4a

accomplished by means of paramagnetic shift reagent studies (see Table II, supplementary material). When **4a·HCl** is treated with Eu(fod)$_3$ the exo protons at C_1, C_4, C_5, and C_7 show little or no downfield shift. More significantly, the methyl group at C_8 shows a marked downfield shift while the aromatic region is virtually unchanged. Assuming that the endo lone pair on oxygen is the probable site of complexation of the shift reagent,[5] it thus appears that the C_8 methyl group is endo. As in the case of melonal, the thermodynamically more stable product is formed in which the less bulky group occupies the more sterically congested endo position.

Hydrochloride **4a** was smoothly hydrogenolyzed to **5**, an attractive precursor for a number of further synthetic transformations involving either the alcohol or amine functions.

Experimental Section

Melting points were obtained in a Thomas-Hoover melting point apparatus (uncorrected). Infrared spectra were determined on a Perkin-Elmer Model 521 spectrometer. Proton magnetic resonance spectra were recorded on either a Varian A-60 or a Varian XL-100 spectrometer using Me$_4$Si as the internal standard. Mass spectra were obtained on an AEI MS 902 mass spectrometer by direct insertion. The following abbreviations are used: (b) broad, (ex) exchangeable with D$_2$O, (s) singlet, (d) doublet. (t) triplet, (q) quartet, and (m) multiplet.

2-Methyl-2-phenyl-5-hexenal (3a). To a solution of 30.8 g (0.14 mol) of **1** in 270 mL of dry THF at −78 °C under N$_2$ was added 110 mL (0.165 mol) of 1.5 M n-BuLi/hexane. The solution was stirred for 1 h at −78 °C, 20.3 g (0.15 mol) of 4-bromo-1-butene in 30 mL of THF was added, and the mixture was warmed to room temperature. The solution was again cooled to −78 °C, 105 mL (0.16 mol) of 1.5 M n-BuLi/hexane was added, the mixture was stirred for 1 h at −78 °C, and 15 mL (0.24 mol) of MeI was added. The solution was warmed to room temperature, stirred overnight, quenched with water, and extracted with ether. The ether extracts were washed with water, dried over Na$_2$SO$_4$, and evaporated to give 40 g (~100%) of crude oily **2a** as a diastereomeric mixture.

The above product was dissolved in 140 mL of THF/140 mL of 95% ethanol at −35 to −45 °C. A solution of 5.4 g (0.14 mol) of NaBH$_4$ in 8 mL of water was added dropwise; 9 N HCl was added as needed to maintain pH 6–8. The solution was stirred for 1 h at −35 °C and kept at pH 7. The mixture was poured into 200 mL of water, made basic with 1 N NaOH, and extracted with ether. The ether extracts were washed with brine, dried over Na$_2$SO$_4$, and evaporated to give 40 g (~99%) of crude oily product.

The tetrahydrooxazine was heated at reflux for 2 h in 220 mL of water containing 70.6 g of oxalic acid. The solution was extracted with ether, washed with water and saturated NaHCO$_3$ solution, dried over Na$_2$SO$_4$, and evaporated to give 17.8 g (68% overall) of **3a** as an oil: bp 72–75 °C (0.20 mm); IR (film) 1721, 1634, 991, 910, 756, 697 cm^{-1}; NMR (CDCl$_3$) δ 1.44 (s, 3 H), 1.95 (m, 4 H), 4.95 (m, 2 H), 5.71 (m, 1 H), 7.27 (s, 5 H), 9.49 (s, 1 H); MS m/e 188 (M$^+$) 159, 144, 105, 91.

Anal. Calcd for C$_{13}$H$_{16}$O: C, 82.93; H, 8.57. Found: C, 83.31; H, 8.31.

2-(Methylthio)-2-phenyl-5-hexenal (3b). The procedure described for the preparation of **2a** was carried out on a 0.14-mol scale using 14.1 g (0.15 mol) of dimethyl disulfide in place of MeI to give 44 g (~100%) of crude **2b**. A 0.07-mol sample of **2b** was reduced with NaBH$_4$ and hydrolyzed to give 5.0 g (32% overall) of oily **3b**: bp 86–88 °C (0.28 mm); IR (film) 1703, 1637, 990, 910, 693 cm^{-1}; NMR (CDCl$_3$) δ 1.78 (s, 3 H), 1.91 (m, 4 H), 4.40 (m, 2 H), 5.64 (m, 1 H), 3.33 (s, 5 H), 9.19 (s, 1 H); MS m/e 220 (M$^+$), 205, 191, 143, 103, 91, 77, 41.

The 2,4-dinitrophenylhydrazone was recrystallized from 95% ethanol, mp 108–109 °C.

Anal. Calcd for C$_{19}$H$_{20}$N$_4$O$_4$S: C, 56.98; H, 5.03; N, 13.99. Found: C, 56.97; H, 5,19; N, 14.21.

***cis-trans*-2,8-Dimethyl-8-phenyl-3-oxa-2-azabicyclo-[3.3.0]octane Hydrochloride (4a).** A solution of 17.6 g (0.093 mol)

of **3a**, 23.3 g (0.28 mol) of N-methylhydroxylamine hydrochloride, 24 mL (0.30 mol) of pyridine, and 300 mL of absolute ethanol was heated at reflux under N$_2$ for 24 h. The mixture was acidified with 1 N HCl, washed with ether, and made basic with 1 N NaOH. After extraction with CH$_2$Cl$_2$, drying over Na$_2$SO$_4$, and evaporation of solvent, the cycloadduct was obtained as an orange oil. The crude product was dissolved in ether/acetone at 0 °C and treated with excess HCl gas. Crystalline **4a** was collected by filtration, washed with ether, and dried to give 13.4 g (57%): mp 176–177 °C; IR (Nujol) 2400, 1106, 766, 700 cm^{-1}; NMR (CDCl$_3$) (see Tables I and II and accompanying spectrum); MS m/e 217 (M$^+$), 200, 105.

Anal. Calcd for C$_{14}$H$_{20}$ClNO: C, 66.26; H, 7.94; N, 5.52. Found: C, 65.89; H, 7.89; N, 5.34.

***cis-trans*-2-Methyl-8-(methylthio)-8-phenyl-3-oxa-2-azabicyclo[3.3.0]octane Hydrochloride (4b).** The procedure described for the preparation of **4a** was followed using 2.5 g (0.011 mol) of **3b** and 3.1 g (0.037 mol) of N-methylhydroxylamine hydrochloride. The yield of **4b·HCl** was 1.95 g (62%): mp 177–178 °C; IR (Nujol) 2320, 1139, 981, 722, 698 cm^{-1}; NMR (Me$_2$SO-d_6) δ 1.60 (s, 3 H, and m, 2 H), 2.44 (m, 2 H), 3.19 (s, 3 H), 3.30 (m, 1 H), 3.88 (m, 1 H), 4.59 (q, 2 H), 7.45 (m, 5 H), 10.8 (b ex, 1 H); MS m/e 249 (M$^+$), 220, 172.

Anal. Calcd for C$_{14}$H$_{20}$ClNOS: C, 58.82; H, 7.05; N, 4.90. Found: C, 58.97; H, 7.15; N, 4.69.

N-Methyl-*cis-trans*-2-hydroxymethyl-5-methyl-5-phenyl-cyclopentylamine Hydrochloride (5). A mixture of 13.8 g (0.054 mol) of **4a·HCl** and 2 g of 10% Pd/C in 330 mL of 95% ethanol was hydrogenated at 25 °C and 40 psi until uptake ceased. The mixture was filtered through Celite, concentrated, and crystallized from ether/acetone to give 12.1 g (88%) of **5**: mp 178–180 °C; IR (Nujol) 3346, 2708, 1588, 1068, 1041, 761, 692 cm^{-1}; NMR (Me$_2$SO-d_6) δ 1.53 (s, 3 H), 1.89 (m, 4 H), 2.46 (s, 3 H, and m, 1 H), 3.77 (m, 1 H), 3.72 (d, 2 H), 7.42 (m, 5 H); MS m/e 219 (M$^+$), 100, 70.

Anal. Calcd for C$_{14}$H$_{22}$ClNO: C, 65.73; H 8.67; N, 5.48. Found: C, 65.43; H, 8.57; N, 5.27.

Supplementary Material Available. The NMR spectrum of **4a·HCl** and LIS data (Tables I and II; 2 pages). Ordering information is given on any current masthead page.

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(4) Examination of molecular models shows the trans compound to be very rigid with the C$_6$ and C$_7$ protons held in an approximately cis eclipse relationship. This geometry requires that the coupling patterns for C$_6$ and C$_7$ be nearly the same, in contrast to the actual spectral data.
(5) The endo lone pair is the more sterically accessible owing to an unfavorable exo$_2$, exo$_3$ interaction.

Organotellurium Chemistry. 2. Dibenzyl Ditelluride: Some Transformations Involving Loss of Tellurium

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Dibenzyl diselenide (4) has been known for over a century,[1] and its chemistry has been extensively investigated.[2-4] In

contrast, the corresponding dibenzyl ditelluride (1) was first synthesized only in 1968,[5] and no chemistry of this compound has as yet been reported. Recently, we described a convenient synthesis of 1.[6] We now report some further properties of this compound, including several chemical reactions which result in tellurium extrusion.

Results and Discussion

NMR Properties. The ^{1}H NMR spectrum of dibenzyl ditelluride (1) in CDCl$_3$ shows an aromatic singlet (10 H) at δ 7.22 and a benzylic singlet (4 H) at δ 4.25. The aromatic signal of the corresponding diselenide 4 appears at almost the same position (δ 7.29), but the benzylic signal now appears upfield at δ 3.89. Substitution of tellurium for selenium in this system thus produces an appreciable deshielding effect on the adjacent methylene protons.

The ^{13}C NMR of ditelluride 1 in CDCl$_3$ shows aromatic carbon signals at δ 141.5, 128.2, 127.9 and 126.0, as well as a benzylic carbon signal at δ 6.58. Dibenzyl diselenide (4) shows corresponding signals at δ 138.3, 128.3, 127.7, 126.3, and 32.6. The benzylic carbon signal of dibenzyl disulfide has been reported as δ 43.1.[7] In the benzylic signals of the dibenzyl dichalcongenides, there is therefore an upfield shift observed on going from S to Se to Te as neighboring atoms. The unusually large shift (δ 32.6 to 6.58) observed on going from Se to Te emphasizes the metallic nature of the Te atom.

Photochemical Lability of Dibenzyl Ditelluride (1). The most striking property of ditelluride 1 is its extraordinary photochemical lability. Exposure of solutions of 1 to ordinary laboratory ceiling lights leads to the rapid appearance of black elemental tellurium; the ditelluride could be crystallized and chromatographed only while working under red photographic safety lights.

Irradiation of ditelluride 1 in CDCl$_3$ (Hanovia lamp) under nitrogen led to a rapid deposition of Te and a shift of the benzylic ^{1}H NMR signal to δ 4.0, due to the formation of dibenzyl telluride (2); the latter decomposed further only very slowly under the reaction conditions employed. When ditelluride 1 was irradiated under oxygen, however, the monotelluride signal at δ 4.0 soon appeared but then vanished after 5 h, the major reaction products being benzaldehyde, toluene, and benzyl alcohol, as well as some 1,2-diphenylethane. Irradiation of authentic dibenzyl telluride (2) under oxygen in the same manner afforded the same products; in a control experiment, monotelluride 2 was unchanged after irradiation (4 h) under nitrogen. Proof that the oxidation of monotelluride 2 was a photochemical process was obtained by allowing a CDCl$_3$ solution of 2 to stand in the dark under oxygen for 24 h, after which time no transformation products were detected.
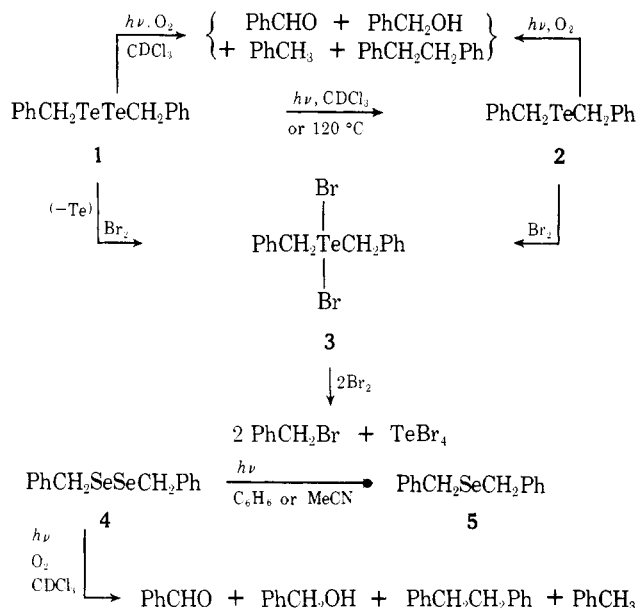
The corresponding photolysis of dibenzyl diselenide (4) to dibenzyl selenide (5) under nitrogen has been reported using both benzene[3] and acetonitrile[4] as solvents. In benzene solution in the presence of oxygen diselenide 4 has been reported to give benzaldehyde (up to 63%) but not benzyl alcohol.[3] For comparison purposes, we have now irradiated diselenide 4 under oxygen in CDCl$_3$ for 30 h; the products of our reaction were unchanged diselenide 4, benzaldehyde, benzyl alcohol, toluene, and 1,2-diphenylethane. The greater variety of products observed in our photooxidation undoubtedly resulted from our use of a closed NMR tube, resulting in an incomplete oxidation of the intermediate benzyl radicals.

Thermal Decomposition of Dibenzyl Ditelluride (1). Although ditelluride 1 can be crystallized without appreciable decomposition from hot hexane (80 °C) under red lights, it is largely decomposed thermally in 10 min at 120 °C (red lights) under nitrogen, the only discernible products being tellurium and monotelluride 2. Under the same conditions, diselenide 4 was recovered completely unchanged. Thermal decompo-

sition of 4 has been reported to occur at temperatures above 150 °C.[8]

Reaction of Dibenzyl Ditelluride (1) with Bromine. The reaction of either ditelluride 1 or monotelluride 2 with excess bromine in CCl$_4$ afforded only TeBr$_4$ and benzyl bromide, as determined by NMR and GC. The result seemed to confirm the earlier expressed opinion that benzylic tellurides were converted by bromine to benzylic bromides in a manner which precluded the isolation of intermediates.[9] A more careful experiment showed, however, that reaction of ditelluride 1 with a little under 1 equiv of bromine gave a dark precipitate (presumably Te) along with a new compound having a benzylic NMR signal at δ 4.60. Preparative isolation of this crystalline material revealed it to be the previously unknown dibenzyltellurium dibromide (3). An independent synthesis of dibromide 3 was achieved by the careful addition of 1 equiv of bromine to dibenzyl telluride (2). As expected, dibromide 3 reacts further with bromine to give benzyl bromide and TeBr$_4$.

The mechanism of the conversion of ditelluride 1 to dibromide 3 is not clear at present. It is interesting to note, however, that the migration of a benzyl group from one tellurium to the other in this reaction is in contrast to the reaction of bromine with diaryl ditellurides, a process which leads to a simple brominolysis of the Te–Te bond.[10]

Experimental Section

Dibenzyl Telluride (2). A. Rongalite Method. Sodium formaldehyde sulfoxylate (Rongalite, 18.0 g) was added under nitrogen at 80 °C to a suspension of tellurium (2.56 g) in a solution of sodium hydroxide (12 g) in water (125 mL). After stirring for 1 h, a solution of benzyl chloride (1.26 g) in a small amount of EtOH was added dropwise at room temperature to the almost colorless telluride solution. After stirring for a further 1 h, extraction with Et$_2$O, followed by removal of the dried solvent and crystallization from petroleum ether (red light illumination), gave dibenzyl telluride (2) as yellow needles (1.09 g, 70%): mp 49–57 °C (lit.[11] mp 53–53.5 °C); NMR δ 4.00

(s, 4 H), 7.22 (br s, 10 H); λ_{max} 209 nm (log ϵ 4.38), 233 (4.46), 390 (1.70); mass spectrum m/e (rel intensity) M^+ 312 (44), 91 (100).

B. Borohydride Method. A mixture of tetramethylammonium borohydride (1.78 g), tellurium powder (1.27 g), and water (100 mL) was heated on the steam bath under nitrogen until the initially produced purple color was discharged. After cooling to room temperature, a solution of benzyl chloride (2.53 g) in EtOH (20 mL) was added slowly with stirring, air being rigorously excluded. After stirring for a further 2 h, the reaction mixture was worked up as in the above experiment to give crystalline 2 (2.56 g, 82%), mp 49–57 °C.

Photochemical Decomposition of 1. A solution of dibenzyl ditelluride (1, 50 mg) in CDCl$_3$ (0.5 mL) in an NMR tube was irradiated in the presence of nitrogen, using a Hanovia lamp, until no more tellurium deposited. The only detectable reaction product (by both NMR and GC) was monotelluride 2, which was unchanged after a further 4 h of irradiation (nitrogen), as confirmed in a control reaction using crystalline 2.

Repetition of the above irradiation of 1 in the presence of oxygen showed (by NMR) that monotelluride 2 was initially formed, but then slowly disappeared with the formation of the following products (by NMR and GC): benzaldehyde (42%), benzyl alcohol (21%), toluene[12] (21%), and 1,2-diphenylethane (7%). The relative amounts of these products were somewhat variable, and seemed dependent upon oxygen concentration.

Thermolysis of 1. Ditelluride 1 was heated at 120 °C without solvent for 10 min under nitrogen and under red lights. The dark melt was dissolved in CDCl$_3$, filtered from tellurium, and analyzed by NMR, which indicated 2 as the only product formed.

Photochemical Oxidation of 2. In a typical photooxidation in CDCl$_3$ under conditions used for 1, the following were detected (NMR and GC) after 24 h: benzaldehyde (42%), benzyl alcohol (24%), unchanged 2 (8%), toluene[12] (4%), and 1,2-diphenylethane (5%). In another experiment using a low concentration of 2 and excess pure oxygen, only benzaldehyde (66%) and benzyl alcohol (33%) were detected. The photooxidation of 2 was done in CCl$_4$. The products detected were benzaldehyde (56%), benzyl alcohol (12%), dibenzyl (2%), toluene (2%), and benzyl chloride (8%).

Photochemical Oxidation of 4. A photooxidation of diselenide 4 in CDCl$_3$, using insufficient oxygen, showed the following products (NMR and GC) after 30 h: unchanged 4 (20%), benzaldehyde (25%), benzyl alcohol (14%), toluene[12] (25%), and 1,2-diphenylethane (5%).

Dibenzyltellurium Dibromide (3). From 1. A solution of 1 (0.500 g) in CCl$_4$ was treated in the dark with a solution of bromine in CCl$_4$. The reaction was monitored by NMR, and GC showed that benzyl bromide was not present. After 10 min, the black precipitate was removed by filtration and the solution concentrated to give 3 (0.340 g, 63%) as white prisms: mp 136–137 °C; NMR δ 4.60 (s, 4 h), 7.40 (m, 10 H); mass spectrum m/e (rel intensity) 389 (M – Br, 62), 91 (100). Anal. Calcd for C$_{14}$H$_{14}$Br$_2$Te: C, 35.80; H, 3.00; Br, 34.02; Te, 27.17. Found: C, 35.66; H, 2.93; Br, 34.26; Te, 27.27.

Treatment of 3 in CCl$_4$ with bromine gave only benzyl bromide, as shown by NMR and by GC.

From 2. A solution of bromine (0.160 g) in CCl$_4$ was added carefully to a solution of 2 (0.344 g) in CCl$_4$. After 10 min, concentration followed by crystallization (CCl$_4$-Et$_2$O) gave 3 (0.375 g, 72%), identical (IR, melting point) with material obtained from 1.

Registry No.—1, 20727-11-1; 2, 62654-03-9; 3, 62654-04-0; 4, 1482-82-2; tellurium, 13494-80-9; benzyl chloride, 100-44-7; benzaldehyde, 100-52-7; benzyl alcohol, 100-51-6; toluene, 108-88-3; 1,2-diphenylethane, 103-29-7.

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Nitroacetoxylation of Isoprene

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The C$_5$ carbon skeleton of isoprene is of fundamental importance in organic chemistry, since this basic unit is encountered in many natural products. It is therefore not surprising that numerous attempts have been made to utilize isoprene preparatively as a C$_5$ building block in the synthesis of naturally occurring substances such as terpenoids in general and vitamin A and carotenoids in particular.[1] In order to effectively use isoprene for these purposes, it has to be appropriately functionalized.[2] The only reaction in this regard which appears to have gained industrial importance[3] is the low-temperature addition of anhydrous hydrogen chloride. Yields of over 90% of isolated product have been reported,[4] indicating very little polymerization of starting material.

The present contribution describes a novel and preparatively efficient *bis* functionalization of isoprene: *nitroacetoxylation*. Treatment of isoprene with acetyl nitrate at room temperature leads, in a fast and highly exothermic reaction, to a virtually quantitative weight yield of an approximately 7:3 mixture of nitro acetates 1 and 2. It appears that within
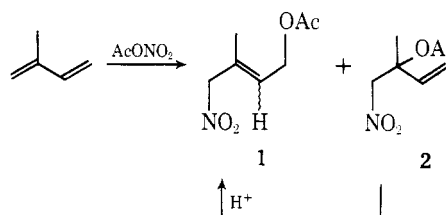
the temperature range of about –20 to 30 °C the ratio of 1 to 2 is not changed substantially, although the highest content of the 1,4-addition product is observed at 25–30 °C. Complete conversion of tertiary acetate 2 into the 1,4-addition product is achieved by treating 2 in acetic acid with a catalytic amount of sulfuric acid. Moreover, subjecting the initial reaction product to rearrangement conditions results in the isolation of 1 as a 85:15 trans/cis mixture in over 80% yield.

A close formal analogy is evident between the low-temperature hydrogen chloride addition and the nitroacetoxylation reaction. Both processes appear to proceed virtually exclusively via a heterolytic pathway.[5] This is borne out by (a) the equally high regiospecificity for both the proton and nitro group introductions at C$_1$ of the isoprene skeleton, (b) the negligible degree of polymerization of starting material observed, and (c) the mixtures of 1,4- and 1,2-addition products obtained.[6] The predominant E configuration for nitro acetate 1 may be primarily the result of the spatial requirements of the O-acetyl and nitromethyl groups.

The novel structures thus produced appear potentially useful as C$_5$ synthons, especially in the area of polyolefin terpenoids. Pertinent studies are currently being carried out in this laboratory.