176. The Chemistry of Thujone. IX[1]). Thujone as a Chiral Synthon for the Synthesis of Optically Active Steroid Analogues. The Vinylpicoline Route

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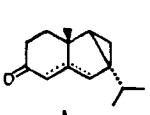
Summary

The thujone-derived enone **1**, upon base-catalyzed reaction with 2-methyl-6-vinylpyridine is converted to the pyridine analogue **5** *(Scheme 1)*. Catalytic reduction of the latter to **6** generates two new centers of chirality which eventually become C(8) and C(14) in the ultimate synthetic steroid analogue **12**. An X-ray analysis of **6** establishes the structure and absolute configuration so as to determine its suitability in subsequent synthetic studies. The acetal derivative **7**, *via Birch* reduction, hydrolysis, and internal aldol cyclization, is converted into the cyclohexenone analogue **10** *(Scheme 2)*. This 'one-pot' process affords an efficient conversion of the pyridine ring into a cyclohexenone system required for A-ring construction of the steroid skeleton. Finally, conversion of **10**, *via* the unsaturated diketone **11**, provides the chiral steroid analogue **12**.

As noted in the accompanying publication [1], our previous studies in [2] had efficiently elaborated the thujone-derived enones **1** to the chiral steroid analogue **2** possessing the incorrect chirality at C(10) when compared to the natural steroids. Solutions to this problem were essential, and several synthetic routes from **1** were considered. The accompanying publication [1] describes a synthesis of the required chiral cardenolide precursor **3** employing enol-lactone intermediates derived from **1**. The present discussion describes our parallel studies with **1** in which a vinyl-picoline **4** serves as a bis-annelating agent. In this manner, optically active 19-norsteroid analogues become readily accessible as intermediates for the eventual syntheses of 19-nor- and A-ring-aromatic steroids. The viability of this route to steroids was demonstrated earlier by *Danishefsky et al.* [3].



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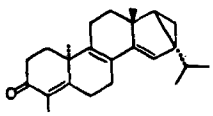

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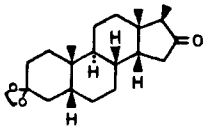

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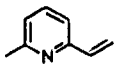

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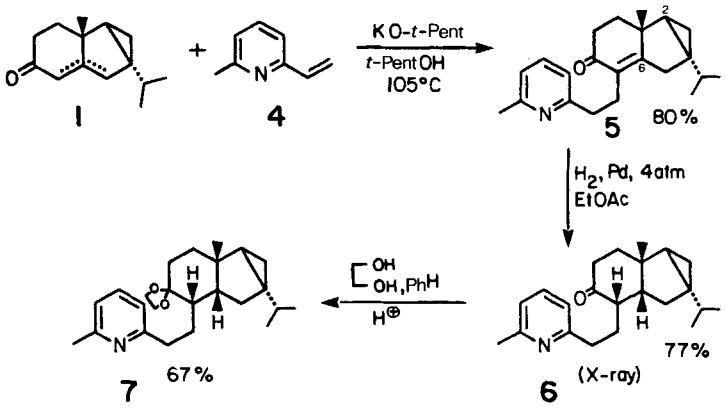
[1]) For Part VIII, see [1].

We have found that 2-methyl-6-vinylpyridine (**4**) reacts readily with the thujone-derived mixture of α,β- and β,γ-unsaturated ketones **1**, providing the annelated enone **5** in 80% yield *(Scheme 1)*. The subsequent reduction of the enone system in **5**

Scheme 1



to the saturated ketone shown in **6** was an important step, particularly as it relates to the configuration at C(8) and C(14) of the steroid analogue to be built. Bearing in mind our parallel studies with a similar reduction of intermediates prepared for the enol lactone route as described in [1], we subjected enone **5** to catalytic reduction whereupon a constitutionally pure crystalline product was obtained in 77% yield. *Birch* reduction of **5** afforded a complex mixture of products containing **6** as the major component and was therefore of little preparative value. The correct absolute configuration as shown in **6** was established by X-ray analysis thereby

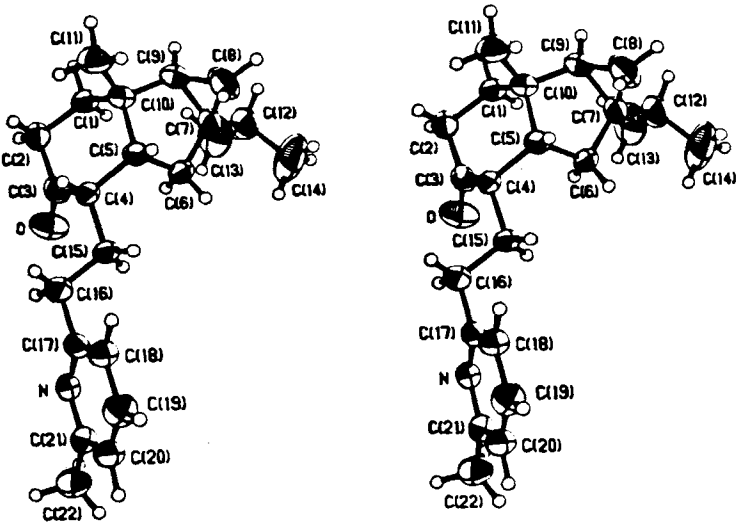


Fig. *Stereoview of* **6**. 50%-probability thermal ellipsoids are shown for O- and C-atoms. H-atoms have been assigned artificially small thermal parameters for the sake of clarity. Numbering is arbitrary.

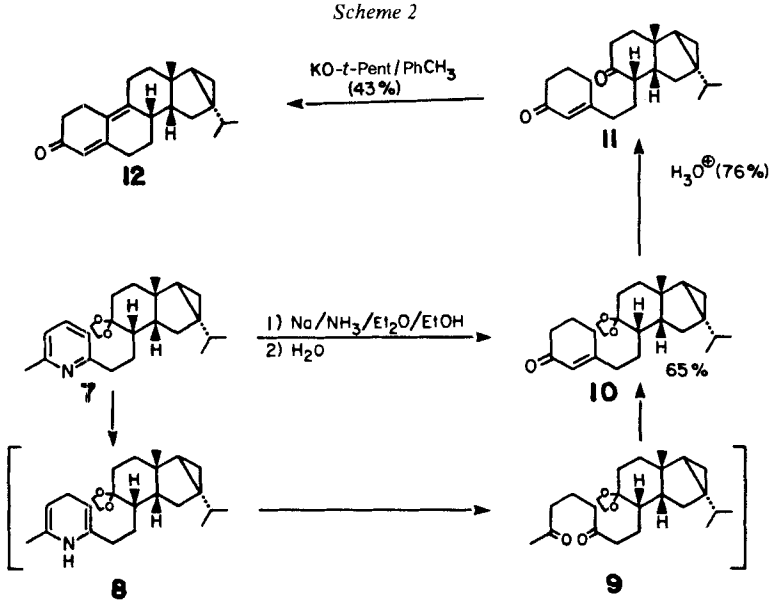
revealing that reduction had occurred from the β-face of the molecule and, in turn, providing the required chirality at C(8) in the resultant steroidal product.

The structure and absolute configuration of **6** are shown in the *Figure*. With the exception of a short O....H–C(18) $(1-x, y, z)$ contact of 2.4 Å, all intermolecular distances correspond to normal *van der Waals* interactions. The cyclohexanone ring has a distorted chair conformation and is *cis*-fused to the five-membered ring which has a C(5)-envelope conformation. The pyridine ring is significantly non-planar ($x^2 = 13.7$ for C_5N), the maximum deviation from the mean plane being 0.014 (6) Å. Bond lengths (*Table 1*, s. *Exper. Part*) and angles are generally as expected, although some bond lengths are apparently shortened by relatively high thermal motion, particularly those associated with the isopropyl side chain and the cyclopropyl moiety.

Although **6** possesses the incorrect *cis*-C/D-ring fusion, alteration of the configuration at C(14) into the desired *trans*-fused system could be soluble through ketonic intermediates obtained during subsequent cyclopropane ring opening reactions (see for example **3**), and therefore, further elaboration of **6** was now undertaken.

To avoid complications during the subsequent reduction of the pyridine ring in **6**, the latter was transformed with ethylene glycol in the presence of *p*-toluenesulfonic acid to the acetal **7** in 67% yield. *Birch* reduction of **7**, followed by hydrolysis and cyclization of the resulting diketone **9**, provided an overall 65% yield of the desired conjugated cyclohexenone derivative **10**. It is presumed that the reduction proceeds *via* the 1,4-dihydropyridine system (or, alternatively the 1,6-isomer) **8**, generated *in situ*, with subsequent hydrolysis to the intermediate diketone **9** *(Scheme 2)*. Indeed, careful hydrolysis of the *Birch* reduction product mixture at room temperature for a brief period (5–10 min) allowed us to isolate the diketone **9**.

Scheme 2



Removal of the acetal protecting group in **10** by acidic conditions afforded **11** in 75% yield. When **11** was reacted with potassium *tert*-pentyl oxide in refluxing toluene the steroid analogue **12** was obtained in 57% yield (overall yield **10**→→**12**, 43%).

It is clear that **12** allows a synthetic entry into 19-nor- and A-ring-aromatic steroid analogues since as we have already shown in [1], acid-catalyzed cyclopropane ring opening of **12** is expected to afford the required D-ring-cyclopentanone system normally found in the natural steroids. Studies in this direction are currently underway in our laboratories.

Financial aid from the Science Council of British Columbia and the *Natural Sciences and Engineering Research Council of Canada* is gratefully acknowledged. The authors would also like to thank *MacMillan Bloedel Limited* and Mr. *Alan Moss* and Associates for generous samples of cedar leaf oil. Computing funds for the structure analysis were provided for by the *Xerox Corporation of Canada* and the University of British Columbia Computing Centre.

Experimental Part

General Remarks. See [2].

4a-Isopropyl-1β-methyl-7-[2'-(6''-methyl-2''-pyridyl)ethyl]tricyclo[4.4.0.0^{2,4}]dec-6-en-8-one (**5**). To a solution of K (160 mg, 4.1 mmol) in *t*-pentyl alcohol (160 ml) was added enone **1** (4.08 g, 20 mmol) over 10 min at 0°. After the resulting solution was stirred for 20 min, freshly distilled 2-methyl-6-vinylpyridine (**4**; 3.6 g, 30 mmol) was added. The solution was stirred at 0° for 20 min, then at 105° for 15 h. After cooling to r.t., glacial AcOH was added to acidify the solution, and the solvent was evaporated to dryness. Chromatography of the crude residue on silica gel with CH_2Cl_2/acetone 3:1 (*v/v*) afforded pure **5**, 5.5 g (80%), as a colourless oil, $[\alpha]_D = +34°$ ($c = 1$, $CHCl_3$). UV (MeOH): 253 (3.94), 273 (3.69). IR (film): 3040, 1675, 1600, 1590. ^{1}H-NMR (400 MHz, $CDCl_3$): 0.59, 0.68 (2 *t*, $J = 6$, 2 H, $H_2C(3)$); 0.79, 0.82 (2 *d*, $J = 7$, 6 H, $(CH_3)_2OH$); 0.98 (*s*, 3 H, $H_3C-C(1)$); 1.01 (*m*, 1 H, H–C(2)); 1.22 (*sept.*, $J = 7$, 1 H, $(CH_3)_2CH$); 1.82 (*d*, $J = 18$, 1 H); 2.0 (*m*, 2 H); 2.36–2.64 (*m*, 5 H); 2.54 (*s*, 3 H, $H_3C-C(6'')$); 2.74 (*m*, 1 H); 2.87 (*m*, 1 H); 6.86 (*d*, $J = 8$, 1 H); 6.96 (*d*, $J = 8$, 1 H); 7.43 (*t*, $J = 8$, 1 H). MS: 323 (26, M^+), 107 (100). MS (HR): 323.2255 (M^+, calc. 323.2249).

$C_{22}H_{29}NO$ (323.48) Calc. C 81.73 H 8.98 N 4.27% Found C 81.72 H 8.95 N 4.23%

4a-Isopropyl-1β-methyl-7a-[2'-(6''-methyl-2''-pyridyl)ethyl]tricyclo[4.4.0.0^{2,4}]decan-8-one **6**. A solution of **5** (1.2 g, 3.7 mmol) in EtOAc (50 ml) containing Et_3N (0.645 g) and 10% Pd/C (0.250 g) was shaken under H_2 at 5 atm for 48 h at r.t. The catalyst was removed by filtration and washed with hot EtOAc (50 ml). The combined filtrate and washings were evaporated. The crude product was chromatographed on silica gel with CH_2Cl_2/acetone 9:1, yielding 0.85 g (77%) of pure crystalline product. Crystallization from petroleum ether gave an analytical sample, m.p. 71–72.5°, $[\alpha]_D = +88°$ ($c = 1$, $CHCl_3$). UV (EtOH): 262 (3.68), 273 (3.56). IR ($CHCl_3$): 3030, 1710, 1590, 1580. ^{1}H-NMR (400 MHz, $CDCl_3$): 0.20 (*d*×*d*, $J = 8$, 6, 1 H, $H_\beta-C(3)$); 0.43 (*t*, $J = 6$, 1 H, $H_a-C(3)$); 0,84, 0.9 (2 *d*, $J = 7$, 6 H, $(CH_3)_2CH$); 0.91 (*m*, 1 H, H–C(2)); 1.2 (*s*, 3 H, $H_3C-C(1)$); 1.23 (*m*, 1 H); 1.33 (*sept.*, $J = 7$, 1 H, $(CH_3)_2CH$); 1.49 (*m*, 1 H); 1.62 (*m*, 1 H); 1.81 (*m*, 3 H); 2.14 (*m*, 2 H); 2.42 (*m*, 1 H); 2.52 (*s*, 3 H, $H_3C-C(6'')$); 2.65 (*m*, 1 H); 2.77 (*m*, 1 H); 6.93 (*t*, $J = 8$, 2 H); 7.44 (*t*, $J = 8$, 2 H). MS: 325 (4, M^+), 107 (100). MS (HR): 325.2413 (M^+, calc. 325.2406).

$C_{22}H_{31}NO$ (325.50) Calc. C 81.23 H 9.53 N 4.30% Found C 81.10 H 9.39 N 4.24%

4a-Isopropyl-1β-methyl-7a-[2'-(6''-methyl-2''-pyridyl)ethyl]tricyclo[4.4.0.0^{2,4}]decan-3-one ethylene acetal (**7**). To a solution of **6** (0.85 g, 2.61 mmol) in toluene (50 ml) was added *p*-toluenesulfonic acid (0.125 g, 0.66 mmol) and ethylene glycol (5.1 ml). The mixture was heated under reflux with azeotropic removal of H_2O for 24 h. The mixture was cooled, washed with $NaHCO_3$, dried (Na_2SO_4), and evaporated. The residue was chromatographed on silica gel with Et_2O/petroleum ether 3:1 to give **7**, yield 0.640 g (67%), $[\alpha]_D = +59°$ ($c = 1$, $CHCl_3$). UV (EtOH): 266 (3.71), 273 (3.59). IR ($CHCl_3$):

3050, 1590, 1580. ^{1}H-NMR (400 MHz, $CDCl_3$): 0.11 (*d*×*d*, *J*=8, 6, 1 H, H_β–C(3)); 0.39 (*t*, *J*=6, 1 H, H_α–C(3)); 0.83 (*m*, 1 H, H–C(2)); 0.88, 0.96 (2 *d*, *J*=7, 6 H, $(CH_3)_2CH$); 0.98 (*s*, 3 H, H_3C–C(1)); 1.20–1.70 (*m*, 8 H); 1.81 (*m*, 1 H); 1.97 (*m*, 2 H); 2.55 (*s*, 3 H, H_3C–C(6″)); 2.66 (*m*, 1 H); 2.80 (*m*, 1 H); 3.82–4.01 (*m*, 4 H, OCH_2CH_2O); 6.95 (*m*, 2 H); 7.47 (*t*, *J*=8, 1 H). MS: 3.69 (13, M^+), 324 (100). MS (HR): 369.2669 (M^+, calc. 369.2668).

$C_{24}H_{35}NO_2$ (369.55) Calc. C 78.04 H 9.48 N 4.00% Found C 78.14 H 9.50 N 3.89%

4α-Isopropyl-1β-methyl-7α-[2′-(3″-oxo-1″-cyclohexenyl)ethyl]tricyclo[4.4.0.0^{2,4}]decan-3-one 3,3-ethylene acetal (**10**). To a solution of **7** (0.369 g, 1 mmol) and abs. EtOH (0.273 g, 6 mmol) in abs. Et_2O (15 ml) and anh. liq. NH_3 (30 ml) maintained at −70° was added Na (0.075 g, 3.1 mmol). The solution was stirred for 60 min at −70°, and the NH_3 was evaporated under a stream of Ar. The residue was dissolved in 40 ml of EtOH/H_2O 1:1 and stirred for 32 h at r.t., then extracted with CH_2Cl_2 (3×25 ml). The combined extracts were dried (Na_2SO_4) and evaporated. Chromatography on silica gel with Et_2O/petroleum ether 3:1 yielded pure **10**, 0.2 g (65%), $[\alpha]_D$=47° (*c*=1, $CHCl_3$). UV (EtOH): 236 (4.16). IR ($CHCl_3$): 3040, 1665, 1625. ^{1}H-NMR ($CDCl_3$): 0.14 (*d*×*d*, *J*=8, 6, 1 H, H_β–C(3)); 0.37 (*t*, *J*=6, 1 H, H_α–C(3)); 0.84 (*m*, 1 H, H–C(2)); 0.88, 0.96 (2 *d*, *J*=7, 6 H, $(CH_3)_2CH$); 0.98 (*s*, 3 H, H_3C–C(1)); 1.25–1.50 (*m*, 6 H); 1.55–1.68 (*m*, 2 H); 1.70–1.83 (*m*, 2 H); 1.90–2.11 (*m*, 4 H); 2.15–2.41 (*m*, 5 H); 3.80–4.1 (*m*, 4 H); 5.85 (*s*, 1 H). MS: 372 (7.2, M^+), 99 (100). MS (HR): 372.2666 (M^+, calc. 372.2665).

$C_{24}H_{36}O_3$ (372.55) Calc. C 77.41 H 9.67% Found C 77.27 H 9.70%

The intermediate diketone, *7α-(3′,7′-dioxooctyl)-4α-isopropyl-1β-methyltricyclo[4.4.0.0^{2,4}]decan-3-one 3,3-ethylene acetal* (**9**), can be isolated from the reaction described above as a predominant product when the time of hydrolysis with EtOH/H_2O 1:1 is reduced from 32 h to 10 min. Extraction with CH_2Cl_2 and chromatography on silica gel, as above, afforded pure **9**, $[\alpha]_D$=+51° (*c*=1, $CHCl_3$). IR ($CHCl_3$): 3040, 1705. ^{1}H-NMR ($CDCl_3$): 0.13 (*d*×*d*, *J*=8, 6, 1 H, H_β–C(3)); 0.36 (*t*, *J*=6, 1 H, H_α–C(3)); 0.84 (*m*, 1 H, H–C(2)); 0.88, 0.95 (2 *d*, *J*=7, 6 H, $(CH_3)_2CH$); 0.97 (*s*, 3 H, H_3C–C(1)); 1.25–1.50 (*m*, 5 H); 1.53–1.73 (*m*, 4 H); 1.8–2.0 (*m*, 4 H); 2.14 (*s*, 3 H); 2.23–2.33 (*m*, 1 H); 2.34–2.41 (*m*, 1 H); 2.43–2.5 (*m*, 4 H); 3.82–4.03 (*m*, 4 H). MS: 390 (12, M^+), 99 (100). MS (HR): 390.2770 (M^+, calc. 390.2770).

$C_{29}H_{38}O_4$ (390.50) Calc. C 73.84 H 9.74% Found C 73.76 H 9.78%

4α-Isopropyl-1β-methyl-7α-[2′-(3″-oxo-1″-cyclohexenyl)ethyl]tricyclo[4.4.0.0^{2,4}]decan-3-one (**11**). To a solution of **10** (0.39 g, 1.04 mmol) in EtOH (30 ml) was added 5% HCl (15 ml). The resulting solution was stirred at r.t. for 2 h, then aq. $NaHCO_3$ was added to pH 8 and the mixture extracted with CH_2Cl_2 (3×25 ml). The combined extracts were washed with H_2O (2×25 ml), then dried (Na_2SO_4), and evaporated. Subsequent chromatography yielded 0.260 g (75%) of pure **11**, $[\alpha]_D$=+59.3° (*c*=1, $CHCl_3$). UV (EtOH): 235 (4.20). IR ($CHCl_3$): 3050, 1710, 1665, 1625. ^{1}H-NMR (400 MHz, $CDCl_3$): 0.22 (*d*×*d*, *J*=8,6, 1 H, H_β–C(3)); 0.41 (*t*, *J*=6, 1 H, H_α–C(3)); 0.93 (*m*, 1 H, H–C(2)); 0.85, 0.91 (2*d*, *J*=7, 6 H, $(CH_3)_2CH$); 1.13–1.23 (*m*, 2 H); 1.24 (*s*, 3 H, H_3C–C(1)); 1.30–1.40 (*m*, 1 H); 1.50–1.90 (*m*, 6 H); 5.86 (*s*, 1 H). MS: 328 (43, M^+), 123 (100). MS (HR): 328.2408 (M^+, calc. 328.2402).

16α-Isopropyl-16,17β-dihydro-3′H-cycloprop[16,17]-19-nor-14β-androsta-4,9-dien-3-one (**12**). To a solution of **11** (0.150 g, 0.45 mmol) in EtOH (25 ml) was added Na (0.02 g) dissolved in *t*-pentyl alcohol (2 ml) at r.t. The resulting solution was heated under reflux for 4 h, then cooled to r.t., diluted with H_2O (30 ml), and extracted with CH_2Cl_2 (3×25 ml). The combined extracts were dried (Na_2SO_4) and evaporated. Column chromatography on silica gel with Et_2O/petroleum ether 3:1 yielded 0.140 g (57%) of **12**, $[\alpha]_D$=−86° (*c*=1, $CHCl_3$). UV (EtOH): 303 (3.93). IR ($CHCl_3$): 3050, 1660, 1615. ^{1}H-NMR (400 MHz, $CDCl_3$): 0.2 (*d*×*d*, *J*=8, 6, 1 H, H_β–C(3′)); 0.34 (*t*, *J*=6, 1 H, H_α–C(3′)); 0.89 (*m*, 1 H, H–C(17)); 0.85, 0.93 (2 *d*, *J*=7, 6 H, $(CH_3)_2CH$); 1.09 (*s*, 3 H, H_3C(18)); 1.20–1.65 (*m*, 7 H); 1.70–1.80 (*m*, 1 H); 2.02–2.14 (*m*, 1 H); 2.30–2.64 (*m*, 7 H); 2.75–2.86 (*m*, 1 H); 5.70 (*s*, 1 H). MS: 310 (100, M^+). MS (HR): 310.2296 (M^+, calc. 310.2296).

X-ray Crystallographic Analysis of **6**. A crystal *ca.* 0.25×0.40×0.45 mm in size was used. Unit-cell parameters were calculated from θ-values for 25 reflections (θ=15–20°) measured on a diffractometer with Mo$K\alpha_1$ radiation (λ=0.70930 Å). Crystal data at 22° are: $C_{22}H_{31}NO$, mol.w.=325.49. Monoclinic: *a*=6.4182 (6), *b*=22.8881 (11), *c*=7.4128 (7) Å, β=115.399 (4)°, *V*=983.7 (1) Å^3, *z*=2, ρ_c=1.099 gcm^{-3}, *F*(000)=356, μ(Mo$K\alpha$)=0.62 cm^{-1}. Absent reflections: 0*k*0, *k* add, space group $P2_1$ (c_2^2, No. 4).

Intensities were measured with graphite-monochromated Mo*Ka* radiation ($\lambda = 0.71073$ Å) on an *Enraf-Nonius-CAD4-F* diffractometer. An ω-2θ scan at 1.55-10.06° · min^{-1} over a range of $(0.80 + 0.35 \cdot \tan\theta)$ degrees in ω (extended by 25% on both sides for background measurement) was employed. Data was measured to $2\theta = 50°$. The intensities of 3 standard reflections, measured every 3600 s throughout the data collection, remained constant to within ±3%. Of the 2321 independent reflections measured, 1318 (56.8%) had intensities greater than $3\sigma(I)$ above background where $\sigma^2(I) = s + 2B + (0.04(s-B))^2$ with s and B normalized scan and background counts, respectively. In view of the low value of μ, no absorption correction was made.

The structure was solved by direct methods, the positions of all 24 non-H-atoms being determined from an *E*-map. Full-matrix leastsquares refinement of the non-H-atoms with anisotropic temperature factors resulted in $R = 0.096$. A difference map revealed the positions of 27 of the 31 H-atoms. Idealized coordinates (based on observed positions in the case of CH-groups) and thermal parameters (20% greater than the equivalent isotropic thermal parameter of the associated C-atom) were derived for the H-atoms which were included as fixed atoms in subsequent cycles of refinement, these parameters being adjusted after each cycle of refinement. The scattering factors of [4] were used for non-H-atoms and those of [5] for H-atoms. The weighting scheme $w = 1/\sigma^2(F)$ where $\sigma^2(F)$ is derived from the previously defined $\sigma^2(I)$ gave uniform average values of $w(|F_o| - |F_c|)^2$ over ranges of $|F_o|$ and was employed in the final stages of refinement. Convergence was reached at $R = 0.058$ and $R_w = 0.067$ for 1318 reflections with $I \geq 3\sigma(I)$. The function minimized was $\Sigma w(|F_o| - |F_c|)^2$, $R = \Sigma \| F_o| - |F_c\| / \Sigma |F_o|$, and $R_w = (\Sigma w(|F_o| - |F_c|^2) / \Sigma m |F_o|^2)^{1/2}$.

On the final cycle of refinement the mean and maximum parameter shifts corresponded to 0.08 and 0.42 σ, respectively. The mean error in an observation of unit weight was 2.59. A final difference map showed no unusual features. The final positional and anisotropic thermal parameters for the non-H-atoms appear in *Tables 1* and *2*, respectively. Bond distances are given in *Table 3*. Calculated coordinates and thermal parameters for H-atoms, bond angles, selected torsion angles, and measured and calculated structure factor amplitudes are available on request from Dr. *J. Trotter*.

Table 1. *Final Positional Parameters* (Fractional × 10^4) *with Estimated Standard Deviations in Parentheses*

Atom	*x*	*y*	*z*
O	9297 (7)	373	6349 (6)
N	2919 (6)	1454 (2)	1841 (6)
C(1)	10225 (8)	−603 (3)	10014 (7)
C(2)	10656 (8)	42 (3)	9687 (7)
C(3)	8803 (8)	221 (3)	7679 (8)
C(4)	6416 (8)	171 (3)	7476 (6)
C(5)	5930 (8)	−458 (3)	7959 (6)
C(6)	5577 (8)	−912 (3)	6308 (7)
C(7)	6077 (9)	−1494 (3)	7374 (8)
C(8)	4986 (11)	−1586 (3)	8781 (10)
C(9)	7373 (9)	−1378 (3)	9556 (7)
C(10)	7815 (8)	−722 (3)	9874 (7)
C(11)	7640 (10)	−496 (3)	11771 (8)
C(12)	6533 (12)	−2026 (3)	6351 (9)
C(13)	8629 (14)	−1955 (3)	5975 (14)
C(14)	4398 (14)	−2188 (5)	4483 (16)
C(15)	4535 (8)	379 (3)	5435 (7)
C(16)	4545 (9)	1043 (3)	5180 (8)
C(17)	2499 (8)	1263 (3)	3375 (7)
C(18)	335 (8)	1262 (3)	3318 (7)
C(19)	−1492 (9)	1479 (3)	1666 (8)
C(20)	−1067 (10)	1693 (3)	106 (7)
C(21)	1115 (9)	1665 (3)	230 (7)
C(22)	1632 (12)	1872 (3)	−1451 (9)

Table 2. *Final Anisotropic Thermal Parameters* ($U_{ij} \times 10^3$ Å^2)[a] *and their Estimated Standard Deviations*

Atom	U_{11}	U_{22}	U_{33}	U_{12}	U_{13}	U_{23}
O	79 (3)	89 (3)	74 (3)	12 (2)	43 (2)	30 (2)
N	51 (2)	36 (2)	42 (2)	−3 (2)	15 (2)	−1 (2)
C(1)	58 (3)	47 (3)	38 (2)	5 (2)	9 (2)	6 (2)
C(2)	53 (3)	44 (3)	55 (3)	−3 (2)	14 (3)	−2 (2)
C(3)	61 (3)	35 (2)	51 (3)	1 (2)	27 (3)	1 (2)
C(4)	50 (3)	35 (2)	30 (2)	0 (2)	11 (2)	−2 (2)
C(5)	48 (3)	39 (2)	37 (2)	3 (2)	17 (2)	4 (2)
C(6)	60 (3)	37 (3)	36 (3)	1 (2)	2 (2)	0 (2)
C(7)	55 (3)	33 (3)	59 (3)	−3 (2)	8 (3)	3 (2)
C(8)	76 (4)	54 (4)	94 (4)	−8 (3)	35 (4)	19 (3)
C(9)	63 (3)	45 (3)	50 (3)	3 (2)	12 (3)	15 (2)
C(10)	58 (3)	47 (3)	36 (2)	0 (2)	16 (2)	8 (2)
C(11)	89 (4)	76 (4)	46 (3)	6 (3)	33 (3)	6 (3)
C(12)	80 (4)	38 (3)	81 (4)	4 (3)	15 (4)	−2 (3)
C(13)	104 (6)	64 (4)	131 (7)	14 (4)	47 (6)	−29 (4)
C(14)	110 (6)	88 (6)	131 (7)	−5 (5)	4 (5)	−59 (5)
C(15)	49 (3)	38 (3)	35 (2)	6 (2)	6 (2)	4 (2)
C(16)	57 (3)	39 (3)	47 (3)	6 (2)	9 (2)	3 (2)
C(17)	59 (3)	30 (2)	38 (3)	4 (2)	18 (2)	0 (2)
C(18)	56 (3)	49 (3)	40 (3)	1 (2)	19 (2)	4 (2)
C(19)	57 (3)	63 (3)	62 (3)	4 (3)	23 (3)	−3 (3)
C(20)	71 (4)	48 (3)	42 (3)	6 (3)	10 (3)	3 (2)
C(21)	51 (3)	41 (3)	40 (3)	−2 (2)	14 (2)	−2 (2)
C(22)	91 (4)	84 (5)	45 (3)	−8 (3)	24 (3)	9 (3)

[a] The anisotropic thermal parameters employed in the refinement are U_{ij} in the expression: $f = f^{\circ} \exp(-2\pi^2 \Sigma \Sigma U_{ij} h_i h_j a_i^* a_j^*)$

Table 3. *Bond Lengths (Å) with Estimated Standard Deviations in Parentheses*

Bond	Length (Å)	Bond	Length (Å)
O–C(3)	1.210 (6)	C(7)–C(12)	1.528 (8)
N–C(17)	1.349 (5)	C(8)–C(9)	1.467 (8)
N–C(21)	1.347 (6)	C(9)–C(10)	1.526 (7)
C(1)–C(2)	1.540 (7)	C(10)–C(11)	1.547 (7)
C(1)–C(10)	1.530 (7)	C(12)–C(13)	1.495 (10)
C(2)–C(3)	1.510 (7)	C(12)–C(14)	1.518 (10)
C(3)–C(4)	1.478 (6)	C(15)–C(16)	1.532 (7)
C(4)–C(5)	1.547 (6)	C(16)–C(17)	1.503 (7)
C(4)–C(15)	1.551 (6)	C(17)–C(18)	1.371 (6)
C(5)–C(6)	1.547 (6)	C(18)–C(19)	1.375 (7)
C(5)–C(10)	1.540 (6)	C(19)–C(20)	1.386 (8)
C(6)–C(7)	1.511 (7)	C(20)–C(21)	1.366 (7)
C(7)–C(8)	1.500 (8)	C(21)–C(22)	1.497 (8)
C(7)–C(9)	1.492 (7)		

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