6.66 (m, 2, OCH_2CH_3), 8.10 (q, 1, J = 6 Hz, $CHCH_3$), 8.62 (d, 3, J = 6 Hz, $CHCH_3$), and 9.01 (t, 3, J = 7.0 Hz, OCH_2CH_3).

Anal. Calcd for $C_{12}H_{14}Cl_2O$: C, 58.79; H, 5.76. Found: C, 58.79; H, 5.40.

α-Chlorocrotonophenone (13a).—A mixture of **11a** (44.8 g, 0.183 mol) and pyridine (1 mol) was heated at 110–120° for 2.5 hr. The cooled mixture was poured into cold water, extracted with petroleum ether (bp 30–60°), and the combined petroleum ether extracts were washed with 1.8% hydochloric acid (*ca.* 800 ml) and water. The extract was dried and concentrated to afford an oil (39.0 g) containing 2-chloro-1-ethoxy-1-phenyl-1,3-butadiene (**12a**). The oil was dissolved in a solution of acetone (340 ml), water (17 ml), and hydrochloric acid (17 ml) and heated at the reflux temperature for 2.5 hr. Water was added to the cooled mixture and the solution was extracted with petroleum ether. The combined extracts were washed with water, aqueous bicarbonate solution, and dried ($MgSO_4$). The petroleum ether was removed *in vacuo* and the resulting solid was crystallized from petroleum ether to give 19.4 g (60%) of **13a**: mp 70.5–71°; nmr (CCl_4) τ 2.20–2.85 (m, 5, C_6H_5), 3.36 (q, 1, J = 7 Hz, $C{=}CHCH_3$), 8.02 (d, 3, J = 7 Hz, $CHCH_3$); uv max (95% C_2H_5OH) 250 mμ (ε 12,000); ir 1660 and 1620 cm^{-1} (COC=C).

Anal. Calcd for $C_{10}H_9ClO$: C, 66.49; H, 5.02; Cl, 19.63. Found: C, 66.19; H, 5.34; Cl, 19.68.

The 2,4-dinitrophenylhydrazone of 13a was prepared in a solution of methanol and hydrochloric acid and was recrystallized from chloroform–menthanol and ethanol–ethyl acetate to give the pure product (45%): mp 198–200°; uv max (95% C_2H_5OH) 375 mμ (ε 31,000).

Anal. Calcd for $C_{16}H_{13}ClN_4O_4$: C, 53.27; H, 3.63; N, 15.53; Cl, 9.83; Found: C, 53.33; H, 3.41; N, 15.57; Cl, 9.88.

5-Methyl-3-phenylpyrazole.—Reaction of **13a** with hydrazine in ethanol (95%) was exothermic at room temperature and afforded the pyrazole in 74% yield, mp 127–128° [from petroleum ether C, bp 100–105° (lit.[16] mp 127–128°]; the picrate had mp 159° (lit.[16] mp 159°).

1,1-Diethoxy-1-phenylhexane.—The reaction of caprophenone (75 g, 0.43 mol, from caproic anhydride) with ethyl orthoformate in absolute ethanol (58 ml) was carried out[17] with hydrogen bromide and afforded the ketal in 90–95% yields: bp 79–81.5° (0.60–0.65 mm); $n^{25}D$ 1.4750.

Anal. Calcd for $C_{16}H_{26}O_2$: C, 76.99; H, 10.59. Found: C, 76.75; H, 10.47.

1-Ethoxy-1-phenyl-1-hexene.—A solution of 1,1-diethoxy-1-phenylhexane (30 g, 0.12 mol) and *p*-toluenesulfonic acid (0.08 g) was heated with stirring at the reflux temperature for 1.5 hr allowing ethanol to distil. Distillation of the residue afforded the vinyl ether in >90% yield: bp 75–76° (0.45–0.50 mm); $n^{25}D$ 1.5085; ir (neat) 1645 cm^{-1} (C=C).

Anal. Calcd for $C_{14}H_{20}O$: C, 82.30; H, 9.87. Found: C, 82.57; H, 10.05.

3-*n*-Butyl-2,2-dichloro-1-ethoxy-1-phenylcyclopropane (11b).—The method was essentially that described for the preparation of **11a**; however, the crude product could not be purified by distillation since it was thermally unstable. Chromatography of the crude product on silica gel (100–200 mesh) and elution with petroleum ether–benzene (3:1) afforded the nearly pure product. Short-path distillation of a small sample of this material at a bath temperature of 62° (0.002 mm) gave the analytically pure product, $n^{28.5}D$ 1.5090.

Anal. Calcd for $C_{15}H_{20}Cl_2O$: C, 62.72; H, 7.02. Found: C, 62.63; H, 7.07.

2-Chloro-1-ethoxy-1-phenyl-1,3-heptadiene (12b).—The reaction of **11b** (6.00 g, 0.021 mol) with pyridine was carried out essentially as that described for the reaction with **11a**. The crude product was distilled to give 3.27 g (62.5%) of **12b**: bp 92–94° (0.03–0.04 mm); $n^{25}D$ 1.5566; nmr (CCl_4) τ 2.66 (s, 5, C_6H_5), 3.98 (m, 2, CH=CH), 6.38 (q, 2, J = 7 Hz, OCH_2CH_3), 7.98 (m, 2, $C{=}CCH_2$), 8.86 (m, 8, CH_3CH_2 and OCH_2CH_3); uv max (95% C_2H_5OH) 285 mμ (ε 13,000).

Anal. Calcd for $C_{15}H_{19}ClO$: C, 71.84; H, 7.64. Found: C, 71.57; H, 7.87.

The over-all yield of heptadiene **12b** from 1-ethoxy-1-phenyl-1-hexene, without purification (chromatography) of the intermediate cyclopropane **11b**, was 36%. The diene slowly turned into a glass upon standing.

2-Chloro-1-phenyl-2-hepten-1-one (13b).—The hydrolysis of **12b** was effected as described for **12a**. The crude yellow product was distilled to give **13b** in 82% yield: bp 74–83° (0.005 mm); $n^{24}D$ 1.5424; nmr (CCl_4) τ 2.46 (m, 5, C_6H_5), 3.46 (t, 1 $C{=}CHCH_2$ 7.57 (m, 2, $C{=}CCH_2$), 8.58 (m, 4, CH_2), and 9.07 (m, 3, CH_3); ir (neat 1670 and 1615 cm^{-1} (COC=C); uv max (95% C_2H_5OH) 251 mμ (ε 13,000).

Anal. Calcd for $C_{13}H_{15}ClO$: C, 70.11; H, 6.79. Found: C, 69.91; H, 6.82.

The 2,4-dinitrophenylhydrazone of 13b was prepared from the diene and from the ketone in ethanolic hydrogen chloride. Crystallization of the crude product from ethyl acetate afforded the analytically pure hydrazone: mp 163–165°; uv max (95% C_2H_5OH) 374 mμ (ε 28,900).

Anal. Calcd for $C_{19}H_{19}ClN_4O_4$: C, 56.65; H, 4.75; N, 13,91; Cl, 8.80. Found: C, 56.25; H, 4.75; N, 13.98; Cl, 8.95.

Registry No.—**2**, 19689-75-9; **10a**, 19689-76-0; **11a**, 19689-77-1; **11b**, 19713-64-5; **12b**, 19713-65-6; **13a**, 19689-78-2; **13a** (2,4-dinitrophenylhydrazone), 19689-79-3; **13b**, 19689-82-8; **13b** (2,4-dinitrophenylhydrazone), 19689-83-9; 1,1-diethoxy-1-phenylhexane, 19689-80-6; 1-ethoxy-1-phenyl-1-hexene, 19689-81-7.

(16) K. V. Auwers and H. Stuhlmann, *Ber.*, **59**, 1043 (1926).

(17) Method of C. R. Noller and R. Adams, *J. Amer. Chem. Soc.*, **46**, 1889 (1924).

The Synthesis of 2-Azetidinones[1a]

JACK N. WELLS[1b] AND ROBERT E. LEE

Department of Medicinal Chemistry, School of Pharmacy and Pharmacal Sciences, Purdue University, Lafayette, Indiana

Received November 7, 1968

In continuing our search for small-ring heterocycles having biological activity,[2,3] we have synthesized a few *cis*-3-azido-4-aryl-2-azetidinones (I). This Note describes their synthesis and reaction with lithium aluminum hydride. The formation of 2-azidoacetyl-2,4,5-triphenyl-2-imidazoline under modified conditions is also described.

N-Substituted 2-azetidinones have been synthesized by the cycloaddition of azidoacetyl chloride to Schiff bases[4] to yield both *cis* and *trans* isomers, the ratio being dependent on the order of addition of reactants. There is, however, no general method available for the preparation of N-unsubstituted 2-azetidinones. Lack of N substitution has been reported to be a structural requirement[5] for reduction of 2-azetidinones to azetidines which were our ultimate goal. The synthesis of N-unsubstituted 2-azetidinones (I) was achieved by the cycloaddition of acidoacetyl chloride (II) to the corresponding α,α-dibenzylideniminotoluene (hydrobenzamide) (III) in the presence of triethylamine followed by hydrolysis.

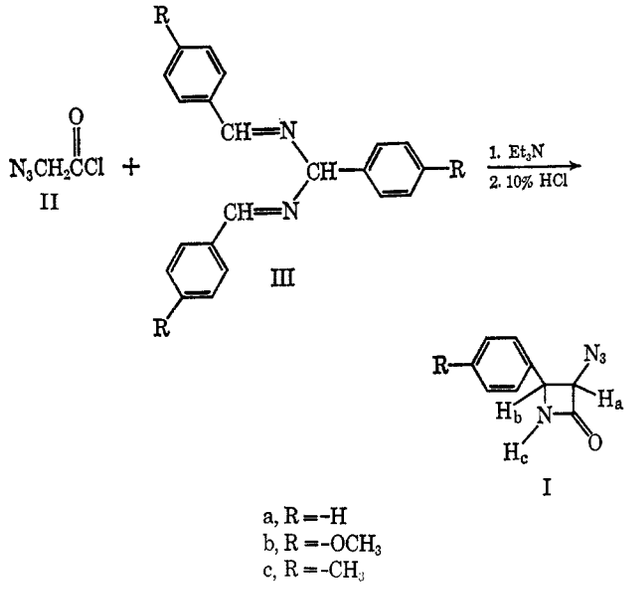
(1) (a) From the Ph.D. Thesis of R. E. Lee. (b) To whom all correspondence should be addressed.

(2) J. N. Wells, A. V. Shirodkar, and A. M. Knevel, *J. Med. Chem.*, **9**, 195 (1966).

(3) J. N. Wells, and F. S. Abbott, *ibid.*, **9**, 489 (1966).

(4) A. K. Bose, B. Anjaneyulu, S. K. Bhattacharya, and M. S. Manhas, *Tetrahedron*, **23**, 4769 (1967).

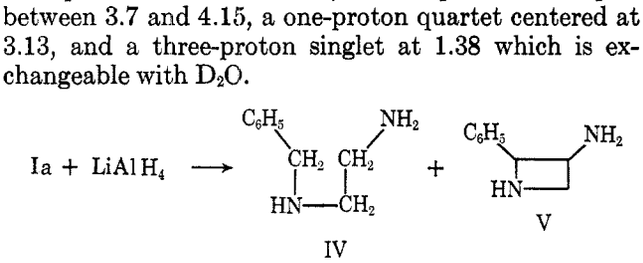
(5) E. Testa, A. Wittgens, G. Maffii, and G. Bianchi in "Research in Organic, Biological and Medicinal Chemistry," Vol. I, U. Gallo and L. Santamaria, Ed., Scuole Grafiche Pavoniane Artigianelli, Milano, Italy, 1964, p 477.



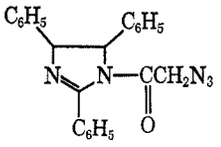
a, R = -H
b, R = -OCH$_3$
c, R = -CH$_3$

The nmr spectrum of Ia exhibited a five-proton aromatic singlet (H_{Ar}) at δ 7.36, a broad, one-proton signal (H_c) at 6.92 which is exchangeable with deuterium oxide, and a two-proton multiplet from 4.7 to 5.1 (H_a, H_b). This latter multiplet resolved (upon exchange with deuterium oxide) into two doublets at δ 4.94 (H_b) and 4.86 (H_a) (J_{ab} = 5 Hz). This value of J_{ab} is consistent with *cis* vicinal coupling in the 2-azetidinones.[6] Compounds Ib and Ic also exhibited characteristic nmr spectrum.

Compound Ia yielded a two-component mixture upon reaction with lithium aluminum hydride. The mixture was composed of N-benzylethylenediamine (IV) which was isolated by fractional crystallization of the hydrochloride salts and a second component which is assigned the 3-amino-2-phenylazetidine structure (V) on the basis of nmr data. The nmr after subtraction of the spectrum of N-benzylethylenediamine showed an aromatic signal between δ 7.0 and 7.5, a one-proton multiplet centered at 4.93, a two-proton multiplet between 3.7 and 4.15, a one-proton quartet centered at 3.13, and a three-proton singlet at 1.38 which is exchangeable with D_2O.



If, instead of adding the acid chloride to a methylene chloride solution of the hydrobenzamide and triethylamine, the triethylamine was added to a mixture of the acid chloride and hydrobenzamide, a compound identified as an imidazoline derivative was isolated. The mass spectrum (mol wt 381) and elemental analysis indicated the molecular formula $C_{23}H_{19}N_5O$. The imidazoline structure would result from intramolecular reaction of the intermediate formed by reaction of the acid chloride with hydrobenzamide. Spectral data are consistent with the structure postulated. The infrared spectrum (KBr) showed strong azide absorption at 2095 cm^{-1} and a strong carbonyl band at 1655 cm^{-1}. The infrared also showed aromatic absorption in the 2000–1660-cm^{-1} region and bands at 758 and 697 cm^{-1} characteristic of a monosubstituted phenyl ring. The nmr spectrum showed broad one-proton singlets at δ 3.33 and 3.42 (methylene), a fifteen-proton aromatic multiplet between δ 7.7 and 7.9, and a two-proton doublet of doublets at δ 6.1 and 7.2 (methine). On the basis of this information we postulate the compound to be 1-azidoacetyl-2.4.5-triphenyl-2-imidazoline (VI). Lactam carbonyl absorption was absent in an ir spectrum of the methylene chloride fraction, indicating that cycloaddition to the azetidinone did not occur in this reaction.



VI

(6) K. D. Barrow and T. M. Spotswood, *Tetrahedron Lett.*, 3325 (1965).

Experimental Section[7]

cis-**3-Azido-4-phenyl-2-azetidinone** (**Ia**).—A solution of 2.4 g (0.02 mol) of II in 75 ml of methylene chloride was added dropwise over 40 min to a stirred solution of 6.0 g (0.02 mol) of III and 2.0 g (0.02 mol) of triethylamine cooled between 0 and 5°. After the addition was complete, the reaction mixture was allowed to warm to room temperature. Acid (100 ml of 10% HCl) was added to the reaction mixture. The resulting precipitate was removed by filtration to yield 3.27 g of a beige solid, mp 152–157°. Recrystallization from methanol and water yielded 1.31 g (40%) of pure white Ia: mp 90–91.5°; ir (KBr) 1742 (lactam C–O) and 2110 cm^{-1} (N_3).

Anal. Calcd for $C_9H_8N_4O$: C, 57.44; H, 4.29. Found: C, 57.67; H, 4.27.

cis-**3-Azido-4-(*p*-methoxyphenyl)-2-azetidinone** (**Ib**) was prepared from IIIb according to the procedure described for the preparation of Ia. The reaction gave a 44% yield of pure Ib: mp 131–132.5° (MeOH and HOH); nmr ($CDCl_3$) δ 7.08 (d of d, 5, Ar, –NH), 4.85 (m, 2, –CHCH–), and 3.79 (s, 3, –OCH_3); ir (KBr) 1750 (C=O) and 2125 cm^{-1} (N_3).

Anal. Calcd for $C_{10}H_{10}N_4O_2$: C, 55.04: H, 4.62. Found: C, 54.86; H, 4.60.

cis-**3-Azido-4-(*p*-methylphenyl)-2-azetidinone** (**Ic**) was prepared from IIIc according to the procedure described for the preparation of Ia. The reaction gave 36% yield of pure Ic: 102–103.5°; ir (KBr) 1750 (C=O) and 2090 cm^{-1} (N_3); nmr ($CDCl_3$) δ 7.16 (s, 4, Ar), 6.75 (broad, 1, –NH), 4.85 (m, 2, –CHCH–), and 2.32 (s, 3, Ar–CH_3).

Anal. Calcd for $C_{10}H_{10}N_4O$: C, 59.40; H, 4.98. Found: C, 59.27; H, 5.13.

Lithium Aluminum Hydride Reduction of 2-Azido-4-phenyl-2-azetidinone (**Ia**).—3-Azido-4-phenyl-2-acetidinone (0.76 g, 0.004 mol) was added in small portions through Gooche tubing to a suspension of lithium aluminum hydride (0.92 g, 0.024 mol) in 100 ml of anhydrous ether cooled to 0°. After the addition the reaction mixture was refluxed for 6 hr, then cooled to 0°. Water (1.75 ml, 0.096 mol) was added dropwise from a 2-ml syringe. The mixture was stirred for 30 min at room temperature and then the solid was removed by vacuum filtration. The filtrate was treated with anhydrous HCl and a white precipitate formed which was removed by filtration: mp 140–230°. This solid was recrystallized from absolute ethanol several times to yield a solid that melted at 250–252°; nmr of free base ($CDCl_3$) δ 7.30 (s, 5, Ar), 3.81 (s, 2, $C_6H_5CH_2$–), 2.76 (broad s, 4, NCH_2CH_2N), and 1.5 (s, 3, –NH–, –NH_2) exchangeable with D_2O. This compound

(7) Melting points were determined on a Büchi apparatus with open capillary tubes and are uncorrected. The ultraviolet spectrum was obtained using a Bausch and Lomb Model 505 recording spectrophotometer. Nmr spectra were obtained with a Varian Associates A-60A spectrophotometer in $CDCl_3$ with tetramethylsilane as an internal standard. Combustion analyses were conducted by Galbraith Laboratories, Inc., Knoxville, Tenn. 37921. Infrared spectra were determined on a Perkin-Elmer Model 21 spectrophotometer and the mass spectrum with a Hitachi RMU-6A at 75 eV.

was identified as N-benzylethylenediamine (lit.[8] mp of hydrochloride, 253°).

If instead of treating the ether filtrate with anhydrous HCl the ether was evaporated, an oil resulted which was shown to be composed of two compounds by tlc. When the signals of the N-benzylethylenediamine were subtracted from the nmr of the mixture, it was determined that the 3-amino-2-phenylazetidine was obtained and that the mixture was composed of 42% azetidine and 58% ethylenediamine. All efforts to separate these compounds failed.

Attempted Synthesis of *trans*-3-Azido-4-phenyl-2-azetidinone.—Hydrobenzamide (11 g, 0.037 mol) and azidoacetyl chloride (4.4 g, 0.037 mol) were dissolved in 200 ml of methylene chloride and treated dropwise at 0° with triethylamine (3.74 g, 0.037 mol) dissolved in 100 ml of methylene chloride. After the addition was complete the reaction mixture was allowed to warm to room temperature. The reaction mixture was then stirred with 100 ml of 10% HCl. The organic layer was separated from the aqueous phase and evaporated to dryness under reduced pressure to yield a dark oil. A small amount of ether was added to this oil and 1.87 g of solid was collected by filtration. Recrystallization from absolute ethanol yielded a solid, mp 218–219°. The structure of this compound was postulated as 1-azidoacetyl-2,4,5-triphenyl-2-imidazoline (VI).

Anal. Calcd for $C_{23}H_{19}N_5O$: C, 72.42; H, 5.02; N, 18.10. Found: C, 72.69: H, 4.99; N, 18.34.

Registry No.—Ia, 19684-83-4; Ib, 19684-84-5; Ic, 19684-85-6; VI, 19689-63-5.

Acknowledgment.—The authors are indebted to Drs. J. M. Cassady and P. E. Manni for helpful discussions during the course of this work.

(8) J. C. Dickerman and A. J. Besozzi, *J. Org. Chem.*, **19**, 1855 (1954).

Free Carbonium Ions in the Anodic Oxidations of Alkanecarboxylates, Alkaneboronates, and Alkyl Halides[1]

JAMES T. KEATING AND PHILIP S. SKELL

Department of Chemistry, The Pennsylvania State University, University Park, Pennsylvania 16802

Received August 26, 1968

A free propyl cation[2] is the postulated intermediate leading to cyclopropane in the deoxideation of *n*-propyl alcohol and in the deamination of *n*-propylamine.[3] Formation of cyclopropane in good amount is a criterion for the free *n*-propyl cation.

Anodic oxidation of *n*-butyrate (the Hofer–Moest or abnormal Kolbe reaction) produces cyclopropane.[4,5] The reaction is best explained with a free *n*-propyl cation (eq 1). The detailed description of the steps leading to the propyl cation is not certain.

$$n\text{-PrCO}_2^- \xrightarrow{-2e^-} CO_2 + n\text{-Pr}^+ \longrightarrow \text{cyclopropane} + H^+ \quad (1)$$

(1) Taken from the Ph.D. Thesis of J. T. K., The Pennsylvania State University, Sept 1968. For a review of anodic oxidation, see A. K. Vijh and B. E. Conway, *Chem. Rev.*, **67**, 623 (1967); J. T. Keating and P. S. Skell in "Carbonium Ions," G. A. Olah and P. von R. Schleyer, Ed., Interscience Publishers, New York, N. Y., in press.

(2) A free carbonium ion is one generated in a state not relaxed with respect to neighbor nucleophiles.

(3) P. S. Skell and I. Starer, *J. Amer. Chem. Soc.*, **81**, 4117 (1959); **82**, 2971 (1960). M. S. Silver, *ibid.*, **82**, 2971 (1960).

(4) R. J. Maxwell, M. S. Thesis (Skell), The Pennsylvania State University, 1963.

(5) W. J. Koehl, *J. Amer. Chem. Soc.*, **86**, 4686 (1964).

Alkaneboronic acids are the Lewis acid counterparts of the Brønsted carboxylic acids and would be expected to undergo anodic oxidation also. We have studied the anodic oxidation of propaneboronate. Cyclopropane is among the products, implicating a free propyl cation. Table I gives the results and compares them with our work on butyrate.

TABLE I

ANODIC OXIDATION OF SODIUM BUTYRATE AND POTASSIUM PROPANEBORONATE AT BRIGHT PLATINUM

	%	
Products	Sodium butyrate[a]	Potassium propaneboronate[b]
Propylene	76	71
Cyclopropane	17	18
Propane	1	1
Hexane	1	2
Ethane	1	2
Ethylene	5	7

[a] The aqueous solution was 1 *M* each in sodium butyrate and sodium hydroxide. [b] The aqueous solution was saturated with potassium propaneboronate (<0.8 *M*) and the pH was adjusted to 11.

The similarity of the products and the product distributions found for propaneboronate and butyrate obtains also in the anodic oxidations of butaneboronate and pentanoate (Table II). This further supports the

TABLE II

ANODIC OXIDATION OF POTASSIUM PENTANOATE AND SODIUM BUTANEBORONATE AT BRIGHT PLATINUM

	%	
Products	Potassium pentanoate[a]	Sodium butaneboronate[b]
1-Butene	56	60
cis-2-Butene	17	20
trans-2-Butene	27	20
n-Butane	Trace	Trace

[a] The aqueous solution was 1 *M* each in potassium pentanoate and potassium hydroxide. [b] This is from the work of A. A. Humffray and L. F. G. Williams, *Chem. Commun.*, 616 (1965). They say only that excess base was used in making up the solution. The results were interpreted in terms of a radical (Kolbe) mechanism.

postulate of a free cation in the alkaneboronate anodic oxidation, linking this reaction with deoxideation, deamination, and the Hofer–Moest reaction.[4,5] Tables I and II also suggest that the formal leaving groups, carbon dioxide and boric acid, have little effect on the behavior of the carbonium ion formed in anodic oxidation at platinum. A possible reason for this is that the radical is the carbonium ion precursor in both cases (eq 2).

$$\begin{aligned} &RCO_2^- \xrightarrow{-e^-} RCO_2\cdot \longrightarrow R\cdot + CO_2 \\ &\qquad\qquad\qquad\qquad\quad \downarrow -e^- \\ &\qquad\qquad\qquad\qquad\quad R^+ \longrightarrow \text{products} \\ &RB(OH)_3^- \longrightarrow RB(OH)_3\cdot \longrightarrow R\cdot + B(OH)_3 \end{aligned} \quad (2)$$

In contrast to the results found at platinum, at a graphite anode the products and product distributions of the butyrate and propaneboronate anodic oxidations are not identical (Table III). It must be that at graphite the carbonium ion precursor is different in each