tive was isolated by extraction and purified by chromatography on neutral alumina followed by sublimation to give 2.1 g. of pure N-acetyl-*endo*-norbornylamine-2-*d*, m.p. 127–128° (lit.[16] 124°), infrared absorption (in CCl_4) at 2.95, 6.05, 6.5 and 7.3μ,[32] deuterium content 1.00 atom per molecule (analysis performed by J. Nemeth, Urbana, Ill.).

***endo*-Norbornylamine-2-*d* Hydrochloride.**—The above acetyl derivative (2.0 g.) was hydrolyzed at reflux for 40 hours with 30 ml. of 6 *N* hydrochloric acid. Evaporation under reduced pressure and crystallization of the residue from ether–cyclohexane gave 1.75 g. of the hydrochloride as colorless silky needles, m.p. 295° dec.

Deamination of *endo*-Norbornylamine-2-*d* in Acetic Acid.—The conditions of Berson and Ben-Efraim[5] were adhered to exactly using 1.70 g. of the amine hydrochloride, 8.95 ml. of glacial acetic acid, 0.945 g. of sodium acetate and 1.28 g. and 0.32-g. portions of sodium nitrite. Distillation of the crude product gave 947 mg. of acetate, b.p. 170° (bath) at 155 mm. This was converted to norborneol with lithium aluminum hydride-ether; isolation of the product by extraction with ether concentration and sublimation at 130° (155 mm.) gave 567 mg. of norborneol, m.p. 119–121°, which by V.P.C. analysis on a 4-meter tricyanoethoxypropane column (15% on firebrick) at 140° was shown to consist of 95 ± 1% *exo* and 5 ± 1% *endo*-norborneol. Deuterium analysis (performed by Mr. J. Nemeth) showed the presence of 1.00 atom deuterium per molecule.

Oxidation of Norborneol-*d* to Norcamphor-*d* with Ruthenium Tetroxide.—To a solution of 37 mg. of the above deuteriated norborneol in 2 ml. of Freon 11 (trichlorofluoromethane) at 0° was added a slight excess (over one equivalent) of a bromine-free solution of ruthenium tetroxide[33]—Freon 11. After a few minutes a few drops of ether was added to destroy the excess oxidizing agent and the mixture was kept for 5 minutes, then filtered and concentrated and sublimed to give 23 mg. of norcamphor, m.p. 88–89°; infrared absorption (CCl_4) at 5.7, 6.9 and 7.1μ. Deuterium analysis of this and several check runs by mass spectrometer[34] showed the presence of 0.42 ± 0.003 deuterium atom per molecule.

Treatment of the deuteriated norcamphor (20 mg.) with 3 ml. of methanol and 2 ml. of *N* sodium hydroxide at reflux under nitrogen for 6 hours and reisolation gave norcamphor (m.p. 88–89°) of essentially the original deuterium content (0.414 ± 0.003 deuterium per molecule), eliminating the possibility that 3-deuteriated 2-norbornyl acetate had been produced in significant amount in the deamination.

The n.m.r. spectrum of the deuteriated norcamphor differed from that of unlabeled norcamphor in that the relative intensities of the two peaks downfield (at 7.43 and 7.62τ) were 1.0 to 0.6 ± 0.05 in the former and 1.0 to 1.0 in the latter, the measurements being made in CCl_4 or CS_2 using a Varian A-60 spectrometer with electronic integration of signal. These two peaks can be assigned to the bridgehead positions since deuteriation of the α-methylene group in norcamphor leaves their intensities unchanged and diminishes the upfield peaks.

***p*-Nitrophenyl-(*m*-chlorosulfonyl) Benzoate.**—*p*-Nitrophenol (5.56 g., 40 mmoles) was added all at once to a solution of 9.56 g. (40 mmoles) of *m*-chlorosulfonylbenzoyl chloride[35] and pyridine (3.20 ml., 40 mmoles) in 110 ml. of dry benzene stirred vigorously at *ca.* 5°. After 10 minutes the mixture was stirred at 40–50° for 0.5 hour, filtered, and the solid washed with *ca.* 20 ml. of benzene. Combined filtrate and washing were evaporated to 50 ml. in vacuum, heated slightly to redissolve the solid, and cooled at about 5° for 0.5 hour. The white crystalline solid which separated was removed by filtration and dried in vacuum. A 64% yield (8.83 g.) was obtained, m.p. 128.5–132°. Two additional crystallizations from benzene (avoid excess heating) gave a sample for analysis, m.p. 135–136°.

Anal. Calcd. for $C_{13}H_8O_6$ NSCl: C, 45.69; H, 2.36; Cl, 10.38. Found: C, 45.76; H, 2.19; Cl, 10.33.

***exo*-Norbornyl-[*m*-carbo-(*p*-nitrophenoxy)] Benzenesulfonate.**—A mixture of 0.4487 g. (4.0 mmoles) of *exo*-norborneol and 1.0251 g. (3.0 mmoles) of *p*-nitrophenyl-(*m*-chlorosulfonyl) benzoate at 5–10° was stirred and treated with 2.0 ml. (30 mmoles) of dry pyridine. The mixture was stirred at 15–20° for 2.5 hours, then filtered. The precipitate was washed with a small portion of benzene, and the combined filtrate and washing were evaporated at reduced pressure without heat. The residual oil was treated with about 5 ml. of toluene, filtered and the precipitate was washed with a small amount of toluene. The solution was then evaporated in vacuum. This process was repeated three times. The residual oil was triturated with pentane, dried at 1 mm. pressure and then used immediately in the solvolysis reaction; it is designated as XI below.

Solvolysis of Sulfonate XI in Tetrahydrofuran-Water.—A solution of 1.459 g. of oil XI (2.85 mmoles) in 59.64 ml. of 0.09885 *N* sodium hydroxide (5.70 mmoles) and 40 ml. of tetrahydrofuran was heated at 60°. A third mole (29.82 ml.) of sodium hydroxide was added over the next 7 minutes to maintain neutrality. After 1 hour the solution was cooled, made strongly basic with sodium hydroxide, and extracted with 2 × 30 ml. of pentane. The pentane was washed with 4 × 15 ml. of water, dried over sodium sulfate, and evaporated through a 4-foot Vigreux column. The residue crystallized on brief evacuation, and was essentially pure *exo*-norborneol (87 mg.) by V.P.C. on 2-ft. silicone gum rubber and TCEP.

Another reaction employing essentially identical conditions but starting with (−)-*exo*-norborneol ($[\alpha]^{25}\text{D}$ − 1.87 ± 0.14°) gave pure *exo*-norborneol ($[\alpha]^{25}\text{D}$ −0.007 ± 0.014°). This material showed a single peak when subjected to V.P.C. on a silicone rubber column.

Solvolysis of Sulfonate XI in *t*-Butanol.—A solution of 3.648 g. (8.75 mmoles) of oily XI in *ca.* 50 ml. of *t*-butyl alcohol (distilled from calcium hydride) was treated with 0.579 *N* benzyltrimethylammonium hydroxide (29.38 ml.) in *t*-butyl alcohol. The volume was made up to 100 ml., and the solution was thermostated at 75°. One-fourth of an additional equivalent of base was added over 2 hours. After about 12 hours the *t*-butyl alcohol was removed by slow distillation through a 4-foot Vigreux column. A V.P.C. analysis of the distillate showed no norborneol but substantial norbornene. The residue was refluxed for 6 hours with 20 ml. of 6 *N* potassium hydroxide, and the hydrolysate was extracted with 3 × 30 ml. of pentane. Washing of the pentane with 3 × 4 ml. of water, concentration through a 4-foot Vigreux column and distillation of the residual oil (2.35 g.) through a Craig micro-still gave a fraction, b.p. 150–180°, which was purified further by V.P.C. *exo*-Norborneol obtained by collection from V.P.C. showed a rotation $[\alpha]^{25}\text{D}$ −0.08 ± 0.08°, starting with *exo*-norborneol of rotation $[\alpha]^{25}\text{D}$ − 0.305°.

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(32) K. Alder, S. Stein, S. Schneider, M. Liebmann, E. Ralland and S. Schulze, *Ann.*, **525**, 183 (1936), have prepared *endo*-norbornylamine by catalytic reduction of norcamphor oxime.

(33) L. M. Berkowitz and P. N. Rylander, *J. Am. Chem. Soc.*, **80**, 6682 (1958).

(34) Consolidated Engineering Corporation, Type 21-103 C, see J. H. Benyon, "Mass Spectrometry and its Application to Organic Chemistry," Elsevier Press, New York, N. Y., 1960, p. 495.

(35) H. Limpricht and L. V. Uslar, *Ann.*, **102**, 250 (1857).

[CONTRIBUTION FROM THE DEPARTMENT OF CHEMISTRY, THE UNIVERSITY OF KANSAS, LAWRENCE, KANS.]

The Synthesis of *o*-Di-*t*-butylbenzene by Classical Reaction Methods[1]

BY ALBERT W. BURGSTAHLER[2] AND M. O. ABDEL-RAHMAN

RECEIVED AUGUST 10, 1962

The synthesis of *o*-di-*t*-butylbenzene (I), *o*-*t*-amylcumene (Vd) and a number of related compounds by stepwise reactions from 1,1,4,4-tetramethyl-2-tetralone (III) is described.

In the course of their extensive studies on the nature and effects of steric strains in organic molecules, Brown and co-workers[3] drew attention to the difficulty of synthesizing the highly strained hydrocarbon *o*-di-*t*-butylbenzene (I) and its homomorphs. From their findings, they concluded that the strain energy associated with I is of the order of 25 kcal./mole, and on this basis pre-

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(1) Portions of this work are taken from the M.S. thesis of M. O. Abdel-Rahman, The University of Kansas, June, 1961, and were also presented by one of us at the Twelfth Annual Kansas City Chemistry Conference, Nov. 18, 1960, and at the 141st National Meeting of the American Chemical Society, Washington, D. C., March, 1962.

(2) Alfred P. Sloan Research Fellow, 1961–1963.

(3) (a) H. C. Brown and K. L. Nelson, *J. Am. Chem. Soc.*, **75**, 24 (1953); (b) H. C. Brown, D. Gintis and L. Domash, *ibid.*, **78**, 5387 (1956).

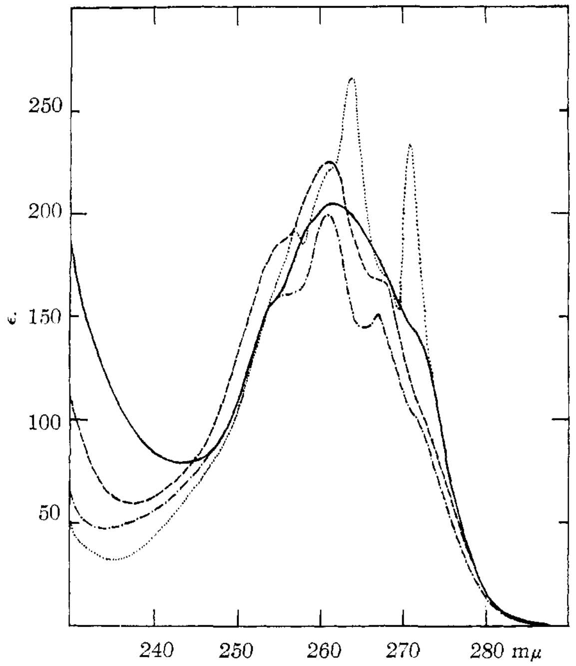
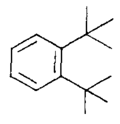
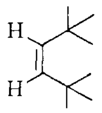


Fig. 1.—Representative ultraviolet absorption spectra in ethanol: *o*-di-*t*-butylbenzene (I), ———; *o*-*t*-amylcumene (Vd), — · —; 1,1,4,4-tetramethyltetralin, ...; α,α′-*o*-phenylenediisobutyraldehyde hydrate (XIV), - - - -.

dicted that the synthesis of I through methods based on direct alkylation of a benzenoid intermediate will not be feasible,[3a] and, furthermore, that the synthesis of I "will probably require reactions of unusually high driving forces and the avoidance of conditions conducive to molecular rearrangement and isomerization."[3b]



I



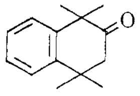
II

More recently, a strain energy of about 10 kcal./mole has been found for *cis*-di-*t*-butylethylene (II)[4] by comparison of its heats of hydrogenation and combustion with those of the *trans* isomer. Since II is sterically analogous to I, except for small differences in bond angles and bond distances, the actual strain in I probably lies somewhere in the range of 10 to 25 kcal./mole. In any event, a destabilization energy of this order of magnitude represents a sizable fraction of the resonance energy of the benzene ring and would be expected to manifest itself in significant alterations of the aromatic properties of I.

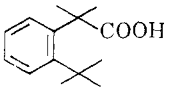
Although the synthesis of II has been readily achieved by partial catalytic hydrogenation of di-*t*-butylacetylene,[4a,5] various approaches[6] to the synthesis of I through conventional-type reactions have not been successful until now.[6a] This lack of success of purely organic routes to I has prompted the exploration of other methods based on the use of organometallic coordination compounds. Through such means, by the reaction of acetylene with the cobalt–carbonyl complex of di-*t*-butylacetylene, two independent groups[7,8] have succeeded recently in synthesizing *o*-di-*t*-butylbenzene (I). In addition, the same complex has been utilized for the synthesis of 1,2,4-tri-*t*-butylbenzene[9] and 1,2,4,5-tetra-*t*-butylbenzene.[10,11] The latter hydrocarbon has also been prepared through the Diels–Alder reaction of *t*-butylacetylene with 2,3,5-tri-*t*-butylcyclopentadienone, which in turn was obtained from the same cobalt-carbonyl complex of di-*t*-butylacetylene.[10] Although detailed studies of the properties of these interesting hydrocarbons have not yet been reported, the strain energy in 1,2,4,5-tetra-*t*-butylbenzene has been estimated to be 31 ± 4 kcal./mole on the basis of its heat of combustion.[10] Moreover, the ultraviolet absorption spectra of these *o*-disubstituted-*t*-butylbenzenes show the presence of appreciable distortion of the aromatic ring, since the usual benzene fine-structure pattern in the 240-280 mμ region is completely replaced by a single broad absorption band.[12]

Our own synthetic work in this area, which was already well advanced[1] at the time of the appearance of the preceding syntheses, is based entirely on reactions of a classical nature. In this paper we present an account of a purely organic route to *o*-di-*t*-butylbenzene (I), *o*-*t*-amylcumene (Vd) and a number of related compounds.

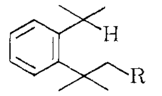
As the key starting material, we employed 1,1,4,4-tetramethyl-2-tetralone (III). This ketone was readily prepared in 33% yield from 2,2,5,5-tetramethyl-tetrahydro-3-furanone by a modification of the procedure of Bruson, Grant and Bobko.[13] In one of the initial methods explored for the synthesis of I from III, the



III



IV



Va, R = COOH
b, R = H
c, R = CH$_2$OH
d, R = CH$_3$

cleavage of III with hot alkali was examined as a possible route to α-(*o*-*t*-butylphenyl)-isobutyric acid (IV).[14] However, even at 300° in molten potassium hydroxide, III was extremely unreactive and was only slowly opened to a carboxylic acid, which proved to be exclusively β-*o*-cumenylisovaleric acid (Va). The structure of Va was established by its nuclear magnetic resonance (n.m.r.) spectrum, which indicates the presence of a methylene group, a methine hydrogen and two kinds of methyl groups, as well as a 1,2-disubstituted benzene system. In addition, the ultraviolet spectrum (*cf.* Fig. 1) reveals slight distortion of the benzene ring,[12] intermediate between that of III and its derivatives, and of I and its derivatives (see later portion of Discussion). The failure of III to be opened by

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[4] (a) W. H. Puterbaugh and M. S. Newman, *ibid.*, **81**, 1611 (1959); (b) R. B. Turner, D. E. Nettleton, Jr., and M. Perelman, *ibid.*, **80**, 1430 (1958).

[5] G. F. Hennion and T. F. Banigan, Jr., *ibid.*, **68**, 1202 (1946).

[6] For leading references, see E. M. Arnett, *J. Org. Chem.*, **25**, 324 (1960); also, M. S. Newman and G. R. Kahle, *ibid.*, **23**, 666 (1958).

[6a] NOTE ADDED IN PROOF.—Since submission of this paper, the synthesis of *o*-di-*t*-butylbenzene by a route based on the same starting material used in the present work has been reported by L. R. C. Barclay, C. E. Milligan and N. D. Hall, *Canad. J. Chem.*, **40**, 1664 (1962).

[7] C. Hoogzand and W. Hübel, *Angew. Chem.*, **73**, 682 (1961).

[8] E. M. Arnett and M. E. Strem, *Chemistry & Industry*, 2008 (1961).

[9] W. Hübel and C. Hoogzand, *Chem. Ber.*, **93**, 103 (1960); U. Krüerke, C. Hoogzand and W. Hübel, *ibid.*, **94**, 2817 (1961).

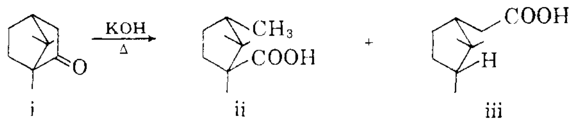
[10] C. Hoogzand and W. Hübel, *Tetrahedron Letters*, 637 (1961).

[11] E. M. Arnett, M. E. Strem and R. A. Friedel, *ibid.*, 658 (1961).

[12] For a comparative study, see J. Dale, *Chem. Ber.*, **94**, 2821 (1961).

[13] H. A. Bruson, F. W. Grant and E. Bobko, *J. Am. Chem. Soc.*, **80**, 3633 (1958).

[14] This mode of cleavage of a hindered ketone is observed in the fusion of camphor (i) with potassium hydroxide to form campholic acid (ii), along with some isocampholic acid (iii) (see J. L. Simonsen and L. N. Owen, "The



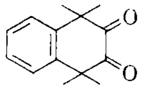
i ii iii

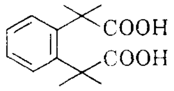
Terpenes," Vol. II, 2nd Ed., Cambridge University Press, New York, N. Y., 1949, p. 443).

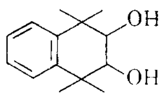
alkali to form a primary carbanion and thence IV can be accounted for by the stabilizing influence of the phenyl group, which therefore favors the production of Va. This behavior also parallels the course of the Favorskiĭ rearrangement of 1-chloro-3-aryl-2-propanones, which yield only β-arylpropionic acids.[15]

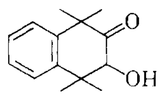
Despite the unsuitability of Va for the synthesis of I, its obvious structural relationship to the unknown hydrocarbon *o*-*t*-butylcumene (Vb), also of considerable theoretical interest, suggested the possibility of carrying out its decarboxylation as a route to Vb. However, efforts in this direction, particularly by means of the Hunsdiecker reaction[16] or modifications of it, were unavailing. Very little brominative decarboxylation of Va occurred; instead, a reaction analogous to the abnormal Hunsdiecker degradation of β,β,β-triphenylpropionic acid, in which the phenyl esters of β,β-diphenylacrylic acid and α-bromo-β,β-diphenylacrylic acid are formed,[17] apparently took place. On the other hand, the conversion of Va into *o*-*t*-amylcumene (Vd), a higher homolog of Vb, was carried out successfully. The methyl ester of Va was reduced with lithium aluminum hydride, and the resulting alcohol Vc was converted into the *p*-toluenesulfonate, followed by formation of the corresponding *n*-butyl thioether and desulfurization of the latter to yield *o*-*t*-amylcumene (Vd).[18] The ultraviolet spectrum (Fig. 1) of this hydrocarbon is virtually identical with that of the starting acid Va.

Since alkaline cleavage of the tetralone III did not occur in the direction necessary for the synthesis of I, we turned to routes based on 1,1,4,4-tetramethyl-2,3-tetralindione (VI), prepared by oxidation of III with selenium dioxide. This yellow dione, m.p. 61–62°, has also been obtained recently by the same method by Barclay and co-workers,[19] who, in addition, reported its further oxidation by periodic acid to α,α′-*o*-phenylenediisobutyric acid (VII), secured earlier by Bruson and co-workers[13] by direct oxidation of III. For our work we made use of VI by reducing it with lithium aluminum hydride to the 2,3-tetralindiol VIII.


VI

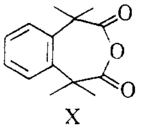

VII

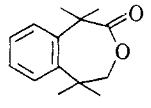

VIII

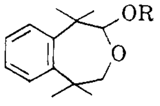

IX

On the basis of the following evidence the *cis* configuration is assigned to VIII. By condensation with acetone it afforded a solid *O*-isopropylidene derivative,[20] m.p. 73–74°, from which VIII could be regenerated, whose n.m.r. spectrum showed the C-2 and C-3 methine hydrogens as a single peak at τ 7.30 p.p.m. Although efforts to prepare a crystalline phenylboronate ester[21] were unsuccessful, the infrared spectrum of VIII exhibited intramolecular hydrogen bonding of the type found in *cis*-1,2-cyclohexanediols.[22] In addition, VIII underwent irreversible complex formation with monopotassium triacetylosmate[23] in the manner characteristic of *cis*-glycols.[24]

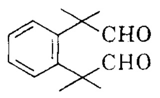
Interestingly, reduction of VI could not be effected by sodium borohydride, although catalytic hydrogenation with Adams catalyst furnished the corresponding α-ketol IX, which on treatment with lead tetraacetate afforded the cyclic anhydride X, m.p. 97–98°, of α,α′-*o*-phenylenediisobutyric acid (VII). This anhydride was also prepared by the action of sodium ethoxide on VI in ethanol–ether in an oxidizing atmosphere.[25] Significantly, its ultraviolet spectrum shows only poorly resolved shoulders at 261 and 268 mμ, in contrast to the distinct maxima associated with the tetramethyltetralin system. By treatment with sodium amalgam, X was reduced to the lactone XI. By further reduction with one equivalent of lithium aluminum hydride at −40°, XI gave the corresponding lactol XIIa which in turn was characterized as its methyl ether XIIb. Although the lactone XI was readily hydrolyzed by aqueous base, attempted recovery of the free hydroxy acid led only to the isolation of the original lactone. Such behavior is not ordinarily observed for a seven-membered lactone and serves to highlight the special steric effects of molecular overcrowding present in this system.[26]

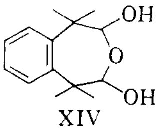

X


XI


XIIa, R = H
b, R = CH_3

Because of the numerous pathways available for the transformation of an aldehyde function into a methyl group, the further sequence based on conversion of the tetramethyltetralindiol VIII into α,α′-*o*-phenylenediisobutyraldehyde (XIII), and thence into I, appeared worthy of careful study.


XIII


XIV

On cleavage with periodic acid VIII gave an oily non-carbonyl-containing product subsequently identified as a mixture of stereoisomers corresponding to the bis-hemiacetal structure XIV. Cleavage of VIII with sodium bismuthate was exceedingly slow, but oxidation with lead tetraacetate under carefully defined conditions furnished the desired free dialdehyde XIII in 95% yield. Besides showing the expected absorption at 3.7 and 5.8 μ in the infrared, this substance displays a single peak at 262 mμ (ε 237) in the benzene fine-structure of the ultraviolet, characteristic of the ring-opened system of *o*-di-*t*-butylbenzene (*cf.* Fig. 1). One of the striking chemical properties of XIII is the facility with which it gives rise to cyclic products.[26] Thus, on attempted crystallization from moist solvents, XIII was converted into a crystalline *dl*- or *meso*-isomer of the

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[15] W. D. McPhee and E. Klingsberg, *J. Am. Chem. Soc.*, **66**, 1132 (1944); *cf.* A. S. Kende, *Org. Reactions*, **11**, 274 (1960).

[16] *Cf.* C. V. Wilson, *ibid.*, **9**, 332 (1957).

[17] J. W. Wilt and D. D. Oathoudt, *J. Org. Chem.*, **23**, 218 (1958).

[18] *Cf.* parallel sequence in the stereospecific synthesis of cantharidin [G. Stork, E. E. van Tamelen, L. J. Friedman and A. W. Burgstahler, *J. Am. Chem. Soc.*, **75**, 384 (1953)].

[19] L. R. C. Barclay, N. D. Hall and J. W. MacLean, *Tetrahedron Letters*, 243 (1961).

[20] Ordinarily acetonides are formed only from *cis*-1,2-cyclohexanediols [J. Böeseken, *Rec. trav. chim.*, **40**, 553 (1921)]. For an exception and further discussion, see S. J. Angyal and C. G. MacDonald, *J. Chem. Soc.*, 686 (1952); also, ref. 22b below (pp. 278–279).

[21] J. M. Sugihara and C. M. Bowman, *J. Am. Chem. Soc.*, **80**, 2443 (1958).

[22] (a) L. P. Kuhn, *ibid.*, **74**, 2492 (1952); (b) *cf.* E. L. Eliel, "Stereochemistry of Carbon Compounds," McGraw-Hill Book Co., Inc., New York, N. Y., 1962, pp. 131 and 277.

[23] R. Criegee, *Angew. Chem.*, **51**, 519 (1938).

[24] R. Criegee, E. Höger, G. Huber, P. Kruck, F. Marktscheffel and H. Schellenberger, *Ann.*, **599**, 93 (1956); *cf.* L. F. Fieser and M. Fieser, "Advanced Organic Chemistry," Reinhold Publishing Corp., New York, N. Y., 1961, p. 187.

[25] *Cf.* A. Lachman, *J. Am. Chem. Soc.*, **45**, 1510 (1923). This ease of formation of X recalls the unusual stability to hydrolysis of α,α,α′,α′-tetramethyladipic anhydride (see ref. 22b, p. 197).

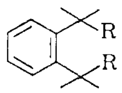
[26] For discussion of related cases, see pp. 196–197 of ref. 22b.

cyclic bis-hemiacetal XIV. It also underwent the Cannizzaro reaction with ease to form the previously mentioned seven-membered lactone XI. Interestingly, this same lactone was also produced from XIII by the action of various acid catalysts, and, as in the case of XI, the lactol XIIa was formed by reduction of XIII with one equivalent of lithium aluminum hydride at −40°.

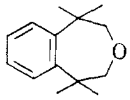
Of the various possible routes to I from XIII, the Wolff–Kishner reduction obviously offered one of the more direct pathways. Since the preparation of 1,1,4,4-tetramethyltetralin from the highly hindered tetralone III was successfully achieved by the Wolff–Kishner method,[13] application of this reaction to XIII seemed potentially promising. In fact, when XIII was treated under the Huang-Minlon conditions,[27] evolution of nitrogen occurrred, and a crystalline, non-carbonyl-containing reduction product was obtained. However, this proved to be identical with 1,1,4,4-tetramethyl-2-tetralol, prepared by the lithium aluminum hydride reduction of III.[13] In view of the proximity of the two aldehyde groups in XIII, this re-formation of the tetralin ring system is not too surprising. A similar result has been observed in the Wolff–Kishner reduction of an 11,12-secosteroid-11,12-dialdehyde to the reclosed 12β-ol.[28]

As an alternative approach to I from XIII, reactions involving formation and desulfurization of the corresponding dithioacetal or dithioaldehyde were also explored. In preliminary experiments, the ethylenethioketal of the highly hindered starting ketone III was readily prepared in 95% yield by the boron trifluoride-catalyzed condensation of III with 1,2-ethanedithiol. However, application to this reaction to XIII under a variety of conditions failed to give the desired bis-ethylenethioacetal. Instead, the major product was the lactone XI, plus sulfur-containing products of undetermined constitution. The latter on desulfurization afforded a mixture of hydrocarbons giving the analysis of a dibutylbenzene ($C_{14}H_{22}$), but whose gas chromatographic behavior and spectral properties indicated that it was a mixture consisting largely of a rearranged hydrocarbon, plus only a small amount of I (see below). This same rearranged hydrocarbon also appeared to result from the desulfurization of a crystalline dithio product obtained by the action of phosphorus pentasulfide on XIII. Its infrared spectrum confirmed that it is an *o*-disubstituted benzene derivative (strong absorption at 13.3 μ), while the ultraviolet spectrum contains the well-developed double maxima at 264 and 271 mμ characteristic of an unstrained phenyl ring.[12] In addition to four adjacent benzenoid protons, the n.m.r. spectrum suggests the presence of at least two types of methyl groups, and also methine and methylene hydrogens. From these spectral properties, plus other data, the hydrocarbon can be tentatively identified as *o*-di-*sec*-butylbenzene. This structure could have resulted from desulfurization of a thio derivative formed by an acid-catalyzed rearrangement of XIII.[29] In support of this interpretation, treatment of XIII with acid catalysts in the absence of ethanedithiol was found to afford, in addition to the lactone XI, a fair amount of ketonic product which gave a slow iodoform test. However, for the present, the constitution of the hydrocarbon must be considered uncertain.

In view of these results, the direct conversion of XIII into thio derivatives suitable for desulfurization obviously did not offer much promise for a satisfactory route to I. Consequently, we turned to the method which was applied successfully to the synthesis of cantharidin.[18] This required β,β′-*o*-phenylenediisobutyl alcohol (XVa), whose preparation from XIII was achieved in 90% yield by reduction with lithium aluminum hydride. This diol, m.p. 115–116°, has been reported recently by Barclay and co-workers,[19,30] who prepared it by the reduction of the dimethyl ester of α,α′-*o*-phenylenediisobutyric acid (VII). However, on a preparative scale we found the route through the dialdehyde XIII easier to manipulate.



XVa, R = CH_2OH
b, R = CH_2OTs
c, R = CH_2S–*n*-Bu



XVI

By reaction of the diol XVa with methanesulfonyl chloride or *p*-toluenesulfonyl chloride in pyridine at 0°, the corresponding dimethanesulfonate and the di-*p*-toluenesulfonate XVb were obtained. Since only the latter derivative (XVb) was crystalline (m.p. 110–111°), it was used in preference to the former for the subsequent steps. Although the ditosylate XVb and also the dimesylate underwent displacement by bromide or iodide ion, the spectral properties of the products obtained after hydrogenolysis showed that considerable skeletal rearrangement had occurred. With lithium aluminum hydride, XVb gave rise to extensive formation of the cyclic ether XVI, along with the desired product I (see below), similar to the experience in the cantharidin synthesis.[18] However, it did react smoothly with potassium *n*-butyl mercaptide in refluxing *t*-butyl alcohol. The resulting dithioether XVc was desulfurized with freshly prepared W-6 Raney nickel in ethanol at 45° or with deactivated Raney nickel in refluxing ethanol. At the temperature of refluxing ethanol, active Raney nickel caused considerable reduction of the aromatic ring, while deactivated Raney nickel was ineffective at lower temperatures.[31]

From the desulfurization reaction, the hydrocarbon I was obtained pure in 35% yield by fractional distillation. It gave a correct elemental analysis for *o*-di-*t*-butylbenzene and exhibited the expected single peak[12] in the ultraviolet in the benzene-fine-structure region (λ_{max} 262 mμ, ε 205; *cf.* Fig. 1).[7,8] After one recrystallization from methanol it melted at 27–28° (lit.[7] 27.5–28.5°). In addition, its infrared and n.m.r. spectra were identical with those recorded[7,8] for samples of I prepared by the cobalt–carbonyl–acetylene route.

Thus, while not accessible by direct alkylation procedures, *o*-di-*t*-butylbenzene is synthesizable indirectly by conventional-type reactions. From this work, the

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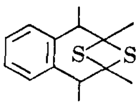
(27) Huang-Minlon, *J. Am. Chem. Soc.*, **68**, 2487 (1946); **71**, 3301 (1949).

(28) J. A. Zderic, H. Carpio, D. C. Limón and A. Ruiz, *J. Org. Chem.*, **26**, 2842 (1961).

(29) *Cf.* the formation of 3-phenyl-2-butanone by the acid-catalyzed rearrangement of α-phenylisobutyraldehyde [M. Tiffeneau and A. P. Orékhov, *Compt. rend.*, **68**, 182 (1926)]. On this basis, plus properties described in the Experimental, the crystalline dithio compound obtained from the P_2S_5 reaction can be formulated tentatively as iv.



iv

(30) By comparing the strain effects exhibited in the ultraviolet spectrum of XVa (*cf.* Fig. 1) with those seen in the spectrum of benzo[1,2:4,5]bicyclobutene [M. P. Cava, A. A. Deana and K. Muth, *J. Am. Chem. Soc.*, **82**, 2524 (1960)] and in the spectra of certain perchloroalkylbenzenes [M. Ballester and J. Castañer, *ibid.*, **82**, 4259 (1960)], Barclay and co-workers (ref. 19) concluded that the substituted *o*-*t*-butyl groups in XVa "have not resulted in serious strain or distortion of the benzenoid ring." However, this view is not in agreement with the findings and interpretation of Hoogzand and Hübel (ref. 9; see also ref. 10 and 12).

(31) *Cf.* G. R. Pettit and E. E. van Tamelen, *Org. Reactions*, **12**, 382 ff. (1962).

synthesis of other highly strained hydrocarbons, such as 2,6-dimethyl-*t*-butylbenzene,[32] also appears feasible, and experiments along these lines are now in progress.

Acknowledgments.—We are indebted to the Air Reduction Co., Inc., for generous supplies of 2,5-dimethyl-3-hexyne-2,5-diol used in the early stages of this work. We also wish to express our appreciation to the University of Kansas for a grant from the General Research Fund, to the Alfred P. Sloan Foundation for fellowship support, and to the donors of the American Chemical Society Petroleum Research Fund for aid to the Department in the purchase of a Cary model-14 spectrophotometer.

Experimental[33]

1,1,4,4-Tetramethyl-2-tetralone (III) was prepared by the method of Bruson, Grant and Bobko,[13] except that the entire neutral product from the Friedel–Crafts cyclialkylation reaction was distilled (b.p. 90–105° (0.5 mm.)) before crystallization. On the 0.9-mole scale described by these authors the yield of recrystallized III, m.p. 75–76° (lit.[13] m.p. 75°), was 55–60 g. (30–33%). The ultraviolet spectrum had $\lambda_{\max}$ 264 and 271 mμ (ϵ 265 and 232, respectively) [lit.[19] $\lambda_{\max}^{C_6H_{12}}$ 264 and 271 mμ (ϵ 281 and 242, respectively)].

The 2,4-dinitrophenylhydrazone of III crystallized from ethanol in yellow plates, m.p. 204–205°.

Anal. Calcd. for $C_{20}H_{22}O_4N_4$ (382.41): C, 62.81; H, 5.80; N, 14.65. Found: C, 63.07; H, 5.97; N, 14.68.

β-*o*-Cumenylisovaleric Acid (Va).—A mixture of 10.1 g. (0.05 mole) of the tetralone III and 30 g. of potassium hydroxide pellets was prepared in three copper tubes ($^3/_4$″ × 8″), which were then sealed and heated in an autoclave at 270–300° for 72 hr. When cool, the tubes were opened, and the contents were washed out, first with water and then with ether, and extracted several times with ether to recover 1.60 g. of unchanged III, m.p. 75–76°, after recrystallization from petroleum ether. The alkaline solution was acidified (concd. hydrochloric acid) and extracted three times with ether. The combined ether extracts were washed with saturated sodium chloride solution, dried over anhydrous sodium sulfate, and evaporated. The organic residue was dissolved in petroleum ether, filtered through a little decolorizing carbon, and the solvent removed by distillation. Recrystallization of the residue from petroleum ether furnished 8.52 g. (77% yield) of colorless needles of Va, m.p. 64–64.5°, $\lambda_{\max}$ 261 mμ (ϵ 205), with a shoulder at 267 mμ (ϵ 160). The n.m.r. spectrum at 60 mc./sec. (courtesy of Dr. Louis A. Cohen, National Institutes of Health) showed a doublet at τ 8.76 and 8.65 (6 protons of the isopropyl methyl groups), a singlet at τ 8.43 (6 protons of the geminal methyl groups), a singlet at τ 7.16 (2 protons of the methylene group), and a multiplet centered at τ 6.40 (1 proton, the methine hydrogen).

Anal. Calcd. for $C_{14}H_{20}O_2$ (220.30): C, 76.32; H, 9.15. Found: C, 76.47; H, 9.25.

Attempted Hunsdiecker Degradation of Va.—Application of various forms of the Hunsdiecker reaction[16] to the acid Va, including recent modifications by Rice[34] and also by Cristol and Firth,[35] gave very little evolution of carbon dioxide and led to the formation of a halogen-free, non-crystalline unsaturated ester of an *o*-disubstituted benzene, b.p. 110–115° (30 mm.), $\lambda_{\max}^{CS_2}$ 5.70 and 13.3 μ. Hydrogenation over palladium–carbon, followed by alkaline hydrolysis, furnished a substituted phenol and an odiferous carboxylic acid which were not examined further.

Sequence to *o*-*t*-Amylcumene (Vd). A.—A solution of 2.2 g. (0.01 mole) of Va in dry ether was treated with excess diazomethane and the resulting methyl ester reduced directly with lithium aluminum hydride in refluxing ether for 2 hr. After hydrolysis of the reaction mixture with ice and 3 *N* hydrochloric acid, the resulting alcohol Vc was separated by extraction with ether and purified by distillation. It was obtained as a viscous oil, b.p. 120–122° (0.3 mm.), n^{30}_D 1.5212, $\lambda_{\max}$ 2.7–2.9 and 13.3 μ (no carbonyl absorption), $\lambda_{\max}$ 261 mμ (ϵ 193), with a shoulder at 267 mμ; yield 1.9 g. (92%).

Anal. Calcd. for $C_{14}H_{22}O$ (206.32): C, 81.50; H, 10.75. Found: C, 80.95; H, 10.40.

B.—One gram (0.005 mole) of the above alcohol Vc in 15 ml. of pyridine at 0° was mixed with a solution of 1.1 g. (0.0057 mole) of *p*-toluenesulfonyl chloride in 10 ml. of pyridine. The resulting mixture was allowed to stand overnight at 0° and was then taken up in 200 ml. of ether, washed several times with 10% sodium hydroxide solution, and finally with water. The ether solution was then dried over anhydrous sodium carbonate and evaporated under reduced pressure. The resulting tosylate of Vc, which proved satisfactory for use directly in the next step, was obtained as a solid melting slightly above room temperature.

C.—A solution of the above tosylate in 25 ml. of *t*-butyl alcohol was added, with stirring, to a solution of potassium *n*-butyl mercaptide prepared from 0.2 g. of potassium, 10 ml. of *t*-butyl alcohol and 0.45 g. of *n*-butyl mercaptan. After refluxing overnight, the mixture was cooled and added to 100 ml. of 10% sodium carbonate solution, and extracted with petroleum ether. The combined petroleum ether extracts were washed several times with water, dried over anhydrous sodium carbonate, and evaporated under reduced pressure. The resulting thioether, which showed the absence of starting tosylate in the infrared spectrum (disappearance of bands at 7.4 and 8.7 μ), was desulfurized with 20 g. of freshly prepared Raney nickel in refluxing 70% ethanol for 2 hr. The mixture was filtered, diluted with water, and extracted with petroleum ether. The petroleum ether extracts were washed with water, dried over anhydrous sodium carbonate, and concentrated by distillation at atmospheric pressure. Finally, the residual hydrocarbon was distilled over sodium to yield 0.6 g. (65% yield from Vc) of *o*-*t*-amylcumene (Vd), b.p. 65–67° (0.4 mm.), n^{30}_D 1.4934; $\lambda_{\max}^{CS_2}$ 7.3(s), 7.4(m), 9.4(s) and 13.3(s) μ; $\lambda_{\max}$ 261 mμ (ϵ 198), with a shoulder at 267 mμ. The n.m.r. spectrum showed a doublet at τ 8.83 and 8.72 (6 protons of the isopropyl methyl groups), a triplet at τ 9.46, 9.33 and 9.20 (3 protons of the methyl group attached to the methylene group), a strong singlet at τ 8.62 (6 protons of the geminal methyl groups), a quartet at τ 6.72, 6.58, 6.47 and 6.39 (1 proton, the methine hydrogen), and a complex pattern at τ 2.84–3.17 (4 benzene protons).

Anal. Calcd. for $C_{14}H_{22}$ (190.32): C, 88.35; H, 11.65. Found: C, 88.47; H, 11.39.

1,1,4,4-Tetramethyl-2,3-tetralindione (VI).—To a solution of 40 g. (0.2 mole) of III in 300 ml. of glacial acetic acid was added 27 g. (0.24 mole) of selenium dioxide, and the resulting mixture was heated at reflux with stirring for 4 hr. The mixture was cooled and filtered, and the acetic acid removed by distillation under reduced pressure. The residue was taken up in 300 ml. of petroleum ether, washed five times with 100-ml. portions of water, dried over anhydrous magnesium sulfate, and the solvent evaporated under reduced pressure. On being allowed to stand at 0°, the solution deposited 39 g. (90% yield) of yellow prisms of VI, m.p. 61–62°, unchanged by further recrystallization (lit.[19] m.p. 64–65°). The ultraviolet spectrum showed maxima at 264 and 271 mμ ($\epsilon_{\max}$ 268 and 233, respectively) [lit.[19] $\lambda_{\max}$ 264 and 271.5 mμ].

Anal. Calcd. for $C_{14}H_{16}O_2$ (216.27): C, 77.75; H, 7.46. Found: C, 77.92; H, 7.53.

The quinoxaline derivative of VI was prepared by condensation of VI with *o*-phenylenediamine in refluxing ethanol and was recrystallized from this solvent in colorless plates (also needles), m.p. 127–128°.

Anal. Calcd. for $C_{20}H_{20}N_2$ (288.38): C, 83.29; H, 6.99; N, 9.71. Found: C, 83.16; H, 7.09; N, 9.42.

The oxidation of VI by periodic acid to form α,α'-*o*-phenylenediisobutyric acid (VII) in high yield has been reported by Barclay and co-workers.[19] The same result has also been achieved in our work by oxidation with lead tetraacetate.

***cis*-1,1,4,4-Tetramethyl-2,3-tetralindiol (VIII).**—Attempted reduction of the dione VI with sodium borohydride in refluxing ethanol resulted in recovery of starting material. However, the action of lithium aluminum hydride in tetrahydrofuran did reduce the dione satisfactorily. In a typical experiment, the entire crop of crude dione VI, derived from the selenium dioxide oxidation of 40 g. (0.2 mole) of the tetralone III, was heated at reflux for 3 hr. with 8 g. of lithium aluminum hydride in 400 ml. of tetrahydrofuran. Ice and dilute hydrochloric acid, barely sufficient to decompose excess reagent and liberate the product, were then introduced. Next, 500 ml. of ether was added, and the entire mixture was dried over anhydrous sodium sulfate. After filtration, the solvent was evaporated and the solid residue recrystallized from benzene–petroleum ether to afford 39 g. (88% over-all yield) of the tetralindiol VIII in fine needles, m.p. 145–146°, $\lambda_{\max}^{CCl_4}$

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(32) *Cf.* H. C. Brown and M. Grayson, *J. Am. Chem. Soc.*, **75**, 20 (1953).

(33) Melting points were taken in open capillaries on a Hershberg apparatus or on a microscope hotstage, both of which were calibrated against standard substances. Boiling points are uncorrected. Infrared spectra were determined in chloroform or, when specified, in carbon disulfide on a Perkin–Elmer model-137 Infracord. Ultraviolet spectra were recorded in ethanol on a Bausch and Lomb model-505 Spectronic or a Cary model-14 spectrophotometer. High-intensity absorption in the 210–220 mμ region (ϵ *ca.* 10,000) is not reported, however, since it was practically the same for all compounds examined. Nuclear magnetic resonance spectra were taken in carbon tetrachloride on a Varian Associates A-60 spectrometer with tetramethylsilane as an internal reference and are reported in τ values (p.p.m.) on the Tiers scale. Petroleum ether refers to the fraction with b.p. 35–45°. Solid analytical samples were dried *in vacuo* at 80–100° or 30° below their melting point, whichever was lower. Analyses were performed by the Huffman Microanalytical Laboratories, Wheatridge, Colo., or by the Schwarzkopf Microanalytical Laboratory, Woodside, N. Y.

(34) F. A. H. Rice, *J. Am. Chem. Soc.*, **31**, 73 (1956).

(35) S. J. Cristol and W. C. Firth, Jr., *J. Org. Chem.*, **26**, 280 (1961).

(Perkin-Elmer, model 21) 2.76 and 2.82 μ (OH and associated OH, intensity ratio unchanged by dilution), $\lambda_{\max}$ 264 and 271 mμ (ε 284 and 245, respectively).

Anal. Calcd. for $C_{14}H_{20}O_2$ (220.30): C, 76.32; H, 9.15. Found: C, 76.26; H, 9.07.

When VIII was added to an acetic acid solution of monopotassium triacetylosmate,[23] the blue color of the reagent was discharged and was not restored by the addition of potassium acetate.[24]

***cis*-2,3-*O*-Isopropylidene-1,1,4,4-tetramethyl-2,3-tetralindiol (Acetonide of VIII).**—A solution of 2.0 g. (0.009 mole) of the tetralindiol VIII and 1.6 g. of *p*-toluenesulfonic acid in a mixture of 75 ml. of acetone and 75 ml. of petroleum ether (b.p. 50–60°) was refluxed in an apparatus equipped with a Dean–Stark trap. After 24 hr. basic lead carbonate was added with stirring until the *p*H of an aliquot in water was slightly higher than 7. After filtration of the solids the solution was filtered through 30 g. of basic alumina (Woelm, activity grade 1) and concentrated. The acetonide (1.4 g., 60%) distilled as a viscous oil, b.p. 115–117° (0.3 mm.), n^{30}D 1.5065. Crystallization from petroleum ether–methanol gave colorless plates, m.p. 73–74°, $\lambda^{CS_2}_{\max}$ 7.3(s), 8.2(s),8.6(m), 9.3(s), 9.6(s), 11.5(m), 12.4(m) and 13.2(s) μ; $\lambda_{\max}$ 264 (broad) and 271 mμ (ε 255 and 207, respectively). In addition to the usual 4 benzene protons, the n.m.r. spectrum showed 2 methine hydrogens at τ 7.30, 6 protons at τ 8.64 (2 methyl groups), 6 protons at τ 8.74 (2 methyl groups), 3 protons at τ 8.99 (1 methyl group), and 3 protons at τ 9.27 (1 methyl group).

Anal. Calcd. for $C_{17}H_{24}O_2$ (260.36): C, 78.42; H, 9.29. Found: C, 78.42; H, 9.53.

To establish that no structural alteration had occurred in the formation of the above derivative, a sample was stirred overnight at reflux in a mixture of dilute alcohol and ethylene glycol containing a few drops of 6 *N* hydrochloric acid. After dilution of the mixture with water and extraction with ether, the original diol VIII, m.p. and mixed m.p. 145–146°, was recovered.

1,1,4,4-Tetramethyl-3-hydroxy-2-tetralone (IX).—Hydrogenation of 430 mg. (2 mmoles) of VI in ethanol over reduced platinum oxide required 20 min. for the absorption of 2 mmoles of hydrogen, at which point the uptake of hydrogen ceased. After removal of the catalyst by filtration and evaporation of the solvent, the product was crystallized from petroleum ether to form 245 mg. (56% yield) of the ketol IX as colorless needles, m.p. 40–41°, $\lambda_{\max}$ 2.8 and 5.85 μ.

Anal. Calcd. for $C_{14}H_{18}O_2$ (218.28): C, 77.03; H, 8.31. Found: C, 77.11; H, 8.25.

Acetylation of this product by boiling with acetic anhydride for 5 min. and slow evaporation of the solvent in a vacuum desiccator over potassium hydroxide pellets yielded a solid derivative, m.p. 65–66°, after crystallization from dilute acetic acid, $\lambda_{\max}$ 5.78 (ester) and 5.85 μ (ketone).

***α,α′-o*-Phenylenediisobutyric anhydride (X)** was obtained either by (A) the action of lead tetraacetate on the ketol IX or by (B) the action of sodium ethoxide in air on the dione VI.

A.—To a solution of 1.0 g. (4.6 mmoles) of IX in 10 ml. of glacial acetic acid buffered with 1.5 g. of anhydrous sodium acetate, an equimolar amount of lead tetraacetate (2.03 g.) was added with mechanical stirring and the mixture allowed to stand for 24 hr. at 23–25°. Ethylene glycol (1 ml.) was then added, the solution taken up in 100 ml. of ether, washed 5 times with 50-ml. portions of water, dried over anhydrous sodium sulfate, and evaporated under reduced pressure. The resulting residue crystallized from petroleum ether to give 0.42 g. (40% yield) of colorless prisms of the anhydride X, m.p. 97–98°, $\lambda^{CCl_4}_{\max}$ (Perkin-Elmer, model 21) 5.58 and 5.72 μ; $\lambda_{\max}$ (shoulders) 261 and 268 mμ (ε 385 and 290, respectively). The preparation of this compound from VII has been described by Barclay and co-workers,[19] but no melting point was recorded. On hydrolysis with refluxing 10% aqueous sodium hydroxide, X yielded *α,α′-o*-phenylenediisobutyric acid (VII), which after recrystallization from benzene melted at 229–230° (lit.[19] 218–219°). A mixture with an authentic sample of this acid, m.p. 229–230°, prepared by the method of Bruson and co-workers[13] or Barclay and co-workers,[19] showed no depression in m.p.

B.—To a solution of 1.5 g. (7 mmoles) of VI in 15 ml. of dry ether and 20 ml. of absolute ethanol was added a solution of sodium ethoxide prepared from 0.25 g. of sodium and 7 ml. of absolute ethanol. The solution gradually acquired a dark red color and after 5 days was concentrated under reduced pressure. The residue was shaken for 2 min. with 2 ml. of cold 20% potassium hydroxide solution and then extracted with ether. Evaporation of the dried ether layer and crystallization of the residue from benzene–petroleum ether gave 0.7 g. of colorless needles of X, m.p. 97–98°, undepressed when mixed with the preceding preparation. On hydrolysis with hot alkali, this product also gave the acid VII, m.p. and mixed m.p. 229–230°.

When the above experiment was conducted under a nitrogen atmosphere in the absence of any oxygen, the starting material, contaminated with unidentifiable oils, was recovered.

2,2,5,5-Tetramethyl-3,4-benzo-ε-caprolactone (XI).—A solution of 380 mg. (1.6 mmoles) of X in 10 ml. of 50% ethanol was stirred with 2% sodium amalgam (prepared from 0.3 g. of sodium) until the evolution of heat ceased. The mixture was carefully acidified with 6 *N* hydrochloric acid, diluted with 100 ml. of water and extracted with three 40-ml. portions of ether. The ether extracts were dried over anhydrous magnesium sulfate and evaporated. Recrystallization of the residue from petroleum ether furnished 120 mg. (34% yield) of colorless needles of the lactone XI, m.p. 59–60°, $\lambda_{\max}$ 5.8 μ, $\lambda_{\max}$ 262 mμ (ε 234), n^{30}D 1.5419 (supercooled melt).

Anal. Calcd. for $C_{14}H_{18}O_2$ (218.28): C, 77.03; H, 8.31. Found: C, 77.16; H, 8.39.

The preparation of XI from the dialdehyde XIII is described in a later portion of the Experimental.

2,2,5,5-Tetramethyl-3,4-benzo-ε-caprolactol (XIIa).—A solution of 1.1 g. (0.005 mole) of the lactone XI in 50 ml. of dry ether was cooled to −40°. A solution of 0.055 g. (0.0013 mole, 10% excess of one equivalent) of lithium aluminum hydride in 50 ml. of ether was added with vigorous stirring over a period of 15–20 min. After the addition was complete the solution was allowed to stand at room temperature for 5 min. and then treated with ice and dilute hydrochloric acid, followed by extraction with three 25-ml. portions of ether. The combined ether extracts were dried over anhydrous magnesium sulfate and evaporated. The residue was crystallized from benzene–petroleum ether to yield 0.68 g. (62%) of the lactol XIIa as colorless prisms, m.p. 142–143°, $\lambda_{\max}$ 2.9 μ (no carbonyl absorption), $\lambda_{\max}$ 262 mμ (ε 237).

Anal. Calcd. for $C_{14}H_{20}O_2$ (220.30): C, 76.32; H, 9.15. Found: C, 75.79; H, 8.77.

The non-identity of XIIa with the tetralindiol VIII, m.p. 145–146°, was evident from the infrared spectra and depressed mixture m.p. behavior (mixed m.p. 125–130°). Attempted Wolff–Kishner reduction of XIIa under the Huang-Minlon[27] conditions resulted only in the recovery of the starting material.

The lactol ether XIIb was prepared by refluxing a solution of 0.75 g. of XIIa in 15 ml. of methanol and 3 drops of concd. sulfuric acid for 12 hr. The solution was poured into 50 ml. of ice-cold 10% sodium carbonate solution and extracted with two 50-ml. portions of ether. The combined ether extracts were washed with water, dried over anhydrous magnesium sulfate, and distilled. After 3 days at −20°, the residue became crystalline. Recrystallization from petroleum ether furnished 0.44 g. (55% yield) of colorless prisms of XIIb, m.p. 47–48°; $\lambda^{CS_2}_{\max}$ 7.4(s), 7.7(m), 8.4(s), 8.85(s), 9.05(s), 9.3–9.4(b) and 13.3(s) μ; $\lambda_{\max}$ 262 mμ (ε 226).

Anal. Calcd. for $C_{15}H_{22}O_2$ (234.33): C, 76.88; H, 9.46. Found: C, 76.97; H, 9.60.

***α,α′-o*-Phenylenediisobutyraldehyde (XIII).**—One of the more satisfactory procedures for eq. cleavage of the diol VIII is typified by the following: A solution of 40 g. (0.18 mole) of VIII in 500 ml. of glacial acetic acid containing 65 g. of anhydrous sodium acetate was treated with 96 g. (0.21 mole) of lead tetraacetate and the resulting mixture stirred overnight at 30°. After destruction of excess oxidizing agent with 10 ml. of ethylene glycol, the mixture was diluted with 2 l. of water and extracted 5 times with 200-ml. portions of ether. The combined ether extracts were washed seven times with water, dried over anhydrous magnesium sulfate, filtered, and evaporated under reduced pressure. On distillation, the dialdehyde XIII was obtained as a nearly colorless viscous oil, b.p. 118–120° (0.4 mm.), n^{25}D 1.5366; $\lambda^{CS_2}_{\max}$ 3.7(m), 5.8(s) and 13.3(s) μ; $\lambda_{\max}$ 262 mμ (ε 237); yield 37.6 g. (95%).

Anal. Calcd. for $C_{14}H_{18}O_2$ (218.28): C, 77.03; H, 8.31. Found: C, 77.20; H, 8.43.

This distilled product did not show signs of crystallization. However, on occasion, the product before distillation crystallized from petroleum ether in long needles, m.p. 80–81°, with spectral properties identical with those of the liquid preparation above.

Anal. Calcd. for $C_{14}H_{18}O_2$ (218.28): C, 77.03; H, 8.31. Found: C, 76.95; H, 8.52.

When either preparation was dissolved in benzene–petroleum ether containing slightly more than one molar equivalent of water, the crystalline **hydrate XIV** (the *dl*- or *meso*- bis-hemiacetal of XIII) gradually deposited from the cooled solution. This was formed in 90% yield and was recrystallized from benzene–petroleum ether; m.p. 131–132°, $\lambda_{\max}$ 2.9(s) μ (no carbonyl absorption), $\lambda_{\max}$ 262 mμ (ε 222).

Anal. Calcd. for $C_{14}H_{20}O_3$ (236.30): C, 71.16; H, 8.53. Found: C, 71.27; H, 8.77.

The Cannizzaro reaction of XIII also occurred readily. A mixture of 300 mg. of XIII and 10 ml. of alcoholic potassium hydroxide was allowed to stand under nitrogen at 25° for 18 hr. The mixture was diluted with 50 ml. of water and extracted twice with 15-ml. portions of ether. The aqueous portion was carefully acidified with concd. hydrochloric acid and extracted with ether. The ether layer was washed with water, dried over anhydrous magnesium sulfate, and evaporated. The residue was crystallized from petroleum ether to yield 230 mg. (77% yield) of colorless needles of the **lactone XI**, m.p. and mixed m.p. 59–60° with a sample prepared by reduction of the anhydride X. The infrared spectrum was indistinguishable from that of the earlier preparation.

When reduced with one equivalent of lithium aluminum hydride in the manner described above for the preparation of XIIa from XI, 0.5 g. (2.3 mmoles) of XIII yielded 0.35 g. of the lactol XIIa, m.p. and mixed m.p. 142–143° after recrystallization from benzene–petroleum ether.

Attempted Wolff–Kishner Reduction of XIII.—A solution of 2.0 g. of the distilled dialdehyde XIII in the same weight of anhydrous hydrazine was refluxed overnight in 20 ml. of ethanolic acetic acid. After removal of the solvent by distillation at reduced pressure, the oily residue was subjected to Wolff–Kishner reduction by the Huang-Minlon technique.[27] Nitrogen evolution commenced when the bath temperature reached 190°, and a product began to co-distil with water into the Dean–Stark trap. Extraction of the distillate with ether furnished 1.1 g. of colorless crystals, m.p. 80–83°, which on recrystallization from petroleum ether formed needles, m.p. 86–87°. A mixed melting point with authentic 1,1,4,4-tetramethyl-2-tetralol, m.p. 86–87°, prepared by lithium aluminum hydride reduction[13] of III, was undepressed. The infrared spectra were likewise identical. Further heating of the Wolff–Kishner reaction mixture furnished a small amount of yellow oil of unknown constitution exhibiting carbonyl absorption at 5.8–5.9 μ.

Preparation and Desulfurization of the Ethylenethioketal of III.—To a solution of 1.0 g. of III in 20 ml. of benzene was added 1.5 ml. of 1,2-ethanedithiol and 5 ml. of freshly distilled boron trifluoride etherate. The resulting solution was allowed to stand overnight at 25°, warmed to 50° for 0.5 hr., and then diluted with 50 ml. of ether and extracted thoroughly with 10% sodium hydroxide solution. The organic phase was dried over anhydrous magnesium sulfate and evaporated on the steam-bath. Crystallization of the residue from ethanol furnished 1.24 g. (95% yield) of the ethylenethioketal of III, m.p. 96–97°.

Anal. Calcd. for $C_{16}H_{22}S_2$ (278.49); C, 69.01; H, 7.96; S, 23.03. Found: C, 69.11; H, 8.00; S, 23.20.

Desulfurization of 1.0 g. of the preceding product with 30 g. of W-6 Raney nickel catalyst in 50 ml. of ethanol, with stirring, at 45° for 4 hr. furnished (after filtration, dilution with water, extraction with petroleum ether and evaporative distillation from sodium) *ca.* 0.45 g. of 1,1,4,4-tetramethyltetralin, n^{25}_D 1.5290 (lit.[36] n^{27}_D 1.5278). The infrared and ultraviolet spectra (the latter having λ_{max} 264 and 271 mμ, ϵ 267 and 233, respectively) were identical with those of a sample prepared by the method of Bruson and Kroeger.[36] The n.m.r. spectrum showed singlets at τ 8.75 (12 methyl protons) and τ 8.33 (4 methylene protons), in addition to an A_2B_2 multiplet centered at τ 2.97 (4 benzenoid protons).

Attempted Preparation of the Bis-ethylenethioacetal of XIII.—Various conditions and reagents were explored for the preparation of the bis-ethylenethioacetal of XIII. It was found, however, that the action of acids on XIII caused considerable rearrangement to the lactone XI. Thus, when a solution of 1.5 g. of XIII and 1.8 ml. of ethanedithiol was treated with a slow current of anhydrous hydrogen chloride[37] for 12 hr. at 25°, and then warmed to 60° for an additional 10 hr., there was obtained, after extraction and chromatography on basic alumina (Alcoa F-80), only a minor fraction (*ca.* 0.2 g.) of a sulfur-containing product which was eluted with petroleum ether and showed no absorption in the carbonyl region of the infrared spectrum. The major fraction (0.8 g.), eluted with 1:1 ether–methanol, was identified as the lactone XI (mixed m.p. and infrared spectrum).

Essentially the same result was obtained by the use of boron trifluoride etherate as a catalyst under various conditions for the formation of the bis-ethylenethioacetal. However, slightly larger yields of carbonyl-free, sulfur-containing products were obtained when the reaction was initiated in acetic acid at 5° and then allowed to proceed at 25° for 5 days. Distillation of this sulfur-containing product gave a viscous oil, b.p. 105–109° (0.1 mm.); $\lambda_{max}^{CS_2}$ 7.3(s), 8.6(m), 9.7(s) and 13.3 (s) μ.

Desulfurization of the preceding product in the manner described above for the desulfurization of the ethylenethioketal of III yielded a hydrocarbon, b.p. 55–57° (0.2 mm.), n^{16}_D 1.5033, whose infrared, ultraviolet and n.m.r. spectra, as well as gas chromatographic behavior, showed that it was largely identical with the hydrocarbon obtained from the desulfurization of the phosphorus pentasulfide product described below.

Since the properties of this hydrocarbon indicate that it is not *o*-di-*t*-butylbenzene (nor 1,1,4,4-tetramethyltetralin), it is clear that the constitution of the sulfur-containing product is not the bis-ethylenethioacetal of XIII. When the dialdehyde XIII was heated in toluene with a few drops of boron trifluoride etherate or concd. hydrochloric acid, the lactone XI was obtained, plus small amounts of a carbonyl-containing product, $\lambda_{max}^{CS_2}$ 5.85 and 13.3 μ, which gave a delayed positive iodoform test.

Attempted Preparation of α,α'-*o*-Phenylenedithiodiisobutyraldehyde.—Attempts to prepare the bis-thioaldehyde analog of XIII by the action of hydrogen sulfide[38] on XIII, with or without an acid catalyst, were unsuccessful. The reaction of phosphorus pentasulfide with XIII was also studied in some detail (different temperatures, solvents and time) and was found to give the highest yield of sulfur-containing product under the following conditions. To a solution of 20 g. of XIII in 200 ml. of tetraethylene glycol dimethyl ether (Ansul Ether 181), 40 g. of phosphorus pentasulfide (recrystallized from carbon disulfide) was added with mechanical stirring. The mixture was heated at 180° for 36 hr. and then poured into 500 ml. of ice-cold 20% sodium hydroxide solution and extracted 4 times with petroleum ether. The organic layer was washed thoroughly with water until neutral, the petroleum ether evaporated, and the residue distilled under reduced pressure. A solid fraction distilling at 70° (0.5 mm.) was identified as 1,4-dithiane, m.p. 111–112°.[39] A second fraction had b.p. 135–140° (0.5 mm.), and a dark red residue remained in the distilling flask. This second fraction was chromatographed over basic alumina (Woelm) and eluted with petroleum ether. After evaporation of the petroleum ether, 0.2 g. of a white crystalline solid slowly deposited at 0°. Recrystallized from petroleum ether, this formed small needles, m.p. 91–92°; $\lambda_{max}^{CS_2}$ 7.0(m), 7.3(s), 7.4(s), 8.4(m), 8.6(m), 9.6(s), 10.75(m) and 13.3(s) μ; λ_{max} 261 (ϵ 278, based on a molecular weight of 250, indicated by Rast determination and analysis).

Anal. Calcd. for $C_{14}H_{18}S_2$ (250.43): C, 67.14; H, 7.25; S, 25.61. Found: C, 67.14; H, 7.17; S, 24.63.

Desulfurization of the non-crystalline portion of the above product at 45° gave a hydrocarbon mixture, which by gas chromatography on a silicone–rubber column showed the presence of two principal components in the ratio 1:4. The minor component had the same retention time as I and could be separated from the mixture by fractional distillation on a spinning-band column. The major component, which was also obtained by desulfurization of the crystalline product above, could not be completely purified. It had b.p. 59–60° (0.5 mm.), n^{22}_D 1.4992; $\lambda_{max}^{CS_2}$ 7.0(m), 7.3(m), 7.4(s), 8.6(m), 9.2(m), 9.4(m), 9.6(m), 10.65(m) and 13.3(s) μ; λ_{max} 264 and 271 mμ (ϵ 227 and 212, respectively). The n.m.r. spectrum showed four benzenoid protons in the region τ 2.68–3.02 (with weak peaks at τ 2.45–2.60 probably due to impurities of I), a quartet centered at τ 6.68 corresponding to 2 tertiary hydrogens, a triplet centered at τ 7.31, assigned to 4 methylene hydrogens, and a complex pattern at τ 8.27–9.04, corresponding to methyl group protons.

Anal. Calcd. for $C_{14}H_{22}$ (190.32): C, 88.35; H, 11.65. Found: C, 88.46, 88.30; H, 11.40, 11.45.

Sequence to *o*-Di-*t*-butylbenzene (I). A. Preparation of β,β'-*o*-Phenylenediisobutyl Alcohol (XVa).—A solution of 21.8 g. (0.1 mole) of XIII in 200 ml. of dry ether was added slowly, with stirring, to a mixture of 4.5 g. (0.11 mole) of lithium aluminum hydride in 200 ml. of ether. After the addition was complete (30 min.), the mixture was refluxed for 2 hr. Ice and dilute hydrochloric acid were added, the mixture filtered, and the organic layer separated. The aqueous layer was extracted twice with 100-ml. portions of ether, the combined ether extracts washed with water, dried over anhydrous magnesium sulfate, and the solvent evaporated. Recrystallization of the residue from methanol gave 20.2 g. (92%) of fine colorless needles of XVa, m.p. 115–116° (lit.[19] 115–116°); $\lambda_{max}^{CS_2}$ 2.8, 2.95, and 13.3 μ (no carbonyl absorption); λ_{max} 262 mμ (ϵ 220) [lit.[19] λ_{max} 265 mμ (ϵ 225)].

B. Preparation and Reactions of β,β'-*o*-Phenylenediisobutyl Alcohol *p*-Toluenesulfonate (XVb).—A cold solution of 11.1 g. (0.05 mole) of the diol XVa in 50 ml. of pyridine was mixed with a solution of 21 g. (0.11 mole) of *p*-toluenesulfonyl chloride in 50 ml. of pyridine and allowed to stand at 0° for 12 hr. The mixture was diluted with 300 ml. of ether, washed five times with 10% sodium carbonate solution, five times with water, dried over anhydrous sodium carbonate, and the solvent evaporated under reduced pressure. Recrystallization of the solid residue from benzene–petroleum ether furnished 25 g. (94% yield) of long needles of the ditosylate XVb, m.p. 110–111°; $\lambda_{max}^{CS_2}$ 7.4, 8.5 and 13.2 μ.

Anal. Calcd. for $C_{28}H_{34}S_2O_6$ (530.71): C, 63.37; H, 6.46; S, 12.08. Found: C, 63.56; H, 6.26; S, 12.01.

Displacement of the ditosylate or of the similarly prepared dimesylate with either potassium bromide or potassium iodide was achieved in ethylene glycol dimethyl ether at 120° for 3 hr. The infrared spectra of the halogen-containing products showed no sulfonate ester absorption; however, the products obtained on hydrogenolysis exhibited ultraviolet spectra (λ_{max} 264 and 271

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(36) H. A. Bruson and J. W. Kroeger, *J. Am. Chem. Soc.*, **62**, 36 (1940).

(37) *Cf.* G. Stork and J. W. Schulenberg, *ibid.*, **84**, 291 (1962).

(38) *Cf.* E. Campaigne, *Chem. Revs.*, **39**, 31 (1946).

(39) H. T. Clarke, *J. Chem. Soc.*, 1805 (1912).

mμ) indicative of skeletal rearrangement and were not examined further.

4,5-Benzo-3,3,6,6-tetramethyl-1-oxacycloheptene (XVI).—A solution of 6.0 g. (0.11 mole) of the ditosylate XVb in 50 ml. of tetrahydrofuran was added, with stirring, to a solution of 1.0 g. of lithium aluminum hydride in 20 ml. of the same solvent. After refluxing for 10 hr. the reaction mixture was decomposed with ice and 3 *N* sulfuric acid, diluted with water, and extracted with ether. After drying and concentration of the ether solution the crude product was chromatographed on 40 g. of basic alumina (Woelm, activity grade 1) and eluted with petroleum ether. The solvent was removed and the residue distilled to give 1.8 g. (77% yield) of slightly impure XVI, b.p. 57–59° (0.4 mm.), whose elemental analysis and infrared and n.m.r. spectra indicated that it was contaminated with significant amounts of I.

Anal. Calcd. for $C_{14}H_{20}O$ (204.30); C, 82.30; H, 9.87; Found: C, 84.01; H, 10.68.

One gram of the above product mixture was rechromatographed on 60 g. of acidic alumina (Woelm, activity grade 1) and the hydrocarbon portion eluted with petroleum ether. The ultraviolet, infrared and n.m.r. spectra of this hydrocarbon were identical with those of *o*-di-*t*-butylbenzene (see below). The second major fraction, eluted with ether, gave 0.8 g. of the purified cyclic **ether XVI**, b.p. 58–60° (0.4 mm.), m.p. 45.5–47° (micro crystals from petroleum ether at −70°), $n^{25}D$ 1.5219; λ^{CS_2} 7.2(m), 7.4(s), 7.7(m), 8.0(w), 8.3(m), 8.9(s), 9.5(m), 9.75(m), 9.9(m), 10.05(m), 11.1(m) and 13.3(vs) μ; λ_{max} 262 and 269 mμ (ε 185 and 170, respectively), λ_{min} 259 and 266 mμ (ε 175 and 165, respectively). The n.m.r. spectrum showed 12 methyl protons as a single peak at τ 8.68, 4 methylene protons at τ 6.42, and 4 benzenoid protons as an A_2B_2 multiplet centered at τ 2.79.

Anal. Calcd. for $C_{14}H_{20}O$ (204.30): C, 82.30; H, 9.87. Found: C, 82.07; H, 9.68.

C. *o*-Di-*t*-butylbenzene (I).—A solution of 16.0 g. (0.03 mole) of the ditosylate XVb in 75 ml. of *t*-butyl alcohol was added to a solution of potassium *n*-butyl mercaptide (prepared from 2.5 g. of potassium, 2.9 g. of *n*-butyl mercaptan and 150 ml. of *t*-butyl alcohol) in *t*-butyl alcohol. The mixture was refluxed for 15 hr., cooled, and poured into 500 ml. of 10% sodium carbonate solution. The mixture was extracted with three 75-ml. portions of petroleum ether. The combined extracts were washed three times with 50-ml. portions of water, dried over anhydrous sodium carbonate, and distilled. The oily dithioether XVc [7.2 g. (0.0197 mole), 66% yield] distilled as a colorless oily liquid, b.p. 135–138° (0.4 mm.), λ_{max} 262 mμ (ε 211). This was desulfurized directly with 140 g. of freshly prepared W-6 Raney nickel in ethanol with stirring at 45–50°. The mixture was filtered, diluted with 4 l. of water and extracted with five 150-ml. portions of petroleum ether. The combined petroleum ether extracts were dried over anhydrous sodium carbonate and the solvent removed by distillation at atmospheric pressure. The fragrant oily residue was chromatographed over basic alumina (60 g., Woelm, activity grade 1) then over acidic alumina (60 g., Woelm, activity grade 1), and the product eluted with petroleum ether was fractionally distilled through a spinning-band column of 25 theoretical plates. The hydrocarbon I distilled at 66–67° (0.4 mm.) or at 121–122° (10 mm.). Recrystallization from methanol furnished 1.3 g. (35% yield from the dithioether) of colorless tiny needles of I, m.p. 27–28° (lit.[7] 27.5–28.5°), $n^{30}D$ 1.5148 (lit.[7] 1.5149); $\lambda_{max}^{CS_2}$ 7.05(w), 7.2(m), 7.4(s), 8.15(m), 8.4(m), 9.45(s), 9.85(w), 10.6(w), 10.95(w), 11.9(w) and 13.3(vs) μ; λ_{max} 261.5 mμ (ε 205) [lit.[8] 261 mμ (ε 189)]. The n.m.r. spectrum showed a singlet at τ 8.50 [lit.[7] τ 8.51, 8.67[8]] (18 protons) and an A_2B_2 multiplet at τ 2.6–3.0 (4 benzene protons).

Anal. Calcd. for $C_{14}H_{22}$ (190.32): C, 88.35; H, 11.65. Found: C, 88.53; H, 11.63.

[Contribution from the Department of Chemistry, Cornell University, Ithaca, N. Y.]

Substitution and Addition Reactions of the Fluoroölefins. V. The Electrophilic Addition of Mercuric Fluoride to Fluoropropenes in Hydrogen Fluoride[1]

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Experimental results on the addition of HgF_2 to $CF_3CH{=}CF_2$ and to $CF_3CF{=}CF_2$ in HF solution are reported. It is shown that the mechanism of addition must involve electrophilic attack on the fluoroölefin by mercury cations. This type mechanism is favored in HF by the resistance of highly fluorinated olefins to protonation, and by the strong solvation and weak nucleophilic reactivity of fluoride ion and weak solvation and strong electrophilic reactivity of metal cations. Attention is directed to electrophilic reactions of π-electron systems as a significant new area of carbon–fluorine chemistry.

Highly fluorinated olefins characteristically react with nucleophiles and resist attack by electrophiles such as strong acids. In fact, electrophilic addition to a perfluoroölefin appears not to have been previously demonstrated. Consequently, it was of considerable interest to find that the addition of mercuric fluoride to 1,1,3,3,3-pentafluoropropene and to hexafluoropropene takes place in hydrogen fluoride solution under conditions which suggest an electrophilic mechanism. Further work has confirmed this view. The present paper presents the experimental results obtained and a discussion of evidence bearing on the mechanism of addition.

The Mercuric Fluoride Addition Reaction.—The formation of bis-(1,1,1,3,3,3-hexafluoroisopropyl)-mercury, $(CF_3CHCF_3)_2Hg$, was first observed in attempting to prepare 1,1,3,3,3-pentafluoropropene from 3,3-dichloro-1,1,3-trifluoropropene by reaction with mercuric oxide and hydrogen fluoride. This result was attributed to the addition of HgF_2 to the first-formed $CF_2{=}CHCF_3$.[2] In the present work we have confirmed this hypothesis by preparing $(CF_3CHCF_3)_2Hg$ directly from $CF_2{=}CHCF_3$ and HgF_2 and have also added HgF_2 to $CF_2{=}CFCF_3$ in HF solution. Most of our work has been carried out with $CF_2{=}CFCF_3$.

Other workers have also recently reported reactions between mercuric fluoride and fluoroölefins. Krespan has described the addition of HgF_2 in AsF_3 solution to the fluoroethylenes $CF_2{=}CF_2$, $CF_2{=}CClF$, $CF_2{=}CHF$ and $CF_2{=}CCl_2$ to form the corresponding substituted diethylmercury compounds. The mechanism of addition was indicated as ionic but was not considered further.[3] Goldwhite, Haszeldine and Mukherjee obtained $CF_3CClFHgF$ in moderate yield and CF_3CF_2-HgF in trace amounts from HgF_2 and $CF_2{=}CClF$ and $CF_2{=}CF_2$ in the absence of a solvent. The reaction was presumed to be a nucleophilic addition with fluoride ion attack on the CF_2 group.[4] Aldrich, Howard, Linn, Middleton and Sharkey have shown that mercuric fluoride in HF is generally applicable as a reagent for the preparation of secondary and tertiary mercurials from terminal fluoroölefins.[5] A related reaction carried out by Young, Tsoukalas and Dresdner consists of the reversible addition of HgF_2 to $CF_2{=}NCF_3$ in the absence of a solvent to form $(CF_3NCF_3)_2$-Hg.[6]

The reaction of mercuric fluoride with 1,1,3,3,3-

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[1] For a preliminary account of this work, see W. T. Miller, Jr., M. B. Freedman, J. H. Fried and H. F. Koch, *J. Am. Chem. Soc.*, **83**, 4105 (1961). Reference (14) is the preceding paper in this series.

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