The reactions of 4-chloro-2-butanol and 3-chloro-1-butanol with aqueous sodium hydroxide, and 1-chloro-2-propanol and 2-chloro-1-propanol with isopropyl amine

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Dedicated to Professor William Bailey on the occasion of his 65th birthday

Abstract

The total reaction of 4-chloro-2-butanol **1** with NaOH(aq) is dominated (74%) by intramolecular substitution (S_Ni), besides which bimolecular substitution (S_N2, 12%) and 1,4-elimination (i.e. fragmentation, contrary to earlier arguments) exhibit a significant contribution (11%). The total reaction of 3-chloro-1-butanol **2** instead is dominated by 1,4- (72%) and 1,2-elimination (25%), the substitution reactions being just observable (S_Ni 2% and S_N2 1%). In **1** both the +I-effect and the conformational factors in the intermediate γ–chloroalkoxy anion favour the S_Ni-reaction, whereas in **2** the situation is opposite and the location of Cl on a secondary carbon also makes the S_Ni-reaction less favourable. The relative proportions of 1,4- and 1,2-eliminations for **2** can be explained by thermodynamic basis since the consequent products are more stable than the corresponding products from **1**. 1-chloro-2-propanol **3** and 2-chloro-1-propanol **4** both react with isopropyl amine giving the same product, namely 1-isopropylamino-2-propanol, which indicates that the reaction proceeds through the propylene oxide intermediate. Compound **1** also reacted with isopropyl amine predominantly *via* S_Ni-reaction, giving first 2-methyloxetane which then further gave 4-isopropylamino-2-butanol, whereas **2** gave 3-isopropylamino-1-butanol through a direct S_N2-reaction.

Keywords: 1,2- and 1,3-Chlorohydrins, reactions in alkali, kinetics, mechanisms

Introduction

In alkaline media 1,3-halohydrins can decompose in the following ways:[1-3]

(1) intramolecular substitution (S_Ni) leading to the formation of an oxetane;

(2) 1,4-elimination (fragmentation) which leads to an alkene and an oxo compound in the consequent cleavage;
(3) 1,2-elimination leading to an α,β- or a β,γ-unsaturated alcohol;
(4) bimolecular substitution (S_N2) leading to a 1,3-diol.

With isopropyl amine the reaction appears to proceed according to routes (1) or (4).[4]

The type of reaction depends on the structure of the substrate and the reaction conditions.[1a,2] Decomposition can take place simultaneously by more than one of the above four routes. In the present case the first alternative is the most interesting:[1,2] According to Bartók *et al*.[1] and Searles *et al.*[2] in the first step a γ-chloroalkoxy anion is formed and then the chlorine is replaced by the oxygen atom and an oxetane is formed (route 1). Alternatively, the γ-chloroalkoxy anion can release the halogen and split into an alkene and oxo compound via 1,4-elimination (route 2).

Only a limited number of studies on the alkaline dehydrochlorination of 1,3-chlorohydrins have been made in rather variable conditions. Bartók and coworkers[1] studied the reactions of several 2-[1b] and 2,2-disubstituted[1c] and 1-[1d] and 1,1-disubstituted 3-chloro-1-propanols[1e] in aqueous 1,4-dioxane (3:7) using $Ba(OH)_2$ as a base. They were obliged to use very high temperatures (even as high as 125 °C). Usually it is recommended that one should follow the studied reactions up till 3 half-lives. However, Bartók *et al*.[1] stopped even after less than 20-30% conversion.

Bartók *et al.*[1] concluded that the predominant reaction route was (1), based on reaction product analyses. However, 1-chloro-3-propanol, 3-chloro-1-phenyl-propanol and 3-chloro-2-phenyl-1-propanol exhibited a variable amount of 1,2-elimination (30, 80 and 70-80%, respectively). The –I-effect and mesomerism of the phenyl group increase the stability of such a conformation which favours 1,2-elimination and splitting.

Searles *et al*.[2] were mainly interested in the syntheses of oxetanes which they tried to prepare by treating several 2- or 2,2-disubstituted 3-bromo-1-propanols with 15 or 50% aqueous KOH. They state that at either base concentrations, substituents at carbon 2 favour the 1,4-elimination process (fragmentation) over intramolecular substitution. However, their own results prove the opposite, i.e. in 50 % aqueous KOH the latter reaction was favoured over the former by a factor of 1.7–8. Similarly, Gaylord *et al*.[5] tried to prepare oxetanes by treating 2-chloro-4-hexanol and 1-phenyl-3-chloro-1-butanol with powdered KOH. In the former case they obtained 25% of 2-ethyl-4-methyloxetane but in the latter none.

Richardson *et al*.[3] studied the basic decomposition of 3-chloro-1-propanol and its 2,2-dimethyl derivative as well as that of 4-chloro-2-methyl-1-butanol in 40% aqueous methanol. It is not easy to understand how their work was really done since in their kinetic experiments the initial substrate to NaOH ratio varied from 2.4 to 11. In other words all of base was consumed after the reaction had proceeded even less than 10%. When determining the products the substrate to base ratio was 0.5, 11 and 0.6, respectively. In the case of 3-chloro-1-propanol and 4-chloro-2-methyl-1-butanol they determined the % yields of different products after 28 and 39% conversion but for 2,2-dimethyl-3-chloro-1-propanol after 10-20 half-lives. In fact in the latter case the outcome would have been the same after ca 10% conversion since all base was then already consumed.

Results and Discussion

Reactions of 4-chloro-2- (1) and 3-chloro-1-butanols (2) with aqueous NaOH

The reactions of **1** and **2** were carried out in water at four different base concentrations (0.1, 0.2, 0.4 and 1.00 M NaOH). The base concentration had no systematic effect on the second-order rate coefficients obtained (Table 1). According to Richardson *et al*.[3] temperature had no remarkable effect on the product ratios either. For determining the activation parameters the reactions were carried out in 0.1 M NaOH(aq) each at 6 different temperatures (Table 2). The activation parameters (E_a, A, $\Delta H^{\#}$ and $\Delta S^{\#}$; Table 3) were calculated according to the normal procedure. The rate constants determined by Bartók and Bozóki-Bartók[1e] at 80 °C for **1** and by Forsberg[6] at 80.07 °C for **1** and **2** are relatively close to those determined in this work (Table 2). However, the activation parameters determined by the former authors are far different from those in this work (Table 4) probably due to the different solvent and relatively mild base. Forsberg,[6] however, determined the decomposition rates for **1** and **2** only at 80.07 °C.

Table 1. The values of second order rate constants for 4-chloro-2-butanol **1** and 3-chloro-1-butanol **2** at various NaOH concentrations (b)

b, mol dm^{-3}	**1**, 60.2 °C, 10^5 k_r $dm^3mol^{-1}s^{-1}$	**2**, 50.0 °C, 10^4 k_r $dm^3mol^{-1}s^{-1}$
0.100	9.77 ± 0.12	3.25 ± 0.04
0.200	9.89 ± 0.04	2.90 ± 0.13
0.400	11.8 ± 0.04	3.23 ± 0.05
1.000	10.8 ± 1.0	3.35 ± 0.26
Average	10.8 ± 1.0	3.16 ± 0.16

Table 2. The values of second order rate constants for 4-chloro-2-butanol **1** and 3-chloro-1-butanol **2** at 0.100 mol dm^{-3} NaOH concentration at various temperatures

Temperature, °C	**1**, 10^5k_r $dm^{-3}mol^{-1}s^{-1}$	**2**, 10^4 k_r $dm^3mol^{-1}s^{-1}$
40.0	-	1.05 ± 0.03
45.0	--	1.91 ± 0.07
50.0	2.63 ± 0.19	3.25 ± 0.04
55.0	5.78 ± 0.20	5.40 ± 0.30
60.0	-	9.80 ± 0.12
60.2	9.77 ± 0.10[a]	-
65.0	15.2 ± 0.9	-
70.0	27.0 ± 0.4	25.2 ± 0.7
79.7	71.3 ± 1.0[b,c]	-[d]

[a]With external standard; all the other cases with internal standard.
[b]85.0 at 80 °C.[1d] [c]82 and [d]75 at 80.07 °C.[4]

The decomposition of **1** was predominated by the S_Ni reaction leading to 2-methyloxetane (Scheme 1 and Table 3) which can be explained by the most favoured conformation of the γ-chloroalkoxy anion in this case (**A**, Scheme 2). Opposite to the statements of Richardson *et al*.[3] and Forsberg[6] that 1,4-elimination can occur only if a substituted alkene is formed, **1** clearly gave ethene (+acetaldehyde, Tables 3 and 4). **2** gave only very small amount of 2-methyloxetane (S_Ni), the main products being 1-propene (+CH_2=O, 1,4-E/fragmentation) and 2-buten-1-ol blanco (1,2-E) besides a small amount of butane-1,3-diol (S_N2, Tables 3 and 4) which is again in agreement with its favoured conformation (**B**, Scheme 2). In general, it can be mentioned that the product analyses have usually been far from complete. The few more comprehensive examples are collected in Table 4. For instance, Bartók and coworkers[1] were also mostly interested in oxetane formation although in some cases they tried to explain also the presence of other products.

Table 3. Kinetic parameters for the total (**T**) and the partial reactions (**S_Ni**, **1,4-E**, and **1,2-E**) in 0.100 N NaOH (aq) and the average distribution of final reaction products at various base concentrations for 4-chloro-2-butanol **1** and 3-chloro-1-butanol **2**

	1	**2**
T: A, $dm^3\,mol^{-1}s^{-1}$	12.2 x 10^{11} (1.7 x 10^{10})[a]	7.0 x 10^{11}
T: E_a, $kJmol^{-1}$	102.9 ± 3.2 (89.6 ± 3.3)[a]	94.9 ± 1.2
T: $\Delta H^{\#}$, $kJmol^{-1}$	100.1 ± 3.2 (86.6 ± 3.4)[a]	92.2 ± 1.1
T: $\Delta S^{\#}$, $Jmol^{-1}K^{-1}$	–22.9 ± 9.5 (-58.9 ± 9.2)[a]	–27.3 ± 3.6
S_Ni: A, $dm^3\,mol^{-1}s^{-1}$	7.5 x 10^{11}	
S_Ni: E_a, $kJmol^{-1}$	102 ± 3	
S_Ni: $\Delta H^{\#}$, $kJmol^{-1}$	100 ± 3	
S_Ni: $\Delta S^{\#}$, $Jmol^{-1}K^{-1}$	–27 ± 8	
1,4-E: A, $dm^3\,mol^{-1}s^{-1}$	2.3 x 10^{11}	6.8 x 10^{10}
1,4-E: E_a, $kJmol^{-1}$	104 ± 4	96 ± 1
1,4-E: $\Delta H^{\#}$, $kJmol^{-1}$	100 ± 2	91 ± 2
1,4-E: $\Delta S^{\#}$, $Jmol^{-1}K^{-1}$	–41 ± 6	–53 ± 6
1,2-E: A, $dm^3\,mol^{-1}s^{-1}$	1.5 x 10^{11}	1.7 x 10^{10}
1,2-E: E_a, $kJmol^{-1}$	102 ± 2	95 ± 1
1,2-E: $\Delta H^{\#}$, $kJmol^{-1}$	99 ± 2	94 ± 1
1,2-E: $\Delta S^{\#}$, $Jmol^{-1}K^{-1}$	–47 ± 5	–34.1 ± 4
Temperature	60.2 °C	50.0 °C
S_Ni-reaction (%)	2-Methyloxetane (74)	2-Methyloxetane (1)
1,4-elimination (%)	Ethene + CH_3CHO (11)	1-Propene + CH_2=O (71.5)
1.2-elimination (%)	-	2-Buten-1-ol (25.5)
S_N2-reaction (%)	Butane-1,3-diol (15)	Butane-1,3-diol (2)

[a]Recalculated from the rate constants by Bartók *et al*.[1e] in 0.015 N $Ba(OH)_2$ solution (b/c_o = 1.46).

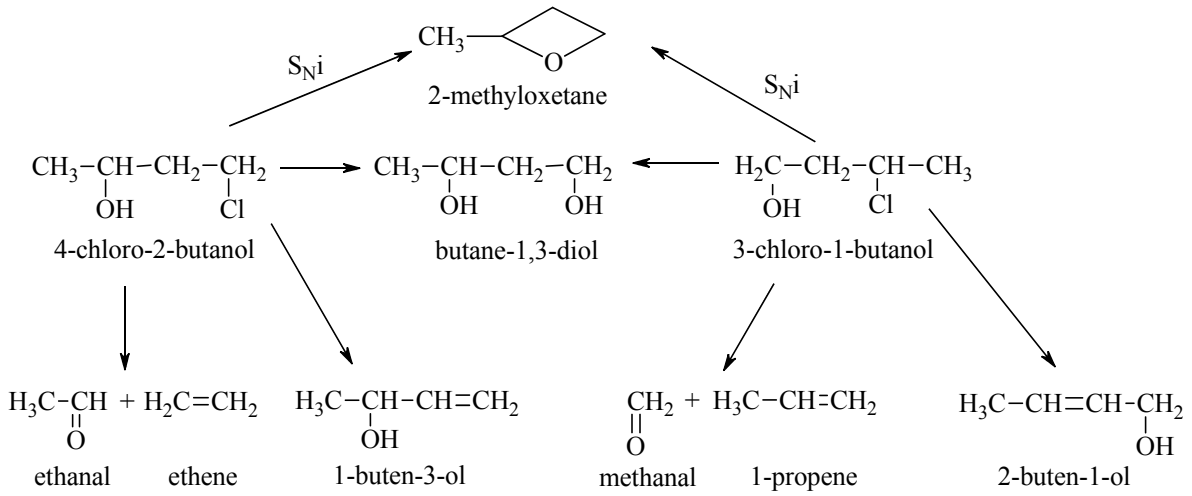
Table 4. Product analyses (%)

1,3-Chlorohydrins	Products			
$HOCH_2CH_2CH_2Cl$ (100 °C)[3]	Oxetane	2-Propen-1-ol	3-Methoxy-1-propanol	Butane-1,3-diol
	15	5	53	28
$(CH_3)_2C(OH)CH_2CH_2Cl$ (100 °C)[3]	2,2-Dimethyloxetane	2-Methyl-3-buten-2-ol	4-Methoxy-2-methyl-2-butanol	
	82	2	16	
$HOCH_2CHC_6H_5CH_2Cl$ (100 °C)[1b]	2-Phenyloxetane	2-Phenyl-2-propen-1-ol		
	20 - 30	70 – 80		
$HOCH_2C(CH_3)_2CH_2Cl$ (85 °C)[3]	3,3-Dimethyloxetane	2-Methyl-1-propene		
	46	54		
$CH_3CHOHCH_2CHClCH_2CH_3$ (75-100 °C)[5]	2-Ethyl-4-methyloxetane	4-Hexen-3-ol	1-propene	Propanoic acid
	25	25	21	18
$CH_3CHOHCH_2CH_2Cl$ 1 (60 °C)	2-Methyloxetane		Ethene + Ethanal	Butane-1,3-diol
	74		11	15
$HOCH_2CH_2CHClCH_3$ 2 (50 °C)	2-Methyloxetane	2-Buten-1-ol	1-Propene + Methanal	Butane-1,3-diol
	1	25.5	71.5	2

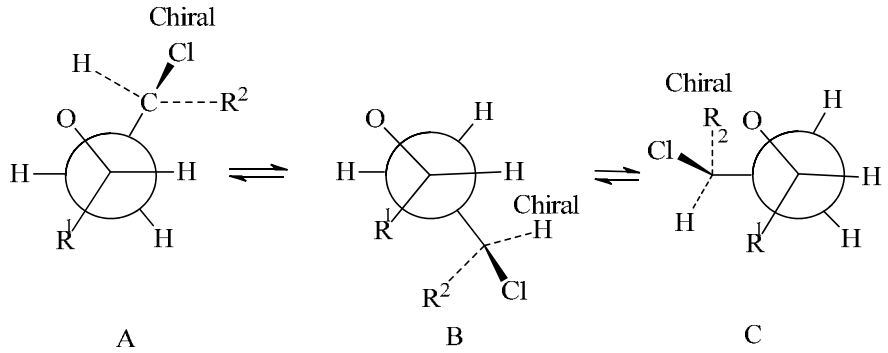
The reactions of 1,3-chlorohydrins with base fall into the category of parallel second-order reactions[3], where the overall rate coefficient (k_r) equals the sum (Σk_i) of the second-order rate coefficients for the S_Ni, 1,4-E (fragmentation), S_N2 and 1,2-E reactions, i.e.

$$k_i = k_r(\%\ \text{yield of i}/100).$$

Taking this into account together with the fact that according to Richardson *et al.*[3] the percentage yield of various products does not seem to depend much on temperature we were able to evaluate the approximate activation parameters for the partial main reactions of **1** and **2** (Table 3).



Scheme 1. Different routes for alkaline dehydrochlorination of **1** and **2**.



Scheme 2. Conformational illustration of γ-chloroalkoxy anion, **1** $R^1 = CH_3$, $R^2 = H$; **2** $R^1 = H$, $R^2 = CH_3$.

When inspecting the activation parameters shown in Table 3 it appears that the faster dehydrochlorination of **2** is mainly due to the 8 kJ mol^{-1} lower activation enthalpy. The activation parameters (E_a and $\Delta H^{\#}$) for the partial reactions (Table 3) of **1** or **2** do not differ very much from those for the total reaction except the A and entropy terms. When comparing our activation parameters (E_a, $\Delta H^{\#}$ and $\Delta S^{\#}$) for the partial reactions of **1** they are very close to those determined by Richardson et al.[3] for the same type of partial reactions of 3-chloro-1-propanol and 4-chloro-2-methyl-2-butanol despite the fact that the latter reactions were carried out in 40% aqueous methanol.

As to the reactions of chlorohydrins in mere water or in acid solution it has been shown especially with 1,2-chlorohydrins that practically no reaction occurs or at least they are extremely slow.[7]

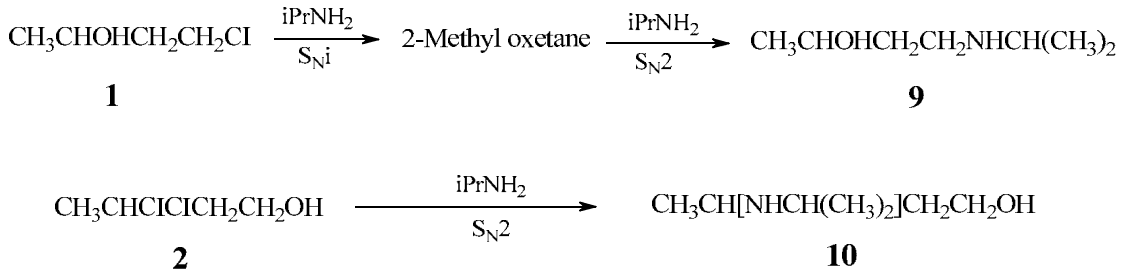
Reactions of 1-chloro-2- (3) and 2-chloro-1-propanols (4) with isopropylamine

In a course of studies related to licence arguments concerning the synthesis of propranolol we showed that the reaction of 1-chloro-3-(1-naphthoxy)-2-propanol **5** gave 1-isopropylamino-3-(1-naphthoxy)-2-propanol **6** (propranolol) with a rate 1.22×10^{-5} s^{-1} in isopropyl amine whereas that of 1,2-epoxy-3-(1-naphthoxy)-2-propane **7** gave the same product with 10-fold rate, 1.22×10^{-4} s^{-1} both at 60 °C.[8] The epoxide formation in the reaction of **5** could be verified with thin layer chromatography using a 35:10:1 C_6H_6+CH_3OH+CH_3COOH eluent. When this reaction was followed gas chromatographically (SE-30 column, t = 170 °C) it was found that some epoxide was still present after several half-lives as compared to the reaction of **7**. This is an indication that epoxide is an intermediate (rate determining step in case of **5**) which reached a so-called steady-state making its observation a bit less easy.

Both the reaction of 1-chloro-2-propanol **3** and that of 2-chloro-1-propanol **4** with isopropyl amine gave principally the same product, namely 1-isopropylamino-2-propanol **8** the rate ratio being 7:1,[9] the first-order rate coefficients being $(9.8 \pm 0.7) \times 10^{-6}$ and $(1.3 \pm 0.1) \times 10^{-6}$ for **3** and **4**, respectively. Since the reaction of propylene oxide with isopropyl amine[6,8] gave the same end product we could conclude that the reaction of **3** and **4** first gives the epoxide with S_Ni-mechanism, which then reacts further with another molecule of isopropyl amine with S_N2-mechanism leading to compound **8** in agreement with the results mentioned above. Literature results indicate that even conformational factors favour the reaction proceeding via the epoxide.[4,10]

Reactions of 4-chloro-2- (1) and 3-chloro-1-butanols (2) with isopropylamine

In relation to the reactions of chlorides **1** and **2** with NaOH (aq) it was also interesting to study their reactions with isopropyl amine since based on their reactions with NaOH(aq) one could expect that they would give different products as indeed was the case (see experimental). As to **1** the reaction can proceed first with S_Ni-mechanism leading to 2-methyloxetane which reacts then with another molecule of isopropylamine leading to the product.[9a] Alternatively **1** can react directly to 4-isopropylamino-2-butanol **9** by S_N2-mechanism (Scheme 3) which is however quite unlikely. In the case of **2** the product analyses proved[9a] that it gave 3-isopropylamino-1-butanol **10**, with a direct S_N2-mechanism (Scheme 3). Obviously the secondary chloride reacts much slower since **1** reacts 80-times faster than **2** with isopropyl amine. The first-order rate constant was $(45.0 \pm 1.3) \times 10^{-6}$ s^{-1} for **1** and $(0.55 \pm 0.02) \times 10^{-6}$ s^{-1} for **2**, the rate ratio being 80:1. When comparing the reactions of **3** and **4** with those of **1** and **2** with isopropyl amine **3** reacts ca 5 times slower than **1** whereas **4** reacts ca. 2 times faster than **2**.



Scheme 3

Conclusions

4-Chloro-2-butanol **1** reacts with NaOH(aq) predominantly with S_Ni-mechanism whereas 3-chloro-1-butanol **2** reacts mainly through 1,4-elimination (fragmentation, Scheme1) owing to their different I- and conformational effects. Correspondingly they also react with isopropyl amine giving different products, namely 4-isopropylamino-2-butanol **9** or 3-isopropylamino-1-butanol **10**, respectively. 1-Chloro-2-propanol **3** and 2-chloro-1-propanol **4** instead both react with isopropyl amine giving 1-isopropylamino-2-propanol **8** and this reaction occurs in both cases *via* propylene oxide which gave the same product when reacted with isopropyl amine.

Experimental Section

General. 3-Chloro-1-butanol **2** was obtained in 79% yield by reducing 3-chlorobutanoic acid by $LiAlH_4$ as reported by Searles *et al.*[10] Yield 79%, b.p. 55–61 °C/1.2 kPa, n_D^{20} 1.4410 (Lit.[11] bp. 74 °C/2.1 kPa, n_D^{20} 1.4398). 4-Chloro-2-butanol **1** was prepared in 76% yield by reducing 4-chlorobutanone by $LiAlH_4$ as reported by Germain and Mirjolet.[12] Yield 79%, bp. 52–55 °C/1.3 kPa, n_D^{20} 1.4415 (Lit.[13] bp. 67 °C/2.6 kPa, n_D^{20} 1.4408). 4-Chlorobutanone **1** was obtained by saturating freshly distilled methyl vinyl ketone at 0 °C with dry HCl gas about 1 h as reported by Smith and Sprung.[14] Yield 34%, bp. 40–41 °C/1.3 kPa (Lit.[14] bp. 38 °C/2 kPa).

1-Chloro-2-propanol (3) was prepared from chloroacetone by reducing with $LiAlH_4$.[15] After redistillation bp. 50–57 °C/4.1 kPa, n_D^{20} 1.4365 (Lit.[15] bp. 64.5 °C, n_D^{25} 1.4366). 2-chloro-1-propanol **4** was obtained by reducing α-chloropropionyl chloride with $LiAlH_4$.[16] After redistillation bp. 68–70 °C/10 kPa, n_D^{20} 1,4365 (Lit.[16] bp. 38 °C/1.7 kPa, n_D^{25} 1.4362).
1-chloro-3-(1-naphthoxy)-2-propanol **5**, 1-isopropylamino-3-(1-naphthoxy)-2-propanol (propranolol, **6**) and 1,2-epoxy-3-(1-naphthoxy)-2-propane **7** were kindly donated by Medipolar–Farmos Co.[7]
Reactions of (1) and (2) with isopropyl amine. 1 g (0.009 mol) of 4-chloro-2-butanol **1** and 8.7 g (0.147 mol) of isopropyl amine were placed in two tightly closed screw cap test tubes and placed in

an 80 °C oil bath for 5 days. The tubes were opened and the solutions filtered and the extra amine evaporated off. 10 ml of water was added and the mixture made alkaline by adding 30% NaOH(aq). Then the mixtures were extracted with Et_2O and dried with Na_2SO_4. Based on chromatographic analysis **1** was completely converted to 4-isopropylamino-2-butanol **9**, yield was practically quantitative (1.3 g, 99%). ^{1}H NMR (ppm): $(CH_3)_2$ 1.06; $(CH_3)_2CH$ and CH_2NH 2.82, CHOH 3.94 and $CHOHCH_2$ 1.55. ^{13}C NMR (ppm): $(CH_3)_2$ and CH_3 22.7, 23.0 and 23.6 (not separately assigned), CHOH 69.9, $CHOHCH_2$ 37.6, CH_2NH 46.0 and $(CH_3)_2CH$ 48.8.

2 g (0.018 mol) of 3-chloro-1-butanol **2** and 17.4 g (0.294 mol) of isopropyl amine were heated in an 80 °C oil bath. Thereafter one was proceeding as above. Based on gas chromatographic analysis **2** was completely converted in 3-isopropylamino-1-butanol **10**, yield 1.8 g, 74%. ^{1}H NMR (ppm): $(CH_3)_2$ 1.05; $(CH_3)_2CHNHCH$ 2.89, CH_2OH 3.79 and $HOCH_2CH_2$ 1.61. ^{13}C NMR (ppm): $(CH_3)_2$ and CH_3 21.0, 22.5 and 24.2 (not separately assigned), CH_2OH 62.6, $HOCH_2CH_2$ 38.0, CHNH 51.5 and $(CH_3)_2CH$ 45.5.

Reactions of (3, 4) and propylene oxide with isopropyl amine. The reactions were carried out in 10–16-fold excess of isopropyl amine at 80–100 °C in an oil bath [e.g. 4.7 g (0.05 mol) of **3** in 16-fold excess of isopropyl amine at 80 °C in a tightly closed test tube]. The mixtures were cooled to room temperature and filtered. Then 13–30 ml of water was added and the mixtures were hydrolysed by making them alkaline with 30% NaOH. The water solutions were extracted 3 times with Et_2O giving 38% **3** and 33% **4** of $CH_3CHOHCH_2NHCH(CH_3)_2$, 1-isopropyl amino-2-propanol **8**. The reaction of propylene oxide with isopropyl amine was carried out with Krassusky's method[17] and also this reaction gave **8** as the product. Yield 58%, bp. 75-78 °C/3.35 kPa. In all three cases **8** gave identical ^{1}H NMR spectra. ^{13}C NMR (ppm): CH_3 20.9, $(CH_3)_2$ 22.5, CHOH 65.5, NHCH 49.1 and CH_2NH 54.1.

Kinetic measurements

A weighed amount of 4-chloro-2- **1** and 3-chloro-1-butanols **2** (+ internal standard n-amyl alcohol if used) and the base (NaOH) solution were thermostated at least 1h in the measuring temperature The base solution was poured quickly with mixing into the reaction vessel containing the substrate, the initial concentration of which was then obtained as c_o. Thereafter a sample was withdrawn immediately to determine gas chromatographically the peak area (A_o) of the substrate and that (A_o^{IS}) of the internal standard (if used).

The substrate concentrations of samples withdrawn at suitable intervals were obtained based on the gas chromatographic analyses as follows:

Method with internal standard: $c_t = (A_t/A_t^{IS})/(A_o/A_o^{IS})c_o$

Method with external standard a constant amount injected: $c_t = (A_t/A_o)c_o$

c_t is the substrate concentration (mol dm^{-3}) at time t and c_o that when t = 0. A_t is the peak area (mVs) of the substrate at time t and A_o that at time t = 0. A_t^{IS} is the peak area (mVs) of the internal standard at time t and A_o^{IS} that at time t = 0.

The gas chromatograph used for kinetic measurements was a Hewlett Packard 5700 equipped with a flame-ionization detector (FID). The column used was a 5% Carbowax 20M-TPA/Chromosorb G AW-DMCS 80/100 mesh packed in a 1/8" steel column. The chromatographic conditions were:
(a) With internal standard: Injection chamber 200 °C, detector 250 °C, column oven 70 (4 min) –190 °C (8 min)/7 °C/min, injection volume 10 μl (Hamilton 710).
(b) With external standard: Injection chamber 200 °C, detector 250 °C, column oven 110 (2 min) –190 °C (8 min)/7 °C/min, injection volume 10 ± 0.1 μl (Hamilton CR 700-20).
The peak areas and retention times were determined on a Varian 220-240D Chromatography computer system. The composition of the reaction mixtures was obtained from the equation:

$$\text{Contribution of component i(mol-\%)} = f_iA_i/\sum_{i=1}^{n} f_iA_i$$

where f_i is the response factor for component i and A_i the peak area given by component i.

Table 5. Response factors determined for the initial reactants and reaction products

Compound	f
Ethene	35.7
1-Propene	23.8
2-Methyloxetane	23.3
2-Buten-1-ol	24.1
Butane-1,3-diol	24.1
4-Chloro-2-butanol (**1**)	24.1
3-Chloro-1-butanol (**2**)	24.9

Alkenes were identified with a Varian 2800 Gas chromatograph equipped with two serially coupled 1/8" aluminium columns, of which the first (15 m) was packed with 15% Sebaconitrile/Chromosorb P AW-MMCS 60/80 mesh and the second (3 m) with 10% Squalane/Chromosorb P AW-DMCS 60/80 mesh. At the column temperature of 45 °C the retention times of ethene (670 ± 5 s) and propene (880 ± 5 s) were strictly comparable to the retention times measured for hydrocarbon mixtures.
Second order rate constants k_r for the reactions in NaOH(aq) were calculated from the equation

$$y = k_rt + a \text{ where}$$
$$y = [1/(c_o-b)]\ln(bc_t)/[(c_o(b-x)]$$

t = time, a = a constant, c_o initial substrate concentration (mol dm^{-3}), b initial NaOH concentration (mol dm^{-3}), x the amount of substrate (mol dm^{-3}) reacted at time t (Table 4). The base concentration appears to have no effect on k_r (Table 4). The apparent fist-order rate constants for the reactions of **1**–**4** with isopropyl amine were easy to determine since the reactions were carried out in over 16-fold excess of the latter. The prepared mixtures as stated above were divided in 10-15 tightly closed

screw cap test tubes and placed in an oil bath at 80 °C. The samples withdrawn at suitable intervals were analysed with a Perkin-Elmer F11 gas chromatograph equipped with flame ionization detector and two SE-30 columns. The column temperature was raised by 20 °C/min from 50-175 °C. The following rate (k_t) equation was applied

$$k_t = (1/t)\ln [(A_1+A_2)/A_1]$$

where t = time, A_1 the peak area of the substrate and A_2 the peak area of the product.

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