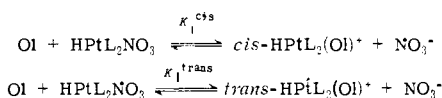(12) H. C. Clark and L. E. Manzer, *J. Amer. Chem. Soc.*, **95**, 3813 (1973).
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$K_1 = K_1{}^{cis} + K_1{}^{trans}$ where

$$Ol + HPtL_2NO_3 \xrightleftharpoons{K_1{}^{cis}} cis\text{-}HPtL_2(Ol)^+ + NO_3^-$$

$$Ol + HPtL_2NO_3 \xrightleftharpoons{K_1{}^{trans}} trans\text{-}HPtL_2(Ol)^+ + NO_3^-$$

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Resolution and Chiroptic Properties of a Dissymmetric Cyclopentanone with Exceptional Rotatory Power

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Abstract: The resolution and chiroptic properties of an extremely rigid cyclopentanone showing unusually high rotatory power are presented. The high observed molecular ellipticity is thought to be due to an unprecedented number of perturbing atoms all lying in octants of the same sign augmented by five-membered ring nonplanarity. Because the carbonyl chromophore is isolated, the ketone must be regarded as inherently achiral in spite of a normal n $\rightarrow$ π^* transition.

Recently, the efficient cyclic coupling of olefins to carbon monoxide induced by iron carbonyls has been reported[1,2] and the mechanism[3] of this novel reaction discussed. One example of the process is illustrated by reaction 1. In the absence of metal complexing substituents[2b] at the bridge position of the active norbornyl ring, the isolated ketones belong to the C_2 point group having the exo-trans-exo stereochemistry illustrated in reaction 1. Although diene **1** belongs to the C_s point group, ketone **1a** is dissymmetric, being formed as a racemic mixture. Each enantiomer has all four chiral centers of the cyclopentanone ring of the same designated absolute configuration; for example, that illustrated in reaction 1 has the S configuration.[4]

(1)

1

1a
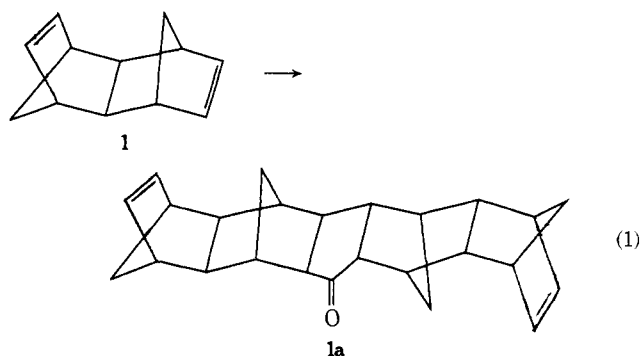
A striking feature of ketone **1a** and related materials[1,2,5] is the extreme rigidity imposed upon the cyclopentanone ring by the presence of the two fused norbornyl systems. Consequently, at room temperature in cyclohexane, the n $\rightarrow$ π^* transition shows a well-resolved vibrational progression with level spacing of approximately 1260 cm^{-1} corresponding to the pseudo carbon–oxygen single bond of the π^* state. This progression is as well resolved as those of

many ketones in low-temperature glasses. Indeed, even in ethanol the n $\rightarrow$ π^* transition of **1a** is resolved into its vibrational components, although compared with cyclohexane as solvent the resolution is greatly reduced. A detailed discussion of the nature of this unusual electronic excitation will be presented separately.

In the following presentation, we wish to discuss the resolution and chiroptic properties observed for ketone **1a**, an inherently achiral system with exceptional rotatory power. Inherent achirality of unstrained cyclopentanones exemplified by n $\rightarrow$ π^* transitions of normal intensity and normal rotational strength is illustrated by 2-phenylcyclopentanone[6,7] and 2-methyl-2-phenylcyclopentanone[8] whose molecular rotations are 253 and 166°, respectively. Thomas and Mislow[7] have discussed the chiroptic properties of the 3-phenyl-2-norbornanones in comparison with 2-norbornanone and have noted that neither the extinction coefficients nor the molar ellipticities are abnormally high. The octant rule[9] has proved itself to be an effective semiempirical tool for predicting the sign of Cotton effects as a function of absolute configuration when applied to the n $\rightarrow$ π^* transition of inherently achiral carbonyl chromophores;[9,10] conversely, one is often able to determine the absolute configuration of an enantiomer by measuring the sign of the Cotton effect. The octant rule has been extended to inherently chiral ketones, when the carbonyl n $\rightarrow$ π^* transition is coupled to a remote π system[11] or pseudo-π system.[12] For example, the n $\rightarrow$ π^* transition of β,γ-unsaturated ketones shows enhanced absorption and rotatory power.[12,13] Nevertheless, this treatment relies upon the availability of a nearby π system and does not apply to ketones having normal molar absorptions for the n $\rightarrow$ π^* transition in the range of 20–80.[11,14] Relative orientations of the carbonyl and cyclopropyl chromophores in β,γ-cyclopropylnorbornanones determine whether the carbonyl chromophore appears to be inherently chiral or
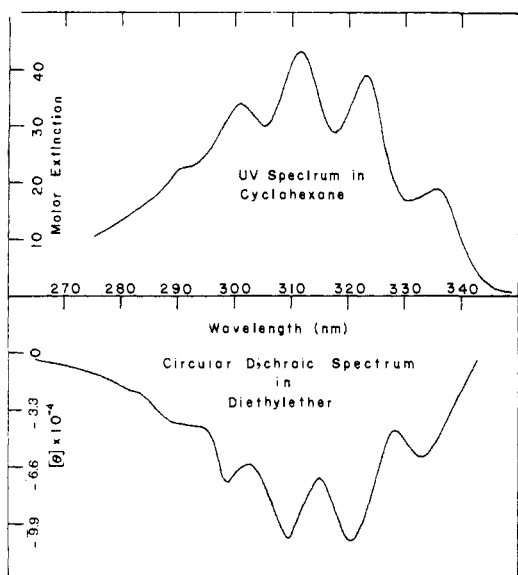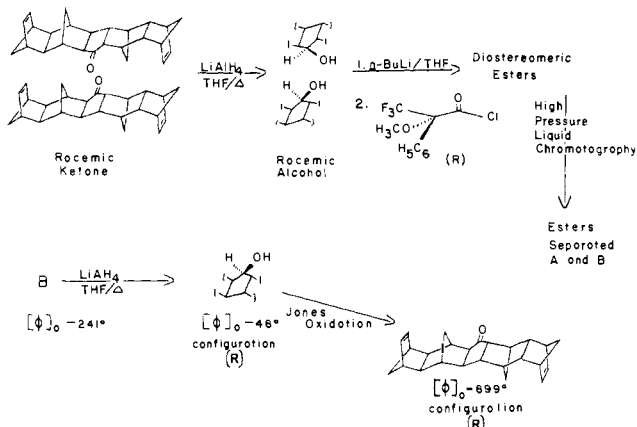
Figure 1. n → π* spectra of ketone **1a**.

achiral.[12] The applicability of front octants has been discussed recently by Lightner.[15]

Method

Racemic ketone was resolved according to Scheme I. (−)-(S)-α-Trifluoromethylphenylacetic acid[16] was purchased from the Aldrich Chemical Co. and used as the acid

Scheme I. Resolution of Ketone **1a**

chloride. Reduction of the ketone to the corresponding alcohol has been described;[1] reductive cleavage of the ester with LiAlH₄ and Jones oxidation of the alcohol were accomplished according to standard procedures.[17] Ester formation was facilitated by first forming the alkoxide of the alcohol with a 10% excess of n-BuLi. Because the hindered cyclopentanone ring system is unreactive, all reaction times were far greater than those normally employed. At each stage, products were chromatographically purified on silica gel with an eluent mixture of benzene–dichloromethane–pentane in a ratio of 1:1:0.1. Baseline separation of the diastereomeric esters was accomplished by high-pressure liquid chromatography (Waters Associates, Milford, Mass.) eluting 80 mg of diastereomeric ester with 50% CHCl₃–50% hexane on a 6 ft × ⅜ in. Porasil A column. This extremely efficient method for separation of diastereomers will certainly find increasing use. A satisfactory carbon–hydrogen analysis was obtained for the racemic ester. (*Anal.* Calcd for C₃₅H₃₇F₃O₃: C, 74.71; H, 6.63. Found: C, 74.2; H, 6.3). Measurement of the circular dichroism spec-

trum was obtained using a Cary 60 spectropolarimeter with a repetitive scan accessory, 1115.

Discussion

As is seen in Figure 1, the molar extinction coefficient describing the n → π* transition of ketone **1a** is of normal intensity, while the molecular ellipticity is exceptionally high (θ_{max} = 1.0 × 10⁵). Indeed, the molecular rotation is [φ]D 899°. In view of the fact that there appears to be nothing unusual about the n → π* transition in spite of the great rotatory power of this chiral ketone, we are faced with two possibilities. The carbonyl chromophore may be either inherently chiral or the inherently achiral chromophore is drastically perturbed by dissymmetrically disposed groups and is quite different from inherently achiral chromophores generally encountered. The absence of strong near-ultraviolet absorptions combined with unusually high rotatory power has been suggested as *prima facie* evidence for active inherent chirality.[11] Nevertheless, in order for the carbonyl chromophore to be inherently chiral, it must be part of a larger system so as to permit strong perturbation.[18]

While all ketone chromophores are inherently achiral, those with localized n → π* transitions are generally weakly perturbed, allowing application of the octant rule to determine absolute configuration. When the chromophore is part of an extended system, making the designation of inherent chirality appropriate, the octant rule may not be applied as the Cotton effect is not determined by perturbations of the n → π* carbonyl transition alone. Consequently, in applying the octant rule to ketone chromophores, one must exercise care to ensure that the n → π* transition is not part of an extended system. In the case of **1a**, the olefinic linkages on the extremities of the molecule are too far removed from the carbonyl group to induce conjugation or electrostatic coupling and inherent chirality.

The observed high rotatory power of ketone **1a** must be understood if the octant rule is reasonably to be applied. Dreiding models of **1a** suggest that the cyclopentanone ring is planar and highly strained. Indeed, a recent calculation[19] on the corresponding syn ketone[2c] derived from norbornen-5-one-2 shows an unusually long bond length (1.61 Å) for the C–C bond opposite the carbonyl group of the cyclopentanone ring. Microwave studies, as well as calculations, show that cyclopentanone itself assumes a twisted conformation in the ground state[20] which if rigidly maintained would be expected to influence the rotatory power of the carbonyl chromophore. The effect of cyclopentanone nonplanarity upon the rotatory power of the n → π* transition has been considered by both Klyne[21,22] and by Snatzke.[21,22] Data collected for a series of hexahydroindanones[22] have been convincingly interpreted in terms of twisting of the five-membered ring with the suggestion that the half-chair (C_2) structure has the greatest rotatory power of the possible conformations. Of the two perturbations expected to influence the rotatory power of methyl-substituted cyclopentanones, direct chromophore perturbation and ring conformation changes, the latter is thought to be of greatest importance. The high rotatory power observed for *trans*-hexahydroindan-2-ones is interpreted to arise from the out-of-plane ring atoms. Nevertheless, alteration of the five-membered ring conformation is found to change only the magnitude and not the sign of the Cotton effect.

Because of the presence of the rigid norbornyl ring systems of **1a**, the barrier to ring puckering of a twisted cyclopentanone ring would be sufficiently large to effectively remove such a vibration. Furthermore, twisting of the cyclopentanone ring from planarity will induce considerable additional strain in the norbornyl rings and for this reason is expected to be minor. It should be noted that the twisting of

strained ring systems has been previously reported for nor-bornane derivatives on the basis of X-ray diffraction analysis,[23] however. The observed coupling between the 2 and 3 protons might in principle supply collaborative data for cyclopentanone ring nonplanarity, but pmr spectroscopy is insufficiently sensitive to permit such interpretation.[24]

While the extremely large molecular rotations and ellipticities associated with inherently chiral molecules such as hexahelicene[25] are well known, it is difficult to estimate the extent to which a small amount of ring twisting would influence these parameters. Nevertheless, the rigid C_2 symmetry present in ketone 1a is consistent with a large Cotton effect derived from the out-of-plane atoms of a half-chair conformation. Sterically nonrigid cyclopentanone derivatives, such as 2-phenylcyclopentanone and 2-methyl-2-phenylcyclopentanone which are free to adopt an envelope conformation, exhibit normal chiroptic properties.

Thus we must conclude that the large molecular ellipticity displayed by 1a results from perturbation effects on an inherently achiral carbonyl chromophore perhaps strongly augmented by the conformation of the cyclopentanone ring. The contribution which perturbation effects have on the sign of the Cotton effect may be easily described using the back octant approach employed for cyclohexanones by Mislow for the previously mentioned norbornanone derivatives. Based on the back octant projection displayed in Figure 2, one would predict a positive Cotton effect for the illustrated S configuration. This leads to the conclusion that the R configuration is that for which the CD spectrum is reported.

As is seen in Figure 2, all the noncyclopentanone ring atoms lie in octants contributing the same sign to the Cotton effect. As analogous systems with so many perturbing atoms have not been reported, it is difficult to estimate the expected magnitude of the rotatory power of 1a other than to say that it should be abnormally high even in the case of cyclopentanone ring planarity. A contribution from suggested out-of-plane ring atoms would contribute to an indicated (+) Cotton effect for the S configuration if the 3,3' atoms are also rotated into the (+) octants.

One additional conclusion may be drawn from the shape of the CD spectrum. The Cotton effect associated with each component of the n → π* transition has the same sign, strong evidence that the vibrational progression superimposed on the electronic transition arises from but one molecular motion. Given this information and the regularity of the observed progression, we conclude that there is only one vibration being considered, and that it is the carbon–oxygen stretching mode of the π* excited state, as previously indicated.
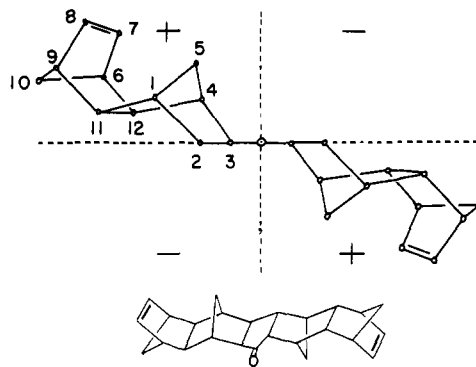
Figure 2. Back octant projection (S) configuration.

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