Catalytic Decomposition of Ethyl Diazopyruvate in the Presence of Electron-Deficient and Hydrocarbon Alkenes. Cyclopropanation vs. Carbon-Hydrogen Insertion[1a]

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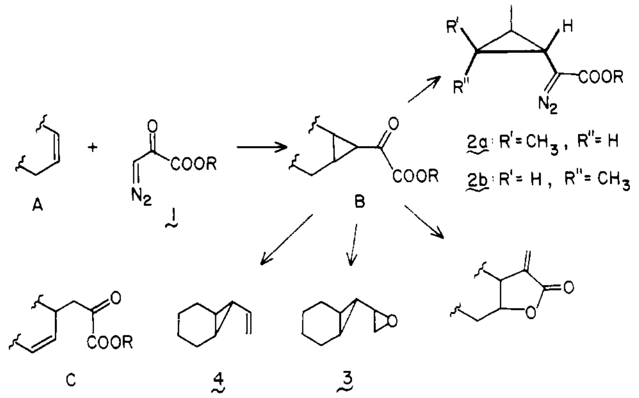
The bis(copper acetylacetonate)-catalyzed decomposition of ethyl diazopyruvate (EDP, 1) in the presence of electron-deficient and hydrocarbon alkenes has been examined. The steric and electronic factors governing the reaction were evaluated. While mono- and disubstituted hydrocarbon alkenes such as cyclohexene, 4-(*tert*-butylmethylene)cyclohexane, styrene, and indene furnished the corresponding ethoxalylcyclopropane derivatives in moderate to satisfactory yields, polysubstituted alkenes such as 1-methylcyclohexene and 1,2-dimethylcyclohexene did not give separable adducts. Electron-withdrawing substituents (Cl, Br, NO_2) directly bound to the substrate olefin and substitution of two phenyl groups in conjugation with the alkene precluded the formation of adducts. Only α-chloro- and *p*-chlorostyrene were found reactive toward the EDP-derived copper carbenoid. No C-H insertion products were detected in any case. It is shown that products of apparent allylic C-H insertion are actually the consequence of a 1,5 hydrogen shift of the initially formed cyclopropane. The evidence collected suggests that the EDP copper carbenoid is slightly less electrophilic than the copper carbenoid derived from ethyl diazoacetate.

The literature abounds in reports of synthetic uses of cyclopropane ketones and esters and derivatives thereof.[2] By contrast, the introduction of additional substituents in the vicinity of the carbonyl unit that may influence electronically its reactivity and, hence, the reactivity of cyclopropane itself has remained practically unexplored. In particular, electron-withdrawing groups directly bonded to the carbonyl function would impart an increased reactivity of the cyclopropane ring toward carbon-carbon bond disconnection and the various concomitant processes of hydride migration,[3] [1,3] sigmatropic rearrangement,[4] 1,5 hydrogen shift,[5] 1,5-addition,[2] or β elimination[6] that it would trigger.

Scheme I



One such electron-attracting group could be, for instance, the alkoxycarbonyl group which would require the use of an alkyl 3-diazo-2-oxopropionate (1) if the cyclopropane ring is to be constructed from the [1 + 2] cycloaddition reaction of a metal salt catalyzed decomposition of the pertinent diazocarbonyl compound in the presence of an olefin.[7] Further, the ready availability of two reactive moieties such as those of α-keto esters B, would pave the way toward the synthesis of a considerable number of synthons linked to cyclopropane (see Scheme I). In this

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(1) (a) Taken in part from the M.Sc. Thesis of P. Jano. (b) Gran Mariscal de Ayacucho Fellowship Holder 1975-1977. (c) Gran Mariscal de Ayacucho Fellowship Holder 1976-1978.

(2) (a) For the acid-catalyzed ring opening of cyclopropanes, see: Kharasch, M.; Rudy, T.; Nudenberg, W.; Büchi, G. *J. Org. Chem.* **1953**, *18*, 1030; DePuy, C. H. *Acc. Chem. Res.* **1968**, *1*, 33; Julia, M.; Julia, S.; Guegan, R. *Bull. Soc. Chim. Fr.* **1960**, 1072; Wenkert, E.; Mueller, R. A.; Reardon, E. J., Jr.; Sathe, S. S.; Scharf, D. J.; Tosi, G. *J. Am. Chem. Soc.* **1970**, *92*, 7428; Wenkert, E.; McPherson, C. A.; Sânchez, E. L.; Webb, R. L. *Synth. Commun.* **1973**, *3* 255; Wenkert, E.; Buckwalter, B. L.; Sathe, S. S. *Ibid.* **1973**, *3*, 261; Ceccherelli, P.; Pelliciari, R.; Golob, N. F.; Smith, R. A. J.; Wenkert, E. *Gazz. Chim. Ital.* **1973**, *103*, 599; Coates, R. M.; Sandefur, L. O.; Smillie, R. D. *J. Am. Chem. Soc.* **1975**, *97*, 1621; Marshall, J. A.; Ellison, R. H. *J. Org. Chem.* **1975**, *40*, 2070; Rynbrandt, R. H.; Dutton, F. E. *Ibid.* **1975** *40*, 2282; Corey, E. J.; Ulrich, P. *Tetrahedron Lett.* **1975**, 3685; Wenkert, E.; Golob, N. F.; Hatch, R. P.; Wenkert, D.; Pelliciari, R. *Helv. Chim. Acta* **1977**, *60*, 1; Wenkert, E.; Chou, K. J.; Hatch, R. P. *Synth. Commun.* **1977**, *7*, 375. (b) For the hydrogenolysis of cyclopropanes, see: Jacobus, J.; Majerski, Z.; Mislow, K.; Schleyer, P. v. R. *J. Am. Chem. Soc.* **1969**, *91*, 1998 and references cited. (c) For the reduction of cyclopropane carbonyl derivatives, see: Norin, T. *Acta Chem. Scand.* **1965**, *19*, 1289; Dauben, W. C.; Deving, E. J. *J. Org. Chem.* **1966**, *31*, 3794. (d) For base treatment of acylcyclopropanes, see: Bonet, J. J.; Wehrli, H.; Schaffner, K. *Helv. Chim. Acta* **1962**, *45*, 2615; Ginsig, R.; Cross, A. D. *J. Am. Chem. Soc.* **1965**, *87*, 4629; Sims, J. J.; Honvad, V. K. *J. Org. Chem.* **1969**, *34*, 496. (e) For the pyrolysis of cyclopropane esters and ketones, see: Hanafus, T.; Birladenau, L.; Winstein, S. *J. Am. Chem. Soc.* **1965**, *87*, 3510; Sims, J. J. *Ibid.* **1965**, *87*, 3511; Sims, J. J.; Selman, L. H. *Tetrahedron Lett.* **1969**, 561; Monti, S. A.; Cowherd, F. G.; McAninch, T. W. *J. Org. Chem.* **1975**, *40*, 858; Wenkert, E.; de Sousa, J. R. *Synth. Commun.* **1977**, *7*, 457. (f) For 1,5-additions to acylcyclopropanes, see: Kierstead, R. W.; Linstead, R. W.; Weedon, B. C. L. *J. Chem. Soc.* **1952**, 3610; Stewart, J. M.; Westberg, H. H. *J. Org. Chem.* **1965**, *30*, 1951; Dolfini, J. E.; Menich, K.; Corliss, P.; Cavanaugh, R.; Danishefski, S.; Chakrabartty, S. *Tetrahedron Lett.* **1966**, 4421; Frejaville, C.; Jullien, R. *Ibid.* **1971**, 2039; Marshall, J. A.; Ruden, R. A. *Ibid.* **1971**, 2875; Daviaud, G.; Miginiac, P. *Ibid.* **1972**, 997; Corey, E. J.; Fuchs, P. L. *J. Am. Chem. Soc.* **1972**, *94*, 4014; Grieco, P. A.; Finkelhor, R. *J. Org. Chem.* **1973**, *38*, 2100; Fuchs, P. L. *J. Am. Chem. Soc.* **1974**, *96*, 1607; Dauben, W. G.; Hart, D. J. *Ibid.* **1975**, *97*, 1622; House, H. O.; Prabhu, A. V.; Wilkins, J. M.; Lee, L. F. *J. Org. Chem.* **1976**, *41*, 3067; House, H. O.; Snoble, K. A. J. *Ibid.* **1976**, *41*, 3076; Danishefski, S.; Singh, R. K. *Ibid.* **1976**, *41*, 1668 and references cited therein; Berkowitz, W. F.; Grenetz, S. C. *Ibid.* **1976**, *41*, 10. (g) For a review on synthetic uses of oxycyclopropanes, see: Wenkert, E. *Acc. Chem. Res.* **1980**, *13*, 27.

(3) Creary, X.; Hudock, F.; Keller, M.; Kerwin, J. F., Jr.; Dinnocenzo, J. P. *J. Org. Chem.* **1977**, *42*, 409. Wenkert, E.; Chou, K. J.; Hatch, R. P. *Synth. Commun.* **1977**, *7*, 375.

(4) (a) McGreer, D. E.; McKinley, J. W. *Can. J. Chem.* **1973**, *51*, 1487. (b) Doering, W. v. E.; Sachdev, K. *J. Am. Chem. Soc.* **1974**, *96*, 1168.

(5) Roberts, R. M.; Landolt, G. G.; Greene, R. N.; Heyer, E. W. *J. Am. Chem. Soc.* **1967**, *89*, 1404. Bickelhaupt, F.; De Graaf, W. L.; Klump, G. W. *Chem. Commun.* **1968**, 53. Dauben, W. G.; Schutte, L.; Wolf, R. E. *J. Org. Chem.* **1969**, *34*, 1849. Garin, D. L. *Ibid.* **1969**, *34*, 2355. Ando, W. *Tetrahedron Lett.* **1969**, 929. Gajewski, J. J.; Weber, R. J.; Braun, R.; Manion, M. L.; Hymen, B. *J. Am. Chem. Soc.* **1977**, *99*, 816.

(6) Alonso, M. E.; Gômez, M. *Tetrahedron Lett.* **1979**, 2763.

(7) Kirmse, W. "Carbene Chemistry", 2nd ed.; Acedemic Press: New York, 1971. Moss, R. A. *Sel. Org. Transform.* **1969**, *1*, 35. Vinod, D.; Warnhoff, E. W. *Org. React.* **1970**, *18*, 217. Cowell, G. W.; Ledwith A. *Q. Rev., Chem. Soc.* **1970**, *24*, 119. Regitz, M. *Synthesis* **1972**, 351. Peace, B. W.; Wulfman, D. S. *Ibid.* **1973**, 137. Moss, R. A.; Jones, M., Jr., Eds. "Carbenes"; Wiley-Interscience: New York, 1975; Vol. I, II. Marchand, A. P.; Brockway, N. M. *Chem. Rev.* **1974**, *74*, 431. Wulfman, D. S. *Tetrahedron* **1976**, *32*, 1231.

0022-3263/80/1945-5299$01.00/0

connection, the transformation of B into *cis*- and *trans*-(dimethylcyclopropyl)diazoacetates **2a,b**,[8] the cyclopropyloxirane **3**, the vinylcyclopropane **4**,[9a] and fused *trans*-α-methylene γ-lactones[9c] has been reported recently.

The cyclopropanation behavior of ethyl diazopyruvate (**1**) (EDP) remains insufficiently understood. Of the few articles dealing with its chemistry[8-13] only those of Jones,[8] Bien,[9a,b] and Lawton[9c] report cyclopropanation. The scarcity of data and the intriguing catalyst-product dependency[9b] displayed by EDP make it desirable at this stage to expand our knowledge about the reactivity pattern of this remarkable compound with olefins of wider scope. Below we report the outcome of experiments addressed to this issue.

In the present study we have investigated the copper salt catalyzed additions of EDP to hydrocarbon and electron-deficient alkenes. In the available examples of the former,[8,9] cyclopropanation and formal allylic C–H insertion and/or rearrangement processes were reported, in close resemblance to other α-diazocarbonyl compounds.[7] The olefinic substrate employed could not provide the necessary evidence to distinguish between actual allylic C–H insertion and thermal homo-1,5-hydrogen shift of cyclopropane[5] in EDP additions since both processes account for the formation of species C. In order to shed some light onto this problem, we examined the addition of **1** to polysubstituted olefins, so constituted as to afford additional evidence in connection with the electronic enhancement by alkyl substitution vs. steric encumbrance dilemma.[14] 1-Methylcyclohexene and 1,2,6-trimethylcyclohexene were chosen as working models. In contrast to the analogous reaction with cyclohexene,[9a] the bis(copper acetoacetonate)-catalyzed decomposition of EDP in 1-methylcyclohexene furnished a complex mixture from which the cyclopropane adducts **5a** and **5b** (see Chart I), detected (NMR) in the crude product, could not be isolated without extensive decomposition.[15] Efforts to obtain more stable derivatives also met with failure. Not unexpectedly 1,2,6-trimethylcyclohexene yielded intractable tars.[16a] Presumably, steric hindrance overcomes the increased nucleophilicity of the olefin toward the carbenoid species, giving rise to uncontrolled reactions.[16b]

Undeterred by these results, we proceeded to study the addition of EDP to the exocyclic olefin **6**[17] in the hope that the actual allylic C–H insertion product **9** would readily be detectable. Only the cyclopropane **7** along with traces of **8** was isolated in 45% yield.[18] Compound **7** was characterized as the cyclopropylcarbinol ester **10** which was obtained in 85% yield by the sodium borohydride reduction of **7** at -5 °C. The quantitative transformation of **7** into **8** by heating at 190 °C for 15 min and the absence of the exocyclic olefin keto ester **9** led to the conclusion that in EDP additions to simple alkenes allylic C–H insertion of the copper carbenoid does not take place to a detectable extent. Consequently those adducts equivalent to C–H insertion products reported as such in earlier work[9] are actually generated thermally in the reaction medium via the well-known homo-1,5-hydrogen shift,[5] which is particularly favorable in compound **7** in view of the strong electron-withdrawing power of the ethoxalyl group and its particular configuration in which the γ-proton lies in the vicinity of the carbonyl oxygen atom.

The reactivity of EDP toward double bonds in conjugation with aromatic systems was also examined. Styrene (**11**), indene (**12**), and *trans*-stilbene (**13**) served as substrate models. While bis(copper acetylacetonate)-promoted decomposition of EDP in excess **11** furnished a 49% yield of *cis*- and *trans*-cyclopropanes **14a** and **14b** in a 1:3 ratio, a similar reaction performed with ethyl diazoacetate gave a 51% yield of a 1:2 ratio of cis and trans adducts **15a** and **15b** (see Chart II). Although this result is suggestive of a slighly higher selectivity of the EDP-derived copper carbenoid as compared with the ethyl diazoacetate homologue, it has been shown that the cis–trans ratio is strongly dependent upon the ligand of the metal catalyst.[19] Further, the well-known epimerization of cyclopropane ketones[20] would also contribute to the overall cis–trans ratio observed. In order to evaluate more properly these aspects, we studied a rigid styrene-type system, i.e., indene. Its interaction with compound **1** under copper acetylacetonate catalysis furnished the unstable *exo*-cyclopropane derivative **16a** as the sole tractable product. The appearance of individual methylene and methyl signals of the ethyl ester in the NMR spectrum and the coupling constant (J = 2.0 Hz) of the α-carbonyl cyclopropyl methyne (δ 2.33) allowed the assignment of this structure.[21] Conversely, the N-epimer **16b** was not detected, in contrast with a similar reaction of indene with ethyl diazoacetate in which a 2:1 ratio of E to N adducts was obtained.[22]

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[8] Galluci, R. R.; Jones, M., Jr. *J. Am. Chem. Soc.* **1976**, *98*, 7704.

[9] (a) Bien, S.; Segal, Y. *J. Org. Chem.* **1977**, *42*, 3983. (b) Bien, S.; Segal, Y. *Ibid.* **1977**, *42*, 1685. (c) Mueller, L. G.; Lawton, R. G. *Ibid.* **1979**, *44*, 4741.

[10] Ernest, I. *Collect. Czech. Chem. Commun.* **1954**, *19*, 1179.

[11] Sorm, F.; Ratusky, J. *Chem. Listy* **1957**, *51*, 1091.

[12] E. Fahr, *Justus Liebigs Ann. Chem.* **1958**, *617*, 11.

[13] Baganz, H.; May, H. J. *Chem. Ber.* **1966**, *99*, 3766.

[14] Neil, T. C. Ph.D. Thesis, Pennsylvania State University, 1964. Jones M., Jr.; Kulczycki, A., Jr.; Hummel, K. F. *Tetrahedron Lett.* **1967**, 183. Jones, M., Jr.; Ando, W.; Kulczycki, A., Jr. *Ibid.* **1967**, 1391.

[15] High-performance liquid chromatographic analysis on silica gel columns (Merck Hibar Si-60, 25 cm, 5-μm column) of distillable material indicated the formation of no less than 17 compounds whose separation at the preparative scale became impossible. Thus, for synthetic purposes the interaction of EDP with trisubstituted olefinic hydrocarbons appears useless.

[16] (a) 1,2-Dimethylcyclohexene failed to yield [1 + 2] addition products in its reaction with dimethyl diazomalonate under copper catalysis. Only allylic C–H "insertion" compounds were detected. See: Peace, B. W.; Wulfman, D. S. *Synthesis* **1973**, 137. (b) The relative reactivity of the series cyclohexene, 1-methylcyclohexene, and 1,2-dimethylcyclohexene toward the copper carbenoid of dimethyl diazomalonate has been found to be 5:1:≪0.01. See: Wulfman, D. S.; Peace, B. W. *J. Chem. Soc. D* **1971**, 1360.

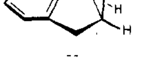
[17] Cross, B.; Whitman, G. H. *J. Chem. Soc.* **1960**, 3892.

[18] No effort was made at this stage to distinguish cyclopropane diastereoisomers **7a** and **7b**, products of equatorial and of axial attack, respectively. These results bear on the transition-state geometries involved and will be the topic of a separate investigation.

[19] Paulisse, R.; Hubert, A. J.; Teyssie, P. *Tetrahedron Lett.* **1972**, 1465.

[20] (a) Dauben, W. G.; Shaffer, G. W. *J. Org. Chem.* **1969**, *34*, 2301. (b) McGreer, D. E.; McKinley, J. W. *Can. J. Chem.* **1973**, *51*, 1487. (c) Zimmerman, H. E.; Boettcher, R. J.; Braig, W. *J. Am. Chem. Soc.* **1973**, *95*, 2155. (d) Garin, D. L. *J. Chem. Soc., Chem. Commun.* **1973**, 403. (e) Griffin, G. W.; O'Connell, E. J.; Hammond, H. A. *J. Am. Chem. Soc.* **1963**, *85*, 1001. Nye, M. J.; Subramangan, G. *Proc. Chem. Soc. London* **1964**, 144. Zimmerman, H. E.; Fletcher, T. W. *J. Am. Chem. Soc.* **1970**, *92*, 6931. Zimmerman, H. E.; Moore, C. M. *Ibid.* **1970**, *92*, 2023. Shaffer, G. W. *J. Org. Chem.* **1972**, *37*, 3282.

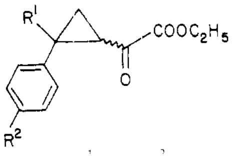
[21] The frequency assignments of the NMR spectrum were made on the basis of comparison with spectra of the closely related compounds **14a,b** and other cyclopropane derivatives not reported in the present work. See: Alonso, M. E. Ph.D. Dissertation, Indiana University, Bloomington, IN, 1974. Our assignment of cyclopropane protons on C$_{6a}$, C$_1$, and C$_{1a}$ of compound **16a** indicated in the Experimental Section are in opposition to those made by Hixson and Borovsky,[22] who assigned δ 1.18 to C$_1$ H and δ 2.25–2.50 to C$_{6a}$ H in compound **22**. Examination of molecular models suggests that the latter should be less deshielded than C$_1$ H. Thus, in our opinion the correct assignments should appear inverted.



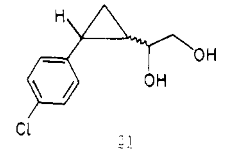
While this result entails the operation of a more selective carbenoid of EDP as compared to ethyl diazoacetate, it also suggests that EDP–olefin cyclopropane adducts do not undergo epimerization under the reaction conditions employed.[23]

That the formation of C–H insertion compounds is precluded in copper-catalyzed additions of EDP to olefins was confirmed by the absence of pyruvate ester derivative **17**.

Despite the high yields of 2,3-diphenyl-1-(ethoxycarbonyl)cyclopropane obtained from the copper-catalyzed decomposition of ethyl diazoacetates in stilbene,[24] this substrate failed to react with EDP under a variety of reaction conditions.[25,26] Presumably, conjugation with the aromatic rings imparts a decreased nucleophilicity to the double bond; thus the latter becomes unable to trap the electrophilic carbenoid species. A similar reasoning may be applied to explain the behavior of olefins containing electron-withdrawing substituents. In fact, mono- and dihaloalkenes such as 1-chlorocyclohexene,[27] β-chloro- and β-bromostyrene,[28] and β-dihalostyrenes[29] failed to interact with the EDP–copper carbenoid complex in consonance with earlier results obtained with ethyl diazoacetate.[30,31] Only α-chlorostyrene[28] yielded the unstable chlorocyclopropane keto ester **19** when reacted with EDP, albeit in low yield,[32] again in parallel with diazoacetate behavior. Not unexpectedly, nitroethylene, a potential substrate for the preparation of biologically active nitrofuran derivatives,[33] furnished intractable mixtures when exposed to EDP under copper catalysis.



19: $R^1 = Cl$, $R^2 = H$
20: $R^1 = H$, $R^2 = Cl$



21

A smooth cyclopropanation took place, however, when the distance between the electron-withdrawing group and the reactive olefin was increased by means of conjugation through an aromatic ring. Thus, *p*-chlorostyrene yielded the corresponding mixture of *cis*- and *trans*-cyclopropane keto esters **20** in 52% yield in the same 1:3 ratio as observed with styrene. The unstable adduct could be characterized as the crystalline glycol derivative (**21**) obtained by sodium borohydride reduction of **20** in ethanol at room temperature.[34]

The literature contains numerous reports of the synthetic uses of α-keto esters, cyclopropane ketones, and derivatives thereof.[2] The introduction of alkoxalylcyclopropanes generalized in the present report may prove to be of widespread use in synthesis in the future. Further advances in this connection are in progress in our laboratory.

Experimental Section

Infrared spectra were measured on a Perkin-Elmer 337 spectrophotometer. NMR spectra were obtained by using Varian A-60 and EM-390 spectrometers operating at 60 and 90 MHz, respectively, with tetramethylsilane as internal standard and deuteriochloroform as solvent unless otherwise stated. Mass spectra were obtained from a Du Pont spectrometer, Model 21-492.[35] The experimental conditions described furnish maximum yields of cyclopropane adducts. Ethyl diazopyruvate was prepared as reported earlier[10] and purified by sublimation at 70 °C (2 torr).

1-Ethoxalyl-6-*tert*-butylspiro[2.5]octane (7). A solution of 1.0 g (7 mmol) of ethyl diazopyruvate in 40 mL of dry benzene was added dropwise over a 3-h period to a mixture of 1.5 g (9.9 mmol) of 4-(*tert*-butylmethylene)cyclohexane and 5 mg of bis(copper(II) acetylacetonate) in 15 mL of dry benzene with stirring at 80 °C under a nitrogen atmosphere. The reaction progress was followed by the disappearance of $\nu = 2100\ \mathrm{cm}^{-1}$ of the $C–N_2$ group in the IR spectrum. After the addition was complete, the mixture was refluxed for an additional 30 min. The cold brown solution was filtered through a pad of basic alumina (activity III) and evaporated in vacuo. The residue was chromatographed on a short column of basic alumina (activity III). Elution with hexane and hexane–benzene (1:1) yielded 840 mg (45%) of **7** as a colorless oil: IR (neat) 1745 (s, C=O ester), 1710 (s, C=O ketone), 1255 (m, CO) cm^{-1}; NMR δ 0.85 (s, 9, 3 CH_3), 1.35 (t, 3, CH_3CH_2, $J = 7.0$ Hz), 1.70–2.05 (m, 11, methylenes and methyne), 2.60 (m, 1, cyclopropane methyne), 4.30 (q, 2, CH_3CH_2); mass spectrum, *m/e* (relative intensity) 266 (M^+, 3), 193, ($M^+ - CO_2Et$, 13), 57 (100).

Ethyl 2-Oxo-4-(4-*tert*-butyl-1-cyclohexenyl)butyrate (8). A 0.5-g sample of compound **7** was heated in a microdistillation apparatus to 190 °C for 15 min and a vacuum was applied (2.5 torr) to distill all volatile material. Pure keto ester **8** was recovered: 0.41 g (82%); NMR δ 0.85 (s, 9, 3 CH_3), 1.35 (t, 3, CH_3CH_2, $J = 7.0$ Hz), 2.28 (br t, 2, $CH_2C=$, $J = 7.0$ Hz), 2.93 (t, 2, $CH_2C=O$, $J = 7.0$ Hz), 4.27 (q, 2, CH_3CH_2, $J = 7.0$ Hz), 5.45 (m, 1, $=CH$); these assignments were confirmed by decoupling experiments; exact mass calcd for $C_{16}H_{26}O_3$ (M^+) 266.1883, found 266.1879.

1-[(Ethoxycarbonyl)hydroxymethyl]-6-*tert*-butylspiro[2.5]octane (10). A mixture of 0.5 g (1.87 mmol) of α-keto ester **7** and 70 mg (1.87 mmol) of sodium borohydride in 15 mL of ethanol was stirred for 2.5 h at -5 to 0 °C. The mixture was then poured into a cold 3% aqueous sodium hydroxide solution and extracted three times with 20-mL portions of chloroform. The organic layer was dried over magnesium sulfate, the solvents were evaporated, and the residue was chromatographed on silica gel. Elution with hexane–chloroform (4:1) furnished 425 mg (95%) of **10** as a white solid which was recrystallized from hexane: mp 70–71 °C; IR (neat) 3450 (s, OH), 1745 (s, C=O), 1210 (s, CO) cm^{-1}; NMR δ 0.85 (s, 9, 3 CH_3), 1.28 (t, 3, CH_3CH_2, $J = 7.0$ Hz), 2.73 (m, 1, OH), 3.75 (m, 2, CH_2CH), 4.28 (q, 2, CH_3CH_2, $J = 7.0$ Hz).

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[22] Hixson, S. S.; Borovsky, J. *J. Am. Chem. Soc.* **1976**, *98*, 2840.

[23] Studies to substantiate this point of view and to evaluate the apparent multiplicity of the EDP–copper carbenoid are presently in progress in our laboratory.

[24] Burger, A.; Markees, D. G.; Nes, W. R.; Yost, W. C. *J. Am. Chem. Soc.* **1949**, *71*, 3307. Hager, G. P.; Smith, C. I. *J. Am. Pharm. Assoc.* **1952**, *41*, 193. Jones, W. M. *J. Am. Chem. Soc.* **1959**, *81*, 3776. Blatchford, J. K.; Orchin, M. *J. Org. Chem.* **1964**, *29*, 839. Walbrick, J. M.; Wilson, J. W.; Jones, W. M. *J. Am. Chem. Soc.* **1968**, *90*, 2895.

[25] The extreme case of this series of substituted olefins represented by tetraphenylethylene has been shown to act not as a substrate but rather as a low-temperature catalyst for carbene generation from α-diazocarbonyl compounds.[26] In our hands, however, tetraphenylethylene failed to promote nitrogen evolution from EDP under a variety of reaction conditions.

[26] Ho, Chi-Tang; Conlin, T. T.; Gaspar, P. P. *J. Am. Chem. Soc.* **1974**, *96*, 8109.

[27] Braude, E. A.; Coles, J. A. *J. Chem. Soc.* **1950**, 2114.

[28] Emerson, W. S.; Agnew, E. P. *J. Am. Chem. Soc.* **1945**, *67*, 518.

[29] Rabinowitz, R. *J. Am. Chem. Soc.* **1962**, *84*, 1312 and references cited therein.

[30] Farkas, J.; Novák, J. J. K. *Collect. Czech. Chem. Commun.* **1960**, *25*, 1815.

[31] Other highly electrophilic carbenes have been reacted successfully with chloroalkenes, notably dichlorocarbene generated from phenyl(trihalomethyl)mercury derivatives. See, inter alia: Clark, H. C.; Willis, C. J. *J. Am. Chem. Soc.* **1960**, *82*, 1888; Seyferth, D.; Hopper, S. P. *J. Org. Chem.* **1972**, *37*, 4070; Seyferth, D.; Murphy, G. J. *J. Organomet. Chem.*, in press; Couch, E.; Landgrebe, J. A.; Castaneda, E. *J. Org. Chem.* **1975**, *40*, 1529.

[32] Isolation of this compound could not be accomplished since it decomposed rapidly on exposure to air, alumina, silica gel, and Florisil and upon distillation.

[33] Ogawa, H.; Saikachi, H. *Synthesis* **1972**, 138. Jurasek, A.; Kovac, J. *Collect. Czech. Chem. Commun.* **1973**, *38*, 1705.

[34] Although the reduction of aromatic esters with sodium borohydride in refluxing ethanol is well-known, the smooth transformation of an α-keto ester to a 1,2-diol with this reagent at room temperature remains to be exploited synthetically.

[35] We thank Ms. Carmen Cabello for making the mass spectral measurements.

Chart I

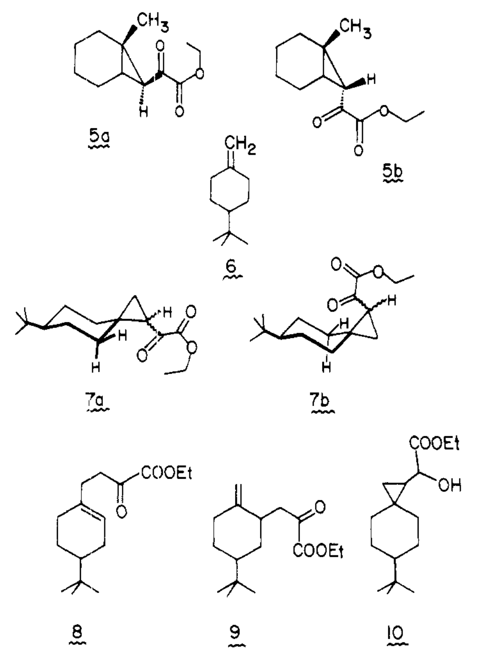
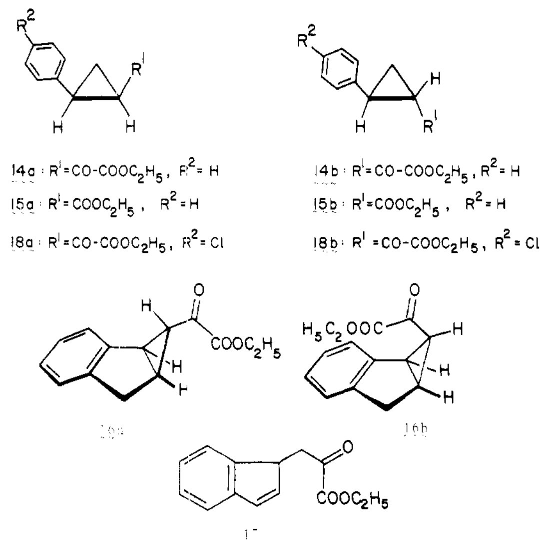


Chart II



14a: R^1=CO-COOC$_2$H$_5$, R^2= H

15a: R^1=COOC$_2$H$_5$, R^2=H

18a: R^1=CO-COOC$_2$H$_5$, R^2= Cl

14b: R^1=CO-COOC$_2$H$_5$, R^2= H

15b: R^1=COOC$_2$H$_5$, R^2= H

18b: R^1 =CO-COOC$_2$H$_5$, R^2= Cl

Anal. Calcd for $C_{16}H_{28}O_3$: C, 71.59; H, 10.52; O, 17.89. Found: C, 71.70; H, 10.38; O, 17.86.

***cis*- and *trans*-1-Ethoxalyl-2-phenylcyclopropane (14a,b).** A solution of 1.0 g (7 mmol) of ethyl diazopyruvate in 30 mL of dry benzene was added dropwise over a 4-h period to a stirred suspension of 4 mg of bis(copper(II) acetylacetonate) in 15 mL of benzene and 1.5 g (14 mmol) of vinylbenzene at reflux temperature under a nitrogen atmosphere. Heating was continued for 1 h after addition was complete. The catalyst was then removed by filtration of the cold reaction mixture through a pad of neutral alumina (activity III), and the solvent and excess vinyl benzene were evaporated in vacuo. The brown residue was distilled at reduced pressure to yield a mixture of **14a** and **14b**: 750 mg (49%); bp 130–135 °C (bath temperature; 0.5 torr); IR (neat) 1730 (s, C=O ester), 1710 (s, C=O ketone), 1275 (s, CO), 710 (s, aromatic CC) cm^{-1}; NMR δ 1.27 (t, 3, CH_3CH_2 of **14a**, J = 7.0 Hz), 1.34 (t, 3, CH_3CH_2 of **14b**, J = 7.0 Hz), 1.50–2.10 (m, 2, cyclopropane CH_2), 2.50–2.75 (m, 1, CHC=O), 2.80–3.15 (m, 1, PhCH), 4.20 (q, 2, CH_3CH_2 of **14a**, J = 7.0 Hz), 4.32 (q, 2, CH_3CH_2 of **14b**, J = 7.0 Hz), 7.18 (m, 5, aromatic CH); mass spectrum, m/e (relative intensity) 218 (M$^+$, 26), 145 (M$^+$ – COOEt, 100).

Anal. Calcd for $C_{13}H_{14}O_3$: C, 71.54; H, 6.46; O, 21.99. Found: C, 71.41; H, 6.49; O, 22.10.

***cis*- and *trans*-1-(Ethoxycarbonyl)-2-phenylcyclopropanes (15a,b).** Ethyl diazoacetate (1.0 g, 8.7 mmol) in 15 mL of dry benzene was added dropwise over a 2-h period to vinylbenzene (1.5 g, 10 mmol) in 15 mL of benzene containing 3 mg of copper(II) acetylacetonate at reflux temperature under a nitrogen atmosphere. Heating was continued for an additional 40 min, and the cold reaction mixture was filtered through a pad of neutral alumina (activity III). The solvent and unreacted vinyl benzene were removed in a rotary evaporator, and the residue was distilled at reduced pressure. The distillate was then treated with ozone in ethyl acetate, followed by reductive workup with acetic acid and zinc powder. Evaporation of the solvent after the usual procedure and vacuum distillation gave cyclopropanes **15a** and **15b** (880 mg, 53%) in a 2:1 ratio:[36] bp 95–97 °C (bath temperature; 0.5 torr); NMR δ 0.95 (t, 3, CH_3CH_2 of **15a**), 1.27 (t, 3, CH_3CH_2 of **15b**), 1.50–2.20 (m, 3, CH_2CHC=O), 2.30–2.80 (m, 1, PhCH), 3.92 (q, 2, CH_3CH_2 of **15a**), 4.15 (q, 2, CH_3CH_2 of **15b**), 7.23 (m, 5, aromatic CH).

***exo*-6-Ethoxalyl-2,3-benzobicyclo[3.1.0]hexane (16a).** A solution of ethyl diazopyruvate (1.5 g, 11 mmol) in 20 mL of dry benzene was added as described above to a mixture of freshly distilled indene (3.0 g, 26 mmol), bis(copper acetylacetonate) (5 mg), and benzene (15 mL) at reflux temperature under a nitrogen atmosphere. After the usual workup, the mixture was chromatographed on a short column of neutral alumina (activity III). Elution with benzene yielded a light brown oil identified as the cyclopropane **16a** (700 mg, 19%). Column or thick-layer chromatography on a variety of stationary phases led to extensive decomposition: IR (neat) 1730 (s, C=O ester), 1710 (s, C=O ketone), 1600 (w, aromatic CC), 710 (s) cm^{-1}; NMR δ 1.28 (m, 1, $CHCH_2$ of cyclopropane), 1.33 (t, 3, CH_3, J = 7.0 Hz), 2.33 (dd, 1, CHC=O, J_1 = J_2 = 2.0 Hz), 2.71 (m, 1, CHC= of cyclopropane), 3.21 (m, 2, CH_2), 4.30 (q, 2, CH_3CH_2, J = 7.0 Hz), 7.18 (m, 4, aromatic CH); mass spectrum, m/e (relative intensity) 230 (M$^+$, 53), 157 (M$^+$ – CO_2Et, 94), 129 (M$^+$ – $COCO_2$Et, 100); exact mass calcd for $C_{14}H_{14}O_3$ (M$^+$) 230.0943, found 230.0941.

***cis*- and *trans*-1-Ethoxalyl-2-(*p*-chlorophenyl)cyclopropanes (18a,b) and 1-(1,2-Dihydroxyethyl)-2-(*p*-chlorophenyl)cyclopropane (21).** Ethyl diazopyruvate (1.0 g, 7 mmol) in 20 mL of dry benzene was added dropwise as described above to a solution of *p*-chlorostyrene (1.5 g, 10.5 mmol) in benzene (5 mL) containing 3 mg of bis(copper acetylacetonate) at 80 °C under a nitrogen atmosphere. After the addition was complete, heating was continued for an additional 2-h period. The cold reaction mixture was filtered through a pad of Florisil, and the solvents were evaporated. The remaining oil, purified by distillation, yielded pure cyclopropyl adduct **18**: 925 mg (52%); bp 160 °C (bath temperature; 0.05 torr); IR 1745 (s, C=O ester), 1710 (s, C=O ketone) cm^{-1}; NMR δ 1.30 (t, 3, CH_3 of **18a**, J = 7.0 Hz), 1.37 (t, 3, CH_3 of **18b**, J = 7.0 Hz), 1.55–2.10 (m, 2, CH_2 of cyclopropane), 2.50–3.20 (m, 2, 2 CH of cyclopropane), 4.23 (q, 2, CH_3CH_2 of **18a**, J = 7.0 Hz), 4.35 (q, 2, CH_3CH_2 of **18b**, J = 7.0 Hz), 7.00–7.40 (m, 4, aromatic CH).

The mixture of **18a** and **18b** (500 mg, 1.98 mmol) was stirred with sodium borohydride (74 mg, 1.98 mmol) in ethanol (10 mL) at room temperature for 4 h. After the usual workup the crude solid material was recrystallized several times from hexane to a constant melting point. This compound was identified as glycol **21**: 322 mg (81%); mp 78–79.5 °C; IR (KBr) 3400 (s, OH) cm^{-1}; NMR δ 0.70–1.35 (m, 3, CH_2 and CH of cyclopropane), 2.10–2.90 (m, 4, 2 OH, CHO and benzylic CH), 3.55 (m, 2, CH_2O), 7.28 (m, 4, aromatic CH).

Anal. Calcd for $C_{11}H_{13}ClO_2$: C, 62.09; H, 6.16; Cl, 16.70; O, 15.05. Found: C, 61.96; H, 6.02; Cl, 16.85; O, 14.89.

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Registry No. **1**, 14214-10-9; **6**, 13294-73-0; **7**, 75399-71-2; **8**, 75399-72-3; **10**, 75399-73-4; **11**, 100-42-5; **12**, 95-13-6; **14a**, 55674-19-6; **14b**, 55674-18-5; **15a**, 946-38-3; **15b**, 946-39-4; **16a**, 75399-74-5; **18a**, 75399-75-6; **18b**, 75399-76-7; **21**, 75399-77-8; ethyl diazoacetate, 623-73-4; *p*-chlorostyrene, 1073-67-2.

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[36] Shono, T.; Nishiguchi, I.; Oda, R. *J. Org. Chem.* **1970**, *35*, 42. Fraisse-Jullien, R.; Fréjaville, C. *Bull. Soc. Chim. Fr.* **1970**, 219.