344-04-7; 2-(pentafluorophenyl)-2-propanol, 715-31-1; acetone, 67-64-1.

Supplementary Material Available: Views showing the crystal packing in **10**, **11**, and **12** and tables of positional and anisotropic thermal parameters, molecular contacts, and selected torsional angles for **10–12** and related compounds (13 pages). (Final structure factor amplitudes for **10–12** are available from the authors.) Ordering information is given on any current masthead page.

The Octant Rule. 21.[1] Antioctant Effects in δ,ε-Unsaturated Ketones

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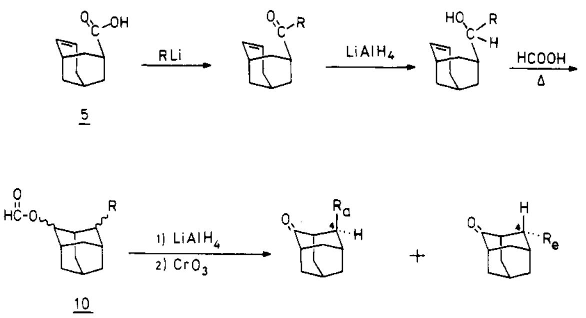
Optically active (1*S*,3*R*)-4(*S*)(a)- and (1*S*,3*R*)-4(*R*)(e)-phenyl- and -benzyladamantan-2-ones have been synthesized, and their n → π* circular dichroism spectra have been recorded. The equatorial benzyl substituent shows greatly enhanced Cotton effect magnitudes over those expected for equatorial alkyl perturbers of the same size, and β-axial phenyl and benzyl substituents are found to be powerful front octant (dissignate) perturbers.

Introduction

Since its formulation over 25 years ago,[2] the octant rule for the n → π* transition of saturated alkyl ketones has enjoyed wide application in extracting stereochemical and conformational information from chiral ketones. The octants are derived from the local symmetry (C_{2v}) of the carbonyl group and a consideration of the relevant orbitals of the n → π* transition. The two carbonyl symmetry planes divide all space about the C=O into quadrants, and a third, nonsymmetry-derived nodal surface divides all space into front and back octants (as viewed down the C=O bond from O to C, Figure 1).[3,4] In practical application,[5] alkyl perturbers lying in lower right and upper left back octants make a (+) contribution to the sign and magnitude of the n → π* rotatory strength, and reflection of a perturber across either of the C=O C_{2v} symmetry planes leads to a mirror image molecular fragment and hence to a (−) contribution. Since the third nodal surface does not follow from symmetry, reflection of a perturber into front octants leads to a sign change without necessarily the same magnitude.

Most of the relatively few cases of antioctant (dissignate[6]) behavior have derived from atoms or groups lying close to the octant rule nodal surfaces, especially the third nodal surface.[7] Antioctant behavior in back octants has almost always been associated with a breakdown of the (orbital) symmetry due to α,β-conjugation[8] or β,γ-homoconjugation,[9] such that the carbonyl group is no longer inherently symmetric but becomes a component of an inherently dissymmetric chromophore.[5c] Because interchromophoric interaction falls off with increasing distance, evidence for nonoctant behavior in back octants is rare for γ,δ-conjugated ketones, and only one case has been reported for a δ,ε-unsaturated ketone.[10] Their unusual octant behavior has been rationalized in terms of "through-bond" interaction of the two chromophores.

Scheme I



We have pursued an investigation of γ,δ-bis-homoconjugation and δ,ε-tris-homoconjugation effects of the ketone carbonyl with phenyl chromophores using the adamantanone system. Adamantanone possesses C_{2v} molecular symmetry, which coincides with the local symmetry of the C=O chromophore, and β-equatorial substituents probe back octants (whereas β-axial substituents can probe front octants).[3] In this work, we describe the synthesis and circular dichroism (CD) spectra of β-equatorial and β-axial phenyl- and benzyladamantanones **1–4**. These compounds provide additional evidence for long-range interchromophoric interaction.

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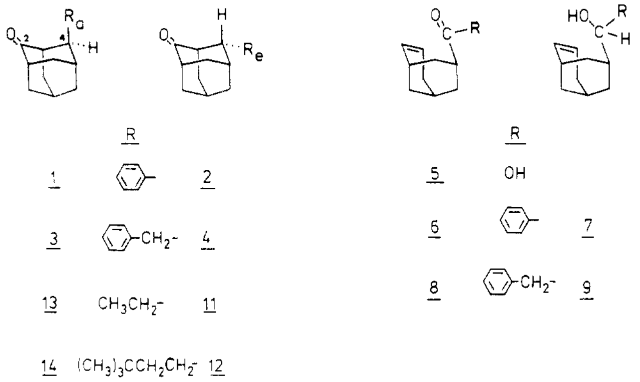

Results and Discussion

Synthesis and Stereochemistry. The key synthetic intermediate in the preparation of aromatic ketones 1–4 was (+)-*endo*-bicyclo[3.3.1]non-6-ene-3(*R*)-carboxylic acid (**5**), which was synthesized from adamantan-2-one in three steps via (1) an abnormal Schmidt reaction (using NaN_3/CH_3SO_3H to give 4(e)-(methanesulfonyloxy)-adamantan-2-one, followed by (2) a quasi-Favorskii reaction (KOH/aqueous ethanol) to give racemic **5**, and then (3) resolution using dehydroabietylamine.[3] Treatment of **5**, as outlined in Scheme I, with phenyllithium or benzyllithium gave the corresponding bicyclo[3.3.1]non-6-en-3-yl ketones. From these ketones the adamantane skeleton was reformed, first by reduction to the alcohol and then by solvolysis in hot formic acid. Saponification of the adamantyl formate diastereomers (**10**) followed by CrO_3 oxidation afforded the desired β-phenyladamantanones (**1** and **2**) and β-benzyladamantanones (**3** and **4**). The epimers were separated by preparative gas chromatography. Their absolute configuration 1*S*,3*R* follows from the known absolute configuration of (+)-**5**.[3]

Circular Dichroism. Because the adamantanone skeleton is symmetric, the equatorial and axial substituents of **1**–**4** may be viewed as the elements controlling the sign and magnitude of the n → π* CD Cotton effect (CE) according to the octant rule. As expected from work with β-alkyladamantanones, the CD spectra of **1** and **3** (Figures 2 and 3) show CEs dominated by front octant perturbers, and the CD spectra of **2** and **4** (Figures 4 and 5) show CEs expected from back octant perturbers. As has been recognized previously, the equatorial substituents lie well behind the carbonyl carbon in a lower right or upper left *back* octant[3] and are therefore expected to make a (+) octant contribution to the CD CE. The CE magnitudes, as measured by their reduced rotatory strengths [*R*], are moderately temperature-dependent (Table I), with the CE signs remaining (+) over a wide temperature range. Thus, the β-equatorial phenyl and benzyl substituents make consignate[6] contributions and obey the octant rule. However, in comparing their CE magnitudes ([*R*]) to those of adamantanones with β-equatorial *alkyl* substituents of comparable size,[3] (+)-(1*S*,3*R*)-4(*R*)(e)-ethyladamantan-2-one (**11**) and (+)-(1*S*,3*R*)-4(*R*)(e)-(3,3-dimethylbutyl)-adamantan-2-one (**12**), the equatorial phenyl substituent appears ordinary over a wide temperature range, but the equatorial benzyl substituent throughout shows considerably enhanced [*R*] values. Only at the very low temperatures does the equatorial phenyl substituent show [*R*] values roughly one-half those of the ethyl and neohexyl. Thus, the CD CEs of **2** and **4**, although dominated by octant contributions, are not quite what one might have expected from the octant rule picture.

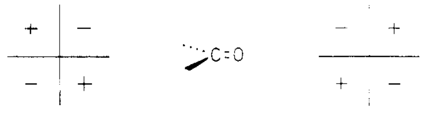

Figure 1. Octant contribution signs that perturbers make in back (left) and front (right) octants. The axes separating the signed octant regions shown correspond to C=O C_{2v} symmetry-derived planes. For applications of octant diagrams to organic stereochemistry, see ref 5.

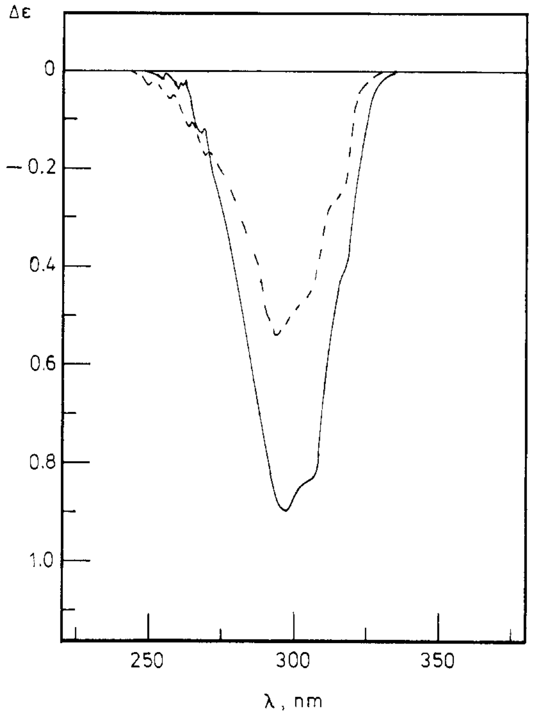

Figure 2. Circular dichroism spectra of 10^{-3} M (1*S*,3*R*)-4(a)-substituted adamantan-2-ones in EPA (ether–isopentane–ethanol, 5:5:2, v/v/v) run at 25 °C and corrected to 100% ee. The axial substituents are (**1**) phenyl (– –), $\Delta\epsilon_{max}^{296} = -0.56$, and (**3**) benzyl (—), $\Delta\epsilon_{max}^{297} = -0.90$.

We take these results as evidence for long-range interchromophoric interaction between the aromatic and the ketone chromophores. With the δ,ε-unsaturated ketone **3** (equatorial benzyl group), an ~50% exaltation of the CD CE is seen vs. the alkyl substituent model. This compares favorably with the only available CD data[10] for long-range interaction in a δ,ε-unsaturated ketone: 7-methylene-5α-cholestan-3-one [$\Delta\epsilon_{max}^{290}$ +1.26 (hexane), $\Delta\epsilon_{max}^{290}$ +1.91 (ethanol)] where an exaltation of ~50% over the parent is observed, 5α-cholestan-3-one [$\Delta\epsilon_{max}^{297}$ +0.84 (hexane), $\Delta\epsilon_{max}^{290}$ +1.32 (ethanol)]. The UV ε values, too, of **4** are considerably enhanced over those of saturated alkyl ketones or even the corresponding phenyl ketone **2** (Figure 5). Just as UV spectroscopy has shown that electronic coupling between chromophores at long interchain distances is geometry-dependent (Figure 6),[11,12] so can one expect the CD contributions from an extended chromophore to be highly dependent on the relative orientation of the independent chromophoric units.[9] This is borne out in the considerably greater temperature influence on [*R*], and hence the conformation, of **2** and **4** relative to **11** and **12** (Table I). The benzyl group in **4** is presumably already in its most favorable orientation for this interchromophoric interaction with the C=O group, whereas the phenyl group in **2** apparently tends to adopt

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Table I. Reduced Rotatory Strengths[a] of (1*S*,3*R*)-4(e)-Phenyl- and (1*S*,3*R*)-4(e)-Benzyladamantan-2-ones

compd	substituent	solvent	$[R]^{25}$	$[R]^{0}$	$[R]^{-50}$	$[R]^{-100}$	$[R]^{-150}$	$[R]^{-175}$
2	C_6H_5	EPA[b]	2.750	2.470	2.052	1.797	1.384	1.245
		MI[c]	2.407	2.303	2.065	1.835	1.430	0.883
4	$CH_2C_6H_5$	EPA	4.933	4.671	4.582	4.728	4.655	4.684
		MI	4.401	4.510	4.856	5.832	6.418	6.576
11[d]	CH_2CH_3	EPA	2.355	2.362	2.232	2.230	2.171	2.177
		MI	2.398	2.367	2.333	2.318	2.242	2.258
12[d]	$CH_2CH_2C(CH_3)_3$	EPA	3.169	3.142	2.991	2.906	2.771	2.773
		MI	2.096	2.112	2.043	2.030	2.034	2.093

[a] [*R*] is rotatory strength (cgs units) × 1.08 × 10^{40}. Values are corrected to 100% ee and for solvent contraction. The superscript numbers are temperatures, ±2°, in °C. [b] EPA = diethyl ether–isopentane–ethanol, 5:5:2 (v/v/v). [c] MI = methylcyclohexane–isopentane, 4:1 (v/v). [d] Data from ref 3.

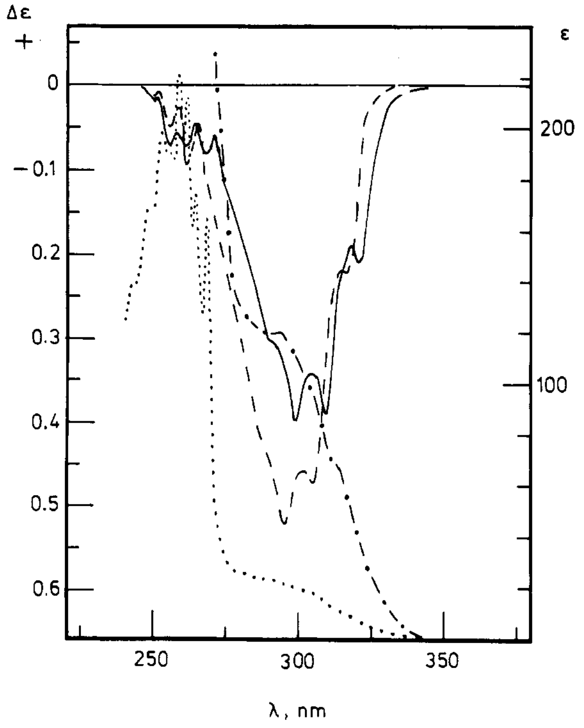

Figure 3. Circular dichroism and ultraviolet spectra of 10^{-3} M (1*S*,3*R*)-4(a)-substituted adamantan-2-ones in MI (methylcyclohexane–isopentane, 4:1, v/v) run at 25 °C and corrected to 100% ee. In the CD spectra the axial substituents are (1) phenyl (– –), $\Delta\epsilon_{max}{}^{296} = -0.52$, and (3) benzyl (—), $\Delta\epsilon_{max}{}^{309}$ −0.41. In the UV spectra the axial substituents are (1) phenyl (···), $\epsilon_{max}{}^{290}$ 30, $\epsilon_{max}{}^{258}$ 277, and (3) benzyl (–·–), $\Delta\epsilon_{max}{}^{296} = 121$, $\Delta\epsilon_{max}{}^{251} = 1077$.

the "interaction" conformation only at low temperatures, where it makes an antioctant contribution on top of the expected octant consignate CE. Antioctant contributions have been reported for *β*,*γ*-unsaturated ketones and attributed to *π* back-donation.[10] In the case of **2**, this mechanism requires alignment of the C_3–C_4 bond in adamantanone with the p-*π* orbital at C_1 of the phenyl chromophore. Apparently, as taken from Dreiding models, the "through-bond" coupling of the C=O *π*,*π** system with the aromatic chromophore's *π*,*π** system in both **2** and **4** involves the favorable primary zig–zag (or W) path.[6] Long-range coupling of *π*-systems through an extended *σ*-framework has been noted previously in ground-state *π* splittings determined by PES.[13]

The *β*-axial phenyl and benzyl chromophores of **1** and **3** do not lie along a primary zig–zag *σ*-coupling pathway.

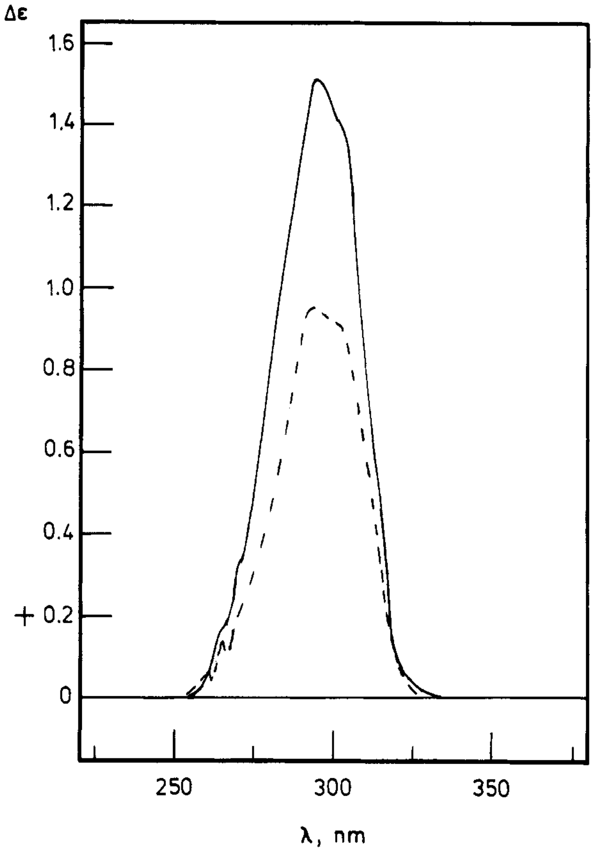

Figure 4. Circular dichroism spectra of 10^{-3} M (1*S*,3*R*)-4(e)-substituted adamantan-2-ones in EPA (ether–isopentane–ethanol, 5:5:2, v/v/v) run at 25 °C and corrected to 100% ee. The equatorial substituents are (2) phenyl (– –), $\Delta\epsilon_{max}{}^{294} = +0.95$, and (4) benzyl (—), $\Delta\epsilon_{max}{}^{297} = +1.5$.

However, since the aromatic chromophore of **3** lies well out and over the C=O group, it should have the greatest potential for "through-space"[13b] interaction with the carbonyl chromophore. And as seen in the UV, its n → *π** and *π* → *π** intensities (Figure 3) are enhanced relative to those of **1**, **11**, or **12** (Figure 6). The UV *ϵ* is similar to that found for the *γ*,*δ*-unsaturated cage compound (**13**, Figure 6)[12] with its aromatic chromophore likewise oriented over the C=O group. Unlike **13**, however, the λ_{max} of **3** (and **1**) were not shifted to longer wavelengths.

Both the *β*-axial phenyl and benzyl groups are powerful dissignate groups, lying well into front regions. Their [*R*] data (Table II) show the same trend toward increasing magnitudes with lowered temperatures as those of *β*-axial alkyl perturbers and, for **4**, qualitatively the same solvent dependence. Just how much of the [*R*] can be attributed to ordinary front octant contributions and how much to interchromophoric interaction is difficult to assess at present and awaits a detailed theoretical treatment.

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Table II. Reduced Rotatory Strengths[a] of (1*S*,3*R*)-4(a)-Phenyl- and (1*S*,3*R*)-4(a)-Benzyladamantan-2-ones

compd	substituent	solvent	$[R]^{25}$	$[R]^{0}$	$[R]^{-50}$	$[R]^{-100}$	$[R]^{-150}$	$[R]^{-175}$
1	C_6H_5	EPA	-1.718	-1.687	-1.919	-2.119	-2.201	-2.381
		MI	-1.745	-1.798	-1.974	-2.260	-2.674	-2.904
3	$CH_2C_6H_5$	EPA	-2.637	-2.680	-2.885	-3.370	-4.040	-4.453
		MI	-1.459	-1.565	-1.558	-1.868	-2.001	-2.303
13[d]	CH_2CH_3	EPA	-0.362	-0.375	-0.450	-0.652	-0.786	-0.880
		MI	-0.200	-0.252	-0.293	-0.404	-0.748	-0.950
14[d]	$CH_2CH_2C(CH_3)_3$	EPA	-0.580	-0.571	-0.678	-0.768	-0.917	-1.072
		MI	-0.300	-0.302	-0.363	-0.598	-0.862	-1.248

[a] [*R*] is rotatory strength (cgs units) × 1.08 × 10^{40}. Values are corrected to 100% ee and for solvent contraction. The superscript numbers are temperatures, ±2°, in °C. [b] EPA = diethyl ether–isopentane–ethanol, 5:5:2 (v/v/v). [c] MI = methylcyclohexane–isopentane, 4:1 (v/v). [d] Data from ref 3.

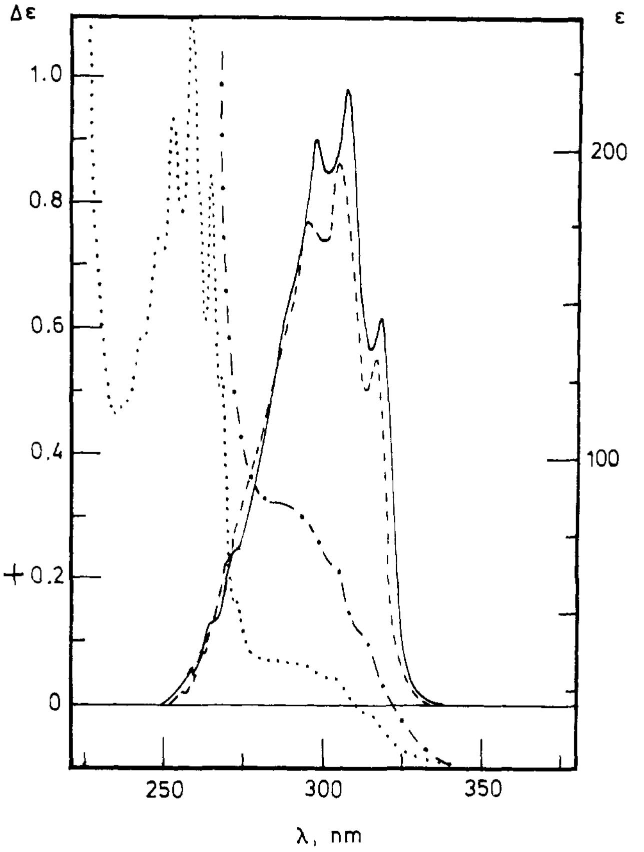

Figure 5. Circular dichroism and ultraviolet spectra of 10^{-3} M (1*S*,3*R*)-4(e)-substituted adamantan-2-ones in MI (methylcyclohexane–isopentane, 4:1, v/v/) run at 25 °C and corrected to 100% ee. In the CD spectra the equatorial substituents are (**2**) phenyl (– –), $\Delta\epsilon_{max}{}^{304}$ = +0.83, and (**4**) benzyl (—), $\Delta\epsilon_{max}{}^{307}$ = +0.98. In the UV spectra the equatorial substituents are (**2**) phenyl (···), $\epsilon_{max}{}^{295}$ 33; $\epsilon_{max}{}^{252}$ 242, and (**4**) benzyl (–·–), $\epsilon_{max}{}^{296}$ 88, $\epsilon_{max}{}^{252}$ 468.

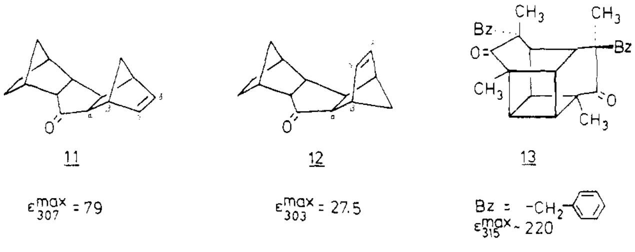

Figure 6. UV data for γ,δ-unsaturated ketones showing the dependence of ϵ on the relative orientation of the component chromophores. Data for the left and middle ketones are from ref 11; data for **13** are from ref 12.

Conclusions

We have shown experimentally that δ,ϵ-unsaturated ketones **2** and **4** may give enhanced n → π* UV and CD intensities as compared with their alkyl analogues. The interchromophoric interaction appears to originate via a through-space interaction between the aromatic chromophore and carbonyl group in the case of the β-axial benzyl (**3**) and a through-bond interaction in the case of the β-equatorial benzyl (**4**). The basis for interchromophoric interaction was less obvious for γ,δ-unsaturated phenyl ketones (**1** and **2**). In both systems (**1** and **3**), the β-axial group is a powerful dissignate contributor to the CD CE.

Experimental Section

General. Circular dichroism (CD) spectra were recorded on a JASCO J-40 instrument equipped with a photoelastic modulator and a J-DPY data processor and a spectroscopic Dewar for variable temperature CD measurements. Ultraviolet (UV) spectra were recorded on a Cary 219, or Beckman 25 spectrophotometer, and rotations were determined in 95% ethanol, unless otherwise indicated, on a Perkin-Elmer 141 polarimeter. All nuclear magnetic resonance (NMR) spectra were determined in $CDCl_3$ and reported in δ (ppm) downfield from tetramethylsilane unless otherwise indicated on a JEOL FX-100 instrument. Mass spectra (MS) were recorded at 70- or 14-eV ionizing voltage on an Kratos MS-50 mass spectrometer at the Midwest Center for Mass Spectrometry, University of Nebraska. Infrared (IR) spectra were measured neat, unless otherwise noted, on a Perkin-Elmer Model 599 instrument. All melting points are uncorrected and were dtermined on a Thomas-Hoover or Mel-Temp capillary apparatus. Combustion analyses were performed by Micro-Analytical Lab, Mountain View, CA, or MicAnal, Tucson, AZ. Analytical gas chromatography (GC) was performed on a Varian-Aerograph Model 2400 F/I instrument on 6 ft × $^1/_8$ in. diameter columns with the indicated stationary phases that were adsorbed on 80/100 Chromosorb W-AW-DMCS: column A (12% QF-1) and column B (20% FFAP). Preparative gas chromatography (GC) was performed on 6 ft × $^3/_8$ in. diameter column C (15% QF-1 on 70/80 Chromosorb W) on a Varian-Aerograph Model 1720 T/C instrument. Spectral data were obtained by using spectral grade solvents (MCB): methylcyclohexane–isopentane, 4:1 v/v (MI), and ethyl ether–isopentane–ethanol, 5:5:2, v/v/v (EPA). Other solvents were distilled and dried before use: benzene, pentane, chloroform, and dichloromethane from P_2O_5; acetone from $KMnO_4$; and diethyl ether from $LiAlH_4$ under N_2. The solvents were used freshly distilled or stored over 4A molecular sieves (Linde).

(+)-(1*R*,5*S*)-*endo*-3(*R*)-Bicyclo[3.3.1]non-6-enyl Phenyl Ketone (6). A solution of phenyllithium (Apache Chemicals) (1.47 M, 14.8 mL, 21.76 mmol) in a mixture of benzene/ether (70:30, v/v) was added dropwise to a mechanically stirred solution of (+)-(1*S*,5*R*)-3-*endo*-bicyclo[3.3.1]non-6-enecarboxylic acid (**5**, 1.6 g, 9.6 mmol), $[\alpha]^{25}_{578}$ +75.03°, $[\alpha]^{25}_{589}$ +71.09° (*c* 1.0), ee 49.93%, in dry ether (150 mL) at 0 °C. At the end of the addition it was seen that the initially formed insoluble lithium salt disappeared completely to give a clear yellow solution, an indication that the reaction was complete. The solution was allowed to stir at 0 °C for an additional 2 h, after which it was added to saturated aqueous NH_4Cl (50 mL). The mixture was stirred for 15 min; then the organic layer was separated and the aqueous layer was extracted with ether (25 mL × 3). The combined organic extracts were washed with water (20 mL), $NaHCO_3$ (20 mL), and finally saturated aqueous NaCl (20 mL). After drying over anhydrous $MgSO_4$, the solvent was removed under reduced pressure to give a yellow viscous oil, crude yield 2.1 g. The crude product, 2.1 g, was purified by redistillation (Kugelrohr) at 5 mmHg, 155–160 °C, to give a colorless oil, yield 1.6 g (73.4%), that was >99% pure by GC on column A: $[\alpha]^{25}_{589}$ +65.34°, $[\alpha]^{25}_{578}$ +68.77°, $[\alpha]^{25}_{546}$ +76.51°, $[\alpha]^{25}_{436}$ +162.67°, $[\alpha]^{25}_{365}$ +423.85° (*c* 1.46); UV (MI) $\epsilon_{\max}{}^{318}$ 74, $\epsilon_{\max}{}^{235}$ 7521; UV (EPA) $\epsilon_{\max}{}^{310}$ 91, $\epsilon_{\max}{}^{234}$ 7726; IR ν 3060–3030, 3100–2880, 1720 cm^{-1}; ^{1}H NMR δ 1.08–2.60 (br m, 10 H), 3.17 (m, 1 H), 5.30 (br m, 2 H), 6.80–7.55 (br m, 5 H).

Anal. Calcd for $C_{16}H_{18}O$ (226): C, 84.91; H, 8.02. Found: C, 84.84; H, 7.89.

(+)-(1*R*,5*S*)-*endo*-3(*R*)-(α-Hydroxybenzyl)bicyclo[3.3.1]non-6-ene (7). Ketone **6** from above (1.2 g, 5.3 mmol) in 20 mL of dry ether was added dropwise to stirred slurry of $LiAlH_4$ (0.2 g, 5.3 mmol) in ether (20 mL). The mixture was heated to reflux, following complete addition, for 1 h. After cooling, the mixture was quenched by addition to saturated aqueous NH_4Cl (25 mL), and the aqueous layer was separated and extracted with ether (3 × 25 mL). The combined ether layers were washed with water (20 mL), then 5% aqueous $NaHCO_3$, followed by saturated aqueous NaCl (20 mL) and dried ($MgSO_4$). Removal of the solvent by rotary evaporation left a yellow liquid, 1.2 g (99%). Kugelrohr distillation (160–162 °C, 2.0 mm) gave 1.1 g (91%) of **7**, which was >99% pure by GC on column A: $[\alpha]^{25}_{589}$ +115.7°, $[\alpha]^{25}_{578}$ +121.8° (*c* 0.99); IR ν 3600–3100, 3070–3030, 3000–2840, 1950 (w), 1880 (w), 1800 (w), 1760, 1050 cm^{-1}; ^{1}H NMR δ 1.1–2.7 (br m, 12 H), 3.60 (br s, 1 H), 5.25 (br s, 2 H), 7.48–6.8 (br m, 5 H).

Anal. Calcd for $C_{16}H_{20}O$ (228): C, 84.21; H, 8.77. Found: C, 84.19; H, 8.65.

(−)-(1*S*,3*R*)-4(*S*)(a)-Phenyladamantan-2-one (1).[14] Alcohol **7** (0.814 g, 3.57 mmol) from above was heated at reflux in formic acid (88%, 1 mL). After heating 4 h, the solution was cooled, poured into cold water (10 mL), and basified with 50% aqueous NaOH. The products were extracted with ether (4 × 20 mL), and the combined ether extracts were washed with water (10 mL) and saturated aqueous $NaHCO_3$ (10 mL) and dried ($MgSO_4$). Evaporation of the ether gave 0.900 g (98%) of a mixture of pale yellow liquid formate esters. Hydrolysis was achieved by dissolving the esters in ether (20 mL) and adding the ether solution dropwise to a stirred slurry of $LiAlH_4$ (150 mg, 4 mmol) in ether (20 mL). The mixture was heated at reflux for 1 h after complete addition, cooled, and quenched by addition to 50 mL of saturated aqueous NH_4Cl. The ether layer was separated and the aqueous layer was extracted with ether (3 × 25 mL). The combined ether layers were washed with water (25 mL) and saturated aqueous NaCl and dried ($MgSO_4$). The solvent was removed under reduced pressure to give a mixture of epimeric alcohols that was oxidized to the corresponding ketones (**1** and **3**) by Jones reagent. Excess oxidant was decomposed by adding 2-propanol. The solution was diluted with ether (25 mL) and neutralized with 5% aqueous $NaHCO_3$. Solids were removed by filtration, the filtrate was extracted with ether, and the ether layer was dried ($MgSO_4$) to give a 54:46 mixture of **1** and **3** (GC, column B) as a pale yellow oil, of which the faster moving component of the mixture was separated by preparative GC on column C to give a 52% yield, >99% pure: $[\alpha]^{25}_{589}$ −39.7°, $[\alpha]^{25}_{578}$ −40.2°, $[\alpha]^{25}_{546}$ −42.1°, $[\alpha]^{25}_{436}$ −58.0°, $[\alpha]^{25}_{365}$ +11.5° (*c* 0.18); UV (MI) $\epsilon_{\max}{}^{290}$ 30, $\epsilon_{\max}{}^{268}$ 207, $\epsilon_{\max}{}^{264}$ 218, $\epsilon_{\max}{}^{260}$ 262, $\epsilon_{\max}{}^{258}$ 277, $\epsilon_{\max}{}^{252}$ 248; UV (EPA) $\epsilon_{\max}{}^{295}$ 21; CD (MI) $\Delta\epsilon_{242} = 0$, $\Delta\epsilon_{250} = -0.04$, $\Delta\epsilon_{257} = -0.138$, $\Delta\epsilon_{262} = -0.24$, $\Delta\epsilon_{269} = -0.28$, $\Delta\epsilon_{296} = -0.52$, $\Delta\epsilon_{306} = -0.47$, $\Delta\epsilon_{317} = -0.23$, $\Delta\epsilon_{328} = 0$; CD (EPA) $\Delta\epsilon_{247} = 0$, $\Delta\epsilon_{256} = -0.09$, $\Delta\epsilon_{263} = -0.18$, $\Delta\epsilon_{269} = -0.24$, $\Delta\epsilon_{296} = -0.56$, $\Delta\epsilon_{315} = -0.48$, $\Delta\epsilon_{325} = 0$ (CD run at room temperature and data corrected to 100% ee); IR ν 3060–3030, 3000–2850, 1950, 1870, 1800, 1750, 1700 cm^{-1}; ^{1}H NMR δ 1.54 (br s, 1 H), 1.84 (br m, 2 H), 2.10 (br m, 7 H), 2.50 (br s, 1 H), 3.03 (br s, 1 H), 3.49 (br s, 1 H), 7.26 (br s, 5 H); MS, *m/z* (relative intensity) 226.1356 [M$^+$; calcd for $C_{16}H_{18}O$ 226.1358] (100).

Anal. Calcd for $C_{16}H_{18}O$ (226): C, 84.91; H, 8.02. Found: C, 84.79; H, 8.16.

(+)-(1*S*,3*R*)-4(*R*)(e)-Phenyladamantan-2-one (2). The equatorial phenyl epimer **2** formed above and separated by preparative GC (45% yield) had the following: $[\alpha]^{25}_{589}$ +131.1°, $[\alpha]^{25}_{578}$ +139.2°, $[\alpha]^{25}_{546}$ +154.0°, $[\alpha]^{25}_{436}$ +252.5°, $[\alpha]^{25}_{365}$ +357.7° (*c* 0.22); UV (MI) $\epsilon_{\max}{}^{292}$ 33, $\epsilon_{\max}{}^{264}$ 192, $\epsilon_{\max}{}^{258}$ 242, $\epsilon_{\max}{}^{248}$ 171; UV (EPA) $\epsilon_{\max}{}^{290}$ 22; CD (MI) $\Delta\epsilon_{250} = 0$, $\Delta\epsilon_{258} = +0.05$, $\Delta\epsilon_{263} = +0.12$, $\Delta\epsilon_{284} = +0.55$, $\Delta\epsilon_{294} = +0.76$, $\Delta\epsilon_{304} = +0.83$, $\Delta\epsilon_{315} = +0.52$, $\Delta\epsilon_{330} = 0$; CD (EPA) $\Delta\epsilon_{252} = 0$, $\Delta\epsilon_{257} = +0.06$, $\Delta\epsilon_{263} = +0.17$, $\Delta\epsilon_{269} = +0.29$, $\Delta\epsilon_{294} = +0.95$, $\Delta\epsilon_{303} = +0.91$, $\Delta\epsilon_{314} = +0.32$, $\Delta\epsilon_{326} = 0$ (CD data run at room temperature and data corrected to 100% ee); IR ν 3060–3030, 3000–2800, 1950, 1880, 1800, 1760, 1695 cm^{-1}; ^{1}H NMR δ 1.52 (br s, 1 H), 1.81 (br s, 1 H), 2.10 (br m, 6 H), 2.64 (br s, 2 H), 3.23 (br s, 1 H), 7.32 (br s, 5 H); MS, *m/z* (relative intensity) 226.1356 [M$^+$ calcd for $C_{16}H_{18}O$ 226.1358] (100).

Anal. Calcd for $C_{16}H_{18}O$ (226): C, 84.91; H, 8.02. Found: C, 84.87; H, 8.02.

(+)-(1*S*,5*R*)-*endo*-3(*R*)-Bicyclo[3.3.1]non-6-enyl Benzyl Ketone (8). The benzyl ketone was prepared as above for the corresponding phenyl ketone **6**, except benzyllithium was used in place of phenyllithium. Thus, 13 mL (8.3 mmol) of an ether solution of benzyllithium (prepared by reaction of tribenzyltin chloride[15] with methyllithium)[16] was added dropwise to a well-stirred solution of (+)-(1*R*,5*S*)-3(*R*)-*endo*-bicyclo[3.3.1]non-6-enecarboxylic acid (**5**, 500 mg, 3.01 mmol, 49.93% ee) in 20 mL of ether at 0 °C. The reaction was carried out and worked up as for **6** to give a pale yellow oil that was distilled (Kugelrohr) at 150–160 °C (3 mmHg), yielding a white waxy solid, mp 60–70 °C, that was >99% pure by GC on column A: $[\alpha]^{25}_{589}$ +4.03°, $[\alpha]^{25}_{578}$ +4.15°, $[\alpha]^{25}_{546}$ +4.68°, $[\alpha]^{25}_{436}$ +7.74°, $[\alpha]^{25}_{365}$ +10.59° (*c* 0.34, CH_2Cl_2); IR ν 3030, 1715 cm^{-1}; ^{1}H NMR δ 1.3–2.0 (br m, 11 H), 3.70 (s, 2 H), 7.18 (m, 2 H), 7.26 (m, 3 H); MS, *m/z* (relative intensity) 240.1519 [M$^{\bullet+}$ calcd for $C_{17}H_{20}O$ 240.1514] (3), 149.0956 [M − benzyl) (64), 121.1011 [C_9H_{13}] (100), 91.0549 [C_7H_7] (52).

Anal. Calcd for $C_{17}H_{20}O$ (240): C, 85.00; H, 8.33. Found: C, 84.94; H, 7.99.

(−)-(1*S*,3*R*)-4(*S*)(a)-Benzyladamantan-2-one (3). As in the synthesis of **1** and **3**, benzyl ketone **8** was reduced ($LiAlH_4$/ether) to give an essentially quantitative yield of alcohol **9**, which was treated under cyclizing conditions in hot formic acid to afford, after workup and oxidation, a 63:37 mixture of **3** and **4**. The mixture was separated by preparative GC on column C to give a 36% yield of >99% pure **3**: $[\alpha]^{25}_{589}$ 0°, $[\alpha]^{25}_{579}$ 0°, $[\alpha]^{25}_{436}$ −21.02°, $[\alpha]^{25}_{365}$ −33.03° (*c* 0.033); UV (MI) $\epsilon_{\max}{}^{296}$ 121, $\epsilon_{\max}{}^{251}$ 1077; UV (EPA) $\epsilon_{\max}{}^{295}$ 144, $\epsilon_{\max}{}^{251}$ 940; CD (MI) $\Delta\epsilon_{290} = -0.317$, $\Delta\epsilon_{299} = -0.414$, $\Delta\epsilon_{305} = -0.357$, $\Delta\epsilon_{309} = -0.409$, $\Delta\epsilon_{318} = -0.198$, $\Delta\epsilon_{321} = -0.220$, $\Delta\epsilon_{345} = 0$; CD (EPA) $\Delta\epsilon_{297} = -0.901$, $\Delta\epsilon_{306} = -0.829$, $\Delta\epsilon_{317} = -0.528$, $\Delta\epsilon_{336} = 0$ (CD run at room temperature and corrected to 100% ee); IR (CCl_4) ν 3064, 3030, 2919, 1721, 915 cm^{-1}; ^{1}H NMR δ 0.9 (br s, 1 H), 1.8–2.4 (br m, 10 H), 2.46, 2.55 (br m, 4 H), 7.16 (s, 5 H); MS, *m/z* (relative intensity) 240.1518 [M$^{\bullet+}$ $C_{17}H_{20}$] (32), 222 [M − H_2O] (20), 149 [M − benzyl] (39), 121 (C_9H_{13}] (100), 91 [C_7H_7) (23).

Anal. Calcd for $C_{17}H_{20}O$ (240): C, 85.00; H, 8.33. Found: C, 85.13; H, 8.24.

(+)-(1*S*,3*R*)-4(*R*)(e)-Benzyladamantan-2-one (4). The equatorial benzyl epimer 4 formed above and separated by preparative GC (20% of yield) had the following: $[\alpha]^{25}_{589}$ +23.3°, $[\alpha]^{25}_{546}$ +25.0°, $[\alpha]^{25}_{436}$ +56.7°, $[\alpha]^{25}_{365}$ +130.8° (*c* 0.06); UV (MI) $\epsilon_{\max}{}^{296}$ 88, $\epsilon_{\max}{}^{252}$ 468, $\epsilon_{\max}{}^{258}$ 464; UV (EPA) $\epsilon_{\max}{}^{295}$ 106, $\epsilon_{\max}{}^{252}$ 501, $\epsilon_{\max}{}^{258}$ 501; CD (MI) $\Delta\epsilon_{250} = 0$, $\Delta\epsilon_{297} = +1.442$, $\Delta\epsilon_{301} = +1.33$, $\Delta\epsilon_{307} = +1.55$, $\Delta\epsilon_{315} = +0.889$, $\Delta\epsilon_{318} = +0.977$, $\Delta\epsilon_{340} = 0$; CD (EPA) $\Delta\epsilon_{247} = 0$, $\Delta\epsilon_{297} = +1.504$, $\Delta\epsilon_{345} = 0$ (CD run at room temperature and corrected to 100% ee); IR (CCl_4) ν 3085, 3066, 3026, 2921, 1724, 1717, 1019, 868 cm^{-1}; ^{1}H NMR δ 1.2–2.1 (br m, 11 H), 2.39, 2.54 (br, 2 H), 2.86 (dd, 2 H, $J = 7.3$ Hz, $J = 13.5$ Hz), 7.15 (m, 5 H); MS, *m/z* (relative intensity) 240.1517 [M$^{\bullet+}$ $C_{17}H_{20}O$] (15), 149 [M − benzyl] (77), 121 [C_9H_{13}] (100), 91 [C_7H_7] (23).

Anal. Calcd for $C_{17}H_{20}O$ (240): C, 85.00; H, 8.33. Found: C, 84.92; H, 8.30.

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