separation of this fraction by flash chromatography (Wakogel, C-300; CH_2Cl_2) afforded 5 fractions, two of which, designated fr. A (540 mg) and fr. B (214 mg), showed the cyclopropane signals in the ^1H NMR spectrum. Repeated separation of fr. A by preparative TLC (Merck, Kieselgel 60, GF_{254}) afforded **8** (5 mg), **9** (3 mg), and **5** (3 mg). Separation of fr. B produced **4** (3 mg) and **9** (8 mg). Similarly, **1** (7 mg) and **6** (3 mg) were obtained from fr. VII (0.5 g), **3** (2 mg) from fr. V (1.2 g), and **7** (2 mg) from fr. IX (0.5 g).

1,10-Epoxy-14-hydroperoxy-4-lepidozene (1). High-resolution MS: *m/e* 252.1724 (M^+, $C_{15}H_{24}O_3$). ^1H NMR spectrum (500 MHz, C_6D_6): δ 0.01 (1 H, ddd, *J* = 11, 5.5, 2.5 Hz, H-7), 0.91 (1 H, m, H-8), 0.99 (3 H, s, H-13), 1.00 (3 H, s, H-12), 1.00 (1 H, overlapping; H-6), 1.16 (1 H, td, *J* = 13, 2.5 Hz; H-9), 1.20 (3 H, s, H-15), 1.45 (1 H, m, H-2), 1.73 (1 H, ddt, *J* = 14, 5, 2.5 Hz, H-8), 2.08 (1 H, dt, *J* = 13, 4 Hz, H-3), 2.12 (1 H, ddd, *J* = 13, 5, 2.5 Hz, H-9), 2.34 (1 H, tt, *J* = 13, 4 Hz, H-2), 2.43 (1 H, td, *J* = 13, 4 Hz, H-3), 2.97 (1 H, dd, *J* = 10, 4 Hz, H-1), 4.28 (1 H, d, *J* = 11.5 Hz, H-14), 4.42 (1 H, d, *J* = 11.5 Hz, H-14), 5.37 (1 H, d, *J* = 9 Hz, H-5), 7.40 (1 H, s, OOH). ^{13}C NMR spectrum (125 MHz, C_6D_6): δ 16.3 (q, C-15), 21.4 (s, C-11), 22.0 (q, c-13), 22.6 (q, C-12), 25.6 (t, C-8), 25.9 (t, C-3), 29.1 (t, C-2), 31.6 (d, C-6), 34.7 (d, C-7), 41.0 (t, C-9), (s, C-10), 62.5 (d, C-1), 82.2 (t, C-14), 132.6 (d, C-5), 133.7 (s, C-4).

1,10-Epoxylepidozenol (2). ^1H NMR spectrum (500 MHz, C_6C_6): δ 0.05 (1 H, ddd, *J* = 9, 4, 2 Hz, H-7), 1.00 (1 H, tdd, *J* = 13, 9, 3 Hz, H-8), 1.05 (1 H, dd, *J* = 8, 4 Hz, H-6), 1.06 (3 H, s, H-12/13), 1.12 (3 H, s, H-13/12), 1.24 (1 H, td, *J* = 13, 3 Hz, H-9), 1.27 (3 H, s, H-15), 1.46 (1 H, ddt, *J* = 13, 9, 4 Hz, H-2), 1.82 (1 H, bd, *J* = 13 Hz, H-8), 2.05 (1 H, dt, *J* = 13, 4 Hz, H-3), 2.18 (1 H, ddd, *J* = 13, 6, 3 Hz, H-9), 2.30 (1 H, tt, *J* = 13, 4 Hz, H-20), 2.47 (1 H, td, *J* = 13, 4 Hz, H-3), 2.96 (1 H, dd, *J* = 9, 4 Hz, H-1), 3.87 (1 H, d, *J* = 9 Hz, H-14), 3.96 (1H, d, *J* = 9 Hz, H-14), 5.36 (1 H d, *J* = 8 Hz, H-5). ^{13}C NMR spectrum [125 NHz (DEPT), C_6D_6; only the region 0–100 ppm was measured]: δ 16.3 (q, C-15), 22.1 (q, C-12/13), 22.8 (q, C-13/12), 25.3 (t, C-8/3), 25.9 (t, C-3/8), 29.2 (t, C-2), 31.6 (d, C-6), 34.6 (d, C-7), 41.2 (t, C-9), 62.4 (d, C-1), 67.5 (t, C-14).

1,10-Epoxylepidozenal (3). ^1H NMR spectrum (500 MHz, $CDCl_3$): δ 0.69 (1 H, ddd, *J* = 11.5, 5, 3 Hz, H-7), 1.10 (1 H, td, *J* = 12, 3 Hz, H-9), 1.20 (3 H, s, H-15), 1.24 (3 H, s, H-12/13), 1.29 (1 H, m, H-8), 1.36 (3 H, s, H-13/12), 1.44 (1 H, dd, *J* = 10, 5 Hz, H-6), 1.44 (1 H, m, H-2), 2.10 (1 H, ddt, *J* = 15, 5, 3 Hz, H-8), 2.19 (1 H, tt, *J* = 13, 4 Hz, H-2), 2.21 (1 H, m, H-9), 2.31 (1 H, td, *J* = 13, 5 Hz, H-3), 2.68 (1 H, dd, *J* = 10, 4 Hz, H-1), 2.72 (1 H, ddd, *J* = 13, 5, 4 Hz, H-3), 6.41 (1 H, d, *J* = 10 Hz, H-5), 9.37 (1 H, s, H–14).

(−)-Lepidozenal (4). ^1H NMR spectrum (500 MHz, C_6D_6): δ 0.13 (1 H, ddd, *J* = 11.5, 5, 3 Hz), 0.72 (1 H, tdd, *J* = 14, 12, 3 Hz), 0.90 (3 H, s), 0.92 (1 H, dd, *J* = 10, 5 Hz), 0.95 (3 H, s), 1.42 (3 H bs), 1,65 (1 H, dq, *J* = 14, 3 Hz), 1.86 (1 H, td, *J* = 13, 3 Hz), 2.01 (1 H, td, *J* = 13, 5 Hz), 2.08 (1 H, dt, *J* = 13, 4 Hz), 2.18 (1 H, tdd, *J* = 13, 7, 4 Hz), 2.43 (1 H, m), 2.94 (1 H, ddd, *J* = 12, 4, 3 Hz), 5.00 (1 H, bt, *J* = 7 Hz), 5.96 (1 H, d, *J* = 10 Hz), 9.38 (1 H, d, *J* = 1 Hz).

(−)-Lepidozenol (5). ^1H NMR spectrum (500 MHz, $CDCl_3$): δ 0.11 (1H, ddd, *J* = 11.5, 5, 3 Hz), 0.76 (1 H, dd, *J* = 9, 5 Hz), 0.89 (1 H, tdd, *J* = 13, 11.5, 3 Hz), 1.01 (3 H, s), 1.09 (3 H, s), 1.62 (3 H, d, *J* = 1.5 Hz), 1.87 (1 H, dq, *J* = 13, 3 Hz), 1.99 (2 H, m), 2.08 (1 H, m), 2.21 (1 H, dt, *J* = 13, 3 Hz), 2.40 (2 H, m), 4.01 (1 H, d, *J* = 12 Hz), 4.11 (1 H, d, *J* = 12 Hz), 5.16 (1 H, bt, *J* = 7.5 Hz), 5.30 (1 H, d, *J* = 9 Hz). ^{13}C NMR spectrum (125 MHz, $CDCl_3$) (assignments; see above): δ 15.5 (q, C-15), 16.6 (s, C-11), 21.8 (q, C-12/13), 22.4 (q, C-13/12), 24.6 (t, C-2/3/8), 26.9 (t, C-3/2/8), 27.1 (t, C-8/3/2), 31.7 (d, C-7), 34.3 (d, C-6), 40.4 (t, C-9), 68.2 (t, C-14), 125.9 (d, C-1/5), 128.5 (d, C-5/1), 133.3 (s, C-4/10), 136.8 (s, C-10/4).

1,10-Epoxy-5-hydroperoxy-4(14)-lepidozene (6). High-resolution MS: *m/e* 252.1734 (M^+, $C_{15}H_{24}O_3$). ^1H NMR spectrum (500 MHz, C_6D_6): δ 0.08 (1 H, bdd, *J* = 11, 5 Hz, H-7), 0.34 (1 H, dd, *J* = 10, 5 Hz, H-6), 0.76 (1 H, ddd, *J* = 14, 11, 3 Hz, H-8), 1.04 (3 H, S, H-12/13), 1.13 (3 H, s, H-13/12), 1.20 (3 H, s, H-15), 2.78 (1 H, dd, *J* = 10, 3.5 Hz, H-1), 3.90 (1 H, d, *J* = 10 Hz, H-5), 5.00 (1 H, s, H-14), 5.22 (1 H, s, H-14), 7.37 (1 H, s, OOH). (Satisfactory ^{13}C NMR spectrum was not obtained because of decomposition during accumulation.)

1,10-Epoxy-4(14)-lepidozen-5-ol (7). ^1H NMR spectrum (500 MHz, $CDCl_3$): δ 0.20 (1 H, bdd, *J* = 10, 5.5 Hz, H-7), 0.56 (1 H dd, *J* = 9.5, 5.5 Hz, H-6), 1.02 (2 H, m, H-8), 1.11 (3 H, s, H-12/13), 1.15 (3 H, s, H-13/12), 1.22 (3 H, s, H-15), 1.45 (1 H, ddd, *J* = 13.5, 6, 3.5 Hz, H-2), 1.98 (1 H, m, H-9), 2.13 (1 H, m, H-9), 2.20 (1 H, m, H-3), 2.32 (1 H, tt, *J* = 13.5, 3.5 Hz, H-2), 2.38 (1 H, m, H-3), 2.89 (1 H, dd, *J* = 10.5, 3.5 Hz, H-1), 3.70 (1 H, d, *J* = 9.5 Hz, H-5), 5.10 (1 H, s, H-14), 5.22 (1 H, s, H-14). ^{13}C NMR spectrum [125 MHz, $CDCl_3$] (only nine signals were observed.): δ 16.0, 22.0, 22.0, 25.6, 27.8, 28.6, 39.6, 78.3, 144.3.

5-Hydroperoxylepidoza-1(10),4(14)-diene (8). High-resolution MS: *m/e* 236.1780 (M^+, $C_{15}H_{24}O_2$). ^1H NMR spectrum (500 MHz, $CDCl_3$): δ 0.04 (1 H, dd, *J* = 10, 5 Hz, H-6), 0.28 (1 H, ddd, *J* = 11, 5, 2 Hz, H-7), 0.95 (1 H, m, H-8), 1.00 (3 H, s, H-12/13), 1.15 (3 H, s, H-13/12), 1.53 (3 H, bs, H-15), 1.88 (1 H, m, H-8), 1.92 (1 H, m, H-3), 1.98 (1 H, td, *J* = 13, 4.5 Hz, H-9), 2.12 (1 H, m, H-2), 2.18 (1 H, bdt, *J* = 13, 4 Hz, H-9), 2.39 (1 H, dtd, *J* = 13, 11, 4 Hz, H-2), 2.52 (1 H, m, H-3), 3.85 (1 H, d, *J* = 10 Hz, H-5), 5.18 (1 H, ddq, *J* = 11, 5.5, 1 Hz, H-1), 5.26 (1 H, s, H-14), 5.32 (1 H, s, H-14), 7.70 (1 H, s, OOH); ^{13}C NMR spectrum (125 MHz, C_6D_6) (only 12 signals were observed): δ 18.5, 21.9, 22.8, 26.2, 30.0, 31.1, 34.9, 39.8, 92.7, 114.0, 126.1, 137.3.

Lepidoza-1(10),4(14)-dien-5-ol (9). High-resolution MS: *m/e* 220.1847 (M^+, $C_{15}H_{24}O$). ^1H NMR spectrum (500 MHz, C_6D_6): δ 0.06 (1 H, ddd, *J* = 11, 5.5, 2.5 Hz, H-7), 0.33 (1 H, dd, *J* = 10, 5.5 Hz, H-6), 0.95 (1 H, m, H-8), 1.09 (3 H, s, H-12/13), 1.20 (3 H, s, H-13/12), 1.52 (3 H, s, H-15), 1.78 (1 H, dtd, *J* = 14, 4, 2.5 Hz, H-8), 1.93 (1 H, m, H-3), 1.96 (1 H, td, *J* = 13, 4 Hz, H-9), 2.10 (1 H, m, H-3), 2.17 (1 H, dt, *J* = 13, 4 Hz, H-9), 2.37 (2 H, m, H-2), 3.49 (1 H, d, *J* = 10 Hz, H-5), 4.97 (1 H, s, H-14), 5.22 (1 H, s, H-14), 5.23 (1 H, bt, *J* = 8 Hz, H-1). ^{13}C NMR spectrum (125 MHz, $CDCl_3$) (one signal is missing): δ 16.1, 17.8, 22.1, 22.2, 26.1, 29.1, 29.8, 37.7, 39.5, 79.9, 114.3, 124.9, 125.9, 133.6.

Reduction of the Hydroperoxides 1 and 8 with Triphenylphosphine. A solution of **1** (700 μg) and triphenylphosphine (1 mg) in benzene (1 mL) was allowed to stand at room temperature for 2 h. TLC (Merck, Keiselgel GF 254; CH_2Cl_2) of the product showed the spots corresponding to triphenylphosphine, triphenylphosphine oxide, and a reduction product. Separation with column chromatography (Merck, Kieselgel 60) afforded **2** (500 μg), which was identified by comparison of its R_f in TLC and ^1H NMR spectrum with those of authentic sample. Reduction of **8** (500 μg) was carried out in the same manner, yielding **9** (300 μg).

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Light-Induced, Iodine-Catalyzed Aerobic Oxidation of Unsaturated Tertiary Amines

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Numerous methods have been reported for the oxidation of amines through use of chemical, electrochemical, microbiological, and photochemical procedures. Among the nonphotochemical methods[1,2] are reactions employing dichromate, lead tetraacetate, manganese dioxide, per-

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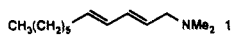
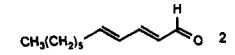
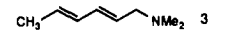
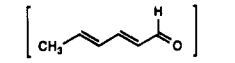
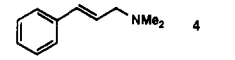
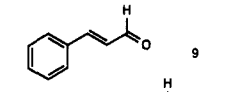
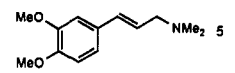
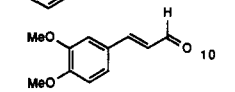
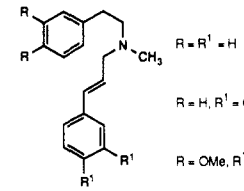
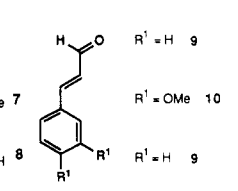
0022-3263/90/1955-3679$02.50/0

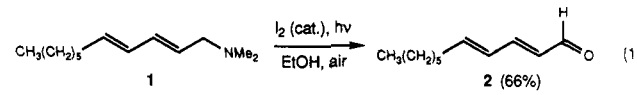
Table I. Oxidation of Unsaturated Amines

amine	product	yield (%)
 1	 2	66%
 3		[a]
 4	 9	35%
 5	 10	40%
 R = R' = H 6 R = H, R' = OMe 7 R = OMe, R' = H 8	 R' = H 9 R' = OMe 10 R' = H 9	37% 57% 80%

[a] Not isolated. See text.

manganate,[2] ozone, mercuric salts,[3] thallic salts, aqueous bromine,[4] ferricyanide,[2,5] molybdicyanide,[2] nitrous acid,[6] 1-chlorobenzotriazole,[7] quinones,[8] perfluoroalkyl iodides/metal catalysts,[9] chlorine dioxide,[2,10] *N*-bromosuccinimide,[11] oxygen or peroxides (with or without metal coreagents or catalysts),[12] dioxygenyl hexafluoroantimonate,[13] iodosobenzene,[14] Polonovski conditions (via *N*-oxide formation then an anhydride),[15] Swern conditions,[16] electrochemical conditions,[17] oxidative enzymes, and microorganisms.[8] Photochemical oxidation of amines,[18] generally occurring by means of electron transfer from the amine to the excited singlet or triplet state of an acceptor, has been the subject of much synthetic and mechanistic work,[19] employing aromatic hydrocarbons, aromatic ketones, aromatic nitriles, and organic dyes.[20] Herein we briefly describe an exceptionally simple set of conditions for accomplishing the oxidation of certain types of conjugated, unsaturated, tertiary amines to aldehydes.

When a solution of the tertiary pentadienylamine **1** in 95% ethanol containing a catalytic amount of iodine is irradiated with a simple tungsten-filament floodlamp while air is bubbled through the solution, a fairly good yield of the corresponding dienal **2** is obtained (eq 1). When *E*/*Z*



(1)

mixtures of the starting amine are used, the all-*E* product **2** is obtained, which is consistent with previous observations of alkene isomerization promoted by iodine under similar conditions.[21] Somewhat surprising is that when the shorter chain pentadienylamine **3** is subjected to the same reaction conditions, the amine is consumed, but the corresponding dienal, sorbaldehyde (2,4-hexadienal), is not isolated. However, this result is most likely due to the fact that sorbaldehyde is a rather sensitive compound. Indeed, an authentic sample of commercially available sorbaldehyde undergoes rapid destruction under our reaction conditions. On the other hand, the new oxidation reaction also occurs in modest to good yields with tertiary cinnamylamines (Table I). Other types of amines, including primary, secondary, saturated, and simple allylic amines, do not appear to be useful substrates under these reaction conditions.

With respect to the sources of the substrates for these reactions, earlier work in our laboratory has provided new methods for the preparation of pentadienylamines through use of [4-amino-2-buten-1-yl]phosphonates in Horner–Wadsworth–Emmons condensations with carbonyl compounds.[22] The cinnamylamines are readily obtained by palladium-catalyzed reactions of the corresponding cinnamyl acetates with secondary amines.[23]

Variations in the reaction conditions for the oxidation were briefly investigated. Appropriate control experiments indicate that each of the components (iodine, air, light) is needed for useful conversion to occur. No advantage is seen upon using more elaborate light sources, including ultraviolet lamps. Other solvents that can be employed in addition to ethanol are acetonitrile, THF, and methylene chloride.

Although we have not performed mechanistic studies on this reaction, the reaction pathway may be related to those proposed previously in related cases.[2,5b,8b,9,10,12c,20f-h] Iminium salts may be considered as possible intermediates

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which then undergo hydrolysis to provide the observed products, but we have neither isolated these salts nor observed them to undergo Mannich-type cyclizations in systems such as 6–8.

In summary, this new oxidation procedure is clearly very limited in scope, but for those types of amines for which it is applicable, this method has as its principal advantages the use of very simple conditions and very inexpensive reagents.

Experimental Section

General Information. Sensitive liquids and solutions were transferred via syringe or cannula and introduced into nitrogen-filled reaction vessels through rubber septa. Methylene chloride and hexanes were distilled under nitrogen from calcium hydride. THF and diethyl ether were distilled under nitrogen from deep blue or purple solutions of sodium benzophenone ketyl or dianion, respectively. Carbonyl compounds were distilled under vacuum from anhydrous sodium sulfate. Infrared spectra were recorded on a Perkin-Elmer 1420 ratio recording infrared spectrophotometer. Mass spectral data were recorded on a Finnigan MAT mass spectrometer. ^{1}H NMR spectra were measured with Magna-Chem A-200 (200 MHz) and General Electric GN-300 (300 MHz) spectrometers. ^{13}C NMR spectra were measured with a GN-300 (75 MHz) spectrometer. All ^{13}C spectra were ^{1}H decoupled. Gas chromatography was done on a Hewlett-Packard Model 5890A chromatograph using a methyl silicone gum capillary column.

Unsaturated Tertiary Amines. Data are provided for representative amines used as substrates for the oxidations reported in this note.

***N,N*-Dimethyl-2,4-undecadien-1-amine (1)** prepared from *n*-heptanal and diethyl [(*E*)-4-(*N,N*-dimethylamino)-2-buten-1-yl]phosphonate,[22] was obtained as a yellow oil as a 17.5:7:1 mixture of 2*E*,4*E*, 2*E*,4*Z*, and 2*Z*,4*E* isomers as determined by NMR: IR (film) 3020, 2965, 2956, 2862, 2820, 2780, 1458, 1019, 930, 903, 730 cm^{-1}; ^{1}H NMR (300 MHz, $CDCl_3$) δ 0.84 (br t, J = 6.6 Hz, 3 H, CH_3), 1.22 (m, 8 H, $(CH_2)_4$), 2.03 (m, 2 H, $CH_2CH_2C{=}C$), 2.23 (s, 5.7 H, CH_3N, 2*E*,4*E* isomer), 2.24 (s, 0.3 H, CH_3N, 2*E*,4*Z* isomer), 2.87 (d, J = 6.8 Hz, 1.9 H, CH_2N, 2*E*,4*E* isomer), 2.89 (d, J = 6.7 Hz, CH_2N, 2*E*,4*Z* isomer), 3.10 (d, J = 7.3 Hz, 0.1 H, CH_2N, 2*Z*,4*E* isomer), 5.40 (dd, J = 18.4, 7.4 Hz, HC=CHCH$_2$C, 2*E*,4*Z* isomer), 5.67 (dt, J = 14.4, 7.09 Hz, HC=CHCH$_2$N, 2*E*,4*E* isomer), 5.83 (dd, J = 7.04, 7.0 Hz, HC=CHCH$_2$C, 2*E*,4*Z* isomer), 6.05 (dd, J = 15.7, 10.4 Hz, HC=CHCH$_2$C, 2*E*,4*E* isomer), 6.14 (dd, J = 15.4, 10.4 Hz, HC=CHCH$_2$N, 2*E*,4*E* isomer), 6.61 (ddd, J = 15.2, 10.9, 1.5, HC=CHCH$_2$N, 2*E*,4*Z* isomer); ^{13}C NMR (50 MHz, $CDCl_3$, only the peaks for the *E,E* isomer are reported here) δ 134.57, 133.47, 129.50, 127.50 (C-2,3,4,5), 62.51 (C-1), 44.81 ($(CH_3)_2$N), 32.46 (C-7), 31.58, 29.10, 28.74, 22.46 (C-8,9,10), 13.90 (C-11). Anal. Calcd for $C_{13}H_{25}N$: C, 79.93; H, 12.90. Found: C, 79.73; H, 12.80.

***N,N*-Dimethyl-3-phenyl-2-propen-1-amine (4).** Into a 250-mL round-bottom flask equipped with a magnetic stirrer were added cinnamyl acetate (9.51 g, 53.9 mmol), $Pd(dba)_2$ (162.8 mg, 0.28 mmol), and 1,2-bis(diphenylphosphino)ethane (dppe) (175.8 mg, 0.44 mmol). The flask was purged with N_2, and 50 mL of THF was added. To this mixture was added dimethylamine (4.71 M in THF, 40 mL, 188.4 mmol) all at once. The solution was stirred at 25 °C for 24 h until GC analysis showed no starting material. The reaction mixture was taken up in ether and washed with water (2 × 50 mL), aqueous $NaHCO_3$ (2 × 50 mL), and brine (2 × 50 mL). The ether layer was then washed with 1 N HCl (3 × 50 mL), the combined aqueous layers were neutralized with 1 N aqueous Na_2CO_3 (3 × 20 mL), and the amine was extracted with Et_2O (3 × 65 mL). The organic layer was washed with brine (1 × 20 mL) and dried ($MgSO_4$). Filtration and concentration in vacuo provided 4 in 68% yield as a light yellow oil: (lit.[24] IR, NMR, MS) IR (film) 3070, 3050, 3020, 2960, 2930, 2820, 2800, 2760 (NCH_3 stretch), 1940, 1870, 1790, 1590, 1486, 1440 (NCH_3 bend), 1350 (C–N stretch), 960, 930, 680 cm^{-1}; ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.31 (m, 5 H, C_6H_5), 6.53 (d, J = 15.8 Hz, 1 H, PhCH=C), 6.29 (dt, J = 15.9, 9.0 Hz, 1 H, C=CHCH$_2$), 3.08 (d, J = 5.4 Hz, 2 H, CH_2N), 2.28 (s, 6 H, $N(CH_3)_2$); ^{13}C NMR (75 MHz, $CDCl_3$) δ 132.22 (PhCH), 126.01, 127.14, 128.23, 136.78 (C_6H_5), 117.95 (CHCH$_2$), 61.78 (CH_2N), 44.98 ($N(CH_3)_2$); MS (EI, 70 eV) m/e (rel intensity) 162 (7, M + 1), 161 (79, M), 146 (22, M – CH_3), 131 (9, M – C_2H_6), 117 (62, M – $N(CH_3)_2$), 91 (38, $C_7H_7^+$), 84 (19, M – PhCH), 77 (10, $C_6H_5^+$), 42 (100, $CH_2{=}N^+{=}CH_2$).

***N*-Methyl-*N*-(3-phenyl-2-propenyl)benzeneethanamine (6).** Appropriate modification of the choices of starting materials in the preceding procedure provided **6** in 93% yield as a light yellow oil: IR (film) 3085, 3065, 3030, 3005, 2990, 2950, 2865, 2840 (NCH_2 stretch), 2790 (NCH_3 stretch), 1947, 1875, 1800, 1745, 1655, 1600, 1580, 1495 (NCH_2 bend), 1450 (NCH_3 bend), 1352 (C–N stretch), 1120, 967, 740, 692 cm^{-1}; ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.25 (m, 10 H, $C_6H_5CH_2$–, C_6H_5CH=C), 6.48 (d, J = 15.9 Hz, 1 H, PhCH=CH), 6.25 (dt, J = 15.9, 6.3 Hz, 1 H, PhCH=CH), 3.18 (d, J = 6.3 Hz, 2 H, PhCH=CHCH_2), 2.79 (dd, J = 9.5, 5.9 Hz, 2 H, PhCH_2CH$_2$), 2.64 (m, 2 H, PhCH$_2$CH_2), 2.13 (s, 3 H, NCH_3); ^{13}C NMR (75 MHz, $CDCl_3$) δ 140.25, 136.92 (PhCH=CH), 132.34, 128.52, 128.34, 128.18, 127.19, 127.13, 126.13, 125.79 ($C_6H_5CH_2$, C_6H_5CH=C), 59.98 (PhCHCHCH$_2$), 58.98 (PhCH$_2$), 41.97 (PhCH$_2$CH$_2$), 33.87 (NCH_3); MS (EI, 70 eV) m/e (rel intensity) 251 (5, M$^+$), 160 (63, PhCH=CHCH$_2$N(CH$_3$)CH$_2^+$), 117 (100, PhCH=CHCH$_2^+$), 105 (4, PhCH$_2$CH$_2^+$), 91 (15, $C_7H_7^+$), 77 (3, $C_6H_5^+$), 65 (3, $C_5H_5^+$).

General Procedure for Oxidation of Tertiary Amines. A round-bottom flask was charged with the amine in 95% ethanol (10 mL/mmol of amine) at 25 °C. Iodine (0.3 mmol/mmol of amine) was added, and magnetic stirring was begun. The flask was fitted with a condenser, and a slow stream of air was bubbled through the mixture. The mixture was irradiated with a flood lamp (Sylvania spot lamp, 150 W, 125 V) from a distance of 18 cm for 24 h. Sufficient saturated aqueous sodium thiosulfate was added to destroy the iodine, and stirring was continued for 20 min. The mixture was concentrated in vacuo, and the residue was taken up in ether. The organic layer was washed with 1 N HCl, water, and brine and dried ($MgSO_4$). The mixture was concentrated in vacuo to give the corresponding aldehyde.

2,4-Undecadienal (2) was obtained as a light yellow oil (lit.[25] IR, NMR): IR (film) 1720 (C=O); ^{1}H NMR (200 MHz, $CDCl_3$) δ 0.88 (m, 3 H, CH_3), 1.26 (m, 6 H, $(CH_2)_3$), 1.59 (m, 2 H, CH_3CH_2), 2.21 (dt, J = 7.8, 5.9 Hz, 2 H, CH_2C=C), 6.1 (dd, J = 11.7, 7.8 Hz, 1 H, C=CHC=C), 6.44 (m, 2 H, CH_2CH=C and OHCCH=C), 7.05 (m, 1 H, C=CHC=C), 9.36 (d, J = 7.8 Hz, 1 H, CHO).

3-Phenyl-2-propenal (9) was obtained as a light yellow oil (lit.[24d] IR, NMR, MS): IR (film) 3080, 3055, 3020, 2850, 2740 (CHO stretch), 1670 (C=O), 1590, 1490, 960, 739, 680 cm^{-1}; ^{1}H NMR (300 MHz, $CDCl_3$) δ 9.72 (d, J = 7.4 Hz, 1 H, CHO), 7.41 (m, 6 H C_6H_5CH=C), 6.73 (dd, J = 16.1, 7.6 Hz, 1 H, CHCHO); MS (EI, 70 eV) m/e (rel intensity) 133 (7, M + 1), 132 (72, M), 131 (100, M – H), 103 (37, M – CHO), 77 (22, $C_6H_5^+$), 51 (10).

3-(3,4-Dimethoxyphenyl)-2-propenal (10) was obtained as a yellow solid: mp 81–82 °C: (lit.[26] mp 83–84 °C, IR, NMR) IR (film) 3090, 3060, 3030, 2960, 2930, 2870, 2740 (CHO stretch), 1670 (C=O), 1590, 1510, 1460, 1447 cm^{-1}; ^{1}H NMR (300 MHz, $CDCl_3$) δ 9.67 (d, J = 7.8 Hz, CHO), 7.42 (d, J = 15.8 Hz, 1 H, ArCH=CH), 7.17, 7.08, 6.91 (m, 3 H, ArH), 6.62 (dd, J = 15.8, 7.7 Hz, 1 H, ArCH=CH), 3.94, 3.93 (s, 6 H, $(CH_3O)_2$Ar); ^{13}C (75 MHz, $CDCl_3$) δ 193.56 (C=O), 152.83, 152.49 (aromatic $CH_3OC{=}COCH_3$), 127.05, 126.72, 123.42, 111.12, 110.05, 108.95 (aromatic and olefinic carbons), 56.04, 55.94 ($(CH_3O)_2$-Ar); MS (CI, isobutane) m/e (rel intensity) 193 (100, M + 1), 192 (36, M), 191 (2, M – H), 161 (6, M – OCH_3), 149 (2, M – CH_2CHO), 131 (10), 119 (4), 107 (15).

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Registry No. (2*E*,4*E*)-**1**, 93039-04-4; (2*E*,4*Z*)-**1**, 126457-65-6; (2*Z*,4*E*)-**1**, 93039-05-5; **2**, 30361-29-6; **3**, 71570-78-0; **4**, 42817-44-7; **5**, 126457-66-7; **6**, 126457-67-8; **7**, 126457-68-9; **8**, 126457-69-0; **9**, 14371-10-9; **10**, 58045-88-8; *n*-heptanal, 111-71-7; diethyl [(*E*)-4-(*N*,*N*-dimethylamino)-2-buten-1-yl]phosphonate, 93039-18-0; cinnamyl acetate, 103-54-8; benzylmethylamine, 103-67-3; iodine, 7553-56-2.

Selective Nucleophilic Addition Reactions of Alkyllithium Reagents with *N*-(Trimethylsilyl)lactams. Synthesis of Cyclic Ketimines

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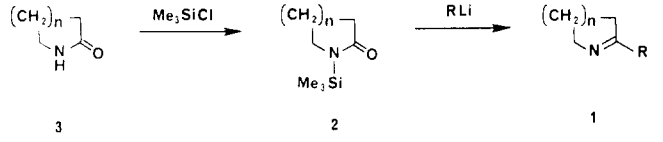
In our studies of the enantioselective synthesis of alkaloids via chiral α-sulfinyl ketimines,[1,2] cyclic ketimines of various ring size and containing diverse substituents, e.g. **1a–h**, were required. Four methods have been reported for the synthesis of cyclic ketimines: (1) additions of organolithium reagents to *N*-vinyllactams,[3] (2) acid-catalyzed rearrangement of tertiary azides,[4] (3) palladium-catalyzed oxidation of amino alkenes,[5] and (4) additions of organolithium[6] or Grignard reagents[7] with lactim ethers. Method 1 requires *N*-vinyllactams of which, however, only *N*-vinylpyrrolidinone is commercially available. Bayer and Geckeler[8] have noted the difficulty of obtaining *N*-vinyllactams in their report on the transvinylation of imides and ϵ-caprolactam with vinyl acetate in the presence of sodium tetrachloropalladate. We found that under these conditions δ-valerolactam (**3d**) was converted into *N*-vinylvalerolactam in only a 20% yield (60% recovery of δ-valerolactam). Method 2 requires a sequence of three steps, two of which utilize HN_3–BF_3·ether and H_2SO_4, respectively. Acid-labile systems like *tert*-butyldimethylsilyl ethers are incompatible with the reagents. Method 3 leads to a mixture of 2-ethyl-1-pyrroline and 2-methyl-1-piperidine (**1d**) in a ratio of 1:2. And, method 4 fails to provide **1d** and 1-aza-2-methyl-1-cycloheptene (**1e**). Herein, we describe a convenient method to prepare cyclic ketimines **1** in high yield from readily available *N*-(trimethylsilyl)lactams **2**.

Silylation of lactams **3** with trimethylsilyl chloride/triethylamine in toluene[9] gave excellent yields of *N*-silyllactams **2**. Nucleophilic additions of organolithium and organomagnesium reagents to **2** provided cyclic ketimines **1** (Scheme I). The results are summarized in Table I. Ethylmagnesium bromide afforded only a 25% yield of ketimine **1c** (entry 3) and 45% of lactam **3a**. Possibly, ethylmagnesium bromide attacks the silicon atom to generate the amide anion. However, high yields of these ketimines were obtained when alkyllithiums were employed.

Scheme I



3 2 1

The general procedure for these reactions consists of treating silyllactams **2** with 1.1 equiv of an alkyllithium at −20 °C for 30 min and then 25 °C for 1 h, or with 1.1 equiv of ethylmagnesium bromide in ether at 0 °C for 15 min and then 40 °C for 3 h.[10] Thus, organolithium reagents attack the carbonyl group of silyllactams; elimination of trimethylsilanol then leads to the products.

Lactams **3a–g** are commercially available. Lactam **3h** was obtained from the reaction of *N*-(trimethylsilyl)lactam **2a** with lithium diisopropylamide (LDA) in THF at −78 °C followed by reaction with bis(trimethylsilyl)peroxide.[11] The crude product was hydrolyzed with acetic acid–H_2O in $CHCl_3$ at 25 °C to give 3-hydroxy-2-pyrrolidinone (**4**) in 43% yield. N,O-Disilylation of **4** with a solution of 2.2 equiv of *tert*-butyldimethylsilyl chloride, 4 equiv of Et_3N, and 0.1 equiv of 4-(dimethylamino)pyridine (DMAP) in CH_2Cl_2 followed by selective N-desilylation with 0.5 equiv of *n*-Bu_4NF in THF at 0 °C for 2 h provided a 91% yield of lactam **3h**.

In summary, nucleophilic additions of alkyllithium reagents to *N*-(trimethylsilyl)lactams selectively provide cyclic ketimines in good to excellent yields. However, the only Grignard reagent used (EtMgBr) apparently attacks the silyllactam mainly at silicon, since the amide anion is generated. Continued utilization of cyclic ketimines in the construction of complex cyclic alkaloids[1,2] is underway.

Experimental Section

General Methods. ^1H and ^{13}C NMR spectra were obtained at 400 and 100 MHz, respectively. Infrared spectral data are reported in wavenumbers (cm^{-1}). Satisfactory elemental analyses were obtained for all compounds, except for ketimines **1f** and **1g**. These two compounds were rapidly hydrolyzed with traces of water into acylic keto amines. Davisil silica gel, grade 643 (200–425 mesh) was used for the flash chromatographic separation. Compounds **1b,c,h** are stable. Cyclic ketimines **1a** and **1d** trimerize upon heating, and the trimerization process is reversible. Compounds **1e–g** are unstable in acid medium or under heat (about 80 °C), leading to polymers. Hence, distillations of these three compounds are carried out under reduced pressure and low temperature. All cyclic ketimines should be stored in the refrigerator.

The following experiment serves to illustrate the general procedure for silylation reactions of lactams **3**.

† Fellow of the Alfred P. Sloan Foundation, 1989–1991.

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