same side of the double bond, rotation of the benzene ring through the position corresponding to coplanarity with the double bond is resisted by interference between the hydrogen at the *o*-position of the benzene ring and the methyl group[15] and thus the perpendicular interaction with a carbonium ion is hindered for *cis*-β-methylstyrene. This interference phenomenon also is shown by a comparison of the ultraviolet absorption spectra of *cis*- and *trans*-β-methylstyrene (see Experimental). Alternately, a more likely explanation is that the transition state configuration resembles the initial state and thus more resonance stabilization is obtained with the *trans* isomer, the actual differences between the *cis* and *trans* isomers being small in the ground state. The fact that the r_2 values are the same may be justified on the basis that additional steric interactions between the β-methylstyrene carbonium ion and *cis*- and *trans*-β-methylstyrene are large enough to overshadow the previously discussed small interference or transition state stabilization factors. Large differences in the reactivity of *cis*- and *trans*- olefins in free radical initiated copolymerizations have been frequently observed.[16] These large differences as compared with the relatively small difference observed by us in the cationic copolymerization of *cis*- and *trans*-β-methylstyrene may be explained by the recent suggestion of Bader, Buckley, Leavitt and Szwarc that the most probable approach of a radical is along the C═C axis[17] as compared to the more perpendicular approach of the carbonium ion and the C═C double bond.

When the methyl group in the β-position is lengthened by one or more methylene units, steric effects become completely dominant over polar influences and the reactivity of the monomer is changed. The shape of the copolymerization composition curves (Fig. 1) show that although *cis*- and *trans*-β-methylstyrene are able to add to themselves in the growing chain this is not possible for β-ethylstyrene where $r_2 = 0$.

When the alkyl group is situated in the nuclear *p*-position, the steric interference is small (if at all) and the reactivity of *p*-ethylstyrene is only slightly less than that of *p*-methylstyrene ($r_2 = 4.1$ and 4.5; $r_1 = 0.29$ and 0.22, respectively). This small difference in reactivity may be explained on the basis of a small additional hyperconjugative stabilization of the carbonium ion formed from *p*-methylstyrene.

Acknowledgment.—We are grateful for the support of the work of D. Tanner by the Office of Naval Research, Contract No. NR-356-262, and of Eli M. Pearce of a fellowship from E. I. du Pont de Nemours and Co., Inc., and a "Grant in Aid" from the Research Corporation.

[15] D. J. Cram, THIS JOURNAL, **71**, 3883 (1949). This interference was previously discussed by this author for *cis*- and *trans*-α,β-dimethylstyrene.

[16] C. Walling, "Free Radicals in Solution," John Wiley and Sons, Inc., New York, N. Y., 1957, pp. 127–129.

[17] A. R. Bader, R. P. Buckley, F. Leavitt and M. Szwarc, THIS JOURNAL, **79**, 5621 (1957).

BROOKLYN 1, N. Y.

[CONTRIBUTION NO. 1398 FROM THE STERLING CHEMISTRY LABORATORY OF YALE UNIVERSITY]

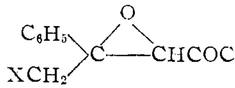
Epoxy Ketones Derived from the Reactions of 1,4-Dihalo-1,4-dibenzoylbutanes with Base[1a,1b]

BY HARRY H. WASSERMAN AND MARINA J. GORBUNOFF

RECEIVED MARCH 20, 1958

As in the reactions of phenacyl halides with alkoxides, epoxy ketones are formed when α-halo- and α,α'-dihalo-1,4-dibenzoylbutanes are treated with bases. Whereas 1-chloro- or 1-bromo-1,4-dibenzoylbutane is converted to a β,γ-epoxy ketone, 1,4-dihalo-1,4-dibenzoylbutanes form γ-halo-α,β-epoxy ketones. The proof of structure of these products is based on ultraviolet absorption spectral measurements of model phenacyl type bromides and chlorides, and on reduction studies using zinc in polar solvents.

In previous articles[2–4] it has been shown that phenacyl halides undergo condensation in base to form *cis*- and *trans*-γ-halo-α,β-epoxy ketones corresponding to structure I.[5]



I, X = Br, Cl

Although the reaction leading to I is analogous in many respects to the Darzens glycidic ester condensation,[6,7] it is unusual in that the reaction involves two molecules of an α-halo ketone instead of the usual combination of aldehyde (or ketone) and α-halo ester. A related example of the use of α-halo ketones in this type of condensation was reported some years ago[8–10] during the course of

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[1] (a) Taken from a dissertation submitted by M. J. Gorbunoff in partial fulfillment of the requirements for the Ph.D. degree, Yale University, 1956. (b) Presented at the Meeting of the American Chemical Society in Dallas, Texas, April, 1956.

[2] H. H. Wasserman, N. E. Aubrey and H. E. Zimmerman, THIS JOURNAL, **75**, 96 (1953).

[3] J. Berson, *ibid.*, **74**, 5175 (1952).

[4] C. L. Stevens, R. J. Church and V. J. Traynelis, *J. Org. Chem.*, **19**, 522 (1954).

[5] For discussions of the stereochemistry of epoxy ketones related to dypnone oxide, see (a) H. H. Wasserman and J. B. Brous, *ibid.*, **19**, 515 (1954); (b) H. H. Wasserman and J. B. Brous, THIS JOURNAL, **76**, 5811 (1954); (c) H. H. Wasserman and N. E. Aubrey, *ibid.*, **77**, 590 (1955); (d) H. H. Wasserman and N. E. Aubrey, *ibid.*, **78**, 1726 (1956); (e) C. L. Stevens and V. J. Traynelis, *J. Org. Chem.*, **19**, 533 (1954); (f) N. H. Cromwell and R. A. Setterquist, THIS JOURNAL, **76**, 5752 (1954).

[6] G. Darzens, *Compt. rend.*, **139**, 1214 (1904).

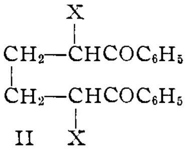
[7] For a review of the Darzens reaction, see M. S. Newman and B. J. Magerlein, "Organic Reactions," Vol. V, 1949, p. 413.

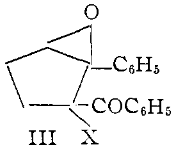
[8] T. Y. Kao and R. C. Fuson, THIS JOURNAL, **54**, 313 (1932).

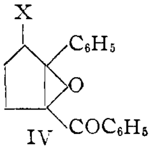
[9] T. Y. Kao, *ibid.*, **62**, 356 (1940).

[10] R. C. Fuson, H. H. Hully, J. F. McPherson and F. W. Spangler, *J. Org. Chem.*, **7**, 462 (1942).

studies on the reaction of a variety of bases with 1,4-dihalo-1,4-dibenzoylbutanes (II), X = Br, Cl). In the early work, the products, $C_{18}H_{15}XO_2$ (X = Br, Cl), were formulated as β,γ-epoxy ketones of structure III, X = Br, Cl.

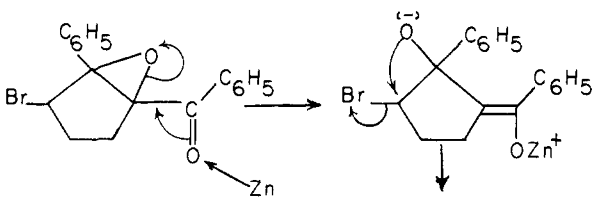

II


III

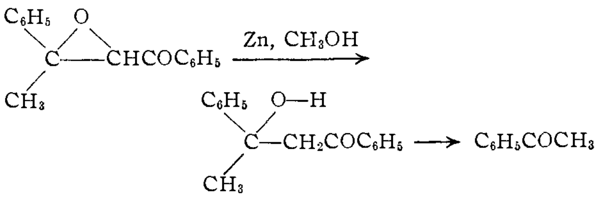

IV

By analogy with the phenacyl halide condensations mentioned above,[2-4] formation of γ-halo α,β-epoxy ketones of structure IV might be expected from II rather than the β,γ-epoxy isomers III. The following will show that this is in fact the case. In the ensuing discussion the epoxy ketone product derived from II will be referred to as compound A.

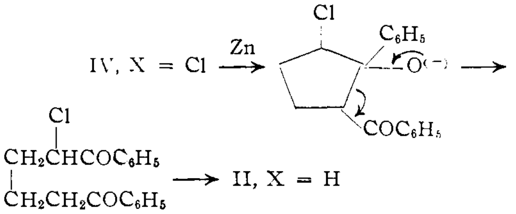
The principal evidence presented by previous workers supporting the α-halo-β,γ-epoxy structure for compound A, lies in the zinc–acetone dehalogenation reaction[9] which leads, in small yields, to 1-phenyl-5-benzoyl-1-cyclopentene oxide (III, X = H). The structure of this reduction product is undoubtedly correct since it can be prepared independently and unambiguously[11] by the action of perbenzoic acid on 1-phenyl-5-benzoyl-1-cyclopentene as well as by the action of zinc on 1,4-dibromo-1,4-dibenzoylbutane (II, X = Br).[12] Formation of this oxide by the reaction of III, X = Br, Cl, with zinc is in accord with expectation since α-halo ketones are known to undergo ready dehalogenation in such reduction processes. On the other hand, it is possible that reduction of the alternative α,β-epoxy structure IV under these conditions could likewise lead to III, X = H, by the process shown below.[13]


III, X = H

This reaction scheme is consistent with our observation that dypnone oxide suffers reduction with zinc in methanol to form an unstable β-hydroxy ketone which undergoes ready dealdolization to acetophenone as shown



Formation of product III, X = H, in the zinc–methanol reduction of compound A might be expected therefore if compound A were either the β,γ-epoxy structure as in III, X = Br, or the α,β-epoxy isomer as in IV, X = Br. There is, however, additional chemical evidence which cannot easily be reconciled with both of the structures under consideration. The further observation made by Fuson[10] that compound A, X = Cl, may be converted to 1,4-dibenzoylbutane by the more vigorous action of zinc and acetic acid is explained easily on the basis of IV, X = Cl, since the intermediate halohydrin could suffer dealdolization as in the dypnone oxide case, and then dehalogenation through the sequence



No such ready explanation for this conversion to II, X = H, follows from a consideration of structure III, X = Cl.[14]

Ultraviolet Absorption Spectral Data.—Evidence strongly favoring the α,β-epoxy ketone structure (IV, X = Br,Cl) for compound A can be derived from ultraviolet absorption measurements of the chloro and bromo derivatives of A compared with a

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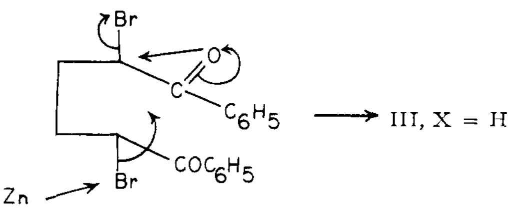
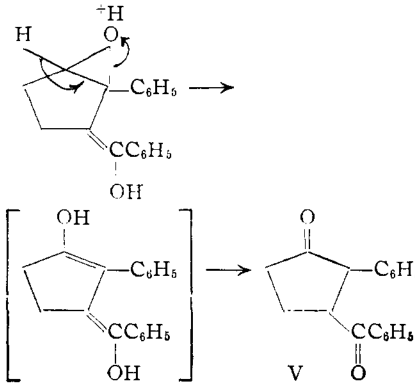
(11) R. C. Fuson and M. W. Farlow, THIS JOURNAL, **56**, 1593 (1934).

(12) This conversion, analogous to the Reformatsky reaction, probably takes place



(13) This transformation is analogous to the zinc reduction of α-ketol acetates (R. B. Woodward, F. Sondheimer, D. Taub, K. Heusler and W. M. McLamore, THIS JOURNAL, **74**, 4225 (1952)), and the reaction of zinc and acetic anhydride with 2,2,4,4-tetramethyloxetanone described by B. L. Murr, G. B. Hoey and C. T. Lester, *ibid.*, **77**, 4430 (1955).

(14) The possibility that a first-stage zinc dehalogenation of III, X = Cl, may be followed by rearrangement of III, X = H, to 1,4-dibenzoylbutane is untenable, since it can be shown that in the presence of zinc and acetic acid the β,γ-epoxide III (X = H) rearranges almost instantaneously to 2-phenyl-3-benzoyl-1-cyclopentanone (V). So sensitive is III, X = H, to the action of acid that mere recrystallization of this substance from ethyl acetate (unless the solvent is pretreated with potassium carbonate) results in substantial 1,4-diketone formation. This acid-catalyzed isomerization first noted by R. C. Fuson, A. Lippert, R. V. Young and H. H. Hully, THIS JOURNAL, **58**, 2633 (1936), may well take place through the di-enol, as



variety of model phenacyl-type halides. It had been reported earlier by Mohler[15] that phenacyl bromide absorbs about 4 mμ higher than phenacyl chloride, and this difference in absorption of the bromide compared to the chloride seems to be characteristic of a variety of phenacyl-type halides. In Table I are listed five pairs of α-halo ketones related to the phenacyl halides. It can be seen that in every case, including the benzoylcyclopentane model, the bromo compounds absorb about 4 mμ higher than do the chloro ketones.[16] In contrast, the two pairs of γ-halo α,β-epoxy ketone models in Table II show little variation in absorption depending on whether the halogen is bromine or chlorine. It is significant that both bromo and chloro derivatives of compound A (Table II) absorb at nearly identical wave lengths in the ultraviolet. This fact, viewed in the light of the data of Table I, makes it extremely unlikely that the halo epoxy ketones under consideration are phenacyl-type halides, and strongly favors the assignment of γ-halo-α,β-epoxy ketone structures IV to compound A.

TABLE I

ULTRAVIOLET ABSORPTION SPECTRA OF MODEL PHENACYL-TYPE HALIDES

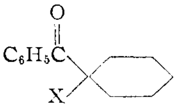
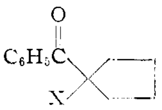
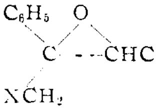
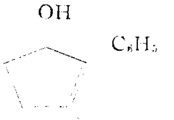
		λmax, mμ	Δ
$C_6H_5COCH_2X$	X = Br	251.0	4
	X = Cl	247.0	
$C_6H_5COCHBrCH_2CH_2CHBrCOC_6H_5$		256.0	4
$C_6H_5COCHClCH_2CH_2CHClCOC_6H_5$		252.0	
	X = Br	253.0	4
	X = Cl	249.0	
	X = Br	254.5	3.5
	X = Cl	251.0	

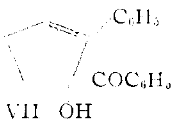
TABLE II

ULTRAVIOLET ABSORPTION SPECTRA OF MODEL γ-HALO-α,β-EPOXY KETONES

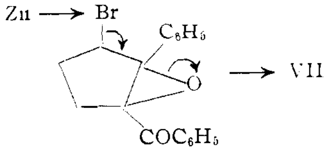
			λmax, mμ	Δ
	α-Series	X = Br	252.0	0.5
		X = Cl	251.5	
	β-Series	X = Br	250.0	0.0
		X = Cl	250.0	
Compound A (bromide)			252.0	0.5
Compound A (chloride)			251.5	

Zinc Reduction Studies.—Convincing chemical evidence favoring structure IV can be derived from further studies on the zinc dehalogenation of A. As reported by Kao,[9] reduction by zinc in acetone leads to the epoxide III, X = H. It has now been found, however, that if the solvent is changed to methanol, the reaction takes a different course and leads to a keto alcohol in 40% yield. This product, having an empirical composition corresponding to either VI or VII, exhibits infrared absorption bands at 2.89 μ, due to hydroxyl, and at 5.95 μ due to a carbonyl group. The α-ketol VII could be

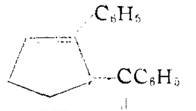

VI

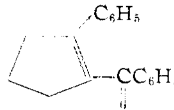

VII

derived from IV, X = Br, by the elimination process shown below, while VI would be the product expected from an analogous dehalogenation of III, X = Br.

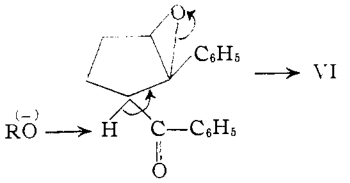


The infrared evidence clearly favors the α-ketol structure VII, since the absorption at 5.95 μ, like that of the model β,γ-unsaturated ketone VIII,[17] shows that the benzoyl carbonyl group is not conjugated to a double bond in the ring. In the conjugated compound exemplified by IX the carbonyl

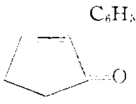

VIII


IX

absorption is shifted to 6.07 μ. The assignment of structure VII to the zinc reduction product is further supported by the fact that it is non-identical with the product obtained by the action of methoxide ion on the β,γ-epoxide III, X = H. The latter product, assigned structure VI, shows the expected carbonyl absorption at 6.05 μ, and is formed most probably by the process



Evidence which shows conclusively that the zinc reduction product has the α-ketol arrangement in VII was derived by oxidation studies with glycol-splitting reagents. Reaction of the ketol with lead tetraacetate in benzene led, on work-up in ethanol, to ethyl benzoate as well as to a crystalline ketone, m.p. 71°, in 70% yield. Similar results, though in poorer yield, were obtained with periodic acid. The ketone was shown to be 2-phenyl-2-cyclopentenone (VIIa) by comparison with an authentic sample pre-


VIIa

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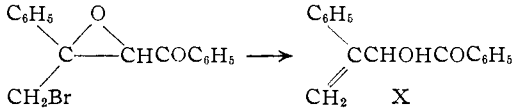
[15] H. Mohler and J. Sorgen, *Helv. Chim. Acta*, **23**, 100 (1940).

[16] The greater bathochromic shift exhibited by the α-bromo ketones in the above series compared to the α-chloro ketones may be due to the greater polarizability of the unshared electrons on bromine compared to chlorine, permitting enhanced conjugation with the adjacent carbonyl group.

[17] Compounds VII and VIII were prepared by the method of E. Bauer, *Compt. rend.*, **155**, 288 (1912).

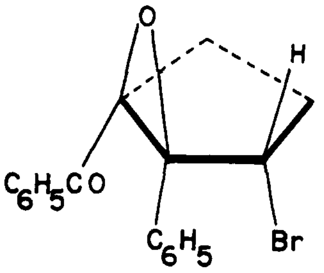
pared by an unambiguous route.[18] This sequence of reactions thus strongly favors structure IV for compound A.

There are analogies for the modifications of the γ-halo-α,β-epoxy ketone system involved in the transformation IV, X = Br, to VII. For example, bromoethylstyrene oxide is converted by zinc in methanol to phenylvinylcarbinol,[19] and the zinc–methanol reduction of the halodiphenacyls[1] yields the unsaturated ketol X[20] as one of the major products.


X

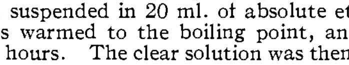
The structure proof of X rests on its empirical analysis, the infrared absorption spectrum, indicating an unconjugated benzoyl carbonyl (5.95 μ), evidence for the presence of unsaturation (decolorization of permanganate and bromine), and a positive ketol test (bismuth oxide). Furthermore, this product can be cleaved by lead tetraacetate to form ethyl benzoate, and undergoes a prototropic shift in base to form the α-diketone, 1,3-diphenyl-1,2-butanedione.[21]

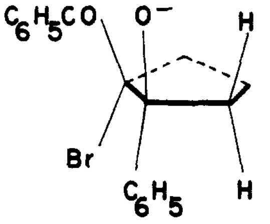
Stereochemistry.—The chemical and physical evidence outlined in the preceding discussion leaves little doubt that the structure of the halo epoxy ketone, A, is IV (X = Br or Cl). The zinc dehalogenation reactions of IV, leading to III, X = H, and to VII are suggestive of the stereochemistry shown in IVa, where epoxide and halogen groups have a *trans* orientation. This assignment of configuration is, however, not rigorous since neither type of conversion (IV to III or IV to VII) has, as yet, been shown to be stereospecific. In particular, elimination reactions analogous to the process IV → VII recently[22] have been shown to be non-stereospecific.

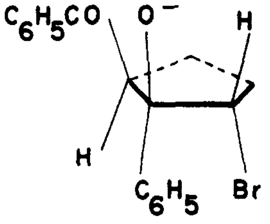

IVa

The Action of Base on Monobromodibenzoylbutane.—In contrast to the reactions of the dihalodibenzoylbutanes with bases, discussed above, 1-bromo-1,4-dibenzoylbutane (XI) is converted under similar conditions to the β,γ-epoxide III, X = H. This result might not be predicted by analogy with other studies in this series and therefore deserves some further consideration.

Removal of the more acidic proton on carbon (a) would lead to an intermediate (XIIa) in which epoxidation should take place by displacement of the more reactive phenacyl halide. Formation of an α,β-epoxy ketone might thereby be expected. On the other hand, it is very likely that the rate-determining step in this reaction, as in the closely related Darzens condensation,[23] is the formation of the new carbon–carbon bond in the process XI → XIIa or XI → XIIb. Thus, considerations of the more acidic proton and/or the more reactive halogen in this case might not be as pertinent as an evaluation of the steric factors involved in the formation of XIIa or XIIb. In XIIa four bulky groups are substituted on only *two* carbon atoms of the ring; in XIIb these bulky groups are spread out over *three* carbon atoms, resulting in less steric interference. This latter steric factor may favor formation of XIIb in the rate-determining step, and thereby account for β,γ-epoxide formation.


$$C_6H_5CO\underset{\underset{Br}{|}}{\overset{(a)}{C}}HCH_2\overset{(b)}{C}H_2CH_2COC_6H_5$$
XI


XIIa


XIIb

Experimental[24]

1-Benzoyl-2-phenyl-3-bromo-1-cyclopentene oxide (compound A, IV, X = Br) was prepared by a modification of the method described by Kao.[9] A sodium methoxide solution, made by dissolving 0.1 g. of sodium in 10 ml. of absolute methanol, was added to 0.5 g. of 1,4-dibromo-1,4-dibenzoylbutane, suspended in 20 ml. of absolute ethanol. The mixture was warmed to the boiling point, and allowed to stand for 10 hours. The clear solution was then diluted with 150 ml. of water and extracted with ether. The ether layer was washed with dilute hydrochloric acid, aqueous bicarbonate and then water. Removal of solvent left 0.4 g. of white solid which was recrystallized from 95% ethanol. The yield of product, m.p. 136–137°, was 0.3 g. (74%). By the method of Kao[9] an identical product, m.p. 138–139° (37%) was obtained.

Anal. Calcd. for $C_{18}H_{15}O_2Br$: C, 62.97; H, 4.47; Br, 23.32. Found: C, 62.90; H, 4.47; Br, 23.05.

Zinc–Acetic Acid Reduction of 1-Phenyl-5-benzoyl-1-cyclopentene Oxide.—A mixture of 1-phenyl-5-benzoyl-1-cyclopentene oxide (0.2 g.) and zinc dust (0.5 g.) was added to 15 ml. of glacial acetic acid. The mixture was heated to 100° and left at room temperature for two hours. The solution was decanted from the zinc dust into 50 ml. of water. The reaction mixture was extracted with 25 ml. of ether, and the ethereal solution was washed with bicarbonate and then water. After the solvent had been removed,

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[18] We are grateful to Dr. David Ginsburg of the Israel Institute of Technology, Haifa, for sending us a sample of 2-phenyl-2-cyclopentenone prepared from the addition product of nitrosyl chloride to 1-phenylcyclopentene, THIS JOURNAL, **76**, 3625 (1954).

[19] Unpublished results from the Ph. D. dissertation of Norman Aubrey, Yale University, 1953.

[20] This product was first isolated by J. Brous, Ph. D. dissertation, Yale University, 1954.

[21] The α-diketone was characterized by conversion to a mono-2,4-dinitrophenylhydrazone identical with the known DNP of IX, reference 5d.

[22] H. O. House and R. S. Ro, THIS JOURNAL, **80**, 182 (1958).

[23] M. Ballester and P. D. Bartlett, *ibid.*, **75**, 2042 (1953).

[24] All melting points and all boiling points are uncorrected. The infrared spectra were determined with a Perkin-Elmer double beam infrared spectrophotometer, model 21. The ultraviolet spectra were determined with a Cary recording spectrophotometer, model 11 MS. The ultraviolet solvent was 95% ethanol except as noted. Microanalyses were performed by Schwarzkopf Microanalytical Laboratory, Woodside 77, N. Y.

0.2 g. of white solid was obtained. After recrystallization from 95% ethanol and then ethyl acetate, white needles were obtained, m.p. 157–158°. This material was identified as 2-phenyl-3-benzoyl-1-cyclopentanone[14] (nearly quantitative yield for the crude reaction mixture), by comparison of the infrared spectrum with an authentic sample.[25]

The Action of Sodium Ethoxide on 1-Phenyl-5-benzoyl-1-cyclopentene Oxide.—1-Phenyl-5-benzoyl-1-cyclopentene oxide (0.4 g.) was added to a sodium ethoxide solution made from 10 ml. of absolute ethanol and 0.1 g. of sodium, and the mixture was allowed to stand overnight. Most of the solvent then was removed *in vacuo*, and the residue diluted with water. The mixture was extracted with 50 ml. of ether, and the ethereal solution was washed with dilute HCl, and then water. The solvent was removed *in vacuo* to give 0.37 g. (92%) of yellow solid melting 89–93°. This material was recrystallized from methanol, yielding 0.2 g. of 1-benzoyl-2-phenyl-3-hydroxy-1-cyclopentene melting 93.5–94.0°. The infrared spectrum of the product shows carbonyl absorption at 6.05 μ indicative of a conjugated carbonyl group.

Anal. Calcd. for $C_{18}H_{16}O_2$: C, 81.81; H, 6.06. Found: C, 81.60; H, 6.03.

Reduction of Compound A with Zinc in Methanol. 1-Phenyl-5-hydroxy-5-benzoyl-1-cyclopentene.—A mixture of 10 g. of compound A (1-benzoyl-2-phenyl-3-bromo-1-cyclopentene oxide), 15 g. of sodium iodide and 10 g. of zinc dust, was refluxed in 100 ml. of absolute methanol for nine hours, and left overnight at room temperature. The reaction mixture was filtered, the insoluble material was washed with 100 ml. of absolute methanol, and the washings were added to the main filtrate. The methanol solution next was poured into 2 l. of water to give a white flocculent precipitate. The precipitate was filtered, and the aqueous solution, after concentration to 400 ml., was extracted with 200 ml. of ether. The ether solution was dried over sodium sulfate, concentrated to 40 ml., and then refrigerated. After four hours, a white precipitate appeared. This was identified as starting material (0.2 g.). After standing for one week in the refrigerator, transparent cubic crystals appeared, m.p. 80–90°. From the crude product, after recrystallization from an ether–alcohol mixture, 1.9 g. (25%) of pure 1-phenyl-5-hydroxy-5-benzoyl-1-cyclopentene was obtained, m.p. 94–95°.

Anal. Calcd. for $C_{18}H_{16}O_2$: C, 81.82; H, 6.06. Found: C, 81.83; H, 5.75.

Lead Tetraacetate Cleavage of 1-Phenyl-5-hydroxy-5-benzoyl-1-cyclopentene.—1-Phenyl-5-hydroxy-5-benzoyl-1-cyclopentene (0.5 g., 0.001 mole) was dissolved in a mixture of 20 ml. of dry benzene and 5 ml. of ethanol. After 0.5 g. of anhydrous potassium carbonate had been added to this solution, 0.9 g. (0.002 mole) of lead tetraacetate was added gradually with vigorous stirring. After two hours of stirring at room temperature, the reaction mixture was filtered, and ether was added to the filtrate until no further turbidity appeared. The ether was then removed at reduced pressure to give a yellow oil. Trituration of the oil with petroleum ether yielded 0.21 g. (70%) of yellow crystals, purified by sublimation, m.p. 70–71°. There was no depression of the melting point when this sample was mixed with an authentic sample of 2-phenyl-2-cyclopentenone.[18] The infrared spectra of the two samples are identical.

Anal. Calcd. for $C_{11}H_{10}O$: C, 83.48; H, 6.32. Found: C, 83.39; H, 5.89.

From the petroleum ether mother liquor, 0.10 g. (35%) of ethyl benzoate was obtained by distillation *in vacuo*. The ester was identified by comparison of its infrared spectrum with the spectrum of an authentic sample.

Debromination of β-Bromodiphenacyl[2,26] (Formation of 1,3-Diphenyl-2-hydroxy-3-buten-1-one).—A mixture of 7.5 g. of β-bromodiphenacyl, 38 g. of zinc dust and 3.55 g. of sodium iodide was refluxed in 150 ml. of 95% ethanol for 2 hours. The reaction mixture was filtered while hot. The zinc dust, removed by filtration, was washed with 50 ml. of boiling 95% ethanol, and the alcohol solution added to the main solution. On cooling, 1.85 g. of dibenzoylethane, m.p. 143–146°, was deposited. The mother liquor was poured into 300 ml. of 0.3 *N* HCl and extracted with 100 ml. of ether in three portions. The ether solution was washed in sequence with a bicarbonate solution, a thiosulfate solution and then water. It next was dried over sodium sulfate for one hour. The solution now was condensed to one-third of its original volume and refrigerated for one hour. An additional 0.3 g. of dibenzoylethane (total yield 38.5%), melting 143–146°, was thereby obtained. All of the ether was then removed to give 2.90 g. (51.7%) of a crude product, (1,3-diphenyl-2-hydroxy-3-buten-1-one), which after two recrystallizations from an ether–petroleum ether mixture gave 0.7 g. of a yellow solid, melting 96–100°. This material showed infrared absorption at 2.92 μ (hydroxyl), 5.95 μ (benzoyl), readily added bromine and decolorized permanganate. It reacted readily with bismuth trioxide indicating the presence of a ketol grouping.

Anal. Calcd. for $C_{16}H_{14}O_2$: C, 80.64; H, 5.92. Found: C, 80.41; H, 5.69.

Lead Tetraacetate Cleavage of 1,3-Diphenyl-2-hydroxy-3-buten-1-one.—1,3-Diphenyl-2-hydroxy-3-buten-1-one (0.6 g.), was dissolved in a mixture of 20 ml. of dry benzene and 5 ml. of absolute ethanol. After 0.5 g. of potassium carbonate had been added, 1.15 g. of lead tetraacetate was introduced with vigorous shaking. After two hours of shaking at room temperature, the reaction mixture was filtered, the solid residue washed with ether, and the washings added to the filtrate. Removal of the solvent left an oil which was distilled, yielding a colorless liquid, b.p. 70–85°. This material (0.3 g., 80%) was shown to be ethyl benzoate (80%) by comparison of its infrared spectrum with an authentic sample. The undistilled residue (0.28 g.), a red-brown viscous oil, was not characterized.

The Isomerization of 1,3-Diphenyl-2-hydroxy-3-buten-1-one (1,3-Diphenyl-1,2-butanedione).—A solution of 1.3 g. of 1,3-diphenyl-2-hydroxy-3-buten-1-one in absolute methanol was treated with a sodium methoxide solution made from 0.2 g. of sodium metal and 10 ml. of absolute methanol. After two hours at room temperature, the deep red reaction mixture was diluted with 75 ml. of water and extracted with 60 ml. of ether. The ethereal solution was washed until it was neutral to litmus. The solvent was then removed leaving 0.65 g. of a yellow oil. The infrared spectrum of this oil shows bands at 5.80 and 5.93 μ corresponding to an α-diketone absorption.[27] The α-diketone was characterized as follows: An ethanolic solution containing 0.27 g. of the oily diketone was treated with a solution of 0.8 g. of 2,4-dinitrophenylhydrazine reagent. After standing for two hours at room temperature, the orange precipitate was filtered, washed with water and dried. After three recrystallizations from an ethanol–ethyl acetate mixture, the hydrazone melted at 195–196°.

Anal. Calcd. for $C_{22}H_{18}N_4O_5$: C, 63.15; H, 4.33; N, 13.39. Found: C, 62.89; H, 4.15; N, 13.07.

The infrared spectrum of this product is identical with the infrared spectrum of the pure 2,4-dinitrophenylhydrazone of 1,3-diphenyl-1,2-butanedione prepared by the alkali isomerization of dypnone oxide.[28]

1-Bromo-1-benzoylcyclohexane.—To a solution of benzoylcyclohexane (34 g.) in 250 ml. of dry ether was added 15 ml. of bromine, with stirring, at 50–60°. After the addition had been completed, the reaction mixture was kept at 60° for ten minutes, cooled, and then washed with a sodium sulfite solution and water. The ether now was removed at low pressure and the orange residue was allowed to crystallize in the refrigerator. After 24 hours, a yellow solid was formed, which upon recrystallization from hexane gave 36.7 g. (75.8%) of white crystals melting 51–52°. After two further recrystallizations the product melted sharply at 52.2–52.8°.

Anal. Calcd. for $C_{13}H_{15}OBr$: C, 58.42; H, 5.62; Br, 29.92. Found: C, 58.63; H, 5.69; Br, 30.15.

1-Chloro-1-Benzoylcyclopentane.—A solution of benzoylcyclopentane (10 g.) in 50 ml. of methylene chloride was mixed with a solution of 6 g. of chlorine in 80 ml. of methylene chloride. After 20 hours at room temperature, and 30 minutes at 50°, all the solvent was removed. The oil thus obtained was dissolved in 5 ml. of petroleum ether (60–75°) and refrigerated for several days at 0° then cooled in

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[25] This substance is the main product obtained when 1-phenyl-5-benzoyl-1-cyclopentene oxide is subjected to the action of acid. It is also formed as the main by-product in attempts to prepare the oxide by the action of peracids on 1-phenyl-5-benzoyl-1-cyclopentene.

[26] This reaction was carried out by Dr. J. B. Geiduschek.

[27] H. O. House, THIS JOURNAL, **76**, 1235 (1954).

[28] This experiment was carried out by Joan S. Mazo.

Dry Ice, whereupon a solid separated. The liquid layer was removed, fresh solvent was added, and the material again cooled in Dry Ice. The solid obtained in this way was dried *in vacuo* at room temperature, and then stored in the cold for several days. The product, thick white needles, m.p. 0–5° (approximate), slowly decomposed unless refrigerated.

Anal. Calcd. for $C_{12}H_{13}OCl$: C, 69.23; H, 6.25; Cl, 16.83. Found: C, 68.95; H, 6.53; Cl, 17.28.

1-Bromo-1-benzoylcyclopentane.—To 7.0 g. of benzoylcyclopentane dissolved in 70 ml. of dry ether, 7 g. of bromine was added gradually with stirring. After the addition was complete the reaction mixture was kept in a water-bath at 50° for 30 minutes. All solvent was then removed, and the residue was dried *in vacuo*. The yellow oil thus obtained was dissolved in 10 ml. of petroleum ether (65–70°) and allowed to crystallize in the cold. After two days of refrigeration, 7.0 g. (40%) of white crystalline material separated, m.p. 28–29.5°.

Anal. Calcd. for $C_{12}H_{13}OBr$: C, 56.92; H, 5.13; Br, 31.62. Found: C, 57.03; H, 5.13; Br, 31.68.

The Action of Sodium Methoxide on 1-Bromo-1,4-dibenzoylbutane.—To 1.5 g. (0.004 mole) of 1-bromo-1,4-dibenzoylbutane dissolved in 50 ml. of absolute ethanol was added 0.22 g. (0.004 mole) of sodium methoxide. The reaction mixture was left overnight at room temperature. The white needle-like precipitate, 0.4 g. (50%), which formed was filtered, washed with water and dried. After two recrystallizations from ethyl acetate this material melted at 165–166° and was identified as 1-phenyl-5-benzoyl-1-cyclopentene oxide by mixture melting point and comparison of infrared spectra. From the mother liquors was obtained 0.75 g. of starting material.

NEW HAVEN, CONN.

[CONTRIBUTION FROM AVERY LABORATORY, UNIVERSITY OF NEBRASKA]

γ-Keto- and γ-Hydroxy-γ-phenylbutyramides. Synthesis, Absorption Spectra and Structure Studies

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The reactions of amines with γ-phenyl-γ-butyrolactone have been shown to produce γ-hydroxy-γ-phenylbutyramides. α-Morpholino-γ-phenyl-γ-butyrolactone has been found to be resistant to ring opening by *sec*-amines, while benzylamine and cyclohexylamine react to produce the corresponding amides of α-morpholino-γ-hydroxy-γ-phenylbutyric acid. Several amides of β-benzoylpropionic acid have been prepared from the reactions of primary and secondary amines with γ-phenyl-$\Delta^{\beta,\gamma}$-butenolide. The absorption spectra of these various products are discussed in connection with their structures and ring–chain tautomerism.

The reactions of γ-lactones with such unsymmetrical reagents as ammonia and amines have not been studied thoroughly. The two possible products would be γ-amino acids or γ-hydroxy amides.[2] If the usual ester reaction mechanism is followed, the main product should be the hydroxy amide.

The reaction between γ-phenyl-γ-butyrolactone and ammonia has been reported to give γ-hydroxy-γ-phenylbutyramide.[3,4] In a previous report[5] it was suggested that γ-phenyl-γ-butyrolactone reacts with morpholine to produce γ-morpholino-γ-phenylbutyric acid. This conclusion was based partly on the fact that the product dissolved in dilute sodium carbonate and in dilute acid. Moreover, this compound I produced morpholine hydrochloride on treatment with hydrogen chloride gas in dry ether solution. It has now been found that the other product from this treatment with hydrogen chloride is γ-phenyl-γ-butyrolactone. These properties seemed plausible for the γ-amino acid structure. From our subsequent studies, however, it now seems highly probable that this product is actually γ-hydroxy-γ-phenylbutyromorpholide (I).

The Nujol mull infrared spectrum of I was reported[5] to show a band at 3430 cm.$^{-1}$ which was assigned to an $\overset{+}{\mathrm{N}}\mathrm{H}$ absorption, but this seems to be high compared to the normal $\overset{+}{\mathrm{N}}\mathrm{H}_3$ absorption which is usually in the 3030–3130 cm.$^{-1}$ region.[6] The 3430 cm.$^{-1}$ band seems to be better suited to an associated OH absorption. An absorption band also appeared at 1618 cm.$^{-1}$ which was previously[5] assigned to the carboxylate ion absorption. However, the amide carbonyl absorption may also occur in this region although this is at the lower limit.

Subsequent reactions between γ-phenyl-γ-butyrolactone and piperidine, dimethylamine, benzylamine and cyclohexylamine have given products (II, III, IV and V) which also show infrared bands in the OH and amide carbonyl regions (see Table I). The greatly increased solubility of some of these compounds in ether strongly suggested that they did not have an amino acid structure. Infrared spectra studies of solutions of two of these compounds cleared up any doubts as to their correct structures. These later solution spectra studies showed that the OH and amide carbonyl bands were shifted to higher frequencies from the solid state data. The relatively low carbonyl and OH infrared bands for these compounds I–V suggests considerable hydroxyl–carbonyl hydrogen bonding in these γ-hydroxy amide structures.

The catalytic hydrogenation of N-cyclohexyl-γ-hydroxy-γ-phenylbutyramide (III), prepared from the reaction of γ-phenyl-γ-butyrolactone and cyclohexylamine, produced N-cyclohexyl-γ-phenylbutyramide, identical with a sample prepared from γ-phenylbutyryl chloride. This result supported

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(1) Monsanto Chemical Co. Research Fellow, 1956–1957.

(2) C. D. Lunsford, R. S. Murphey and E. K. Rose, *J. Org. Chem.*, **22**, 1225 (1957), report that γ-butyrolactone reacts with amines to produce γ-hydroxybutyramides and some γ-aminobutyric acid, and suggest that the latter product may be in equilibrium with the former. Chemical evidence for the presence of γ-aminobutyric acid in the reaction mixture was presented.

(3) R. Fittig and L. S. Morris, *Ann.*, **256**, 156 (1889).

(4) R. R. Russell and C. A. VanderWerf, THIS JOURNAL, **69**, 11 (1947).

(5) N. H. Cromwell, P. L. Creger and K. E. Cook, *ibid.*, **78**, 4412 (1956).

(6) L. J. Bellamy, "Infrared Spectra of Complex Molecules," John Wiley and Sons, Inc., New York, N. Y., 1954.