the product with the starting diacid melted below 155°. The infrared spectrum[27] of the product has a band at 1670 cm.$^{-1}$ (conj. C=O) with a shoulder at 1690 cm.$^{-1}$ (carboxyl C=O) and a band at 1620 cm.$^{-1}$ (conj. C=C); the ultraviolet spectrum[24] has maxima at 240 mμ (ϵ 28,400), 281 (9,300) and 320 (5,700).

Anal. Calcd. for $C_{12}H_{10}O_3$: C, 71.28; H, 4.99. Found: C, 71.13; H, 5.03.

α-(2-Carboxyethyl)-*cis*-cinnamic Acid (XVIIb).—A solution of 2.16 g. of the *trans*-diacid (m.p. 175–177°) in 150 ml. of a benzene-ethyl acetate mixture was irradiated with the light from a low-pressure mercury vapor arc for 21.5 hr. After the solvents had been removed from the mixture, fractional crystallization from ethyl acetate separated 0.252 g. (12%) of the starting *trans*-diacid, m.p. 176–178.5°. Recrystallization of the mother liquors from a benzene-hexane mixture afforded 0.49 g. (23%) of the *cis*-diacid, m.p. 137–139°. The infrared spectrum[27] of the *cis*-acid has bands at 1718 (carboxyl C=O), 1667 (conj. carboxyl C=O) and 1626 cm.$^{-1}$ (conj. C=C) with a shoulder at 1700 cm.$^{-1}$; the ultraviolet spectrum[24] has a maximum at 255 mμ (ϵ 12,500).[27]

Anal. Calcd. for $C_{12}H_{12}O_4$: C, 65.44; H, 5.49. Found: C, 65.22; H, 5.51.

2-(2-Carboxyethyl)-indanone (XX).—Cyclization of α-benzylglutaric acid by the procedure of Ansell and Hey[14] yielded the desired keto acid, m.p. 106.5–108° (lit.[14] 106–108°) which exhibits broad absorption in the infrared[20] at 1710 cm.$^{-1}$ (conj. C=O in a five-membered ring and carboxyl C=O) and has ultraviolet maxima at 245 (13,700) and 291 mμ (ϵ 3,500).

2-(2-Indenoyl)-propionic Acid (XVIII).—A mixture of 10 g. (0.049 mole) of 2-(2-carboxyethyl)-indanone and 8.72 g. (0.049 mole) of N-bromosuccinimide in 200 ml. of carbon tetrachloride was irradiated and heated under reflux with a photo-flood lamp for 30 min. Filtration of the cool reaction mixture separated 4.6 g. (95%) of succinimide, m.p. 122–124°. After the filtrate had been concentrated to dryness under reduced pressure, a solution of the residue in 100 ml. of ether was treated with 50 ml. of γ-collidine and stirred for 6.5 hr. at room temperature. At this time the precipitated γ-collidine hydrobromide (7.0 g. or 71%) was removed by filtration and the filtrate was allowed to stand overnight. An additional 0.2 g. (2%) of γ-collidine hydrobromide separated during this time. The ethereal solution was washed successively with cold, dilute hydrochloric acid, water and aqueous potassium bicarbonate. The crude acidic product (3.9 g.) obtained from the bicarbonate extract was crystallized from acetone to give the desired indenone as yellow needles, m.p. 171–173°, yield 1.49 g. (15%). Recrystallization from acetone increased the melting point of the acid to 177.5–178.5°. The infrared spectrum[27] of the keto acid has a broad band at 1705 cm.$^{-1}$ (conj. C=O in a five-membered ring and carboxyl C=O) and the ultraviolet spectrum[24] has maxima at 236 mμ (ϵ 39,000), 242 (44,200) and 319 (1,370).

Anal. Calcd. for $C_{12}H_{10}O_3$: C, 71.28; H, 4.99. Found: C, 71.00; H, 4.97.

Distillation of the crude, neutral product (4.32 g.) from the dehydrobromination reaction through a short-path still at 0.1 mm. (pot temperature 180–185°) afforded 3.55 g. (36%) of the γ-lactone XXI which solidified on cooling. The pure lactone crystallized from methanol as white platelets, m.p. 86–88°. The product exhibits infrared absorption[20] at 1725 (conj. C=O in a five-membered ring) and 1782 cm.$^{-1}$ (C=O of an unconjugated γ-lactone) and ultraviolet maxima[24]) at 251 (13,100) and 296 mμ (ϵ 2,350).

Anal. Calcd. for $C_{12}H_{10}O_3$: C, 71.28; H, 4.99. Found: C, 71.20; H, 5.25.

3-Acetoxyindene (XXIV).—A solution of 8 g. (0.061 mole) of 1-indanone and 50 mg. of *p*-toluenesulfonic acid in 45 ml. of isopropenyl acetate was refluxed under a fractional distillation column for 3 hr. during which time 17 ml. of distillate containing acetone was removed. The resulting reaction was neutralized with sodium bicarbonate, diluted with ether, washed with water and dried over sodium sulfate. After the ether solution had been concentrated, distillation of the residue afforded 9.7 g. (92%) of the enol acetate as a colorless liquid, b.p. 77–85° (0.2 to 0.25 mm.), which crystallized when cooled. Two recrystallizations of the product from petroleum ether afforded the pure enol acetate as colorless needles, m.p. 48.5–49.5°, which exhibits infrared absorption[23] at 1770 cm.$^{-1}$ (C=O of an unconjugated enol ester) and has an ultraviolet maximum[36] at 252 mμ (ϵ 2,520).

Anal. Calcd. for $C_{11}H_{10}O_2$: C, 75.84; H, 5.79. Found: C, 75.62; H, 5.96.

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(36) Determined as a solution in isoöctane.

[CONTRIBUTION FROM THE DEPARTMENT OF CHEMISTRY, MASSACHUSETTS INSTITUTE OF TECHNOLOGY]

The Synthesis of Hexahydrofluorenone Derivatives

BY HERBERT O. HOUSE, VASKEN PARAGAMIAN, ROLLAND S. RO[1] AND DAVID J. WLUKA[1]

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The *cis* and *trans* isomers of hexahydrofluorenone have been synthesized by several routes. Reaction of either isomeric ketone with acrylonitrile or methyl acrylate yielded derivatives of 1a-(2-carboxyethyl)-*cis*-hexahydrofluorenone (XVI). This acid also was prepared from 2-(2-indenoyl)-propionic acid (XVII).

1,1a,2,3,4,4a-Hexahydrofluoren-9-one (I) has been prepared by cyclization of the acid chloride III of *trans*-2-phenylcyclohexanecarboxylic acid (II) in the presence of aluminum chloride[2] and by the acid-catalyzed cyclization of 1-cyclohexenyl phenyl ketone (VIII) in the presence of either polyphosphoric acid[3] or a mixture of phosphoric and formic acids.[4] In two cases[2,3] the same product, a solid which melted at 42° and formed a 2,4-dinitrophenylhydrazone melting at 190°, was formed. The cyclization of 1-cyclohexenyl phenyl ketone in the presence of formic and phosphoric acids gave a liquid ketonic product which formed a 2,4-dinitrophenylhydrazone melting at 158°.[4] The suggestion was offered that the liquid ketone was the *cis* isomer Ia and the material melting at 42° was the *trans* isomer Ib.

We first prepared hexahydrofluorenone by the method of Cook and Hewett.[2] The required *trans*-2-phenylcyclohexanecarboxylic acid (II) was obtained by reaction of *trans*-cinnamic acid with butadiene and then catalytic hydrogenation of the intermediate cyclohexene derivative.[5] When aluminum chloride was added to a carbon disulfide solution of the acid chloride III derived from II, the product obtained was the ketone Ia, m.p. 40–41°,

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[1] Alfred P. Sloan Postdoctoral Fellow.

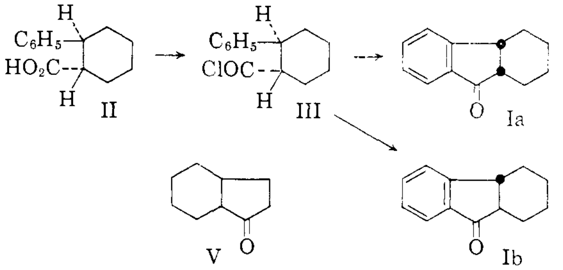
[2] J. W. Cook and C. L. Hewett, *J. Chem. Soc.*, 62 (1936).

[3] S. Dev, *J. Indian Chem. Soc.*, **34**, 169 (1957).

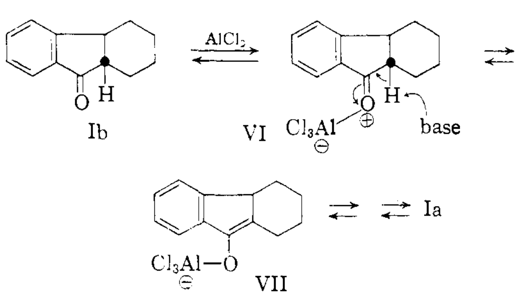
[4] E. A. Braude and W. F. Forbes, *J. Chem. Soc.*, 2208 (1953).

[5] K. Alder, H. Vagt and W. Vogt, *Ann.*, **565**, 135 (1949).

previously described[2,3] which formed a 2,4-dinitrophenylhydrazone, m.p. 190–191°, and a monobromo derivative IV, m.p. 57.5–58.5°. However, when the order of addition of the reactants was reversed, the acid chloride III being added to a suspension of aluminum chloride in carbon disulfide, the major product was an isomeric ketone, m.p. 91–92°. The infrared and ultraviolet spectra of the higher melting ketone suggested it was an isomer of the hexahydrofluorenone, m.p. 40–41°. This inference was confirmed by demonstrating that the two products formed the same α-bromo derivative IV and the same 2,4-dinitrophenylhydrazone. Equilibration of each ketone in ethanolic sodium ethoxide afforded the same equilibrium mixture which contained approximately 15% of the higher melting ketone. The work of Hückel and co-workers[6] with the isomeric hexahydro-1-indanones (V) has shown the *cis* isomer to be more stable than the *trans* isomer. These observations appear to be applicable qualitatively to the hexahydrofluorenone system I since there are no bridgehead substituents or bulky axial substituents bonded to the cyclohexane ring.[7,8] These arguments suggest that the more stable hexahydrofluorenone isomer, m.p. 40–41°, has the *cis* configuration Ia.



The observed product dependence on the order of addition of the reactants is understandable if this stereochemistry is accepted. In the case where the acid chloride III is added to aluminum chloride, the aluminum chloride always being in excess in the reaction mixture, the ring closure of the *trans*-acid chloride III yields the less stable *trans*-ketone Ib. The failure of the *trans*-ketone Ib to be epimerized to the more stable *cis*-ketone Ia in the reaction mixture is apparent if the mechanism for the acid-catalyzed enolization, illustrated in the accompanying equation, is considered. In the reaction being considered the excess aluminum chloride present in the reaction mixture will certainly convert the ketone Ib to its conjugated acid VI. However, the subsequent abstraction of a proton to form the enol VII requires the presence of a base in the reaction mixture. When excess aluminum chloride is present, the basic species (*e.g.*, the uncomplexed ketones I or the uncomplexed acid chloride III) in the reaction mixture are present in very low concentration with the result that enolization, and consequent epimerization, occur very slowly. On the other hand, the slow addition of aluminum chloride to the *trans*-acid chloride III permits the epimerization of the *trans*-ketone Ib to the *cis*-ketone Ia to occur readily since bases of sufficient strength to abstract a proton from the conjugate acid VI are present in appreciable concentration throughout most of the reaction period.



An exact analogy to this situation is found in the "Swamping Catalyst Effect" reported by Pearson and co-workers.[9] These workers found that the usual side-chain bromination of acetophenone was inhibited when quantities of aluminum chloride in excess of one equivalent were added to the acetophenone prior to the addition of bromine. Since the acid-catalyzed bromination of ketones proceeds *via* the enol form of the ketone,[10] the effect of the aluminum chloride on the course of this reaction is readily explicable in terms of the preceding discussion.

Perhaps the clearest demonstration of the inability of ketones to enolize in the presence of an excess of strong acid is provided by the demonstration that optically active α-isobutyldesoxybenzoin is racemized very slowly in concentrated sulfuric acid although the rate of racemization is rapid when more dilute acid is employed.[11] This observation is in accord with the earlier report that (−)-piperitone may be recovered unchanged from its solution in concentrated sulfuric acid.[12]

Our preparation of both the *cis* and the *trans* isomers of hexahydrofluorenone and the demonstration that both compounds formed the same 2,4-dinitrophenylhydrazone, m.p. 190–191°, raised a question as to the nature of the liquid product, which formed a 2,4-dinitrophenylhydrazone melting at 158°, which was reported to be one of the diastereoisomers of hexahydrofluorenone.[4] The preparation of this sample by the acid-catalyzed cyclization of 1-benzoylcyclohexene (VIII) is also open to question on other grounds since the cyclization of the unsaturated ketone VIII in the presence of polyphosphoric acid was subsequently reported to form the known *cis*-hexahydrofluorenone (Ia).[3] In order to clarify these conflicting reports we subjected 1-benzoylcyclohexene (VIII) to a mixture of formic and phosphoric acid as described.[4] The infrared spectrum of the crude product has bands at 1640 and 1710 cm.$^{-1}$ attributable to unchanged 1-benzoylcyclohexene and one of the isomeric hexahydrofluorenones present in minor amount.

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(6) W. Hückel, M. Sachs, J. Yantschulewitsch and F. Nerdel, *Ann.*, **518**, 155 (1935).

(7) For an example in which a *trans* fusion of a five- and six-membered ring is more stable, see D. H. R. Barton and G. F. Laws, *J. Chem. Soc.*, 52 (1954).

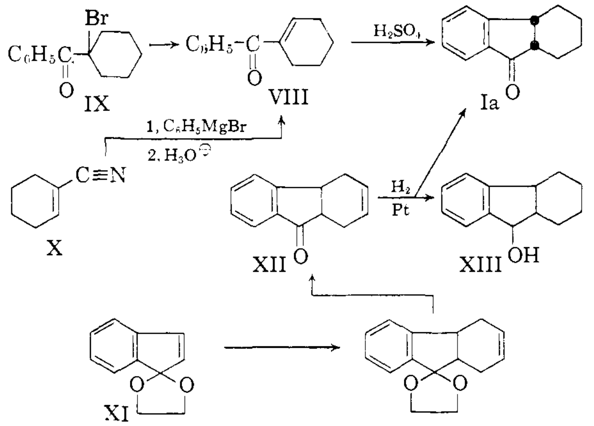
(8) For a review and discussion see G. Quinkert, *Experientia*, **13**, 381 (1957).

(9) D. E. Pearson, H. W. Pope, W. W. Hargrove and W. E. Stamper, *J. Org. Chem.*, **23**, 1412 (1958).

(10) J. Hine, "Physical Organic Chemistry," McGraw-Hill Book Co., Inc., New York, N. Y., 1956, p. 198.

(11) C. G. Swain and A. S. Rosenberg, to be published.

(12) J. Read and H. G. Smith, *J. Chem. Soc.*, **123**, 2267 (1923).

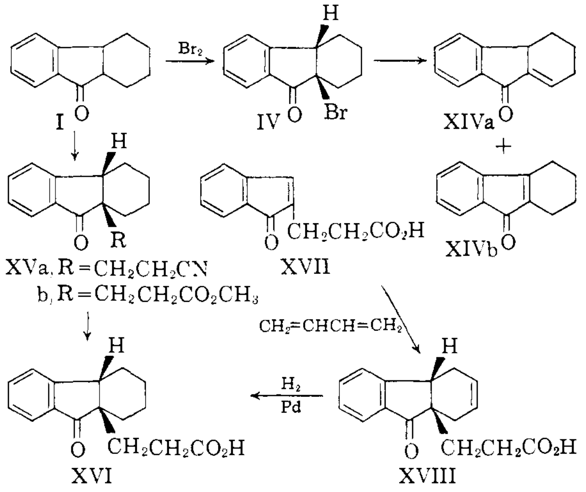


The gas chromatogram of the crude product indicated that about 5% of the hexahydrofluorenone was present in addition to unchanged 1-benzoylcyclohexene. Reaction of the crude product with 2,4-dinitrophenylhydrazine produced a mixture of 2,4-dinitrophenylhydrazones from which a sample of the pure 2,4-dinitrophenylhydrazone of 1-benzoylcyclohexene, m.p. 165–167°, was isolated by chromatography. Consequently, we concluded that the previously described liquid sample was a mixture of unchanged starting material and a small amount of one of the isomeric hexahydrofluorenones, presumably the *cis* isomer Ia. Because of our earlier experience with this type of acid-catalyzed cyclization in the indanone series,[13] the cyclization of the unsaturated ketone VIII in the presence of sulfuric acid was explored. This reaction afforded *cis*-hexahydrofluorenone (Ia) readily and in good yield; in our hands this method of cyclization was definitely superior to the use of polyphosphoric acid.

In the course of this work we were led to explore synthetic routes to 1-benzoylcyclohexene since both previous syntheses[14,15] of this compound were not entirely satisfactory. The first of these methods, the reaction of benzoyl chloride with cyclohexene in the presence of aluminum chloride,[14] has been noted by others[3,15,16] to form a mixture of products. Examination of the gas chromatogram of this mixture, after removal of the halogen components[16] by distillation, indicated that at least six components were present. From their retention times, two of the minor components present could be identified tentatively as *cis*-hexahydrofluorenone (Ia) and 1-benzoylcyclohexene (VIII). The alternative synthetic route described consists of the addition of cyclohexenyllithium to lithium benzoate.[15] Although we were able to obtain a homogeneous sample of the unsaturated ketone VIII in this way we encountered difficulty in reproducing the reported yield because of difficulty in preparing cyclohexenyllithium. Two alternative syntheses were utilized for the ketone VIII, both of which we consider to be more satisfactory than those previously reported. α-Bromocyclohexyl phenyl ketone (IX), obtained by the direct bromination of cyclohexyl phenyl ketone, was dehydrobrominated readily by boiling collidine to form the pure unsaturated ketone VIII. Alternatively, the addition of phenylmagnesium bromide to 1-cyanocyclohexene (X), obtained from cyclohexanone cyanohydrin, followed by acid hydrolysis produced the desired ketone VIII readily, although in this case the product was contaminated with small amounts of biphenyl.

cis-Hexahydrofluorenone (Ia) also was obtained by the reaction of indenone ethylene ketal (XI) with butadiene followed by hydrolysis to form the ketone XII and catalytic hydrogenation. The alcohol XIII was obtained as a by-product in this reduction. The successful use of the ketal XI as a dienophile in the Diels–Alder reaction was not unexpected since indene has been used in a comparable manner.[17] The reaction sequence XI → XII → Ia unfortunately provides no evidence concerning the stereochemistry of the hexahydrofluorenone Ia since the reaction conditions utilized could have epimerized either the intermediate XII or the final product. For this reason we have no reliable basis for the assignment of stereochemistry to compounds XII and XIII.

As noted earlier, both of the hexahydrofluorenones Ia and Ib form a single crystalline α-bromo derivative IV on direct bromination. This bromo derivative has been tentatively assigned the *cis*-configuration IV on the assumption that attack of bromine on the enol of hexahydrofluorenone would be expected to occur from the least hindered side of the molecule.[18] Attempts to dehydrohalogenate the bromo ketone IV with γ-collidine afforded the saturated ketone Ia. The failure of the bromo ketone IV to undergo a ready E2 elimination is consistent with the assigned stereochemistry since the preferred conformation of structure IV would place the bromine atom in an equatorial position with respect to the cyclohexane ring. In this con-



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[13] H. O. House, V. Paragamian, R. S. Ro and D. J. Wluka, THIS JOURNAL, **82**, 1452 (1960).

[14] R. E. Christ and R. C. Fuson, *ibid.*, **59**, 893 (1937).

[15] H. E. Zimmerman, *J. Org. Chem.*, **20**, 549 (1955).

[16] C. L. Stevens and E. Farkas, THIS JOURNAL, **74**, 5352 (1952); **75**, 3306 (1953).

[17] K. Alder and H. F. Rickert, *Ber.*, **71**, 379 (1938).

[18] Because of the planarity of the cyclopentenone ring in the ketones I, attack on the corresponding enol would not be expected to be influenced by the stereoelectronic control discussed by E. J. Corey and R. A. Sneen [THIS JOURNAL, **78**, 6269 (1956)]. For this reason the product of kinetically controlled bromination would be expected to be determined by steric factors.

formation the bromine atom does not occupy a *trans* coplanar arrangement with respect to any of the adjacent hydrogen atoms. The bromo ketone IV was successfully dehydrohalogenated in the presence of lithium chloride and dimethylformamide to form both unsaturated ketones XIV, the product XIVa with the exocyclic double bond being present in larger amount. The structures assigned these compounds are based on the close similarity of their infrared and ultraviolet spectra to the spectra of 2-ethylideneindanone and 2-ethylindenone.[13] When each of the unsaturated ketones XIV was heated with lithium chloride in dimethylformamide, no isomerization to the other conjugated double-bond isomer was detected. Since the stereochemical requirements of dehydrohalogenation reactions effected in the presence of lithium chloride and dimethylformamide have not been established, the dehydrobromination reactions described do not provide evidence useful for the assignment of stereochemistry to the bromo ketone IV.

Reaction of hexahydrofluorenone (I) with either acrylonitrile or methyl acrylate afforded the *cis*-ketones XV, both of which could be hydrolyzed to the *cis*-keto acid XVI. The stereochemistry of this acid was established by its synthesis from 2-(2-indenoyl)-propionic acid (XVII)[13] utilizing the stereospecificity of the Diels–Alder reaction[19] to form the *cis* adduct XVIII. The stereochemical results obtained in these Michael reactions are those which would be anticipated from reaction occurring at the least hindered side of the enolate anion derived from hexahydrofluorenone (I).

Experimental[20]

***trans*-1,1a,2,3,4,4a-Hexahydrofluoren-9-one (Ib).**—A solution of 60 g. (0.3 mole) of *trans*-2-phenylcyclohexanecarboxylic acid (m.p. 108–109°, lit.[21] 108–109°) in 100 g. of thionyl chloride was refluxed for 30 min. and then concentrated under reduced pressure. A solution of the residual, crystalline acid chloride in 100 ml. of carbon disulfide was added, dropwise and with stirring and cooling, to a suspension of 45 g. (0.34 mole) of aluminum chloride in 100 ml. of carbon disulfide. The reaction mixture was stirred at 0° for 90 min. and at room temperature for 30 min. and then poured into an ice–water mixture. The organic phase was separated and washed successively with water and aqueous sodium bicarbonate and then dried over magnesium sulfate and concentrated. The residual crystalline product, amounting to 48 g. (86%), melted at 84–88°. Two recrystallizations from hexane afforded the pure *trans*-ketone, m.p. 91–92°, yield 20 g. (36%). The product exhibits infrared absorption[22] at 1723 cm.$^{-1}$ (conj. C=O in a five-membered ring) and has ultraviolet maxima[23] at 245 mμ (ε 12,000) and 291 mμ (ε 2,500).

Anal. Calcd. for $C_{13}H_{14}O$: C, 83.83; H, 7.58. Found: C, 83.82; H, 7.51.

Reaction of the *trans*-ketone with a slight excess of 2,4-dinitrophenylhydrazine in ethanol containing several drops of sulfuric acid yielded the **2,4-dinitrophenylhydrazone of *cis*-hexahydrofluorenone** which melted at 190–191° after recrystallization from an ethanol–ethyl acetate mixture. The sample was shown to be identical with the subsequently described derivative obtained from *cis*-hexahydrofluorenone by a mixed melting point determination and by comparison of the infrared spectra of the two samples.

Reaction of the *trans*-ketone with one equivalent of bromine in diethyl ether as subsequently described produced **α-bromo-*cis*-hexahydrofluorenone**, m.p. 56.5–58°, which was shown to be identical with the product obtained from the *cis*-ketone both by a mixed melting point determination and by comparison of the infrared spectra of the two samples.

***cis*-1,1a,2,3,4,4a-Hexahydrofluoren-9-one (Ia). A. From *trans*-2-Phenylcyclohexanecarboxylic Acid (II).**—To a solution of the crude, crystalline acid chloride, obtained from 10 g. (0.05 mole) of *trans*-2-phenylcyclohexanecarboxylic acid and 20 g. of thionyl chloride as previously described, in 100 ml. of carbon disulfide, was added in small portions and with stirring 7.3 g. (0.055 mole) of aluminum chloride. The resulting mixture was stirred at 5° for 2 hr. and then worked up as previously described. The pure *cis*-hexahydrofluorenone crystallized from petroleum ether, m.p. 40–41° (lit.[2] 41.5–42°).

B. From Indenone Ethylene Ketal (XI).—A solution of 7.5 g. (0.043 mole) of indenone ethylene ketal, 20 g. (0.37 mole) of 1,3-butadiene and a few crystals of hydroquinone in 30 g. of benzene was heated to 180° in an autoclave for 20 hr. and then concentrated and distilled under reduced pressure. The fractions collected in the range 108–115° (0.2 mm.) were combined and fractionally distilled through a Holtzmann column. The pure **ethylene ketal of 1,1a,4,4a-tetrahydrofluorenone** was collected at 106–113° (0.1 mm.) $n^{27}D$ 1.5650–1.5658. A sample boiling at 113° (0.1 mm.) $n^{27}D$ 1.5658, was taken for analysis. The product absorbs in the infrared[22] at 1050 and 1085 cm.$^{-1}$ (C–O of a ketal) with no absorption in the 6 μ region attributable to a carbonyl function. The ultraviolet spectrum[23] of the product exhibits a series of maxima at 258 mμ (ε 645), 264 (860) and 271 (905).

Anal. Calcd. for $C_{15}H_{16}O_2$: C, 78.92; H, 7.06. Found: C, 78.60; H, 6.99.

A solution of 2.0 g. (0.0088 mole) of 1,1a,4,4a-tetrahydrofluorenone ethylene ketal in a mixture of 5 ml. of water, 5 ml. of concentrated hydrochloric acid and 20 ml. of methanol was refluxed for 3 hr. and then concentrated under reduced pressure and poured into water. The ethereal extract of the resulting mixture was dried over magnesium sulfate and concentrated to leave 1.5 g. (93%) of crude **1,1a,4,4a-tetrahydrofluorenone (XII)** as an oil which exhibited infrared absorption[22] at 1710 cm.$^{-1}$ (conj. C=O in a five-membered ring). A portion of this ketone was characterized as its **2,4-dinitrophenylhydrazone**, m.p. 195–196.5°, which exhibits a maximum in the ultraviolet[24] at 387 mμ (ε 32,600).

Anal. Calcd. for $C_{19}H_{16}N_4O_4$: C, 62.63; H, 4.43; N, 15.38. Found: C, 62.28; H, 4.26; N, 15.52.

A solution of 1.3 g. (0.0071 mole) of crude 1,1a,4,4a-tetrahydrofluorenone in 20 ml. of ethanol was hydrogenated at room temperature and pressure in the presence of 0.5 g. of a 10% palladium-on-carbon catalyst. The reaction, which did not cease after the absorption of 1 equivalent of hydrogen, was stopped when 1.55 equivalents of hydrogen had been absorbed. After the catalyst had been separated by filtration, the solvent was removed from the filtrate under reduced pressure. A solution of the residue in hexane deposited 0.5 g. (39%) of crude **9-hydroxyhexahydrofluorene (XIII)**, m.p. 117–124°. The pure alcohol crystallized from hexane as white needles, m.p. 131–132°, which exhibited infrared absorption[22] at 3620 cm. (unassociated O–H) and 3470 cm.$^{-1}$ (associated O–H) with no absorption in the 6 μ region attributable to a carbonyl function.

Anal. Calcd. for $C_{13}H_{16}O$: C, 82.93; H, 8.57. Found: C, 83.09; H, 8.37.

Concentration of the mother liquors afforded 0.5 g. (39%) of crude *cis*-hexahydrofluorenone, m.p. 38–41.5°. Recrystallization from petroleum ether gave the pure *cis*-ketone, m.p. 41–42.5°, which was shown to be identical with the sample previously described by a mixed melting point determination.

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(19) M. C. Kloetzel, *Org. Reactions*, **4**, 1 (1948); H. L. Holmes, *ibid.*, **4**, 60 (1948); L. W. Butz and A. W. Rytina, *ibid.*, **5**, 136 (1949).

(20) All melting points are corrected and all boiling points are uncorrected. The infrared spectra were determined with either a Baird, model B, or a Perkin–Elmer, model 21, infrared recording spectrophotometer fitted with a sodium chloride prism. The ultraviolet spectra were determined with a Cary recording spectrophotometer, model 11MS. The gas chromatograms were obtained with a 8 mm. × 215 cm. column packed with Dow Silicone Fluid No. 550 suspended on 50–80 mesh ground firebrick. The microanalyses were performed by Dr. S. M. Nagy and his associates and by the Scandinavian Microanalytical Laboratory.

(21) K. Alder, H. Vagt and W. Vogt, *Ann.*, **565**, 148 (1949).

(22) Determined as a solution in carbon tetrachloride.

(23) Determined as a solution in 95% ethanol.

(24) Determined as a solution in chloroform.

C. **From 1-Benzoylcyclohexene (VIII).**—1-Benzoylcyclohexene (26 g. or 0.14 mole) was added, dropwise and with stirring, to 250 ml. of concentrated sulfuric acid with no external cooling. The resulting mixture was heated on a steam-bath for 5 min. and then cooled and poured onto ice. The ether extract of the resulting mixture was washed successively with water and sodium bicarbonate and then dried over magnesium sulfate and concentrated. The residual, crude ketone, amounting to 24.83 g. (96%), crystallized when cooled. Recrystallization from petroleum ether afforded the pure *cis*-hexahydrofluorenone, m.p. 40–42°, yield 17.8 g. (68.5%). The infrared spectrum[22] of this *cis*-ketone, which is identical with the spectra of the previously described samples, has a band at 1717 cm.$^{-1}$ (conj. C═O in a five-membered ring); the ketone exhibits ultraviolet maxima[23] at 246 (11,700) and 291 mμ (ε 2,360).

The reaction of 0.3 g. (0.0016 mole) of *cis*-hexahydrofluorenone with 0.36 g. (0.0018 mole) of 2,4-dinitrophenylhydrazine and 2 ml. of concentrated sulfuric acid in 25 ml. of ethanol yielded 0.54 g. (91.5%) of the crude 2,4-dinitrophenylhydrazone, m.p. 185–189°. Recrystallization from an ethanol–ethyl acetate mixture gave the pure 2,4-dinitrophenylhydrazone, m.p. 191.5–192.5° (lit.[3,4] 190–191°). The ultraviolet spectrum[24] of the derivative has a maximum at 386 mμ (ε 31,300).

Equilibrations of *cis*- and *trans*-Hexahydrofluorenone (I).—A solution of 0.23 g. of *cis*-hexahydrofluorenone, m.p. 40–41°, in 10 ml. of ethanol containing several drops of sodium ethoxide solution was allowed to stand at room temperature for 24 hr. and then poured into water. The ethereal extract of the resulting mixture was dried over magnesium sulfate and concentrated to dryness. The infrared spectrum[22] of the residual solid, 0.21 g. melting over the range 38–52°, indicated the presence of 14 ± 5% of the *trans* isomer in the ketone mixture.

Application of the same procedure to 0.20 g. of the *trans*-ketone, m.p. 90–91°, afforded 0.18 g. of the mixture of ketones, m.p. 38–65°, which was estimated to contain 17 ± 5% of the *trans*-ketone. Fractional recrystallization of a portion of this mixture separated pure *cis*-hexahydrofluorenone, m.p. 39–40°, which did not depress the melting point of an authentic sample.

1a-Bromo-*cis*-hexahydrofluorenone (IV).—A solution, prepared from 12.0 g. (0.075 mole) of bromine and 40 ml. of carbon tetrachloride, was added, dropwise and with stirring, to a solution of 12.65 g. (0.68 mole) of *cis*-hexahydrofluorenone in 200 ml. of ether, cooled in an ice–water-bath, until the bromine color persisted. The resulting ether solution was washed successively with aqueous sodium thiosulfate, aqueous sodium bicarbonate and water and then dried over sodium sulfate. The concentrated ether solution deposited 15.8 g. (87%) of the bromo ketone as colorless prisms, m.p. 58–59°. The infrared spectrum[22] of the bromo ketone exhibits absorption at 1725 cm.$^{-1}$ (conj. C═O in a five-membered ring); the compound has an ultraviolet maxima at 255 (9,700) and 299 mμ (ε 2,300).

Anal. Calcd. for $C_{13}H_{13}BrO$: C, 58.88; H, 4.94; Br, 30.14. Found: C, 58.93; H, 5.03; Br, 30.44.

Dehydrobromination of 1a-Bromo-*cis*-hexahydrofluorenone (IV).—A solution of 28 g. (0.106 mole) of 1a-bromo-*cis*-hexahydrofluorenone and 40 g. (0.94 mole) of lithium chloride in 250 ml. of dimethylformamide was heated to 110–115° for 6.5 hr., a slow stream of nitrogen being passed through the mixture throughout the reaction. The resultant mixture was diluted with water and extracted with ether. The ethereal extract was washed repeatedly with water and then dried over magnesium sulfate and concentrated. Distillation of the residual oil afforded 14.61 g. (75%) of a mixture of the unsaturated ketones XIV, b.p. 110–120° (0.07–0.1 mm.), which crystallized when cooled. The ultraviolet spectrum[23] of the crude product indicated the presence of 40% of 1,2,3,4-tetrahydrofluorenone (XIVb) and 55% of 2,3,4,4a-tetrahydrofluorenone (XIVa). Chromatography of the mixture on 300 g. of Merck acid-washed alumina separated 2.88 g. (14.8%) of 1,2,3,4-tetrahydrofluorenone (XIVb), eluted with petroleum ether, and 6.42 g. (33%) of 2,3,4,4a-tetrahydrofluorenone (XIVa), eluted with 10% benzene in petroleum ether, as well as 3.36 g. of intermediate fractions containing both isomeric unsaturated ketones XIV and final fractions (0.95 g.) from which traces of an unidentified white crystalline solid, m.p. 174–180°, were obtained by crystallization from ethyl acetate–petroleum ether mixtures. The pure **1,2,3,4-tetrahydrofluorenone (XIVb)** separated from petroleum ether as golden yellow prisms, m.p. 41.5–42.5°, yield 2.25 g. (11.5%). This ketone exhibits infrared absorption[22] at 1710 cm.$^{-1}$ (conj. C═O in a five-membered ring) with additional weaker bands at 1635 and 1610 cm.$^{-1}$ and ultraviolet maxima[23] at 238 mμ (ε 39,700), 245 (46,900) and 317 (960) with molecular extinction coefficient of 540 at 267 mμ.[25]

Anal. Calcd. for $C_{13}H_{12}O$: C, 84.75; H, 6.57. Found: C, 84.73; H, 6.55.

The pure **2,3,4,4a-tetrahydrofluorenone (XIVa)** crystallized from ether–petroleum ether mixtures as pale yellow prisms, m.p. 80–82.5°, yield 5.0 g. (25.7%). The product exhibits infrared absorption[22] at 1707 (conj. C═O in a five-membered ring) and 1660 cm.$^{-1}$ (conj. C═C exocyclic to a five-membered ring) as well as a weaker band at 1612 cm.$^{-1}$ and an ultraviolet maximum[23] at 267 mμ (ε 18,800) with a molecular extinction coefficient of 4100 at 238 mμ.[25]

Anal. Calcd. for $C_{13}H_{12}O$: C, 84.75; H, 6.57. Found: C, 84.58; H, 6.60.

When samples of the two pure unsaturated ketones were heated to 110° for 3 hr. with lithium chloride and dimethylformamide and then isolated as previously described, no isomerization of either ketone to the other was detected, only the unchanged ketones and other unidentified products being obtained.

In an attempt to dehydrohalogenate 1a-bromo-*cis*-hexahydrofluorenone with γ-collidine, 10 g. (0.038 mole) of the bromo ketone was refluxed with 130 ml. of γ-collidine for 12 hr. and then worked-up by the procedure subsequently described. Distillation of the crude, halogen-free, neutral product yielded 2.18 g. (31%) of *cis*-hexahydrofluorenone, b.p. 76–81° (0.6–0.8 mm.), which solidified on cooling. After recrystallization from petroleum ether, the material melted at 43–44° and did not depress the melting point of an authentic sample of the ketone. The product also formed a 2,4-dinitrophenylhydrazone, m.p. 190–192°, which did not depress the melting point of an authentic sample of *cis*-hexahydrofluorenone 2,4-dinitrophenylhydrazone.

1-Benzoylcyclohexene (VIII). A. From α-Bromocyclohexyl Phenyl Ketone (IX).—A solution of 33.2 g. (0.124 mole) of the bromo ketone, m.p. 55–56° (lit.[16] 50–51°), in 17 g. (0.14 mole) of γ-collidine was heated to 170–175° for 45 min. and then cooled and diluted with benzene. After the γ-collidine hydrobromide (25.72 g. or 95%) had been separated by filtration, the filtrate was washed successively with dilute hydrochloric acid, aqueous sodium bicarbonate and water and then dried over magnesium sulfate and concentrated. The residual, crude unsaturated ketone, amounting to 22.93 g. (99%), crystallized when cooled. Recrystallization from petroleum ether afforded the pure 1-benzoylcyclohexene as white plates, m.p. 36–37° (lit.[3] 37°), which formed a 2,4-dinitrophenylhydrazone melting at 160–165° in 96.5% yield. Recrystallization from ethanol gave the pure **1-benzoylcyclohexene 2,4-dinitrophenylhydrazone**, m.p. 165.5–167.5° (lit.[3] 166–168°). The unsaturated ketone exhibits infrared absorption[22] at 1650 cm.$^{-1}$ (C═O of a cross conjugated ketone; in chloroform solution this band is found at 1640 cm.$^{-1}$) and ultraviolet maxima[23] at 246 (13,700) and 328 mμ (ε 790). The gas chromatogram of the product has a single peak.

B. **From 1-Cyanocyclohexene (X).**—The crude cyclohexanone cyanohydrin obtained from 454 g. (4.62 moles) of cyclohexanone, 454 g. (9.25 moles) of sodium cyanide, 900 g. (8.65 moles) of sodium bisulfite and 1.5 l. of water as previously described[26] was dissolved in 1200 ml. of pyridine and cooled in an ice–water-bath. To the cold solution was added, dropwise and with stirring over a period of 2 hr., 1 kg. (8.4 moles) of thionyl chloride.[27] The resulting mixture was slowly warmed and, finally, refluxed for 1 hr. and then poured onto ice. The organic product, extracted with three portions of ether, was washed successively with dilute hydrochloric acid and water and then dried over magnesium sulfate and distilled. The 1-cyanocyclohexene, a colorless

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(25) The corresponding values (ref. 13) for 2-ethylideneindanone are 1710 and 1660 cm.$^{-1}$ and λ_{max} 266 mμ (ε 22,600) and for 2-ethylindenone are 1710 cm.$^{-1}$ and λ_{max} 236 mμ (ε 21,800) and 242 mμ (ε 25,300).

(26) O. H. Wheeler and I. Lerner, THIS JOURNAL, **78**, 63 (1956).

(27) This dehydration procedure was adapted from the description of L. E. King and R. Robinson, *J. Chem. Soc.*, 465 (1941).

liquid collected at 74° (8 mm.), $n^{29}_{\rm D}$ 1.4775 (lit.[46] b.p. 86° (18 mm.), $n^{20}_{\rm D}$ 1.4818), amounted to 366 g. (74.5% based on cyclohexanone). The infrared spectrum[22] of the product has absorption at 2215 (conj. $C\equiv N$) and 1630 cm.$^{-1}$ (conj. $C=C$). The gas chromatogram of the product indicates that the nitrile contains less than 2% of impurities. To an ethereal solution of phenylmagnesium bromide prepared from 2.4 g. (0.1 g.-atom) of magnesium and 15.7 g. (0.1 mole) of bromobenzene was added, dropwise and with stirring under a nitrogen atmosphere, 5 g. (0.047 mole) of 1-cyanocyclohexene.[28] The resulting mixture was refluxed with stirring for 14 hr. and then poured into dilute hydrochloric acid and warmed overnight on a steam-bath with stirring. The neutral organic product, extracted with ether and dried over magnesium sulfate, was distilled through a Holtzmann column. After removal of the forerun containing biphenyl, the 1-benzoylcyclohexene was collected at 112–115° (0.3 mm.), yield 4.46 g. (51%). Although the material failed to crystallize when cooled, its infrared spectrum is essentially identical with the spectrum of the sample previously described. The gas chromatogram of the product indicated that the 1-benzoylcyclohexene was contaminated with 9% of biphenyl.

1a-(2-Cyanoethyl)-*cis*-hexahydrofluorenone (XVa).—To a solution of 1 g. (0.0054 mole) of *cis*-hexahydrofluorenone and several drops of 40% aqueous benzyltrimethylammonium hydroxide in 20 ml. of *t*-butyl alcohol was added 1 g. (0.019 mole) of acrylonitrile. The resulting mixture was stirred at room temperature for 30 min. and then diluted with water and extracted with ether. The ethereal extract was washed with water, dried over magnesium sulfate and concentrated. A cold solution of the residual oil in aqueous ethanol deposited 0.55 g. (43%) of the keto nitrile, m.p. 45–50°. Recrystallization from an ethyl acetate–petroleum ether mixture afforded the pure keto nitrile, m.p. 50–51°, which exhibits infrared absorption[22] at 2255 ($C\equiv N$) and 1710 cm.$^{-1}$ (conj. $C=O$ in a five-membered ring).

Anal. Calcd. for $C_{16}H_{17}NO$: C, 80.30; H, 7.16; N, 5.85. Found: C, 80.57; H, 7.27; N, 5.91.

1a-(2-Carbomethoxyethyl)-*cis*-hexahydrofluorenone (XVb).—To a solution of 3.5 g. (0.02 mole) of *trans*-hexahydrofluorenone and 1 ml. of dilute ethanolic sodium ethoxide in 50 ml. of *t*-butyl alcohol was added 2.4 g. (0.04 mole) of methyl acrylate. The mixture was stirred at room temperature for 1 hr. and then diluted with water and extracted with ether. After the extract had been dried over magnesium sulfate and concentrated, distillation of the residue afforded 2.4 g. (44%) of the keto ester, b.p. 150–152° (0.2 mm.), which crystallized on standing. Recrystallization from an ethyl acetate–hexane mixture afforded 2.0 g. (37%) of the pure keto ester, m.p. 50–51°, which exhibits infrared absorption[22] at 1735 (ester $C=O$) and 1710 cm.$^{-1}$ (conj. $C=O$ in a five-membered ring).

Anal. Calcd. for $C_{17}H_{20}O_3$: C, 74.97; H, 7.40. Found: C, 75.04; H, 7.41.

1a-(2-Carboxyethyl)-*cis*-1a,1,4,4a-tetrahydrofluorenone (XVIII).—A solution of 0.97 g. (0.0048 mole) of 2-(2-indenoyl)-propionic acid, 1.35 g. (0.025 mole) of 1,3-butadiene and 30 mg. of 2,5-di-*t*-butylhydroquinone in 10 ml. of benzene was heated to 130° in an autoclave for 15 hr. A benzene solution of the crude product was filtered from polymeric material and extracted with aqueous sodium carbonate. Acidification of the sodium carbonate extract with dilute hydrochloric acid followed by sublimation at 0.07 mm. and a bath temperature of 120–150° of the crude acidic product which separated afforded 0.71 g. (58%) of the keto acid, m.p. 101.5–105°. Recrystallization from a benzene–petroleum ether mixture afforded 0.61 g. (50%) of the pure keto acid, m.p. 108–109°, which exhibits broad infrared absorption[24] at 1710 cm.$^{-1}$ (carboxyl $C=O$ and conj. $C=O$ in a five-membered ring) and ultraviolet maxima[23] at 246 mμ (ϵ 11,300), 290 (2,180) and 296 (2,260).

Anal. Calcd. for $C_{16}H_{16}O_3$: C, 74.98; H, 6.29. Found: C, 75.11; H, 6.27.

1a-(2-Carboxyethyl)-*cis*-hexahydrofluorenone (XVI). The A. From **1a-(2-Cyanoethyl)-*cis*-hexahydrofluorenone (XVa).**—A solution of 5 g. (0.021 mole) of the keto nitrile, 10 ml. of water and 20 ml. of concentrated sulfuric acid in 20 ml. of acetic acid was refluxed for 3 hr. and then diluted with water and extracted with ether. The ether extract was dried over magnesium sulfate and concentrated. Recrystallization of the residue from an ethyl acetate-hexane mixture afforded 3.7 g. (70%) of the keto acid, m.p. 111–112.5°, which has broad infrared absorption[24] at 1705 cm.$^{-1}$ (carboxyl $C=O$ and conj. $C=O$ in a five-membered ring) and exhibits ultraviolet maxima[23] at 247 (13,700) and 293 mμ (broad, ϵ 2,450).

Anal. Calcd. for $C_{16}H_{18}O_3$: C, 74.39; H, 7.02. Found: C, 74.10; H, 7.05.

B. From **1a-(2-Carbomethoxyethyl)-*cis*-hexahydrofluorenone (XVb).**—A solution of 1.2 g. (0.0044 mole) of the keto ester and 0.6 g. (0.0091 mole) of 85% potassium hydroxide in 20 ml. of ethanol was boiled under reflux for 1.5 hr. and then concentrated under reduced pressure. After acidification with dilute hydrochloric acid, the residue was extracted with ether. The ethereal extract was dried over magnesium sulfate and concentrated to leave 1.1 g. (97%) of the crude keto acid. Recrystallization from an ethyl acetate–hexane mixture afforded the pure keto acid, m.p. 109–111°, which was shown to be identical with the sample previously described by a mixed melting point determination and by comparison of the infrared spectra of the two samples.

C. From **1a-(2-Carboxyethyl)-*cis*-1,1a,4,4a-tetrahydrofluorenone (XVIII).**—A solution of 0.545 g. (0.0021 mole) of the unsaturated keto acid in ethanol was hydrogenated at room temperature and atmospheric pressure in the presence of 70 mg. of a 10% palladium-on-carbon catalyst, the hydrogenation being stopped when 47.7 ml. or 1 equivalent of hydrogen had been absorbed. After the catalyst had been removed by filtration, the filtrate was concentrated and the residue was crystallized from an ethyl acetate–petroleum ether mixture. The crude keto acid, m.p. 108.5–110.5°, amounted to 0.355 g. (65%). Recrystallization gave the pure keto acid, m.p. 110–112°, which was shown to be identical with the sample previously described by a mixed melting point determination and by comparison of the infrared spectra of the two samples.

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(28) The reaction of 1-cyanocyclohexene with aliphatic Grignard reagents has been reported by H. Bergs and C. Wittfeld, *Ber.*, **67**, 238 (1934).