realized in the reaction of tri-*n*-butylborane[5] and tri-*n*-hexylborane with *n*-butyl azide. However, as the steric effects are increased, either in the organoborane or in the azide, the reactions become more sluggish and the yields drop off. We are presently searching for a solution to this limitation.

The following procedure for the preparation of cyclopentylethylamine is representative. A dry 50-ml flask, equipped with a septum inlet, reflux condenser, and magnetic stirrer, was flushed with nitrogen. The flask was charged with 10 ml of xylene and 0.98 g, 1.42 ml (10 mmol), of triethylborane. The solution was then heated to reflux and attached to a gas buret. Then 1.11 g (10 mmol) of cyclopentyl azide[6,7] was added. After completion of the evolution of nitrogen, the solution was cooled, 30 ml of diethyl ether was added, and the amine was extracted with 6 *M* hydrochloric acid (two 20-ml portions). The aqueous phase was washed with ether to remove residual borinic acid. The solution was made strongly alkaline with potassium hydroxide and the amine was extracted with ether. Analysis by glpc (10% SE-30 column) revealed a 77% yield of cyclopentylethylamine of high purity.

Primary amines may be synthesized from the reactions of organoboranes with chloramine[8] or hydroxylamine-*O*-sulfonic acid.[8,9] The reaction of dimethylchloramine with organoboranes can evidently be controlled to provide a possible route to the corresponding tertiary amines.[10] The present development opens up a promising new route to the generally more difficultly synthesized secondary amines. We are actively exploring the full potentialities of this new route.

(5) The *n*-butylborane used contained 3% of *sec*-butyl groups. However, the product contained only a trace of *sec*-butyl-*n*-butylamine.
(6) Prepared from cyclopentyl bromide and sodium azide by the method of J. H. Boyer and J. Hamer, *J. Amer. Chem. Soc.*, 77, 951 (1955). The other alkyl azides were prepared similarly.
(7) Phenyl azide was prepared by the method of R. O. Lindsay and C. F. H. Allen, "Organic Syntheses," Collect. Vol. III, Wiley, New York, N. Y., 1955, p 710.
(8) H. C. Brown, W. R. Heydkamp, E. Breuer, and W. S. Murphy, *J. Amer. Chem. Soc.*, 86, 3568 (1964).
(9) M. W. Rathke, N. Inoue, K. R. Varma, and H. C. Brown, *ibid.*, 88, 2870 (1966).
(10) A. G. Davies, S. C. W. Hook, and B. P. Roberts, *J. Organometal. Chem.*, 23, C11 (1970).
(11) National Science Foundation Predoctoral Fellow.

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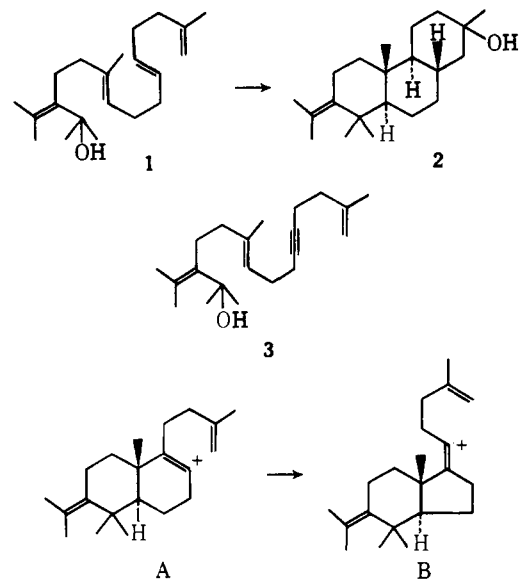
Acetylenic Bond Participation in Biogenetic-Like Olefinic Cyclizations. I. Formation of Five-Membered Rings in Model Systems

Sir:

Since acetylenic bonds can assist the solvolysis of sulfonate esters with concomitant ring formation,[1] we were intrigued by the possibility that these bonds might also participate in polyolefinic cyclizations. The present preliminary communication describes basic studies probing this question which has now been answered in the affirmative.

(1) See P. E. Peterson and R. J. Kamat, *J. Amer. Chem. Soc.*, 91, 4521 (1969), and references cited therein.

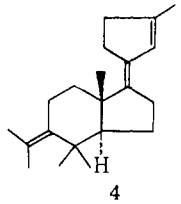


Since the tetraenol **1** has been shown[2] to undergo facile acid-catalyzed cyclization to give good yields of tricyclic material **2** having the rings fused exclusively in the "natural" trans,anti,trans configuration, we elected first to examine the cyclization of the trienynol **3** in order to look for participation of the acetylenic bond. In that event, it was not clear, *a priori*, whether there would be a preference for formation of a six- or five-membered ring *via* the vinyl cations A or B, respectively.[1]

When a mixture of the trienynol **3**,[3] contaminated with 9% of the isomeric homoallylic alcohol (formula **3** with an isopropenyl in place of the isopropylidene group), in methylene chloride containing 2% by weight of trifluoroacetic acid was allowed to stand for 5 min at −70°, the substrate **3** was largely converted (*ca.* 70% yield, by vpc) into a product which proved to be the tricyclic triene **4**.[4] This substance was purified by preparative tlc on silica gel (1:4 EtOAc–pentane, under N_2), and the structure was deduced by the following evidence. The mass spectrum showed a parent peak at *m/e* 284 (M^+), and the uv spectrum, λ_{max}^{MeOH} 245 mμ (ε 10,000), was consistent with the conjugated dienic chromophore shown in **4**.[5] The ir spectrum showed no absorption for the terminal methylene group and the nmr spectrum (60 MHz, $CDCl_3$, TMS internal standard) included singlets at δ 0.96 (3 H), 1.12 (3 H), and 1.37 (3 H) for the three methyl groups attached to quaternary carbon atoms, and at 1.68 (3 H) and 1.78 (3 H) for the isopropylidene methyl groups; in addition there was a broad singlet ($W_{h/2}$ = 4 Hz) at 2.17 (3 H) for the methyl group attached to the olefinic bond in

(2) W. S. Johnson and T. K. Schaaf, *Chem. Commun.*, 611 (1969).
(3) The allylic alcohol substrates **3**, **10**, and **12** were prepared by a modification of a general method that has already been described,[2] namely alkylation of the bis anion of β,β-dimethylacrylic acid (produced by the action of lithium diisopropylamide on the acid in THF) with the appropriate homoallylic bromide, followed by esterification (CH_2N_2), isomerization (KO-*tert*-Bu in *tert*-BuOH) of the resulting β,γ- into the α,β-unsaturated ester, and finally treatment with excess methyllithium in ether. This modification resulted in an increase in yield (*ca.* 85 instead of 50%) at the alkylation step.
(4) The geometrical configuration about the exocyclic olefinic bond at C-1 of the hydrindane ring system is not known.
(5) Calcd: 244 mμ. *Cf.* A. I. Scott, "Ultraviolet Spectra of Natural Products," Pergamon Press, Oxford, 1964, pp 45–52.

the five-membered ring, and a broad "singlet" ($W_{h/2}$ = 5 Hz) at 5.58 (1 H) for the vinylic proton. Finally, oxidative degradation of the cyclization product with excess ruthenium tetroxide[6] in carbon tetrachloride (1 hr, 23°) gave crystalline 4,4,8-trimethyl-*trans*-hydrindan-1,5-dione (**5**): mp 57–59°; $\lambda_{max}^{CHCl_3}$ 5.74, 5.85 μ; mass spectrum *m/e* 194 (M^+), 151 (M − 43), 137 (M − 57), 126 (M − 68), 69 (parent). The nmr spectrum included singlets at δ 1.19 (3 H), 1.20 (3 H), and 1.30 (3 H) for the three methyls attached to quaternary carbon atoms and multiplet absorptions at 2.1–2.7 (4 H) for the protons α to the carbonyl groups. This substance was identical (melting point, mixture melting point, coinjection vpc, tlc, ir, nmr, and mass spectra) with an authentic specimen of the dione **5** prepared by the following independent synthesis.



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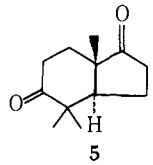

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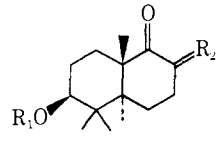
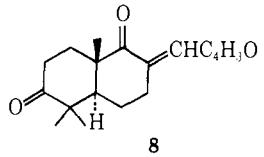


6, R_1 = Ac; R_2 = H_2
7, R_1 = H; R_2 = CHC_4H_3O



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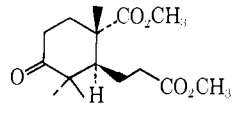

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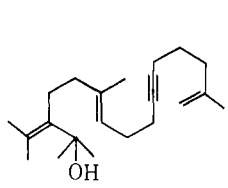
5,5,9-Trimethyl-6β-acetoxy-*trans*-1-decalone (**6**)[7] was transformed, by treatment with furfuraldehyde in aqueous methanolic sodium hydroxide,[8] into the hydroxy furfurylidene ketone **7**, mp 136–137° (*Anal.* Found: C 75.2; H, 8.3) which was oxidized with 7 mol equiv of Collins reagent[9] (10 min, 23°) to give the furfurylidene diketone **8**, mp 102–103.5° (*Anal.* Found: C, 75.35; H, 7.6). According to a previously reported sequence for ring contraction,[8] substance **8** was cleaved by ozonolysis, then methylated with diazomethane to give the keto diester **9** which, without purification was submitted to Dieckmann cyclization (KO-*tert*-Bu, HO-*tert*-Bu). The resulting crude β-keto ester was decarbomethoxylated (HCl–HOAc) and purified by bulb-to-bulb distillation at 120° (0.01 mm) followed by chromatography on Florisil (1:1 benzene–methylene chloride). Recrystallization from hexane gave colorless prisms, mp 58–59.5° (*Anal.* Found: C, 74.0; H, 9.2). The spectral properties of this materal, **5**, were identical with those recorded above for the sample obtained by degradation of **4**.

The trienynol **10**,[3] as in the case of the lower homolog **3**, also underwent cyclization under the conditions described above to give the tricyclic substance **11**[4] (*ca.* 65% yield, by vpc), the spectral properties of which



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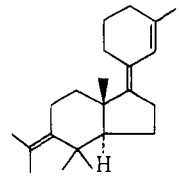
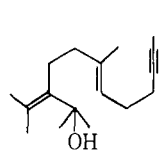


11

were similar to those of the triene **4**. The mass spectrum of **11** showed *m/e* 298 (M^+), and oxidation with ruthenium tetroxide afforded the dione **5** (see above).



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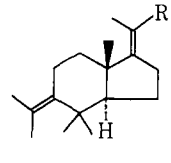
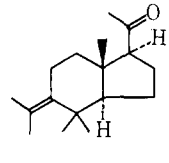


13, R = OCHO
14, R = $NHCOCH_3$



15

Attention was next turned to the cyclization of the simpler dienynol **12**[3] with a methyl group attached to the acetylenic residue. The cyclization procedure had to be modified somewhat in order to supply an appropriate nucleophile to react with the intermediary vinyl cation. One successful procedure consisted of stirring a solution of the substrate in pentane with excess formic acid (two-phase system) for 15 min at 23°. The product, isolated in 90% yield (corrected for *ca.* 25% homoallylic alcohol in starting material) by preparative tlc on silica gel (1:9 EtOAc–hexane) appeared by vpc to be 93% pure enol formate **13**[4] (*Anal.* Found: C, 78.5; H, 10.2): λ_{max}^{film} 5.8 μ; mass spectrum *m/e* 276 (M^+). The nmr spectrum included singlets at δ 0.97 (3 H), 1.12 (3 H), and 1.25 (3 H) for the three methyls attached to quaternary carbon atoms, singlets at 1.70 (3 H) and 1.78 (3 H) for the two methyls of the isopropylidene group, a singlet at 1.87 (3 H) for the methyl attached to the vinyl ester residue, and a singlet at 8.00 (1 H) for the proton attached to the ester carbonyl group. Ruthenium tetroxide degradation gave the hydrindandione **5** (see above). When the enol formate **13** was treated with excess sodium bicarbonate in methanol for 12 hr at 23°, it was hydrolyzed (78% yield) to a ketonic product which appeared by vpc to be a 9:1 mixture of **15** and its C-1α epimer. This product appeared to be 92% pure by vpc, which was improved to 95% by tlc (*Anal.* Found: C, 82.1; H, 11.15): λ_{max}^{film} 5.85 μ; mass spectrum *m/e* 248 (M^+), 205 (M − 43), 43 (M − 205, base peak). The nmr spectrum included singlets at δ 0.72 (3 H), 1.17 (6 H), 1.68 (3 H), and 1.83 (3 H). In addition there was a singlet at 2.10 (3 H) for the methyl attached to the carbonyl group. The preponderant epimer was assumed to be the C-1β isomer **15** by analogy to the well-known relative stability of the C-17 epimers in the 20-keto pregnane series. The conversion of **12** into **15** thus provides a model for the formation of the C/D portion of these steroids and has been adapted to a synthesis of *dl*-progesterone.[10]

(6) H. Nakata, *Tetrahedron*, **19**, 1959 (1963).
(7) F. Sondheimer and D. Elad, *J. Amer. Chem. Soc.*, **80**, 1967 (1958).
(8) W. S. Johnson, B. Bannister, and R. Pappo, *ibid.*, **78**, 6331 (1956).
(9) J. C. Collins, W. W. Hess, and F. J. Frank, *Tetrahedron Lett.*, 3363 (1968).
(10) W. S. Johnson, M. B. Gravestock, and B. McCarry, *J. Amer. Chem. Soc.*, **93**, 4332 (1971).

The dienynol **12** also underwent facile cyclization at −30° (30 min) in acetonitrile containing 1% trifluoroacetic acid. The acetonitrile served as the nucleophile as well as the solvent and the product, which appeared by vpc to be formed in almost quantitative yield, was shown to be the enamide **14**:[4] λ_{max}^{film} 6.0 μ; mass spectrum *m/e* 289, base peak (M^+), 274 (M − 15), 246 (M − 43), 236 (M − 49), 215 (M − 74). The nmr spectrum included, in addition to the three-proton singlets at δ 0.95, 1.11, 1.27, 1.70, and 1.80 (see above), singlets at 1.97 (3 H) for the methyl on the olefinic carbon holding the amido residue, at 2.00 (3 H) for the methyl attached to the amido carbonyl carbon, and at 6.34 (1 H, disappearing on treatment with D_2O) for the proton on the nitrogen atom. This product appeared to be oxygen-sensitive and a satisfactory analytical sample was not obtained. Ruthenium tetroxide degradation of the enamide gave the dione **5**, and treatment of the enamide with 1:1 2 *N* hydrochloric acid–methanol for 8 hr at 23° gave the methyl ketone **15** (β:α ratio 11:1 by vpc).

Acknowledgments. We are indebted to the National Institutes of Health and the National Science Foundation for support of this research.

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Received May 21, 1971

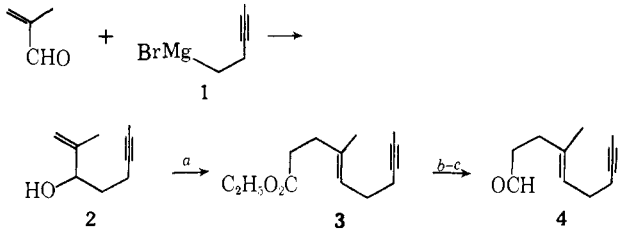
Acetylenic Bond Participation in Biogenetic-Like Olefinic Cyclizations. II. Synthesis of *dl*-Progesterone

Sir:

In an accompanying communication we have disclosed that an appositely placed acetylenic bond can participate in an olefinic cyclization so as to produce a trans-fused five-membered ring; thus the *trans*-hydrindan ring system was formed stereospecifically in one step from an acyclic substrate.[1] In the present communication we report on an extension of this work, *i.e.*, the stereospecific cyclization of the trienynol **11** to give a tetracyclic substrate **12** which in turn is readily converted into *dl*-progesterone (**14**).

The trienynol **11** was produced by a convergent synthesis, the key step being a stereoselective Wittig condensation of the aldehyde **4** with the ylide **7** to produce the diketal **8**. The aldehyde **4** was prepared as outlined in Scheme I. Thus, the Grignard reagent **1**

Scheme I



[a] $CH_3C(OC_2H_5)_3$, 0.3% $CH_3CH_2CO_2H$, 138°, 2.5 hr. [b] $LiAlH_4$, ether, 0°, 1 hr. [c] $CrO_3 \cdot 2C_5H_5N$, CH_2Cl_2, 23°, 1.2 hr.

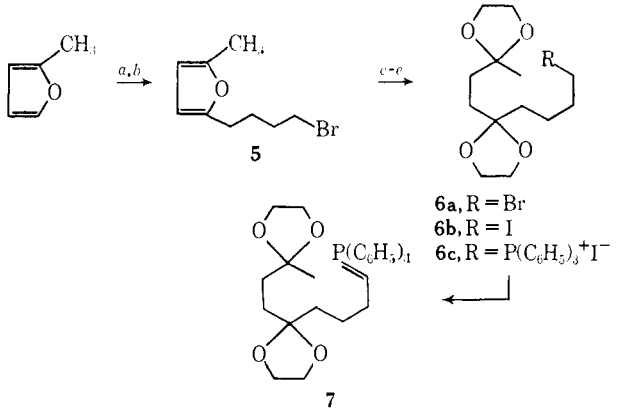
(1) W. S. Johnson, M. B. Gravestock, R. J. Parry, R. F. Myers, T. A. Bryson, and D. H. Miles, *J. Amer. Chem. Soc.*, **93**, 4330 (1971).

from 1-bromo-3-pentyne,[2] on interaction with methacrolein, gave the allylic alcohol **2** which (without purification) was converted, by the ortho acetate Claisen reaction,[3] into the enyne ester **3** in 55% overall yield after distillation[4] at 90° (0.025 mm) (*Anal.* Found: C, 75.2; H, 9.8). The nmr spectrum[5] included a singlet at δ 1.62 (3 H) characteristic of a methyl group on a trans-trisubstituted olefinic bond, and a triplet (J = 2 Hz) at 1.76 (3 H) for the methylacetylenic residue. A sample of the aforementioned allylic alcohol **2** was purified by distillation[4] at 60° (0.05 mm) (*Anal.* Found: C, 78.1; H, 10.15). The nmr spectrum[5] included the triplet (J = 2 Hz) at δ 1.76 (3 H) characteristic of the methylacetylenic residue.

The reduction of the ester **3** gave, in 90% yield, the corresponding enyne alcohol which was 98% pure as ascertained by vpc. A sample was purified by distillation[4] at 80° (0.025 mm) (*Anal.* Found: C, 78.5; H, 10.7). The nmr spectrum,[5] like that of **3**, included a singlet at δ 1.64 (3 H) and a triplet (J = 2 Hz) at 1.77. The unpurified enyne alcohol, on oxidation with Collins reagent,[6] was converted (86% yield) into the aldehyde **4** which was 98% pure by vpc. A sample was purified by distillation[4] at 70° (0.025 mm) (*Anal.* Found: C, 80.7; H, 9.75). The nmr spectrum,[5] like that of **3**, included a singlet at δ 1.57 (3 H) and a triplet (J = 2 Hz) at 1.71 (3 H). In addition there was a singlet at 9.80 (1 H) for the aldehyde proton.

The diketal bromide **6a** (Scheme II) was prepared by a

Scheme II



[a] *n*-BuLi, THF, 4 hr, −30 to −20°. [b] 2.9 equiv of $Br(CH_2)_4Br$, 2.5 hr, −20 to 23°, 14 hr at 23°. [c] (To give **6a**) 3.2 mol equiv of $HOCH_2CH_2OH$, C_6H_6, 0.026 mol equiv of *p*-$CH_3C_6H_4SO_3H$, hydroquinone (trace), 43-hr reflux with removal of H_2O. [d] (To give **6b**) 1.4 equiv of NaI, trace of MgO, $CH_3CH_2COCH_3$, N_2, 40 min, 80°. [e] (To give **6c**) 1.4 equiv of $(C_6H_5)_3P$, C_6H_6, 16 hr, 80°.

method like that already described for producing a homolog.[7] Thus, 2-methylfuran was alkylated with 1,4-dibromobutane to give, after fractional dis-

(2) K. E. Schulte and K. P. Reiss, *Chem. Ber.*, **87**, 964 (1954).
(3) *Cf.* W. S. Johnson, L. Werthemann, W. R. Bartlett, T. J. Brocksom, T-t. Li, D. J. Faulkner, and M. R. Petersen, *J. Amer. Chem. Soc.*, **92**, 741 (1970).
(4) Evaporative bulb-to-bulb distillation using Büchi kugelrohrofen.
(5) The nmr spectrum at 60 MHz, TMS internal standard, $CDCl_3$ solvent, was entirely consistent with the assigned structure. Details are not recorded here, except for absorptions of particular significance.
(6) J. C. Collins, W. W. Hess, and F. J. Frank, *Tetrahedron Lett.*, 3363 (1968).
(7) W. S. Johnson, T-t. Li, C. A. Harbert, W. R. Bartlett, T. R. Herrin, B. Staskun, and D. H. Rich, *J. Amer. Chem. Soc.*, **92**, 4461 (1970).