Synthesis and Characterization of Bridged Tricyclic Ketones[1]

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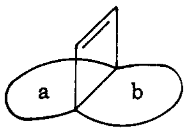
Light-catalyzed addition of 2-butyne to bicyclo[3.3.0]oct-1(5)-en-2-one (**3**) and to bicyclo[4.3.0]non-1(6)-en-7-one (**4**) gave 9,10-dimethyltricyclo[3.3.2.0^{1,5}]dec-9-en-2-one (**5**) and 10,11-dimethyltricyclo[4.3.2.0^{1,6}]-undec-10-en-7-one (**6**), respectively. Photoisomerization of **6** produced a mixture of **6** and 2,3-dimethyltricyclo[5.4.0.0^{3,7}]undec-1-en-4-one (**9**). Treatment of either **6** or **9** with acid gave an equilibrium mixture containing 90% **6** and 10% **9**. Pyrolysis of 2,3-dimethyltricyclo[5.4.0.0^{3,7}]undec-1-en-4-ol (**17**) yielded 2,3-dimethylbicyclo[5.4.0]undec-2-en-4-one (**18**).

Consideration of structures **1** and **2** immediately suggests that a compound having the former structure should be thermally stable with respect to the corresponding diene (**2**). Indeed, provided the rings a and b are sufficiently small, the groups attached to the ethylenic linkages in **2** cannot become coplanar; thus the dienes are incapable of existence. With these ideas in mind, we set out to explore the thermal decomposition of tricyclic compounds of the type **1**. In this paper we describe the synthesis of some of these compounds and the transformations related to the structural assignments.[2]



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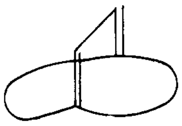

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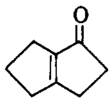
Eaton,[3] Criegee,[4] and Seebach[5] have demonstrated the facility with which cyclobutenes may be obtained from photochemical addition of 2-butyne to cyclopentenone and to maleic anhydride. We find that irradiation of either of the bicyclic enones, **3** or **4**, and excess 2-butyne either in benzene or in methylene chloride solution yield the desired tricyclic adduct, **5** or **6**, respectively.



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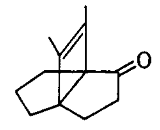

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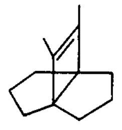

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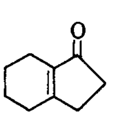

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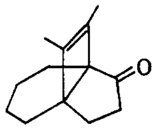

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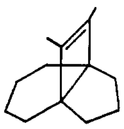

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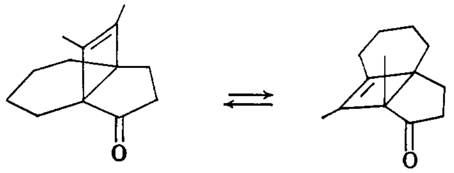
That the new ketones have the correct molecular formula was established by mass spectrometry[6] and by elemental analysis of the crystalline semicarbazones. In each ketone the cyclopentanone carbonyl absorption appears at 1725–1730 cm.$^{-1}$ and the carbon–carbon double-bond stretching absorption is found at 1685 cm.$^{-1}$.[7] The n.m.r. spectra of **5** and **6** present no evidence of vinyl hydrogens and in each case signals for the nonequivalent vinyl methyls appear at 8.34 and 8.45 and at 8.42 and 8.49 p.p.m. (τ scale,) respectively. In both cases long-range spin coupling between the two methyls is evident. Wolff–Kishner reduction of **5** and **6** yielded hydrocarbons **7** and **8**. The vinyl methyls in each hydrocarbon are equivalent (single sharp resonance at 8.56 and at 8.57 p.p.m., respectively). The nonplanar β,γ-unsaturated ketone array is evidenced by the enhanced n–π^* absorption[9]: $\lambda_{\max}^{\mathrm{EtOH}}$ 307 mμ (ϵ 210) for **5**, and 307 mμ (ϵ 340) for **6**. The spectral data and the reduction to symmetrical hydrocarbons, together with the analogous findings of Eaton,[3] Criegee,[4] and Seebach[5] provide convincing evidence for the structures of ketones **5** and **6**.

The addition of 2-butyne to **4** produced not only **6**, but an isomeric ketone (**9**) as well. Irradiation of either pure **6** or **9** yielded a photostationary-state mixture containing 70% **9** and 30% **6**. In support of the assigned structure for the "iso" ketone (**9**) we find $\lambda_{\max}^{\mathrm{EtOH}}$ 310 mμ (ϵ 460) (nonplanar β,γ-unsaturated ketone) and $\nu_{\max}$ 1725 and 1680 cm.$^{-1}$ (cyclopentanone and 1,2-disubstituted cyclobutene). Two singlets in the n.m.r. spectrum at 8.49 and at 8.99 p.p.m. indicate the presence of a vinyl methyl and a methyl on quaternary carbon. Reference to the previously observed photointerconversions of β,γ-unsaturated ketones,[3,4,8] together with the spectral data, leads one directly to the structure **9** for the "iso" ketone. Further chemical evidence for structure **9** is described in a later section of this paper.



6 **9**

Although the addition of 2-butyne to **3** produced several isomeric ketones, **5** amounted to 90% of the isolated mixture. The second most abundant ketone, **10**, comprised 5.5% of the product. Irradiation of pure

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[1] Portions of this work have been reported at the 148th and the 149th National Meetings of the American Chemical Society, Chicago, Ill., Aug. 1964 [Abstracts, p. 25 S], and Detroit, Mich., April 1965 [Abstracts, p. 28 P].

[2] Two compounds having the structural features of **1** have been described, the trimer and the tetramer of cyclohexyne: (a) G. Wittig and U. Mayer, *Ber.*, **96**, 342 (1963); (b) G. Wittig and J. Weinlich, *ibid.*, **98**, 471 (1965).

[3] P. E. Eaton, *Tetrahedron Letters*, 3695 (1964).

[4] R. Criegee and H. Furrer, *Ber.*, **97**, 2949 (1964); R. Criegee, U. Zirngibl, H. Furrer, D. Seebach, and G. Freund, *ibid.*, **97**, 2942 (1964).

[5] D. Seebach, *ibid.*, **97**, 2953 (1964).

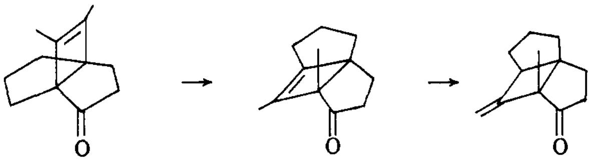
[6] Mass spectra of **5** and **10** were measured by Mr. P. Chastagner of the Savannah River Laboratory. All other mass spectra were determined by Professor A. L. Burlingame, University of California, Berkeley.

[7] These values are typical for several bicyclo[3.2.0]hept-6-en-2-ones.[3-5,8]

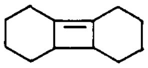
[8] G. Büchi and E. M. Burgess, *J. Am. Chem. Soc.*, **82**, 4333 (1960).

[9] A. I. Scott, "Interpretation of the Ultraviolet Spectra of Natural Products," The MacMillan Co., New York, N. Y., 1964, p. 75, and references cited therein.

5 gave mostly recovered starting material; however, several small peaks appeared in the gas chromatogram of the recovered product. The relative area of one of the new peaks was increased when the irradiation mixture was coinjected with pure **10**. The new ketone is a β,γ-unsaturated ketone, λ_{max}^{EtOH} 304 mμ (ε 170), and has a methyl on quaternary carbon (sharp singlet at 8.98 p.p.m.) and an exocyclic methylene (ν_{max} 1665 and 890 cm.$^{-1}$, and a pair of doublets at 5.16 and 5.30 p.p.m., J = 2 c.p.s.). The assigned structure (**10**) is consistent with the spectral evidence. Compound **10** probably arises from **5** (reirradiation experiment) *via* the intermediate **11** (*cf.* **6** → **9**). The excessive strain in **11** provides the necessary driving force for an allylic proton shift to produce **10**.


5 **11** **10**

In addition to the photochemical interconversion of **6** and **9**, we also found equilibration of these isomers by *p*-toluenesulfonic acid in warm benzene (50°) possible. Equilibrium was approached from both pure ketones and the final mixture contained 90% **6** and 10% **9**. The greater thermodynamic stability of **6** is not surprising in view of the expected distortion of the bicyclo[4.2.0]oct-1(8)-ene moiety in **9**. The surprising observation in our view is that the free-energy difference between **6** and **9**, as reflected by the position of equilibrium, is only 1.4 kcal./mole. On the other hand, the known stability of **12** and **13**[10-12] (**12** is only 95% converted to diene after 30 min. at 300°)[11] is ample evidence that the bicyclo[4.2.0]oct-1(8)-ene system is not highly strained. Conversely, the fruitless attempt[12] to prepare compounds of the bicyclo[3.2.0]hept-1(7)-ene type (**14**) and our failure to detect **11** in any of our reaction products reveal the excessive strain of this system.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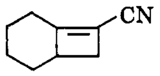

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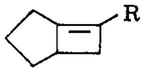

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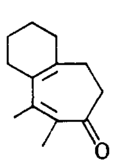
Since thermal ring opening in **9** is not prevented, we felt that isomerization of **9** to the dienone **15** would establish firmly the structure of **9**. Pyrolysis experiments with **9**, however, appeared to be unpromising. We, therefore, turned to the alcohols resulting from **6** and **9** by reduction with lithium aluminum hydride. In each case a single, crystalline alcohol was obtained in good yield, **16** and **17**, respectively.[13]

Pyrolysis of **17**, or more conveniently, a mixture of **16** and **17**, at 340–350° for 10 min.[14] yielded a new ketone (**18**) as the major product. That **18** is an α,β-unsaturated ketone is clear from spectral data, λ_{max}^{EtOH} 258 mμ (ε 8750) and ν_{max} 1670 and 1625 cm.$^{-1}$. Both vinyl methyls give rise to an unresolved absorption centered at 8.26 p.p.m.[15] The absence of vinyl hydrogens is also evident from the n.m.r. spectrum. Oxidative degradation of **18** *via* the keto acid **19** yielded the known *trans*-3-(2-carboxycyclohexyl)propionic acid (**20**)[16] (see Scheme I).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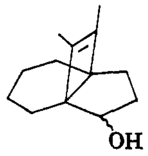

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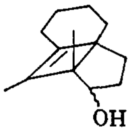

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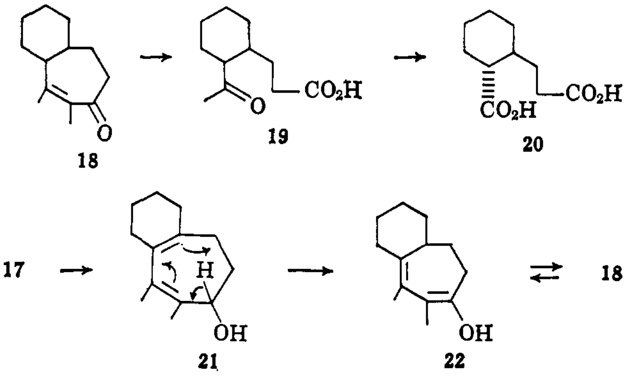
SCHEME I



18 **19** **20** **21** **22**

The isomerization of **17** to **18**, at first a surprising result, is easily rationalized in terms of a 1,5-hydrogen shift in the dienol (**21**).[17,18] That transannular 1,5-hydrogen shifts in cycloheptadienes and cycloheptatrienes are usually more rapid than is cyclobutene ring opening is evident from comparison of the activation parameters for the two processes: E^*, 26.5–32 kcal./mole, log A, 10.9–11.5 for the hydrogen-shift reaction[19-21]; and E^*, 31.5–36.1 kcal./mole, log A, 13.1–13.9 for cyclobutene isomerization.[23-26] A 1,5-hydro-

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[10] K. J. Crowley, *Proc. Chem. Soc.*, 334 (1962).

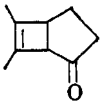
[11] W. G. Dauben and R. L. Cargill, unpublished results.

[12] I. Fleming and J. Harley-Mason, *J. Chem. Soc.*, 2165 (1964).

[13] The stereochemistry of alcohols **16** and **17** is not yet known with certainty, and since the configuration of the hydroxyl group has little or no effect on the outcome of the pyrolysis experiments, discussion of the stereochemistry of these and other similar reductions is deferred until later.

[14] In a separate experiment, **16** was shown to be stable under these conditions.

[15] The nonequivalent vinyl methyls of i also give rise to a single broad resonance in the n.m.r. spectrum.[3]


i

[16] W. S. Johnson, *J. Am. Chem. Soc.*, **65**, 1317 (1943).

[17] J. Wolinsky, B. Chollar, and M. D. Baird, *ibid.*, **84**, 2775 (1962).

[18] G. Büchi and E. M. Burgess, *ibid.*, **84**, 3104 (1962).

[19] A. P. ter Borg, H. Kloosterziel, and V. van Meurs, *Rec. trav. chim.*, **82**, 717 (1963).

[20] A. P. ter Borg and H. Kloosterziel, *ibid.*, **82**, 1189 (1963); **84**, 241, 245 (1965).

[21] D. S. Glass, J. Zirner, and S. Winstein, *Proc. Chem. Soc.*, 276 (1963).

[22] W. Cooper and W. D. Walters, *J. Am. Chem. Soc.*, **80**, 4220 (1958).

[23] E. Thiele and J. D. J. Wilson, *Can. J. Chem.*, **37**, 1035 (1959).

[24] W. P. Hauser and W. D. Walters, *J. Phys. Chem.*, **67**, 1328 (1963).

[25] H. M. Frey, *Trans. Faraday Soc.*, **58**, 957 (1962); **59**, 1619 (1963); **60**, 83 (1964).

[26] The activation parameters for cyclobutenes are for monocyclic compounds only. Bicyclo[3.2.0]hept-6-enes undergo valence isomerization to cycloheptadienes much more slowly.[4,27,28] Kinetic data for the bicyclic compounds are not yet published.

[27] R. B. Woodward and R. Hoffmann, *J. Am. Chem. Soc.*, **87**, 395, 2046 (1965).

[28] H. C. Longuet-Higgins and E. W. Abrahamson, *ibid.*, **87**, 2045 (1965).

gen transfer leads from **21** to **22**, the enol of **18**.[29] The major product of such a thermal hydrogen transfer reaction should be the compound of greatest thermodynamic stability, in this case, the α,β-unsaturated ketone (**18**). Although Δ^3-cycloheptenone predominates over the conjugated isomer at equilibrium (*ca.* 80:20),[30] a result readily explained on conformational grounds, the tetrasubstituted nature of the α,β double bond in **18** and the exocyclic nature (to a cyclohexane ring) of the double bond in the β,γ-unsaturated isomer combine to make **18** the more stable isomer.[31]

The conversion of **17** to **18** represents, to our knowledge, the first example of a 1,5-hydrogen shift in a cycloheptadienol intermediate and presents a new synthesis of cycloheptenones.

Preliminary pyrolysis experiments with **5**, **6**, and **16** indicate that compounds of the structural type **1** are very stable thermally. Subsequent papers in this series will deal with the thermal reactions of these compounds.

Experimental Section[32]

Addition of 2-Butyne to Bicyclo[4.3.0]non-1(6)-en-7-one (4).[33]—A solution of 4.766 g. (35.04 mmoles) of bicyclo[4.3.0]non-1-(6)en-7-one (**4**) and 10 ml. of 2-butyne in 80 ml. of dry benzene was irradiated with a Hanovia high-pressure mercury arc lamp, internal probe, type L, with a Corex filter, cooled by circulating tap water through the cooling jacket. The solution was stirred with a magnetic stirrer and the reaction progress was followed by gas chromatography over diethylene glycol succinate (DEGS, 5-ft. column) at 170°. After 8.5 hr. the irradiation was stopped and the solvent was removed by distillation at reduced pressure. The residual oil was distilled at reduced pressure, b.p. 65–70° (0.55 mm.), giving 5.00 g. (75.1%) of a mixture of two compounds in a ratio of *ca.* 3:7. Chromatography in the vapor phase over DEGS and collection of the two compounds gave **6** and **9**.

10,11-Dimethyltricyclo[4.3.2.0^{1,6}]undec-10-en-7-one (**6**), $C_{13}H_{18}O$, had mol. wt. 190.25[6]; $\lambda_{\max}^{\text{EtOH}}$ 228 (sh) mμ (ϵ 1550) and 307 mμ (ϵ 340); $\nu_{\max}^{\text{CCl}_4}$ 1725 and 1685 (sh) cm.$^{-1}$; τ = 8.49 (s) (3H) and 8.41 (s) (3H) p.p.m.; and semicarbazone m.p. 222–224° dec. from aqueous ethanol.

Anal. Calcd. for $C_{14}H_{21}N_3O$ (295.28): C, 67.98; H, 8.56; N, 16.99. Found: C, 68.21; H, 8.59; N, 16.95.

2,3-Dimethyltricyclo[5.4.0.0^{3,7}]undec-1-en-4-one (**9**), $C_{13}H_{18}O$, had mol. wt. 190.25[6]; $\lambda_{\max}^{\text{EtOH}}$ 228 (sh) mμ (ϵ 1940) and 310 mμ (ϵ 460); $\nu_{\max}^{\text{CCl}_4}$ 1725 and 1680 (sh) cm.$^{-1}$; τ = 8.49 (s) (3H) and 8.99 (s) (3H) p.p.m.; and semicarbazone m.p. 218–220° dec. from aqueous ethanol.

Anal. Calcd. for $C_{14}H_{21}N_3O$ (259.28): C, 67.98; H, 8.56; N, 16.99. Found: C, 67.73; H, 8.62; N, 17.12.

9,10-Dimethyltricyclo[3.3.2.0^{1,5}]dec-9-en-2-one (5).—Irradiation of 5.24 g. (42.8 mmoles) of bicyclo[3.3.0]oct-1(5)-en-2-one (**3**)[34] in the manner described above for 20–25 hr. gave, from three runs, 13.7 g. of distillate, b.p. 57–60° (0.3 mm.). Preparative gas chromatography (DEGS) yielded 4.96 g. of **5** and 312 mg. of **10**.

9,10-Dimethyltricyclo[3.3.2.0^{1,5}]dec-9-en-2-one (**5**), $C_{12}H_{16}O$, had mol. wt. 176.25[6]; $\lambda_{\max}^{\text{EtOH}}$ 225 mμ (sh) (ϵ 1200) and 307 mμ (ϵ 210); $\nu_{\max}^{\text{CCl}_4}$ 1730 and 1680 cm.$^{-1}$; τ = 8.34 (s) (3H) and 8.45 (s) (3H) p.p.m.; and semicarbazone m.p. 214° dec.

Anal. Calcd. for $C_{13}H_{19}N_3O$ (233.31): C, 66.92; H, 8.21; N, 18.01. Found: C, 66.84; H, 8.21; N, 17.99.

3-Methyl-2-methylenetricyclo[5.3.0.0^{3,7}]decan-4-one (**10**), $C_{12}H_{16}O$, had mol. wt. 176.25[6]; $\lambda_{\max}^{\text{EtOH}}$ 304 mμ (ϵ 170); $\nu_{\max}^{\text{CCl}_4}$ 3075, 1735, 1665, and 887 cm.$^{-1}$; τ = 8.98 (s) (3H), 5.16 (d), and 5.30 (d) [J = 2 c.p.s. (2H)] p.p.m.; and semicarbazone m.p. 221° dec.

Anal. Calcd. for $C_{13}H_{19}N_3O$ (233.31): C, 66.92; H, 8.21; N, 18.01. Found: C, 66.94; H, 8.38; N, 17.87.

Wolff–Kishner Reduction of 10,11-Dimethyltricyclo[4.3.2.0^{1,6}]-undec-10-en-7-one (**6**).—A mixture of 277 mg. (1.45 mmoles) of **6**, 0.3 ml. of hydrazine hydrate, 40 mg. of potassium hydroxide, and 5 ml. of diethylene glycol was boiled under a reflux condenser, maintained at −10° by circulating a methanol–water mixture through a cooling bath, for 4 hr. The mixture was cooled and extracted with several portions of pentane, and the pentane extracts were dried over magnesium sulfate. After removal of the drying agent, the solvent was distilled through a Vigreux column, leaving a liquid residue (130 mg., 51.0%). Chromatography in the vapor phase over tris-β-cyanoethoxypropane (TCEP) at 110° and collection of the product gave **8**, m.p. 33.5–34.0°.

10,11-Dimethyltricyclo[4.3.2.0^{1,6}]undec-10-ene (**8**), $C_{13}H_{20}$, had mol. wt. 176.29[6]; $\nu_{\max}^{\text{CCl}_4}$ 1685 cm.$^{-1}$; and τ = 8.57 (s) (6H) p.p.m.

9,10-Dimethyltricyclo[3.3.2.0^{1,5}]dec-9-ene (7).—Reduction of **5** in the above manner yielded **7**, as a mobile liquid.

9,10-Dimethyltricyclo[3.3.2.0^{1,5}]dec-9-ene (**7**), $C_{12}H_{18}$, had mol. wt. 162.26[6]; $\nu_{\max}^{\text{CCl}_4}$ 1690 cm.$^{-1}$; and τ = 8.56 (s) (6H) p.p.m.

Photoisomerization of 6.—A solution containing 727 mg. (3.82 mmoles) of **6** (10% impurity of **9**) in 45 ml. of benzene was irradiated with the mercury arc lamp. The progress of the reaction was followed by gas chromatography over DEGS. After 3-hr. irradiation, no further change in the composition of the reaction mixture was observed and the irradiation was stopped. The solvent was removed by distillation at reduced pressure. Gas chromatography of the residual oil and comparison of infrared spectra indicated a mixture of 30% 10,11-dimethyltricyclo-[4.3.2.0^{1,6}]undec-10-en-7-one (**6**) and 70% 2,3-dimethyltricyclo-[5.4.0.0^{3,7}]undec-1-en-4-one (**9**).

Photoisomerization of 9.—Irradiation of 80 mg. (0.42 mmole) of **9** in 45 ml. of benzene by the foregoing procedure gave a mixture of **6** and **9** identical with that obtained by irradiation of **6**.

Irradiation of 5.—A solution of 326 mg. (1.85 mmole) of **5** in 60 ml. of benzene was irradiated as above under a nitrogen atmosphere for 21 hr. The solvent was removed and the residue was distilled in a microstill, bath temperature 100–150° (0.7 mm.). The distillate, 210 mg., was mostly recovered **5**; however, the presence of **10** was inferred by gas chromatography (coinjection with **10**).

Attempted Isomerization of 5 with Acid.—A mixture of 116 mg. of **5** and 34 mg. of *p*-toluenesulfonic acid monohydrate in 6.5 ml. of benzene was heated at reflux in the dark for 2 hr. The mixture was cooled, washed with aqueous sodium bicarbonate and then with water, and dried. The solvent was removed and the residue was distilled in a microstill, bath temperature 100° (2 mm.). The distillate, 85 mg., consisted only of recovered **5**.

Acid-Catalyzed Equilibration of 6 and 9.—A solution of 190 mg. (1.00 mmole) of **9** and 15 mg. of *p*-toluenesulfonic acid in 10 ml. of benzene was heated at 50° under nitrogen for 6 hr. The benzene solution was washed with 5% sodium hydroxide solution and with water, dried, and concentrated. Gas chromatography of the residual oil indicated that it was a mixture containing 90%

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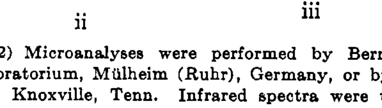
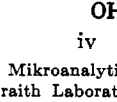
(29) J. A. Berson and M. Jones [*J. Am. Chem. Soc.*, **86**, 5017, 5019 (1964)] have reported the formation of ketones in a similar manner *via* the oxy-Cope rearrangement.

(30) I. Maclean and R. P. A. Sneeden, *Tetrahedron*, **21**, 31 (1965).

(31) The conversion of **17** to **18** is analogous to the thermal isomerization of ii to iii observed in this laboratory. The pyrolysis of ii and of iv will be the subject of a later paper.





iv

(32) Microanalyses were performed by Bernhardt Mikroanalytisches Laboratorium, Mülheim (Ruhr), Germany, or by Galbraith Laboratories, Inc., Knoxville, Tenn. Infrared spectra were taken on a Perkin-Elmer Model 337 grating spectrophotometer in carbon tetrachloride solution. Ultraviolet spectra were recorded on a Cary Model 14M spectrophotometer. The n.m.r. spectra were recorded on a Varian A-60 n.m.r. spectrometer in carbon tetrachloride using tetramethylsilane and chloroform as internal standards. Gas chromatographic analyses and separations were performed with an Aerograph, Model A-90-P-3, gas chromatograph. Melting points and boiling points are uncorrected.

(33) We are indebted to Professor F. T. Bond, Oregon State University, for the details of the preparation of **4**.

(34) We are grateful to Professor W. G. Dauben, University of California, Berkeley, and to the Badische Anilin- und Soda-Fabrik for a generous supply of **3**.

10,11-dimethyltricyclo[4.3.2.$0^{1,6}$]undec-10-en-7-one (6) and 10% 2,3-dimethyltricyclo[5.4.0.$0^{3,7}$]undec-1-en-4-one (9). The same mixture was obtained by acid treatment of 9 for 12 hr. at room temperature (23–26°) in benzene solution. Treatment of 6 in the above manner gave the same 90:10 mixture of 6 and 9.

Reduction of 6.—Lithium aluminum hydride was added to a solution of 46 mg. (0.24 mmole) of 6 in 5 ml. of dry ether until vigorous reaction had subsided. The reaction mixture was stirred for 2 hr. Water was added slowly to decompose unreacted hydride, followed by 10% sulfuric acid to dissolve hydroxides. The ether layer was separated and the aqueous layer was extracted twice with 10-ml. portions of ether. The ethereal solutions were combined and dried. After removal of the ether at reduced pressure, the residual oil was distilled in a short-path still, bath temperature 80° (0.55 mm.). After having stood overnight in a refrigerator, the distillate solidified. The solid was sublimed, yielding 34.5 mg. (75.1%) of **16**, m.p. 34–35°.

10,11-Dimethyltricyclo[4.3.2.$0^{1,6}$]undec-10-en-7-ol (16), $C_{13}H_{20}O$, had mol. wt. 192.25[6]; $\nu_{\max}^{CCl_4}$ 3620, 3450 (broad), and 1690 cm.$^{-1}$; and τ = 8.52 (s) (3H), 8.41 (s) (3H), and 6.40 (m) (1H) p.p.m.

Anal. Calcd. for $C_{13}H_{20}O$ (192.25): C, 81.20; H, 10.48. Found: C, 80.98; H, 10.20.

Reduction of 9.—Reduction of 85 mg. (0.45 mmole) of **9** in the manner described for reduction of **6** yielded 65 mg. (75%) of a single alcohol (**17**), m.p. 61–62°.

2,3-Dimethyltricyclo[5.4.0.$0^{3,7}$]undec-1-en-4-ol (17), $C_{13}H_{20}O$, had mol. wt. 192.25[6]; $\nu_{\max}^{CCl_4}$ 3620, 3470 (broad), and 1700 cm.$^{-1}$; and τ = 8.90 (s) (3H), 8.48 (s) (3H), and 6.50 (m), (1H) p.p.m.

Anal. Calcd. for $C_{13}H_{20}O$ (192.25): C, 81.20; H, 10.48. Found: C, 81.18; H, 10.41.

Pyrolysis of 17.—Pyrolysis of 40 mg. (0.21 mmole) of **17** in a sealed, evacuated, 0.5 × 5 cm. Pyrex tube, maintained at 340–350° for 10 min. in an electric furnace, gave a yellow pyrolysate which was found by vapor phase chromatography to be a mixture of several compounds. The major component (**18**, *ca.* 40%) was isolated by gas chromatography (DEGS).

2,3-Dimethylbicyclo[5.4.0]undec-2-en-4-one (18), $C_{13}H_{20}O$, had mol. wt. 192.25[6]; $\nu_{\max}^{CCl_4}$ 1670 and 1625 cm.$^{-1}$; $\lambda_{\max}^{EtOH}$ 258 mμ (ϵ 8750); τ = 8.26 (s) (6H) p.p.m.; and 2,4-dinitrophenylhydrazone m.p. 147–148° from ethanol.

Anal. Calcd. for $C_{19}H_{24}N_4O_4$ (372.41): C, 61.27; H, 6.48; N, 15.05. Found: C, 61.68; H, 6.17; N, 15.28.

Degradation of 18. A. Permanganate–Periodate Oxidation.[35]—The oxidant was prepared by dissolving 200 mg. of potassium carbonate, 21 mg. of potassium permanganate, and 1.205 g. of sodium metaperiodate in 120 ml. of water and adjusting the pH to 7.7 with sodium hydroxide solution. To 95 ml. of this solution was added 61 mg. (0.32 mmole) of **18** in 3 ml. of dioxane. The solution was stirred at room temperature for 40 hr. After acidification with 5 ml. of dilute sulfuric acid and addition of 2 ml. of saturated sodium bisulfite solution, the reaction mixture was extracted with three 50-ml. portions of ether. The ethereal extracts were combined and washed with saturated sodium bicarbonate solution. The bicarbonate washings were acidified and extracted with several portions of ether. The ethereal solution was dried and then concentrated to a brown oil which has an infrared spectrum indicative of a keto acid (**19**): $\nu_{\max}^{neat}$ 3100 (broad), 1735, and 1710 cm.$^{-1}$.

B. Hypochlorite Oxidation.—The oil obtained from the Lemieux oxidation was dissolved in 3 ml. of 2 *N* potassium hydroxide and 5 ml. of 5.4% sodium hypochlorite solution was added. After the reaction mixture had been stirred for 6 hr., sodium sulfite was added to destroy excess hypochlorite. The solution was then acidified with hydrochloric acid and extracted with three 25-ml. portions of ether. After the extract was dried, the ether was distilled, leaving an oily residue which crystallized when cooled by a stream of nitrogen (25 mg., 41% from **18**). The residue was dissolved in hot water and the solution deposited white crystals, m.p. 139–140°, upon cooling. The infrared spectrum of these crystals is superimposable upon that of authentic *trans*-3-(2-carboxycyclohexyl)propionic acid (**20**).[16] Further recrystallization from hot water gave colorless crystals, m.p. 141–142°, which showed no melting point depression upon admixture with authentic acid.

Acknowledgment.—We are grateful to Mr. P. Chastagner and to Professor A. L. Burlingame for the mass spectra of our compounds. We thank the Research Corporation for a Frederick Gardner Cottrell Grant and the National Science Foundation for as institutional grant toward the purchase of a Varian A-60 n.m.r. spectrometer.

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Configurations of Epimeric 6-Hydroxymethyl-5-propyl-2,4,6-triethyl-2-cyclohexen-1-ols and Corresponding Aldols. Stereochemistry of the Aldol Condensation

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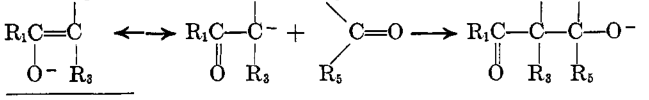
The configurations of four epimeric 6-hydroxymethyl-5-propyl-2,4,6-triethyl-2-cyclohexen-1-ols (IIIa–d), derived from the corresponding aldols (IIa–d) by Cannizzaro or lithium aluminum hydride reduction, have been established. Manganese dioxide oxidation of the glycols produced the related ketols (Va and b) which were reduced with lithium aluminum hydride to regenerate the glycols having equatorial C-1 hydroxyl. The infrared frequency differences, $\Delta\nu$, between free and intramolecularly bonded hydroxyl stretching frequencies were determined for the glycols IIIa–d and their unsaturated analogs and compared with values for related substances of known configuration. The assignments of configuration and isomer distribution of the cyclic aldols (IIa–d) formed under conditions of kinetic and thermodynamic control at 25 and 110° are discussed relative to the known facts regarding aldol-condensation stereochemistry. A transition state which does not resemble products and repulsions between bulky groups in the acyclic precursor at, or removed from the bond-forming site, appear to be important features of aldol-condensation stereochemistry.

The aldol condensation is an important example of a nucleophilic addition of a carbanion (enolate anion) to a double bond (C=O). Knowledge of the stereochemistry of this[2] and other[3,4] additions of carbanions to double bonds is limited. The related Michael addition involves addition of a carbanion to an olefinic double bond of a conjugated system, *e.g.*, C=C—C=O.



$$R_1C(O^-)=CR_2R_3 \longleftrightarrow R_1C(=O)-C^-R_2R_3 + R_4R_5C=O \longrightarrow R_1C(=O)-CR_2R_3-CR_4R_5-O^-$$

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