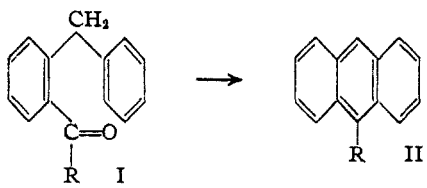
[CONTRIBUTION FROM THE CHEMICAL LABORATORY OF DUKE UNIVERSITY]

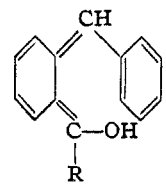
Aromatic Cyclodehydration. XI.[1] The Mechanism of the Cyclization of *o*-Benzylphenones[2a,b]

BY CHARLES K. BRADSHER[3] AND E. STUDLEY SMITH[4]

Bergmann[5] has made the observation that the acetal of *o*-benzylbenzaldehyde (I, R = H) on hydrolysis with hydrochloric acid gives not only the expected aldehyde, but also a small quantity of anthracene. From our studies in the phenanthrene series,[6] we recognized this as a simple case of what should be a general reaction and we were able to extend it to *o*-benzylphenones, yielding, in this case, the corresponding *meso*-substituted anthracenes (II).[7,8]

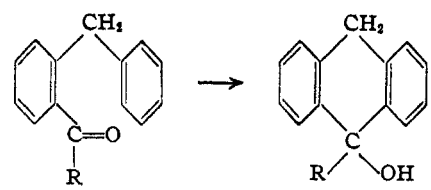


Bergmann regarded the cyclization of *o*-benzylbenzaldehyde as "a modification of the Elbs synthesis of anthracene derivatives" and proposed a mechanism based upon that of Cook[9] for the latter reaction. We pointed out[7] the closer relationship to the acid-catalyzed cyclizations previously studied by us and as "a satisfactory working hypothesis" made the assumption that the intermediate in this reaction was the enolic form (III) of the aldehyde or the ketone which cyclized with the loss of the elements of water to yield the hydrocarbon.



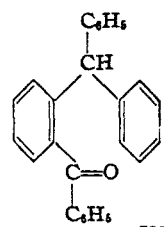
III

Our decision to accept this hypothesis sprang from two sources: first, the observation that the rate of cyclization was considerably slower than that observed in the phenanthrene series[6] and, second, that the rate of cyclization seemed to be independent of the nature of the "R" group of the ketone. The first of these observations *seemed* to be explained by the extremely small amount of enolization that could be expected under conditions of the cyclization and the second *seemed* to preclude the possibility of the alternate mechanism to which we will refer as an "aldol-like" condensation.



"Aldol-like" Mechanism

As a first test, we undertook the study of the cyclization of *o*-benzhydrylbenzophenone (IV).



IV

If the reaction did involve enolization, it would be expected that in this compound in which the hydrogen to be enolized is activated by an addi-

(1) For the preceding communication of this series see THIS JOURNAL, **65**, 451 (1943).

(2a) This contribution is drawn from material presented before the Organic Division at the 103rd meeting of the American Chemical Society in Memphis, Tenn., April, 1942. In the interim, and prior to the presentation of the present paper for publication, a paper has been published by Berliner (THIS JOURNAL, **64**, 2894 (1942)) dealing, in part with the same problem and arriving at the same conclusions, however, without the amount of experimental evidence which we have been able to adduce. Since Mr. Berliner has interpreted some of our earlier statements in a manner which we had not intended, we have taken space to present fully our views, both as presented earlier, and at the Memphis meeting.

(2b) A copy of this manuscript was sent to Mr. Berliner and in returning it to me he wrote as follows: "My only knowledge of the substance of the address by Dr. Bradsher and Mr. Smith was derived from the printed abstract published by the Organic Division. This abstract did not make clear to me the implication of their proposed aldol type' of condensation and included no mention or formulation of a proton addition to the carbonyl group. In presenting an electronic mechanism of cyclization it was my belief that this was a complete departure from any of the mechanisms considered by Dr. Bradsher and Mr. Smith, but I am now glad to acknowledge the prior presentation, in their address, of the same concept."—*The Editor*.

(3) National Research Fellow (participating basis) 1941–1942.

(4) Eastman Kodak Scholar (1941–1942).

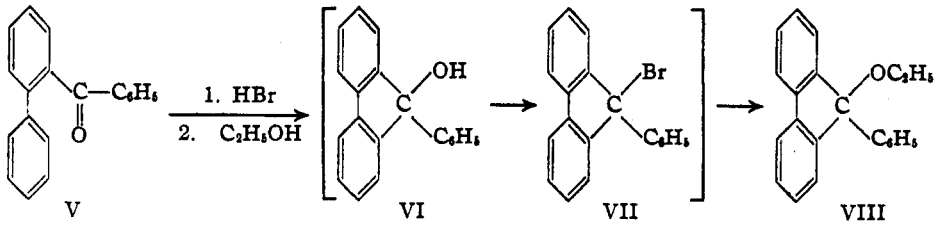
(5) Bergmann, *J. Org. Chem.*, **4**, 1 (1939).

(6) *E. g.*, Bradsher and Schneider, THIS JOURNAL, **60**, 2960 (1938); Bradsher and Rosher, *ibid.*, **61**, 1524 (1939); Bradsher and Tess, *ibid.*, **61**, 2184 (1939); Bradsher, *ibid.*, **61**, 3131 (1939).

(7) Bradsher, *ibid.*, **62**, 486 (1940).

(8) This synthesis has been applied in the preparation of carcinogenic hydrocarbons [Bradsher, *ibid.*, **62**, 1077 (1940)] and of 9-phenyl-10-alkyl- and 10-aryl-anthracenes (ref. 1).

(9) Cook, *J. Chem. Soc.*, 487 (1931).



V VI VII VIII

tional phenyl group, the rate of cyclization would be greater than that of *o*-benzylphenone (I, R = C_6H_5). It was actually observed[1] that in this more highly substituted compound, the rate of cyclization was *slower*.

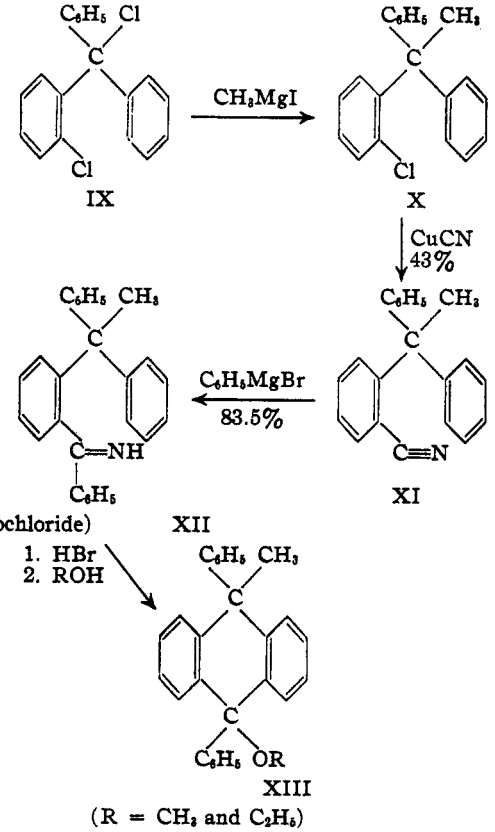
To determine whether ring-closure would, indeed, take place where enolization was impossible, we attempted the cyclization of *o*-phenylbenzophenone (V).

The use of the usual acetic acid–hydrobromic acid mixture[7,8] resulted in the formation of a resinous mass,[10] produced probably by the self-condensation of 9-phenylfluorenol-9 (VI), the expected product.

In order to avoid this difficulty, the cyclization was repeated using 48% hydrobromic acid *without* acetic acid. After twenty-four hours, an oily compound, probably 9-phenyl-9-bromofluorene (VII), was isolated and this when refluxed with absolute alcohol gave an over-all yield of 65% of 9-phenyl-9-ethoxyfluorene (VIII). The identity of the latter was verified by comparison with a sample prepared from fluorenone by known methods.[11] It was found that boiling 48% hydrobromic acid would likewise effect the cyclization of *o*-benzylbenzophenone (I, R = C_6H_5). In this case, a yield of 66% of phenylanthracene was obtained after refluxing had been continued for twenty-four hours.

While it was felt that this cyclization offered very strong support for the "aldol-like" mechanism, it might be objected that the formation of a five-membered ring is not exactly comparable to that of a six-membered ring. For this reason, another series of reactions was undertaken.

The starting material, *o*-chlorotriphenylmethyl chloride[12] (IX), was treated with methylmagnesium iodide and the resulting *o*-chloro-1,1,1-triphenylethane (X) converted to the nitrile (XI) by heating with cuprous cyanide. The action of phenylmagnesium bromide on the nitrile produced an imine (XII) especially resistant to hydrolysis. Finally, abandoning efforts to effect isolation of



the expected ketone, the imine (as the hydrochloride) was submitted for seven days to the action of boiling hydrobromic acid.[13] At the conclusion of this period, the crude bromide was refluxed with ethyl alcohol to produce a 57% yield of a compound having the composition of 9,10-diphenyl - 9 - methyl - 10 - ethoxy - 9,10 - dihydroanthracene (XIII, R = C_2H_5). Substituting methyl for ethyl alcohol, the corresponding methoxy compound (XIII, R = CH_3)[14] was obtained.[15]

(10) From this mass, Berliner (note 2) was able to obtain a few milligrams of 9-phenylfluorenol-9.

(11) Kliegl, *Ber.*, **38**, 284 (1905).

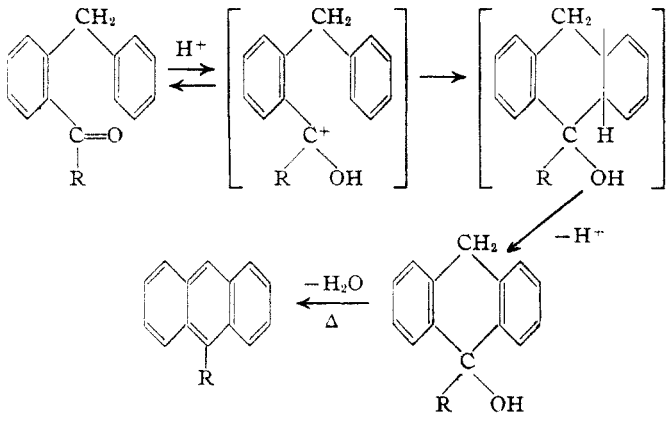
(12) Gomberg and Cone, *ibid.*, **39**, 1466 (1906); Gomberg and Van Slyke, THIS JOURNAL, **33**, 531 (1911).

(13) The comparable *o*-benzhydrylbenzophenone required ten days for cyclization to 9,10-diphenylanthracene (note 1).

(14) The preparation of the methoxy compound was not included in our paper presented at the Memphis meeting (note 2).

(15) It had been hoped at the outset that it would be possible to synthesize the two ether derivatives (XIII) by another method, but we were prevented by the extreme resistance to hydrolysis of the nitrile (XI) which we had planned to use as a starting material.

The mechanism for the cyclization of *o*-benzylphenyl ketones must, therefore, account for the following facts: (1) the reaction does not involve enolization, (2) the reaction is catalyzed by acid, and (3) the rate of the reaction seems to be practically independent of the nature of the "R" group attached to the carbonyl. We believe that the mechanism illustrated accounts for all of these facts.



The first step must be the addition of a proton to the oxygen atom of the carbonyl group. This leaves the carbon with an electron deficiency and what follows is essentially an intramolecular Friedel and Crafts reaction[16] which we have formulated according to the mechanism proposed by Price[17] for the latter reaction. Following expulsion of the proton, the anthrol undergoes transannullar elimination of water, a process which may be purely thermal.[18,19]

Considered in the light of this mechanism, it does not appear incongruous that the rate of cyclization of *o*-benzylphenones is roughly independent of the nature of the "R" group, since cyclization does not involve addition, in the classical sense, to the carbon-to-oxygen double bond.

Experimental

Cyclization of *o*-Phenylbenzophenone[20] (V). (Experiment by C. K. B.).—The ketone (0.5 g.) was suspended in 48% hydrobromic acid (10 cc.) and the mixture refluxed for twenty-four hours. The crude bromide was extracted with benzene, filtered from a small amount of insoluble material and the last traces of water removed by addition of a few drops of acetyl chloride. The benzene was evaporated and the residue refluxed for two hours with 15 cc. of ethyl alcohol. Upon cooling, the **9-ethoxy-9-phenylfluorene (VIII)** crystallized. Recrystallized, 0.36 g. (65%) of white crystals were obtained, m. p. 114–115°. This material gave no depression in melting point when mixed with an authentic sample prepared from fluorenone by the method of Kliegl.[11]

Action of 48% Hydrobromic Acid on *o*-Benzylbenzophenone (I, R = C_6H_5).—The ketone (0.5 g.) was suspended in 48% hydrobromic acid (10 cc.) and refluxed for twenty-four hours. The product was once recrystallized from ethyl alcohol, m. p. 152–153°; yield 0.31 g. (66%).

9-Phenyl-9-methyl-9,10-dihydroanthracene Series

***o*-Chlorotriphenylmethyl chloride (IX)** was prepared essentially as described by Gomberg and Van Slyke[12] except that it was found unnecessary to isolate the intermediate carbinol. The product of the Grignard reaction, after the impurities had been steam-distilled, was converted directly to the chloride by the action of hydrogen chloride. The yield (56.5%) was somewhat better by this procedure and considerable time was saved. The product, m. p. 130–132° (lit.[12] 133 and 136°), was pure enough for further reactions.

***o*-Chloro-1,1,1-triphenylethane (X).**—The Grignard reagent was prepared from 49 g. of methyl iodide and 8.4 g. of magnesium. To this was added a benzene solution containing 54 g. of 2-chlorotriphenylmethyl chloride and the mixture refluxed for four hours. The product was then decomposed with acid and the benzene–ether solution washed, dried over magnesium sulfate, concentrated and the residue distilled through a Widmer column. The fraction boiling at 197–198° (6 mm.) was recrystallized from ethyl alcohol. The over-all yield of product suitable for further reactions (m. p. 102–104°) was 26%. An analytical sample obtained by repeated crystallization consisted of white prisms, m. p. 107.5–108.5°.

Anal. Calcd. for $C_{23}H_{17}Cl$: C, 82.04; H, 5.85; Cl, 12.11. Found: C, 82.11; H, 5.99; Cl, 11.76.

***o*-Cyano-1,1,1-triphenylethane (XI).**—A mixture of 2.9 g. of *o*-chloro-1,1,1-triphenylethane, 1.1 g. of cuprous cyanide and 2 cc. of pyridine was heated for forty-eight hours at 215–225°. Worked up in the usual way, distilled and recrystallized from alcohol, there was obtained 1.2 g. (43%) of nitrile, m. p. 116–118°. This material probably contained a small quantity of unchanged halide, but was pure enough for further reactions. A sample purified by repeated recrystallizations melted at 123–124°.

Anal. Calcd. for $C_{21}H_{17}N$: C, 89.02; H, 6.05; N, 4.95. Found: C, 89.18; H, 6.38; N, 4.75.

The nitrile was resistant to hydrolysis by boiling alcoholic potassium hydroxide (one week) and by boiling hydrochloric acid.

The Imine Hydrochloride of *o*-Benzoyl-1,1,1-triphenylethane (XII).—A Grignard reagent was prepared in ether from 6.2 g. of bromobenzene and 0.96 g. of magnesium. Two-thirds of the ether was distilled off, 3 g. of

(16) Berliner prefers the words "internal aromatic substitution" (note 2).

(17) Price, *Chem. Rev.*, **29**, 37 (1941).

(18) This is the mechanism as it was presented by us at the Memphis meeting. Berliner (note 2) arrived at essentially the same conclusion.

(19) Upon more mature consideration, it now appears probable that the acid also catalyzes the dehydration reaction. We hope to make this the subject of a future communication.

(20) Schlenk and Bergmann, *Ann.*, **464** 1, 34 (1928).

the nitrile (XI) was added in 50 cc. of benzene and the mixture was refluxed overnight. The reaction mixture was decomposed by dilute hydrochloric acid, whereupon the imine hydrochloride precipitated and was collected; yield 3.5 g. (83.5%). A sample was purified for analysis by repeated conversion to the free base and reprecipitation from organic solvents by hydrochloric acid.

Anal. Calcd. for $C_{27}H_{24}NCl$: N, 3.52. Found: N, 3.41.

9,10-Diphenyl-9-methyl-10-ethoxy-9,10-dihydroanthracene (XIII, R = C_2H_5).—A mixture of 0.5 g. of the imine hydrochloride (XII) and 15 cc. of 48% hydrobromic acid was refluxed for seven days. At the end of this period, the suspended solid (probably impure bromide) was collected and added to 50 cc. of absolute alcohol. The solution was refluxed for one hour during which the ethyl ether crystallized from the boiling solution. Once recrystallized from alcohol, it gave 0.28 g. (57%) of white plates, m. p. 203–204°.

Anal. Calcd. for $C_{29}H_{28}O$: C, 89.21; H, 6.70. Found: C, 88.93; H, 6.87.

9,10-Diphenyl-9-methyl-10-methoxy-9,10-dihydroanthracene (XIII, R = CH_3) was prepared as described above, but using methyl instead of ethyl alcohol. The product crystallized from methanol as irregular white prisms, m. p. 284–286°.

Anal. Calcd. for $C_{28}H_{24}O$: C, 89.32; H, 6.43. Found: C, 89.08, 88.90; H, 6.65, 6.40.

Summary

By cyclization of ketones of such a nature that elimination of water cannot take place, we have been able to offer very strong support to the theory that the cyclization of *o*-benzylphenones does *not* involve enolization.

The function of the acid in this cyclization has been discussed and an effort has been made to show that this reaction is not a modification of the Elbs synthesis, but could most aptly be described as a reaction of the Friedel and Crafts type.

DURHAM, N. C. RECEIVED JANUARY 18, 1943

[CONTRIBUTION FROM THE CHEMISTRY DEPARTMENT, UNIVERSITY OF MARYLAND]

Molar Polarizations in Extremely Dilute Solutions. II[1,2]

BY RAYMOND DAVIS, HERBERT S. BRIDGE AND W. J. SVIRBELY

The abnormal behavior sometimes observed in the polarization curves at high dilution on plotting polarization values against mole fractions has been supported by some investigators and denied by others.[3] The purpose of this investigation was to study the very dilute solution ranges more thoroughly than before[3a] in an attempt to decide whether an anomalous behavior did exist for certain compounds or whether experimental error was responsible. The molar polarizations and dipole moments of chlorobenzene, nitrobenzene, ethyl benzoate, benzamide, *m*-nitroaniline, *d,l*-pinene, 3,6-dichloro-2,5-dimethoxybenzoquinone, and 2,3-dichloro-5,6-dimethoxybenzoquinone were determined in benzene or in dioxane as the nonpolar solvents.

Materials

Benzene.—Thiophene was removed from General Chemical Company technical benzene by either refluxing over aqueous mercuric acetate or by shaking with concentrated sulfuric acid. After either of these treatments, the benzene was washed with water and dried over calcium chloride. The benzene was distilled over sodium through 3 feet of a 1.5-inch column packed with glass rod, discarding the first 10% and also the residue amounting to 10–20% of the initial volume. After use the benzene was recovered by distilling through the same column discarding the first 10%. The benzene was stored in a glass bottle over sodium wire and used as required.

Dioxane.—Union Carbon and Carbide Co. dioxane was refluxed over sodium for six hours and distilled over sodium through the above column. The first 10–15% and a residue of 20% were discarded. The dioxane after use was recovered by distilling over sodium.

Nitrobenzene.—Eastman Kodak Co. nitrobenzene was distilled through a 10-inch Vigreux column and the middle 50% was collected; b. p. 210–210.5°.

Chlorobenzene.—Coleman and Bell chlorobenzene was distilled as above; b. p. 132°.

Ethyl Benzoate.—Eastman pure ethyl benzoate was distilled as above; b. p. 212.0–212.5°.

Pinene.—Eastman technical *d,l*-pinene was distilled as above; b. p. 162–162.3°.

***m*-Nitroaniline.**—Eastman pure *m*-nitroaniline was recrystallized from water and dried in a desiccator for three days; m. p. 114° (cor.).

Benzamide.—Eastman pure benzamide was recrystallized from water and dried as above; m. p. 130° (cor.).

2,3-Dichloro-5,6-dimethoxybenzoquinone was furnished through the courtesy of the Dow Chemical Company and was used without further purification.

(1) Presented in part at the Detroit meeting of the American Chemical Society, September, 1940.

(2) Abstracted from the Master's Thesis of Raymond Davis, University of Maryland, June, 1940.

(3) (a) Svirbely, Ablard and Warner, THIS JOURNAL, **57**, 652 (1935); (b) Maryott, *ibid.*, **63**, 3079 (1941); (c) Halverstadt and Kumler, *ibid.*, **64**, 2988 (1942); (d) Hoecker, *J. Chem. Phys.*, **4**, 431 (1936); (e) Pohl, Hobbs and Gross, *Annals of the New York Academy of Sciences*, **40**, 389 (1940). These are but a few papers referring to the subject.