between two smooth platinum electrodes (2 × 3 cm) at a potential of 98 v (dc) until it became basis to litmus (7 hr). The current varied from 0.16 to 0.40 amp during the course of the electrolysis. The resulting yellow solution was acidified with acetic acid, filtered to remove a small amount of insoluble material, and the filtrate was evaporated under reduced pressure to give 4.0 g of a viscous oil. This material was dissolved in a small amount of benzene and placed on a column (36 × 2.5 cm) of acid-washed alumina packed with cyclohexane. The column was then eluted with cyclohexane, cyclohexane–benzene mixtures, benzene, and finally methanol. The oil (600 mg) eluted with benzene slowly crystallized on standing. Recrystallization from ether–pentane gave the pure lactone VII: mp 131–133°. The nuclear magnetic resonance spectrum determined in deuteriochloroform exhibited signals at τ 2.52–2.64 (ten protons), τ 4.87 (one proton), τ 7.13, 7.22, 7.26, 7.32, 7.42 (three protons), and a carbonyl absorption band appears at 1757 cm^{-1} (KBr).

ϵ-Truxillic Acid.—A mixture of 15 g of α-truxillic acid and 60 g of potassium hydroxide was heated in an open beaker maintained at 300–320° by means of a beaker mantle. The melt was stirred occasionally with a glass rod until the mixture began to darken (usually 2–3 hr). The resulting product was allowed to cool and dissolved in 600 ml of water. The insoluble potassium silicate was collected on a filter and the light yellow filtrate was acidified with concentrated hydrochloric acid. The white precipitate was collected on a filter and crystallized from aqueous ethanol (Norit): yield 13.0 g, mp 190–191° (lit.[10] mp 192°).

***trans,trans,trans*-1,3-Dicarboxy-2,4-dicarbomethoxycyclobutane (III).**—ϵ-Truxillic acid (7 g) dissolved in ether was treated with excess diazomethane solution (ether). The reaction mixture, after standing overnight, was dried over anhydrous magnesium sulphate. Removal of the volatile solvent gave 6.5 g of dimethyl ϵ-truxillate XIV as a viscous, sweet smelling oil (lit. mp 64°). Gas–liquid partition chromatographic analysis on a 210 × 0.6 cm glass column packed with 30% SE-30 on 60–80-mesh acid- and base-washed Chromosorb P at 200° showed that the product was homogeneous. The ester was dissolved in 275 ml of acetic acid and 50 ml of water and ozonized for 20 hr at room temperature. To the resulting clear solution was added 75 ml of 30% hydrogen peroxode. The mixture was then allowed to stand at room temperature for 48 hr. The excess hydrogen peroxide was finally decomposed by the addition of a small amount of platinum black. After filtration the clear solution was evaporated under reduced pressure to a white crystalline solid which was rigorously dried in a vacuum desiccator over sodium hydroxide. Recrystallization from the solvent mixture methylethyl ketone–cyclohexane gave 3.1 g (52%) of white crystals: mp 173–175°; $\nu_{\max}^{\mathrm{KBr}}$ 3300–2500 (carboxyl OH), 1732 (ester C=O), and 1713 cm^{-1} (acid C=O). After repeated recrystallization from methyl ethyl ketone–cyclohexane the sample melted at 181–183°. Elemental analytical data for III were consistently poor; however, treatment with diazomenthane gave *trans,trans,trans*-1,2,3,4-tetracarbomethoxycyclobutane[9] which confirmed beyond doubt the structure of III.

Anal. Calcd for $C_{10}H_{12}O_8$: C, 46.16; H, 4.65. Found: C, 45.27, 45.64, 45.75; H, 4.80, 4.51, 4.68.

***cis*-2,4-Dicarbomethoxybicyclobutane (XVII).**—A 1.0-g (3.85 mmole) sample of the diacid–diester was dissolved in 40 ml of dry methanol. Enough sodium (0.010 g, 0.4 mmole) was added to convert 5% of the diacid–diester to the sodium salt. The system was purged with dry nitrogen before the reactants were added. After the addition of the sodium the system was sealed and the gases produced in the electrolysis were allowed to expand into a balloon. The solution was electrolyzed between two smooth platinum electrodes (2 × 3 cm) at a potential of 80–90 v (dc) until it became basic (4–5 hr). The current varied from 1.0 amp to 0.55 amp. During the course of electrolysis the reaction mixture was cooled with an ice bath. After the solution had become basic, most of the methanol was removed under reduced pressure while keeping the reaction mixture cold. The residual dark yellow solution (2–3 ml) was chromatographed on a 2 m × 6 mm column containing 30% SE-30 on Chromosorb P heated to 220°. Under these conditions a white crystalline solid, 0.10 g, was collected. Repeated sublimation of this material at 40–50° (0.05 mm) gave a sample, mp 83–85° with softening at 78–79°, $\nu_{\max}^{\mathrm{KBr}}$ 1729 cm^{-1} (ester C=O).

Anal. Calcd for $C_8H_{10}O_4$: C, 56.47; H, 5.92. Found: C, 56.63; H, 5.87.

Hydrogenation of *cis*-2,4-Dicarbomethoxybicyclobutane (XVII).—Platinum oxide (12 mg) was prereduced (1.0 psi of H_2) in 1 ml of dry dimethoxyethane. A 23-mg sample of the diester dissolved in 0.25 ml of dimethoxyethane was added to the reaction mixture contained in a serum-capped vessel by means of a syringe. The hydrogenation was continued for 20 hr at 1 psi. The catalyst was removed and the mixture was separated into three components on a 3 m × 10 mm column containing 30% Carbowax 20M on acid-washed Chromosorb P heated to 210°. The three components were identified as *cis*-1,3-dicarbomethoxycyclobutane, dimethyl adipate, and dimethyl α-methylglutarate (15:1:21) by their retention times and comparison of infrared spectra.

Acknowledgment.—The authors are indebted to the National Institutes of Health for financial support of this research.

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(14) R. Stoermer and E. Emmel, *Ber.*, **53**, 497 (1920).

Synthesis of Benzocyclobutenes from Trichloromethylbenzenes[1a]

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Received February 4, 1966

Trichloromethylpentamethylbenzene (I), on heating to 110°, is converted in good yield to the dichlorotetramethylbenzocyclobutene (II). The method constitutes a general synthesis of highly substituted benzocyclobutenes, as illustrated by the conversion of trichloromethylmesitylene (VIII) to dichlorodimethylbenzocyclobutene (IX) and trichloromethylchlorodurene (XII) to trichlorotrimethylbenzocyclobutene (XIII). The 1,1-dichlorobenzocyclobutenes thus formed are readily hydrolyzed to the corresponding benzocyclobutenones. Conversion of tetramethylbenzocyclobutenone (III) to the corresponding alcohol, bromide, nitrile, and carboxamide is described. Reduction of III with lithium aluminum hydride or sodium borohydride leads to ring-opened products (pentamethylbenzyl alcohol and hexamethylbenzene). Wolff–Kishner reduction of III, however, gives tetramethylbenzocyclobutene (XVIII). Ketones such as III are reversibly protonated on oxygen in concentrated sulfuric acid, as shown by nmr and ultraviolet studies. The nmr spectra of benzocyclobutenes with one substituent on the four-membered ring are briefly discussed.

One general method for the synthesis of benzocyclobutenes involves 1,4 elimination from adjacent benzylic positions, followed by ring closure of the resulting *o*-quinone dimethide. The original Finkelstein[2,3] synthesis of 1,2-dibromobenzocyclobutene is an example (X = Y = Br; reagent = I$^-$).[4] We wish to report that

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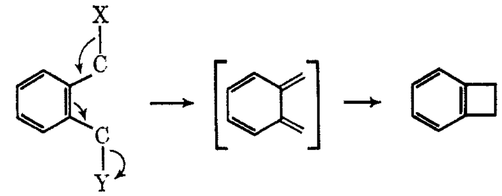
[1] (a) For a preliminary account, see H. Hart and R. W. Fish, *J. Am. Chem. Soc.*, **82**, 749 (1960); (b) author to whom reprint requests should be addressed.

[2] H. Finkelstein, Ph.D. Dissertation, University of Strassburg, 1909; *Chem. Ber.*, **92**, 37 (1959).

[3] M. P. Cava and D. R. Napier, *J. Am. Chem. Soc.*, **79**, 1701 (1957).

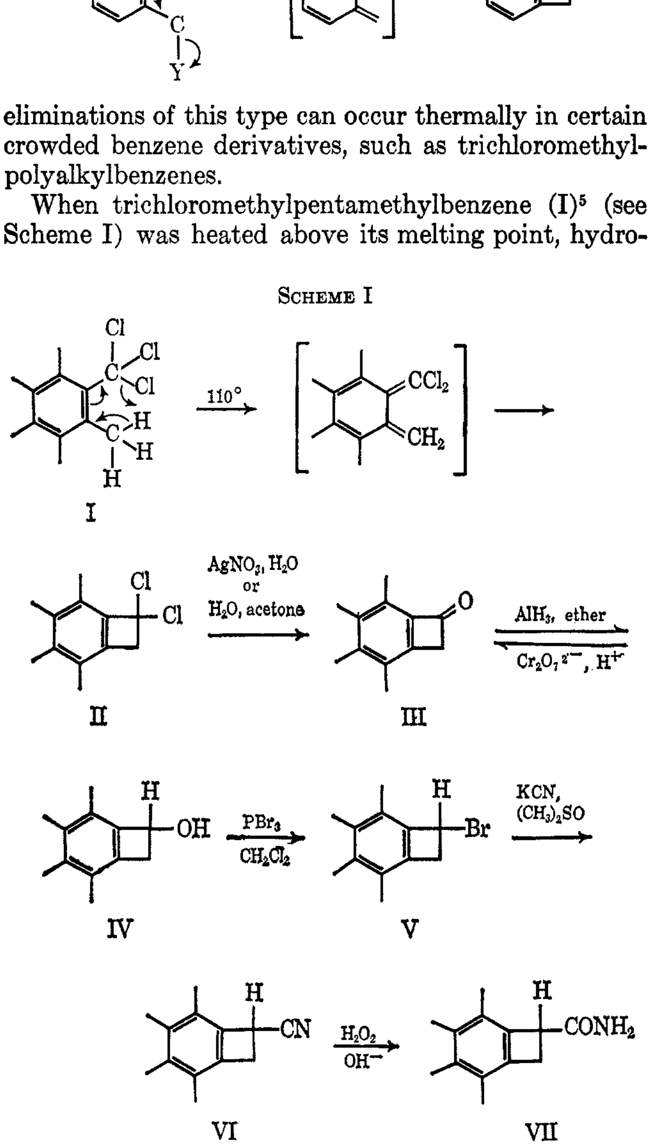
[4] For other examples, see F. R. Jensen and W. E. Coleman, *ibid.*, **80**, 6149 (1958); M. P. Cava and A. A. Deana, *ibid.*, **81**, 4266 (1959).



eliminations of this type can occur thermally in certain crowded benzene derivatives, such as trichloromethylpolyalkylbenzenes.

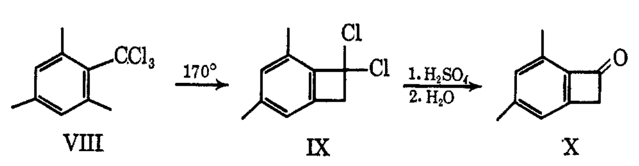
When trichloromethylpentamethylbenzene (I)[5] (see Scheme I) was heated above its melting point, hydrogen chloride was eliminated. A quantitative experiment showed that at 110–125° only 1 mole of hydrogen chloride was produced; work-up led to the crystalline dichlorotetramethylbenzocyclobutene II,[6] mp 73–74°, in nearly 90% yield. The reaction probably proceeds *via* a quinone dimethide intermediate, as shown. The thermal conversion of I to II occurs even in a sealed tube, suggesting that II is the more thermodynamically stable of the two compounds, despite the ring strain. This may be due to two factors, steric strain in I[5] and stabilization of the four-membered ring in II by the buttressing effect of the aromatic ring substituents.

SCHEME I

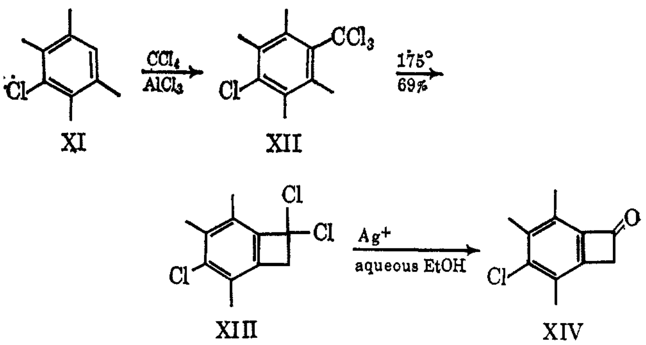


The structure of II is based on its elemental analysis, spectra, and subsequent conversions. Compound II gave an immediate precipitate with aqueous alcoholic silver nitrate; after removing the silver chloride, work-up of the filtrate gave an excellent yield of crystalline ketone III: mp 153–154°. Alternately, the ketone could be prepared by refluxing II with 90% aqueous acetone. Compound III had a split $\nu_{C=O}$ at 1773 and 1761 cm^{-1}, reasonable for a benzocyclobutenone.[7] It formed crystalline carbonyl derivatives (oxime and 2,4-DNP) and could be reduced by aluminum hydride in ether to the corresponding carbinol IV, mp 137–138°, whose structure was confirmed by oxidation to III with dichromate and acid. The alcohol was also converted, by conventional reactions, to the bromide V, nitrile VI, and carboxamide VII.

Trichloromethylmesitylene (VIII)[8] could also be converted in high yield to a benzocyclobutene (IX), mp 55–60°, but a temperature of 160–170° was required. IX was readily hydrolyzed to ketone X by dissolution in concentrated sulfuric acid and pouring the resulting deep red solution onto ice. The infrared spectrum of X showed a split carbonyl band at 1782 and 1750 cm^{-1}.[7] The nmr spectrum of X was consistent with the proposed structure, showing two aromatic protons (τ 2.94 and 3.10, singlets), two methylene protons (τ 6.25, singlet), and two methyl groups on the aromatic ring (τ 7.63 and 7.68, singlets).



The synthesis can be extended to benzocyclobutenes with groups other than alkyl on the aromatic ring. *E.g.*, chlorodurene (XI) was trichloromethylated and the resulting product (XII) converted in good yield to the trichlorotrimethylbenzocyclobutene XIII: mp 40–40.5°. Hydrolysis afforded the crystalline ketone XIV: mp 182.5–184°.



A number of transformations starting with ketone III (Scheme II) have been carried out, some of which will be reported here. Numerous attempts to reduce III to IV with various metal hydrides met with failure before the successful conversion with aluminum hydride, described above, was discovered. *E.g.*, when III was treated with sodium borohydride in diglyme at 90°, the only reduction product was pentamethylbenzyl alcohol (XV). With lithium aluminum hydride in refluxing tetrahydrofuran, the major product was pentamethylbenzyl alcohol (80%) but 10% of hexamethylbenzene (XVI) was also formed; at room temperature, the product was a mixture of IV and XV. It seems likely that reduction to IV is followed, in the alkaline

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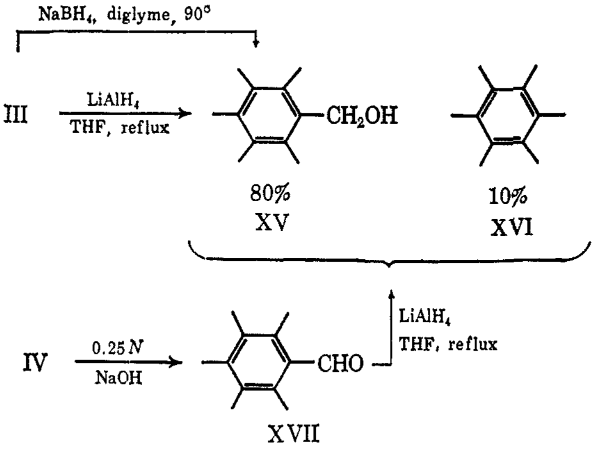
[5] H. Hart and R. W. Fish, *J. Am. Chem. Soc.*, **82**, 5149 (1960).

[6] Although this nomenclature is somewhat ambiguous, it is much more convenient and easier to visualize than the more systematic name (7,7-dichloro-2,3,4,5-tetramethylbicyclo[4.4.0]octa-1,3,5-triene) and will be used throughout. The position of the methyl groups (*i.e.*, on the aromatic ring, and not on the four-membered ring) should be clear from the context.

[7] M. P. Cava and K. Muth, *ibid.*, **82**, 652 (1960).

[8] H. Hart and R. W. Fish, *ibid.*, **83**, 4460 (1961).

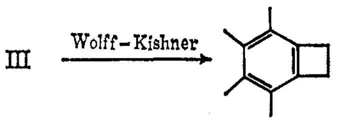
SCHEME II



reducing medium, by ring opening to pentamethylbenzaldehyde (XVII) which is the precursor of the pentamethylbenzyl alcohol and hexamethylbenzene. Separate experiments showed that IV was completely converted to XVII by 0.25 *N* aqueous sodium hydroxide in a few hours on the steam bath. Furthermore, reduction of XVII with lithium aluminum hydride in refluxing tetrahydrofuran gave the same mixture of XV and XVI as obtained from III under similar conditions.

The carbinol IV was not alone in being sensitive to ring opening by base. When ketone III was heated at reflux with 0.1 *N* 80% ethanolic sodium hydroxide, a high yield of pentamethylbenzoic acid was obtained. Similar reactions were reported for benzocyclobutenone itself,[7] but in that case the ring opened in both possible directions (*i.e.*, both *o*-toluic and phenylacetic acids were produced). Ring opening of III appears to be unidirectional.[9]

In view of these facile base-catalyzed ring-opening reactions, it is perhaps remarkable that III can be reduced to the tetramethylbenzocyclobutene (XVIII) in fair yield by the Huang-Minlon[10] modification of the

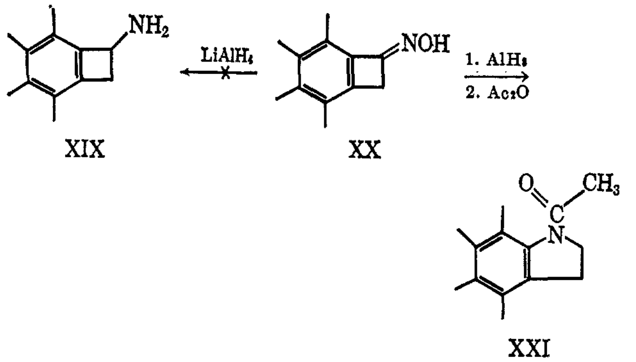


XVIII

Wolff-Kishner reduction. Compound XVIII is a crystalline hydrocarbon, mp 138–139°, with an infrared spectrum only slightly different from that of hexamethylbenzene. The structure is clear, however, from the nmr spectrum, which consisted of three singlets at τ 7.09, 7.94, and 8.00 with relative areas of 2:3:3 (τ for hexamethylbenzene is 7.85). The mass spectrum of XVIII tended to confirm the structure. The major peak was at the parent mass, *m/e* 160; the next most intense peak was at *m/e* 145 (M − CH_3). Decomposition to ethylene and tetramethylbenzyne was not a major fragmentation path, since there was virtually no peak at *m/e* 132 and only a minor peak at *m/e* 28. The ultraviolet spectrum of XVIII was quite different from that of hexamethylbenzene (Figure 1), showing both a shift to longer wavelength and an increase in absorption intensity.

In an attempt to prepare 1-aminotetramethylbenzocyclobutene (XIX), the oxime XX was reduced in various ways. Lithium aluminum hydride led only to sensitive products which rapidly decomposed to highly colored materials. Reduction with aluminum hydride did afford a basic product which, however, was not the desired amine.

Acetylation gave crystalline N-acetyl-4,5,6,7-tetramethyl-2,3-dihydroindole (XXI), whose structure followed from its analysis and nmr spectrum (see Experimental Section). This product probably arose from a Beckmann rearrangement of XX brought about by aluminum chloride in the reductant.



The major product from the reduction of XX was not basic. It was probably a nitroso dimer, as shown by infrared bands at 1280 and 2320 cm^{-1}, and by its reconversion to XX on refluxing in isopropyl alcohol.[11]

Nmr Spectra.—The nmr spectra of benzocyclobutenes have been discussed by several groups.[12–14] The general picture derived from such studies seems to be that the four-membered ring is not planar, but skewed, and possibly not flipping.[14] The angles of skew calculated by application of the Karplus equation[15] are much larger than those observed in the crystal[16] and we are inclined to view such calculations[12,14] with skepticism.

The nmr spectra of IV and V agree reasonably well with those of similar compounds.[14] The three protons on the four-membered ring of IV appeared as a doublet at τ 4.20 and an AB quartet centered at τ 6.94, the low-field half of which was further split into a doublet corresponding to the τ 4.20 proton. Analysis as an ABX system gave chemical shifts of τ 7.26, 6.62, and 4.20 with $J_{AB} = 13.5$ cps, $J_{AX} \leqslant 1$ cps, $J_{BX} = 4$ cps. Reduction of III with aluminum deuteride gave XXII, whose nmr spectrum (except for the allylic methyls)

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[9] In footnote 6 of ref 1a it was claimed that III underwent a base-catalyzed exchange of hydrogen for deuterium, without ring opening. Numerous subsequent attempts to repeat this experiment, and many variations of it, have led to failure (R. W. F. and J. A. H.). It must be concluded that III does not readily form an enolate ion in base. Compound III was also recovered unchanged from refluxing 1*N* ethanolic hydrogen chloride.

[10] Huang-Minlon, *J. Am. Chem. Soc.*, **68**, 2487 (1946).

[11] D. H. R. Barton, J. M. Beaton, L. E. Geller, and M. M. Pechet, *ibid.*, **82**, 2640 (1960).

[12] A. T. Blomquist and C. G. Bottomley, *Ann.*, **653**, 67 (1962).

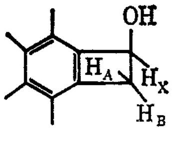
[13] H. Nozaki, R. Noyori, and N. Kozaki, *Tetrahedron*, **20**, 641 (1964).

[14] G. Fraenkel, Y. Asahi, M. J. Mitchell, and M. P. Cava, *ibid.*, **20**, 1179 (1964). Several rather confusing errors appear in this paper. *E.g.*, in the text (p 1182, top) $J_{cis} < J_{trans}$, whereas in the Table I where the data are presented, these values are reversed. We assume the table to be correct, since these results are consistent with those of other workers. At the same point (p 1182, top) the data of Blomquist and Bottomley (our ref 12) are misquoted, and the assignment reversed to coincide with the above error in the text.

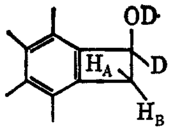
[15] M. Karplus, *J. Chem. Phys.*, **30**, 11 (1959).

[16] G. L. Handgrove, Jr., *U. S. At. Energy Comm.*, 8803, 70 (1959); *Chem. Abstr.*, **56**, 2875 (1960).

consisted of the expected AB quartet, with no further splitting of either branch.



IV

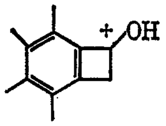


XXII

The nmr spectrum of V was similar to that of IV: a doublet at τ 4.78 and a quartet at τ 6.76 and 6.36, with the lower branch further split into doublets. Coupling constants were J_{AB} = 14 cps, J_{AX} $\lesssim$ 1 cps, and J_{BX} = 4 cps. The low-field proton of the AB quartets in IV and V is assigned to the proton *trans* to the functional group, *i.e.*, $J_{cis} > J_{trans}$ for protons on the four-membered ring.[12-14] Values of J_{trans} seem to be considerably smaller in these compounds than when the benzene ring is unsubstituted. The values of these coupling constants may be affected by the electronegativity of the groups attached to both rings, thus clouding the significance of angles calculated from the Karplus equation.

The behavior of ketones III and X in concentrated sulfuric acid indicated that they could be reversibly protonated on the carbonyl oxygen without ring opening. The nmr spectrum of III in carbon tetrachloride consisted of a singlet at τ 6.32 due to the methylene group, and two peaks at τ 7.81 and 7.88 corresponding to 9 and 3 methyl protons, respectively. In 98% D_2SO_4, the methylene protons were shifted downfield to τ 5.80, and the peaks due to the aryl methyls became equal in intensity, at τ 7.67 and 7.84. Hydrolysis of the sulfuric acid solution gave quantitative recovery of the ketone. Similar shifts were observed with X (these are described in the Experimental Section).

These change in the nmr spectra were accompanied by parallel changes in the ultraviolet spectra. Thus the spectrum of III in ethanol consists of two broad maxima at 306 mμ (log ϵ 3.47) and 265 mμ (log ϵ 4.18). These are changed, in 100% sulfuric acid, to peaks at 380 mμ (log ϵ 3.31) and 320 mμ (log ϵ 4.26). Thus it would appear that carbonium ions of the type XXIII are reasonably stable. Indeed, we have prepared a number of stable benzocyclobutenyl cations with aryl groups in place of the hydroxyl group, in XXIII. These will be the subject of a separate paper.



XXIII

Experimental Section[17]

1,1-Dichlorotetramethylbenzocyclobutene (II).[6]—Into each of three 8-in. test tubes was placed 3.00 g (0.0113 mole) of trichloromethylpentamethylbenzene.[5] The reaction tubes were heated in an oil bath at 115–120° under a stream of nitrogen for 3 hr. Hydrogen chloride evolution, as measured by passing the exit nitrogen stream through a trap containing standard sodium hydroxide solution, was complete after this time period. The brown oil which remained solidified upon cooling. The combined solids were recrystallized from pentane, using Norit for decolorization, and yielded 6.95 g (89%) of II as white platelets: mp 69–71°. Several further recrystallizations raised the melting point to 73–74°.

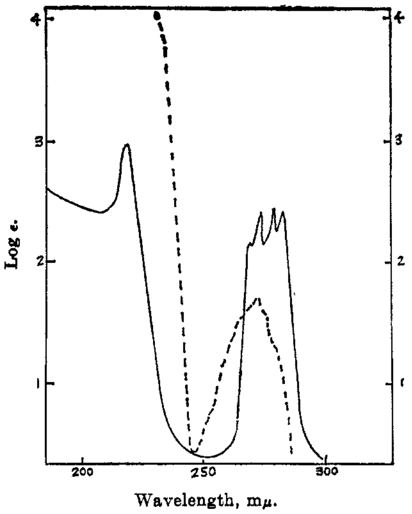


Figure 1.—The ultraviolet absorption spectra of (———), tetramethylbenzocyclobutene (XVIII); (- - - -), hexamethylbenzene (XVI). The solvent is cyclohexane.

Anal. Calcd for $C_{12}H_{14}Cl_2$: C, 62.89; H, 6.16; Cl, 30.95. Found: C, 62.93; H, 6.27; Cl, 30.88.

The ultraviolet spectrum in cyclohexane showed a complex series of bands [six maxima at 253, 260, 265, 276, 283, and 287 mμ (log ϵ 3.22, 3.22, 3.26, 3.43, 3.44, and 3.47, respectively] to be contrasted with the spectrum of I, which showed only two broad maxima at 302 mμ (log ϵ 3.19) and 250 mμ (log ϵ 3.89) in the same solvent.

Tetramethylbenzocyclobutenone (III).—The procedure for preparation of II was followed to the point at which crude II was obtained. This was then refluxed for 4 hr in 75 ml of 90% aqueous acetone. The solvent was then evaporated on a steam bath, leaving a tan solid which was recrystallized twice from 95% ethanol, giving 4.84 g (82% over-all) of III as white needles: mp 153–154°. The same ketone was obtained in nearly quantitative yield by warming II (3.5 g) with a solution of 6.5 g of silver nitrate in 100 ml of 80% aqueous ethanol, filtration of the silver chloride, evaporation to dryness, and recrystallization from 95% ethanol.

Anal. Calcd for $C_{12}H_{14}O$: C, 82.72; H, 8.10. Found: C, 82.75; H, 8.16.

The ketone had a split carbonyl band at 1773 and 1761 cm^{-1} (CS_2 solution) which appeared as a single band at 1765 cm^{-1} in carbon tetrachloride solution. The ultraviolet spectrum in ethanol had two broad maxima, at 306 mμ (log ϵ 3.47) and 265 mμ (log ϵ 4.18). The nmr spectrum of III consisted of a singlet at τ 6.32 (2H), and two broad peaks at τ 7.81 and 7.88 corresponding to nine and three protons, respectively.

In 98% D_2SO_4, the nmr spectrum consisted of singlets at τ 5.80, 7.67, and 7.84 with relative areas 1:3:3. The ultraviolet spectrum in 100% H_2SO_4 had maxima at 380 mμ (log ϵ 3.31) and 320 mμ (log ϵ 4.26). The ketone was recovered quantitatively (melting point, infrared spectrum) when sulfuric acid solutions of it were hydrolyzed within 1–2 hr; longer standing resulted in structural changes, as judged by changes in the nmr spectrum.

The oxime XX consisted of white granules: mp 179–180° (from cyclohexane–ether).

Anal. Calcd for $C_{12}H_{15}NO$: C, 76.15; H, 7.99; N, 7.40. Found: C, 76.06; H, 7.91; N, 7.56.

The 2,4-dinitrophenylhydrazone consisted of long red-orange needles: mp 300° dec (from ethyl acetate–ethanol).

Anal. Calcd for $C_{18}H_{18}N_4O_4$: C, 61.06; H, 5.12; N, 15.81. Found: C, 61.08; H, 5.08; N, 15.73.

Tetramethylbenzocyclobutenol (IV).—Aluminum hydride was prepared from 1.05 g (0.0273 mole) of lithium aluminum hydride and 1.19 g (0.0090 mole) of aluminum chloride in 50 ml of anhy-

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[17] All analyses by Spang Microanalytical Laboratory, Ann Arbor, Mich. Melting points are uncorrected.

drous ether.[18] The filtered clear solution of aluminum hydride was diluted with 50 ml of dry ether, and 6.00 g (0.0345 mole) of tetramethylbenzocyclobutenone in 50 ml of ether was added slowly with stirring over a 0.75-hr period. After the addition was complete the mixture was stirred for 4 hr. Small chips of ice were added to hydrolyze any excess aluminum hydride before the reaction mixture was poured into 100 ml of water containing 10 ml of concentrated hydrochloric acid. The ether layer was separated, washed with 50 ml of water, and dried over anhydrous calcium chloride. The ether was evaporated, leaving 5.85 g (96.5%) of white solid which was recrystallized once from petroleum ether (bp 60–90°) to produce 5.58 g (92.1%) of fine white needles of IV: mp 137–138°.

Anal. Calcd for $C_{12}H_{16}O$: C, 81.77; H, 9.15. Found: C, 81.66; H, 9.08.

The infrared spectrum (CCl_4 solution) showed a sharp hydroxyl band at 3585 cm^{-1} and a broader, less intense band at 3493 cm^{-1}. The nmr spectrum (in $CHCl_3$) is discussed in the text.

The deuterio analog (XXII) was synthesized in the same way, using lithium aluminum deuteride in place of the hydride. Its nmr spectrum (in $CDCl_3$) consisted of a two-proton quartet centered at τ 6.62 and 7.26 (J = 14 cps) and two broad singlets at τ 7.89 and 7.95 corresponding to nine and three protons, respectively. The infrared showed a weak C–D stretch band at 2160 cm^{-1}.

Compound IV was reoxidized to III as follows. To a stirred solution of 0.50 g (0.00284 mole) of IV in 10 ml of ether was added in 15 min a solution containing 5 ml of water, 0.5 ml of 96% sulfuric acid, and 0.30 g (1.14 mmoles) of sodium dichromate. The aqueous layer turned green in a short time. After 6 hr the ether layer was separated and washed with 15 ml of 5% sodium bicarbonate solution and two 15-ml portions of water. The ether was evaporated to give 0.40 g of white needles: mp 153–154° (from ethanol). The infrared spectrum was identical with that of authentic tetramethylbenzocyclobutenone.

1-Bromo-3,4,5,6-tetramethylbenzocyclobutene (V).—A flask containing 5.40 g (0.020 mole) of phosphorus tribromide was chilled in an ice bath and 7.00 g (0.0402 mole) of tetramethylbenzocyclobutenol in 100 ml of methylene chloride was added dropwise. After the addition was complete, stirring was continued for 1 hr. Small chips of ice were added to slowly hydrolyze excess phosphorus tribromide, and then the reaction solution was poured into 100 ml of water. The methylene chloride layer was separated, washed with water, and dried over anhydrous calcium chloride. The methylene chloride was evaporated, leaving a low melting solid which was recrystallized from methanol–water to give 5.60 g (58%) of white crystals: mp 44.4–46°. One more recrystallization gave small needles: mp 45–46°. Repetition of this reaction produced 1-bromotetramethylbenzocyclobutene (V) in 71, 31, and 57% yields.

Anal. Calcd for $C_{12}H_{15}Br$: C, 60.26; H, 6.32. Found: C, 60.34; H, 6.37.

The nmr spectrum (CCl_4 solution) had a doublet at τ 4.78 (one proton, J = 4 cps), an AB quartet at τ 6.36 and 6.76 (one proton each, J = 14 cps), with the lower field branch further split into doublets (J = 4 cps), and two singlets at τ 7.88 and 7.94 (nine and three protons, respectively).

1-Cyano-3,4,5,6-tetramethylbenzocyclobutene (VI).—A solution of 0.80 g (3.35 mmoles) of 1-bromo-3,4,5,6-tetramethylbenzocyclobutene (V) and 0.34 g (6.9 mmoles) of sodium cyanide in 9 ml of dimethyl sulfoxide was allowed to stand for 0.5 hr at room temperature. The solution was cooled in an ice bath and 30 ml of water was added, causing a white precipitate to form which was extracted with 30 ml of ether. The ether was evaporated leaving a cream solid. Recrystallization of this material once from petroleum ether produced 0.52 g (83%) of white crystals: mp 62–65°. Two more recrystallizations from ethanol produced pure VI as white needles: mp 70–71°.

Anal. Calcd for $C_{13}H_{15}N$: C, 84.28; H, 8.16. Found: C, 84.16; H, 8.00.

The infrared spectrum (CCl_4 solution) showed a sharp C≡N band at 2217 cm^{-1}. The nmr spectrum of VI in CCl_4 solution consisted of complex multiplets at τ 6.15 and 6.70 and two singlets at τ 7.87 and 7.97, with relative areas 1:2:9:3.

1-Carboxamido-3,4,5,6-tetramethylbenzocyclobutene (VII).—To 0.50 g (0.0027 mole) of 1-cyanotetramethylbenzocyclobutene (VI) was added 1 ml of 30% hydrogen peroxide and 2 ml of 20% sodium hydroxide solution. The mixture was stirred for 15 min and warmed on a steam bath to 60° until oxygen evolution ceased (15 min). Ethanol (10 ml) was added and warming was continued for an additional 10 min. On cooling, a white precipitate formed which was filtered, washed with water, and dried to produce 0.30 g (55%) of VII as a white solid: mp 237–240°. The compound was recrystallized from methanol to give white needles: mp 260-261°. The infrared spectrum (mineral oil mull) showed a carbonyl band at 1642 cm^{-1}.

Anal. Calcd for $C_{13}H_{16}NO$: C, 77.19; H, 7.97. Found: C, 76.93; H, 7.91.

1,1-Dichloro-4,6-dimethylbenzocyclobutene (IX).—In each of three 8-in. test tubes was placed 5.68 g (0.0239 mole) of trichloromethylmesitylene.[8] The tubes were heated in an oil bath, under a stream of nitrogen. Hydrogen chloride evolution commenced when the bath temperature reached 160°. The temperature was maintained at 170° for 3 hr, after which hydrogen chloride evolution ceased. The tubes were cooled to room temperature, producing a light tan solid. The combined product was recrystallized twice from pentane, yielding 12.10 g (84%) of IX as white cubes: mp 55–60°.

Anal Calcd for $C_{10}H_{10}Cl_2$: C, 59.72; H, 5.01; Cl, 35.26. Found: C, 59.90; H, 5.10; Cl, 35.27.

4,6-Dimethylbenzocyclobutenone (X)—To 55 ml of concentrated sulfuric acid cooled in an ice bath was slowly added (1 hr), with stirring, a solution of 9.00 g (0.0448 mole) of IX in 15 ml of ethanol. Hydrogen chloride was evolved, and the solution turned dark red. It was poured over 300 g of ice, and a white precipitate formed immediately. This precipitate was taken up in 50 ml of pentane and washed once with 25 ml of 5% sodium bicarbonate and twice with 25 ml of distilled water. The pentane was evaporated under a stream of dry air, leaving a white solid which was recrystallized twice from ethanol–water to yield 5.71 g (87%) of X as white needles: mp 45–46°.

Anal. Calcd for $C_{10}H_{10}O$: C, 82.16; H, 6.89. Found: C, 81.84; H, 7.07.

The same conversion could be affected using ethanolic silver nitrate, as described above for III The infrared spectrum of X in carbon tetrachloride showed a split carbonyl band at 1782 and 1750 cm^{-1}. Its nmr spectrum in carbon tetrachloride showed singlets at τ 2.94, 3.10, 6.25, 7.63, and 7.68 with relative areas 1:1:2:3:3. In 98% sulfuric acid, this was changed to singlets at τ 2.66, 5.66, 7.45, and 7.53 with relative areas 2:2:3:3.

Trichloromethylation of Chlorodurene.—A slurry of 37.2 g (0.28 mole) of powdered anhydrous aluminum chloride and 100 ml of carbon tetrachloride was warmed to 37–42° while a solution of 23.6 g (0.14 mole) of chlorodurene in 100 ml of carbon tetrachloride was added, with stirring, dropwise over a 2-hr period. After addition was complete, heating and stirring were continued for an additional 2 hr.

The deep purple mixture was hydrolyzed by adding it slowly, with vigorous stirring, to a mixture of 100 g of ice, 10 ml of concentrated hydrochloric acid, and 150 ml of carbon tetrachloride. The organic layer was separated, and two 50-ml carbon tetrachloride extracts of the aqueous layer were added to it. Combined organic layers were washed successively with 100 ml of water, two 100-ml portions of 5% sodium carbonate, and 100 ml of water. After drying over calcium chloride, and removal of the solvent, the dark oily residue was dissolved in pentane, treated with Norite, cooled in Dry Ice, and the brown precipitate was filtered under a nitrogen atmosphere. Four recrystallizations from pentane gave 22 g (56%) of white plates of 4-chloro-2,3,5,6-tetramethylbenzotrichloride (XII): mp 72–73°. The nmr spectrum of XII in carbon tetrachloride consisted of two equal singlets at τ 7.43 and 7.64.

Anal. Calcd for $C_{11}H_{12}Cl_4$: C, 46.18; H, 4.23; Cl, 49.58. Found: C, 46.49; H, 4.35; Cl, 49.58.

1,1,4-Trichloro-3,5,6-trimethylbenzocyclobutene (XIII).—A flask containing 5.0 g (.0175 mole) of 4-chloro-2,3,5,6-tetramethylbenzotrichloride (XII) was heated in an oil bath at 175° for 3 hr, with a stream of dry nitrogen passing through. At the end of this time, no further hydrogen chloride was evolved. The residue, on cooling, remained an oil and could not be induced to crystallize. It was distilled, the major fraction being collected from 94–104° (0.5 mm). This crystallized on standing, and, after recrystallization from pentane, gave 3.10 g (69%) of colorless XIII: mp 40.0–40.5°.

Anal. Calcd for $C_{11}H_{11}Cl_3$: C, 52.94; H, 4.44; Cl, 42.62. Found: C, 53.07; H, 4.46; Cl, 42.40.

4-Chloro-3,5,6-tetramethylbenzocyclobutenone (XIV).—To 0.50 g of XIII in 10 ml of ethanol was added a solution of

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[18] M. J. Jorgenson, *Tetrahedron Letters*, **No. 13**, 559 (1962).

0.71 g of silver nitrate in 10 ml of 80% aqueous ethanol. The immediately formed precipitate of silver chloride was removed by filtration, and the filtrate was evaporated to dryness. The residue was stirred with anhydrous ether and filtered; the filtrate was evaporated to dryness, yielding 0.35 g (89%) of crude product, which was recrystallized from aqueous ethanol, then sublimed to give white needles of XIV: mp 182.5–184°.

Anal. Calcd for $C_{11}H_{11}ClO$: C, 67.87; H, 5.70; Cl, 18.21. Found: C, 67.81; H, 5.79; Cl, 18.23.

The main carbonyl band was at 1754 cm^{-1} (CS_2 solution) but sharp, small shoulders were noted at 1842 and 1689 cm^{-1} (possibly overtones). The nmr spectrum in carbon tetrachloride consisted of two rather sharp singlets at τ 6.25 and 7.68, relative areas 2:9.

Reduction of III with Sodium Borohydride.—A solution of 1.90 g (0.0109 mole) of tetramethylbenzocyclobutenone (III) in 50 ml of diglyme was added 1.5 hr), with stirring, to 2.50 g of sodium borohydride in 50 ml of diglyme. The temperature was raised to 90° and maintained there for 8 hr. The mixture was then poured over 100 g of ice and 25 ml of concentrated hydrochloric acid. Work-up gave a crude product which showed carbonyl and hydroxyl absorption in the infrared. The product was chromatographed on an alumina column using petroleum ether (bp 30–60°) as eluent. Two materials were separated and identified by melting point and infrared spectrum. They were unchanged III (0.38 g, 20%) and pentamethylbenzyl alcohol: mp 158–159° (1.07 g, 55%).[19]

Reduction of III with Lithium Aluminum Hydride.—To a stirred refluxing solution of 2.00 g (0.0527 mole) of lithium aluminum hydride in 100 ml of freshly distilled tetrahydrofuran was added 1.80 g (0.0103 mole) of tetramethylbenzocyclobutenone dissolved in 50 ml of freshly dried tetrahydrofuran, over a 1-hr period. The solution was stirred at reflux for 4 hr after addition was complete. Work-up with acid hydrolysis yielded 1.62 g of a white powder: mp 153–157°. Its infrared spectrum showed no carbonyl absorption. The mixture was chromatographed on 25 g of 24 F Alcoa alumina using petroleum ether as eluent. The first product through the column was hexamethylbenzene: mp 160–161° (0.16 g, 10%). The second material was 1.46 g (80%) of pentamethylbenzyl alcohol: mp 158–159°. It had an identical infrared spectrum with an authentic sample.[19]

A similar reduction for four hours at room temperature led to a mixture of alcohols, mp 138–140°, which was predominantly (*ca.* 90%, using nmr for analysis) IV, but contained about 10% of XV. The mixture could not be resolved by recrystallization from petroleum ether, chromatography on alumina, or vacuum sublimation.

Reaction of IV with Alkali.—A mixture of 0.05 g (0.28 mmole) of tetramethylbenzocyclobutenol (IV) and 2 ml of 0.25 *N* aqueous sodium hydroxide was shaken at room temperature for 2 hr; the mixture was then filtered and the solid washed with distilled water. It was entirely recovered unchanged IV (infrared). A similar mixture was heated for 5 hr on the steam bath; work-up gave a quantitative yield of pentamethylbenzaldehyde, mp 137–138°, identical (infrared) with an authentic sample.[20]

Reduction of Pentamethylbenzaldehyde with Lithium Aluminum Hydride.—A solution of 1.50 g of pentamethylbenzaldehyde in 25 ml of tetrahydrofuran was added to a refluxing mixture of 1.50 g of lithium aluminum hydride in 25 ml of tetrahydrofuran, and the whole refluxed for 8 hr. The white product which was obtained on acidic work-up consisted of 90% pentamethylbenzyl alcohol and 10% hexamethylbenzene, as determined by vpc (20% silicone on Chromosorb, 180°) and by column chromatography. The products from a similar reduction of III were obtained in the same weight per cent ratio.

Reaction of III with base and acid.—A solution of 0.29 g of tetramethylbenzocyclobutenone (III) in 5 ml of ethanol and 3 ml of water containing 0.1 g of dissolved sodium metal was refluxed for 3 hr; addition of 30 ml of ice–water and extraction with pentane led to only a trace of unchanged III. Acidification of the aqueous layer gave a white precipitate which was identified (melting point, infrared) as pentamethylbenzoic acid;[19] the yield was over 90%.

When the experiment was repeated using only 0.50 g of sodium, and D_2O in place of H_2O, 41% of III was recovered unchanged. Integration of its nmr peak at τ 6.32 showed no decrease (no D exchange) and the infrared spectrum showed no C–D stretching band. Acidification led to recovery of 44% of pentamethylbenzoic acid.

Similar experiments, but using *p*-toluenesulfonic acid or hydrochloric acid (1 *N*) led to complete recovery of III and no deuterium exchange. Experiments with 98 and 100% sulfuric acid are described in the text.

Tetramethylbenzocyclobutene (XVIII).—A mixture of 2.00 g (0.0115 mole) of tetramethylbenzocyclobutenone, 35 ml of triethylene glycol, and 30 ml of 85% hydrazine hydrate was heated to reflux for 0.5 hr before 2.00 g of potassium hydroxide in 10 ml of water was added. Reflux was continued for another 0.5 hr. Water and excess hydrazine were distilled from the flask until the reaction temperature reached 180°. White material began to sublime and collect on the sides of the reaction vessel. The reaction temperature was maintained at 180° for an additional 3 hr. The sublimed material was collected on a cold condenser and recrystallized from petroleum ether to give 0.83 g (46%) of XVIII as white crystals: mp 138–139°.

Anal. Calcd for $C_{12}H_{16}$: C, 89.95; H, 10.05. Found: C, 89.92; H, 10.04.

The infrared spectrum (CCl_4 solution) was relatively simple; besides the broad C–H band at 2930 cm^{-1} there was another broad, intense band at 1463 cm^{-1}, and less intense, sharper bands at 1410, 1383, 1333, 1261, 1200, and 1067 cm^{-1}. The nmr spectrum (CCl_4 solution) consisted of three singlets at τ 7.09, 7.94, 8.00, relative areas 2:3:3. The mass spectrum had predominant peaks and relative intensities as follows: 160 (100), 145 (58), 130 (16), 129 (14), 128 (13), 115 (13), 105 (10), 91 (14), 77 (10), 51 (11), 40 (21), 27 (17); peaks with intensity below 10 are not given.

Reduction of Tetramethylbenzocyclobutenone Oxime (XX).—Aluminum hydride in 100 ml of ether was prepared in the amounts as described above in the preparation of IV. To this solution was added a solution of 1.70 g (0.0090 mole) of tetramethylbenzocyclobutenone oxime in 100 ml of ethyl ether. The reaction mixture was stirred at room temperature under a stream of dry nitrogen for 4 hr, then poured into an equal quantity of water, extracted with 25 ml of 5% hydrochloric acid, and washed with 25 ml of water. The hydrochloric acid solution was neutralized to pH 8 and treated with 5 ml of acetic anhydride. Sodium acetate was added to the solution until it was neutral. A white precipitate formed which was filtered and recrystallized twice from pentane to give 0.10 g of white needles: mp 120–121°. The infrared spectrum had strong absorption at 1650 cm^{-1}, but no absorption in the frequency range characteristic of N–H stretch. The nmr spectrum showed two triplets of equal intensity centered at τ 6.00 and 7.15 (J = 7.0 cps) which integrated for two protons each. There were three singlets at τ 7.89, 7.95 and 7.97 which integrated for 15 protons. This compound was identified as N-acetyl-4,5,6,7-tetramethyl-2,3-dihydroindole (XXI).

Anal. Calcd for $C_{14}H_{19}NO$: C, 77.38; H, 8.81; N, 6.44. Found: C, 77.15; H, 8.91; N, 6.40.

The ether-soluble product which was not extracted into the hydrochloric acid gave a heavy white precipitate on evaporation to dryness. The product melted and decomposed at 182–184° and gave a melting point of 177–179° when mixed with starting material. The nmr spectrum in $CDCl_3$ showed singlets at τ 6.20, 6.37, and 7.44 with area ratios 2:1:2 and a multiplet at 7.78. This product has not been positively identified, but it is thought that the most plausible structure is that of a nitroso dimer.

Strong infrared absorption at 1280 cm^{-1} can be assigned to the *trans* nitroso dimer[21] and absorption at 2320 cm^{-1} can be assigned to a NO, N=O combination band.[22]

An ether solution of this product quickly turned black when hydrogen chloride was bubbled through it.

It is well documented[11] that nitroso dimers are easily converted to oximes when refluxed in isopropyl alcohol. Approximately 0.10 g of the white solid product from the reduction was refluxed for 4 hr in 5 ml of isopropyl alcohol and the solution then cooled in the refrigerator. A fair yield of white crystals formed: mp 171–175° (compare with 179–180° for the oxime). The infrared spectrum of this material in a mineral oil mull was identical with that of tetramethylbenzocyclobutenone oxime.

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[19] O. Jacobsen, *Ber.*, **22**, 1215 (1889).

[20] H. Clement, *Bull. Soc. Chim. France*, **55**, 1011 (1938).

[21] P. Kabasakalian and E. R. Townley, *J. Am. Chem. Soc.*, **84**, 2711 (1962).

[22] L. J. Bellamy, "The Infrared Spectra of Complex Molecules," John Wiley and Sons, Inc., New York, N. Y., 1959, p 307.

Additional attempts to reduce (XX) with lithium aluminum hydride were made, but in each case products were formed which quickly decomposed to highly colored materials which decomposed further. No attempt was made to characterize these products.

Acknowledgment.—We are indebted and grateful to the National Science Foundation (J. A. H.) and to the Petroleum Research Fund of the American Chemical Society (R. W. F., R. R. R.) for financial support.

6-Substituted Bicyclo[3.1.1]heptanes[1]

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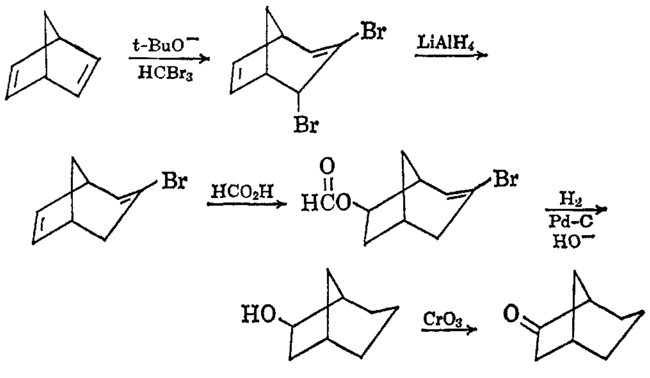
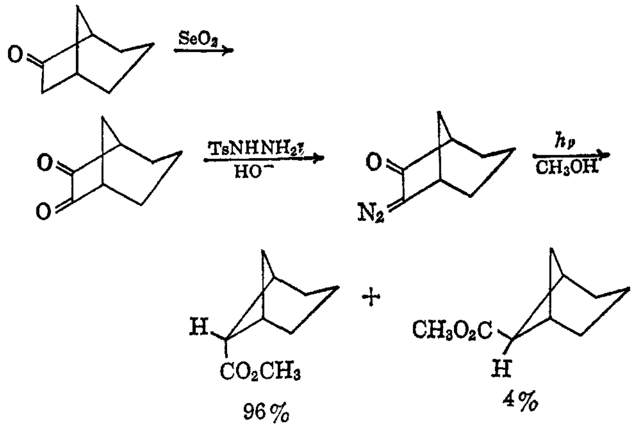
Received February 15, 1966

The synthesis of some 6-substituted bicyclo[3.1.1]heptanes is described, and the nmr spectra are discussed and compared with those of the corresponding bicyclo[2.1.1]hexanes.

In connection with another study, several 6-substituted bicyclo[3.1.1]heptanes were needed. The simplest method for obtaining these compounds would be *via* the ring contraction of bicyclo[3.2.1]octan-6-one, in analogy with the preparation of 5-substituted bicyclo[2.1.1]hexanes from norcamphor and its derivatives.[3] The preparation of 3-bromobicyclo[3.2.1]oct-3-en-6-yl formate was effected by the procedure of Sauers[4] in which dibromocarbene is added to norbornadiene,[5] followed by lithium aluminum hydride reduction and addition of formic acid. Hydrogenation using palladium on carbon in basic solution led to reduction of the double bond, hydrogenolysis of the bromine, and hydrolysis of the formate group, leading to bicyclo[3.2.1]octan-6-ol. Oxidation with chromic acid gave the ketone.



Selenium dioxide converted the ketone to bicyclo[3.2.1]octa-6,7-dione (76%) which was converted to the monotosylhydrazone (75%) and then to 7-diazobicyclo[3.2.1]octan-6-one (83%) with aqueous base. Photolysis of the diazo ketone in anhydrous methanol gave methyl bicyclo[3.1.1]heptane-6-carboxylate (75%). Vapor phase chromatography indicated the presence of two compounds in a 96:4 ratio.



The major fraction from the photolysis was shown to be the *endo* isomer by its nmr spectrum. It had a doublet at τ 8.76 ($J = 9.0$ cps) which corresponds to the upfield doublet of the 5-*endo*-substituted bicyclo[2.1.1]hexanes.[3,6] The proton is presumably the *endo* hydrogen on the methylene bridge, and the coupling constant is that for the *gem* coupling. The minor fraction appeared to be the *exo* isomer, because of the identity of its retention time with that of an authentic sample of the *exo* ester prepared as described below. The *exo* isomer could be identified by its nmr spectrum. It had a multiplet at τ 8.71 corresponding to two doublets ($J = 9.0$ and 6.0 cps). The 9.0-cps coupling constant results from the *gem* coupling, and the 6.0-cps constant results from the long-range coupling between the *endo* protons on the four-membered ring. This is again analogous to the bicyclo[2.1.1]hexanes.[3,6] Throughout the series of compounds to be discussed, the configuration could be established by an examination of the upfield band. The nmr spectra of all of the compounds will be discussed at the end of this paper.

The pure *endo* methyl ester was isolated by preparative vpc. Reduction with lithium aluminum hydride gave *endo*-bicyclo[3.1.1]heptane-6-carbinol.

endo-Bicyclo[3.1.1]heptane-6-carboxylic acid was prepared by base-catalyzed hydrolysis of the ester. It was converted to the acid chloride with thionyl chloride, and still had the *endo* configuration as shown by the nmr spectrum. The acid chloride was treated with the magnesium salt of diethyl malonate, and the product was subjected to acid hydrolysis giving bicyclo[3.1.1]heptyl-6 methyl ketone. The upfield nmr band was a multiplet, suggesting that epimerization had

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(1) This work was supported by the Army Research Office (Durham).

(2) Taken from part of the Ph.D. thesis of B.A.H., 1966.

(3) L. Horner and E. Spietschka, *Ber.* **88**, 934 (1955); J. Meinwald and P. G. Gassman, *J. Am. Chem. Soc.*, **82**, 2857 (1960); **82**, 5445 (1960); K. B. Wiberg, B. R. Lowry, and T. H. Colby, *ibid.*, **83**, 3998 (1961); K. B. Wiberg and B. R. Lowry, *ibid.*, **85**, 3188 (1963); J. Meinwald, C. B. Jensen, A. Lewis, and C. Swithenbank, *J. Org. Chem.*, **29**, 3469 (1964).

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