possibility for ionization, make it clear that II is not an isomer of I and afford a strong indication that it is a dimer.

## EXPERIMENTAL<sup>7</sup>

Photodimerization of acridizinium bromide. One gram of crystalline acridizinium bromide monohydrate I was irradiated under a General Electric sunlamp for about 5.5 hr. with occasional stirring to ensure complete exposure. As the reaction progressed, the color of the material changed from yellow to light tan and the crystals disintegrated. Recrystallization from ethanol-ether yielded .96 g. (93%) of colorless prisms, m.p. 260-263°.

Similar results may be obtained by the use of direct sunlight. In one experiment it was demonstrated that irradiation in a stoppered glass vial for a total of 16 hr. produced no detectable change in weight although conversion was practically complete.

An analytical sample was prepared by recrystallization from ethanol-ether, m.p. 260-264°.8

Anal. Calcd. for  $(\tilde{C}_{14}H_{16}NBr\cdot 3/2 H_2O)_2$ : C, 54.51; H, 4.22; N, 4.89. Found: C, 54.86; H, 4.03; N, 4.70.

Properties of irradiated acridizinium bromide. The new product (II) is less soluble in water and ethanol than is the starting material I, and the solutions lack the fluorescence characteristic of the acridizinium ion.

The irradiation product was unaffected by drying at 75° for 24 hr. or refluxing in 48% hydrobromic acid for 2 hr.

When 0.23 g. of the irradiation product (II) was refluxed for 18 hr. in 15 ml. of 95% ethanol it yielded 0.19 g. (82.5%) of acridizinium bromide, m.p. 236-237° (lit.<sup>2</sup> 239-240°). The identity of the product was established by means of the ultraviolet absorption spectrum.

Hydrogenolysis of the irradiation product. Hydrogenation of 0.5 g. of irradiated acridizinium bromide was carried out in about 50 ml. of ethanol using Adams' catalyst, a little more than eight molar equivalents of hydrogen being absorbed. The solution was filtered and concentrated yielding 0.3 g. of fine white crystals m.p.  $200-228^{\circ}$ . These were converted to the picrate in ethanol yielding yellow needles m.p.  $160^{\circ}$  (lit.<sup>9</sup>  $161-162^{\circ}$ ) of benzo[c]azabicyclo[4.4.0]decane picrate (III) identified by a mixed melting point determination with an authentic sample.

Boiling-point elevation in ethanol. The boiling point elevation caused by solution of 0.300 g. of the bromide in 10 ml. of absolute ethanol was observed and compared with a value calculated on the assumption that no ionization had occurred, and using 1.2° as the molal boiling point elevation constant for ethanol.

Acridizinium bromide (278). Observed, 0.180°; Calcd. 0.162°. Irradiated acridizinium bromide (574). Observed 0.068°, 0.078°. Calcd. 0.078°.

In the first of the two determinations on irradiated acridizinium bromide (II), refluxing in the molecular weight apparatus was continued for 3 hr., during which the boilingpoint elevation rose to 0.133°. There was no indication that a maximum in boiling-point had been reached.

The picrate of the irradiation product II was prepared in ethanol as yellow crystals, m.p. 280-283°.

Anal. Calcd. for  $(C_{19}H_{12}N_4O_7\cdot 1/2 H_2O)_2$ : C, 54.71; H, 3.14; N, 13.42. Found: C, 54.65; H, 3.06; N, 13.21.

(7) All melting points were taken on a Fisher-Johns apparatus and are uncorrected. Ultraviolet absorption spectra were measured in 95% ethanol (1 cm. silica cells). Analyses are by Micro-Tech Laboratories, Skokie, Ill.

(8) Melting point obtained with fairly rapid heating. If the compound is heated very slowly it turns yellow, melting at 238°. It is noteworthy that acridizinium bromide melts at  $239-240^{\circ}$  (ref. 2).

(9) N. J. Leonard, S. Swann, Jr., and G. Fuller, J. Am. Chem. Soc., 76, 3193 (1954).

The nitrate of the irradiation product II was formed when a small quantity of II was heated on the steam bath for 15 min with 6N nitric acid in an attempt to bring about oxidation. The salt, recovered by pouring the solution on ice, was recrystallized from alcohol-ether as colorless needles, m.p. 228-230°.

Anal. Calcd. for  $C_{26}H_{20}N_4O_6\cdot 3/2$  H<sub>2</sub>O: C, 61.00; H, 4.53; N, 10.84. Found: C. 60.84; H, 4.28; N, 10.55.

The perchlorate of the irradiation product II was prepared by addition of perchloric acid to a water solution of the bromide and recrystallized from water as colorless needles, m.p. 294°.

Anal. Caled. for  $(C_{13}H_{10}NClO_4)_2$ : C, 55.79; H, 3.60; N, 5.01. Found: C, 55.66; H, 3.85; N, 4.97.

A 0.15 g. sample of the perchlorate (m.p. 290°) was refluxed overnight in 95% ethanol. The solution was concentrated and cooled yielding 0.1 g. (67%) of yellow needles, m.p. 205°. This was identified as acridizinium perchlorate (lit.<sup>2</sup> 205-206.2°) by means of the ultraviolet absorption spectrum.

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# Base-Catalyzed Cleavage of $\beta$ -Hydroxy Acids and Their Esters

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The cleavage of a  $\beta$ -hydroxy acid or ester, in the manner indicated *below*, has been described frequently in the literature.<sup>3</sup>

The effect of molecular structure on base-catalyzed decomposition of  $\beta$ -hydroxy acids and esters was investigated rather extensively by Ivanov and coworkers.<sup>4</sup> All of the  $\beta$ , $\beta$ -disubstituted  $\alpha$ -aryl- $\beta$ hydroxypropionic acids studied by them were decomposed readily into arylacetic acids and ketones.

(2) Sterling-Winthrop Fellow.

(3) In 1880, H. Schnapp [Ann., 201, 62 (1880)] observed that  $\alpha, \alpha$ -diethyl- $\beta$ -hydroxybutyric acid decomposed, under the influence of heat, into diethylacetic acid and acetaldehyde. Subsequently, a number of similar decompositions have been reported; in most instances the cleavage was catalyzed by a base. Of practical interest is the cleavage of  $\beta,\beta$ -disubstituted  $\alpha$ -phenyl- $\beta$ -hydroxypropionic acids which has been observed in several instances during the attempted preparation of basic esters of these acids [A. W. Weston and R. W. DeNet, J. Am. Chem. Soc., 73, 4221 (1951); F. F. Blicke and H. Raffelson, J. Am. Chem. Soc., 74, 1730 (1952); F. F. Blicke and R. H. Cox, J. Am. Chem. Soc., 77, 5401 (1955)].

# $\lim_{R^3 \mathbb{R}^4 COH} \longrightarrow \mathbb{R}^3 \mathbb{R}^2 CHCOOR + \mathbb{R}^3 \mathbb{R}^4 CO$

R is hydrogen or alkyl R<sup>3</sup>R<sup>4</sup>CO is an aldehyde or ketone

(4) D. Ivanov and J. Popov, Bull. soc. chim., [5] 49, 1547 (1931); D. Ivanov, M. Mihova, and T. Christova, Bull. soc. chim., [4] 51, 1321 (1932).

<sup>(1)</sup> This paper represents part of a dissertation submitted by R. H. Cox in partial fulfillment of the requirements for for the Ph.D. degree in the University of Michigan, 1954.

R<sup>1</sup>R<sup>2</sup>CCOOR

Cleavage of  $\beta$ -monosubstituted  $\alpha$ -aryl- $\beta$ -hydroxypropionic acids took place less readily.<sup>5</sup> In all instances it appeared that the presence of a  $\beta$ -aryl group facilitated the decomposition. Of the  $\alpha$ -alkyland  $\alpha, \alpha$ -dialkyl- $\beta$ -hydroxypropionic acids studied,<sup>6</sup> only those acids which contained two substituents in the  $\beta$ -position, at least one of which was aromatic, were cleaved; those acids which contained only an aryl substituent, or one or two alkyl substituents, in the  $\beta$ -position were not decomposed under the experimental conditions.

During this investigation of the decomposition of  $\beta$ -hydroxy acids, the required acid was refluxed with two molecular equivalents of 3.2% aqueous sodium hydroxide for sixteen hours.

In the case of the following six  $\beta$ , $\beta$ -disubstituted  $\alpha$ -phenyl- $\beta$ -hydroxypropionic acids, at least 96% of the calculated amount of phenylacetic acid was isolated after alkaline treatment:  $\alpha$ -phenyl- $\beta$ methyl- $\beta$ -hydroxybutyric,  $\alpha$ -phenyl- $\beta$ -propyl- $\beta$ -hydroxycaproic,  $\alpha$ -phenyl- $\alpha$ -(1-hydroxycyclohexyl)acetic,  $\alpha$ -phenyl- $\alpha$ -(1-hydroxycyclooctyl)acetic,  $\alpha$ phenyl- $\beta$ -cyclohexyl- $\beta$ -hydroxybutyric, and  $\alpha$ , $\beta$ -diphenyl- $\beta$ -hydroxybutyric acid. The one acid in this group which contained an aryl substituent in the  $\alpha,\beta$ -diphenyl- $\beta$ -hydroxybutyric  $\beta$ -position. acid. decomposed very rapidly. Quantitative observations clearly indicated that the  $\beta$ -cyclohexyl analog,  $\alpha$ -phenyl- $\beta$ -cyclohexyl- $\beta$ -hydroxybutyric acid, decomposed more slowly. It is interesting to note that we obtained practically complete decomposiof  $\alpha$ -phenyl- $\alpha$ -(1-hydroxycyclohexyl)acetic  $\operatorname{tion}$ acid into phenylacetic acid and cyclohexanone under relatively mild conditions while Linstead<sup>7</sup> found that a solution of 1-hydroxycyclohexylacetic acid, when refluxed for twenty-four hours with a tenfold excess of 10% aqueous potassium hydroxide, yielded only a trace of cyclohexanone; only when a tenfold excess of 60% aqueous potassium hydroxide was employed was substantial cleavage of the acid noted.

In order to investigate the possible influence of an  $\alpha$ -hydrogen atom in the cleavage of a  $\beta$ -substituted  $\alpha$ -phenyl- $\beta$ -hydroxypropionic acid, we studied  $\alpha$ -phenyl- $\alpha$ -(1-hydroxycyclohexyl)butyric acid, a compound which does not contain such an atom. This compound was cleaved almost quantitatively into  $\alpha$ -phenylbutyric acid and cyclohexanone.

In the case of the following three  $\beta$ -monosubstituted  $\alpha$ -phenyl- $\beta$ -hydroxypropionic acids, the firstmentioned acid underwent the most decomposition and the last-mentioned acid the least:  $\alpha$ -phenyl- $\beta$ hydroxybutyric,  $\alpha$ -phenyl- $\beta$ -cyclohexyl- $\beta$ -hydroxypropionic and  $\alpha$ -phenyl- $\beta$ -hydroxypelargonic acid.

 $\alpha$ -Phenyl- $\beta$ -hydroxypropionic (tropic) acid has been shown<sup>8,9</sup> to undergo dehydration readily when treated with alkali. In our experiments we also obtained dehydration of this acid; however, to some extent the acid decomposed with the evolution of formaldehyde which was identified by its odor and by a Schiff test.

After alkaline treatment, the following  $\alpha$ -cyclohexyl- $\beta$ -hydroxy acids were recovered unchanged in at least 96% yield: a-cyclohexyl-\$\beta-hydroxypro- $\alpha$ -cyclohexyl- $\beta$ -hydroxybutyric,  $\alpha$ -cyclopionic, hexyl- $\beta$ -methyl- $\beta$ -hydroxybutyric,  $\alpha$ -cyclohexyl- $\beta$ -propyl- $\beta$ -hydroxycaproic,  $\alpha$ -cyclohexyl- $\alpha$ -(1-hy- $\alpha,\beta$ -dicyclohexyl- $\beta$ -hydroxycyclohexyl)acetic,  $\alpha,\beta$ -dicyclohexyl- $\beta$ -hydroxybudroxypropionic, tyric,  $\alpha$ -cyclohexyl- $\beta$ -hydroxypelargonic, and  $\alpha$ cyclohexyl- $\alpha$ -(1-hydroxycyclooctyl)acetic acid. However, the last two compounds especially were observed to undergo slight decomposition which was established by the isolation and identification of the carbonyl compound and by the lowered melting point of the recovered acid.

 $\beta,\beta$ -Diphenyl- $\beta$ -hydroxypropionic acid (m.p. 212°), after alkaline treatment, was recovered in practically quantitative yield but the recovered acid melted at 202–207° which indicated some decomposition.  $\beta,\beta$ -Dicyclohexyl- $\beta$ -hydroxypropionic acid was unaffected by the alkaline treatment.

When we heated the methyl esters of  $\alpha$ -phenyl- $\beta$ -hydroxypropionic acid and  $\alpha$ -cyclohexyl- $\beta$ -hydroxypropionic acid with excess hydrazine monohydrate, the corresponding hydrazides were obtained. However, the methyl esters of  $\alpha$ -phenyl- $\alpha$ -(1-hydroxycyclohexyl)acetic,  $\alpha$ -phenyl- $\alpha$ -(1-hydroxy-4methylcyclohexyl)acetic and  $\alpha$ -phenyl- $\alpha$ -(1-hydroxycyclooctyl)acetic acid, when treated similarly at room temperature, were converted quantitatively into phenylacethydrazide.

Methyl  $\alpha$ -phenyl- $\alpha$ -(1-hydroxcyclooctyl)acetate, when treated with excess liquid ammonia, was partially (25%) decomposed into phenylacetamide and cyclooctanone.

Subsequent to our investigation, Rondestvedt and Rowley<sup>10</sup> obtained quantitative data on the base-catalyzed cleavage of  $\beta$ -hydroxy acids which permit generalizations regarding the mechanism of cleavage.

#### EXPERIMENTAL

 $\alpha$ -Phenyl- $\beta$ -cyclohexyl- $\beta$ -hydroxypropionic,<sup>11</sup>  $\alpha$ -phenyl- $\beta$ -hydroxybutyric acid, and the other acids employed, with the exception of the one reported below, have been described.<sup>12,13</sup>

 $\alpha$ -Phenyl- $\alpha$ -(1-hydroxycyclohexyl)butyric Acid. This acid was prepared by a variation of the general procedure.<sup>14</sup> Ap-

(10) C. S. Rondestvedt and M. E. Rowley, J. Am. Chem. Soc., 78, 3804 (1956).

(11) F. F. Blicke and H. Zinnes, J. Am. Chem. Soc., 77, 6247 (1955).

(12) F. F. Blicke and H. Raffelson, J. Am. Chem. Soc., 74, 1730 (1952).

(13) F. F. Blicke and R. H. Cox, J. Am. Chem. Soc., 77, 5401, 5403 (1955).

(14) D. Ivanov and A. Spassov, Bull. soc. chim. [4] 49, 19 (1931).

<sup>(5)</sup> D. Ivanov, Bull. soc. chim., [4] 53, 321 (1933).

<sup>(6)</sup> D. Ivanov, Bull. soc. chim., [5] 7, 569 (1940).

<sup>(7)</sup> R. P. Linstead, J. Chem. Soc., 362 (1927).

<sup>(8)</sup> K. Kraut, Ann., 148, 236 (1868).

<sup>(9)</sup> H. S. Raper, J. Chem. Soc., 123, 2558 (1923).

proximately 2 moles of isopropylmagnesium chloride was allowed to react with 0.5 mole of  $\alpha$ -phenylbutyric acid. To the mixture there was added 1.6 moles of cyclohexanone. The yield was 62%; m.p. 125–128° after recrystallization from benzene-petroleum ether (60–70°).

Anal. Calcd. for  $C_{16}H_{22}O_3$ : C, 73.26; H, 8.45; neut. equiv., 262.2. Found: C, 73.12; H, 8.68; neut. equiv., 261.8.

The following esters were obtained by the use of diazomethane.

Methyl  $\alpha$ -phenyl- $\alpha$ -(1-hydroxycyclohexyl)acetate. The yield was 81%; m.p. 84° after recrystallization from petroleum ether (60-70°).

Anal. Caled. for  $C_{15}H_{20}O_3$ : C, 72.55; H, 8.12. Found: C, 72.29; H, 8.08.

Methyl  $\alpha$ -phenyl- $\alpha$ -(1-hydroxy-4-methylcyclohexyl)acetate. The yield was 77%; m.p. 113-114° after recrystallization from petroleum ether (90-100°).

Anal. Caled. for C<sub>16</sub>H<sub>22</sub>O<sub>8</sub>: C, 73.26; H, 8.45. Found: C, 73.60; H, 8.89.

Methyl  $\alpha$ -phenyl- $\alpha$ -(1-hydroxycyclooctyl)acetate. The ester was obtained in 74% yield; m.p. 93–95° after recrystallization from petroleum ether (60–70°).

Anal. Calcd. for C17H24O3: C, 73.88; H, 8.75. Found: C, 73.85; H, 8.53.

The following hydrazides were prepared by heating the required methyl esters with a fourfold excess of hydrazine monohydrate on a steam bath until a homogeneous solution was obtained.

 $\alpha$ -Phenyl- $\beta$ -hydroxypropionhydrazide. The yield was 81%; m.p. 169–171° after recrystallization from water.

Anal. Calcd. for  $C_9H_{12}O_2N_2$ : C, 59.98; H, 6.71. Found: C, 60.14; H, 6.75.

 $\alpha$ -Cyclohexyl- $\beta$ -hydroxypropionhydrazide. This compound melted at 213–214° (dec.) after recrystallization from water; yield 60%.

Anal. Calcd. for C<sub>9</sub>H<sub>18</sub>O<sub>2</sub>N<sub>2</sub>: C, 58.04; H, 9.74. Found: C, 58.33; H, 9.76.

Base-catalyzed cleavage. The required acid (0.02 mole) was dissolved in 50 cc. of aqueous sodium hydroxide solution which contained 1.6 g. (0.04 mole) of sodium hydroxide, the solution was refluxed for 16 hours and then extracted with ether (nonacidic fraction). The alkaline solution was then acidified and the precipitate (acidic fraction) was filtered; ether extraction of the filtrate yielded an additional amount of acidic fraction.

The acidic fraction was composed of the acid formed by cleavage, the original acid, or a mixture of the two acids. Each acid was characterized by a mixed melting point and by a neutralization equivalent.

In those instances in which cleavage occurred, the carbonyl compound, found in the nonacidic fraction, was identified by its boiling point and/or the melting point of a known derivative.

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## Aromatic Nucleophilic Substitution Reaction in Qualitative Organic Chemistry: The Reaction of 2,4-Dinitrofluorobenzene with Phenols

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The preparation of derivatives of phenols, for identification purposes, by reactions of the corresponding sodium phenoxides with 2,4-dinitrochlorobenzene is described or mentioned in several texts and laboratory manuals<sup>2-6</sup> for organic qualitative analysis. The procedure, based upon work of Bost and Nicholson,<sup>7</sup> appears to be simple but the products obtained are frequently oils rather than crystalline solids. The 2,4-dinitrophenyl ether has therefore not found favor as a derivative in the identification of phenols.

The reason for the formation of the oils lies in the choice of solvent for this reaction. In the alcohol water solvent used, there are generally three nucleophilic ions present, hydroxide, phenoxide, and ethoxide.<sup>8</sup> Since the nucleophilic attacking power of these ions is in the order ethoxide > phenoxide >hydroxide,<sup>8</sup> one generally obtains two ethers, 2,4dinitrophenetole as well as the expected substituted diphenyl ether. Any phenol formed by the reaction with an excess of hydroxide ion is readily removed from the desired derivative by washing with dilute base. However, the two ethers cannot be separated by this simple washing, so that an oil results. If Bost and Nicholson's procedure is carefully followed so that equimolar amounts of NaOH, phenol, and 2,4-dinitrochlorobenzene are used, little ethoxide ion is present and only one ether, a crystalline derivative, is obtained. A more promising method of obtaining crystalline derivatives is to use a solvent which does not give nucleophilic ions by reacting with hydroxide ion, or to use an aqueous solvent and remove the 2,4-dinitrophenol which is the by-product.

The change in solvent to water was not practical with the solid 2,4-dinitrochlorobenzene for the heterogeneous reaction at room temperature is slow. However, the liquid, 2,4-dinitrofluorobenzene, contains the more highly activated fluorine atom,<sup>9</sup> so that a Schotten-Bauman reaction at room temperature was possible. Fifteen ml. of 5% NaOH (an excess), 0.005 mole of phenol, and 0.005 mole of 2,4-

(3) N. D. Cheronis and J. B. Entriken, Semimicro Qualitative Organic Analysis, Crowell, New York (1947), p. 221 and 381-385.

(4) F. Wild, Characterization of Organic Compounds, Cambridge Press, Cambridge (1948), p. 70-71 and 34-37.

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(6) Staff of Hopkin and Williams Research Laboratory, Organic Reagents for Organic Analysis, Chemical Publishing Co., Inc., Brooklyn (1946), p. 52.

(7) R. W. Bost and F. Nicholson, J. Am. Chem. Soc., 57, 2368 (1935).

(8) J. F. Bunnett and G. T. Davis, J. Am. Chem. Soc., 76, 3011 (1954).

(9) A. L. Beckwith, J. Miller, and G. D. Leahy, J. Chem. Soc., 3552 (1952).

<sup>(1)</sup> From the independent study theses submitted to the College of Wooster in partial fulfillment of the degree of Bachelor of Arts, of James P. Douglas, 1954, Howard Leister, 1955, and Martha B. Voelkel, 1956.

<sup>(2)</sup> J. W. Chittum, Laboratory Manual of Organic Chemistry, 6th Edition, Edwards Brothers, Ann Arbor, Mich. (1947), p. 36-38.