Photoisomerization of Nopinone

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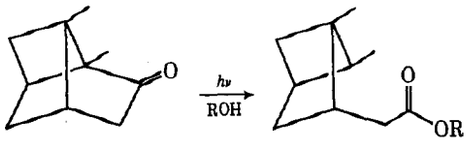
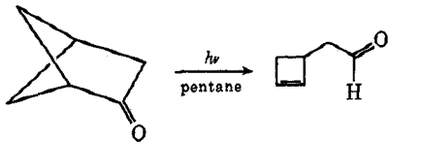
Irradiation of nopinone in methanol gives an 80:20 mixture of *cis*-1-formyl-2,2-dimethyl-3-vinylcyclobutane (**3**) and 3-(2′,2′-dimethyl-$\Delta^{3'}$-cyclobutenyl)-1-propanal (**7**). Irradiation in *tert*-butyl alcohol gives **3**, **7**, and 4-isopropenyl-5-hexenal (**4**).

Cycloalkanones are well known[1] to undergo photochemical α cleavage to give ketenes and/or unsaturated aldehydes. The direction of cleavage is preferentially toward the more highly substituted α-carbon atom. α-Ketocyclobutanes in bicyclic systems are considerably abnormal in this regard. Some, such as carvone camphor and bicyclo[2.1.1]hexan-2-one (eq 1 and 2),[2,3]

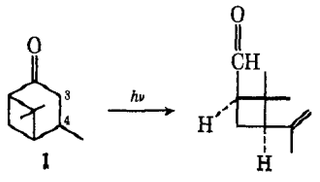


(1)



(2)

photochemically undergo α cleavage of the more substituted bond, but others, such as verbanone (**1**) (eq 3)[4] and 5,5,7,7,8,8-hexamethylbicyclo[4.2.0]octan-2-one (eq 4),[5] are reported to cleave the least substituted bond



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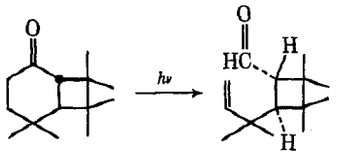
(3)

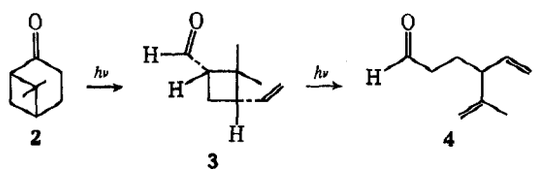


(4)

α to the carbonyl. This abnormal α cleavage has been rationalized[4] for **1** by the fixed conformation causing excellent orbital overlap between the hydrogen at C-4 and the carbonyl group and resulting in hydrogen migration concurrent with α cleavage.

We wish to report the photochemistry of an analogous compound, nopinone (6,6-dimethylbicyclo[3.1.1]heptan-2-one) (**2**), including evidence that photocleavage of **2** occurs at both bonds α to the carbonyl to give a mixture of aldehydes.

Irradiation of **2** in methanol solution until 90–95% disappearance of starting material on glc gave one major product (75–80%) and a few very minor products. The major product was collected by preparative glc. Its spectral data (see Experimental Section) was consistent with *cis*-1-formyl-2,2-dimethyl-3-vinylcyclobutane (**3**), an analogous product to that found from verbanone. Irradiation of **2** in *tert*-butyl alcohol increased one of the minor products with a concurrent decrease in the amount of **3**. This product was also isolated by preparative glc and identified on the basis of spectral data (see Experimental Section) as 4-isopropenyl-5-hexenal (**4**), which is the normal Norrish II product of the primary photoproduct **3** (eq 5). This



2 **3** **4**

(5)

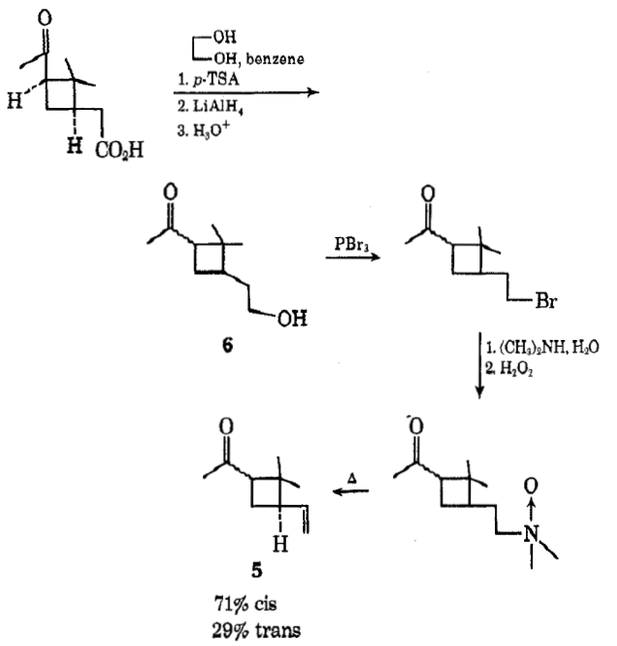
was confirmed by isolation of **3** from a methanol irradiation of **2** and reirradiation in *tert*-butyl alcohol. Initially, 17% (glc) of **4** formed and then this percentage remained constant as the amount of polymeric material increased. Apparently, in methanol the initial aldehyde **3** forms a hemiacetal, thus preventing further light absorption. This increase in yield of an aldehydic photoproduct by the use of methanol as solvent has been observed before.[3]

Isolation of photoproduct **3** by careful spinning-band distillation gave material with an nmr spectrum not identical with that previously obtained by preparative glc. There were minor differences in the vinylic region, but the major change was the appearance of two methyl singlets at τ 8.83 and 8.91 in addition to the methyl singlets of **3** at τ 8.70 and 9.03. By nmr integration, the unknown:**3** ratio was 1:4.

At first we entertained the possibility that this product was *trans*-**3** since the relative nmr positions of the methyl singlets were consistent with those observed[6] for *cis*- and *trans-gem*-dimethylcyclobutane derivatives. Since the initial configuration of **3** must be cis due to the geometry of nopinone, the existence of *trans*-**3** would have to involve a rather unusual epimerization of a cyclobutyl ketone. This was not the case, as shown by independent synthesis of *cis*- and *trans*-1-acetyl-2,2-dimethyl-3-vinylcyclobutane (**5**) from *cis*-pinonic acid (Scheme I) and comparison of this material to a sample of **5** prepared from **3**. The synthesis was straightforward except for introduction of the terminal vinylic group. After several unsuccessful approaches,[7] the double bond was introduced with ease by pyrolysis of the *N*-oxide.[8]

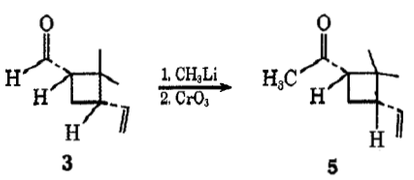
(1) O. L. Chapman, *Advan. Photochem.*, **1**, 366 (1963).
(2) J. Meinwald, R. A. Schneider, and A. F. Thomas, *J. Amer. Chem. Soc.*, **89**, 70 (1967).
(3) J. Meinwald and R. A. Chapman, *ibid.*, **90**, 3218 (1968).
(4) T. Matsui, *Tetrahedron Lett.*, 3761 (1967).
(5) P. J. Nelson, D. Ostrem, J. D. Lassila, and O. L. Chapman, *J. Org. Chem.*, **34**, 811 (1969).
(6) L. R. Subramanian and G. S. K. Rao, *Tetrahedron*, **25**, 1749 (1969).
(7) Attempts to form the double bond by elimination of the terminal bromide, tosylate, or trimethylammonium iodide were unsuccessful, as also were attempts to pyrolyze the ketoacetate or hydroxyacetate.
(8) A. C. Cope, D. C. McLean, and N. A. Nelson, *J. Amer. Chem. Soc.*, **77**, 1628 (1955).

SCHEME I



Epimerization of the acetyl group occurred during the conversion of *cis*-pinonic acid to keto alcohol **6**. The stereochemical assignment for the epimers of **5** is based on the nmr methyl region (singlets at τ 8.72 and 9.20, 71%; singlets at τ 8.85 and 9.00, 29%) and the fact that the cis epimer is the thermodynamically favored epimer of a 1,3-disubstituted cyclobutane.[9]

Reaction of **3**, containing 20% of the unknown, with methyllithium followed by Jones[10] oxidation (eq 6)

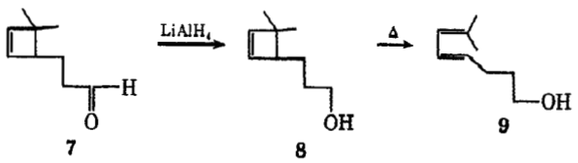


(6)

occurred without any epimerization and gave a ketonic mixture whose major component (79% by nmr) was identical with the sample of synthetic *cis*-**5**, thus proving the structure of photoproduct **3**. The minor ketone (21% by nmr) had methyl singlets in the nmr spectrum at τ 8.83 and 8.91, which were not identical with those of *trans*-**5**.

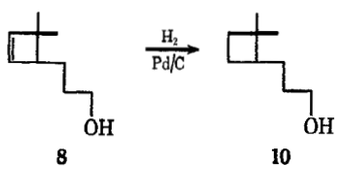
The unknown photoproduct was then assigned the structure of 3-(2′,2′-dimethyl-$\Delta^{3'}$-cyclobutenyl)-1-propanol (**7**) based on the results of a lithium aluminum hydride reduction of the nopinone photomixture. Glc analysis of this mixture on Carbowax 20M showed three alcohols in order of elution: A, 67%; B, 15%; C, 18%. After glc collection, A and B were identified as the alcohols corresponding to **3** and nopinol, respectively.

Compound C was identified as 7-methyl-4,6-octadien-1-ol (**9**) on the basis of the following spectral data: ir(neat) 3300–3400, 1052, 981, and 953 cm^{-1}; λ_{max}^{MeOH} 237 nm (ϵ 20,600); nmr (τ, ppm), 3.45–4.73 (three vinylic hydrogens), 8.26 (broad vinylic methyl singlet). This was the first indication by glc analysis that aldehyde **3** was impure and contained **7**. Apparently, aldehyde **7** and the methyl ketone corresponding to **7** do not survive the hot glc injector (250°), and alcohol **8** thermally rearranges to dienol **9** under the same conditions (eq 7).



(7)

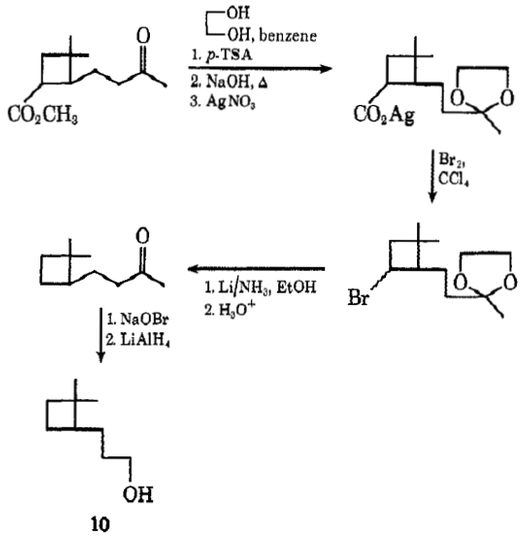
Hydrogenation of the mixture of alcohols over palladium on charcoal again gave three peaks on glc and the 3-(2′,2′-dimethylcyclobutyl)-1-propanol (**10**) (24% of the mixture) was isolated by preparative glc (eq 8).



(8)

The structural assignment was proven by comparison of the reduced photoproduct to a sample of **10** which had been synthesized by an independent route (Scheme II).

SCHEME II



We have no direct proof of the double bond position in **7**; however, the isolation of dienol **9** and the reasonable mechanism (Scheme III) for formation of **7** during the irradiation of **2** indicates that the double bond is positioned as shown in **7**.

The photoisomerizations of nopinone (**2**) can then be summarized as in Scheme III.[11] The major product arises from α cleavage on the least substituted side; however, the "normal" cleavage does occur to the extent of 20%. Probably, analogous cyclobutene aldehydes will be observed as minor products from irradiation of other bicyclic α-ketocyclobutanes.

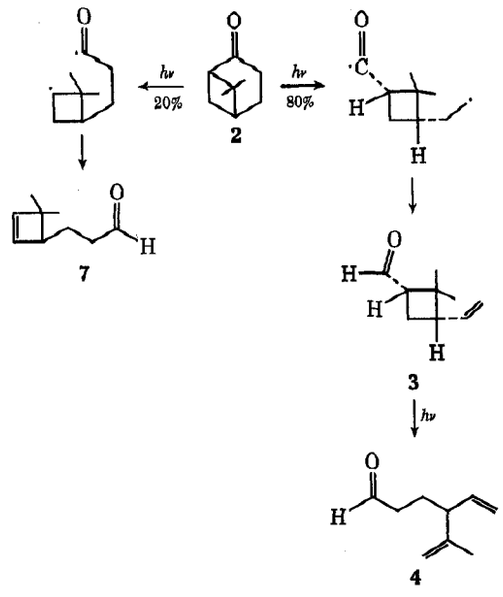
Photocleavage of bicyclo[3.1.1]-2-heptanones appears to be a facile reaction even though the bond with the lesser degree of substitution is broken. This was con-

(9) N. L. Allinger and L. A. Tushaus, *J. Org. Chem.*, **30**, 1945 (1965).

(10) A. Bowers, T. G. Halsall, E. R. H. Jones, and A. J. Lemin, *J. Chem. Soc.*, 2548 (1953).

(11) This mechanism denotes a diradical intermediate for both pathways, whereas in fact the hydrogen atom migration may be concerted with ring cleavage to give aldehyde **3** directly.

SCHEME III



firmed by measuring the quantum yields for ketone disappearance of bicyclo[3.1.1]-2-heptanones as compared to the yields measured by Wagner[12] for substituted cyclohexanones (Table I).

TABLE I

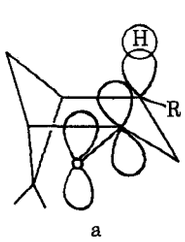
QUANTUM YIELDS FOR DISAPPEARANCE OF KETONES IN BENZENE

Ketone	Φ_{-K}
Nopinone	0.32[a]
Verbanone	0.40[a]
Cyclohexanone	0.20[b]
2-Methylcyclohexanone	0.46,[a] 0.50[b]
3-Methylcyclohexanone	0.083[b]

[a] 6–10% disappearance of ketone using 3000-Å Rayonet lamps. [b] Reference 12 using 3130 Å.

The quantum yields for nopinone and verbanone are intermediate to those of cyclohexanone (no α substitution) and 2-methylcyclohexanone (α substitution). It is interesting that a β-methyl group in the bicyclo[3.1.1]-2-heptanone system does not decrease Φ_{-K} as is the case for the cyclohexanone system (compare verbanone to 3-methylcyclohexanone).

The explanation[4] of Matsui that the rigid geometry of the bicyclo[3.1.1]-2-heptanone molecule allows excellent overlap of the carbonyl group and the sp^3 orbital of the β hydrogen (see structure a), such that hydrogen atom migration can occur before or at the same time as the ring cleavage, reasonably accounts for this efficient cleavage of the least substituted α bond. In addition, the release of molecular strain by α cleavage in the direction of the coplanar aligned hydrogen may play a role in increasing the quantum yield.



a

Experimental Section

Preparative irradiations were carried out with a 450-W medium pressure Hanovia mercury lamp in a quartz immersion probe. The filter was a glass cylinder of Corex (>255 nm) insertable between the lamp and the probe. Solutions were outgassed with argon before and during the irradiations.

Infrared spectra were taken as neat samples on a Perkin-Elmer 457 and absorptions are reported as inverse centimeters; uv spectra were taken on a Beckman Acta III; nmr spectra were taken on a Varian A-60A as chloroform-d_1 solutions and are reported as τ units relative to TMS (τ 10.0); and molecular weights were determined from mass spectra obtained with a Perkin-Elmer 270. Gas–liquid chromatography (glc) was done on a 10% Carbowax 20M (12 ft × 1/8 in.) column unless otherwise stated.

Nopinone (6,6-Dimethylbicyclo[3.1.1]heptan-2-one) (2).—Nopinone (2), prepared by ozonolysis[13] of β-pinene (Aldrich Chemical Co.), had the following spectral characteristics: mol wt 138; ir 1715 (s), 1461 (m), 1202 (m), 1030 (m); λ_{max}^{MeOH} 277 nm (ϵ 29); nmr 7.26–8.55 (8 H, multiplet), 8.65 (3 H, singlet, methyl H), 9.14 (3 H, singlet, methyl H).

Irradiation of Nopinone (2).—A solution of 3.00 g of nopinone (2) in 150 ml of methanol (0.145 M) was irradiated with Corex-filtered light until starting material was 90–95% gone (2.5–3.0 hr). Solvent was removed under reduced pressure, three runs were combined, and the residual oil was distilled at 15 mm pressure. The distillate (5.61 g) consisted, by glc, of one major component (75–80%) with 20–25% of three other components including unreacted 2. The major component was isolated pure by glc collection and was identified as *cis*-1-formyl-2,2-dimethyl-3-vinylcyclobutane (3): *mol wt* 138; *ir* 2870 (m), 2715 (m), 1718 (s), 1638 (m), 1000 (m), 918 (s); nmr (100 MHz) 0.18 (1 H, d, J = 2 Hz, aldehydic H), 4.07–4.49 (1 H, multiplet, vinylic H), 4.92 (1 H, sharp absorption with fine splitting, terminal methylene H), 5.00–5.12 (1 H, multiplet, terminal methylene H), 7.1–8.4 (4 H, multiplet, cyclobutyl H), 8.73 and 9.06 (6 H, two s, methyl H); nmr (60 MHz) methyl singlets at 8.70 and 9.03.

When the major component was isolated by careful spinning-band distillation [bp 53–56° (10 mm)], the nmr spectrum (60 MHz) had two additional methyl singlets (confirmed as singlets by 100-MHz spectrum) at 8.83 and 8.91. By integration, the ratio of the 8.70 and 9.03 singlets to the 8.83 and 8.91 singlets was 4:1. The 20% component was identified as 3-(2′,2′-dimethyl-$\Delta^{3'}$-cyclobutenyl)-1-propanal (7) by reduction and comparison to a synthetic sample of 3-(2′,2′-dimethylcyclobutyl)-1-propanol (see below).

When the irradiation was done in *tert*-butyl alcohol, the major glc peak, isolated by distillation, was the same 4:1 mixture of components as was formed during the methanol irradiation. However, extending the irradiation in *tert*-butyl alcohol resulted in an increase of a third product (retention time relative to 3 equalled 1.2) as well as a large increase in the amount of polymeric material. This compound was isolated by preparative glc and identified as 4-isopropenyl-5-hexenal (4): mol wt 138; ir 2715 (w), 1720 (s), 895 (m); nmr 0.29 (1 H, broadened singlet, aldehydic H), 3.93–4.64 (1 H, multiplet, vinylic H), 4.83–5.32 (4 H, multiplet, terminal methylene H), 7.15–7.83 (3 H, multiplet, allylic H and H α to carbonyl), 8.00–8.53 (5 H, multiplet with vinylic methyl H at 8.34 (doublet, J = 1 Hz)).

When a 4:1 mixture of 3 and 7, isolated by distillation of a nopinone–methanol irradiation, was reirradiated in *tert*-butyl alcohol, 17% of 4 formed initially and then remained at this percentage as the amount of polymeric material increased. After irradiation (1.50 g of 3 and 7, 150 ml of *tert*-butyl alcohol, 0.048 M, Corex filter, 3.5 hr), an nmr spectrum of the distillable portion (27%) of the oil showed the vinylic methyl group of 4 at τ 8.32.

Conversion of *cis*-1-Formyl-2,2-dimethyl-3-vinylcyclobutane (3) to *cis*-1-Acetyl-2,2-dimethyl-3-vinylcyclobutane (5).—A solution of 0.51 g (3.7 mmol) of 3 (containing *ca.* 20% of 7), isolated by spinning-band distillation of a nopinone irradiation mixture, in 50 ml of dry ether, was stirred under nitrogen at room tem-

(12) P. J. Wagner and R. W. Spoerke, *J. Amer. Chem. Soc.*, **91**, 4437 (1969).

(13) J. Meinwald and P. G. Gassman, *ibid.*, **82**, 5448 (1960).

perature and 5.0 ml of methyllithium–ether solution (*ca.* 2.3 *M*, 11 mmol) was added dropwise. The solution was heated under reflux for 3 hr and allowed to cool and stand overnight. An excess of saturated ammonium chloride solution was added dropwise, the layers were separated, and the aqueous layer was extracted with ether (three 50-ml portions). The combined ethereal extract was dried over magnesium sulfate, filtered, and concentrated.

The crude oil (0.57 g), which was not purified further, was identified as mainly 1-(1′-hydroxyethyl)-2,2-dimethyl-3-vinylcyclobutane on the basis of the following data: mol wt 154; ir 3350 (broad), no carbonyl stretching band; nmr 3.80–4.47 (1 H, multiplet, vinyl H), 4.82–5.26 (2 H, multiplet, terminal methyl H), 5.98–6.55 (1 H, multiplet, H geminal to OH), 7.34–8.80 (5 H, multiplet, methine, methylene, and hydroxyl H), 8.84–9.13 (9 H, multiplet, methyl H). Glc showed two major peaks (53–47%) assigned as diastereomers. These two peaks, each separately glc collected, gave essentially identical mass and nmr spectra.

The major impurity by glc, whose percentage varied from 0 to 20% with various runs, was glc collected and identified (mass spectrum, nmr) as the reduction product of **3**, *cis*-1-hydroxymethyl-2,2-dimethyl-3-vinylcyclobutane, by comparison with a sample obtained by lithium aluminum hydride reduction of **3**.

A solution of the above alcohol mixture (0.49 g, 3.2 mmol) in 15 ml of reagent acetone was oxidized at 0° with excess Jones reagent.[10] After work-up, the major component of the residual oil (0.38 g, 86% pure by glc) was identified as *cis*-1-acetyl-2,2-dimethyl-3-vinylcyclobutane (**5**) and was identical (ir, nmr, and mass spectra, glc retention time) to a synthetic sample of *cis*-**5** (see below).

The nmr spectrum of the oxidation product had two additional methyl singlets at τ 8.83 and 8.91 (21% by nmr integration). These singlets were at different positions than those of synthetic *trans*-**5** (see below) and were tentatively assigned as the methyl singlets of 4-(2′,2′-dimethyl-$\Delta^{3'}$-cyclobutenyl)-2-butanone from reaction of **7** with methyllithium followed by oxidation.

Conversion of 3-(2′,2′-Dimethyl-$\Delta^{3'}$-cyclobutenyl)-1-propanal (7) to 3-(2′,2′-Dimethylcyclobutyl)-1-propanol (10).—A mixture of 5.60 g of **3** and **7** (80% **3** and 20% **7** by nmr) containing some nopinone was reduced with excess lithium aluminum hydride. Glc of the residual oil showed three peaks in order of elution: A, 67%; B, 15%; C, 18%. The components were isolated by preparative glc on Carbowax 20M.

Alcohol A was identified as *cis*-1-hydroxymethyl-2,2-dimethyl-3-vinylcyclobutane on the basis of the following data: ir 3300–3400 (s), 1630 (m), 1004 (s), 992 (s), 905 (s); nmr 3.89–4.49 (1 H, multiplet, vinyl H), 4.88–5.28 (2 H, multiplet, terminal methylene H), 6.34–6.54 (2 H, three-peak multiplet, H α to OH), 7.07 (1 H, singlet, hydroxyl H), 7.30–8.65 (4 H, multiplet, methine and methylene H), 8.89 and 9.10 (6 H, two singlets, methyl H).

Alcohol B was identified as nopinol by comparison (nmr spectrum and glc retention time) to nopinol prepared by lithium aluminum hydride reduction of nopinone.

Alcohol C was identified as 7-methyl-4,6-octadien-1-ol on the basis of the following data: ir 3300–3400 (s), 1438 (s), 1052 (s), 981 (m), 953 (s); λ_{max}^{MeOH} 237 nm (ϵ 20,600); nmr 3.45–4.73 (3 H, multiplet, vinyl H), 6.39 (2 H, triplet, J = 6.5 Hz, H α to OH), 7.2 (1 H, broad absorption, hydroxyl H), 7.60–8.04 (2 H, multiplet, allylic H), 8.1–8.9 (8 H, multiplet with broad vinylic methyl singlet at 8.26). This product was not present in the mixture prior to glc collection as shown by the absence of the strong vinylic methyl absorption at τ 8.26 in the nmr spectrum of the crude reaction mixture after reduction.

A mixture of the above alcohols (2.91 g), 50 ml of absolute ethanol, and 0.2 g of 5% palladium on carbon was hydrogenated on a Parr shaker (30–50 psi) until hydrogen uptake ceased. After filtration and concentration, glc analysis of the residual oil (2.80 g) showed three peaks in order of elution: A, 71%; B, 24%; nopinol, 5%. Components A and B were isolated by preparative glc on Carbowax 20M.

Alcohol A was identified as 1-hydroxymethyl-2,2-dimethyl-3-ethylcyclobutane on the basis of the following data: mass spectrum, last peak at 124 (M − 18); ir 3300–3400 (s); nmr 6.36–6.57 (2 H, three-peak multiplet, H α to OH), 7.39 (1 H, singlet, hydroxyl H), 8.90 and 9.08 (two singlets, methyl H), 9.08 (triplet, J = 7 Hz, methyl H).

Alcohol B was identified as 3-(2′,2′-dimethylcyclobutyl)-1-propanol (**10**) by comparison (ir, nmr, and mass spectra, glc retention time) with an independently synthesized sample (see below).

Synthesis of 1-Acetyl-2,2-dimethyl-3-vinylcyclobutane (5).—A solution of 92.0 g (0.434 mol) of *cis*-pinonic acid (Aldrich), 124 g (2.0 mol) of ethylene glycol, 700 ml of benzene, and 0.4 g of *p*-toluenesulfonic acid was heated under reflux with a continuous water separator until the theoretical amount of water (0.9 mol) was collected. The solution was concentrated under reduced pressure, diluted with 200 ml of anhydrous ether, washed with half-saturated sodium carbonate solution, dried, filtered, and concentrated. The crude oil (137 g) was not purified further; the ir spectrum had a single carbonyl band at 1742 cm^{-1} (s) with no absorption for remaining ketone.

A solution of 137 g (0.5 mol, 1.0 equiv) of the ester ketal in ether was reduced with lithium aluminum hydride (17.8 g, 1.9 equiv) to give, after work-up with excess 10% sulfuric acid, a residual oil (61.4 g) which was identified as 1-acetyl-2,2-dimethyl-3-(2′-hydroxyethyl)cyclobutane: ir 3390 (s), 1700 (s), 1368 (m), 1181 (m), 1050 (s); nmr 6.43 (2 H, triplet, J = 6.5 Hz, H geminal to hydroxyl group), 6.90–7.53 (2 H, multiplet, H α to carbonyl and hydroxyl H), 7.83–8.60 [8 H, multiplet with acetyl methyl singlets at 7.93 (trans) and 7.97 (cis)], 8.70 (cis), 8.78 (trans), 9.00 (trans), and 9.13 (cis) (6 H, four singlets, methyl H). By integration of the nmr methyl singlets, the isomer ratio was 67% cis and 33% trans.

To a solution of 56.0 g (0.329 mol) of 1-acetyl-2,2-dimethyl-3-(2′-hydroxyethyl)cyclobutane in 3 l. of benzene was added, dropwise with stirring, 30.0 g (0.111 mol) of phosphorus tribromide. After addition, the solution was heated under reflux for 2 hr, allowed to cool, and quenched into 4 l. of ice and water. The layers were separated, the aqueous phase was extracted with benzene, and the combined organic phase was washed with half-saturated salt solution, dried, filtered, and concentrated. Distillation of the crude oil (67.4 g) gave pure 1-acetyl-2,2-dimethyl-3-(2′-bromoethyl)cyclobutane: 30.5 g (40% yield); bp 87–88° (0.5–1.0 mm); ir (CCl_4) 1706 (s), 1362 (m), 1351 (m), 1178 (m), 1042 (w); nmr 6.68 (2 H, triplet, J = 6.5 Hz, H geminal to bromine), 7.14 (1 H, misshapen triplet, J = 8–9 Hz, H α to carbonyl), 7.60–8.50 (8 H, multiplet with acetyl methyl singlet at 7.96), 8.68 (cis), 8.77 (trans), 8.98 (trans), and 9.11 (cis) (6 H, four singlets, methyl H). By integration of the nmr methyl singlets, the isomer ratio was 71% cis and 29% trans.

A solution of 30.5 g (0.131 mol) of 1-acetyl-2,2-dimethyl-3-(2′-bromoethyl)cyclobutane in 100 ml of methanol was added dropwise to a stirred solution of 300 ml of 40% dimethylamine in water. After addition, the solution was heated under reflux for 1 hr, allowed to cool, and diluted with 100 ml of ether and 100 ml of saturated salt solution. The layers were separated and the aqueous phase was extracted with ether. The combined organic phase was extracted with 10% sulfuric acid and the acidic extract was then basified with 20% sodium hydroxide solution. The basic layer was extracted with ether which was then dried, filtered, and concentrated to give 1-acetyl-2,2-dimethyl-3-(2′-*N*,*N*-dimethylaminoethyl)cyclobutane: 24.2 g (94% yield); ir (CCl_4) 2849 (m), 2801 (m), 1721 (s), 1466 (m), 1370 (m), 1357 (m), 1182 (m), 1043 (m); nmr 6.16–7.50 (3 H, multiplet, H geminal to nitrogen and α to carbonyl), 7.64–8.62 [14 H, multiplet with *N*,*N*-dimethyl singlet at 7.80 and acetyl methyl singlets at 7.95 (trans) and 7.97 (cis)], 8.72 (cis), 8.78 (trans), 9.01 (trans), and 9.13 (cis) (6 H, four singlets, methyl H). By integration of the nmr methyl singlets, the isomer ratio was 72% cis and 28% trans.

To a cold solution of 12.0 g (0.061 mol) of 1-acetyl-2,2-dimethyl-3-(2′-*N*,*N*-dimethylaminoethyl)cyclobutane in 100 ml of methanol was added, dropwise with stirring, 21.2 g (0.187 mol) of 30% hydrogen peroxide solution. After addition, the solution was stirred at room temperature for 25 hr, and then a small amount of platinum black was added and the mixture was stirred at room temperature for 2 days. The mixture was filtered and concentrated, and the residual material (8.20 g) was heated in an oil bath (from 120 to 200°) under vacuum, and the distillate, bp 51–64° (0.5 mm), collected from a short path condenser into a receiver cooled in a Dry Ice–acetone mixture. The distillate (two layers, 6.35 g) was diluted with ether and water, and the layers were separated. The organic layer was washed with cold dilute hydrochloric acid, washed with sodium carbonate solution, and then was dried, filtered, and concentrated to give pure 1-acetyl-2,2-dimethyl-3-vinylcyclobutane (**5**): 2.49 g (27% overall yield); mol wt 152; ir 1700 (s), 1634 (m), 1460 (s),

1361 (s), 1180 (s), 996 (s), 912 (s); nmr 3.97–4.59 (1 H, multiplet, vinylic H), 4.94 (1 H, broad singlet, terminal methylene H), 5.07–5.27 (1 H, multiplet, terminal methylene H), 6.93–8.44 [7 H, multiplet with acetyl methyl singlets at 7.97 (trans) and 8.00 (cis)], 8.72 (cis), 8.85 (trans), 9.00 (trans), and 9.20 (cis) (6 H, four singlets, methyl H). By integration of the nmr methyl singlets, the isomer ratio was 71% cis and 29% trans.

Anal. Calcd for $C_{10}H_{16}O$: C, 78.90; H, 10.59. Found: C, 78.62; H, 10.32.

Synthesis of 4-(2′,2′-Dimethylcyclobutyl)-2-butanone.—A solution of 31.0 g (0.15 mol) of 4-(2′,2′-dimethyl-4′-carbomethoxycyclobutyl)-2-butanone, obtained by esterification of the corresponding acid derived from ozonolysis of caryophyllene,[14] 18.0 g (0.29 mol) of ethylene glycol, 0.1 g of *p*-toluenesulfonic acid, and 150 ml of benzene was heated under reflux while using a continuous water separator. After the theoretical amount of water was collected, the solution was cooled and neutralized with 10% sodium hydroxide, and the product was isolated. The resulting ethylene ketal of 4-(2′,2′-dimethyl-4′-carbomethoxycyclobutyl)-2-butanone was not purified further: 33.8 g; nmr 6.09 (4 H, singlet, ketal H), 6.34 (3 H, singlet, methyl ester H), 8.71, 8.92, and 8.96 (9 H, three singlets, methyl H).

A mixture of 33.8 g (0.13 mol) of the above ketal, 5.2 g (0.13 equiv) of sodium hydroxide, and 50 ml of water was heated under reflux for 5 hr. Periodically, the pH was adjusted to 9–10 by the addition of small amounts of 10% sodium hydroxide solution. The mixture was allowed to cool and extracted with ether. The aqueous phase was returned to the flask and a solution of 24.0 g (0.14 equiv) of silver nitrate in 100 ml of water was added at room temperature. After addition, the mixture was stirred 1 hr and filtered, and the silver salt was washed with water and methanol and dried in the dark under vacuum to give 36.2 g of a pale gray powder.

The silver salt (36.0 g, 0.12 mol) was added portionwise over 0.5 hr to a stirred solution of 18.0 g (0.11 mol) of bromine in 100 ml of carbon tetrachloride at −15 to −20°. After addition, the mixture was stirred 0.5 hr at −15°, allowed to warm to room temperature, and filtered. The filtrate was washed with water, 10% sodium hydroxide solution, again with water, dried, and concentrated. An ir spectrum of the resultant oil (18.9 g) showed a strong carbonyl band; therefore, the above ketalization was repeated to give 19.0 g of the ethylene ketal of *cis*- and *trans*-4-(2′,2′-dimethyl-4′-bromocyclobutyl)-2-butanone: nmr 5.2–5.7 (1 H, multiplet, H α to Br), 6.05 (4 H, singlet, ketal H), 8.65, 8.68, 8.79, 8.82, 8.91, and 9.01 (9 H, six singlets, methyl H).

To a solution of the above bromide (19.0 g, 0.069 mol) and 5 ml of 1,2-dimethoxyethane in 500 ml of freshly distilled liquid ammonia, was added 1.0 g (0.14 equiv) of lithium in portions. After addition, the blue solution was stirred for 1 hr, and then 10 ml of absolute ethanol was added dropwise followed by the cautious addition of 8.0 g (0.15 equiv) of solid ammonium chloride. The ammonia was allowed to evaporate, the salts were dissolved in water, and the ethylene ketal of 4-(2′,2′-dimethylcyclobutyl)-2-butanone was isolated by extraction with ether: 9.63 g; nmr 6.07 (4 H, singlet, ketal H), 8.70, 8.95, and 9.00 (9 H, three singlets, methyl H).

A solution of the above ketal (9.60 g), 200 ml of acetone, 20 ml of water, and 3 ml of concentrated hydrochloric acid was heated under reflux for 2–3 hr and allowed to cool. The solution was neutralized with 10% sodium hydroxide, partially concentrated under reduced pressure, and diluted with water, and the organic material was isolated by extraction with ether. The residual oil (5.80 g) was chromatographed on 325 g of silica gel slurry-packed with hexane into a 2.5-cm i.d. column. The hexane and benzene eluted material (0.18 g) was discarded. Benzene–ether mixtures and ether eluted 85% pure 4-(2′,2′-dimethylcyclobutyl)-2-butanone: 3.73 g (16% overall yield); mol wt 154; ir 1709; nmr 7.89 (3 H, singlet, methyl α to carbonyl), 8.95 and 9.00 (6 H, two singlets, methyl H).

Anal. Calcd for $C_{10}H_{18}O$: C, 77.87; H, 11.76. Found: C, 77.77; H, 11.76.

Synthesis of 3-(2′,2′-Dimethylcyclobutyl)-1-propanol (10).—To a solution of 0.39 g (2.5 mmol) of 4-(2′,2′-dimethylcyclobutyl)-2-butanone, 10 ml of water, and 36 ml dioxane, cooled to 0°, was added dropwise, a solution of sodium hypobromite, prepared from 1.36 g (34 mequiv) of sodium hydroxide, 12 ml of water, 1.41 g (9 mmol) of bromine, and 8 ml of dioxane. After 3 hr at 0°, a solution of 0.56 g of sodium sulfite in 5.6 ml of water was added and the reaction mixture was poured into 15 ml of 10% sodium hydroxide solution and extracted with ether. The aqueous phase was acidified with concentrated hydrochloric acid to pH 1 and extracted with ether. The ethereal extract was washed with water, dried, and concentrated to give 3-(2′,2′-cyclobutyl)-propionic acid: 0.16 g; ir, 2500–3500 (broad), 1700 (s); nmr 0.75 (1 H, broad singlet, acidic H), 8.95 and 8.99 (6 H, two singlets, methyl H).

A solution of the above acid (0.16 g, 1 mmol) in 5 ml of anhydrous ether was added dropwise to a stirred mixture of 0.2 g (20 mequiv) of lithium aluminum hydride. After addition, the mixture was heated under reflux for 5 hr, allowed to cool, and then saturated ammonium chloride solution was added dropwise until the salts settled. The mixture was filtered, and the filtrate was diluted with ether, washed with 10% sodium hydroxide solution, washed with water, dried, and concentrated to give 0.09 g (26% overall yield) of 3-(2′,2′-dimethylcyclobutyl)-1-propanol (**10**): mass spectrum last peak at 124 (M − 18); ir 3200–3400 (s), 1460 (s), 1380 (m), 1365 (s), 1056 (s); nmr 6.3–6.6 (2 H, misshapen triplet, J = 5–6 Hz, H α to OH), 7.25 (1 H, broad singlet, hydroxyl H), 8.98 and 9.02 (6 H, two singlets, methyl H).

Anal. Calcd for $C_9H_{18}O$: C, 76.00; H, 12.76. Found: C, 76.07; H, 12.57.

Quantum Yields for Disappearance of Nopinone and Verbanone.—Quantum yields were determined according to the procedure of Wagner.[12] Solutions 0.20 M of each ketone in benzene containing octadecane as an internal standard were placed in 1.1-cm Pyrex tubes, degassed, sealed, and irradiated in parallel at 33° on a merry-go-round using 8-RUL 3000-Å Rayonet lamps. At this concentration, the ketones absorbed ≥99% of the 300-nm radiation. The amount of ketone that disappeared was measured by glc analysis (4% UCW 98, 12 ft × $^1/_8$ in.) by comparing the ketone:standard area ratios before and after irradiation.

Two tubes containing 1.0 M acetone and 0.20 M *cis*-1,3-pentadiene in cyclohexane were irradiated in parallel with the above samples. The average yield of *trans*-1,3-pentadiene (9–10%) was measured on an 18 ft × $^1/_8$ in. column packed with 10% GE-SE-54 using electronic peak integration. The quantum yield for the cis to trans isomerization, after being corrected for back reaction, is 0.555.[15] The quantum yields for disappearance (6–10%) of ketone were: 2-methylcyclohexanone, 0.46 (reported[12] 0.50); nopinone, 0.32 ± 0.02; verbanone,[16] 0.40 ± 0.02.

Registry No.—**2**, 24903-95-5; **3**, 32319-47-4; **4**, 32319-48-5; *cis*-**5**, 32319-49-6; *trans*-**5**, 32319-50-9; **7**, 32319-66-7; **9**, 32319-51-0; **10**, 32319-52-1; 1-(1′-hydroxyethyl)-2,2-dimethyl-3-vinylcyclobutane, 32319-53-2; *cis*-1-hydroxymethyl-2,2-dimethyl-3-vinylcyclobutane, 32319-54-3; *cis*-1-acetyl-2,2-dimethyl-3-(2′-hydroxyethyl)cyclobutane, 32319-55-4; *trans*-1-acetyl-2,2-dimethyl-3-(2′-hydroxyethyl)cyclobutane, 32319-56-5; 1-hydroxymethyl-2,2-dimethyl-3-ethylcyclobutane, 32380-98-6; *cis*-1-acetyl-2,2-dimethyl-3-(2′-bromoethyl)cyclobutane, 32319-57-6; *trans*-1-acetyl-2,2-dimethyl-3-(2′-bromoethyl)cyclobutane, 32319-58-7; *cis*-1-acetyl-2,2-dimethyl-3-(2′-*N*,*N*-dimethylaminoethyl)-cyclobutane, 32319-59-8; *trans*-1-acetyl-2,2-dimethyl-3-(2′-*N*,*N*-dimethylaminoethyl)cyclobutane, 32319-60-1; ethylene ketal, 4-(2′,2′-dimethyl-4′-carbomethoxycyclobutyl)-2-butanone, 32319-61-2; ethylene ketal, *cis*-4-(2′,2′-dimethyl-4′-bromocyclobutyl)-2-butanone, 32319-62-3; ethylene ketal, *trans*-4-(2′,2′-dimethyl-4′-bromocyclobutyl)-2-butanone, 32319-63-4; ethylene ketal, 4-(2′,2′-dimethylcyclobutyl)-2-butanone, 32319-64-5; 4-(2′,2′-dimethylcyclobutyl)-2-butanone, 32319-65-6.

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