was also unsuccessful. A small amount of ketone XXIX was the only product that was isolated.

3,3,5,5-Tetramethyl-1-thiacyclohexan-4-one (V).—A solution of 5 g (0.023 mol) of hydroxycarboxylic acid III and 2.8 g (0.023 mol) of $SOCl_2$ in 40 ml of benzene was refluxed for 2 hr. The reaction mixture was concentrated, and the residue was chromatographed over silica gel. Upon elution with CH_2Cl_2, 3.0 g (76%) of the ketone V was obtained. Distillation, bp 88 (12 mm), gave an analytical sample: ir (neat) 1690 cm^{-1} (C=O); nmr (CCl_4) τ 7.37 (s, methylene protons) and 8.82 (s, methyl protons).

Anal. Calcd for $C_9H_{16}OS$ (172.30): C, 62.72; H, 9.36; S, 18.61. Found: C, 62.9, 62.8; H, 9.4, 9.4; S, 18.6, 18.5.

Attempts to prepare an oxime of ketone V using standard procedures were unsuccessful. Starting material was recovered almost quantitatively.

Registry No.—III, 17539-59-2; IV, 17539-60-5; V, 17539-61-6; IX, 17539-62-7; X, 17539-63-8; XI, 17539-64-9; XV, 17539-65-0; XIX, 17539-66-1; XIX (free acid), 17539-67-2; XX, 17539-68-3; XXI, 17539-69-4; XXII, 17539-70-7; XXIII, 17605-19-5; XXV, 17539-71-8; XXVII, 17539-72-9; XXVIII, 17539-73-0; XXIX, 17539-74-1.

Synthesis and Nuclear Magnetic Resonance Spectra of 2-Oxazolidones

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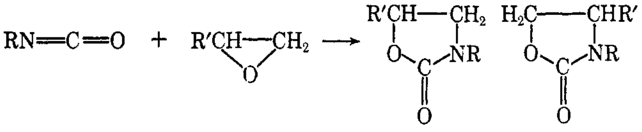
N-substituted 2-oxazolidones have been prepared from isocyanates and epoxides in refluxing DMF with lithium chloride as catalyst. Although the major products are 5-substituted 2-oxazolidones, 4-substituted isomers were also isolated in several cases. The nmr spectra of the 2-oxazolidones were determined, and chemical shift–structure relationships are reported.

The reaction of organic isocyanates with 1,2-epoxides has been reported to yield 2-oxazolidones.[3] A number of catalysts and solvents have been used with varying degrees of success. Most workers reported the formation of only the 5-substituted 2-oxazolidone (I) from the reaction of an isocyanate with an unsymmetrically substituted epoxide. In one case,[3b] however, the product from the reaction of phenyl isocyanate with phenyl glycidyl ether was assigned the structure of the isomeric 4-substituted 2-oxazolidone (II, R′ = $PhOCH_2$; R = Ph). Previous workers had reported the structure I (R′ = $PhOCH_2$; R = Ph) for this reaction product.



I II

Of interest to us were the literature reports that only one isomeric 2-oxazolidone is obtained from the reaction of isocyanates with unsymmetrical 1,2-epoxides despite the relatively vigorous conditions employed (reaction temperatures *ca.* 150° or greater) and possible effects (steric, conjugative, and polar) of substituent groups in the epoxide on the reaction course. We have examined the reaction in more detail and have shown that, although the 5 isomer predominates, some 4 isomer is also formed.

We have also examined the nmr spectra of a variety of N-substituted (I and II) (Table I) and unsubstituted (III and IV) (Table II) 2-oxazolidones, and have made structural assignments on the basis of the results obtained. In one case, that involving **1** (Table I), independent confirmation of the nmr assignments was made by synthesis and hydrolysis studies. The rationale and discussion of the nmr assignments will be given presently. The preparation of the N-unsubstituted 2-oxazolidones and the N-phenyl-5-decyl- and -dodecyl-2-oxazolidones (**8** and **9**) has been described elsewhere.[4] The remaining N-substituted 2-oxazolidones based on *p*-tolyl and *n*-butyl isocyanates were prepared by adding the requisite isocyanate to a solution of the epoxide and lithium chloride catalyst in refluxing N,N-dimethylformamide (DMF). After completing the addition of isocyanate, the reaction mixtures were refluxed for 6 hr and then worked up to give the 2-oxazolidones in good yields (70% or better). These general reaction conditions were arrived at by briefly examining the effect of solvent, catalyst, and mode of addition of reactants on the yield of the 2-oxazolidone prepared from *p*-tolyl isocyanate and styrene oxide.

Weiner[5] has shown that aryl isocyanates react with DMF at elevated temperatures to give formamidines (**11**). To suppress this reaction, we added the isocyanate to a refluxing DMF solution containing the epoxide and catalyst. Initially, using this mode of addition and tetramethyl ammonium iodide as the catalyst, N′-tolyl-N,N-dimethylformamidine (**11**, R = *p*-tolyl), was the only reaction product identified; it accounted for 35% of the starting isocyanate. When the reaction was repeated with lithium chloride as the catalyst, formamidine formation was negligible, and the superiority of lithium chloride as a catalyst for 2-oxazolidone formation was confirmed.

$$RN{=}C{=}O + HC(O)N(Me)_2 \longrightarrow \underset{\mathbf{11}}{RN{=}CHN(Me)_2} + CO_2$$

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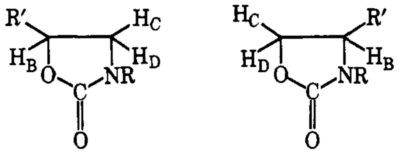
[3] (a) M. E. Dyen and D. Swern, *Chem. Rev.*, **67**, 197 (1967), and references therein; (b) S. Sandler, *J. Polym. Sci.*, **A1-5**, 1481 (1967); (c) R. DiLeone, *Polymer Preprints*, **9**, 1 (1968).

[4] M. E. Dyen and D. Swern, *J. Org. Chem.*, **33**, 379 (1968); *J. Amer. Oil Chem. Soc.*, **45**, 325 (1968).

[5] M. L. Weiner, *J. Org. Chem.*, **25**, 2245 (1960).

TABLE I

NMR DATA AND ASSIGNMENTS FOR N-SUBSTITUTED 2-OXAZOLIDONES



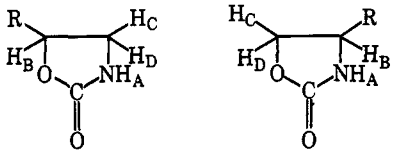
I II

Compound	R	R′	Mp or bp (mm), °C	Isomer	Chemical shifts, ppm (δ) (TMS = 0)			
					H_B	H_C, H_D	H_E	H_F
1	*p*-Tolyl	Phenyl	95–97	I	5.58 (d, d, $J_{BC} = 7.5$, $J_{BD} = 8.5$ cps)	3.87 (d, d, $J_{CB} = 7.5$, $J_{CD} = 8.5$ cps) 4.33 (t, J_{DB}, $J_{DC} = 8.5$ cps)		
2	*p*-Tolyl	Phenyl	107–109	II	5.34 (d, d, $J_{BC} = 6.0$, $J_{BD} = 8.5$ cps)	4.14 (d, d, $J_{CB} = 6.0$, $J_{CD} = 8.5$ cps) 4.72 (t, J_{DB}, $J_{DC} = 8.5$ cps)		
3	$CH_3(CH_2)_2CH_{2E}$	Phenyl	142.5–144.5 (0.13)	I	5.63 (d, d, $J_{BC} = 7.5$, $J_{BD} = 9.0$ cps)	3.49 (d, d, $J_{CB} = 7.5$, $J_{CD} = 9.0$ cps) 4.03 (t, J_{DB}, $J_{DC} = 9.0$ cps)	3.4 (t, $J = 7.0$ cps)	
4	$CH_3(CH_2)_2CH_{2E}$	Phenyl	142.5–144.5 (0.13)	II[a]	5.55 (t, $J = 8.0$ cps)	4.75 (m) 4.1 (m)	3.4 (m)	
5	$CH_3(CH_2)_2CH_{2E}$	$PhOCH_{2F}$	41.5–43.5	I	5.06 (m)[b]	3.64 (d, d, $J_{CB} = 7.0$, $J_{CD} = 9.0$ cps) 3.86 (t, J_{DB}, $J_{DC} = 9.0$ cps)	3.42 (t, $J = 7.5$ cps)	4.31 (d, $J = 5.0$ cps)
6	$CH_3(CH_2)_2CH_{2E}$	$CH_3(CH_2)_2CH_{2F}OCH_{2F}$	132–139 (0.25)	I	4.6 (m)[b]	3.45 (m)[c]	3.45 (m)	3.45 (m)
7	*p*-Tolyl	$PhOCH_{2F}$	153.5–155.5	I	5.12 (m)[b]	4.27 (m)[c]		4.34 (d, $J = 5.0$ cps)
8	*p*-Tolyl	$CH_3(CH_2)_2CH_{2F}OCH_{2F}$	185.5–188 (0.2)	I[d]	4.55 (m)[b]	3.68 (m)[c]		3.68 (m)
9[e]	Phenyl	Decyl	68.5–69	I	4.55 (m)[b]	3.59 (d, d, $J_{CB} = 7.5$, $J_{CD} = 8.5$ cps) 4.04 (t, J_{DB}, $J_{DC} = 8.5$ cps)		
10[e]	Phenyl	Dodecyl	74–75	I	4.62 (m)[b]	3.64 (d, d, $J_{CB} = 7.5$, $J_{CD} = 8.5$ cps) 4.09 (t, J_{DB}, $J_{DC} = 8.5$ cps)		

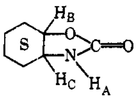
[a] Compound **4** was contaminated with its isomer, **3**. H_B proton appears as a triplet (broad center peak) but should be a double doublet. The multiplicity of H_C, H_D, and H_E is also not readily discernible owing to the presence of **3**. [b] The methine proton H_B appears as a multiplet owing to interaction with H_F, H_C, and H_D. [c] The multiplicity of H_C and H_D could not be determined owing to the overlap of the signal with H_F. [d] Determined in carbon tetrachloride solution. [e] See ref 4.

TABLE II

NMR DATA AND ASSIGNMENTS FOR UNSUBSTITUTED 2-OXAZOLIDONES



III (5 isomer) IV (4 isomer)

Compound	R	Mp, °C	Isomer	Chemical shifts, ppm (δ) (TMS = 0)		
				H_A	H_B	H_C, H_D
13[a]	Decyl	86.5–87.5	III	6.47 (s, broad)	4.57 (m)	3.22 (t, J_{CD}, $J_{CB} = 8.5$ cps) 3.68 (t, J_{DB}, $J_{DC} = 8.5$ cps)
14[a]	Decyl	31.5–32.5	IV		4.48 (m)	3.93 (m)
15[a]	Dodecyl	88–89	III	6.39 (s, broad)	4.62 (m)	3.23 (t, J_{CD}, $J_{CB} = 8.5$ cps) 3.70 (t, J_{DB}, $J_{DC} = 8.5$ cps)
16[a]	Dodecyl	46–47	IV	6.71 (s, broad)	4.45 (m)	3.87 (m)
17[b]	Phenyl	87–88	III[c]	6.83 (s, broad)	5.54 (d, d, $J_{BC} = 8.0$, $J_{BD} = 8.5$ cps)	3.42 (d, d, $J_{CB} = 8.0$, $J_{CD} = 8.5$ cps) 3.87 (t, J_{DB}, $J_{DC} = 8.5$ cps)
18[b]		54–55		6.73 (s, broad)	4.65 (sextet, axial)	3.8 (H_C, q, broad, equatorial)
19[d]	—CN—	94.5–95.5	III[e]	*ca.* 7.0 (broad)	5.65 (d, d, $J_{BC} = 5.0$, $J_{BD} = 8.5$ cps)	3.9 (d, d, $J_{CB} = 5.0$, $J_{CD} = \sim 10.0$ cps) 4.16 (t, J_{DB}, $J_{DC} = \sim 9.0$ cps)
20[d]	$CH_3OC(O)$	66–67	III[f]	6.48 (broad)	5.06 (d, d, $J_{BC} = 6.0$, $J_{BD} = 9.0$ cps)	3.7 (d, d, $J_{CD} = 9.0$, $J_{CB} = 6.0$ cps) 3.93 (t, J_{DB}, $J_{DC} = 9.0$ cps)

[a] See ref 4. [b] See ref 7. [c] Exchange of H by D on nitrogen sharpens the signals of H_A, H_B, and H_C and permits accurate determination of multiplicity and J values. [d] T. A. Foglia and D. Swern, *J. Org. Chem.*, **33**, 766 (1968). [e] Determined in hexadeuterioacetone. [f] Methyl protons, δ 3.85 (s).

A number of other highly polar solvents were used as reaction media (Table III) and all, except triethyl phosphate, gave satisfactory results. With triethyl phosphate, 84% of the styrene oxide was recovered; a considerable amount (46%) of the isocyanate was converted into its corresponding trimer and dimer; and only a small amount of the desired 2-oxazolidone was isolated. Since the use of solvents such as sulfolane, DMSO, and N-methyl-2-pyrrolidone did not appear to offer any advantage over DMF, the latter was used in all subsequent reactions.

TABLE III

PREPARATION OF N-*p*-TOLYL-4- AND -5-PHENYL-2-OXAZOLIDONES (1 AND 2) FROM *p*-TOLYL ISOCYANATE (0.1 MOL) AND STYRENE OXIDE (0.1 MOL) IN DIFFERENT SOLVENTS

Reaction solvent	Catalyst	Reaction products, % yield	
		1	2
DMF[a]	$Me_4\overset{+}{N}\overset{-}{I}$		
DMF[b]	LiCl	76.5	14.6
N-Methyl-2-pyrrolidone	LiCl	73	3.0
DMSO	LiCl	66.5	6.7
Triethyl phosphate[c,d]	LiCl	10.7	0.8
Tetramethylene sulfone (sulfolane)[e]	LiCl	74	

[a] N′-tolyl-N,N-dimethylformamidine (**11**, R = *p*-tolyl) [bp 92–94° (0.15 mm), $n^{20}D$ 1.5844 (accounting for 35% of the isocyanate)] was the only reaction product identified. *Anal.* Calcd for $C_{10}H_{14}N_2$ (**11**, R = *p*-tolyl): C, 74.03; H, 8.70; N, 17.27; mol wt, 162. Found: C, 74.34; H, 8.82; N, 17.07; mol wt, 155 (cryoscopically in benzene). [b] Details in Experimental Section. [c] A mixture of styrene oxide and DMF was recovered from the reaction mixture by distillation. Separation was effected by glpc using a 6 ft × 0.25 in. column containing 5% free fatty acid phase on Chromosorb G (60–80 mesh). The results showed that 84% of the styrene oxide had not reacted. [d] The dimer and trimer of *p*-tolyl isocyanate, mp 174–177° and 269–273°, respectively, were isolated and identified by mixture melting point with authentic samples. They accounted for 1.3 and 14% respectively, of the isocyanate. In addition, *p*-tolylurea (5 mmol) was also isolated. [e] The reaction mixture was poured into cold water to precipitate **1**.

The ability of a highly polar, basic solvent such as DMF to enhance the formation of 2-oxazolidone was further demonstrated when an equimolar mixture of *p*-tolyl isocyanate and styrene oxide at room temperature and in the presence of a catalytic amount of lithium chloride (solvent absent) was heated to 156° for 7 hr; only a 25% yield of crude 2-oxazolidones (**1** and **2**) was realized. The remaining *p*-tolyl isocyanate was accounted for as its trimer. Repetition of the reaction in DMF increased the yield of crude 2-oxazolidones (**1** and **2**) to 54%. The amount of isocyanate trimer present upon work-up of the reaction mixture accounted for only 19% of the starting isocyanate. In contrast, addition of the isocyanate to a refluxing DMF solution of the epoxide and catalyst gave optimum yields of the 2-oxazolidones (**1** and **2**), and trimer formation was not observed. Another procedure that gave equally satisfactory results was the addition of an equimolar mixture of isocyanate and epoxide to a refluxing solution of DMF containing catalyst (LiCl).

The reaction of styrene oxide and *p*-tolyl isocyanate carried out in DMF using lithium chloride as a catalyst gave two reaction products of differing melting points but possessing elemental analyses and molecular weights corresponding to the isomeric 2-oxazolidones **1** and **2** (Table I). The two products were shown to be the 5 and 4 isomers of the 2-oxazolidone (**1-I** and **2-II**). In every case, the low melting product (**1-I**), mp 95–97°, was obtained in much larger amounts than the higher melting material (**2-II**), mp 107–109° (>4:1 by weight).

Confirmation of the low melting product as the 5 isomer (**1**) was obtained by hydrolyzing it with alcoholic potassium hydroxide to 2-*p*-tolylamino-1-phenyl-1-ethanol (**12**), determined by elemental analysis, nmr, and synthesis *via* an alternate route[6] (see Experimental Section).

Reaction of *n*-butyl isocyanate with styrene oxide also gave a mixture of isomeric oxazolidones (**3-I** and **4-II**). The liquid isomers were separated by preparative glpc. The 5 isomer (**3-I**) was again the major component of the isomeric mixture (>4:1 by weight). Reaction of *n*-butyl and *p*-tolyl isocyanates with epoxides of the glycidyl ether type, *e.g.*, *n*-butyl and phenyl glycidyl ethers, also gave predominantly 5-substituted 2-oxazolidones (**5**–**8**).

Tables I and II give the chemical shifts and multiplicity of the pertinent protons in the 5- and 4-substituted 2-oxazolidones prepared. The isomeric pair **1-I** and **2-II** are clearly distinguished and identified by nmr. In the 5 isomer (**1-I**), H_B is an anticipated double doublet farther downfield than the corresponding proton H_B in **2-II** which is on a carbon atom attached to nitrogen, a less electronegative atom. Conversely, H_C and H_D in **1-I** are farther upfield than H_C and H_D in **2-II**. The same first order analysis has been used to identify **3-I** and **4-II**, **13-III** and **14-IV**, and **15-III** and **16-IV**. Thus, in 5-substituted 2-oxazolidones the chemical-shift difference between H_B and $H_{C,D}$ is greater than that in isomeric 4-substituted 2-oxazolidones. These results have been confirmed by unequivocal chemical synthesis in several related cases,[7] and by hydrolysis of **1** and identification of the resulting amino alcohol (**12**) (see above and Experimental Section for synthesis of **12**).

Compounds **9** and **10**, Table I, are assigned the 5-substituted 2-oxazolidone structure on the basis of the similarity of their nmr spectra with those of analogs unsubstituted on nitrogen (**13** and **15**, Table II). Compounds **5**, **6**, and **7** are assigned the 5 structure because they are the predominant products of the epoxide ring-opening reaction, now known to yield the 5 isomer as the major reaction product. The nmr spectra are consistent with the structural assignment.

Compounds **17**, **19**, and **20** were prepared by independent, unequivocal synthesis from styrene, acrylonitrile, and methyl acrylate, respectively, by addition of N,N-dichlorourethan (DCU) followed by washing the adduct with aqueous sodium bisulfite and then pyrolysis.[7]

Compound **18** was prepared from cyclohexene by a similar sequence and also by the method of Hassner

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[6] 2-*p*-Tolylamino-1-phenyl-1-ethanol (**12**) was prepared by a two-step synthesis. 2-Bromoacetophenone was condensed with *p*-toluidine to give 2-*p*-tolylaminoacetophenone, mp 127.5–131°, which was reduced by sodium borohydride in monoglyme to give an 82% yield of **12**. A mixture melting point of the reduction product with **12** obtained from the hydrolysis of **1** showed no depression.

[7] T. A. Foglia and D. Swern, *J. Org. Chem.*, **32**, 75 (1967).

and Heathcock.[8] The downfield signal at 4.65 ppm is assigned to H_B, the proton attached to the ring carbon linked to oxygen, and the upfield signal at 3.8 ppm is assigned to H_C. Since H_B is a sextet and H_C a quartet, the protons must be axial and equatorial, respectively.

From these results and those obtained from a study of the nmr spectra of simple 2-oxazolidones of known structure and stereochemistry,[9] J_{cis} and J_{gem} are approximately 8-10 cps and J_{trans} is 5-7.5 cps. Thus 2-oxazolidones are another heterocyclic ring system in which *cis* coupling is larger than *trans*, a result previously noted.[10]

Experimental Section

General.—Isocyanates and epoxides were freshly distilled prior to use. Solvents used as reaction media were dried and purified by distillation.

Melting points are corrected. Elemental analyses were performed by Galbraith Laboratories, Inc., Knoxville 21, Tenn. Infrared absorption spectra were obtained on a Perkin-Elmer Model 337 spectrophotometer. The pmr spectra were determined on a Varian A-60 spectrometer using TMS as an internal standard and, except where noted, deuteriochloroform as a solvent. An F & M Model 500 chromatograph and an Aerograph Autoprep (Model A-700) were used for glpc. Tables I and II list the 2-oxazolidones studied. Only those previously unreported are described here.

N-*p*-Tolyl-5-phenyl-2-oxazolidone (1).—*p*-Tolyl isocyanate (13.3 g, 0.1 mol) and styrene oxide (12.0 g, 0.1 mol) were heated in several different solvents in the presence of catalysts (Table III). The reactions were carried out by adding the isocyanate and solvent (10 ml) in 30 min to a stirred solution of the epoxide and catalyst in solvent (40 ml) heated at *ca.* 155° under a nitrogen atmosphere. Upon completing the addition of isocyanate, the reaction mixtures were heated at *ca.* 160° for 6 hr.

After *ca.* 16 hr at ambient temperatures, unreacted starting materials and solvent were removed by vacuum distillation with still temperature below 150°. The still residues were treated with hot carbon tetrachloride or hexane and then worked up to yield the isomeric 2-oxazolidones and various other products (Table III).

In the reaction utilizing DMF and lithium chloride as solvent and catalyst (Table III), respectively, the still residue (25.1 g), a cream-colored solid, was dissolved in 50 ml of boiling carbon tetrachloride and filtered. The filtrate on cooling afforded 18.6 g of a cream-colored solid, mp 89-91°. Recrystallization of the crude product from hexane gave **1** as glistening plates (16 g, 63 mmol): mp 95-97°; ir (KBr) 1733 (vs, C=O), 1515 (s), 1480 (s), 1420 (s), 1405 (s), 1315 (s), 1233 (s), 1129 (s), 1118 (s), 1025 (s), 804 (s), 748 (s), and 690 (s) cm^{-1}.

Anal. Calcd for $C_{16}H_{15}NO_2$ (**1**): C, 75.87; H, 5.97; N, 5.53; mol wt, 253. Found: C, 76.00; H, 5.98; N, 5.56; mol wt, 245 (cryoscopically in benzene).

The carbon tetrachloride filtrate was chromatographed over alumina to yield 0.75 g (3.0 mmol) of **1** identified by melting point and mixture melting point. In addition, 3.7 g (14.6 mmol) of the crude 4-substituted 2-oxazolidone **2** was eluted using carbon tetrachloride and chloroform and mixtures thereof. Analytically pure **2**, mp 107-109°, was obtained after three recrystallizations from hexane: ir (KBr) 1740 (vs, C=O), 1515 (s), 1405 (s), 1226 (m), 1130 (w), 1043 (m), 810 (s), and 693 (w) cm^{-1}.

Anal. Calcd for $C_{16}H_{15}NO_2$ (**2**): C, 75.87; H, 5.97; N, 5.53; mol wt, 253. Found: C, 76.27 and 76.09; H, 6.10 and 6.02; N, 5.32 and 5.28; mol wt, 254 (cryoscopically in benzene).

Hydrolysis of N-*p*-Tolyl-5-phenyl-2-oxazolidone (1).—A mixture of **1** (5.06 g, 20 mmol) and alcoholic potassium hydroxide (1.6 g, 29 mmol in 50 ml of 95% alcohol) was refluxed for 6.5 hr. After 12 hr at ambient temperatures, the reaction mixture, consisting of a pale yellow solid and clear, colorless liquid phase, was distilled at reduced pressure (water aspirator, pot temperature <96°). The pale yellow solid residue was extracted twice with 25-ml portions of warm ether. On cooling of the combined ether extracts, a white solid (1.3 g, 5.1 mmol) precipitated and was identified as **1** by melting point and mixture melting point. The ethereal filtrate was extracted four times with 5-ml portions of 3 *N* hydrochloric acid; evaporation of ether yielded additional **1** (0.7 g, 2.8 mmol).

The combined aqueous acidic extracts were made alkaline with aqueous 10% sodium hydroxide. The aqueous alkaline mixture was extracted with ether, and the combined ether extracts were concentrated to dryness. The dried solid residue (2.7 g, 11.9 mmol) melted at 78-82°. Three recrystallizations from carbon tetrachloride gave analytically pure **12**: mp 80.5-81.5°;[6] ir (KBr) 3340 (vs, NH), 3200 (s, OH), 2920 (m), 2845 (m), 1620 (m), 1525 (vs), 1450 (s), 1302 (m), 1245 (m), 1090 (m), 1060 (s), 1043 (m), 898 (m), 815 (vs), 742 (s), and 692 (s) cm^{-1}; nmr ($CDCl_3$) δ 2.24 (s, 3, CH_3), 3.20 (d, 2, J = 3.5 cps, —CH_2—), 3.30 (s, 1, NH), 3.41[11] (s, 1, OH), 4.80 (d d, 1, —CH—), 6.53 (d, 2, H_A), 6.99 (d, 2, H_B $J_{A'B} = J_{AB'}$ = 8.5 cps, *p*-tolyl), and 7.34 (s, 5, phenyl).

Anal. Calcd for $C_{15}H_{17}NO$ (**12**): C, 79.26; H, 7.54; N, 6.16; mol wt, 227. Found: C, 79.43; H, 7.68; N, 6.17; mol wt, 251 (cryoscopically in benzene).

Reaction of Butyl Isocyanate with Styrene Oxide.—*n*-Butyl isocyanate (9.9 g, 0.1 mol) and styrene oxide (12.6 g, 0.105 mol) were heated in DMF with lithium chloride as catalyst, as described for **1**. Removal of solvent by distillation *in vacuo* left 21.2 g of a clear pale yellow oil. The residual oil was distilled twice *in vacuo* to give 15.7 g (72% yield) of a pale yellow liquid, bp 142.5-144.5° (0.13 mm). The liquid distillate analyzed correctly for **3** and **4**: ir (neat) 2965 (s), 2935 (s), 2875 (m), 1755 (vs), 1498 (m), 1460 (m), 1430 (m), 1255 (s, broad), 1138, (m, broad), 1065 (m, broad), 1040 (m, broad), 1027 (m, broad), 998 (m), 756 (s), and 695 (s) cm^{-1}.

Anal. Calcd for $C_{13}H_{17}NO_2$ (**3** and **4**): C, 71.20; H, 7.82; N, 6.39; mol wt, 219. Found: C, 71.41; H, 7.83; N, 6.51; mol wt, 226 (determined in benzene by vapor pressure osmometry).

A portion of the distillate was analyzed by glpc on columns 2.5 ft × 0.25 in. containing 10% Carbowax 20M and terephthalic acid on Chromosorb WAW (60-80 mesh). The column temperature was programmed from 100-240° at the rate of 11°/min. Three peaks were observed.

Integration indicated that the three components were present in the following amounts by weight (given in order of elution): A, 0.7%; B, 18.9%; and C, 80.4%. The initial peak A accounting for 0.7% of the material had a retention time similar to that of butyl isocyanate trimer chromatographed under comparable conditions.[12]

Still another sample of the distillate was fractionated by preparative glpc at 225° using a 10 ft × $^3/_8$ in. column packed with 10% Apiezon L on Chromosorb WAW (60-80 mesh); the two major components (B and C), the isomeric oxazolidones (**4** and **3**), were collected after 13 and 14 min, respectively.

N-Butyl-5-butoxymethylene-2-oxazolidone (6).—*n*-Butyl isocyanate (9.9 g, 0.1 mol) and *n*-butyl glycidyl ether (13.65 g, 0.105 mol) were allowed to react in DMF using lithium chloride catalyst as described. After removal of solvent, the pale amber residual oil (20.7 g) was distilled twice to give 16.3 g of a colorless liquid, bp 132-139° (0.25 mm). The distillate was fractionated by preparative glpc at 225° using a 10 ft × $^3/_8$ in. column packed with 10% Apiezon L on Chromosorb WAS (60-80 mesh). Two components were collected. The initially eluted component (13.2% by weight) was identified as *n*-butyl isocyanate trimer by ir (neat): 2965 (s), 2935 (s), 2870 (m), 1685 (vs), 1465 (vs), 1420 (s), 1375 (m), 1330 (m), and 760 (s) cm^{-1}. The major component (86% by weight, 78% yield) gave ir (neat) 2965 (s), 2940 (m), 2870 (m), 1750 (vs, C=O), 1490 (m), 1450 (m, broad), 1265 (m, broad), 1135 (m, broad), 1060 (m, broad), and 757 (w) cm^{-1}.

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[11] Shifted to δ 3.88 on adding trifluoroacetic acid. The position of other signals was essentially unchanged.

[12] The nmr spectrum of pure *n*-butyl isocyanate trimer in $CDCl_3$ showed multiplets at δ 0.97 (CH_3–, 9 H) and 1.51 (–CH_2CH_2–, 12 H) and a triplet at 3.91 (methylene protons adjacent to ring nitrogens, 6 H).

Anal. Calcd for $C_{12}H_{23}NO_3$ (**6**): C, 62.85; H, 10.11; N, 6.11; mol wt, 229. Found: C, 62.82; H, 10.08; N, 6.22; mol wt, 237 (determined in benzene by vapor phase osmometry).

N-*p*-Tolyl-5-*n*-butoxymethylene-2-oxazolidone (8).—After reaction of *p*-tolyl isocyanate (26.6 g, 0.2 mol) with butyl glycidyl ether (27.3 g, 0.21 mol) and removal of the solvent as described earlier, an amber oil (54 g) remained. The oil was distilled twice to yield 38 g of **8**: bp 185.5–188° (0.2 mm); n^{20}_{D} 1.5255; ir (neat) 2965 (s), 2935 (s), 2870 (m), 1753 (vs), 1523 (s), 1425 (s), 1410 (s), 1320 (s), 1228 (s), 1135 (s), 983 (m), 810 (m), and 750 (w) cm^{-1}.

Anal. Calcd for $C_{15}H_{21}NO_3$ (**8**): C, 68.41; H, 8.04; N, 5.32; mol wt, 263. Found: 68.32; H, 7.99; N, 5.52; mol wt, 264 (determined in benzene by vapor phase osmometry).

Glpc of analytically pure **8** at 250° using an 8 ft × $^1/_8$ in. column packed with 3% SE-52 on Chromosorb W indicated the presence of two components: a minor component A, thought to be the 4 isomer, (*ca.* 4% by weight), and a major component B, **8** (*ca.* 96% by weight, 70% yield).

The reaction was repeated using 0.98 mol of *p*-tolyl isocyanate and 1.03 mol of *n*-butyl glycidyl ether to provide a 78% yield of analytically pure **8**.

N-*p*-Tolyl-5-phenoxymethylene-2-oxazolidone (7).—Reaction of *p*-tolyl isocyanate (26.6 g, 0.2 mol) with phenyl glycidyl ether (31.5 g, 0.21 mol) in the presence of a catalytic amount of lithium chloride (0.08 g) gave 48.2 g (0.17 mol, 85% yield) of crude **7**, mp 153–155°, after removing the solvent (DMF) and subsequent treatment with ice-cold carbon tetrachloride. Recrystallization from boiling 95% ethyl alcohol gave analytically pure **7**: mp 153.5–155.5°; ir (KBr) 1735 (vs), 1595 (m), 1520 (s), 1500 (m), 1445 (m), 1420 (m), 1405 (s), 1340 (s), 1253 (s), 1226 (m), 1146 (s), 1095 (m), 1085 (m), 1043 (m), 988 (m), 803 (m), 753 (s), and 687 (m) cm^{-1}.

Anal. Calcd for $C_{17}H_{17}NO_3$ (**7**): C, 72.06; H· 6.05; N, 4.94; mol wt, 283. Found: C, 71.84; H, 5.88; N, 5.01; mol wt, 280 (determined in benzene by vapor phase osmometry).

N-*n*-Butyl-5-phenoxymethylene-2-oxazolidone (5).—The preceding reaction was repeated using 19.8 g (0.2 mol) of *n*-butyl isocyanate. Removal of solvent (DMF) *in vacuo* left 51.6 g of an oily amber solid. One recrystallization from carbon tetrachloride (35 ml)-hexane (70 ml) provided 41.7 g (168 mmol, 84% yield) of **5**, mp 35–39°. Analytically pure **5**, mp 41.5–43.5°, was obtained after recrystallization from 50% aqueous alcohol and then from cyclohexane: ir (KBr) 2950 (m), 2920 (m), 2860 (w), 1740 (s), 1580 (m), 1480 (m), 1445 (m), 1240 (m), 1055 (m, broad), 750 (w), and 685 (w) cm^{-1}.

Anal. Calcd for $C_{14}H_{19}NO_3$ (**5**): C, 67.45; H, 7.68; N, 5.62; mol wt, 249. Found: C, 67.70; H, 7.68; N, 5.51; mol wt, 243 (determined in benzene by vapor phase osmometry).

Registry No.—**1**, 17539-79-6; **2**, 17539-80-9; **3**, 17539-81-0; **4**, 17539-82-1; **5**, 17539-83-2; **6**, 17539-84-3; **7**, 5255-84-5; **8**, 17539-86-5; **9**, 17539-87-6; **10**, 17539-88-7; **11** (R = *p*-tolyl), 7549-96-4; **12**, 17539-90-1; **13**, 7693-76-7; **14**, 7693-82-5; **15**, 14627-60-2; **16**, 17539-94-5; **17**, 7693-77-8; **18**, 17539-96-7; **19**, 15042-67-8; **20**, 15042-69-0.

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The Thermal Rearrangement of Some Optically Active Pyrroles[1]

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At 575° (+)-N-(1-phenylethyl)pyrrole isomerizes to the corresponding 2- (42 ± 3%) and 3-(1-phenylethyl)-pyrrole (11 ± 1%), each isomer being formed with 77 ± 3% retention of configuration. Under the same conditions (+)-2-(1-phenylethyl)pyrrole is converted into the 3 isomer in 18% yield, the 2 isomer being recovered with 73 ± 3% retention of configuration. Likewise at 600° the *sec*-butyl group in N-(*sec*-butyl)pyrrole migrates to both the 2 and 3 positions with 85 ± 1 and 75 ± 2% retention of configuration, respectively. (+)-N-(1-Phenylethyl)- or N-(*sec*-butyl)-2,5-dimethylpyrrole on pyrolysis give mixtures of 2-alkyl-3,5-dimethylpyrrole and 3-alkyl-2,5-dimethylpyrrole. When the migrating group is 1-phenylethyl, migration produces both isomers with 40% retention of configuration; when the migrating group is *sec*-butyl, the 2 and 3 isomers are produced with 77 and 75% retention of configuration, respectively. The results are consistent with the formation of a 2H-pyrrole intermediate arising through a closely associated transition state.

Alkyl[2] and benzyl[3] substituents in N-substituted pyrroles migrate at high temperatures to the 2 and 3 positions in the pyrrole ring by a homogeneous unimolecular process. The large negative entropies of activation observed imply a cyclic transition state. In addition, the facts that activation energies were about 90% as large as the estimated bond dissociation energies and that all substituents (in substituted benzyl substituents) increased the reaction rate led Pine[3] to suggest that homolytic bond breaking had occurred to the extent of 90% in the transition state.

To investigate further the nature of a migration involving a radicallike species, thermal isomerizations were carried out with pyrroles in which the migrating group was asymmetric. The results of experiments in which (+)-N-(1-phenylethyl)-, (+)-2-(1-phenylethyl)-, (+)-N-(*sec*-butyl)-, and (+)-2-(*sec*-butyl)-pyrrole were pyrolyzed are reported in Table I. The precision of the data is indicated by the average deviations obtained from duplicate and triplicate experiments.

While the extent of the isomerization (and decomposition) was dependent on temperature and heat exchanger (catalysis by Berl saddles) in the N-phenylethylpyrrole pyrolyses, the amount of retention of configuration was not influenced appreciably by these variables. In the N-*sec*-butylpyrrole experiments, catalysis by the Berl saddles was nil. The expected increase in product formation with higher temperatures was observed. Also the 2 isomer was formed with a greater degree of stereospecificity than the 3 isomer in the migration of the *sec*-butyl group.

The estimate of the extent of retention of configuration for the formation of 3 isomer previously reported (10%)[1] was based upon the rotation of an impure sample (3-*sec*-butylpyrrole) and upon the erroneous

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(1) (a) Supported by the U. S. Army Research Office, Durham. (b) A portion of these results were communicated previously: J. M. Patterson and L. T. Burka, *J. Amer. Chem. Soc.*, **88**, 3671 (1966).

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(3) L. A. Pine, *Dissertation Abstr.*, **24**, 522 (1963).