 mg (4 mmol) of ethyl diazopyruvate (1) and 1.00 g (10 mmol) of *n*-butyl vinyl ether led to 467 mg (62%) of liquid ester 5a: bp 90–91 °C (0.25 torr); IR C=O 1725 (s), C=C 1620 (s) cm^{-1}; ^{1}H NMR δ 0.88 (t, 3, J = 7 Hz, Me), 1.24 (t, 3, J = 7 Hz, ester Me), 1.40 (m, 4, methylene), 2.50 (ddd, 1, J = 18, 3, 3 Hz, H-4 trans to BuO), 2.88 (ddd, 1, J = 18, 6, 3 Hz, H-4 cis to BuO), 3.64 (m, 2, OCH_2), 4.18 (q, 2, J = 7 Hz, ester OCH_2), 5.57 (dd, 1, J = 6, 3 Hz, OCHO), 5.82 (t, 1, J = 3 Hz, olefinic H); MS, *m/e* (relative intensity) 214 (M$^+$, 20), 169 (base).

Anal. Calcd for $C_{11}H_{18}O_4$: C, 61.66; H, 8.47; O, 29.87. Found: C, 61.64; H, 8.47; O, 29.88.

Ethyl 5-(Methoxy)-4-ethyl-4,5-dihydrofuroate (5b). A reaction of 800 mg (6 mmol) of ethyl diazopyruvate (1) with 2.10 g (24 mmol) of a 2:1 mixture of (*Z*)- and (*E*)-1-methoxy-1-butene (4b) led to 512 mg (46%) of liquid ester 5b: bp 65–68 °C (0.2 torr); IR C=O 1735 (s), C=C 1640 (s) cm^{-1}; ^{1}H NMR δ 0.97 (t, 3, J = 7 Hz, Me), 1.31 (t, 3, J = 7 Hz, ester Me), 1.55 (m, 2, CH_2), 2.97 (m, 1, H-4), 3.48 (s, 3, OMe), 4.20 (q, 2, J = 7 Hz, OCH_2), 5.05 (d, <1, J = 3 Hz, OCHO of *E* isomer), 5.36 (d, <1, J = 7 Hz, OCHO of *Z* isomer), 5.79 (d, 1, J = 2 Hz, olefinic H).

Anal. Calcd for $C_{10}H_{16}O_4$: C, 59.97; H, 8.06; O, 31.97. Found: C, 60.01; H, 8.04; O, 31.93.

Ethyl 5-Ethoxy-4,4-dimethyl-4,5-dihydrofuroate (5c). A reaction of 800 mg (6 mmol) of ethyl diazopyruvate (1) wity 5.00 g (47 mmol) of 1-ethoxy-2-methyl-1-propene (4c) in 20 mL of benzene led to 964 mg (79 %) of liquid ester 5c: bp 63–65 °C (0.25 torr); IR C=O 1730 (s), C=C 1630 (s) cm^{-1}; ^{1}H NMR δ 1.07, 1.12 (s, 3 each, C-4 Me), 1.20 (t, 3, J = 8 Hz, Me) 1.29 (t, 3, J = 7 Hz, ester Me), 3.70 (AB, 2, J = 8, 7 Hz, OCH_2), 4.15 (q, 2, J = 7 Hz, ester OCH_2), 4.99 (s, 1, OCHO), 5.74 (s, 1, olefinic H).

Anal. Calcd for $C_{11}H_{18}O_4$: C, 61.64; H, 8.47; O, 29.88. Found: C, 61.60; H, 8.50; O, 29.86.

Ethyl 5-Methoxy-4,4-pentamethylene-4,5-dihydrofuroate (5d). A reaction of 1.42 g (10 mmol) of ethyl diazopyruate (1) with 2.52 g (20 mmol) of (methoxymethylene)cyclohexane (4d)[13] in 40 mL of benzene yielded 1.22 g (50%) of liquid ester 5d: IR C=O 1740 (s), C=C 1690 (s) cm^{-1}; ^{1}H NMR δ 1.32 (t, 3, J = 7 Hz, Me), 1.45 (m, 10, methylene), 3.45 (s, 3, OMe), 4.29 (q, 2, J = 7 Hz, OCH_2), 4.98 (s, 1, OCHO), 5.96 (s, 1, olefinic H); MS, *m/e* (relative intensity) (M$^+$, 14), 167 (13), 139 (base).

Anal. Calcd for $C_{13}H_{20}O_4$: C, 64.98; H, 8.39; O, 26.63. Found: C, 64.75; H, 8.41; O, 26.70.

4-Phenylfuroic Acid (6a). Reaction between 1.00 g (7 mmol) of ethyl diazopyruvate (1) and 1.50 g (11 mmol) of a freshly distilled *E*/*Z* stereoisomer mixture of 3-methoxystryene (4e), chromatography of the crude product on basic alumina (activity III) (hexane elution leading to the recovery of some styrene starting compound), and elution with 2.5:1 hexane–ether gave 588 mg (36%) of colorless, liquid ester 5e: IR C=O 1735 (s), C=C 1620 (s) cm^{-1}; ^{1}H NMR δ 1.39 (t, 3, J = 7 Hz, Me), 3.38 (s, <3, OMe of *E* isomer), 3.59 (s, <3, OMe of *Z* isomer), 4.0–4.3 (m, 1, H-4) 4.35 (q, 2, J = 7 Hz, OCH_2), 5.38 (d, <1, J = 3 Hz, H-5 of *E* isomer), 5.66 (d, <1, J = 8 Hz, H-5 of *Z* isomer), 6.13 (d, 1, J = 3 Hz, olefinic H), 7.33 (m, 5, aromatic H). In view of its decomposition on distillation, the dihydrofuroate was converted into furoic acid by dissolution in a 5% potassium hydroxide solution in aqueous methanol and the mixture being refluxed for 2 h. The usual workup led to 432 mg (99%) of crystalline material (mp 169–172 °C) whose crystallization from hexane–ether gave 415 mg of crystalline acid 6a: mp 172.5–173 °C; IR OH 3400 (m), C=O 1710 (s) cm^{-1}; MS, *m/e* (relative intensity) 188 (M$^+$, base), 171 (31), 115 (93), 94 (13).

Anal. Calcd for $C_{11}H_8O_3$: C, 70.20; H, 4.29; O, 25.52. Found: C, 70.17; H, 4.24; O, 25.61.

Ethyl 5-Methoxy-5-phenyl-4,5-dihydrofuroate (5f). A reaction of 1.00 g (7 mmol) of ethyl diazopyruvate (1) with 2.60 g (17 mmol) of α-methoxystyrene (4f) in 25 mL of benzene led to 1.11 g (64%) of liquid ester 5f: bp 135–136 °C (0.6 torr); IR C=O 1725 (s), C=C 1635 (s) cm^{-1}; ^{1}H (NMR δ 1.32 (t, 3, J = 7 Hz, Me), 2.91 (AB, 2, J = 15, 3 Hz, CH_2), 3.15 (s, 3, OMe), 4.25 (q, 2, J = 7 Hz, OCH_2), 5.86 (t, 1, J = 3 Hz, olefinic H), 7.2–7.6 (m, 5, aromatic H).

Anal. Calcd for $C_{14}H_{16}O_4$: C, 67.71; 6.50; O, 25.79. Found: C, 67.74; H, 6.48; O, 25.74.

Dihydrofuroate 9. Reaction of 142 mg (1 mmol) of ethyl diazopyruvate (1) with 308 mg (2 mmol) of enol ether 8[3] in 8 mL of benzene led to a solid whose crystallization from hexane yielded 123 mg (46%) of crystalline ester 9: mp 57.5–58 °C; IR C=O 1740 (s), C=C 1610 (m) cm^{-1}; ^{1}H NMR δ 1.30 (t, 3, J = 7 Hz, Me), 2.2–2.5 (m, 1, allyl H), 3.13 (s, 3, OMe), 4.27 (q, 2, J = 7 Hz, OCH_2), 5.99 (d, 1, J = 3 Hz, olefinic H), 6.25 (d, 1, J = 7 Hz, OCHO); MS, *m/e* (relative intensity) 268 (M$^+$, 8), 237 (16), 112 (base).

Anal. Calcd for $C_{14}H_{20}O_5$: C, 62.66; H, 7.52; O, 29.83. Found: C, 62.48; H, 7.42; O, 30.01.

Ethyl 2,2-Dimethoxycyclopropane-1-carboxylate (11b). A solution of 1.00 g (9 mmol) of ethyl diazoacetate in 10 mL of dry benzene and a solution of 2.50 g (38 mmol) of 1,1-dimethoxyethylene (10d)[14] in 10 mL of dry benzene were added simultaneously, slowly, to a stirring, refluxing suspension of 10 mg of (acetoacetonato)copper(II) and 0.50 g of ketene acetal 10d in 2 mL of benzene under nitrogen. Upon completion of the addition, the refluxing was continued for 0.5 h and the mixture then filtered through a short column of neutral alumina (activity IV). Evaporation of the filtrate and distillation (80–85 °C (0.5 torr)) of the residue yielded 882 mg (55%) of liquid ester 11b: IR C=O 1720 (s) cm^{-1}; ^{1}H NMR δ 1.27 (t, 3, J = 7 Hz, Me), 1.43 (m, 2, CH_2), 2.10 (dd, 1, J = 10, 7 Hz, COCH), 3.42 (s, 6, 2 OMe), 4.23 (q, 2, J = 7 Hz, OCH_2).

Anal. Calcd for $C_8H_{14}O_4$: C, 55.14; H, 8.10; O, 36.75. Found: C, 55.22; H, 8.05; O, 36.51.

Ethyl 5,5-Dimethoxy-4,5-dihydrofuroate (12a). Identical reaction and workup conditions applied to 1.00 g (7 mmol) of ethyl

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[12] Murayama, S. T.; Spencer, T. A. *Tetrahedron Lett.* **1969**, 4479.

[13] Lavielle, G.; Reinsdorf, D. *C. R. Acad. Sci. Paris, Ser. C* **1971**, *272*, 100.

[14] McElvain, S. M.; Kundiger, D. *Org. Synth.* **1973**, *23*, 8, 45.

diazopyruvate (1) and 2.70 g (31 mmol) of 1,1-dimethoxyethylene (**10d**)[14] led to a crude product whose distillation (105–110 °C (1.5 torr)) yield 825 mg (58%) of liquid ester **12a**: IR C=O 1725 (s), C=C 1610 (m) cm^{-1}; ^{1}H NMR δ 1.33 (t, 3, J = 7 Hz, Me), 2.87 (d, 2, J = 3 Hz, CH$_2$), 3.43 (s, 6, 2 OMe), 4.32 (q, 2, J = 7 Hz, OCH$_2$), 6.02 (t, 1, J = 3 Hz, olefinic H); ^{13}C NMR δ 14.2 (Me), 37.4 (C-4), 50.5 (OMe), 61.2 (OCH$_2$), 110.2 (C-5), 125.3 (C-3), 146.2 (C-2), 159.7 (C=O); MS, *m/e* (relative intensity) 202 (M$^+$, 3), 170 (58), 99 (base); exact mass, *m/e* 202.0840 (calcd for $C_9H_{14}O_5$, 202.0841).

Ethyl 5,5-Diethoxy-4-methyl-4,5-dihydrofuroate (12b). Identical reaction and workup conditions applied to 1.00 g (7 mmol) of ethyl diazopyruvate (1) and excess of 1,1-diethoxy-1-propene (**10e**) in benzene led to a crude product whose distillation (130–135 °C (0.5 torr)) yielded 639 mg (37%) of liquid ester **12b**: IR C=O 1730 (s) cm^{-1}; ^{1}H NMR δ 1.15 (d, 3, J = 8 Hz, Me), 1.20 (t, 6, J = 8 Hz, 2 ether Me), 1.30 (t, 3, J = 7 Hz, ester Me), 3.10 (dq, 1, J = 8, 4 Hz, H-4) 3.62, 3.80 (q, 2 each, J = 8 Hz, 2 ether OCH$_2$), 4.22 (q, 2, J = 7 Hz, ester OCH$_2$), 5.91 (d, 1, J = 3 Hz, olefinic H); MS, *m/e*, (relative intensity) 244 (M$^+$, 5), 198 (52), 43 (base); exact mass, *m/e* 244.1316 (calcd for $C_{12}H_{20}O_5$; 244.1311).

Ethyl *cis*-4,5-Dimethoxy-4,5-dihydrofuroate (14a). Chromatography of the crude product on silica gel and elution with 4:1 hexane-ethyl acetate gave a 90% yield of liquid ester **14a**: IR C=O 1730 (s), C=C 1630 (m) cm^{-1}; ^{1}H NMR δ (CCl$_4$) 1.30 (t, 3, J = 7 Hz, Me), 3.35, 3.58 (s, 3 each, OMe), 4.20 (q. 2, J = 7 Hz, OCH$_2$), 4.50 (dd, 1, J = 6, 2 Hz, H-4), 5.28 (d, 1, J = 6 Hz, H-5), 5.82 (d, 1, J = 2 Hz, H-3); exact mass, *m/e* 202.0830 (calcd for $C_9H_{14}O_5$, 202.0841).

Ethyl *trans*-4,5-Dimethoxy-4,5-dihydrofuroate (14b). Similar choromatography and elution led to 82% of liquid ester **14b**: IR C=O 1720 (s), C=C 1540 (m) cm^{-1}; ^{1}H NMR δ 1.24 (t, 3, J = 7 Hz, Me), 3.28, 3.48 (s, 3 each, OMe), 4.25 (q, 2, J = 7 Hz, OCH$_2$), 4.29 (dd, 1, J = 3, 2 Hz, H-4), 5.25 (d, 1, J = 2 Hz, H-4), 5.25 (d, 1, J = 2 Hz, H-5), 5.91 (d, 1, J = 3 Hz, H-3); exact mass, *m/e* 202.0836 (calcd for $C_9H_{14}O_5$, 202.0841.

Kugelrohr distillation of 300 mg of ester **14a** over 25 mg of ethyldiisopropylammonium *p*-toluenesulfonate at atmospheric pressure for 45 min gave 280 mg (93%) of liquid ester **14b**; spectra are identical with those above.

Ethyl 5-Methoxyfuroate (15a). A mixture of 100 mg of ester **14b** and 25 mg of ethyldiisopropylammonium *p*-toluenesulfonate in 2 mL of carbon tetrachloride was heated at 160 °C for 3 h under vacuum in a sealed ampule. Whereas ^{1}H NMR analysis of the product mixture showed the presence of ca. 30% starting ester, longer reaction time led to polymer formation. Chromatography of the mixture on silica gel and elution with 9:1 hexane–ethyl acetate afforded 30 mg (36%) of liquid ester **15a**: IR (CHCl$_3$) C=O 1725 (s), C=C 1625 (m) cm^{-1}; ^{1}H NMR δ (CCl$_4$) 1.35 (t, 3, J = 7 Hz, Me), 3.96 (s, 3, OMe), 4.26 (q, 2, J = 7 Hz, OCH$_2$), 5.28 (d, 1, J = 4 Hz, H-4), 7.05 (d, 1, J = 4 Hz, H-3); exact mass, *m/e* 170.05985 (calcd for $C_8H_{10}O_4$, 170.05789).

4-Methoxyfuroic Acid (6b). A mixture of 100 mg of ester **14a** and a 10-fold molar excess of potassium hydride (in a mineral oil dispersion) in 25 mL of dry ether was stirred at room temperature for 3 h. Addition of 5 mL of water caused the ether suspension to reflux. After 10 min the organic layer was separated and the water solution made acid with 6 N hydrochloric acid. Extraction with ether, drying of the extract over sodium sulfate, and evaporation yielded 67 mg (95%) of crystalline acid **6b**: mp 141–142 °C (lit.[15] mp 142 °C); IR (CHCl$_3$) OH 3030 (br, m), C=O 1705 (s), C=C 1615 (s) cm^{-1}; ^{1}H NMR δ 3.80 (s, 3, OMe), 7.10 (s, 1, H-5), 7.30 (s, 1, H-3); ^{1}H NMR δ (Me$_2$SO-d_6) identical with reported spectrum.[15]

Ethyl 5-Methoxy-4-vinyl-4,5-dihydrofuroate (17b) and Ethyl 2,7-Dioxo-5-heptenoate (18). Chromatography of the crude product on Florisil and elution with 9:1 hexane–ethyl acetate gave colorless liquid **17b** (8%): IR C=O 1720(s), C=C 1635 (m) cm^{-1}; ^{1}H NMR δ 1.33 (t, 3, J = 7 Hz, Me), 3.45 (m, 1, H-4), 3.51 (s, 3, OMe), 4.29 (q, 2, J = 7 Hz, OCH$_2$), 5.1–5.8 (m, 3, vinyl), 5.22 (d, 1, J = 2 Hz, H-5), 5.94 (d, 1, J = 3 Hz, H-3); ^{13}C NMR δ 14.1 (Me), 53.3 (C-4), 56.1 (OMe), 61.1 (OCH$_2$), 111.2 (vinyl CH), 112.6 (C-5), 117.4 (vinyl CH$_2$), 134.7 (C-3), 146.7 (C-2), 160.0 (C=O); exact mass, *m/e* 198.08921 (calcd for $C_{10}H_{14}O_4$, 198.08921).

Further elution afforded highly unstable, liquid ester **17a**: IR C=O 1725 (s), C=C 1630 (m) cm^{-1}; ^{1}H NMR δ (CCl$_4$) 1.35 (t, 3, J = 7 Hz, Me), 2.2–3.0 (m, 2, CH$_2$), 3.55 (s, 3, OMe), 4.18 (q, 2, J = 7 Hz, OCH$_2$), 4.92 (t, 1, J = 10 Hz, H-5), 5.08 (t, 1, J = 15 Hz, vinyl H), 5.70 (t, 1, J = 3 Hz, H-3), 6.55 (d, 1, vinyl OCH). The compound did not survive chromatography on silica gel.

A mixture of 10 mL of 2 N hydrochloric acid solution and 500 mg of ester **17a** in 10 mL of methylene chloride was stirred for 2.5 h. Saturated sodium bicarbonate solution was added and the mixture extracted with dichloromethane. The extract was dried (Na$_2$SO$_4$) and evaporated, yielding 355 mg (90%) of liquid aldehyde ester **18**: IR CHO 2730 (m), C=O 1730 (s), 1690 (s), C=C 1640 (m) cm^{-1}; ^{1}H NMR δ (CCl$_4$) 1.35 (t, 3, J = 7 Hz, Me), 2.4–2.8 (m, 2, allyl CH$_2$), 2.9–3.1 (m, 2, COCH$_2$), 4.25 (q, 2, J = 7 Hz, OCH$_2$), 5.8–6.2 (m, 1, H-6), 6.88 (dt, 1, J = 18, 7 Hz, H-5), 9.48 (d, 1, J = 7 Hz, CHO); exact mass, *m/e* 184.07430 (calcd for $C_9H_{12}O_4$, 184.07354).

Ethyl 5-Methoxy-5-vinyl-4,5-dihydrofuroate (17c) and Ethyl 5-Methoxy-4,7-dihydrooxepin-2-carboxylate (19). Chromatography of the crude product on Florisil and elution with 9:1 hexane–ethyl acetate gave liquid ester **17c** (78%): IR C=O 1730 (s), C=C 1630 (m) cm^{-1}; ^{1}H NMR δ 1.32 (t, 3, J = 7 Hz, Me), 2.84 (d, 2, J = 3 Hz, CH$_2$), 3.32 (s, 3, OMe), 4.25 (q, 2, J = 7 Hz, OCH$_2$), 5.2–6.2 (m, 3, vinyl H), 5.90 (t, 1, J = 3 Hz, H-3); exact mass, *m/e* 198.08894 (calcd for $C_{10}H_{14}O_4$, 198.08921).

Further elution gave liquid ester **19** (9%): IR C=O 1720 (s), C=C 1655 (s) cm^{-1}; ^{1}H NMR δ (CCl$_4$) 1.30 (t, 3, J = 7 Hz, Me), 3.10 (d, 2, J = 6 Hz, CH$_2$), 3.55 (s, 3, OMe), 4.15 (q, 2, J = 7 Hz, OCH$_2$), 4.50 (d, 2, J = 8 Hz, allyl OCH$_2$), 4.92 (d, 1, J = 8 Hz, H-6), 5.72 (t, 1, J = 6 Hz, H-3); exact mass, *m/e* 198.08836 (calcd for $C_{10}H_{14}O_4$, 198.08921.

Chromatography of ester **19** on silica gel converted it quantitatively into ester **17c**.

Ethyl 5-Vinylfuroate (15b). A solution of 100 mg of ester **17c** in 2 mL of carbon tetrachloride was heated at 170 °C for 2 h under vacuum in a sealed ampule. Chromatography of the mixture on silca gel and fast elution with 9:1 hexane–ethyl acetate gave 58 mg (70%) of colorless, highly unstable, oily ester **15b**: ^{1}H NMR δ 1.38 (t, 3, J = 7 Hz, Me), 4.36 (q, 2, J = 7 Hz, OCH$_2$), 5.3–6.8 (m, 3, vinyl H), 6.38 (d, 1, J = 3 Hz, H-4), 7.10 (d, 1, J = 3 Hz, H-3). The compound was too short-lived for elemental analysis.

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Registry No. 1, 14214-10-9; **2**, 52772-56-2; **3**, 86480-32-2; **4a**, 111-34-2; (*E*)-**4b**, 10034-13-6; (*Z*)-**4b**, 10034-12-5; **4c**, 927-61-7; **4d**, 19096-89-0; (*E*)-**4e**, 4110-75-2; (*Z*)-**4e**, 14371-19-8; **4f**, 4747-13-1; **5a**, 86471-21-8; (*E*)-**5b**, 86471-22-9; (*Z*)-**5b**, 86471-23-0; **5c**, 86480-33-3; **5d**, 86471-24-1; (*E*)-**5e**, 86471-25-2; (*Z*)-**5e**, 86471-26-3; **5f**, 86471-27-4; **6a**, 86471-28-5; **6b**, 32460-47-2; **7**, 25098-17-3; **8**, 86471-29-6; **9**, 86471-30-9; **10d**, 922-69-0; **10e**, 21504-43-8; **11b**, 56579-54-5; **12a**, 86471-31-0; **12b**, 86471-32-1; **13a**, 7062-96-6; **13b**, 7062-97-7; **14a**, 86471-33-2; **14b**, 86471-34-3; **15a**, 86471-35-4; **15b**, 86471-36-5; (*E*)-**16a**, 10034-09-0; **16b**, 3588-30-5; (*E*)-**17a**, 86471-37-6; **17b**, 86471-38-7; **17c**, 86471-39-8; **18**, 86471-40-1; **19**, 86471-41-2; bis(acetoacetonato)copper(II), 13395-16-9; α-tetralone, 529-34-0; ethyl diazoacetate, 623-73-4; dirhodium tetraacetate, 15956-28-2.

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[15] Sornay, R.; Meunier, J.-M.; Fournari, P. *Bull. Soc. Chim. Fr.* **1971**, 990.