crop of benzpinacol (750 mg). Acetone–petroleum ether (1:4) eluted an oil (1.5 g) believed to be a dimeric product of the unsaturated ester. Ethyl 2-ethoxycarbonyl-3-carbamoylhydrocinnamate (1.43 g, 40% yield), mp 119–121° (acetone–petroleum ether) was eluted with acetone–petroleum ether (1:3) and isolated from the oily fraction by crystallization, ν_{max}^{KBr} 1680 and 1718 cm^{-1}; nmr ($CDCl_3$), two triplets centered at τ 9.1 (3 H, J = 7 cps; CH_2CH_3) and 8.7 (3 H, J = 7 cps, CH_2CH_3), two quartets centered at 6.1 (2 H, J = 7 cps, CH_2CH_3) and 5.8 (2 H, J = 7 cps, CH_2CH_3) on which a singlet is superimposed at 5.75 (2 H), a broad band at 4.0 (2 H, NH_2), and a band at 2.6 (5 H, aromatic protons).

Anal. Calcd for $C_{15}H_{19}NO_5$; C, 61.42; H, 6.53; N, 4.78. Found: C, 61.70; H, 6.51, N, 4.72.

Alkaline hydrolysis of the amido diester led to the tricarboxylic acid which was decarboxylated at 190–200° to give phenyl succinic acid, mp and mmp 165–167°, lit.[25] mp 164–166°.

Acetone–petroleum ether (3:7) finally eluted benzilic acid amide (300 mg), mp 150–152°.

H. Ethyl Maleate and Formamide without Benzophenone.—A mixture of ethyl maleate (8 g) and formamide (110 g) was irradiated for 45 hr. (A quartz filter was used for this experiment.) The usual work-up led to 1.3 g (25%) of diethyl carbamoylsuccinate.

Similar results were obtained when ethyl fumarate was employed.

Acknowledgment.—We are indebted to the Feinberg Graduate School at the Weizmann Institute of Science for maintenance of a fellowship to one of us (J. R.).

(25) A. Lapworth and W. Baker, "Organic Syntheses," Coll. Vol. 1, John Wiley and Sons, Inc., New York, N. Y., 1941, p 451.

The Structures and Spectral Properties of Enamines and Iminium Salts of 1-Azabicycloalkanes

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The infrared and nuclear magnetic resonance spectra of several enamines of 1-azabicycloalkanes and their corresponding iminium salts have been determined and interpreted to afford the following conclusions. (i) The position of the double bond in the enamines appears to be controlled by the same factors which are responsible for the relative stability of simple olefins and not those which are important for many enamines of cyclic ketones. (ii) The nmr spectra of the iminium salts contain characteristic, well-resolved peaks which are quite useful for structure determinations. (iii) The diagnostic generalization that converting an enamine to its salt results in a shift of the 6-μ infrared peak to higher frequencies is subject to exceptions.

The structures of enamines of unsymmetrical ketones and iminium salts are of theoretical and synthetic significance. For example, the preferential formation, in certain cases, of the less substituted enamines of cyclic ketones[2-7] has been rationalized by stereochemical arguments[2,8-11] which have proven to be of value in the conformational analysis of other systems.[12] From the synthetic point of view, the structures of the products obtained by electrophilic substitutions on the β carbon atoms of enamines have been assumed,[2,13,14] by analogy with the isoelectronic enolate ion,[15] to reflect the location of the double bond in the starting enamine.

One class of enamines whose structures have not been thoroughly investigated is that prepared[16] from the readily available[17] 1-azabicycloalkanes. In conjunction with another study[14] the infrared and nuclear magnetic resonance spectra of several such enamines and their iminium salts have been obtained and structural correlations have been established.

Results and Discussion

The enamines in Table I were prepared by the mercuric acetate oxidation[16,17] of the corresponding 1-azabicycloalkanes, the synthesis of all but two of which were reported previously from this laboratory.[17] Although one of these two, 1-ethylindolizidine (**4a**), was prepared in high yield by the Raney nickel catalyzed cyclization method[17] (**1** → **2** → **3** → **4**), the phenyl-substituted piperidyl alcohol **3b** (Scheme I) was converted to a diastereoisomeric mixture of 1-phenylindolizidenes (**4b**) to the extent of only 9% under identical conditions. The failure of the piperidyl alcohol **3b** to undergo normal cyclization apparently was due to poisoning of the catalyst since the Raney nickel recovered from the reaction mixture was no longer active in the cyclization of the piperidylalcohol **3** (R = H) to indolizidine[17] (**4**, R = H). 1-Phenylindolizidine (**4b**) was finally prepared in satisfactory yield by basification of the bromide–hydrobromide of the piperidyl alcohol **3b**.

The nmr spectra of these enamines (Table I) contain four general areas of proton absorption. The vinyl protons appear as broad singlets, or in one case (**9**) a poorly resolved triplet, at τ = 5.65–5.98 ppm. The abnormally high chemical shifts of these peaks[18] has

(1) (a) To whom inquiries should be sent at Texas Christian University; (b) National Science Foundation Summer Teaching Fellow, 1963; National Institute of Health Predoctoral Fellow in Chemistry, 1963–1965.

(2) G. Stork, A. Brizzolara, H. Landesman, J. Szmuszkovikz, and R. Terrell, *J. Am. Chem. Soc.*, **85**, 207 (1963).

(3) M. E. Kuehne, *ibid.*, **81**, 5400 (1959).

(4) W. D. Gurowitz and M. A. Joseph, *Tetrahedron Letters*, 4433 (1965).

(5) S. K. Malhotra and F. Johnson, *ibid.*, 4027 (1965).

(6) G. Stork, XVIth National Organic Symposium Abstracts, Seattle, Wash., June 1959, p 44.

(7) G. Opitz and H. Mildenberger, *Ann.*, **650**, 115 (1961).

(8) W. R. N. Williamson, *Tetrahedron*, **3**, 314 (1958).

(9) H. J. Schaeffer and V. K. Jain, *J. Org. Chem.*, **29**, 2595 (1964).

(10) F. Johnson and A. Whitehead, *Tetrahedron Letters*, 3825 (1964).

(11) S. Danishefsky and M. Feldman, *ibid.*, 1131 (1965).

(12) F. Johnson and S. K. Malhotra, *J. Am. Chem. Soc.*, **87**, 5492 (1965).

(13) G. Bianchetti, D. Pocar, P. D. Croce, and A. Vigevani, *Chem. Ber.*, **98**, 2715 (1965).

(14) M. G. Reinecke and L. R. Kray, *J. Org. Chem.*, **30**, 3671 (1965).

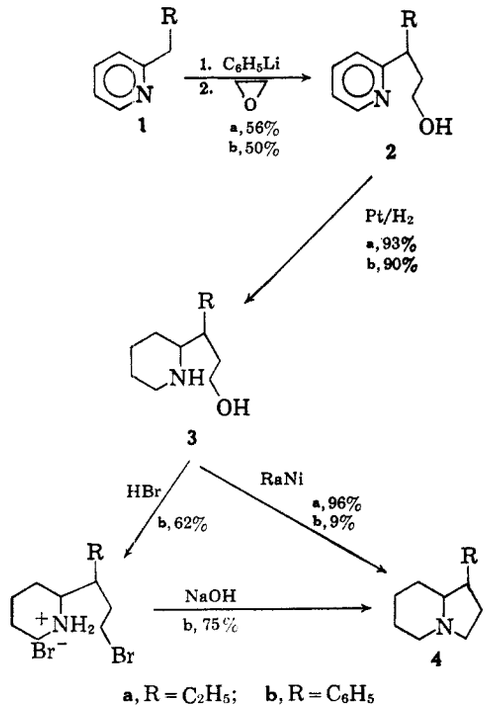
(15) H. House, "Modern Synthetic Reactions," W. A. Benjamin, Inc., New York, N. Y., 1965, p 133.

(16) N. J. Leonard, A. S. Hay, R. W. Fulmer, and V. W. Gash, *J. Am. Chem. Soc.*, **77**, 439 (1955).

(17) M. G. Reinecke and L. R. Kray, *J. Org. Chem.*, **29**, 1736 (1964).

(18) L. M. Jackman, "Applications of Nuclear Magnetic Resonance Spectroscopy in Organic Chemistry," Pergamon Press Inc., New York, N. Y., 1959, p 61.

SCHEME I



a, R = C_2H_5; b, R = C_6H_5

been observed previously[2,4,11,13,19,20] and explained[4] by contributing resonance structures of the type below.

The methylene hydrogens adjacent to the nitrogen atom lead to broad triplets or multiplets centered at τ = 7.1–7.3 ppm,[19–21] while the C-methyl protons give peaks at τ = 8.4–8.5 and 8.8–9.0 ppm, typical for allylic[22] and homoallylic[23] C-methyl groups, respectively. The remaining protons of the enamines in Table I produce very broad multiplets at τ = 7.5–8.5 ppm.

These nmr data permit the assignment of structures to those enamines (**5**, **7**, **8**, **11–13**) which might exist as mixtures of isomers. The relative area of either the vinyl or the C-methyl proton peaks of the enamine of 1-methylindolizidine (**8**) is two-thirds of that predicted for the Δ^8 isomer (**8a**). This observation suggests that the enamine **8** is a 2:1 mixture of the Δ^8 (**8a**) and the $\Delta^{1(9)}$ (**8b**) isomers, respectively. The presence of the latter isomer is substantiated by the allylic methyl absorption at τ 8.43. A similar analysis indicates that the enamine **11** is a 2:1 mixture of the Δ^9 (**11a**) and the $\Delta^{1(10)}$ (**11b**) isomers, respectively, in qualitative agreement with the conclusions of Leonard, *et al.*[24]

The enamine of indolizidine itself (**5**) has been reported to be a mixture of the $\Delta^{1(9)}$ and the Δ^8 isomers on the basis of infrared evidence.[25] An examination of the infrared spectra of a series of 1-azabicycloalkanes (*vide infra*) indicates that this criteria may be equivocal, however. Furthermore, the nmr spectrum of indolizidine enamine suggests that the Δ^8 isomer **5** is by far the major constituent since only one vinyl proton peak is observed and that at a chemical shift similar to that of the unambiguous Δ^8-dehydroindolizidine (**9**) rather than the alternative $\Delta^{1(9)}$-isomer (**10**). In addition the position and shape of the CH_2—N absorption of **5** is more like that of **9** than of **10**.

If the formation of the enamines in Table I by basification of the corresponding iminium salts is assumed to result in equilibrium mixtures,[19] then the composition of these mixtures is a measure of the relative sta-

TABLE I

NMR SPECTRA OF ENAMINES OF 1-AZABICYCLOALKANES[a]

Compd	H—C=C	CH_2—N	C—CH_3
5	5.92	7.14 t (J = 7)	
6	5.80	7.25[b]	
7		7.23 t (J = 7)	8.50
8a	5.97[c]	7.17 t (J = 7)	8.95 d (J = 7)[c]
8b			8.43
9	5.98 t (J = 4)	7.13 t (J = 7)	8.95
10	5.56	7.3[b]	8.85
11a		7.3[b]	8.44
11b	5.63[c]		8.95 d (J = 7)[c]
12	5.89[e]	7.15[b]	9.1[b,f]
13		7.2[b]	2.95[b,h]

[a] Unless otherwise noted all spectra were taken in CCl_4 solution with tetramethylsilane (TMS) as an internal standard on vpc collected samples. Chemical shifts are expressed in τ, J in cycles per second, and doublets and triplets as d and t, respectively. [b] Center of broad multiplet. [c] The relative area of these peaks suggests an approximately 2:1 mixture of the **a** to the **b** isomer. [d] In tetrachloroethylene, which has no appreciable effect on the chemical shift values. [e] The relative area of this peak (1:16) indicates that very little if any $\Delta^{1(9)}$ isomer is present. [f] Very distorted triplet with an apparent J of 7 cps. [g] Purified by vacuum distillation. [h] Phenyl protons.

(19) N. J. Leonard, C. K. Steinhardt, and C. Lee, *J. Org. Chem.*, **27**, 4027 (1962).
(20) H. Weitkamp and F. Korte, *Chem. Ber.*, **95**, 2896 (1962).
(21) Reference 18, p 56.
(22) Reference 18, p 58.
(23) Reference 18, p 53.
(24) N. J. Leonard, R. W. Fulmer, and A. S. Hay, *J. Am. Chem. Soc.*, **78**, 3457 (1956).
(25) N. J. Leonard, W. J. Middleton, P. D. Thomas, and D. Choudhury, *J. Org. Chem.*, **21**, 344 (1956).

bility of the two possible isomers, and correlations between structure and stability of enamines of 1-azabicycloalkanes may be obtained. Several generalizations emerge from such an analysis. (i) The double bond of indolizidine enamines prefers to be *endo* to the six- and *exo* to the five-membered ring. This is illustrated by the exclusive (**5**, **7**, **12**) or preponderant (**8**) formation of Δ^8 over $\Delta^{1(9)}$-dehydroindolizidines. (ii) The stabilizing effect of substituents on a double bond is exemplified by the predominance of the $\Delta^{1(10)}$ over the Δ^9 isomer of the enamine of 1-methylquinolizidine (**11**) and by the presence of at least some of the $\Delta^{1(9)}$-dehydroindolizine in the case of **8b** but not in the case of **5** and **7**. The nature of the substituent must also be important, however, since no $\Delta^{1(9)}$ isomer is observed for **12**, the ethyl homolog of **8**. (iii) Isomers whose double bonds are conjugated are favored as shown by the fact that only the $\Delta^{1(9)}$ isomer of the enamine of 1-phenylindolizidine (**13**) appears to be formed.

It is apparent from the foregoing analysis that the structural features which appear to determine the position of the double bond in enamines of 1-azabicycloalkanes and simple olefins are the same.[26,27] This is not generally true of the enamines of cyclic ketones[2-7] but has been observed with some other types.[11,19]

The iminium salts obtained by acidification of the enamines of 1-azabicycloalkanes have very characteristic nmr spectra as illustrated by that of $\Delta^{4(9)}$-indolizidinium perchlorate (**14**) (Figure 1). Assignment of the peaks at τ = 5.85 and 6.30 ppm to the $-CH_2-\overset{+}{N}=$ groups and those at τ = 6.80 and 7.21 ppm to the $-CH_2-C=$ groups was based on their relative areas (two protons each) and on the previous observations[28,29] that the chemical shift of the former type of proton is at lower field than that of the latter. Within each of these pairs, the downfield peak was assigned to the five-membered ring protons, since similar protons occur at lower fields in Δ^1-pyrrolidinium salts than in Δ^1-piperidinium salts.[29] The same conclusion is suggested by the presence of fine structure in these peaks, a situation similar to that observed for the allylic protons of cyclopentene and methylenecyclopentane[30] but not cyclohexene and methylenecyclohexane.[31] This differentiation probably originates in the ability of the six- but not the five-membered ring to average out vicinal coupling constants by rapid conformational changes. The broad, six-proton multiplet in Figure 1 is assigned to the nonallylic hydrogens of which those in the five-membered ring are responsible for the more structured peaks at lower field for the reasons just discussed.

The above assignments were substantiated by the nmr spectra of the iminium salts in Table II, since in each case the expected peak diminished in intensity or disappeared entirely as substituents were introduced

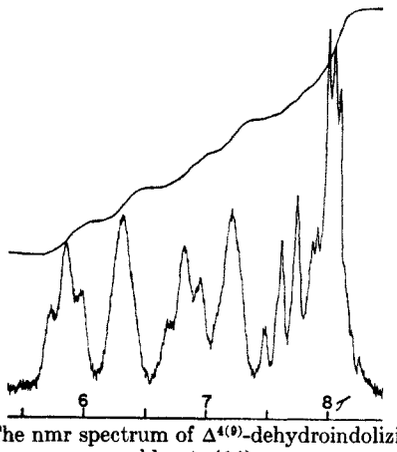
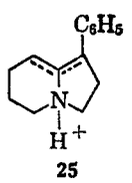


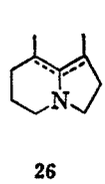
Figure 1.—The nmr spectrum of $\Delta^{4(9)}$-dehydroindolizidinium perchlorate (**14**).

or the ring size was altered. Because the chemical shift of a particular type of proton appears to be restricted to a very narrow range, the nmr spectra of these iminium salts may prove useful for structural determination. For example, the fact that the methylation product of indolizidine enamine (**5**) was actually a mixture of the mono- and dimethyl salts, **16** and **19**, was first suspected[14] from its nmr spectrum. Similarly, the iminium salt obtained by mercuric acetate oxidation of 1-methylquinolizidine[17,24] is not pure **21** but apparently a 3–4:1 eutectic mixture of **21** to **22**,[14] determined by integration of the C-methyl peaks in its nmr spectrum as well as by elemental analysis. The properties of pure **21** are described in the Experimental Section.

Two additional aspects of the spectra in Table II are noteworthy. First of all, the *gem*-methyl groups of the salts **18** and **19**, as well as of their respective free bases **9** and **10** (Table I), are magnetically equivalent in contrast to those of the corresponding saturated amines and their salts.[32] This distinction is not surprising and can be rationalized easily on stereochemical grounds. A second point of interest is that the nmr spectrum of the salt obtained from the 1-phenylindolizidine enamine, **13**, is consistent only with the iminium compound **24** and not the N-protonated isomers **25**.



25



26

C protonation of enamines with concomitant loss of conjugation between a double bond and a benzene ring is in accord with many[33-35] but not all[36] previous observations.

Characterization of enamines by the shift of their 6-μ infrared peak to higher frequencies on formation of

(26) E. S. Gould, "Mechanism and Structure in Organic Chemistry," Henry Holt and Co., Inc., New York, N. Y., 1959, Chapters 1 and 2.

(27) H. C. Brown, J. H. Brewster, and H. Shechter, *J. Am. Chem. Soc.*, **76**, 467 (1954).

(28) N. J. Leonard and K. Jann, *ibid.*, **84**, 4806 (1962).

(29) O. Červinka, A. R. Katritzky, and F. J. Swinbourne, *Collection Czech. Chem. Commun.*, **30**, 1736 (1965).

(30) N. S. Bhacca, L. F. Johnson, and J. N. Shoolery, "NMR Spectra Catalog," Vol. 1, Varian Associates, Palo Alto, Calif., 1962, Spectrum No. 132.

(31) Reference 30, Spectrum No. 180.

(32) 1,1-Dimethylindolizidine τ = 9.04 and 9.12 ppm; perchlorate τ = 8.88 and 8.77 ppm; 8,8-dimethylindolizidine τ = 9.08 and 9.14 ppm; perchlorate τ = 8.93 and 8.90 ppm; conditions as described in footnote *a* of Tables I and II.

(33) N. J. Leonard and F. P. Hauck, Jr., *J. Am. Chem. Soc.*, **79**, 5279 (1957).

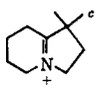
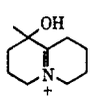
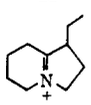
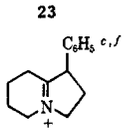
(34) R. Lukeš, V. Dědek, and L. Novotny, *Collection Czech. Chem. Commun.*, **24**, 1117 (1959).

(35) A. T. Blomquist and E. J. Moriconi, *J. Org. Chem.*, **26**, 3761 (1961).

(36) A. L. Logothetis, *ibid.*, **29**, 1834 (1964).

TABLE II

NMR SPECTRA OF IMINIUM PERCHLORATES[a]

Compound	Ring size 5 $-CH_2-N-$	6	5 $-CH-C=$	6	5 $-CH_2-C-$	6
 14	5.85 t (J = 8)	6.30	6.80 t (J = 9)	7.21		
 15		6.29		7.23		
 16	5.79	6.29	6.82	7.25[b]		8.64 d (J = 7)
 17	5.88 t (J = 8)	6.29	6.7[b]	7.26	8.64 d (J = 8)	
 18	5.70 t (J = 8)	6.06		7.10	8.55	
 19	5.77	6.24	6.80 t (J = 8)			8.63
 20	5.88 t (J = 7)	6.25	6.6[b]	7.1[b]	8.64 d (J = 7.5) 8.62 d (J = 7.5) 8.59 d (J = 7)	
 21		6.20		7.19		8.63 d (J = 8)
 22		6.20[d]		6.95[d]		8.46[d]
 23	5.86	6.24	6.7[b]	7.28	9.00 t (J = 7)[e]	
 24	5.54 t (J = 8)	6.01	5.2–5.5[g]	7.31	2.55[b,h]	

[a] Unless otherwise noted all spectra were taken in $DCCl_3$ solution with TMS as an internal standard. Chemical shifts are expressed in τ and J in cycles per second; d = doublet, t = triplet. [b] Center of broad multiplet. [c] In trifluoroacetic acid which causes a downfield shift over $DCCl_3$ of *ca.* τ 0.1. [d] Obtained by subtracting spectrum of **21** from that of a mixture of **21** and **22**. The resulting spectrum was identical in shape and the relative position of the peaks with an uncalibrated spectrum of pure **22** in D_2O. [e] CH_3 of ethyl group. [f] With trinitrobenzenesulfonate anion whose protons appear as a sharp singlet at τ 1.32. [g] Suggested by fact that integration of the triplet at τ 5.54 indicates three protons. [h] Phenyl protons.

the iminium salt[37] has been considered by some[38] to be one of "the three important stages in the evolution of enamine chemistry." While most of the enamines and iminium salts in Table III do display this characteristic shift, the 8-methyl and 1,8-dimethyl combinations, **7**, **16** and **26**, **20**, respectively, do not. Several other examples of enamine to iminium salt conversions which are not accompanied by the expected[37] frequency shifts are known, but in all cases[19,39] save one[40] the lack of a shift is due to the abnormally low frequency of the iminium salt and not the abnormally high frequency of the enamine as is the case

(37) N. J. Leonard and V. W. Gash, *J. Am. Chem. Soc.*, **76**, 2781 (1954).

(38) J. Szmuszkovicz, "Advances in Organic Chemistry: Methods and Results," Vol. 4, R. A. Raphael, E. C. Taylor, and H. Wynberg, Ed., Interscience Publishers, Inc., New York, N. Y., 1963, p 8.

(39) W. Musliner and P. C. Kelley, Ph.D. Theses, University of Illinois, 1965; N. J. Leonard, personal communication.

(40) A. G. Cook, W. C. Meyer, K. E. Ungrodt, and R. H. Mueller, *J. Org. Chem.*, **31**, 14 (1966).

TABLE III

INFRARED ABSORPTION MAXIMA OF ENAMINES AND THEIR SALTS[a]

Enamine	ν_{max}[b]	Iminium perchlorate	ν_{max}[c]
5	1676, 1647 sh[d]	14	1692[e]
6	1653[f]	15	1696[g]
7	1689	16	1685
8	1672	17	1695
9	1666	18	1691
10	1631[h]	19	1676
26	1690	20	1680
11	1652[i]	21	1678[j]
	1648		
12	1678	23	1695
13[h,k]	1629	24	1685[l]
	1598[m]		1605[m]

[a] Unless otherwise noted all spectra were taken on a Perkin-Elmer Model 421; ν_{max} was reported as ± 1 cm^{-1}. [b] Film of vpc collected sample. [c] Nujol mull. [d] Lit.[28] 1672 and 1646 cm^{-1}. [e] Lit.[28] 1689 cm^{-1}. [f] Lit.[16] 1652 cm^{-1}. [g] Lit. 1696 cm^{-1}. [h] Taken on Beckman IR-10, ± 4 cm^{-1}. [i] Lit.[24] 1656 cm^{-1}. [j] Lit.[24] 1692 cm^{-1}. [k] Purified by vacuum distillation. [l] Trinitrobenzenesulfonate. [m] Phenyl ring.

with **7** and **26**. Although insufficient examples of this phenomenon are available to permit any meaningful rationalization as to its origin, it is at least worth noting that exceptions to the generalization[37] do exist and may lead to difficulties in structure determinations.[14]

Another interesting conclusion which may be drawn from the infrared spectra of the enamines in Table III is that the presence or absence of shoulders on the 6-μ peak is not necessarily an indication of the presence of isomers. Thus the 6-μ peaks of **9**, whose structure is unambiguous, and of **7**, which has been shown to be exclusively the Δ^8 isomer by nmr (Table I), display shoulders similar to those of **5** which has been considered to be a mixture of the Δ^8 and $\Delta^{1(9)}$ isomers.[28] Not only the shape but also the position of the 6-μ peak of **5** is consistent with the Δ^8 structure predicted from the nmr data in Table I, since it is much closer to that of **9** than of **10**. The rather low frequency of this peak in the infrared spectrum of the latter compound is similar to that in other enamines which have a double bond exocyclic to a five-membered ring.[34]

One other enamine (**13**) possesses an unusually low-frequency 6-μ peak in its infrared spectrum. This observation is consistent with other phenyl conjugated enamines[33-36] thereby substantiating the structure assigned to **13** from nmr evidence.

Experimental Section[41]

3-(2′-Pyridyl)-1-pentanol (2a).—Using the general procedure described previously,[17] 2-*n*-propylpyridine (**1a**) was alkylated with phenyllithium and ethylene oxide to give **2a** in 56% yield as a viscous oil, bp 125–126° (1.0 mm) [lit.[42] 83–86° (0.5 mm)]. The 2,4,6-trinitrobenzenesulfonate derivative (**2a·TNBS**), mp 114–115°, was prepared.

Anal. Calcd for $C_{10}H_{15}NO \cdot C_6H_3N_3O_9S$ (**2a·TNBS**): C, 41.92; H, 3.96. Found: C, 42.27; H, 3.97.

3-Phenyl-3-(2′-pyridyl)-1-propanol (2b).—Once again the previously published procedure[17] was followed exactly to prepare **2b** as a viscous oil [bp 160–161° (0.5 mm)] in 50% yield from 2-benzylpyridine (**1b**), phenyllithium, and ethylene oxide. The TNBS derivative had mp 81–82°.

Anal. Calcd for $C_{14}H_{15}NO \cdot C_6H_3N_3O_9S$ (**2b·TNBS**): C, 47.40; H, 3.58. Found: C, 46.94; H, 3.97.

3-(2′-Piperidyl)-1-pentanol (3a).—The catalytic reduction of **2a** was carried out as previously described[17] to produce **3a** in 93% yield as a clear, viscous oil, bp 100–103° (1.0 mm) [lit.[42] 89–90° (0.3 mm)], which formed a TNBS derivative, mp 176–177°.

Anal. Calcd for $C_{10}H_{21}NO \cdot C_6H_3N_3O_9S$ (**3a·TNBS**): C, 41.37; H, 5.21. Found: C, 41.81; H, 5.16.

3-Phenyl-3-(2′-piperidyl)-1-propanol (3b).—Catalytic reduction of **2b** with platinum oxide in glacial acetic acid[17] gave **3b** in 90% yield as a clear, viscous oil [bp 180–183° (0.05 mm)] which slowly solidified (mp 70–107°) and formed a TNBS derivative, mp 194–195°.

Anal. Calcd for $C_{14}H_{21}NO \cdot C_6H_3N_3O_9S$ (**3b·TNBS**): C, 46.87; H, 4.72. Found: C, 47.00; H, 4.81.

1-Ethylindolizidine (4a).—The Raney nickel catalyzed cyclization[17] of **3a** led to **4a** in 96% yield. Although vapor phase chromatography indicated the presence of a mixture, presumably diastereoisomers, a single picrate, mp 145–146° (lit.[43] 146–147°), was obtained.

1-Phenylindolizidine (4b). A. Raney Nickel Method.—Upon subjecting 37.5 g of the piperidyl alcohol **3b** to the Raney nickel cyclization procedure,[17] only the first 100 ml of distillate was strongly basic. An additional 100 ml was collected and the combined distillates were saturated with potassium carbonate and extracted with three 100-ml portions of ether. The ether extracts were dried over anhydrous potassium carbonate, the ether was removed by distillation, and the remaining colorless oil was distilled through a small Vigr x column [1] bp 130–134° (0.5 mm) [1] to afford 3 g (9%) of a diastereoisomeric mixture (vpc) of 1-phenylindolizidines (**4b**).

The aqueous solution remaining in the cyclization flask was decanted from the Raney nickel catalyst, saturated with potassium carbonate, and extracted with three 100-ml portions of chloroform which were dried and evaporated to afford 30 g (80%) of the starting piperidyl alcohol **3b**.

B. Bromide–Hydrobromide Method.[44]—A sealed tube containing 5 g (0.023 mole) of the piperidyl alcohol **3b** and 80 ml of 48% hydrobromic acid was heated in a steam cylinder for 18 hr. The reaction mixture was transferred to a 250-ml round-bottom flask and taken to dryness on a rotary evaporator; the light brown solid residue crystallized from absolute ethanol–ether (Norit) to give 5.1 g (62%) of the bromide–hydrobromide of **3b** as white crystals, mp 210–211°.

Anal. Calcd for $C_{14}H_{20}NBr \cdot HBr$ (**3b·HBr**, OH=Br): C, 46.31; H, 5.83. Found: C, 46.32; H, 5.98.

The bromide–hydrobromide (10 g) was heated on a steam bath for 30 min with 250 ml of 2 *N* sodium hydroxide, and the resulting solution was steam distilled until the distillate was no longer basic to litmus (700 ml). The distillate was saturated with

TABLE IV

PROPERTIES AND YIELDS OF IMINIUM PERCHLORATES

Compd	Yield, %	Mp, °C	Calcd, % C	Calcd, % H	Found, % C	Found, % H
14	55	218–219 dec[a]				
15	60	234–235 dec[b]				
16	53	258–260 dec[c]				
17	62	235–237 dec[d]				
18	60	230–231 dec	47.72	7.16	47.94	7.21
19	61	235–237 dec[e]				
20	54	238–239 dec[f]				
21	49	268–270 dec[g]	47.72	7.16	47.78	7.42
22	5	219–220[h]				
23	52	160–161	47.72	7.16	47.52	7.00
24[i]	32	222–224 dec	48.74	4.06	48.75	4.33

[a] Lit.[25] 218–219° dec. [b] Lit.[16] 234–235° dec. [c] Lit.[17] 258–260° dec. [d] Lit.[17] 235–237° dec. [e] Lit.[14] 235–237° dec. [f] Lit.[17] 238–239° dec. [g] Lit. 253–255° dec,[17] 252–253° dec.[24] [h] Lit.[24] 219–220°. [i] Trinitrobenzenesulfonate anion; neither the perchlorate, bromide, nor chloride was obtained crystalline.

(41) All melting points and boiling points are corrected; proton magnetic resonance spectra were recorded on a Varian A-60 instrument; vpc analyses were carried out with a Wilkens Aerograph A-90-C on a 10-ft, 10% silicone on Fluoropack column; analyses were determined by Mr. C. F. Geiger, Ontario, Calif.

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potassium carbonate and extracted with three 100-ml portions of ether. The combined ether extracts were dried over anhydrous potassium carbonate, the ether was removed by distillation, and the remaining colorless oil was distilled through a Vigreux column [bp 130–132° (0.5 mm)] to give 4.15 g (75%) of 1-phenylindolizidine (**4b**).

A picrate, mp 172–173°, was prepared from picric acid in ethanol.

Anal. Calcd for $C_{14}H_{19}N \cdot C_6H_3N_3O_7$ (**4b**·**picrate**): C, 55.81; H, 5.15. Found: C, 55.64; H, 4.94.

Preparation of Iminium Salts and Enamines.—With the one exception noted below, the iminium salts whose properties, analyses and yields are listed in Table IV were prepared according to previously published procedures.[16,17] The corresponding enamines were obtained from these salts by basification and purified for infrared and nmr measurements by vapor phase chromatography except for **13** which was vacuum distilled.

The product obtained by oxidation of 1-methylquinolizidine with mercuric acetate was separated by crystallization into two fractions with melting points of 219–220° (5% yield) and 253–255° dec (49% yield). Although these melting points are in agreement with the reported values[24] for **22** and **21**, respectively, the nmr spectrum of the latter compound contains three peaks in the C-methyl region at such positions and relative areas as to suggest an *ca.* 3–4:1 mixture of **21**:**22**. An elemental analysis of the salt, mp 253–255° dec, was obtained.

Anal. Calcd for 80% $C_{10}H_{18}ClNO_4$ (**21**) and 20% $C_{10}H_{18}ClNO_5$ (**22**): C, 47.14; H, 7.13. Found: C, 47.22; H, 6.99.

Vapor phase chromatography of the free base obtained from this salt substantiated the above composition and provided a sample of the enamine **11** which was converted to authentic $\Delta^{5(10)}$-dehydroquinolizidinium perchlorate (**21**).

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Reduction of 1,2-Cyclohexanedione by Aluminum Isopropoxide. Stoichiometric Control of Stereochemistry[1]

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1,2-Cyclohexanedione has been reduced to 1,2-cyclohexanediol by aluminum isopropoxide in toluene at 105°. The isomeric product composition has been observed to vary from 57 ± 2% *cis* (68 ± 5% total 1,2-cyclohexanediols) with a dione/Al(O-*i*-Pr)$_3$ molar ratio of 0.25, to 75 ± 2% *cis* (18 ± 7% glycols) with a molar ratio of 2.0. Dependence of the reductive path on reagent stoichiometry is suggested to explain this stoichiometric control of stereochemistry.

The equilibrium consisting of the Meerwein–Ponndorf–Verley (MPV) reduction of ketones and the Oppenauer oxidation of secondary alcohols is of sig-

$$3R^1\text{—}\overset{\overset{O}{\|}}{C}\text{—}R^2 + Al(OCHR^3R^4)_3 \rightleftharpoons 3R^3\text{—}\overset{\overset{O}{\|}}{C}\text{—}R^4 + Al(OCHR^1R^2)_3$$

nificant interest to organic chemists and has been the subject of two major reviews[2] and several recent publications.[3] Although monofunctional ketones and alcohols have received considerable attention, vicinal diones, diols, and hydroxyketones appear to have been relatively neglected. Reported MPV studies indicate that reduction by aluminum isopropoxide in isopropyl alcohol converts benzil to 90–94%,[4,5] and benzoin to 90%[4] *meso*-hydrobenzoin, that reduction of benzoin with aluminum ethoxide produces both *meso*- and *rac*-hydrobenzoin in a temperature-dependent (or temperature- and solvent-dependent) ratio,[6] and that Oppenauer oxidation of benzoin and the isomeric hydrobenzoins proceeds in 74–87% yield.[7]

Rather high stereoselectivities seem to occur generally in hydridic reductions of benzil to hydrobenzoin, regardless of the nature of the reductant. The following yields of *meso*-hydrobenzoin have been reported in reductions of benzil: 90% with Al(O-*i*-Pr)$_3$;[4] 84–87%, $(C_6H_5)_2SnH_2$;[8,9] 93%, $(n\text{-}C_4H_9)_2SnH_2$;[9] 95%, $LiAlH_4$–$AlCl_3$;[10] 70–81%, $NaBH_4$ (82–92% hydrobenzoin)[11] and 56% (89% hydrobenzoin);[12] 81–90%, $LiAlH_4$ (86–90% hydrobenzoin).[13] These variable, but frequently high stereoselectivities may be rationalized by a variety of reductive pathways and suggest the desirability of a comprehensive study of the stereochemistry of the Meerwein–Ponndorf–Verley–Oppenauer (MPVO) equilibria of vicinal diones, diols, and hydroxy ketones. Initial results of such a study, including an apparently unique stoichiometric control of stereochemistry, are reported here.

Results

Dione Reduction.—Hydridic reductions of benzil appear to produce predominantly *meso*-hydrobenzoin. Free rotation about the carbonyl–carbonyl bond permits at least two reductive routes to this isomer: in one, both carbonyls of a cisoid dicarbonyl system are reduced by a single metal hydride molecule; in the other each carbonyl of a transoid system is reduced by

(1) Presented at the 151st National Meeting of the American Chemical Society, Pittsburgh, Pa., March 1966.

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