

from 13 to 14 and attributed this low degree of polymerization to resonance stabilization of the monomer by transfer of the  $\alpha$ -hydrogen atom to a chain radical. Later work by these authors<sup>19</sup> showed that this was the case.

Consideration of the proposed cyclic intramolecular polymerization of diallyl phthalate by Simpson, Holt and Zeite<sup>7</sup> and the degradative chain transfer in the polymerization of allyl acetate by Bartlett and co-workers<sup>18,19</sup> leads to the belief that the polymerization of allyl quaternary derivatives is affected by both factors. Cyclic intramolecular polymerization, greatly influenced by chain termination caused by  $\alpha$ -hydrogen transfer, could account for the soluble, non-cross-linked, low molecular weight and unsaturated polymers obtained in this work.

This study has provided evidence that a suggested alternating intramolecular-intermolecular chain propagation occurs when unsaturated quater-

(19) P. D. Bartlett and F. A. Tate, *THIS JOURNAL*, **75**, 91 (1953).

nary ammonium salts are polymerized and shows that a polymer of average degree of polymerization of approximately 25 or 50 is obtained when diethyldiallylammonium bromide is polymerized under nitrogen with *t*-butyl hydroperoxide as catalyst. It also shows that this chain propagation mechanism is followed by an average of four-fifths of the monomer units entering the chain, leaving an average degree of unsaturation in the polymer equivalent to one-fifth double bond per monomer unit in the chain.

**Acknowledgment.**—We wish to express our appreciation to the Atomic Energy Commission who supported this work under terms of Contract No. AT-(40-1)-1353. Thanks are also due to Dr. C. S. Marvel of the University of Illinois for reading the original manuscript and to Dr. Alan Crawshaw of this Department for many helpful suggestions.

GAINESVILLE, FLORIDA

[CONTRIBUTION FROM THE DEPARTMENTS OF BIOLOGICAL CHEMISTRY AND CHEMISTRY OF THE UNIVERSITY OF UTAH]

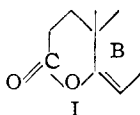
## Rearrangement in the Addition of Grignard Reagents to Enol Lactones

BY KENNETH D. ZWAHLEN,<sup>1</sup> W. J. HORTON AND GEORGE I. FUJIMOTO

RECEIVED DECEMBER 6, 1956

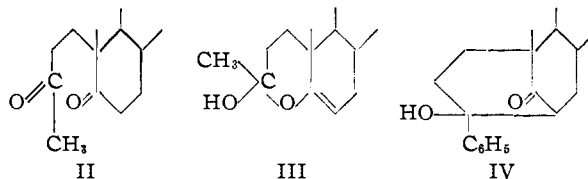
Grignard reagents add to the acyl portion of enol lactones with rearrangement of this acyl carbon to the  $\beta$ -olefinic carbon atom. Further addition of Grignard reagent is subject to steric considerations. Such rearrangements were found in the case of a model steroid enol lactone and also in the addition of Grignard reagents to vinyl acetate and isopropenyl acetate.

The addition of methylmagnesium halide to enol lactones derived from steroids (I) has been a useful method for the synthesis of  $\Delta^4$ -3-keto steroids containing C<sup>14</sup> at position 4<sup>2</sup> and for the closure of the A ring in the synthesis of steroids.<sup>3</sup>



An intermediate in this process has been assigned various structures (II,<sup>2a</sup> III,<sup>2c</sup> with phenylmagnesium bromide IV).<sup>4</sup> Structure II for the intermediate from the enol lactone derived from cholestenone, however, is not identical with II from an independent source.<sup>2c,5</sup>

The present investigation was undertaken in order to test whether a structure of type IV would satisfy the requirements for the intermediate obtained when the enol lactone from cholestenone was



combined with methylmagnesium halide.<sup>6</sup> For this purpose a model V of a steroid enol lactone was studied.

Model V, when treated with methylmagnesium iodide or phenylmagnesium bromide, gave VI and VII, respectively. The structure of VII was confirmed by an independent synthesis (formulas V-X). Reduction of VII with lithium aluminum hydride gave VIII, thus adding support for VII. This diol formed a cyclic sulfite ester IX which enables the assignment of an  $8\beta,11\alpha$ -configuration. These reactions are not easily explainable on the basis of the hemiketal structure (type III).

The reaction of V to yield VI (or VII) involves the migration to an olefinic carbon atom. Such migrations occur when Grignard reagents are added to the simplest enol esters. Methylmagnesium iodide, added to isopropenyl acetate (XI), gave 2,4-dimethyl-2,4-pentanediol (XIII), identical with material prepared as reported.<sup>7</sup> Similarly, ethyl-

(6) The part of this work which was carried out on steroids is to be the material in a separate paper.

(7) (a) P. H. Hermans, *Z. anorg. Chem.*, **142**, 101 (1925); (b) J. English, Jr., and F. V. Brucher, Jr., *THIS JOURNAL*, **74**, 4279 (1952); (c) J. Lemaire, *Rec. trav. chim.*, **29**, 22 (1910).

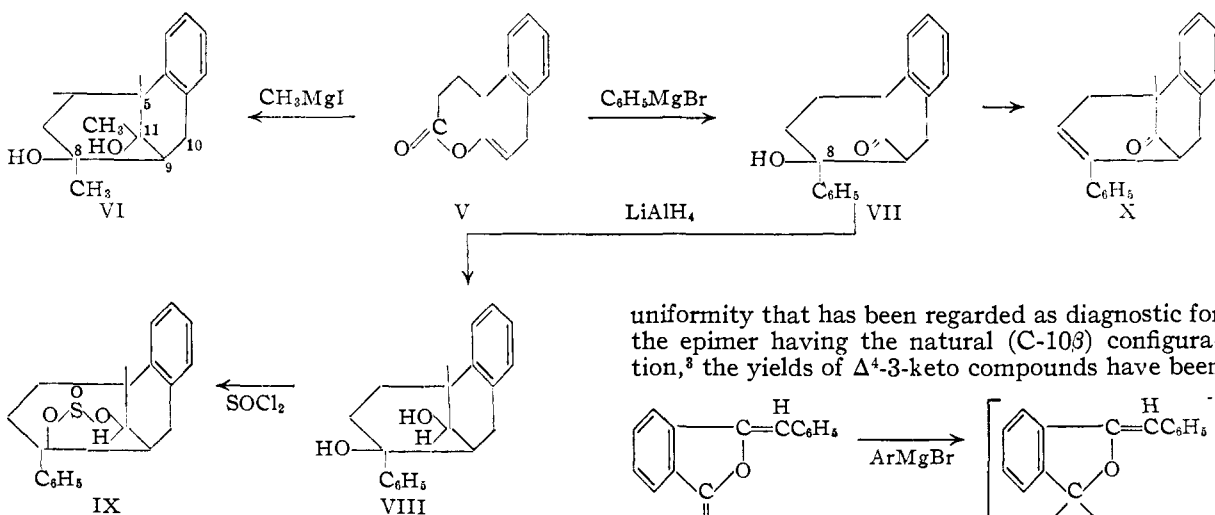
(1) From the Doctoral Dissertation of K. D. Zwahlen, Eastman Kodak Fellow, 1955-1956.

(2) (a) G. I. Fujimoto, *THIS JOURNAL*, **73**, 1856 (1951); (b) G. I. Fujimoto and J. Prager, *ibid.*, **75**, 3259 (1953); (c) R. D. H. Heard and P. Ziegler, *ibid.*, **73**, 4036 (1951).

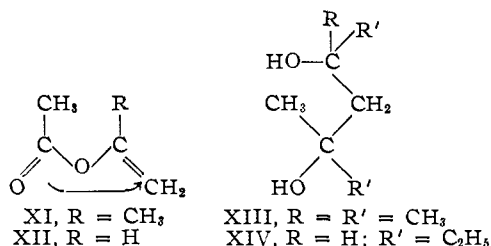
(3) (a) R. B. Woodward, F. Sondheimer, D. Taub, K. Heusler and W. M. McLamore, *ibid.*, **74**, 4223 (1952); (b) P. Wieland, H. Ueberwasser, G. Anner and K. Miescher, *Helv. Chim. Acta*, **36**, 1231 (1953); (c) L. B. Barkley, *et al.*, *THIS JOURNAL*, **76**, 5014 (1954); **78**, 4111 (1956).

(4) S. A. Julia, A. Eschenmoser, H. Heusser and N. Tarköy, *Helv. Chim. Acta*, **36**, 1885 (1953).

(5) H. Schmid and K. Kagi, *ibid.*, **33**, 1582 (1950).



magnesium bromide, added to vinyl acetate (XII) gave 3-methyl-3,5-heptanediol (XIV).<sup>8</sup> In both cases the product obtained may be understood if the rearrangement proposed above is followed by further addition of Grignard reagent to the carbonyl group liberated from its enolic form.



Investigation reveals only a few reports on the reaction of enol lactones with Grignard reagents. A six-membered enol lactone containing the olefinic bond in the lactone ring<sup>9</sup> might be expected to react without rearrangement since the rearrangement proposed above would require a ring contraction to a four-membered ring. Benzaldehyde (XV) gave XVII when treated with arylmagnesium bromides.<sup>10a</sup> The analogous reaction with benzaldehyde<sup>11</sup> (XVIII) gave a colorless intermediate. The properties of the intermediate were satisfied by assigning to it a hemiketal structure (type III or XVI) and XVI was suggested<sup>11</sup> for the intermediate from XV which could not be isolated.

We propose that all of the properties found for the intermediate from XVIII would also be expected of the structure XIX which would arise if the Grignard-enol lactone rearrangement occurred. The single exception is the recovery of unchanged intermediate on treatment with phenylmagnesium bromide, a behavior which might be expected if XIX were highly enolic.

If the addition or non-addition of Grignard reagent to XX depended on steric factors, it would account for the experience of those employing this procedure for the synthesis of steroids. With a

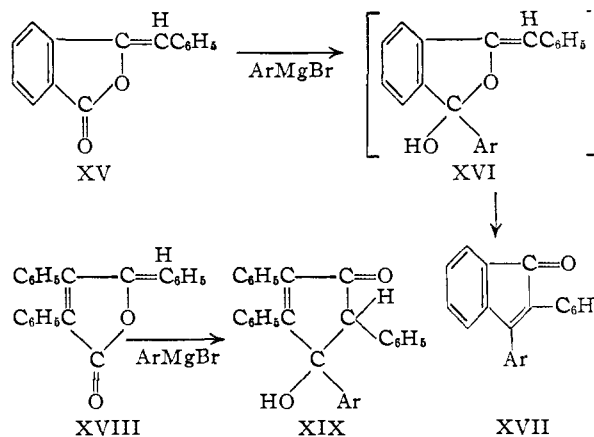
(8) Pastureau and Zamenhof, *Bull. soc. chim.*, **39**, 1430 (1926).

(9) B. Belleau, *THIS JOURNAL*, **73**, 5441 (1951).

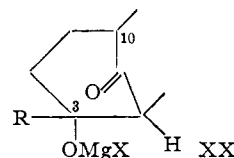
(10) (a) R. Weiss and R. Sauermann, *Ber.*, **58B**, 2736 (1925); (b) R. Weiss, K. Grobstein and R. Sauermann, *ibid.*, **59B**, 301 (1926).

(11) A. Lowenbein and G. Ulrich, *ibid.*, **58B**, 2662 (1925).

uniformity that has been regarded as diagnostic for the epimer having the natural (C-10 $\beta$ ) configuration,<sup>8</sup> the yields of  $\Delta^4$ -3-keto compounds have been



good, whereas the yields with the epimer having the C-10 $\alpha$ -configuration have been poor. Variation in experimental conditions and in amounts of the methyl Grignard reagent did not improve this result.<sup>3a</sup> It, appears likely therefore, that akin to our reaction with V to yield VI, further addition of methyl Grignard reagent in the steroid synthesis work gave rise to a diol which could not dealdol with base and hence could not close again to the de-



sired  $\Delta^4$ -3-keto compound. In the natural series, steric factors prevented further Grignard addition to the carbonyl bridge, thus yielding a  $\beta$ -hydroxyketone which was converted by base to a  $\Delta^4$ -3-keto compound. Our isolation of VII suggests that further addition of Grignard reagent in this case must be controlled by the configuration at C-8 (methanocyclooctabenzene numbering) since V is composed only of enantiomorphs.

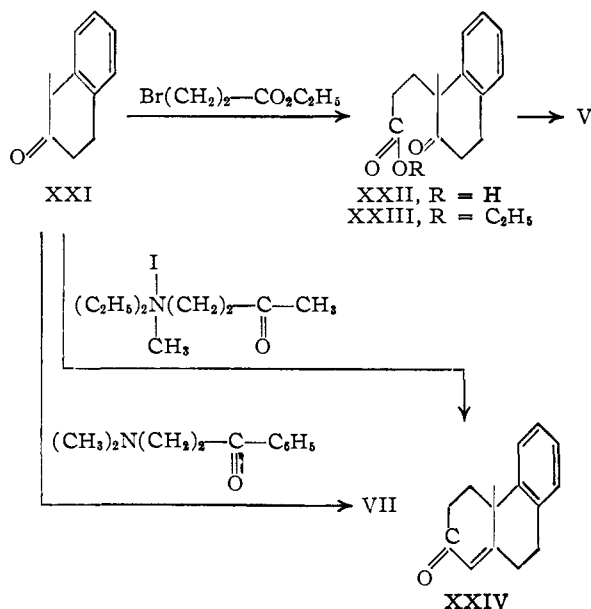
The model compound V was obtained by lactonization of XXII which in turn was obtained from known<sup>12</sup> 1-methyl-2(1H)-3,4-dihydronaphthalenone (XXI) by alkylation with ethyl  $\beta$ -bromopropionate. Excess of methylmagnesium iodide at room temperature gave VI (42%). The analytical data clearly indicated that two moles of

(12) (a) N. V. Organon, Dutch Patent 67,888, May 15, 1951 (*Chem. Abstr.*, **46**, P2580 (1952)); (b) J. W. Cornforth, R. Cornforth and R. Robinson, *J. Chem. Soc.*, 689 (1942).

the Grignard reagent had been acquired as opposed to three moles if a structure such as II had been available. An attempt to prepare the diketone similar to II by the addition of the methiodide of 1-diethylamino-3-butanone to XXI<sup>13</sup> failed because cyclization occurred to XXIV as shown by analytical data, ultraviolet absorption at 236  $\mu$  and strong absorption at 5.97  $\mu$  (carbonyl group).

The addition of phenylmagnesium bromide to V gave VII (33%) identical with the product from XXI and  $\beta$ -dimethylaminopropiophenone. The identity of these materials was shown by their infrared and ultraviolet absorption curves. The carbonyl group was demonstrated by the preparation of an oxime and a 2,4-dinitrophenylhydrazone. The reduction of the carbonyl with lithium aluminum hydride to VIII, the formation of a cyclic sulfite ester IX and the dehydration of VII to an olefin X which contains a carbonyl group are reactions consistent with the proposed structure for VII. Catalytic hydrogenation of X gave a product whose analysis indicated that one mole of hydrogen had been added, but this material gave no 2,4-dinitrophenylhydrazone and was inert to Huang-Minlon reduction. By Clemmensen reduction, dihydro-X gave an oil, C<sub>20</sub>H<sub>20</sub>, according to the analytical data. The rearrangement which seems to take place was not investigated.

This work was supported in part by research grants from the National Cancer Institute, National Institutes of Health, United States Public Health Service, and from the American Cancer Society upon recommendation of the Committee on Growth of the National Research Council. The award of a fellowship and financial assistance by the Eastman Kodak Co. are gratefully acknowledged.



### Experimental<sup>14</sup>

#### Ethyl $\beta$ -[1-(1-Methyl-2-oxo-1,2,3,4-tetrahydronaphthyl)]-

(13) A. L. Wilds and C. H. Shunk, *THIS JOURNAL*, **65**, 469 (1943).

(14) Melting points of analytical material were taken on a Kofler hot-stage and are corrected. Petroleum ether refers to the fraction b.p. 30–60°.

propionate (XXIII).—2(1H)-3,4-Dihydronaphthalenone was prepared according to a published procedure<sup>15</sup> in 68% yield, b.p. 132° (14 mm.), reported<sup>12b</sup> 139° (18 mm.). It was alkylated with methyl iodide<sup>12a</sup> to yield XXI in 50% yield, b.p. 134° (14 mm.), reported<sup>12b</sup> b.p. 137–138° (18 mm.). When the unreacted and the dimethylated compounds were not removed,<sup>12b</sup> lower yields were obtained in the subsequent reactions.

In an atmosphere of nitrogen 39.0 g. (0.238 mole) of XXI was added over a 30-minute period with stirring to 9.2 g. (0.236 mole) of powdered potassium in 500 ml. of benzene. The reaction was refluxed for 1 hr., cooled and 50.0 g. (0.275 mole) of ethyl  $\beta$ -bromopropionate was added dropwise. The reaction was refluxed for 1 hr. and allowed to stand overnight. After acidification with dilute sulfuric acid and addition of water, the benzene layer was separated, the aqueous layer was extracted with ether and the ether-benzene solution was washed with 5% sodium bicarbonate and with water. The solvents were removed at reduced pressure and the residue was rapidly distilled. The fraction b.p. 140–160° (0.5 mm.) (33.7 g.) was redistilled. The fraction b.p. 133–136° (0.2–0.3 mm.) (28.4 g., 48%) was a pale yellow viscous liquid. A portion redistilled for analysis boiled at 133–134° (0.2 mm.),  $n_D^{20}$  1.5250.

*Anal.* Calcd. for C<sub>16</sub>H<sub>20</sub>O<sub>2</sub>: C, 73.82; H, 7.74. Found: C, 73.50; H, 7.70.

The semicarbazone crystallized from aqueous ethanol melted at 123.5–125°.

*Anal.* Calcd. for C<sub>17</sub>H<sub>23</sub>O<sub>2</sub>N<sub>2</sub>: C, 64.33; H, 7.30; N, 13.24. Found: C, 64.42; H, 7.22; N, 13.08.

The bicarbonate-soluble acid XXII obtained (88%) by saponification in aqueous alcoholic sodium hydroxide was a light yellow oil which was used without further purification.

The semicarbazone of the acid crystallized from absolute ethanol and melted at 189–190° (gas evol.) when inserted at 170° and heated 3° per minute.

*Anal.* Calcd. for C<sub>15</sub>H<sub>19</sub>O<sub>2</sub>N<sub>2</sub>: C, 62.27; H, 6.62; N, 14.52. Found: C, 62.02; H, 6.64; N, 14.00.

$\beta$ -[1-(1-Methyl-2-hydroxy-1,4-dihydronaphthyl)]-propionic Acid Lactone (V).—A solution of 22.2 g. of XXII and 2 g. of *p*-toluenesulfonic acid in 75 ml. of acetic anhydride and 100 ml. of benzene was allowed to stand at room temperature overnight. After addition of 1 g. of sodium acetate the solvents were removed *in vacuo* at room temperature. The residue was combined with benzene, the salts were removed by filtration and the solution was distilled to yield 17.7 g. (87%), b.p. 155–162° (0.6 mm.). The distillate crystallized slowly to a pale yellow solid, m.p. 98–100°. The analytical sample sublimed at 95° (bath temperature) (0.2 mm.), m.p. 99–102°.

*Anal.* Calcd. for C<sub>14</sub>H<sub>14</sub>O<sub>2</sub>: C, 78.48; H, 6.59. Found: C, 78.17; H, 6.70.

The compound was hygroscopic and hydrolyzed unless stored in a desiccator.

8,11-Dihydroxy-5,8,11-trimethyl-5,6,7,8,9,10-hexahydro-5,9-methanocyclooctabenzene (VI).—Methylmagnesium iodide (from 1.3 g. (54 mmoles) of magnesium) in 25 ml. of ether was treated with 2.00 g. (9.5 mmoles) of V in 50 ml. of ether. After 3 hr. at room temperature 100 ml. of saturated ammonium chloride was added, the layers were separated and the water layer extracted with ether. The combined ether layers, washed with water and dried over calcium sulfate, were distilled *in vacuo*. The residual pale yellow oil weighed 2.2 g. Chromatographed on 200 g. of acid-washed alumina, the acetone eluate weighed 0.97 g. (42%), m.p. 130–135°. Crystallized from benzene-petroleum ether and then several times from dilute methanol, the material melted at 143–145°, softening at 141°.

*Anal.* Calcd. for C<sub>18</sub>H<sub>22</sub>O<sub>2</sub>: C, 78.00; H, 9.00. Found: C, 78.23; H, 8.82.

4a-Methyl-4,4a,9,10-tetrahydro-2(3H)-phenanthrone (XXIV).—The methiodide from 11 g. of 1-diethylamino-3-butanone was prepared by the addition of 11 g. of methyl iodide in small portions over a 30-minute period while cooling in an ice-bath. It was then allowed to stand in the ice-bath for 1 hr. and for 45 minutes at room temperature. A solution of 12.4 g. of XXI in 75 ml. of benzene was added, the air in the flask was replaced by nitrogen and a solution of 4.76 g. of potassium in 75 ml. of absolute ethanol was added

(15) J. A. Barltrop and J. E. Saxton, *J. Chem. Soc.*, 1038 (1952).

over a 5-minute interval with cooling. After 1.5 hr. in the ice-bath with occasional swirling followed by 30 minutes of refluxing, the cooled mixture was acidified with dilute sulfuric acid and diluted with water. The benzene layer was separated, the aqueous layer was extracted with ether and the ether-benzene solution was washed with water, 5% sodium bicarbonate and finally with water. After drying over sodium sulfate the solvents were distilled *in vacuo* and the residue distilled, b.p. 130–160° (0.5 mm.), 5.60 g. (34%). The material crystallized from benzene-petroleum ether, m.p. 90–91°,  $\lambda_{\text{max}}^{\text{observed}}$  236 m $\mu$  (log  $\epsilon$  4.23), strong infrared absorption at 5.97  $\mu$  indicating an  $\alpha,\beta$ -unsaturated carbonyl group.

*Anal.* Calcd. for  $C_{16}H_{16}O$ : C, 84.86; H, 7.60. Found: C, 84.89; H, 7.56.

**8-Hydroxy-5-methyl-11-oxo-8-phenyl-5,6,7,8,9,10-hexahydro-5,9-methanocyclooctabenzene (VII).** (a).—Phenylmagnesium bromide (from 0.27 g. of magnesium) in 25 ml. of ether was added during 1 hr. with constant stirring to a suspension of 2.0 g. of V in 25 ml. of ether with cooling in an ice-bath. Stirring was continued for 30 minutes and then the mixture was refluxed for 1 hr. and allowed to stand overnight. The product was isolated according to the procedure with methylmagnesium iodide above and the pale yellow oil obtained crystallized when benzene and petroleum ether were added. The product weighed 0.87 g. (33%), m.p. 173–174°. Crystallized from benzene-petroleum ether, it melted at 178–179° and at 180–182° on admixture with the material obtained below. The infrared and ultraviolet spectra of the two products were identical.

(b).<sup>16</sup>—Thirty-nine grams (0.2 mole) of  $\beta$ -dimethylaminopropiophenone hydrochloride<sup>17</sup> in 400 ml. of ethyl alcohol at the boiling point was treated with 32 g. (0.2 mole) of XXI and then with 16 g. (0.4 mole) of sodium hydroxide in 80 ml. of water added in one portion. After 15 minutes refluxing, the solution was cooled in an ice-bath, acidified with hydrochloric acid and concentrated to one-third its volume by distillation from a steam-bath at reduced pressure. The waxy solid was filtered, washed with water and dried. Two crystallizations from benzene-petroleum ether gave 24.0 g. (41%) of crystals, m.p. 169–175°. Repeated crystallization from benzene-petroleum ether yielded material, m.p. 184.5–186°.

*Anal.* Calcd. for  $C_{20}H_{20}O_2$ : C, 82.16; H, 6.90. Found: C, 82.15; H, 6.90.

The oxime, crystallized from aqueous dioxane-ethanol, melted at 248–251° with slight darkening.

*Anal.* Calcd. for  $C_{20}H_{21}O_2N$ : C, 78.15; H, 6.89; N, 4.56. Found: C, 77.82; H, 6.72; N, 4.9.

The 2,4-dinitrophenylhydrazone from aqueous ethanol melted at 214–218°.

*Anal.* Calcd. for  $C_{28}H_{24}O_6N_4$ : C, 66.09; H, 5.12; N, 11.86. Found: C, 66.50; H, 5.21; N, 11.51.

**8,11-Dihydroxy-5-methyl-8-phenyl-5,6,7,8,9,10-hexahydro-5,9-methanocyclooctabenzene (VIII).**—A solution of 2.92 g. (10 mmoles) of VII in 200 ml. of anhydrous ether was added slowly to a slurry of 0.4 g. of lithium aluminum hydride in 50 ml. of ether. After 3 hr. a slight excess of water was added, the ether was decanted and the residual salts were washed with chloroform. On removal of the solvents 2.8 g. of colorless solid, m.p. 170–188°, remained. Crystallization from acetone gave 2.0 g. (68%), m.p. 178–184°, and further purification from acetone gave VIII, m.p. 197–198°.

*Anal.* Calcd. for  $C_{20}H_{22}O_2$ : C, 81.59; H, 7.53. Found: C, 81.66; H, 7.35.

The Cyclic Sulfite Ester IX from VIII.—The diol VIII (2.0 g.) suspended in 50 ml. of anhydrous ether and 1.6 g. of pyridine was cooled in an ice-bath and a solution of 1.2 g. of thionyl chloride in 25 ml. of ether was added over a 30-minute period with stirring. Stirring was continued for 2 hr. while the reaction mixture came to room temperature. The pyridine hydrochloride was filtered and washed well with ethyl acetate. Evaporation of the ether-ethyl acetate solution gave 1.8 g. of colorless crystals which decomposed below 150° with gas evolution. Crystallization from ben-

zene-petroleum ether and then repeatedly from acetone gave IX, m.p. 142–143° dec., if inserted at 120° and heated 3° per minute.

*Anal.* Calcd. for  $C_{20}H_{20}O_2S$ : C, 70.56; H, 5.92; S, 9.42. Found: C, 70.28; H, 5.88; S, 9.55.

**5-Methyl-11-oxo-8-phenyl-5,6,9,10-tetrahydro-5,9-methanocyclooctabenzene (X).**—After 40 hr. refluxing of a solution containing 24 g. of VII in 750 ml. of acetic acid and 125 ml. of hydrochloric acid, the solution was distilled under reduced pressure on the steam-bath. A benzene solution of the residue was washed with water, 5% sodium bicarbonate and finally with water. The dried benzene was then distilled at reduced pressure and the residue was distilled. The fraction b.p. 160–175° (0.5 mm.) was a pale yellow extremely viscous oil (16.9 g., 75%). The analytical sample boiled at 168° (0.4 mm.).

*Anal.* Calcd. for  $C_{20}H_{18}O$ : C, 87.55; H, 6.61. Found: C, 87.21; H, 6.59.

The 2,4-dinitrophenylhydrazone was obtained from ethyl acetate-ethanol as orange crystals, m.p. 206–206.6°. From chloroform-ethanol yellow crystals were obtained, m.p. 150° (gas evol.), with solidification and remelting at 205–206°.

*Anal.* Calcd. for  $C_{28}H_{22}O_4N_4$ : C, 68.71; H, 4.88; N, 12.33. Found: C, 68.50; H, 4.96; N, 12.32.

When a solution of 7.0 g. of X in 75 ml. of absolute ethanol with 500 mg. of platinum oxide was shaken under hydrogen at slightly above atmospheric pressure, one mole of hydrogen was consumed in 20 minutes and hydrogenation stopped. The product, isolated after removal of the catalyst, solidified when benzene and petroleum ether were added. It was crystallized once from aqueous ethanol (5.2 g., m.p. 135–139°) and repeated crystallization brought the melting point to 147.8–149°.

*Anal.* Calcd. for  $C_{20}H_{20}O$ : C, 86.91; H, 7.29. Found: C, 86.86; H, 7.17.

This dihydro-derivative of X failed to react with 2,4-dinitrophenylhydrazine and was recovered unchanged from hydrazine-sodium hydroxide treatment according to Huang-Minlon.<sup>18</sup>

On Clemmensen reduction of 4.0 g. of the dihydro-derivative of X, an oil (2.1 g.), b.p. 160–175° (0.6 mm.), was obtained. The sample for analysis boiled at 168° (0.5 mm.).

*Anal.* Calcd. for  $C_{20}H_{20}$ : C, 92.26; H, 7.74. Found: C, 92.37; H, 7.22.

**2,4-Dimethyl-2,4-pentanediol (XIII).**—Methylmagnesium iodide (from 23 g. of magnesium) in 500 ml. of ether was cooled in an ice-bath, and 40 g. of isopropenyl acetate was added over a 45-minute interval with constant stirring. After standing overnight at room temperature, the mixture was treated with ammonium chloride and the product isolated in the usual manner. The fraction, b.p. 102–104° (19 mm.), weighed 28.6 g. (54%). Redistillation through an 8-inch Vigreux column gave material, b.p. 100° (17 mm.),  $n_{\text{D}}^{20}$  1.4327. Reported constants are b.p. 89° (5 mm.),  $n_{\text{D}}^{20}$  1.4327<sup>7a</sup>; b.p. 64° (2 mm.),  $n_{\text{D}}^{20}$  1.4378.<sup>7b</sup>

The borate ester was prepared as described,<sup>7a</sup> m.p. 103–105°, after crystallization from benzene-petroleum ether; reported<sup>7a</sup> m.p. 102°.

The bis-3,5-dinitrobenzoate prepared by the excellent method using *p*-toluenesulfonyl chloride<sup>19</sup> gave colorless needles from aqueous ethanol, m.p. 166.5–168.2°.

*Anal.* Calcd. for  $C_{21}H_{20}O_{12}N_4$ : C, 48.46; H, 3.87; N, 10.77. Found: C, 48.43; H, 3.83; N, 10.88.

A sample of XIII prepared as described<sup>7c</sup> from diacetone alcohol and methylmagnesium iodide (in 34% yield) boiled at 100° (18 mm.),  $n_{\text{D}}^{20}$  1.4327. The borate ester from this material melted at 104–106° after crystallization from benzene-petroleum ether. The infrared spectra of the diols from each source were identical as were the spectra of the two borate esters.

**3-Methyl-3,5-heptanediol (XIV).**—In the manner described above, vinyl acetate (0.4 mole) was added to 1 mole of ethylmagnesium bromide. The product boiled at 120–122° (19 mm.) (34%). The sample obtained on fractionation through an 8-inch Vigreux column boiled at 117° (16

(16) A. C. Cope and E. C. Herman, *THIS JOURNAL*, **72**, 3405 (1950).

(17) C. E. Maxwell, "Organic Syntheses," Coll. Vol. III, John Wiley and Sons, Inc., New York, N. Y., 1955, p. 305.

(18) Huang-Minlon, *THIS JOURNAL*, **68**, 2487 (1946).

(19) J. H. Brewster and C. J. Ciotti, Jr., *ibid.*, **77**, 6214 (1955).

mm.),  $n_D^{21}$  1.4416,  $n_D^{18}$  1.4430; reported b.p. 112–114° (12 mm.),  $n_D^{21}$  1.4418; b.p. 121° (23 mm.),  $n_D^{18}$  1.4467.<sup>8</sup>

The bis-3,5-dinitrobenzoate prepared as in the above case

(20) J. E. Dubois, *Ann. chim. (Paris)*, **6**, 406 (1951).

crystallized from acetone-methanol; m.p. 156.3–157°.

*Anal.* Calcd. for  $C_{22}H_{22}O_{12}N_4$ : C, 49.44; H, 4.15; N, 10.48. Found: C, 49.77; H, 4.32; N, 10.30.

SALT LAKE CITY 12, UTAH

[CONTRIBUTION FROM THE CHEMICAL RESEARCH INSTITUTE OF NON-AQUEOUS SOLUTIONS, TOHOKU UNIVERSITY]

## The Beckmann Rearrangement in Liquid Sulfur Dioxide. II.<sup>1</sup> Rearrangement by Halogen

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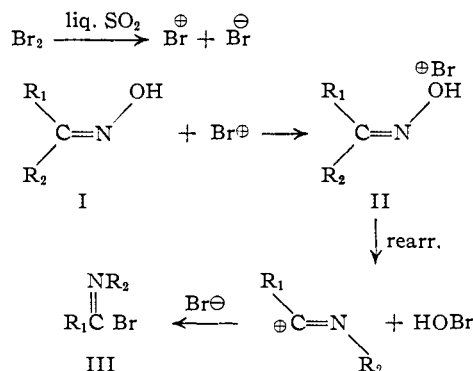
The Beckmann rearrangement of ketoximes may be effected by bromine and iodine in liquid sulfur dioxide at room temperature. Chlorine and sulfonyl chloride are without effect, but the addition of a small quantity of bromine (0.02:1 mole ratio) to these reagents leads to rearrangement. The oximes studied were those from cyclohexanone, cyclopentanone, acetophenone and benzophenone; in the case of aromatic oximes the reaction products were brominated or chlorinated amides. A possible mechanism is discussed.

Previous work has shown that the Beckmann rearrangement may be carried out in liquid sulfur dioxide at room temperature with sulfur trioxide,<sup>1,2</sup> with thionyl chloride and with a variety of phosphorus compounds.<sup>1</sup> It now has been found that the rearrangement may also be effected in sulfur dioxide solution by bromine, by iodine and by chlorine or sulfonyl chloride in the presence of small amounts of bromine (1:1:0.02 mole ratio for oxime:chlorine:bromine). Chlorine and sulfonyl chloride did not induce rearrangement when they were used without added bromine.

Rearrangements of the oximes of cyclohexanone, cyclopentanone, acetophenone and benzophenone were studied under varying conditions. Table I contains the results of experiments with cyclohexanone oxime in liquid sulfur dioxide. The best results were obtained with a 1:1 mole ratio of bromine to oxime (58 and 64% yield of  $\epsilon$ -caprolactam for reaction periods of 1 and 24 hr., respectively) and with chlorine and sulfonyl chloride containing a small amount of bromine (67–72% yield of lactam). The yield of amide was not increased by increasing amounts of bromine, but a decrease in the bromine to oxime ratio to 0.5:1 decreased the yield of amide to 39%.

The bromine procedure (1:1 mole ratio, 1 hr. at 20°) and the chlorine-bromine procedure (1:1:0.02 mole ratio for oxime:chlorine:bromine, 1 hr. at 20°) were applied to the oximes of cyclopentanone, acetophenone and benzophenone. The results are given in Table II. Amides from acetophenone oxime and benzophenone oxime were halogenated under these conditions. Halogenation evidently occurred after the rearrangement reaction, since the products from benzophenone oxime were those to be expected from the halogenation of benzanilide.

The mechanism of the rearrangement is thought to be



This mechanism requires a 1:1 mole ratio of bromine to oxime for complete reaction. The formation of an amide from the intermediate III may occur during the reaction or at the time of addition of water to the reaction mixture. An alternate

TABLE I  
ACTION OF HALOGEN ON CYCLOHEXANONE OXIME IN LIQUID  $\text{SO}_2^a$

Reagent	Molar ratio of oxime to halogen	Lactam formed, yield, %
$\text{Br}_2, \text{H}_2\text{O}^b$	1:1	0
$\text{Br}_2, \text{H}_2\text{O}^c$	1:1	0
$\text{Br}_2$	1:0.5	39.2 <sup>e</sup>
$\text{Br}_2$	1:1	58.0
$\text{Br}_2$	1:1.4	59.2
$\text{Br}_2^d$	1:1	64.0
$\text{I}_2$	1:1	34.0
$\text{Cl}_2$	1:1	0
$\text{SO}_2\text{Cl}_2$	1:1	0
$\text{Cl}_2, \text{Br}_2$	1:1:0.1	72.4
$\text{Cl}_2, \text{Br}_2$	1:1:0.02	67.2
$\text{Cl}_2, \text{Br}_2$	1:1:0.02	66.8
$\text{Cl}_2, \text{I}_2$	1:1:0.1	12.4
$\text{SO}_2\text{Cl}_2, \text{Br}_2$	1:1:0.02	70.4

<sup>a</sup> Reaction carried out at 20° for 1 hr., with 25 g. (0.22 mole) of the oxime and 200 ml. of liq.  $\text{SO}_2$ . <sup>b</sup> Molar ratio of bromine to water was 1:2. <sup>c</sup> Molar ratio of bromine to water was 1:1. <sup>d</sup> Reaction carried out at 20° for 24 hr. <sup>e</sup> 78.4% on the basis of bromine used.

(1) For the first paper of this series, see N. Tokura, R. Asami and R. Tada, *Sci. Reports Research Inst., Tohoku Univ.*, **8**, 149 (1956).

(2) German Patent 858,397 (1952); *C. A.*, **48**, 12810 (1954); British Patent 732,899 (1955); *C. A.*, **50**, 5738 (1956).