are the result of a double bond shift which is fast on the time scale of the nmr and X-ray experiment. Providing the barrier for this process is not appreciably higher than kT, both structural models—a square, fully delocalized, and a rectangular, rapidly interconverting species—would yield delusively similar electron density maps. In order to choose between these alternatives, accurate temperature factors obtained at sufficiently low temperature would be mandatory.

We conclude that donor–acceptor substituted cyclobutadienes such as **1** owe their remarkable stability not so much to the intervention of zwitterionic structures but to strong second-order bond fixation[10] in the dynamic sense, an inference which is fully in accord with the analysis given in ref 5. There are indications that the bond distortion in **1** is comparable to, or even greater, than that encountered in biphenylene whose coannular bonds have a length of 1.51 Å.[11] The 584-Å photoelectron spectrum of this molecule[12] shows peaks at 7.61, 8.90, 9.68, and 10.08 eV which correlate with the benzene e_{1g} band at 9.24 eV. Using a crude first-order perturbation argument, the coannular π resonance integral is estimated from these data to be -1.2 eV, *i.e.*, even larger than that deduced for **1** from the difference in the first IP's of **1** and **2**.

Acknowledgment. One of the authors (W. S.) wishes to thank Mr. H. J. Lempka and Perkin-Elmer Ltd. (Beaconsfield, U. K.) for their hospitality and the opportunity to obtain the 584-Å photoelectron spectra.

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[10] For terminology, see G. Binsch and E. Heilbronner in "Structural Chemistry and Molecular Biology," A. Rich and N. Davidson, Ed., W. H. Freeman, San Francisco, Calif., 1968, p 815.

[11] J. K. Fawcett and J. Trotter, *Acta Crystallogr.*, 20, 87 (1966).

[12] Photoelectron spectra of nonbenzenoid hydrocarbons, including biphenylene, have been discussed by W. Schmidt, Conference on The Photoelectron Spectroscopy of Molecules, The Chemical Society, Brighton, Sept 1972.

R. Gompper, F. Holsboer, W. Schmidt,* G. Seybold
Institute für Organische und Anorganische
Chemie der Universität München
8 Munich-2, Germany

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Properties of the [4]Annulene System. Induced Paramagnetic Ring Current

Sir:

Recent remarkable achievements in annulene[1] chemistry are, undoubtedly, the spectral characterization of [4]annulene (cyclobutadiene) (**1**) detained in a matrix at low temperatures[2–6] and the isolation of its derivatives in a pure state.[7] We have extensively examined (or reexamined) several approaches toward the construction of this reactive system and have unexpectedly found that a classical ring-expansion method *via* Δ^2-cyclopropenylmethylene does indeed proceed remarkably well with highly substituted precursors. We wish to record herein physical and chemical properties of methyl tri-*tert*-butyl[4]annulenecarboxylate (**2**) and tri-*tert*-butyl[4]annulene (**3**), in comparison with those of **1**. Compound **3** is of particular significance in that it represents the first demonstration of the chemical shift of a proton (protons) directly attached to the [4]-annulene ring, and thus provides important information concerning the induced ring current of the cyclic 4π-electron system.[8]

Reaction of methyl lithiodiazoacetate[9] with tri-*tert*-butylcyclopropenium fluoroborate[10] in a 1:1 mixture of diethyl ether and tetrahydrofuran at $-110°$ provided a yellow crystalline adduct (**4**) in 88% yield. Photolysis of **4** in oxygen-free pentane at $-78°$ proceeded smoothly, and when a *ca.* 1 *M* solution was irradiated, there formed, toward the cessation of nitrogen evolution, a large amount of crystalline precipitate, which was recrystallized from pentane ($-80°$) to afford light brown needles (**2**).[11] The yield is estimated to be more than 90% and **2** readily sublimes at 50° (0.01 mm) despite its molecular weight of 278.4. Spectral data of **2** as shown in Table I are clearly consistent with the formulation of the [4]annulene system for this compound and the nmr spectra show the presence of four olefinic carbons and C_{2v} (but not C_{3v}) symmetry in **2**. Chemical reactions of **2** further support the above structural assignment. Thus, addition of 1.2 equiv of maleic anhydride to a pentane solution of **2** at $-30°$ led to the quantitative formation of an adduct, which is formulated as **5**, but not as a dihydrobenzvalene derivative.[12] Although the absorptions of the two olefinic carbons appear in a somewhat lower region than normally expected,[13] the (chemical shift) values compare very well with those of tri-*tert*-butylcyclobutene (**6**) (see Table I). As expected,[14] the pmr (and cmr) spectra of

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[1] This term is defined by F. Sondheimer and R. Wolovsky, *J. Amer. Chem. Soc.*, **84**, 260 (1962).

[2] C. Y. Lin and A. Krantz, *J. Chem. Soc., Chem. Commun.*, 1111 (1972); A. Krantz, C. Y. Lin, and M. D. Newton, *J. Amer. Chem. Soc.*, **95**, 2744 (1973).

[3] S. Masamune, M. Suda, H. Ona, and L. M. Leichter, *J. Chem. Soc., Chem. Commun.*, 1268 (1972).

[4] G. Maier and B. Hoppe, *Tetrahedron Lett.*, 861 (1973). Alkyl substituted **1** was generated in a matrix earlier: G. Maier and M. Schneider, *Angew. Chem., Int. Ed. Engl.*, 10, 809 (1971); G. Maier, G Fritschi, and B. Hoppe, *ibid.*, **9**, 529 (1970).

[5] O. L. Chapman, C. L. McIntosh, and J. Pacansky, *J. Amer. Chem. Soc.*, **95**, 614 (1973); O. L. Chapman, D. De La Cruz, R. Roth, and J. Pacansky, *ibid.*, **95**, 1337 (1973).

[6] The lifetime of **1** in the gas phase was determined: (a) W. J. R. Tyerman, M. Kato, P. Kebarle, S. Masamune, O. P. Strausz, and H. E. Gunning, *Chem. Commun.*, 497 (1967); (b) E. Hedaya, R. D. Miller, D. W. McNeil, P. F. D'Angelo, and P. Schissel, *J. Amer. Chem. Soc.*, **91**, 1875 (1969).

[7] (a) H. Kimling and A. Krebs, *Angew. Chem., Int. Ed. Engl.*, 11, 932 (1972); (b) R. Gompper and G. Seybold, *ibid.*, 7, 824 (1968).

[8] Because of the intrinsic nature, cmr absorptions are relatively insensitive to ring current effects, even if carbons are uniquely positioned in the system to detect them. Obviously, signals due to the annular carbons provide virtually no information about the effects. See A. V. Kemp-Jones, A. J. Jones, M. Sakai, C. P. Beeman, and S. Masamune, *Can. J. Chem.*, **51**, 767 (1973); H. Günther, H. Schmickler, H. Konigshoten, K. Recker, and E. Vogel, *Angew. Chem., Int. Ed. Engl.*, **12**, 243 (1973). V. Boekelheide, private communication, May 3, 1973.

[9] U. Schöllkopf and H. Frasnelli, *Angew. Chem., Int. Ed. Engl.*, **9**, 301 (1970); Recent review: M. Regitz, *Synthesis*, 351 (1972).

[10] J. Ciabattoni and E. C. Nathan, III, *J. Amer. Chem. Soc.*, **91**, 4766 (1969); J. Ciabattoni, E. C. Nathan, III, A. E. Feiring, and P. J. Kocienski, *Org. Syn.*, in press.

[11] Compounds **2** and **3**, as obvious from the test, are extremely reactive toward oxygen, and all operation involving these species was performed either in a vacuum system or drybox, using argon as an inert gas.

[12] For the chemical behavior of 1,3-di-*tert*-butyl[4]annulene, see P. Reeves, J. Henery, and R. Pettit, *J. Amer. Chem. Soc.*, **91**, 5888 (1969).

[13] G. C. Levy and G. L. Nelson, "Carbon-13 Nuclear Magnetic Resonance for Organic Chemists," Wiley-Interscience, New York, N. Y., 1972, Chapter 3; J. B. Stothers, "Carbon-13 NMR Spectroscopy," Academic Press, New York, N. Y., 1972, Chapter 3.

[14] Restricted rotation along the axis of C(sp^3)–C(sp^3) single bond was first observed by J. P. N. Brewer, H. Heaney, and B. A. Marples, *Chem. Commun.*, 27 (1967), and reviewed by H. Kessler, *Angew. Chem., Int. Ed. Engl.*, **9**, 219 (1970). The isolation of rotational isomers was recently achieved by M. Ōki and G. Yamamoto, *Chemistry Lett.*, 45 (1972). Also see M. Ōki and O. Yamamoto, *Tetrahedron Lett.*, 727 (1973), and references quoted therein.

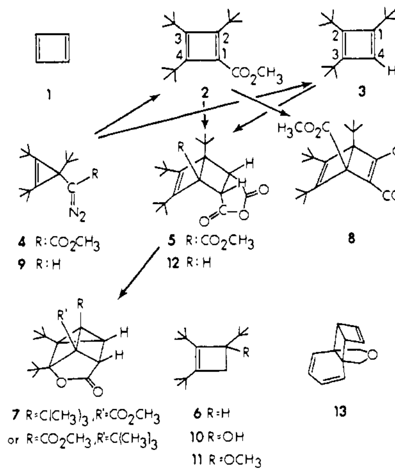

Figure 1.

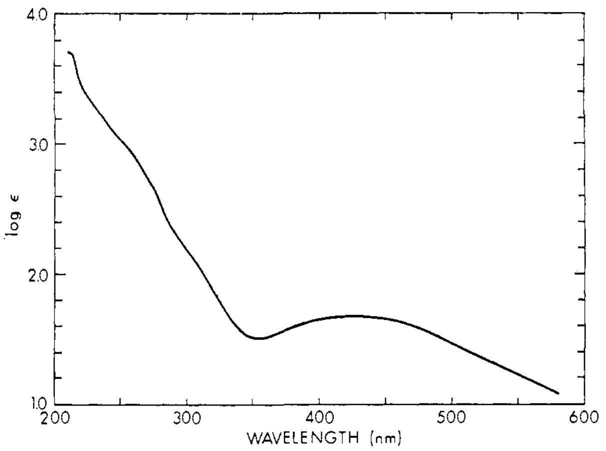

Figure 2. The uv spectrum of **2** in pentane.

Table I. Spectral Properties of Compounds

2	Mp 70.0°; pmr[a] (methylcyclohexane-d_{14}) δ 1.13 (s, 18),[b] 1.19 (s, 9), 3.45 (s, 3); cmr[a] (methylcyclohexane-d_{14}) δ 29.73 (CH_3C), 31.6, 31.8 (quart. *C* of *t*-Bu), 50.4 (OCH_3), 147.0 (*C*-3), 154.5 (*C*-1 overlaps with *C*-2, *C*-4), 165.7 ($C{=}O$)
3	Pmr (tetrahydrofuran-d_8) δ 1.05 (s, 9), 1.22 (s, 18), 5.38 (s, 1)
4	Mp 46.0–47.5°; ir[c] $\bar{\nu}_{max}$ 2080 cm^{-1}, 1698; pmr δ 0.93 (s, 9), 1.26 (s, 18), 3.72 (s, 3)
5	Mp 213–215°; uv (ether) 215 nm (ϵ 3240), 225 (1665), 235 (680); ir (Nujol) $\bar{\nu}_{max}$ 1845 cm^{-1}, 1796, 1715, 1273, 1250, 1220; pmr[d] (HMDS, acetone-d_6, 70°) δ 1.10 (s, 9), 1.20 (s, 9), 1.30 (s, 9), 3.64 (s, 3), 3.65, 4.23 (AB, J = 8.3 Hz); cmr (dioxane-d_8, 70°) δ 27.8, 31.0, 32.8 (CH_3C), 33.7, 34.4, 34.9 (quart. *C* of *t*-Bu), 40.9, 41.4 (tert. *C*), 57.2, 68.6 (other quart. *C*) 152.8, 157.4 (olefinic *C*), 171.7, 172.5, 172.7 ($C{=}O$)
6	Uv (ether) 215 nm (ϵ 2640), 225 (294), 235 (61); cmr δ 28.3, 31.0 (CH_3C), 29.4 (CH_2), 32.6, 32.7 (quart. *C*), 49.8 (tert. *C*), 148.1, 148.3 (olefinic *C*)
7	Mp >200°; ir $\bar{\nu}_{max}$ 1785 cm^{-1}, 1735, 1300, 1200, 1008; pmr[d] (HMDS, chlorobenzene, 150°) δ 0.96 (s, 9), 1.11 (s, 9), 1.22 (s, 9), 3.45 (s, 3), 3.12, 3.53 (AB, J = 11.2 Hz)
8	Mp 99.5–100.5°; uv (ether) λ sh 238 nm (ϵ 2800); ir $\bar{\nu}_{max}$ 1740 cm^{-1}, 1635, 1280, 1270; pmr δ 1.16 (s, 9), 1.23 (s, 9), 1.26 (s, 9), 3.36 (s, 3), 3.79 (s, 6); cmr δ 28.6, 30.6, 31.5 (CH_3C), 33.8, 34.4, 34.6 (quart. *C* of *t*-Bu), 51.1, 51.8 (OCH_3), 61.2, 73.7 (other quart. *C*), 144.4, 152.7, 153.1, 157.9 (olefinic *C*), 162.3, 164.8, 171.8 ($C{=}O$)
9	Ir (CCl_4) $\bar{\nu}_{max}$ 2060 cm^{-1}; pmr (tetrahydrofuran-d_8) δ 0.98 (s, 9), 1.17 (s, 18), 4.07 (s, 1)
10	Mp 43–44°; ir (CCl_4) $\bar{\nu}_{max}$ 3610 cm^{-1}, 3550–3400; pmr δ 1.08 (s, 9), 1.17 (s, 9), 1.25 (s, 9), 1.57 (s, OH), 1.90 and 2.57 (AB, J = 12.5 Hz)
11	Pmr δ 0.99 (s, 9), 1.15 (s, 9), 1.18 (s, 9), 2.03 and 2.31 (AB, J = 13 Hz) 3.18 (s, 3)
12	Mp 123–124.5°; ir (CCl_4) $\bar{\nu}_{max}$ 1847 cm^{-1}, 1777; pmr δ 0.96 (s, 9), 1.12 (s, 9), 1.16 (s, 9), 3.1–3.5 (ABC); cmr δ 27.0, 36.6, 32.1 (H_3CC) 32.8, 33.2, 33.5 (quart. *C* of *t*-Bu) 38.3, 40.6, 41.5 (tert. *C*), 61.9 (other quart. *C*), 153.7, 154.8 (olefinic *C*), 172.5, 172.7 ($C{=}O$)

[a] Nmr spectra use TMS as reference and $CDCl_3$ as solvent, unless otherwise specified. [b] The number following multiplicity in pmr indicates the relative intensity of signal. [c] Ir spectra use $CHCl_3$ as solvent, unless otherwise specified. [d] Spectra are temperature dependent.

5 are temperature dependent; rotation of the carbomethoxy group is completely frozen at −60° to result in a *ca.* 3:1 mixture of rotational isomers, and the *tert*-butyl groups exhibit a complex pattern of absorptions, showing that rotation of the latter groups is also, at least partially, frozen. The similarity of the uv spectra of **5** and **6** and the nmr spectra of **5** suggest that the carbomethoxy group is located at a bridgehead position as indicated in Figure 1. Electrochemical decarboxylation of the dicarboxylic acid derived from **5** afforded, in 48% yield, a lactone (**7**),[15] which indicates the endo configuration of the acid anhydride group of **5**. Condensation of **2** with dimethyl acetylenedicarboxylate proceeded in a manner similar to that with maleic anhydride to give a quantitative yield of **8**. Compound **2** is extremely reactive toward oxygen and decomposed instantaneously in contact with air, giving three or more oxygen-containing compounds.[16] Compound **2** is characterized by a weak, broad absorption around 425 nm (see Figure 2), and its bathochromic shift caused by increasing substitution [**1**, λ_{max} 300–305 nm (ϵ ~100)][3] is in line with Maier's observations.[4] The three *tert*-butyl groups, undoubtedly, force the carbomethoxy group out of conjugation and may possibly distort the coplanarity of the ring system. The X-ray analysis will obviously reveal the extent of this distortion.[17]

The diazo compound **9**, a precursor of tri-*tert*-butyl[4]annulene (**3**) was prepared in a conventional manner. Condensation of tri-*tert*-butylcyclopropenium fluoroborate with sodium cyanide afforded 3-cyanotri-*tert*-butylcyclopropene ($\bar{\nu}_{max}$ 2200 cm^{-1}), which was reduced to the corresponding amine with lithium aluminum hydride. Acylation with ethyl chloroformate, then nitrosation with N_2O_4, and finally treatment with sodium methoxide in aqueous methanol at −30° converted the amine to **9** in addition to variable amounts of hydroxy- and methoxytri-*tert*-butylcyclobutene (**10** and **11**). Compound **9** either in methylcyclohexane-d_{14} or tetrahydrofuran-d_8 at −70° was irradiated in a manner similar to that for **4**. Monitoring the progress of photolysis by nmr spectroscopy revealed that a new signal at δ 5.38 (1 H) (tetrahydrofuran-d_8) in addition to two singlets at 1.22 (18 H) and 1.05 (9 H) appeared at the expense of those ascribed to **9**. These new signals and the bright yellow color of the photolyzed solution disappeared almost instantly either on exposure to air

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(15) Less highly substituted compounds of the same skeleton behaved in exactly the same manner, S. Masamune and M. Kato, unpublished work.

(16) V. R. Sandel and H. H. Freedman, *J. Amer. Chem. Soc.*, **90**, 2059 (1968).

(17) The substitution pattern of **2** and **3** is such that the CC bonds of 1–2 and 1–4 in **2** and 1–2 and 2–3 in **3** are structurally equivalent, unlike the [4]annulene derivative prepared by Kimling and Krebs (ref 7).

or warming to room temperature. Although the reactivity of **3**, compared to **2**, precludes further purification at present, the pmr signals are evidently due to **3** and the maleic anhydride adduct (**12**) of **3** has been well characterized (see Table I). Using the C-2 proton (δ 6.42) of cyclopentadiene as a reference, the difference, $\Delta\delta = 1.04 = 6.42 - 5.38$, may be taken as the paramagnetic contribution by the induced ring current in **3**. If one neglects the perturbation of the electronic structure of **1** caused by the three *tert*-butyl substituents of **3** and then adopts (i) the equation (1)[18] to calculate the induced ring current in an [M]annulene, advanced by Pople and Untch,[18] (ii) the rectangular geometry predicted by Dewar,[19] and (iii) Coulson and Golebiewski's equation for the estimate of λ,[20] one obtains a paramagnetic contribution of 1.18 ppm for [4]annulene. The agreement between the experimental and calculated values is excellent, but subject, of course, to the arbitrary choice of the reference compound.[21]

We conclude this note with a remark concerning the ground-state multiplicity of **1**. In repeated experiments, the esr spectra of **1** generated in a manner previously reported[3,22] showed no indication of signals that can be attributed to the triplet ground state of **1**, as in the case of tetramethyl[4]annulene.[4] These results, the observation of sharp nmr signals of **2** and **3** and the above adoptation of Dewar's theoretical treatment, all are, at least superficially, incompatible with the conclusion about the geometry of **1** drawn from its infrared spectra[2,5] and implications of their theoretical treatment.[2] These subtle, important points remain to be clarified.[23]

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(18) J. A. Pople and K. G. Untch, *J. Amer. Chem. Soc.*, **88**, 4811 (1966). The equation (1) is

$$I = -(\pi^2e^2\beta_0/h^2c)S(32\lambda^{1/2}M^2) \times \sum_j^{\text{occ}} [1 + 2\lambda \cos(4\pi j/M) + \lambda^2]^{-3/2}[\lambda + (1 + \lambda^2) \times \cos(4\pi j/M) + \lambda \cos^2(4\pi j/M)]$$

where I, S, λ, and β_0 are induced ring current per unit magnetic field, area of the ring, the degree of band alternation, and β value for benzene, respectively. $\Delta\delta = Ix$ spatial factor (Biot-Savart law).

(19) M. J. S. Dewar, M. C. Kohn, and N. Trinajstic, *J. Amer. Chem. Soc.*, **93**, 3437 (1971).

(20) C. A. Coulson, and A. Golebiewski, *Proc. Phy. Soc., London*, **78**, 1310 (1961).

(21) A referee has suggested that cyclobutene (C-1 H, δ 5.97) would be a better reference. We have chosen cyclopentadiene as a cyclic diene closest in structure to [4]annulene without a significant ring current, if any. In either case the calculated value is consistent with experiment.

(22) The possible detention of **1** in methyltetrahydrofuran at 77°K is owing to the rigidity of its matrix compared to that of an inert gas. *Cf.* ref 2 and 5. Our precursor (**13**) of **1** is now relatively readily available from the 2:1 adduct of [4]annuleneiron tricarbonyl and acetylenedicarboxylate, as found by H. Prinzbach, *et al.*, private communication, June 13, 1973.

(23) We are grateful to Mr. K. Morio of this laboratory for the calculation of $\Delta\delta$ and to the National Research Council of Canada for financial support.

S. Masamune,* Nobuo Nakamura
M. Suda, H. Ona
Department of Chemistry, University of Alberta
Edmonton, Alberta, Canada

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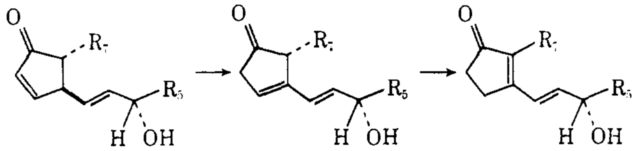
A Simple Synthesis of 8-Methylprostaglandin C_2

Sir:

One pathway for deactivation of prostaglandin A_2 (PGA_2) in mammalian blood is the conversion *via* PGC_2[1] to PGB_2. In view of this possibility and also the recently discovered biological potency of PGC_2,[1] we have undertaken the development of a synthesis of 8-MePGC_2, a substance which is structurally protected against transformation to the PGB_2 series. An especially simple synthetic route to 8-MePGC_2 (**9**) is reported here.



PGA PGC PGB

2-Methylcyclopentane-1,3-dione, a common and readily available intermediate for steroid total synthesis,[2] was converted by reaction with thallous ethoxide (1 equiv) in tetrahydrofuran (THF) into the colorless thallium salt (recrystallized from ethanol), which upon heating with methyl 7-iodo-5-heptynoate[3] (1 equiv) in a few volumes of benzene at 62–64° for 5–6 days afforded the C-alkylation product **1**[4] in 87% yield as a colorless oil.[5] Reduction of **1** using Lindlar's catalyst-hydrogen afforded quantitatively the *cis* olefin **2** (colorless oil). Reaction of **2** with an ethereal solution of the lithium reagent **3**,[6] prepared from (*S*)-3-*tert*-butyldimethylsilyloxy-*trans*-1-octenyl iodide in ether and 2 equiv of *tert*-butyllithium (in hexane),[6] afforded the desired tertiary alcohol, **4** (mixture of stereoisomers), in addition to some unchanged **2**. Treatment of the mixture with thionyl chloride (3 equiv) and pyridine (7 equiv) in methylene chloride at −30 to −35° for 12 hr, followed by chromatography to separate **2** from the dehydration product, gave the two diastereomeric 8-MePGC_2 derivatives **5** and **6** (30% overall yield from **2**,[7] $\text{uv}_{\max}$

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(1) (a) R. L. Jones, *J. Lipid Res.*, **13**, 511 (1972); (b) R. L. Jones and S. Cammock, *Advan. Biol. Sci.*, **9**, 61 (1973).

(2) We are indebted to Dr. Horst Witzel of Schering AG, Berlin, and Dr. Herchel Smith, Wyeth Laboratories, Philadelphia, Pa., for generous gifts of this intermediate which is also commercially available.

(3) This iodide was prepared by the following sequence. Propargyl tetrahydropyranyl ether → lithium derivative (1 equiv *n*-BuLi in THF) → 6-chloro-2-octyn-1-ol tetrahydropyranyl ether (1-chloro-3-bromopropane in THF, 20 hr at 70–75°) (80% yield) [see A. I. Rachlin, N. Wasyliw, and M. W. Goldberg, *J. Org. Chem.*, **26**, 2688 (1961)] → 6-cyano-2-octyn-1-ol tetrahydropyranyl ether (sodium cyanide in dimethyl sulfoxide at 40–45° for 48 hr and 55° for 3 hr) (95% yield) → 7-tetrahydropyranyloxy-5-heptynoic acid (10% sodium hydroxide in aqueous methanol at reflux for 16 hr) (95% yield) → methyl 7-tetrahydropyranyloxy-5-heptynoate (CH_2N_2 in ether) (97% yield) → methyl 7-hydroxy-5-heptynoate (Amberlite IR 120, acid form, methanol 3 hr at 25°) (97% yield) → methyl 7-bromo-5-heptynoate (triphenylphosphite–bromine complex–pyridine in THF at 0° for 1 hr and 20° for 3 hr) (90% yield) [see D. K. Black, S. R. Landor, A. N. Patel, and P. F. Whiter, *Tetrahderon Lett.*, 483 (1963)] → methyl 7-iodo-5-heptynoate (excess sodium iodide in acetone at 25° for 20 hr) (99% yield). A similar process has been used by Bagli, *et al.*, for the preparation of this iodo ester [personal communication from J. F. Bagli and also J. F. Bagli and T. Bogri, *Tetrahedron Lett.*, 3815 (1972)].

(4) The structures assigned to the substances reported herein are supported by infrared and proton magnetic resonance spectra and molecular formula determination by high-resolution mass spectra using an AEI MS-9 instrument. Samples employed for spectral characterization were homogeneous by chromatographic analysis (tlc or high-pressure liquid chromatography) using several solvent systems.

(5) For the use of thallium salts in the C-alkylation of β-dicarbonyl compounds, see E. C. Taylor, G. H. Hawks, III, and A. McKillop, *J. Amer. Chem. Soc.*, **90**, 2421 (1968).

(6) (a) E. J. Corey and D. J. Beames, *J. Amer. Chem. Soc.*, **94**, 7210 (1972); (b) E. J. Corey and J. Mann, *ibid.*, **95**, 6832 (1973).

(7) The mixture of diastereomeric ester silyl ethers **5** and **6** could not be separated chromatographically and, for example, showed only a single spot of R_f 0.73 after tlc on silica gel using methyl chloride–ethyl acetate (15:1) for development.