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REACTION OF ORGANOBORANES WITH α-LITHIUM FURAN

A CONVENIENT SYNTHESIS OF 4,4-DIALKYL-*CIS*-2-BUTEN-1,4-DIOLS FROM OLEFINS *VIA* HYDROBORATION

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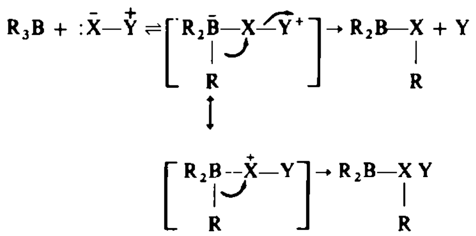
Abstract—The reactions between organoboranes and α-lithium furan were found to give 1,6,6-trialkyl-1,2-boroxarocyclohex-4-enes (**8**) in good yields. Alkaline hydrogen peroxide oxidation of these compounds afforded quantitatively the corresponding 4,4-dialkyl-*cis*-2-buten-1,4-diols (**9**).

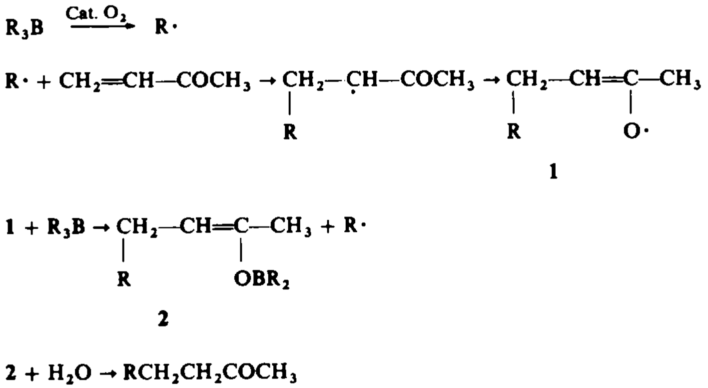
The discovery that organoboranes are readily obtained by hydroboration of olefins with diborane, has created intense interest in the organic synthesis by means of organoboranes.[1] Although the reaction mechanisms of organoboranes with many reactants have not yet been confirmed, judging from the experimental facts which have been clarified to date, there appear to be two different types of mechanisms. One is a coordination process and the other is a radical chain process. Owing to the vacant electron structure of the boron atom, the organoboranes exhibit a strong tendency to share an electron pair with a nucleophile. Such a coordination should greatly increase the carbanion-like character of the alkyl groups of organoboranes, and thereby facilitate reactions in which the alkyl group is transferred with its electron pair to the near positive atom, as shown in Eqns 1 and 2. Actually, there are many examples which have been reported to proceed by such coordination mechanisms, including protonolysis of organoboranes with carboxylic acid,[2] reactions of organoboranes with carbon monoxide,[1a] nitric oxide,[3] iso-nitriles,[4] quinones,[5] ylids,[6] and carbanions.[7] On the other hand, the radical chain mechanism has been recently discovered in the reaction of organoboranes with α,β-unsaturated carbonyl compounds to produce the corresponding saturated carbonyl derivatives,[8–11] as revealed in Eq. 3. Oxidation of organoboranes was also demonstrated to proceed through such a free radical mechanism.[12]



$$R_3B + :\bar{X}-\overset{+}{Y} \rightleftharpoons \left[\begin{array}{l} R_2\bar{B}-X-Y^{+} \\ \;| \\ \;R \end{array}\right] \rightarrow \begin{array}{l} R_2B-X \\ \quad\;\; | \\ \quad\;\; R \end{array} + Y \tag{1}$$

$$\left[\begin{array}{l} R_2B-\overset{+}{X}-Y \\ \;| \\ \;R \end{array}\right] \rightarrow \begin{array}{l} R_2B-X\,Y \\ \quad\;\; | \\ \quad\;\; R \end{array} \tag{2}$$

Reactions of organoboranes with carbenes which should be considered to proceed through a coordination process have been reported in the case of phenyl (bromodichloromethyl) mercury,[13] lithium carbenoids,[14] methoxy carbene,[15] diazoketones,[16, 19] diazoacetnitrile[17] and diazodiketone,[18] although there was little evidence to confirm whether organoboranes react with real carbenes or with true carbenoids.



$$R_3B \xrightarrow{\text{Cat. } O_2} R\cdot$$

$$R\cdot + CH_2{=}CH{-}COCH_3 \rightarrow \underset{R}{CH_2}{-}\dot{C}H{-}COCH_3 \rightarrow \underset{\mathbf{1}}{\underset{R}{CH_2}{-}CH{=}\underset{O\cdot}{C}{-}CH_3}$$

$$\mathbf{1} + R_3B \rightarrow \underset{\mathbf{2}}{\underset{R}{CH_2}{-}CH{=}\underset{OBR_2}{C}{-}CH_3} + R\cdot \qquad (3)$$

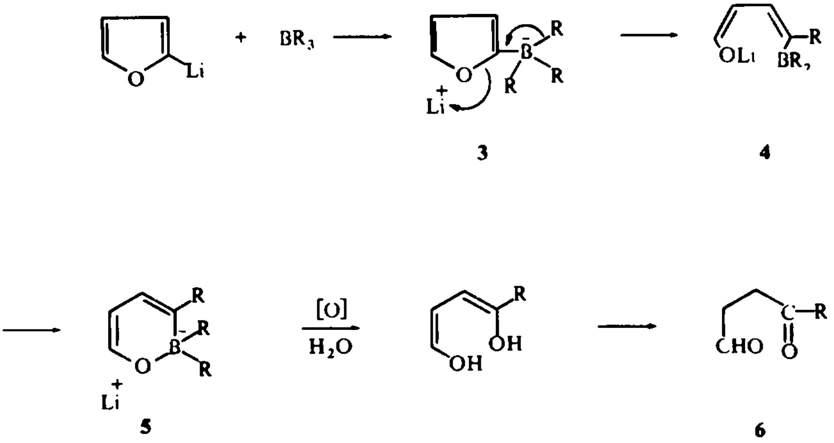
$$\mathbf{2} + H_2O \rightarrow RCH_2CH_2COCH_3$$

We report the reaction of organoboranes with α-lithium furan, which is regarded as a co-ordination process.

RESULTS AND DISCUSSION

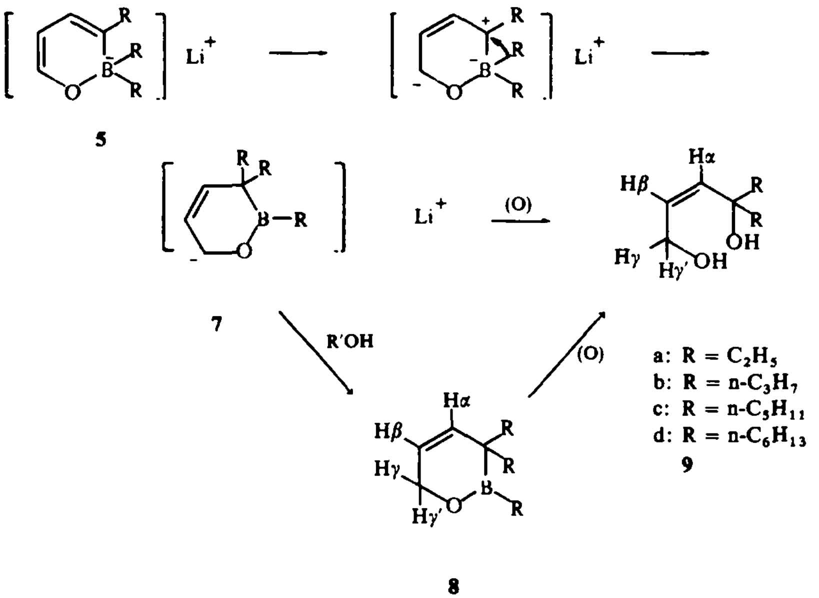
At first, it was expected that the reaction of organoborane with α-lithium furan readily obtained from furan and butyl lithium,[20] should give the corresponding ketoaldehyde (6) through the following reaction path (Eq. 4).

The reaction product actually obtained after the usual alkaline hydrogen peroxide oxidation, however, was not the ketoaldehyde (6) but an unsaturated diol. For example, triethylborane gave an olefin diol, n_D^{20} 1·4619, bp. 135° at 17 mm, the elemental



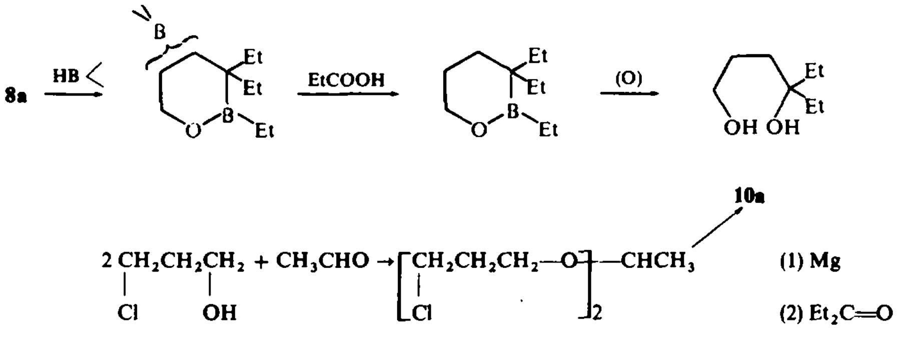
(4)

analysis of which coincided with $C_8H_{16}O_2$. The IR spectrum bands at 3015, 700 cm^{-1} due to *cis*-CH=CH-structure and 3350 cm^{-1} for OH group. The authors assumed at this stage the compound to be 4,4-diethyl-2-buten-1,4-diol (**9a**), which should be prepared from the intermediate (**5**) in Eq. 4, as shown in Eq. 5. In order to confirm the carbon skeleton, the cyclic borate (**8a**) was subjected to hydroboration,



(5)

then to protonolysis by propionic acid and finally to hydrogen peroxide oxidation. The product thus obtained, was identified as 4,4-diethyl-butan-1,4-diol (**10a**) by direct comparison with an authentic sample which was synthesized from 1-chloro-3-propanol.



(6)

It has been reported[21, 22] that, the Karplus equation[23, 24] is applied to vicinal couplings in olefins (H—C=C—H') as well as saturated systems. One can therefore predict that *trans*-olefinic protons will show larger vinyl proton coupling constants (~ 17 Hz) than *cis*-olefinic protons (~ 10 Hz). In the NMR spectrum of the product obtained by the reaction of tripropylborane with α-lithium furan, which should be 4,4-di-n-propyl-2-buten-1,4-diol (**9b**), the olefinic protons (H_α and H_β) and the methylene protons at C_1 (H_γ) give rise to an ABX^2 pattern. The resonance of the proton,

H_α is centered at 5·30 and splits into a doublet with $J_{\alpha\beta} = 13·5$ Hz. Another olefinic proton, H_β, affords six lines centered at 5·53 with $J_{\alpha\beta} = 13·5$ Hz and $J_{\beta\gamma} = 4·5$ Hz, and the methylene protons, H_γ, centered at 4·18, split into a doublet with $H_{\beta\gamma} = 4·5$ Hz and $J_{\alpha\gamma} = 0$. This assignment was supported by the good agreement with the theoretical spectrum which was calculated by using a JEOL EC-5 Spectrum Computer. As the olefinic proton coupling constant, $J_{\alpha\beta}$, however, is just between the reported values of *cis*- and *trans*-olefinic coupling constants, this procedure to determine such structural relationships was not applied to the characterization of the olefin structure.

Eventually, the structure of the olefinic alcohol was identified as a *cis*-compound by comparing with an authentic sample synthesized by George's method.[25] Furthermore, the *cis*-structure was supported by the NMR studies of the intermediate (**8**) which was obtained by protonolysis of **7** in Eq. 5. When the mixture prepared by the reaction of organoborane with α-lithium furan was treated with acetic acid at room temperature, the corresponding cyclic borate (**8**) was obtained. For example, triethylborane gave a compound, $C_{10}H_{19}OB$, with n_D 1·4478, which has an absorption peak at 1660 cm^{-1} due to $\nu_{C=C}$ and 1405 for δ_{C-H} of *cis*-CH=CH-structure. The resonance of the proton, H_α centered at 5·13 splits into double triplets with $J_{\alpha\beta} = 10·5$ and $J_{\alpha\gamma} = 2·3$ Hz. The proton, H_β at 5·77 also splits into double triplets with $J_{\alpha\beta} = 10·5$ and $J_{\beta\gamma} = J_{\beta\gamma'} = 2·3$ Hz. The resonance of H_γ and $H_{\gamma'}$ is centered at 4·47 with coupling constants $J_{\alpha\gamma} = J_{\beta\gamma} = J_{\alpha\gamma'} = J_{\beta\gamma'} = 2·3$ Hz.

Since it was found that organoboranes react with α-lithium furan to form the corresponding cyclic borate (**8**), we attempted to find the optimum conditions of the preparation for such a borate. In the reaction of one mole of tri-ethylborane with two moles of α-lithiumfuran at room temperature, the relationship between the reaction time and the yield which was based on an organoborane was as follows:

Reaction time (min)	5	30	180
Yield of **8a**, %	78	85	88

Therefore, the reaction was carried out for one hour at room temperature. The result is summarized in Table 1. Generally speaking, the bulky alkyl group in organoboranes gives a low yield of the corresponding cyclic borate (**8**). Especially, in the organoboranes with sec-alkyl groups such as tricyclopentyl and tricyclohexyl

TABLE 1. REACTION OF ORGANOBORANES WITH α-LITHIUM FURAN

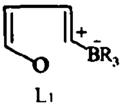
Organoborane	Amount of α-lithium furan[a]	Yield of **8**[b], %
Triethyl	1	54
	2	89
Tri-n-propyl	1	51
	2	59
Tri-n-pentyl	1	41
	2	65
Tri-n-hexyl	1	35
	2	65

[a] α-Lithiumfuran/R_3B

[b] Based on the organoborane used

boranes, the yields were too low to separate the products. This may be due to the steric hindrance of such alkyl groups. In the reactions which seem to proceed through a radical chain mechanism, there is no case,[8–11] in which such a steric inhibition by sec-alkyl group has been reported.

The authors proposed that the reaction should proceed, as illustrated in Eqns 4 and 5. From the fact that this reaction gives a cyclic borate (**8**), it is pointed out that trialkylborane converts α-lithium furan first to **3** in Eq 4, and then to **4** and **5**. In the step from **3** to **4**, the carbon to which the alkyl group migrated is inverted. This stereospecificity, therefore, rules out any possibility of a boron ylid intermediate (**11**), and the alkyl group migration should proceed by a remarkable contribution of the O atom in furan ring as shown in **12** or **13**. Such alkyl migrations have been described in the cases of 1-halo-1-hexenylboranes[26] and 1-chloro-2-methyl-2-phenyl vinyl boranes.[14]



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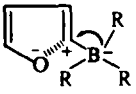

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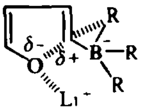

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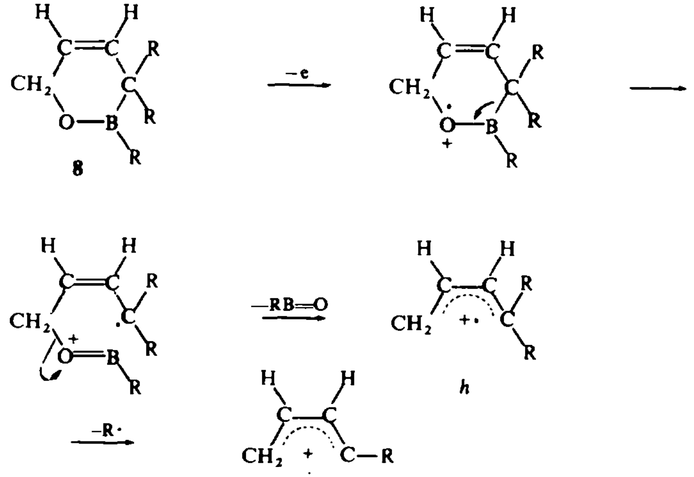
Further, a crossover experiment revealed that the migration of alkyl group in organoborane is intramolecular.

The mass spectra of the cyclic borates (**8**) (Figs 1a and 1b) were recorded in order to obtain information concerning the mass spectral behaviour of the parent compound (**8**) with an unsaturated cyclic borate system. The mass spectra measured in this study exhibit two characteristic peaks, **h** and **i** and high resolution mass measurements indicate that these peaks correspond to the fragment of composition, M-RBO, and to the fragment of composition, M-RBO-R, respectively. These fragmentation patterns should be explained as is illustrated in Eq. 7.



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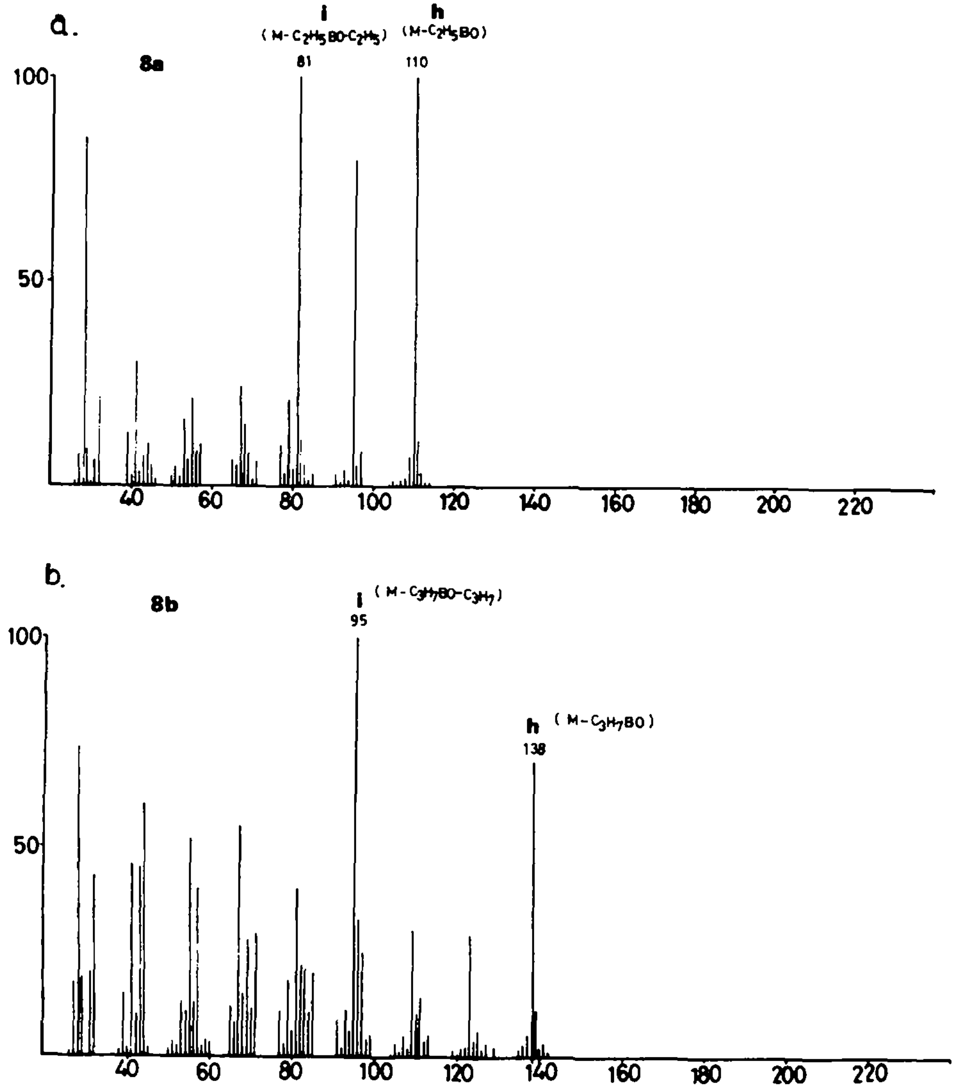

FIG 1. The mass spectra of the cyclic borates, (**8a**) and (**8b**)

TABLE 2. THE ALKALINE HYDROGEN PEROXIDE OXIDATION OF CYCLIC BORATES (**8**)

Cyclic borate (**8**)	Product (**9**)	Yield[a], %
8a	**9a**	80
8b	**9b**	98
8c	**9c**	100

[a] Based on cyclic borate (**8**)

Finally, we tried to oxidize the cyclic borates (**8**) to form the corresponding olefinic diols (**9**). Cyclic borates were oxidized with hydrogen peroxide in an alkaline aqueous solution at room temperature by the usual procedure.[27] The oxidation gives the corresponding olefinic diol (**9**) in an almost quantitative yield. The results are summarized in Table 2. Consequently, the present reaction provides a convenient procedure to synthesize such alcohols from olefins *via* hydroboration.

EXPERIMENTAL

The purification of THF, diglyme and BF_3-etherate, and the preparation of diborane were carried out by the usual procedure.[27] All the NMR spectra were taken by using a JEOL 3H-60 high resolution NMR spectrometer. IR spectra were recorded on a Hitachi Infracord. Mass spectra were determined by use of a Hitachi RMU-7 mass spectrometer.

Reaction of organoboranes with α-lithiumfuran. The following procedure is representative of the reaction. A 25 ml round-bottomed flask equipped with a rubber septum inlet, a N_2 inlet, a reflux condenser and a bar of magnetic stirrer was flushed with N_2. The flask was charged with 0·25 ml (3·4 mmol) furan, which was treated with 3·4 ml 1M BuLi soln in ether. The mixture was maintained under stirring at reflux for 6 hr. Then, 1·0 ml of 1·5 M-tri-n-pentyl-borane soln in THF was added gradually at room temp through the septum inlet by a syringe. After 1 hr, the mixture was treated with 0·2 ml AcOH, and AcOLi thus precipitated was removed by filtration. GLPC analysis (70 cm column of 20% FFAP on Diasolid L, 190°C) indicated the presence of 0·98 mmol of **8c**, a yield of 65% based on pentylborane. The cyclic borates **8** were separated by an Autoprep (column, FFAP) and their elemental analyses and physical properties are summarized in Table 3.

TABLE 3. CYCLIC BORATES (8) PREPARED FROM ORGANOBORANES AND α-LITHIUM FURAN

Cyclic borate	n_D[a]	NMR,[b] δ	Elemental analyses Calcd, %	Elemental analyses Found, %
8a	1·4478	4·47 (t), 5·13 (dt), 5·77 (d)	C, 72·30; H, 11·40	C, 72·09; H, 11·20
8b	1·4480	4·48 (t), 5·23 (dt), 5·76 (d)	C, 75·60; H, 11·65	C, 75·30; H, 11·81
8c	1·4492	4·47 (t), 5·20 (dt), 5·73 (d)	C, 78·10; H, 12·67	C, 78·19; H, 12·65
8d	1·4510	4·47 (d), 5·20 (dt), 5·72 (d)	C, 79·00; H, 12·81	C, 78·84; H, 12·74

Alkaline hydrogen peroxide oxidation of cyclic borate (**8**). The product obtained by the above procedure was oxidized with 0·6 ml 3N NaOH and 0·6 ml 30% H_2O_2 at room temp for 5 hr. The mixture was saturated with K_2CO_3, extracted with ether, and the combined extracts were analyzed by GLPC (70 cm column of 20% FFAP on Diasolid L, 160°C). The analysis showed the presence of 0·98 mmol 4-pentyl-2-nonene-1,4-diol, a yield of 100% based on the cyclic borate. The pure sample was separated by an Autoprep (column, FFAP). The elemental analyses and physical properties of such olefinic diols are described in Table 4.

TABLE 4. OLEFINIC DIOLS (9) PREPARED BY ALKALINE HYDROGEN PEROXIDE OXIDATION OF CYCLIC BORATES (8)

Olefinic diol	n_D[a]	NMR,[b] δ	Elemental analyses Calcd, %	Elemental analyses Found, %
9a	1·4619	4·20 (d), 4·67 (s), 5·40 (d), 5·57 (dt)	C, 66·63; H, 11·18	C, 66·47; H, 11·37
5d	1·4670	4·18 (d), 4·65 (s), 5·30 (d), 5·53 (dt)	C, 69·72; H, 11·70	C, 69·89; H, 11·29
9c	1·4683	4·14 (d), 5·25 (d), 5·52 (dt)	C, 73·70; H, 12·20	C, 73·50; H, 11·99

[a] Measured at 20°C

[b] s = singlet, d = doublet, t = triplet, dt = double triplet.

Preparation of 4,4-*diethylbutan*-1,4-*diol* (**10a**) *from* 1-*chloro*-3-*propanol*. In a 100 ml test tube were placed 45·4 g (0·486 mol) trimethylene chlorohydrine and 4·4 g (0·04 mol) granulated anhyd $CaCl_2$. The mixture was cooled under 8° in an ice bath and then 11 g (0·25 mol) freshly distilled acetaldehyde was gradually added. The test tube was tightly closed with a cork stopper and was shaken for 2 days. To the soln, water was added and the product was extracted with ether. Then the combined extracts were washed and dried over Na_2SO_4. The fractional distillation using a Vigreux column gave 23 g (44%) of the acetal, b.p. 132°C at 23 mmHg. (Found, C, 44·51; H, 7·32. Calcd. for $C_8H_{16}O_2Cl_2$, C, 44·7; H, 7·50%).

In a 300 ml round-bottomed flask, fitted with a stirrer, a separatory funnel and a reflux condenser with a dry tube was charged with 2·6 g (0·10 mol) Mg turnings. A mixture of 23 g (0·10 mol) of the acetal obtained above and 75 ml absolute ether was added at such a rate that the mixture boiled continuously. After 2 hr the mixture was cooled and 9·2 g (0·107 mol) diethyl ketone in 30 ml ether was added dropwise. The reaction flask was heated at 34° for another hr. The mixture was poured into cold H_2SO_4 aq and then refluxed for 6 hr. Finally, the product was extracted several times with ether. The extracts, after being dried over Na_2SO_4, were fractionally distilled at a reduced pressure. Thus, 5·8 g of 4,4-diethylbutan-1,4-diol, b.p. 139° at 15 mmHg, n_D 1·4635, was obtained. (Found, C, 65·55; H, 12·46. Calcd. for $C_8H_{18}O_2$, C, 65·71; H, 12·41%).

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