

These three esters were analyzed for bromine and checked with the calculated percentages. Acetone was used as solvent for recrystallizations. No precipitate was obtained upon acidifying the alkaline filtrate from the ortho acid. From the meta acid a precipitate, presumably *N-p*-bromophenacyl-*m*-aminobenzoic acid, was obtained. It melted at 198°. From the para acid a precipitate, presumably *N-p*-bromophenacyl-*p*-aminobenzoic acid, was obtained which melted at 208°.

### Summary

1. The esters formed by phenacyl bromide and *p*-bromophenacyl bromide with the aminobenzoic acids are shown to be substituted in the amine group as well as the carboxyl group.

2. A number of substituted benzoic acids have been converted to the phenacyl and *p*-bromophenacyl esters and their melting points recorded.

WORCESTER, MASSACHUSETTS

[CONTRIBUTION FROM THE BAKER LABORATORY OF CHEMISTRY, CORNELL UNIVERSITY]

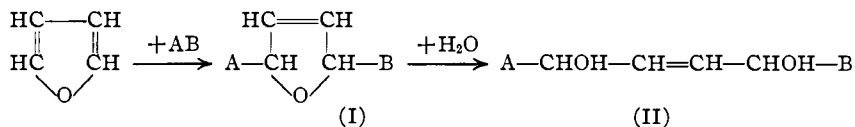
## REARRANGEMENT OF UNSATURATED 1,4-GLYCOLS. 2-METHYL-2-BUTENE-1,4-DIOL

BY A. F. SHEPARD<sup>1</sup> AND JOHN R. JOHNSON

RECEIVED JUNE 27, 1932

PUBLISHED NOVEMBER 5, 1932

It has been suggested that the mechanism of a number of reactions of furan and its simple derivatives involves a preliminary 1,4-addition to the furan ring. Such reactions include the processes of halogenation<sup>2</sup> and nitration,<sup>3</sup> as well as the rearrangement of the  $\alpha$ -furfuryl group in metathesis<sup>4</sup> and in ring opening reactions.<sup>5,6</sup> The postulation of 1,4-addition leads to the formulation of an intermediate 2,5-dihydrofuran derivative (I), which is merely the cyclic ether of a substituted 2-butene-1,4-diol (II).



<sup>1</sup> This article is an abstract of a portion of a thesis submitted by A. F. Shepard to the Faculty of the Graduate School of Cornell University, in partial fulfillment of the requirements for the degree of Doctor of Philosophy, in June, 1929.

<sup>2</sup> Gilman and Wright, *THIS JOURNAL*, **52**, 3349 (1930).

<sup>3</sup> Freure and Johnson, *ibid.*, **53**, 1142 (1931).

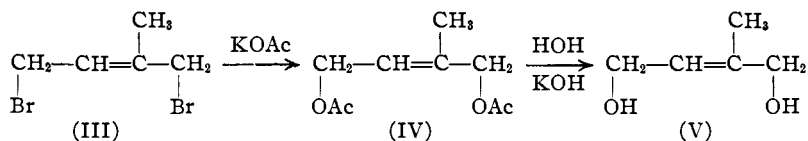
<sup>4</sup> (a) Reichstein, *Ber.*, **63**, 749 (1930); (b) Runde, Scott and Johnson, *THIS JOURNAL*, **52**, 1284 (1930).

<sup>5</sup> Pummerer and Gump, *Ber.*, **56**, 999 (1923).

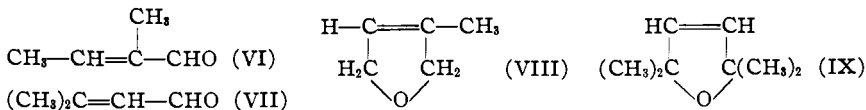
<sup>6</sup> In dealing with furan derivatives such as  $\text{C}_4\text{H}_5\text{O} \text{---} \text{CH} \text{=} \text{CH} \text{---} \text{CO} \text{---} \text{R}$ , in which the conjugated system extends into the side chain, it has been suggested that 1,6- or 1,8-addition may occur.<sup>2</sup>

The present investigation deals with a study of the preparation and reactions of a simple aliphatic compound containing this system.

For the synthesis of a typical glycol of the desired structure, isoprene was used as the starting material.<sup>7</sup> This was treated with bromine to give 1,4-dibromo-2-methylbutene-2 (III), the structure of which has been established.<sup>8</sup> The dibromide was converted to the corresponding diacetate, 1,4-diacetoxy-2-methylbutene-2 (IV); the structure of this ester was established by catalytic hydrogenation, which gave the diacetate of 2-methylbutane-1,4-diol. The unsaturated ester, upon hydrolysis with alkalis, gave the expected glycol, 2-methyl-2-butene-1,4-diol (V). That no change of structure had occurred during hydrolysis was shown by the fact that the product upon catalytic hydrogenation gave 2-methylbutane-1,4-diol. The latter was identified through its bis-diphenylurethan and by conversion into 3-methyltetrahydrofuran.



The unsaturated glycol was found to undergo dehydration very easily upon warming with halogen acids, and a liquid having the composition  $\text{C}_5\text{H}_8\text{O}$  and boiling at  $116.5\text{--}117.5^\circ$  was produced in yields up to 65%. The same product was also obtained by warming the glycol with zinc chloride, or by subjecting its diacetate (IV) to the action of alcoholic hydrogen chloride. The liquid product,  $\text{C}_5\text{H}_8\text{O}$ , took up two atoms of bromine and it was thought at first to be 3-methyl-2,5-dihydrofuran (VIII). Further examination disclosed that the substance gave the reactions of an aldehyde and proved it to be tiglic aldehyde (VI). This was established by means of physical and chemical properties and by comparison of its semicarbazone with that of authentic tiglic aldehyde. A careful examination indicated that neither 3-methyl-2,5-dihydrofuran nor 3-methyl-2-butenal (VII) was present in appreciable quantity.



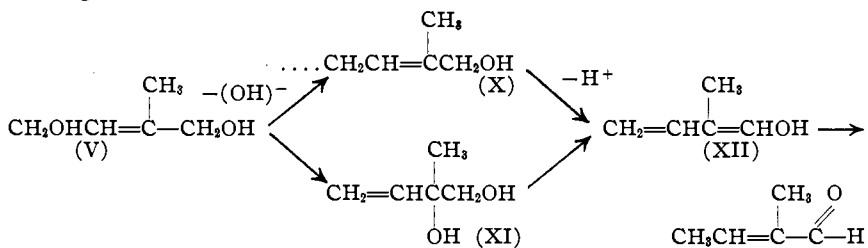
In view of the observation that an analogous unsaturated 1,4-glycol containing tertiary alcohol groups (2,4-dimethyl-3-hexene-1,4-diol) is readily

<sup>7</sup> We wish to express our appreciation to Mr. Thomas Midgley, Jr., for his generous gift of the isoprene used in this work, and to Dr. Albert L. Henne for valuable suggestions in the course of the experimental work.

<sup>8</sup> (a) Bergmann, *J. Russ. Phys.-Chem. Soc.*, **52**, 24 (1920), [*Chem. Abstracts*, **17**, 1420 (1923)]; (b) Staudinger, Muntwyler and Kupfer, *Helv. Chim. Acta*, **5**, 756 (1922).

dehydrated to the corresponding dihydrofuran (IX),<sup>9</sup> and the ease with which saturated 1,4-glycols undergo ring closure to form derivatives of tetrahydrofuran, the observed rearrangement was quite unexpected. It is of interest to note that Prévost<sup>10</sup> has reported the formation of small amounts of crotonic aldehyde and of  $\gamma$ -methylcrotonic aldehyde, respectively, as by-products in the hydrolysis of 1,4-dibromo-2-butene and 1,4-dibromo-2-pentene by aqueous sodium carbonate. He has suggested a mechanism for the rearrangement and considers the reaction to be quite general for unsaturated 1,4-dihalides of this type, provided at least one primary halogen ( $-\text{CH}_2\text{X}$ ) is present.

The observed rearrangement of an unsaturated 1,4-glycol is like that of a number of saturated glycols (hydrobenzoin rearrangements). It appears that the presence of the double bond in the 1,4-glycol (and in similar 1,4-dihalides) allows a 1,4-shift to occur in this unsaturated system as readily as a 1,2-shift occurs in a saturated structure. In considering a mechanism for this rearrangement it seems inadvisable to assume the formation of 3-methyl-2,5-dihydrofuran (VIII) as an intermediate stage, since this compound would hardly be expected to undergo ring opening under the various conditions used to bring about the rearrangement (particularly, heating with zinc chloride).



It is more likely that an unstable open-chain enol (XII) is formed as an intermediate stage and the enol undergoes a 1,4-tautomeric shift to produce tiglic aldehyde. This 1,4-tautomeric shift is strictly analogous to the 1,4-enolization of crotonic aldehyde suggested by Prévost<sup>10</sup> and by Kuhn and Ishikawa.<sup>11</sup> The formation of the intermediate enol may occur by a direct non-simultaneous elimination of hydroxyl and hydrogen from the 4- and 1-positions, respectively, through the unstable structure (X) or by a preliminary  $\alpha,\gamma$ -allylic shift of the 4-hydroxyl group to produce an unsaturated 1,2-glycol (XI), followed by 1,2-dehydration. On the whole, it seems quite unnecessary to assume the  $\alpha,\gamma$ -allylic shift suggested as the second alternative. The latter would imply a detachment of the hydroxyl from the 4-position and removal to the 2-position, only to become detached

<sup>9</sup> Salkind, *Ber.*, **56**, 189 (1923).

<sup>10</sup> Prévost, *Bull. soc. chim.*, [4] **43**, 1005 (1928).

<sup>11</sup> Kuhn and Ishikawa, *Ber.*, **64**, 2348 (1931).

a second time and finally converted to water by combination with a hydrogen from the 1-position.

It is evident from the behavior of the particular 2-butene-1,4-diol under examination that a further study of these structures is necessary before the results can be used with assurance in dealing with the reactions of substituted 2,5-dihydrofuran structures.

### Experimental Part

**Isoprene.**—The isoprene used in these experiments was obtained from Mr. Thomas Midgley, and had been prepared from crepe rubber by the process described by Midgley and Henne.<sup>12</sup> The material boiled at 34–36°, and contained small amounts of the isomeric 2-methylbutenes as impurities.

**1,4-Dibromo-2-methylbutene-2 (Isoprene Dibromide).**—To a well-stirred solution of 68 g. (1 mole) of isoprene in 100 cc. of chloroform, maintained below –25° with a slush of ether and carbon dioxide snow, was added dropwise an ice-cold solution of 160 g. (1 mole) of bromine in 250 cc. of chloroform. A fairly sharp end-point of the reaction could be noted when practically all the bromine had been added. The slight excess of bromine was removed by shaking with sodium bisulfite, and the chloroform was removed by heating on a water-bath. The purification of the dibromide was tedious and involved loss of material through decomposition during the repeated distillations.

The product from 145 g. of isoprene after three fractionations under reduced pressure gave 165 g. of a fraction boiling at 90–96° under 12 mm. This fraction corresponds with that used by Staudinger<sup>8b</sup> in his proof of the 1,4 structure of the dibromide. The lachrymatory product was only slightly colored when freshly distilled, but darkened rapidly on standing.

*Anal.* Calcd. for C<sub>8</sub>H<sub>8</sub>Br<sub>2</sub>: Br, 70.14. Found: Br, 71.12, 70.97.

**Diacetate of 2-Methyl-2-butene-1,4-diol.**—A mixture of 147 g. of the above dibromide, 149 g. of freshly fused, finely powdered potassium acetate and 100 cc. of glacial acetic acid was heated for eighteen hours on a boiling water-bath. The reaction mixture was poured into a liter of water, and the brown oily layer was separated. The water solution was extracted several times with ether, and after removal of the ether this extract was combined with the oily layer and vacuum distilled. The main fraction (120 g.) distilled from 110–132° at 14 mm., and still contained about 7% of combined bromine.

To complete the removal of bromine the product was refluxed for eight hours with 30 cc. of glacial acetic acid and 40 g. of potassium acetate. The product was isolated as before, and upon careful fractionation gave 70 g. of a fraction boiling at 120.5–122.5° under 10 mm. Analysis of this material showed that it contained only a trace of bromine (0.27%). Physical constants were determined on a specimen of this purity:  $d_4^{20}$  1.0703,  $n_D^{20}$  1.4494,  $M_{R_D}$ , calcd. 46.60, obs. 46.67.

*Anal.* Calcd. for C<sub>8</sub>H<sub>14</sub>O<sub>4</sub>: C, 58.03; H, 7.58. Found: C, 57.90, 58.08; H, 7.64, 7.59; (Br, 0.27).

The diacetate is a colorless and practically odorless liquid; it is miscible with alcohol and ether but is sparingly soluble in water. It adds bromine readily; a solution of 0.05 mole of the diacetate in carbon tetrachloride at –25° took up 0.05 mole of bromine. The structure of the diacetate was established by catalytic hydrogenation, which gave the diacetate of 2-methylbutane-1,4-diol.

<sup>12</sup> Midgley and Henne, *THIS JOURNAL*, 51, 1215 (1929).

In preparing large quantities of the diacetate of 2-methyl-2-butene-1,4-diol, it was found advantageous to convert the crude isoprene dibromide directly to the diacetate, by the method described above, without subjecting the dibromide to repeated fractionations. In this way there was obtained from 204 g. (3 moles) of isoprene, 200–230 g. of the purified diacetate (32–40% of the theoretical yield). As by-products of the reaction a mixture of lower boiling unsaturated bromides (b. p. 140–160°) and a quantity of complex decomposition products are formed.

**Diacetate of 2-Methylbutane-1,4-diol.**—A solution of 27 g. (0.14) of the unsaturated diacetate (b. p. 111.5–113.5° at 8 mm.) in 20 cc. of alcohol was reduced catalytically using 0.1 g. of platinum oxide.<sup>13</sup> Five grams of pure calcium carbonate was added to neutralize any hydrobromic acid produced from traces of bromide in the diacetate. The calcium carbonate appeared to diminish the rate of reduction but it was found that in the absence of a neutralizing agent, more than one mole of hydrogen was taken up.

The theoretical quantity (0.14 mole) of hydrogen was taken up in about two hours and no more was absorbed thereafter. The entire product distilled at 110–122° under 17 mm.; the principal fraction was collected at 115.5–116.5° (17 mm.) and had the following constants:  $d_4^{20}$  1.0476,  $n_D^{20}$  1.43301;  $MR_D$  (calcd.) 47.07, (obs.) 46.67. This diacetate has been described by Harries and Nerescheimer,<sup>14</sup> who prepared it from the glycol obtained by reducing ethyl methylsuccinate with metallic sodium and alcohol. They reported the following constants: b. p. 116–117 at 17 mm.,  $d_4^{20}$  1.0415,  $n_D^{20}$  1.42717,  $MR_D$  (obs.), 46.3.

**2-Methylbutane-1,4-diol.**—For further identification the saturated diacetate was hydrolyzed with barium hydroxide and the saturated glycol was isolated: b. p. 127.5–128.5° at 13 mm.,  $n_D^{18}$  1.4515 (previously reported: b. p. 124–125° at 13 mm.,  $n_D^{18}$  1.4517). The bis-diphenylurethan of this glycol melted at 99.5–100.5° (corr.) after one crystallization from ligroin (b. p. 70–80°). Harries and Nerescheimer reported the melting point of 102° for the bis-diphenylurethan of 2-methylbutane-1,4-diol.

**3-Methyltetrahydrofuran.**—A sample of the saturated glycol was converted into 3-methyltetrahydrofuran by warming with 25% sulfuric acid and distilling off the volatile product during the course of the heating. In this way 15 g. of the glycol gave 5 g. of 3-methyltetrahydrofuran: b. p. 84–88°,  $n_D^{20}$  1.4090 (previously reported:<sup>14</sup> b. p. 86–87°,  $n_D^{20}$  1.4112).

Several attempts to dehydrogenate 3-methyltetrahydrofuran were unsuccessful. It was unaffected by passage through a 40-cm. tube of platinized asbestos at 300–450°. When passed over a nickel catalyst at 400°, about one-half of the material was lost. The condensed product had the same characteristic ethereal odor and the same refractive index as the original preparation and did not give the furan test (green coloration) with concd. hydrochloric acid.

**2-Methyl-2-butene-1,4-diol.**—Twenty-three grams of the diacetate of 2-methylbutenediol was refluxed for two hours with 15 g. of potassium hydroxide in 100 cc. of methyl alcohol. After distilling off the solvent, the glycol was removed from the residual semi-solid mass by distillation under reduced pressure. There was obtained 8 g. of the crude glycol, which distilled at 130–135° under 12 mm., and on redistillation 4 g. of a pure product: b. p. 127.5–128° at 7 mm.,  $d_4^{20}$  1.0434,  $n_D^{20}$  1.4815,  $MR_D$  (calcd.) 27.87, (obs.) 27.87.

*Anal.* Calcd. for  $C_6H_{10}O_2$ : C, 58.79; H, 9.87. Found: C, 58.93, 59.02; H, 9.74, 9.97.

<sup>13</sup> "Organic Syntheses," John Wiley and Sons, Inc., New York, 1928, Vol. VIII, pp. 10, 92.

<sup>14</sup> Harries and Nerescheimer, *Ann.*, **383**, 168 (1911).

The glycol had a very faint yellow color even when freshly distilled, and a slightly sweet burnt taste. It is miscible with alcohol and water, but is practically insoluble in ether, benzene and carbon tetrachloride. It decolorized a solution of bromine in carbon tetrachloride.

The glycol was much more conveniently obtained by refluxing the diacetate with ten parts of ethyl alcohol and twice the theoretical amount of powdered barium hydroxide for five hours. The dissolved barium salts separated out nearly completely on cooling and were filtered off and washed with alcohol. The small amount of dissolved barium salts was then completely removed by passing in carbon dioxide. After filtration, 80–85% of the theoretical amount of pure glycol could be recovered from the alcoholic solution by vacuum distillation.

Five grams of the unsaturated glycol was dissolved in 50 cc. of alcohol, to which 0.1 g. of platinum oxide and 1.0 g. of sodium bicarbonate were added, and reduced with hydrogen. The reduction was complete in about twenty minutes. After filtering the solution and removing the solvent, the product boiled entirely from 127–135° at 15 mm. and no other fraction was obtained. The saturated glycol obtained thus was identical with the specimen of 2-methylbutane-1,4-diol described above. The bis-diphenylurethan melted at 99–100° and a mixture of this urethan and the one previously prepared melted at 99.5–100.5°. This glycol was also converted to 3-methyltetrahydrofuran by heating with 25% sulfuric acid.

**Tiglic Aldehyde (2-Methyl-2-butenal).**—2-Methyl-2-butene-1,4-diol was converted into tiglic aldehyde in several ways. On warming 4.0 g. of the glycol with 0.3 g. of anhydrous zinc chloride, in a 10-cc. distilling flask provided with a condenser attached directly to the side arm, a vigorous reaction occurred and a liquid distilled at 110–120°. This distillate consisted of 0.7 g. of water and 2.7 g. of crude tiglic aldehyde. This aldehyde was also obtained merely by heating the glycol at atmospheric pressure, by warming the glycol in the presence of a trace of hydrogen chloride and by warming the diacetate with a solution of hydrogen chloride in methyl alcohol. The procedure described below was found to be a convenient method for use with quantities of 40–50 g. of the glycol.

To 41 g. (0.4 mole) of 2-methyl-2-butene-1,4-diol, maintained at 0°, was added slowly 37.6 g. (0.4 mole) of 11 *N* aqueous hydrochloric acid. After shaking thoroughly the solution was allowed to stand at 0° for two hours, when 31.6 g. (0.4 mole) of pyridine was added. On warming gently the solution separated into two layers, and the tiglic aldehyde was removed by distilling the aqueous mixture. The product was freed from pyridine by steam distillation from slightly acid solution, and dried over anhydrous sodium sulfate. On fractionation there was obtained 22 g. (65% yield) of tiglic aldehyde, b. p. 115–119°. All preparations of the aldehyde contained small amounts of high-boiling material which was easily removed by distillation. No low-boiling fraction (in which 3-methyl-2,5-dihydrofuran would have appeared) was found in any of the preparations. For analysis and determination of physical constants a redistilled specimen was used: b. p. 116.5–117.5° (corr.) at 738 mm.,  $d_4^{20}$  0.8710,  $n_D^{20}$  1.4475,  $M_R$  (calcd.) 24.83, (obs.) 25.81.

*Anal.* Calcd. for  $C_6H_8O$ : C, 71.38; H, 9.59. Found: C, 71.10, 71.00; H, 9.57, 9.45.

The physical constants are in reasonably good agreement with those reported for tiglic aldehyde by previous investigators:<sup>15,16</sup> b. p. 115.8° at 739 mm.; b. p. 116°,  $d_4^{18}$  0.870,  $n_D$  1.44956. The isomer, 3-methyl-2-butenal, has the following properties:<sup>17</sup> b. p. 132–133° at 730 mm.,  $d_4^{20}$  0.8722,  $n_D^{20}$  1.4526; semicarbazone, m. p. 221–222°.

<sup>15</sup> Lieben and Zeisel, *Monatsh.*, **7**, 55 (1886).

<sup>16</sup> Grignard and Abelmann, *Bull. soc. chim.*, [4] **7**, 644 (1910).

<sup>17</sup> Fischer, Ertel and Löwenburg, *Ber.*, **64**, 30 (1931).

The aldehyde gave a strong positive test with Schiff's aldehyde reagent and produced a silver mirror on warming with ammoniacal silver oxide. The semicarbazone, after crystallization from alcohol and drying at  $110^{\circ}$ , melted in a capillary tube at  $200-209^{\circ}$ , with slight decomposition; on the Maquenne block it melted at  $234^{\circ}$ . Grignard and Abelmann reported that tiglic aldehyde semicarbazone melts at  $225^{\circ}$  (uncorr.) but did not state the manner in which this value was determined. To confirm the identity of the semicarbazone in hand, an authentic specimen of tiglic aldehyde was synthesized from acetaldehyde and propionaldehyde by their procedure and its semicarbazone was prepared for comparison: m. p. (capillary tube)  $200-208^{\circ}$ ; (Maquenne block)  $232^{\circ}$ . A mixture of equal parts of our semicarbazone and the authentic semicarbazone melted in a capillary tube (in the same bath) at  $200-208^{\circ}$ ; on the Maquenne block the mixture melted at  $233^{\circ}$ .

**Dibromides of Tiglic Aldehyde (2,3-Dibromo-2-methylbutanal).**—A solution of 14.3 g. of bromine in 15 cc. of chloroform was added slowly to 7.5 g. of tiglic aldehyde in 15 cc. of chloroform, cooled to  $-10^{\circ}$ . The addition of the last 5% of the bromine gave the solution an orange-red coloration which faded slowly on standing. After distilling off the solvent under reduced pressure, there was obtained 15 g. of a colorless, slightly viscous liquid: b. p.  $71-73^{\circ}$  (corr.) at 3.5 mm.,  $d_4^{20}$  1.7747,  $n_D^{20}$  1.5228,  $MR_D$  (calcd.) 40.83, (obs.) 41.96.

*Anal.* Calcd. for  $C_5H_8OBr_2$ : Br, 65.80. Found: Br, 65.99, 65.82.

On cooling to  $+18^{\circ}$ , crystals separated in the liquid but the mass did not solidify completely even when cooled to  $0^{\circ}$ . A sample of the liquid was removed for analysis when approximately half of the material had solidified, and it was found that the bromine content of the liquid (65.61%) was the same as that of the original specimen. This result indicates that the product of the addition of bromine is a mixture of the two racemic forms of the dibromide, which arise from the presence of two unlike asymmetric carbon atoms.

### Summary

2-Methyl-2-butene-1,4-diol has been synthesized from isoprene, through 1,4-dibromo-2-methylbutene-2 and 1,4-diacetoxy-2-methylbutene-2. The structures of this glycol and the intermediate diacetate were established by catalytic hydrogenation to 2-methylbutane-1,4-diol and its diacetate.

2-Methyl-2-butene-1,4-diol was found to undergo dehydration and rearrangement, under various conditions, to give tiglic aldehyde (2-methyl-2-butenal). The isomeric ring compound, 3-methyl-2,5-dihydrofuran, was not detected as a product of dehydration of this glycol. Tiglic aldehyde was also produced by the action of hydrogen chloride (in methyl alcohol) upon 1,4-diacetoxy-2-methylbutene-2.

It is suggested that the mechanism of this rearrangement involves 1,4-elimination of water and 1,4-tautomeric shift of the resulting enol.

ITHACA, NEW YORK