Entry 5, Table I. The crude solid reaction product was subjected to preparative TLC. Extraction of the two most intense bands afforded 4 (NR$_2$ = NHBn),[8b,9] as a solid, mp 99–101 °C (lit.[9c] mp 100–102 °C) and 3 (NR$_2$ = NHBn),[9a] as a solid, mp 73–75 °C: ^{1}H NMR δ 7.42–7.22 (m, 10 H, ArH), 3.82 (dd, 1 H, $J_{a,b}$ = 4.3 Hz, $J_{a,c}$ = 8.7 Hz, H$_a$), 3.77 (d, 1 H, J = 13.0 Hz, PhCH_AH$_B$N), 3.71 (dd, 1 H, $J_{a,b}$ = 4.3 Hz, $J_{b,c}$ = 10.6 Hz, H$_b$), 3.59 (dd, 1 H, J = 13.0 Hz, PhCH$_A$$H_B$N), 3.55 (dd, 1 H, $J_{a,c}$ = 8.7 Hz, $J_{b,c}$ = 10.6 Hz, H$_c$). Anal. Calcd for $C_{15}H_{17}NO$: C, 79.26; H, 7.53; N, 6.15. Found: C, 79.35; H, 7.84; N, 6.25.

Entry 6, Table I. The crude reaction product was subjected to preparative TLC. Extraction of the two most intense bands afforded 4 (NR$_2$ = piperidine),[8b,10,11] as a solid, mp 69–71 °C (lit.[11] mp 71–72.5 °C), and 3 (NR$_2$ = piperidine), as a liquid: ^{1}H NMR δ 7.36–7.14 (m, 5 H, ArH), 3.98 (m, 1 H, H$_a$), 3.64 (m, 2 H, H$_b$ and H$_c$), 2.62–2.24 (m, 4 H, CH_2NCH_2), 1.65–1.30 (m, 8 H, aliphatic H). Anal. Calcd for $C_{13}H_{19}NO$: C, 76.05; H, 9.32; N, 6.82. Found: C, 76.15; H, 9.41; N, 6.91.

Entry 7, Table I. The crude semisolid reaction product was subjected to preparative TLC; extraction of the fastest moving band afforded pure 3 (NR$_2$ = NHBu) as a liquid: ^{1}H NMR δ 7.38–7.26 (m, 5 H, ArH), 3.80–3.49 (unresolved, 3 H, H$_a$, H$_b$, and H$_c$), 2.57–2.44 (m, 2 H, NHCH_2), 1.50–1.25 (m, 4 H, $(CH_2)_2$), 0.87 (t, 3 H, J = 7.1 Hz, CH$_3$). Anal. Calcd for $C_{12}H_{19}NO$: C, 74.57; H, 9.90; N, 7.24. Found: C, 74.37; H, 9.75; N, 7.31. Oxalate: mp 140–141 °C. Anal. Calcd for $C_{14}H_{21}NO_5$: C, 59.77; H, 7.52; N, 4.94. Found: C, 59.85; H, 7.63; N, 4.80.

The slower moving band contained 4 (NR$_2$ = NHBu).[8b,12]

Entry 8, Table I. The crude reaction product was subjected to preparative TLC. Extraction of the two most intense bands afforded 3 and 4 (NR$_2$ = NH-*t*-Bu).

3 (NR$_2$ = NH-*t*-Bu),[13] as a solid: mp 60–61 °C (lit.[13] mp 61–62 °C); ^{1}H NMR δ 7.39–7.21 (m, 5 H, ArH), 3.85 (dd, 1 H, $J_{a,b}$ = 4.9 Hz, $J_{a,c}$ = 9.6 Hz, H$_a$), 3.53 (dd, 1 H, $J_{b,c}$ = 10.4 Hz, $J_{a,b}$ = 4.9 Hz, H$_b$), 3.28 (dd, 1 H, $J_{b,c}$ = 10.4 Hz, $J_{a,c}$ = 9.6 Hz, H$_c$), 1.01 (s, 9 H, *t*-Bu).

4 (NR$_2$ = NH-*t*-Bu),[13] as a solid: mp 85–87 °C (lit.[13] mp 86–87 °C); ^{1}H NMR δ 7.36–7.22 (m, 5 H, ArH), 4.66 (dd, 1 H, $J_{a,b}$ = 3.6 Hz, $J_{a,c}$ = 9.0 Hz, H$_a$), 2.81 (dd, 1 H, $J_{b,c}$ = 11.7 Hz, $J_{a,b}$ = 3.6 Hz, H$_b$), 2.63 (dd, 1 H, $J_{b,c}$ = 11.7 Hz, $J_{a,c}$ = 9.0 Hz, H$_c$), 1.07 (s, 9 H, *t*-Bu).

Entry 9, Table I. 4 (NR$_2$ = N(*i*-Pr)$_2$),[11] as a liquid; ^{1}H NMR δ 7.40–7.23 (m, 5 H, ArH), 4.54 (dd, 1 H, $J_{a,b}$ = 3.9 Hz, $J_{a,c}$ = 10.5 Hz, H$_a$), 3.09 (septet, 2 H, J = 6.6 Hz, 2CHMe$_2$), 2.71 (dd, 1 H, $J_{b,c}$ = 13.4 Hz, $J_{a,b}$ = 3.9 Hz, H$_b$), 2.32 (dd, 1 H, $J_{b,c}$ = 13.4 Hz, $J_{a,c}$ = 10.5 Hz, H$_c$), 1.10 and 0.99 (2d, 6 H each, J = 6.6 Hz, 4 Me). Hydrochloride: mp 130–131 °C. Anal. Calcd for $C_{14}H_{24}ClNO$: C, 65.22; H, 9.38; N, 5.43. Found: C 65.10; H, 9.45; N, 5.65.

Entry 10, Table I. The crude solid reaction product was recrystallized from hexane/ether to give pure 4 (NR$_2$ = N(Cy)$_2$) as a solid: mp 59–60 °C; ^{1}H NMR δ 7.36–7.20 (m, 5 H, ArH), 4.52 (dd, 1 H, $J_{a,b}$ = 3.8 Hz, $J_{a,c}$ = 10.5 Hz, H$_a$), 2.87 (dd, 1 H, $J_{b,c}$ = 13.3 Hz, $J_{a,b}$ = 3.8 Hz, H$_b$), 2.36 (dd, 1 H, $J_{b,c}$ = 13.2 Hz, $J_{a,c}$ = 10.5 Hz, H$_c$). Anal. Calcd for $C_{20}H_{31}NO$: C, 55.77; H, 10.36; N, 4.64. Found: C, 55.85; H, 10.21; N, 4.55.

Reaction of 1 with Dicyclohexylamine in EtOH. A solution of epoxide 1 (0.60 g, 5.0 mmol) in EtOH (3 mL) was treated with dicyclohexylamine (2.0 mL, 10.0 mmol), and the reaction mixture was stirred and heated at 80 °C for 3 days. Evaporation of the solvent afforded a crude liquid residue consisting of an 1:1 mixture of the opening product 4 (NR$_2$ = N(Cy)$_2$) and of the starting unreacted epoxide 1 (^{1}H NMR).

Entry 11, Table I. The crude reaction product was subjected to preparative TLC. Extraction of the two most intense bands afforded 3 and 4 (NR$_2$ = NEt$_2$).

3 (NR$_2$ = NEt$_2$),[9a] as a liquid; ^{1}H NMR δ 7.36–7.17 (m, 5 H, ArH), 4.00–3.85 (m, 2 H, H$_b$ and H$_c$), 3.69–3.60 (m, 1 H, H$_a$), 2.81–2.63 (m, 2 H, CH$_2$N), 2.33–2.16 (m, 2 H, CH$_2$N), 1.08 (unresolved t, 6 H, J = 7.1 Hz, 2 CH$_3$). Anal. Calcd for $C_{12}H_{19}NO$: C, 74.57; H, 9.90; N, 7.24. Found: C, 74.43; H, 9.70; N, 7.42.

4 (NR$_2$ = NEt$_2$),[8b,9a,14] as a liquid: ^{1}H NMR δ 7.40–7.17 (m, 5 H, ArH), 4.63 (dd, 1 H, $J_{a,b}$ = 3.7 Hz, $J_{a,c}$ = 10.5 Hz, H$_a$), 2.78–2.20 (m, 6 H, 3 CH$_2$N), 1.06 (unresolved t, 6 H, J = 7.2 Hz, 2 CH$_3$).

Reaction of Epoxide 5 with Dimethylamine in the Presence of LiClO$_4$. A solution of epoxide 5 (0.177 g, 1 mmol) and anhydrous LiClO$_4$ (0.214 g, 2 mmol) in anhydrous acetonitrile (0.2 mL) was cooled at 0 °C then treated with dimethylamine (0.13 mL, 1.96 mmol). The reaction mixture was stirred at rt for 40 h and then diluted with water and extracted with ether. Evaporation of the washed (water) ether extracts afforded a crude product (0.23 g) consisting of a 46:54 mixture of 6 and 7 (^{1}H NMR and GC).[16]

Acknowledgment. This work was supported by Consiglio Nazionale delle Ricerche (CNR) and Ministero della Università e della Ricerca Scientifica e Tecnologica (MURST), Roma.

Registry No. 1, 96-09-3; 3 (NR$_2$ = *p*-NO$_2$C$_6$H$_4$NH), 135285-97-1; 3 (NR$_2$ = PhNH), 135285-98-2; 3 (NR$_2$ = PhMeN), 135285-99-3; 3 (NR$_2$ = *p*-MeOC$_6$H34NH), 135286-00-9; 3 (NR$_2$ = BnNH), 135357-90-3; 3 (NR$_2$ = 1-piperidinyl), 135286-01-0; 3 (NR$_2$ = BuNH), 135286-02-1; 3 (NR$_2$ = *t*-BuNH), 135286-03-2; 3 (NR$_2$ = Et$_2$N), 135357-91-4; 4 (NR$_2$ = *p*-NO$_2$C$_6$H$_4$NH), 135286-04-3; 4 (NR$_2$ = PhNH), 99342-73-1; 4 (NR$_2$ = PhMeN), 135286-05-4; 4 (NR$_2$ = *p*-MeOC$_6$H$_4$NH), 135286-06-5; 4 (NR$_2$ = BnNH), 107171-75-5; 4 (NR$_2$ = 1-piperidinyl), 40116-77-6; 4 (NR$_2$ = BuNH), 135357-92-5; 4 (NR$_2$ = *t*-BuNH), 14467-51-7; 4 (NR$_2$ = (i-Pr)$_2$N), 135286-07-6; 4 (NR$_2$ = Cy$_2$N), 135286-08-7; 4 (NR$_2$ = Et$_2$N), 135357-93-6; PhNH$_2$, 62-53-3; PhNHMe, 100-61-8; *p*-MeOC$_6$H$_4$NH$_2$, 104-94-9; BnNH$_2$, 100-46-9; BuNH$_2$, 109-73-9; *t*-BuNH$_2$, 75-64-9; (*i*-Pr)$_2$NH, 108-18-9; Cy$_2$NH, 101-83-7; Et$_2$NH, 109-89-7; *p*-NO$_2$C$_6$H$_4$NH$_2$, 100-01-6; LiClO$_4$, 7791-03-9; Zn(Tf)$_2$, 54010-75-2; Mg(ClO$_4$)$_2$, 10034-81-8; CaCl$_2$, 10043-52-4; NClO$_4$, 7647-14-5.

Activation Energy for a 1,2-Hydrogen Shift in (Phenoxymethyl)chlorocarbene

John E. Chateauneuf

Radiation Laboratory, University of Notre Dame, Notre Dame, Indiana 46556

Michael T. H. Liu*

Department of Chemistry, University of Prince Edward Island, Charlottetown, Prince Edward Island, Canada C1A 4P3

Received April 19, 1991

The application of laser flash photolysis (LFP) to the area of carbene chemistry has been extremely popular in recent years.[1] While there are numerous absolute rate constants and Arrhenius parameters for intermolecular carbene reactions, less is known about intramolecular 1,2-hydrogen shifts for carbene reactions. Only recently, the 1,2-hydrogen shifts of benzylchlorocarbene,[2,3] methylchlorocarbene,[4,5] and alkylchlorocarbenes[6] have been determined.

As well, theoretical predictions[7] of activation energies for 1,2-hydrogen shifts in singlet carbenes have been advanced, but there are only few experimental values available for comparison. We now report the Arrhenius parameters for a 1,2-H shift in (phenoxymethyl)chlorocarbene (PMCC).

---

(1) (a) Scaiano, J. C. In *Chemical Kinetics of Small Organic Radicals*; Alfassi, Z. B., Ed.; CRC Press: Boca Raton, FL, 1988; Vol. III, p 73. (b) Liu, M. T. H.; Stevens, I. D. R. In *Chemistry of Diazirines*; Liu, M. T. H., Ed.; CRC Press: Boca Raton, FL, 1987; Vol. 1, p 111. (c) Moss, R. A.; Turro, N. J. In *Kinetic and Spectroscopy of Carbenes and Biradicals*; Platz, M. S., Ed.; Plenum: New York, 1990.

(2) Jackson, J. E.; Soundararajan, N.; White, W.; Liu, M. T. H.; Bonneau, R.; Platz, M. S. *J. Am. Chem. Soc.* 1989, *111*, 6874.

(3) Liu, M. T. H.; Bonneau, R. *J. Am. Chem. Soc.* 1990, *112*, 3915.

(4) LaVilla, J. A.; Goodman, J. L. *J. Am. Chem. Soc.* 1989, *111*, 6877.

(5) Liu, M. T. H.; Bonneau, R. *J. Am. Chem. Soc.* 1989, *111*, 6873.

(6) Bonneau, R.; Liu, M. T. H.; Rayez, M. T. *J. Am. Chem. Soc.* 1989, *111*, 5973.

(7) Evanseck, J. D.; Houk, K. N. *J. Phys. Chem.* 1990, *94*, 5518.

0022-3263/91/1956-5942$02.50/0

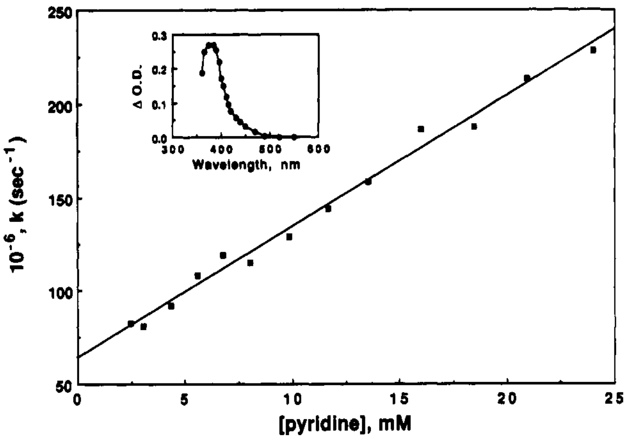


Figure 1. Plot of the observed pseudo-first-order rate constant at 0 °C for growth of ylide absorption at 380 nm vs pyridine concentrations. The slope gives $k_y = 7.01 \times 10^9$ M^{-1} s^{-1}, and the intercept yields $k_i = 6.37 \times 10^7$ s^{-1}. The insert is the point-by-point absorption spectrum for the pyridinium ylide produced by LFP of diazirine in isooctane containing pyridine.

Table I. Rate Constants for 1,2-Hydrogen Shift for (Phenoxymethyl)chlorocarbene (k_i) and for the Formation of Pyridinium Ylide (k_y)

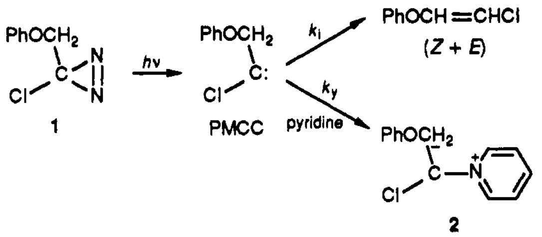
temp, °C	$k_i \times 10^{-6}$, s^{-1}	$k_y \times 10^{-9}$, M^{-1} s^{-1}
23.7	114.70 ± 5.98	9.04 ± 0.69
17.8	80.02 ± 4.13	8.64 ± 0.59
10.0	76.91 ± 6.19	7.70 ± 0.64
0.0	63.74 ± 6.19	7.01 ± 0.22
-5.1	54.91 ± 9.47	7.17 ± 0.71
-10.3	59.81 ± 4.34	6.77 ± 0.28

Results and Discussion

LFP of 3-(phenoxymethyl)-3-chlorodiazirine (1) in isooctane (Ar purged) revealed no transient absorptions due to PMCC. The pyridinium ylide method[8] was used to probe the carbene's absolute kinetics. LFP of 1 in isooctane in the presence of pyridine (2–20 mM) gave ylide 2, λ_{max} = 380 nm (Figure 1 insert). This spectrum is similar to the transient spectra of the ylides derived from tBuCCl,[8] PhCH$_2$CCl,[2] alkylchlorocarbenes,[6] and pyridine. A plot (Figure 1) of the observed pseudo-first-order rate constant for growth of ylide 2 vs pyridine is linear. The slope gives the rate constant for the reaction of PMCC with pyridine, k_y, and the intercept, extrapolated to zero pyridine concentration, gives the sum of the rates of all reactions other than trapping. Since the isolated yield for PhOCH=CHCl is 90% and no azine was detected, it is reasonable to assume that the intercept yields the rate constant for 1,2-H shift, k_i. It is true that k_{obsd} has a slight dependence on diazirine concentration,[9,10] but under the conditions of the LFP experiment, [1] ≤ 0.03 M, the correction due to carbene–diazirine reaction is negligible since the azine is undetected under these conditions.

The values of k_y and k_i measured by this method at six temperatures in the -10 to 24 °C range are given in Table I. Within experimental error, the rate constant for ylide formation is diffusion controlled with $E_a = 1.32 \pm 0.18$ kcal mol^{-1} and log $A = 10.90 \pm 0.14$ M^{-1} s^{-1}. Least-squares analysis for log k_i against $1/T$ yields the rate constant for 1,2-H shift in PMCC, $k_i = 10^{10.1\pm0.48} \exp(-2.83 \pm 0.61/RT)$ s^{-1} where R = 1.987 cal K^{-1} mol^{-1} (see Scheme I).

Scheme I



The lifetime of PhCH$_2$CCl by direct observation[3] of the carbene decay at 24 °C is 18 ns. The lifetimes of CH$_3$CH$_2$CCl, C$_2$H$_5$CH$_2$CCl, and (CH$_3$)$_2$CHCCl have all been *estimated*[6] to be approximately 10 ns (25 °C). If log A = 10, then the activation energies for all these reactions will be ~2.7 kcal mol^{-1}. Data in Table I gave lifetimes of 9 and 17 ns for PhOCH$_2$CCl at 24 and -10 °C, respectively. It is to be noted that the 9-ns lifetime is approaching the limit of nanosecond laser apparatus. Indeed, PMCC exhibits the largest measured rate constant for 1,2-H shift thus far. Substitution of PhO for Ph in PhCH$_2$CCl resulted in a lowering of E_a by only ~1 kcal mol^{-1} and produced no significant effect for 1,2-H migration.

Experimental Section

3-(Phenoxymethyl)-3-chlorodiazirine (1) (λ = 333 nm, IR 1580 cm^{-1}) was prepared by Graham oxidation[11] of the corresponding amidine hydrochloride. Photolysis of 1 at 350 nm in isooctane yielded (*Z*)- and (*E*)-1-chloro-2-phenoxyethylene in 90% isolated yield (*Z*/*E* = 2.0). GC analysis using biphenyl as internal standard confirmed this result and revealed that, in the photolysis of 0.03 M 1, no azine was present.

(*Z*)-1-Chloro-2-phenoxyethylene: ^{1}H NMR δ 5.45 (d, J = 6 Hz, 1 H), 6.78 (d, J = 6 Hz, 1 H), 6.95–7.55 (m, 5 H); MS, *m/e* 154 (100, M), 119 (36, M - Cl).

(*E*)-1-Chloro-2-phenoxyethylene: ^{1}H NMR δ 5.95 (d, J = 12 Hz, 1 H), the second doublet is under the aromatic, 6.95–7.55 (m, 5 H); MS, *m/e* 154 (100, M), 119 (36, M - Cl).

The LFP experiments were carried out in 9 × 6 mm^2 Suprasil quartz cells. Perpendicular 355-nm laser excitation (~8 mJ, pulse width ~ 6 ns) from a Quanta Ray DCR-1 Nd:YAG laser system was used with a 1000-W pulse xenon lamp as the monitoring source.

Acknowledgment. We thank the Office of Basic Energy Sciences of the Department of Energy (Notre Dame Radiation Laboratory Contribution No. NDRL-3357) and the National Sciences and Engineering Research Council of Canada for support.

Registry No. 1, 104678-42-4; 2, 135284-82-1; PMCC, 104678-23-1; pyridine, 110-86-1; (*Z*)-1-chloro-2-phenoxyethylene, 1850-00-6; (*E*)-1-chloro-2-phenoxyethylene, 1850-01-7.

---

(8) Jackson, J. E.; Soundarajan, N.; Platz, M. S.; Liu, M. T. H. *J. Am. Chem. Soc.* **1988**, *110*, 5595.

(9) Moss, R. A.; Ho, G.-J. *J. Am. Chem. Soc.* **1990**, *112*, 5642.

(10) Morgan, S.; Jackson, J. E.; Platz, M. S. *J. Am. Chem. Soc.* **1991**, *113*, 2782.

(11) Graham, W. H. *J. Am. Chem. Soc.* **1965**, *87*, 4396.

Stereoselective Synthesis of 1-*O*-Pivaloyl-β-D-glucopyranuronic Acid

Mikael Bols*,[1]

Leo Pharmaceutical Products, Industriparken 55, DK-2750 Ballerup, Denmark

Received March 26, 1991

β-D-Glucopyranosiduronic acids are common metabolites of many drugs and endogenous substances.[2] It is often