was neutralized with aqueous sodium hydroxide and continuously extracted with ethyl acetate. Two recrystallizations from water yielded pure 2-iodopurine (50%), mp 233-236 °C. Anal. Calcd for $C_5H_3IN_4$: C, 24.41; H, 1.23. Found: C, 24.38; H, 1.08. The crude product mentioned above yielded 2-chloropurine (87%) with 36% hydrochloric acid and 2-bromopurine (55%) when 47% hydrobromic acid was used. The identity of the 2-chloro- and 2-bromopurine was established by UV and mass spectrometry.

Preparation of 8-Deuteriopurines. 2-Chloro-8-deuteriopurine and 8-deuterio-2-(methylthio)purine were obtained by refluxing 2-chloropurine and 2-(methylthio)purine, respectively, for 4 h in deuterium oxide.[2,3,20] The position of deuteration was proven by NMR spectroscopy.[21,22] For NMR measurements the deuterium-labeled compounds were diluted to about 50% deuterium content.

Amination Procedure. The amination reactions were carried out in exactly the same manner as described in a previous paper.[2] The amination of the compounds **1a-d** gave known products. However, from **1e** 2-amino-6-phenylpurine (**2**, R = C_6H_5), mp 257-259 °C, was obtained. The structure of this product was proven by ^{13}C and ^1H NMR: ^1H NMR ($CDCl_3/CD_3OD$) δ 7.98 (s, 1 H), 7.49 and 8.36 (m, 5 H); ^{13}C NMR (Me_2SO-d_6) 160.3 (C-2), 155.8 (C-4), 123.7 (C-5), 153.0 (C-6), 140.9 (J = 210 Hz, C-8), C_6H_5, 128.3, 129.1, 130.4, 136.3; UV λ_{max}(CH_3OH) 331 nm. Anal. Calcd for $C_{11}H_9N_5$: C, 62.54; H, 4.30. Found: C, 62.28; H, 4.24.

Acknowledgment. This investigation was carried out under the auspices of the Netherlands Foundations for Chemical Research (SON) and with financial aid from the Netherlands Organization for Advancement of Pure Research (ZWO). We are indebted to Dr. C. A. Landheer and Mr. W. P. Combé for the mass spectroscopic data, Mr. A. van Veldhuizen for measuring the NMR spectra, Mr. H. Jongejan for carrying out the microanalyses, and Mr. A. Koudijs for the synthesis of 2-chloro-6,8-di-*tert*-butylpurine.

Registry No. **1a**, 1681-15-8; **1b**, 1598-61-4; **1c**, 33512-51-5; **1d**, 1681-19-2; **1e**, 73747-11-2; **2** (R = H), 452-06-2; **2** (R = C_6H_5), 73747-12-3; **3** (R = C_6H_5), 73758-12-0; **7** (R = H), 31458-49-8; **8** (R = H), 28128-16-7; 2-chloro-4,5-diamino-6-phenylpyrimidine, 19796-43-1; 2-chloro-6,8-di-*tert*-butylpurine, 73747-13-4; 2-Cl-8-*D*-purine, 73747-14-5; 2-SCH_3-8-*D*-purine, 73747-15-6.

(20) Pugmire, R. J.; Grant, D. M.; Robins, R. K.; Rhodes, G. W. *J. Am. Chem. Soc.* **1965**, *87*, 2225.
(21) Barlin, G. B.; Young, A. C. *J. Chem. Soc. B* **1971**, 821.
(22) Brown, D. J.; Ford, P. W. *J. Chem. Soc. C.* **1969**, 2620.

1-Nitro-1-(phenylthio)propene as a New Nitro Olefin Reagent for 3-Methylfuran Annulation and Its Application to the Synthesis of Some Furanoterpenoids

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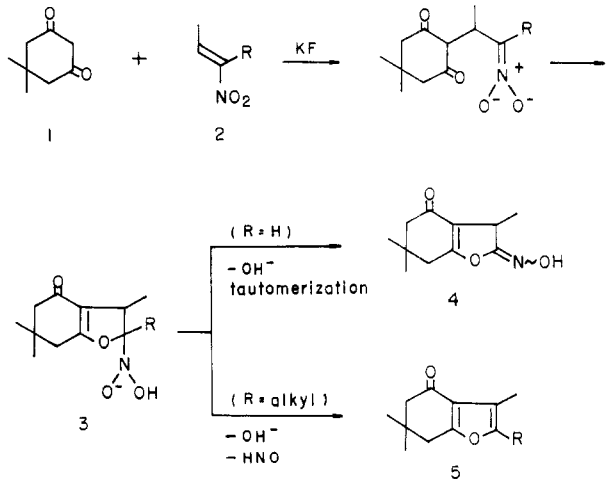
1-Nitro-1-(phenylthio)propene (**9**) was synthesized from (phenylthio)acetic acid (**6**) in five steps. This nitro olefin reacted with dimedone (**1**) with KF catalysis to yield dihydrofurans **10a** and **10b**, both of which were converted to 3-methylfuran **13** on $NaIO_4$ oxidation followed by elimination of benzenesulfenic acid from the resulting sulfoxides in good overall yields. As an application of this reagent, the furanomonoterpenoid evodone (**24**) and the furanosesquiterpenoids ligularone (**25**) and isoligularone (**26**) were synthesized from diones **21** and **34**, respectively. The stereoselective synthesis of dione **34** from the known enone **27** is also described.

Aliphatic, conjugated nitro olefins, readily available from nitroalkanes and aldehydes or ketones[1] or from olefins,[2] are potentially useful synthons, and their synthetic versatility has recently been demonstrated by us[3] and other groups.[2b,4] Our finding[3c] that the KF-catalyzed reaction of 1,3-dicarbonyl compounds and nitro olefins resulted in the direct formation of the 2-alkyl-4-acylfuran system led us to extend this type of reaction to the synthesis of the 3-acyl-4-methylfuran system that has been frequently found in terpenoids. In this paper we describe details on the preparation of the new nitro olefin reagent 1-nitro-1-(phenylthio)propene (**9**) and its reaction with 1,3-diones, leading to the 3-acyl-4-methylfuran system[5] which cul-

Scheme I



(1) For general reviews on the syntheses and chemistry of aliphatic nitro olefins, see: (a) Baer, H. H.; Urbas, L. "The Chemistry of the Nitro and Nitroso Groups"; part 2, Feuer, H., Ed.; Interscience: New York, 1970; Part 2, pp 75-200; (b) Müller, E., Ed.; "Methoden der Organischen Chemie (Houben-Weyl)"; Georg Thieme Verlag: Stuttgart, 1971; Vol. 10/1, pp 9-462; (c) Kochany, J. *Wiad. Chem.* **1978**, *32*, 723; (d) Seebach, D.; Colvin, E. W.; Lehr, F.; Weller, T. *Chimia* **1979**, *33*, 1.
(2) (a) Review: Larson, H. O. "The Chemistry of the Nitro and Nitroso Groups"; Feuer, H., Ed.; Interscience: New York, 1969; Part 1, pp 316-324; (b) Corey, E. J.; Estreicher, H. *J. Am. Chem. Soc.* **1978**, *100*, 6294.
(3) (a) Yanami, T.; Kato, M.; Yoshikoshi, A. *J. Chem. Soc., Chem. Commun.* **1975**, 726; (b) Miyashita, M.; Yanami, T.; Yoshikoshi, A. *J. Am. Chem. Soc.* **1976**, *98*, 4679; (c) Yanami, T.; Ballatore, A.; Miyashita, M.; Kato, M.; Yoshikoshi, A. *J. Chem. Soc., Perkin Trans. 1* **1978**, 1144; (d) Yanami, T.; Ballatore, A.; Miyashita, M.; Yoshikoshi, A. *Synthesis*, in press.
(4) Patterson, J. W.; McMurry, J. E. *J. Chem. Soc. D* **1971**, 488. Ranganathan, S.; Ranganathan, D.; Mehrotra, A. K. *J. Am. Chem. Soc.* **1974**, *96*, 5261. Ehrig, V.; Seebach, D. *Chem. Ber.* **1975**, *108*, 1961. Seebach, D.; Leitz, H. F.; Ehrig, V. *Ibid.* **1975**, *108*, 1924. Seebach, D.; Ehrig, V.; Leitz, H. F.; Henning, R. *Ibid.* **1975**, *108*, 1946. Pitacco, G.; Risaliti, A.; Trevisan, M. L.; Valentin, E. *Tetrahedron* **1977**, *33*, 3145. Grieco, P. A.; Ohfune, Y. *J. Org. Chem.* **1978**, *43*, 2720. Danishefsky, S.; Prisbylla, M. P.; Hiner, S. *J. Am. Chem. Soc.* **1978**, *100*, 2918.

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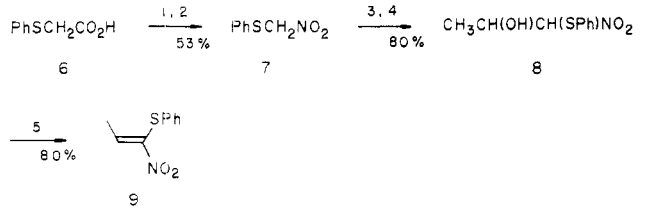
Scheme II[a]



[a] 1, BuLi, THF then $PrONO_2$; 2, aqueous HCl; 3, 5% KOH, MeOH, MeCHO; 4, AcOH; 5, $MeSO_2Cl$, NEt_3, CH_2Cl_2.

minated in the total syntheses of racemic evodone (**24**),[5] ligularone (**25**), and isoligularone (**26**).[6]

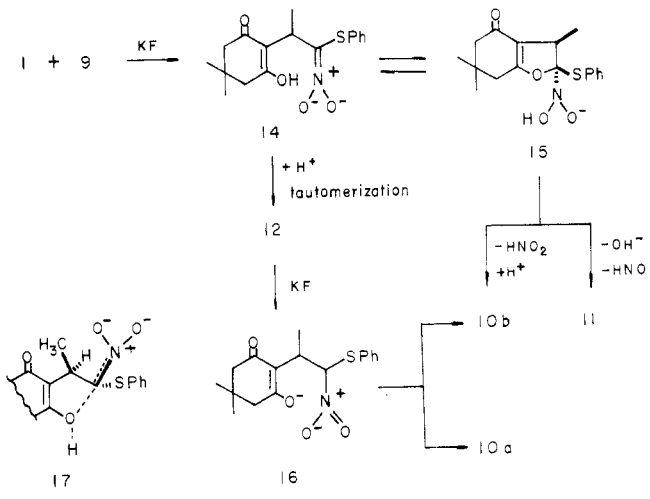
Results and Discussion

By analogy with our previous work, we first examined the KF-catalyzed reaction of dimedone (**1**) and (*E*)-1-nitropropene (**2**, R = H), readily obtainable by dehydration of 1-nitro-2-propanol[7] with phthalic anhydride.[8] Contrary to the expectation of direct formation of methylfuran **5** (R = H), a stereoisomeric mixture of (hydroxyimino)dihydrofurans (**4**), separable by chromatography, was obtained in good yield (Scheme I). This outcome may be rationalized, when R is hydrogen, by elimination of a hydroxide anion from dihydrofuran intermediate **3** followed by tautomerization to **4**. When R is an alkyl group, the intermediate produces the furan derivative **5** by elimination of hydroxide anion and nitroxyl as we observed earlier.[3c] To prevent the undesired tautomerization to the hydroxyimino compounds, we envisaged the use of the new nitro olefin 1-nitro-1-(phenylthio)propene (**9**), because the phenylthio group in the expected product **11** would be removable by reductive desulfurization.

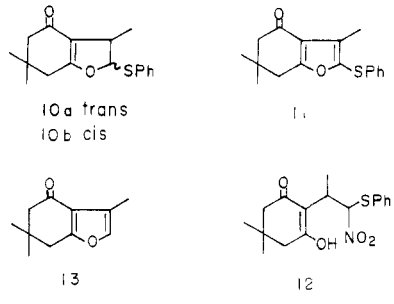
The requisite reagent **9** was conveniently prepared as shown in Scheme II. Addition of propyl nitrate to the dianion[9] of (phenylthio)acetic acid (**6**) prepared with BuLi in tetrahydrofuran at 0 °C, followed by acidification with dilute HCl gave nitro(phenylthio)methane[10] (**7**) in acceptable yield. Nitro aldol condensation of **7** and acetaldehyde with methanolic KOH, followed by neutralization with acetic acid, produced a diastereomeric mixture of nitro alcohols **8** in good yield. Since dehydration of **8** employing McMurry's procedure[11] resulted in low and variable yields (30–48%) of **9**, probably owing to its instability toward base, the procedure was modified. Thus, when **8** was added to a solution of methanesulfonyl chloride and triethylamine in dichloromethane at −78 °C and then the mixture was gradually warmed to 0 °C, (*Z*)-1-nitro-1-(phenylthio)propene (**9**) was stereoselectively obtained in good yield.

The geometrical assignment was made on the basis of the methyl proton singlet, which was slightly deshielded by the phenylthio group (δ 2.13), and the olefin proton quartet, which was strongly deshielded by the nitro group (δ 7.56), both of which were consistent with the reported values for the corresponding protons of (*E*)- and (*Z*)-1-nitropropene.[12] Obviously, the bulkier nitro group rather than the phenylthio group controlled the product geometry.

Scheme III



With the desired reagent **9** in hand, we focused our attention on its reaction with 1,3-diones. The reaction of **9** and 1,3-diones was carried out as described previously;[3c] when a suspension of dimedone (**1**), KF, and **9** in xylene was heated at 110 °C, unlike our previous observation of the direct formation of furan derivatives, the reaction afforded a 1:4 diastereomeric mixture of dihydrofurans **10a** and **10b** in 71% yield along with a small amount of the expected 2-(phenylthio)furan **11**. The stereochemistry of



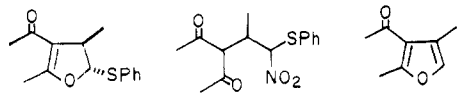
these dihydrofurans was assigned, as described later, by the ease of thermal desulfenylation of the corresponding sulfoxides to methylfuran **13**. At lower temperatures the reaction ceased at the stage of the initial conjugate addition, in particular, when 1,2-dimethoxyethane (DME) was employed as the solvent; heating a mixture of **1**, **9**, and KF in this solvent at 50 °C resulted in exclusive formation of crystalline **12** as a diastereomeric mixture (approximate ratio of 4:3) in quantitative yield. The IR and ^1H NMR spectra of **12** revealed that this compound existed largely as enol forms. Compound **12** could be converted to a 5:3 mixture of dihydrofurans **10a** and **10b** in 76% yield on further treatment with KF in hot xylene. It is noteworthy that the diastereomeric ratio of **10** in the latter case, unlike that in the direct formation from **1** in xylene, was predominantly trans. The above experimental result of the formation of dihydrofurans **10a** and **10b** in different ratios may be rationalized by the two feasible reaction paths as shown in Scheme III. Conjugate addition of dimedone (**1**) to the nitro olefin **9** resulted in formation of nitronate ion **14**, whose enolic hydroxyl group then intramolecularly adds to the carbon–nitrogen double bond to afford **15**. In

(5) Preliminary communication: Miyashita, M.; Kumazawa, T.; Yoshikoshi, A. *J. Chem. Soc., Chem. Commun.* **1978**, 362.
(6) Preliminary communication: Miyashita, M.; Kumazawa, T.; Yoshikoshi, A. *Chem. Lett.* **1979**, 163.
(7) Henry, L. *Bull. Soc. Chim. Fr.* **1895**, *13*, 999. An improved procedure was used in this work (see Experimental Section).
(8) Buckley, G. D.; Scaife, C. W. *J. Chem. Soc.* **1947**, 1471. (*E*)-1-Nitro-1-propene obtained by this method is contaminated by a minor quantity of the *Z*-isomer.[12]
(9) Pfeffer, P. E.; Silbert, L. S. *Tetrahedron Lett.* **1970**, 699. BuLi was used here to generate the dianion in place of lithium diisopropylamide as proposed by the original authors.
(10) During the course of this study, an alternative preparation of **7** was reported, although detailed results were not given: Seebach, D.; Lehr, F. *Angew. Chem.* **1976**, *88*, 540.
(11) Melton, J.; McMurry, J. E. *J. Org. Chem.* **1975**, *40*, 2138.
(12) Baskov, Y. V.; Urbański, T.; Witanowski, M.; Stefanik, L. *Tetrahedron* **1964**, *20*, 1510.

this cyclization, the formation of **15** in preference to its stereoisomer is rational because, in the transition state of the cyclization, a cis arrangement of the C(3)-methyl and the nitronate group which is bulkier than the phenylthio group, as shown in **17**, is unfavorable. Attendant elimination of nitrous acid followed by kinetic protonation at C-2 leads to **10b**, while concomitant elimination of hydroxide anion and nitroxyl affords (phenylthio)furan **11**. In the reaction of **12** and KF, the enolate anion **16** formed would intramolecularly displace the nitro group to produce the dihydrofuran ring.

The respective isomers **10a** and **10b** were converted to methylfuran **13** by oxidation with $NaIO_4$ to the corresponding sulfoxide followed by elimination of benzenesulfenic acid in refluxing carbon tetrachloride containing pyridine in high overall yield (91 and 83%, respectively). In contrast to facile desulfenylation of the sulfoxide from **10a**, we had to add active alumina in the reaction of the latter sulfoxide to effect the elimination, the catalyst causing epimerization and subsequent syn elimination of its phenylsulfinyl group. This result allowed us to assign the stereochemistries of **10a** and **10b** as depicted.

As an example for acyclic compounds, acetylacetone was subjected to this reaction. While this dione yielded a mixture of dihydrofuran **18** and adducts **19** under standard



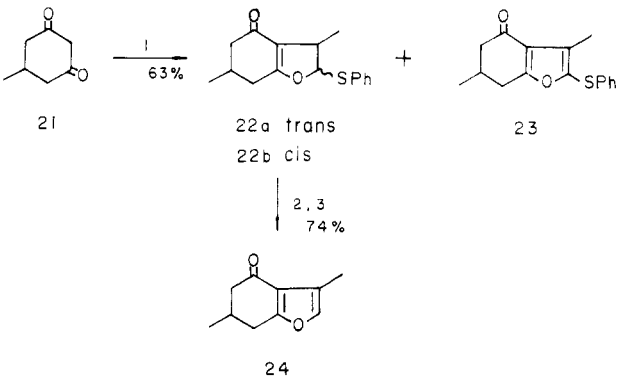
18 19 20

conditions (in xylene at 120 °C) in low yield, the reaction in refluxing benzene gave only **19** as a diastereomeric mixture in 89% yield. Conversion of **19** into **18** in moderate yield (46%) was achieved by treatment with *p*-toluenesulfonic acid in benzene. The dihydrofuran **18** obtained was homogeneous and had a trans stereochemistry as shown by facile elimination of benzenesulfenic acid from the corresponding sulfoxide, giving volatile dimethylfuran **20**.[13]

We then turned our attention to the synthesis of some terpenoids possessing the 3-acyl-4-methylfuran system. The synthesis of evodone (**24**), a furanomonoterpene isolated from *Evonia hortensis* Forst.,[14] was accomplished by straightforward application of the above reaction sequence to 5-methylcyclohexane-1,3-dione (**21**, Scheme IV). Like the reaction with dimedone (**1**), **21** gave a mixture of two diastereomeric dihydrofurans, **22a** and **22b** (1:4), and a minor quantity of (phenylthio)furan **23**. These dihydrofurans were transformed into racemic evodone (**24**) by the same reaction sequence in good yields.[15] Although the configurations of the methyl groups on the cyclohexanone rings in **22a** and **22b** remained ambiguous, stereochemical assignment of substituents on their dihydrofuran rings was made in the same manner as described above.

In order to illustrate the potential of the present methylfuran annulation on more complex systems, we then set about the synthesis of ligularone (**25**),[16] a representative

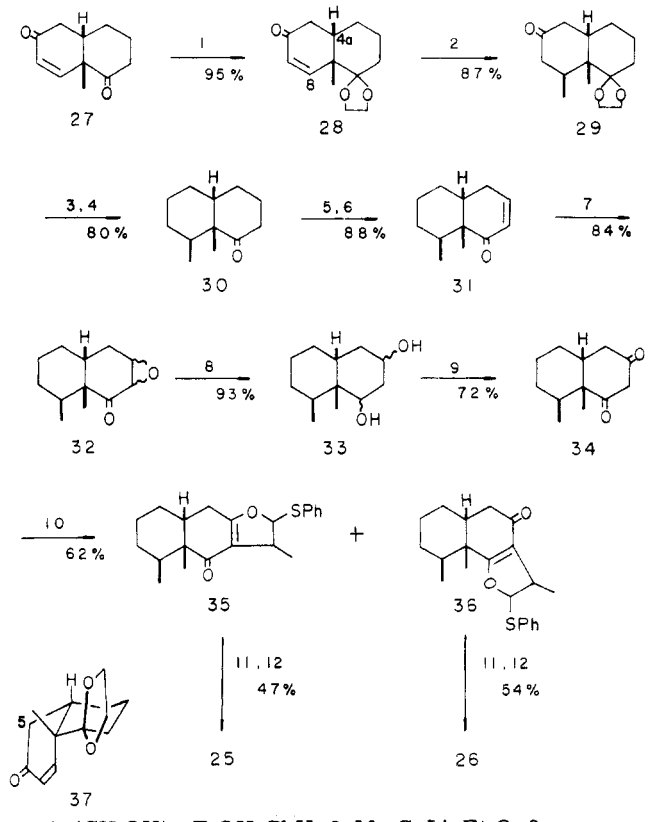
Scheme IV[a]



21 22a trans 22b cis 23 24

[a] 1, MeCH=C(SPh)NO_2, KF, PhH; 2, $NaIO_4$, MeOH; 3, Δ, CCl_4 (Al_2O_3).

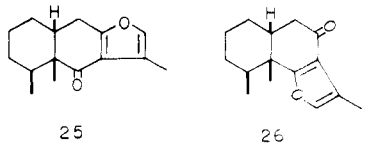
Scheme V[a]



27 28 29 30 31 32 33 34 35 36 37 25 26

[a] 1, $(CH_2OH)_2$, TsOH, PhH; 2, Me_2CuLi, Et_2O; 3, $NH_2NH_2H_2O$, NH_2NH_2·HCl, KOH, $(HOCH_2CH_2)_2O$; 4, aqueous AcOH; 5, $PhMe_3NBr_3$, THF; 6, Li_2CO_3, $AcNMe_2$; 7, H_2O_2, NaOH, MeOH; 8, Li, liquid NH_3; 9, Jones reagent; 10, MeCH=C(PhS)NO_2, KF, DME, then KF, PhH; 11, $NaIO_4$, aqueous MeOH; 12, Δ, C_5H_5N, Al_2O_3.

furanoeremophilanoid isolated from *Ligularia sibirica* Coss., and its thermal isomerization product isoligularone (**26**).[17]



25 26

Bicyclic dione **34**, an important key intermediate in this synthesis, was stereoselectively synthesized by starting from the known dione **27**[18] (Scheme V). Selective ke-

(13) Batty, J. W.; Howes, P. D.; Stirling, C. J. *J. Chem. Soc. D* **1971**, 534; *J. Chem. Soc., Perkin Trans. 1* **1973**, 65. Howes, P. D.; Stirling, J. M. *Org. Synth.* **1973**, *53*, 1.

(14) Birch, A. J.; Richards, R. W. *Aust. J. Chem.* **1956**, *9*, 241 and references cited therein.

(15) For alternative syntheses of evodone, see: (a) Stetter, H.; Lauterbach, R. *Angew. Chem.* **1959**, *71*, 673; (b) Stetter, H.; Lauterbach, R. *Chem. Ber.* **1960**, *93*, 603; (c) Moiseekov, A. M.; Lakhvich, F. A.; Akhrem, A. A. *Aktual. Probl. Izuch. Efirnomaslichn. Rast. Efirnykh Masel Tezisy Dokl. Simp., 2nd* **1970**, 159; *Chem. Abstr.* **1972**, *76*, 99847.

(16) Ishii, H.; Tozyo, T.; Minato, H. *Tetrahedron* **1965**, *21*, 2605. Tada, M.; Moriyama, Y.; Tanahashi, Y.; Takahashi, T. *Bull. Chem. Soc. Jpn.* **1974**, *47*, 1999.

(17) Tada, T.; Takahashi, T. *Tetrahedron Lett.* **1973**, 3999.

talization of **27** with ethylene glycol gave oily ketal **28** in excellent yield. The ^1H NMR spectrum of **28** showed its C(8) proton as a doublet of doublets (J = 10 and 1.8 Hz) centered at δ 6.76. The smaller coupling constant is due to the long-range coupling between the C(8) and C(4a) protons,[19] providing convincing evidence of the preferential conformation, **37**, of this compound. Conjugate addition of lithium dimethylcuprate to **28** resulted in formation of a single isomer, which was assigned as the desired *cis*-dimethyloctalone **29** by anticipating that the conjugate addition would be highly stereoselective and occur on the convex face of substrate **28**. This surmise was ultimately proved correct by the successful conversion to ligularone (**25**). Conformational analysis of enone **28** suggests that the steroid conformation **37** should be favored over the nonsteroid conformation by an interaction of the ketal grouping with an axial hydrogen at C-5 in the latter conformation. Hence, the cis adduct **29** would predominate in the 1,4 conjugate addition due to steric factors, because the geometry in the transition state should resemble the conformer **37**, in which the stereoelectronically favored antiparallel attack of the reagent is effectively blocked by the concave geometry.[20]

Huang-Minlon reduction of **29** and subsequent hydrolysis with aqueous acetic acid gave decalone (**30**). The conversion of **30** to enone **31** was performed by bromination with phenyltrimethylammonium tribromide followed by dehydrobromination with Li_2CO_3 in *N,N*-dimethylacetamide. Oxidation of **31** with alkaline hydrogen peroxide afforded a mixture of epoxides **32**, which was then treated with Li in liquid ammonia to give diol **33** as a diastereomeric mixture. Jones oxidation of the product afforded the desired dione **34**.

The crucial step was conducted by heating **34**, **9**, and KF in DME at 50–60 °C followed by treatment with KF in benzene at 80 °C,[21] producing a 1:2 mixture of dihydrofurans **35** and **36** which were diastereomers. This isomeric mixture of **35** and **36** was cleanly separated on chromatography. Ligularone (**25**) was synthesized by heating sulfoxides, obtained from **35** on $NaIO_4$ oxidation, in refluxing benzene containing pyridine and active alumina. By the same sequence of reactions, **36** was transformed into isoligularone (**26**). The racemic ligularone and isoligularone obtained were spectroscopically identified in comparison with the natural compounds.

Experimental Section

Melting points were determined with a Yamato melting point apparatus, Model MP-21, and are uncorrected. Infrared spectra (IR) were recorded on a Hitachi EPI-S2 or a JASCO A-3 spectrophotometer. Proton nuclear magnetic resonance spectra (^1H NMR) were recorded on a JEOL C-60HL (60 MHz) instrument, except where noted, in CCl_4. Chemical shifts are expressed in δ values relative to Me_4Si as internal standard. Coupling constants (J) are given in hertz. Solvent systems that developed the major reaction products in a moderate R_f range (0.4–0.6) are described for preparative, silica gel, thin-layer chromatography (TLC). Microanalyses were performed by the Microanalytical Laboratory in this institute.

2,3,4,5,6,7-Hexahydro-2-(hydroxyimino)-4-oxo-3,6,6-trimethylbenzofuran (4). A mixture of dimedone (**1**; 140 mg, 1 mmol) and KF (88 mg, 1 mmol) in dry DME (2.5 mL) was stirred at room temperature for 30 min under N_2, and 1-nitropropene[8] (131 mg, 1.5 mmol) was then added with a microsyringe. After being stirred for 3 h at 70 °C, the cooled mixture was filtered through a short silica gel column with ether. Evaporation of the eluate left an oil which was purified by TLC [ether–petroleum ether (2:3) as solvent] to give polar (84 mg, 40%) and less polar (85 mg, 41%) oximes **4** showing the following spectral properties. For the polar oxime: IR ($CHCl_3$) 3300, 1710, 1655, 1450, 955 cm^{-1}; ^1H NMR ($CDCl_3$) 1.15 (s, 6 H), 1.43 (d, 3 H, J = 7), 2.30 (s, 2 H), 2.48 (apparent d, 2 H), 3.5–4.0 (br m, 1 H); mass spectrum, m/e 209 (M^+). For the less polar oxime: IR ($CHCl_3$) 3300, 1710, 1650, 1557, 1400 cm^{-1}; ^1H NMR ($CDCl_3$) 1.13 (s, 6 H), 1.53 (d, 3 H, J = 7), 2.30 (s, 2 H), 2.43 (m, 2 H), 3.7–4.2 (br m, 1 H); mass spectrum, m/e 209 (M^+). Anal. Calcd for $C_{11}H_{15}NO_3$: C, 63.14; H, 7.23; N, 6.69. Found (polar oxime): C, 62.76; H, 7.20; N, 6.88. Found (less polar oxime): C, 62.85; H, 7.18; N, 6.44.

Nitro(phenylthio)methane (7). To a solution of (phenylthio)acetic acid (7.0 g, 42 mmol) in dry THF (150 mL) was added dropwise at 0 °C under N_2 a 1.6 M solution of BuLi (60 mL, 97 mmol) in hexane. After the mixture was stirred 45 min at 0 °C, propyl nitrate (13.1 g, 125 mmol) was added, and the mixture was stirred for 2 h at the same temperature. The mixture was acidified with dilute HCl and stirred at room temperature for 2 h to complete decarboxylation. The mixture was poured into cold water and extracted with ether. The extract was washed with aqueous $NaHCO_3$, water, and saturated brine and dried. Evaporation of the solvent gave an oil which was chromatographed on silica gel (100 g) with petroleum ether–ether (10:1) to afford **7** (3.80 g, 53%) as a yellow oil. An analytical sample was obtained by short-path distillation: bp 70–75 °C (bath temperature; 0.4 mmHg); IR (CCl_4) 1550, 1352 cm^{-1}; ^1H NMR 5.32 (s, 2 H) and 7.20–7.67 (m, 5 H). Anal. Calcd for $C_7H_7NO_2S$: C, 49.69; H, 4.17; N, 8.28. Found: C, 49.52; H, 4.44; N, 8.37.

1-Nitro-1-(phenylthio)-2-propanol (8). To a solution of **7** (3.80 g, 22.5 mmol) and acetaldehyde (85% assay, 1.58 g, 30.5 mmol) in MeOH (5 mL) was added dropwise at −10 °C under N_2 a 1.5 M methanolic KOH solution (15 mL, 22.5 mmol) over 20 min, and stirring was continued for 1 h at −10 °C and then for 7 h at 0 °C. The reaction mixture was neutralized with acetic acid (1.4 mL, 25 mmol), and the resulting solution was stirred at room temperature for 2 h. The mixture was then shaken with water and ether. The organic layer was washed with water and saturated brine and dried. Removal of the solvent in vacuo gave a yellow oil, which was chromatographed on silica gel (50 g). Elution with petroleum ether–ether (5:1) gave **8** (3.86 g, 80%) as a yellow oil: IR (liquid) 3400, 1550, 1360 cm^{-1}; ^1H NMR 1.32 and 1.37 (2 d, 3 H total, J = 6), 3.40 (br s, 1 H, OH), 3.80–4.50 (m, 1 H), 5.20 and 5.27 (2 d, 1 H total, J = 6, 4), 6.93–7.50 (m, 5 H). An analytical sample was prepared by distillation: bp 90–98 °C (bath temperature; 0.3 mmHg). Anal. Calcd for $C_9H_{11}NO_3S$: C, 50.69; H, 5.20; N, 6.57. Found: C, 50.74; H, 4.93; N, 6.26.

(*Z*)-1-Nitro-1-(phenylthio)propene (9). Triethylamine (4.51 g, 44.7 mmol) was added dropwise to a solution of methanesulfonyl chloride (5.12 g, 44.7 mmol) in dry CH_2Cl_2 (35 mL) at −78 °C under N_2. After the mixture was stirred for 5 min, a solution of **8** (3.18 g, 14.9 mmol) in CH_2Cl_2 (10 mL) was added dropwise at the same temperature over 5 min. The mixture was gradually warmed to 0 °C during 3 h and poured into water, and this mixture was extracted with ether. The extract was washed with water and saturated brine and dried. After evaporation of the solvent, the residue was chromatographed on silica gel (60 g) with petroleum ether–ether (10:1) to afford **9** (2.33 g, 80%) as a yellow oil: IR (liquid) 1528, 1320 cm^{-1}; ^1H NMR 2.13 (d, 3 H, J = 7.4), 7.17 (s, 5 H), 7.65 (q, 1 H, J = 7.4). An analytical sample was prepared by distillation; bp 70–75 °C (bath temperature; 0.1 mmHg). Anal. Calcd for $C_9H_9NO_2S$: C, 55.38; H, 4.65; N, 7.18. Found: C, 55.09; H, 4.80; N, 6.98.

Reaction of Dimedone (1) and 1-Nitro-1-(phenylthio)-propene (9). (a) In Xylene. A suspension of **1** (70 mg, 0.5 mmol) and KF (6 mg, 0.1 mmol) in dry xylene (2 mL) was stirred at room temperature for 30 min under N_2, and **9** (120 mg, 0.6 mmol) was then added with a microsyringe. Stirring was continued for 4 h at 110 °C and for 13 h at 80 °C. The cooled reaction mixture was passed through a short silica gel column with ether. The residue obtained by evaporation was separated by TLC [petroleum eth-

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(19) For analogous examples, see: Nozoe, T.; Cheng, T. S.; Toda, T. *Tetrahedron Lett.* **1966**, 3663. Miyashita, M.; Uda, H.; Yoshikoshi, A. *Chem. Commun.* **1969**, 1396.
(20) Marshall, J. A.; Andersen, N. H. *J. Org. Chem.* **1966**, *31*, 667. Marshall, J. A.; Cohen, C. M. *Ibid.* **1971**, *36*, 877.
(21) The two-step procedure described here gave the annulation product in better yield than does one-step treatment in benzene. The initial reaction in DME gave the normal Michael adduct along with minor quantities of **35** and **36**.

er–ether (5:3) as solvent] to give 11 (14 mg, 10%), **10a** (21 mg, 15%), and **10b** (81 mg, 56%) in increasing order of polarity. For **10a**: yellow oil; bp 140–150 °C (bath temperature; 1.5 mmHg); IR (CCl_4) 1645, 1398, 1210 cm^{-1}; ^1H NMR 1.05 (s, 6 H), 1.28 (d, 3 H, J = 7), 2.08 (s, 2 H), 2.25 (q, 2 H, an AA′ type, J = 12), 2.87–3.45 (m, 1 H), 5.46 (d, 1 H, J = 5.6), 7.13–7.66 (m, 5 H). For **10b**: yellow oil; bp 135–150 °C (bath temperature; 1.5 mmHg); IR (CCl_4) 1643, 1396, 1210 cm^{-1}; ^1H NMR 1.08 (s, 3 H), 1.12 (s, 3 H), 1.35 (d, 3 H, J = 7), 2.12 (s, 2 H), 2.28 (br s, 2 H), 3.28–3.68 (m, 1 H), 6.02 (d, 1 H, J = 9), 7.12–7.58 (m, 5 H). Anal. Calcd for $C_{17}H_{20}O_2S$: C, 70.80; H, 6.99. Found for **10a**: C, 71.05; H, 6.96. Found for **10b**: C, 70.64; H, 6.87. For 11: colorless crystals; mp 68–71 °C; bp 100–105 °C (bath temperature; 2 mmHg); IR (CCl_4) 1678, 1605, 1555 cm^{-1}; ^1H NMR 1.20 (s, 6 H), 2.30 (s, 5 H), 2.72 (s, 2 H), 6.9–7.4 (m, 5 H). Anal. Calcd for $C_{17}H_{18}O_2S$: C, 71.30; H, 6.33. Found: C, 70.90; H, 6.49.

(b) In DME. A suspension of **1** (140 mg, 1.0 mmol) and KF (12 mg, 0.2 mmol) in dry DME (2.5 mL) was stirred at room temperature for 30 min under N_2, and **9** (254 mg, 1.3 mmol) was then added with a microsyringe. After being stirred for 3 h at 50–60 °C, the cooled reaction mixture was placed on a silica gel column. After elution of excess **9** with petroleum ether, ether eluted crystals of **12** (332 mg, 100%) as a diastereomeric mixture. An analytical sample was obtained by recrystallization from ethanol: mp 136 °C dec; IR (CCl_4) 2900, 1580, 1552, 1382 cm^{-1}; ^1H NMR ($CDCl_3$) 0.80–1.67 (9 H), 2.00–2.70 (br d, 4 H), 3.50–4.12 (m, 1 H), 6.18 and 6.27 [d, J = 11.2 each, 1 H total (integrated ratio of 4:3), assigned to $CH(NO_2)$], 7.10–7.61 (5 H), 8.0–8.6 (a broadened one-proton signal assigned to enolic OH). Anal. Calcd for $C_{17}H_{21}NO_4S$: C, 60.88; H, 6.31; N, 4.18. Found: C, 60.66; H, 6.42; N, 4.43.

Conversion of 12 to a Mixture of 10a and 10b. A mixture of **12** (332 mg, 1.0 mmol) and KF (12 mg, 0.2 mmol) in dry xylene (2.5 mL) was stirred for 4 h at 110 °C. The cooled mixture was passed through a short, neutral-alumina column (Woelm, activity III) with ether. The residue obtained by evaporation was purified by TLC [petroleum ether–ether (5:3) as solvent] to give a mixture of **10a** and **10b** (220 mg, 76%) in a ratio of 5:3 (^1H NMR analysis).

3,6,6-Trimethyl-6,7-dihydrobenzofuran-4(5*H*)-one (13). (a) From 10a. To a solution of **10a** (21 mg, 0.07 mmol) in methanol (1 mL) was added at 0 °C a solution of $NaIO_4$ (30 mg, 0.14 mmol) in water (0.5 mL). After being stirred 24 h at room temperature, the reaction mixture was shaken with CH_2Cl_2 and water, and the organic layer was washed with water and saturated brine and dried. After evaporation of the solvent, the residue was dissolved in CCl_4 (1 mL) containing pyridine (17 μL) and the mixture stirred at reflux for 1.5 h. Removal of the solvent gave an oil which was purified by TLC [petroleum ether–ether (2:1) as solvent] to afford **13**: 12 mg (91%); IR (CCl_4) 1675, 1605, 1560 cm^{-1}; ^1H NMR 1.50 (s, 6 H), 2.16 (d, 3 H, J = 2), 2.27 (s, 2 H), 2.68 (s, 2 H), 7.03 (br s, 1 H). An analytical sample was prepared by distillation; bp 112–117 °C (bath temperature; 35 mmHg). Anal. Calcd for $C_{11}H_{14}O_2$: C, 74.13; H, 7.92. Found: C, 74.25; H, 8.23.

(b) From 10b. The oxidation product of **10b** (57 mg, 0.2 mmol) with $NaIO_4$ (86 mg, 0.4 mmol) obtained by the same procedure as described above was vigorously stirred at reflux in a suspension of active Al_2O_3 (0.5 g) in dry benzene (2 mL) containing pyridine (50 μL) for 3 h. The reaction mixture was filtered, and the filtrate was evaporated to leave an oil which was purified by TLC [petroleum ether–ether (2:1) as solvent] to give **13** (29.5 mg, 84%), as identified by the IR and ^1H NMR spectra.

3-[1-Methyl-2-nitro-2-(phenylthio)ethyl]-2,4-pentanedione (19). A suspension of acetylacetone (100 mg, 1.0 mmol) and KF (29 mg, 0.5 mmol) in dry benzene (5 mL) was stirred at room temperature for 30 min under N_2. The nitro olefin **9** (254 mg, 1.3 mmol) was then added, and the mixture was stirred at 80 °C for 8 h. The reaction mixture was cooled and passed through a short silica gel column with ether. Evaporation of the solvent left an oil which was purified by TLC [petroleum ether–ether (3:2) as solvent] to give **19** (262 mg, 89%) as a diastereomer mixture: IR (liquid) 1700, 1552, 1365 cm^{-1}; ^1H NMR 1.04 and 1.07 (d, J = 7 each, 3 H total), 2.06–2.30 (6 H), 2.8–3.5 (m, 1 H), 3.85 (d, 1 H, J = 8), 5.58 (t, 1 H, J = 5.8), 7.33 (5 H). Anal. Calcd for $C_{14}H_{17}NO_4S$: C, 56.93; H, 5.80. Found: C, 57.16; H, 5.98.

4-Acetyl-2,3-dihydro-3β,5-dimethyl-2α-(phenylthio)furan (18). A mixture of **19** (88 mg, 0.3 mmol) and *p*-toluenesulfonic acid (9 mg) in dry benzene (2.5 mL) was stirred at reflux for 4 h. The cooled reaction mixture was passed through a short, neutral-alumina column (Woelm, activity III) with ether. Removal of the solvent gave an oil which was purified by TLC [petroleum ether–ether (5:3) as solvent] to afford **18**: 34 mg (46%); IR (CCl_4) 1628, 1217 cm^{-1}; ^1H NMR 1.22 (d, 3 H, J = 7), 2.12 (s, 3 H), 2.17 (d, 3 H, J = 1), 2.86–3.45 (m, 1 H), 5.32 (d, 1 H, J = 4), 7.13–7.60 (5 H). An analytical sample was prepared by distillation; bp 110–115 °C (bath temperature; 5 mmHg). Anal. Calcd for $C_{14}H_{16}O_2S$: C, 67.71; H, 6.49. Found: C, 67.75; H, 6.71.

3-Acetyl-2,4-dimethylfuran (20). The crude sulfoxide, prepared from **18** (54 mg, 0.22 mmol) and $NaIO_4$ (94 mg, 0.44 mmol) in 65% aqueous methanol as described for the preparation of **13** (vide ante), was dissolved in ether (3 mL), and the resulting solution was stirred at reflux for 2 h. Removal of the solvent left an oil which was purified by TLC [petroleum ether–ether (3:2) as solvent] at 5 °C, giving **20** as a colorless volatile oil:[13] IR (CCl_4) 1670, 1590, 1547 cm^{-1}; ^1H NMR 2.13 (d, 3 H, J = 1), 2.33 (s, 3 H), 2.51 (s, 3 H), 6.93 (br s, 1 H). The yield was calculated on the basis of its 2,4-dinitrophenylhydrazone: 60 mg (86%); mp 174.5–175.5 °C (recrystallized from methanol). Anal. Calcd for $C_{14}H_{14}N_4O_5$: C, 52.83; H, 4.43. Found: C, 53.11; H, 4.77.

Reaction of 5-Methylcyclohexane-1,3-dione (21) and 9. A mixture of **21** (126 mg, 1.0 mmol), **9** (254 mg, 1.3 mmol), and KF (12 mg, 0.2 mmol) in dry benzene (4 mL) was stirred at 80 °C for 8 h under N_2. The crude product was treated as before and separated by TLC [petroleum ether–ether (5:3) as solvent] to give **23** (17.5 mg, 6%), **22a** (31 mg, 11%), and **22b** (140 mg, 52%) in increasing order of polarity. For **23**: bp 110 °C (bath temperature; 5 mmHg); IR (CCl_4) 1678, 1595 cm^{-1}; ^1H NMR 1.13 (d, 3 H, J = 5), 1.35 (d, 3 H, J = 7), 7.0–7.5 (5 H). Anal. Calcd for $C_{16}H_{16}O_2S$: C, 70.56; H, 5.92. Found: C, 70.62; H, 6.25. For **22a**: bp 130 °C (bath temperature; 4.8 mmHg); IR (liquid) 1637, 1396, 1205 cm^{-1}; ^1H NMR 1.11 (d, 3 H, J = 5), 1.30 (d, 3 H, J = 6), 1.80–2.55 (5 H), 2.70–3.40 (m, 1 H), 5.41 (d, 1 H, J = 5.2), 7.17–7.60 (m, 5 H). For **22b**: bp 130 °C (bath temperature; 4.5 mmHg); IR (liquid) 1637, 1396, 1205 cm^{-1}; ^1H NMR 1.05–1.55 (6 H), 1.82–2.60 (5 H), 3.19–3.80 (m, 1 H), 5.98 (d, 1 H, J = 9.2), 7.19–7.60 (m, 5 H). Anal. Calcd for $C_{16}H_{18}O_2S$: C, 70.04; H, 6.61. Found for **22a**: C, 69.87; H, 6.74. Found for **22b**: C, 70.04; H, 6.61.

(±)-Evodone (24). (a) From 22a. By the same sequence of reactions described for the conversion of **10a** to **13**, **22a** (21.5 mg, 0.08 mmol) was converted to the crude product, which was purified by TLC [petroleum ether–ether (2:1) as solvent], yielding crystals (9 mg, 70%) of **24**: mp 66.5–67 °C (lit.[15b] mp 72–73 °C); IR (KBr) 1660, 1603, 1560 cm^{-1}; ^1H NMR 1.16 (d, 3 H, J = 5), 2.0–2.9 (5 H), 2.14 (d, 3 H, J = 1.5), 6.98 (br s, 1 H). Anal. Calcd for $C_{10}H_{12}O_2$: C, 73.14; H, 7.37. Found: C, 72.97; H, 7.64.

(b) From 22b. By the same procedure, **22b** (54 mg, 0.2 mmol) was transformed into **24** (24 mg, 74%).

***cis*-8a-Methyl-3,4,4a,8a-tetrahydronaphthalen-1,6-(2*H*,5*H*)-dione 1-Ethylene Acetal (28).** A mixture of **27**[18] (178 mg, 1.0 mmol), ethylene glycol (372 mg, 6.0 mmol), and *p*-toluenesulfonic acid monohydrate (4 mg) in benzene (6 mL) was heated at 90 °C (bath temperature) for 1 h with a water separator. The mixture was washed with aqueous Na_2CO_3, water, and saturated brine and then dried. Evaporation gave a yellow oil which was purified by TLC [petroleum ether–ether (2:1) as solvent] to afford **28**: 212 mg (95%); IR (liquid) 1680 cm^{-1}; ^1H NMR 1.23 (s, 3 H), 3.95 (s, 4 H), 5.83 (d, 1 H, J = 10), 6.76 (2 d, 1 H, J = 10, 1.8). An analytical sample was prepared by distillation: bp 85–95 °C (bath temperature; 0.1 mmHg). Anal. Calcd for $C_{13}H_{18}O_3$: C, 70.24; H, 8.16. Found: C, 70.16; H, 8.36.

***cis*-8β,8aβ-Dimethyl-3,4,4a,7,8,8a-hexahydronaphthalen-1,6(2*H*,5*H*)-dione 1-Ethylene Acetal (29).** An ethereal solution of MeLi (1.1 M, 9.1 mL, 10 mmol) was added to a stirred suspension of CuI (950 mg, 5.0 mmol) in dry ether (8 mL) at −5 °C under Ar. To the resulting solution was added dropwise at −5 °C a solution of **28** (222 mg, 1.0 mmol) in dry ether (4 mL). After an additional 2 h of being stirred in the cold, the reaction mixture was quenched with saturated NH_4Cl and filtered through a pad of Celite with ether. The filtrate was washed with water and saturated brine and dried. Evaporation gave an oil which was purified by TLC [petroleum ether–ether (3:1) as solvent] to afford **29** (206 mg, 87%) as crystals: mp 67 °C (recrystallized from petroleum ether); IR (supercooled liquid) 1710 cm^{-1}; ^1H NMR

1.0 (d, 3 H, J = 6.5), 1.05 (s, 3 H), 3.75–4.07 (m, 4 H). Anal. Calcd for $C_{14}H_{22}O_3$: C, 70.55; H, 9.31. Found: C, 70.81; H, 9.63.

***cis*-8β,8aβ-Dimethyl-3,4,4a,5,6,7,8,8a-octahydronaphthalen-1(2*H*)-one (30).** A mixture of **29** (118 mg, 0.5 mmol), 100% hydrazine hydrate (0.5 mL), hydrazine hydrochloride (5 mg), and diethylene glycol (6 mL) was stirred at 100–105 °C (bath temperature) for 3 h. Then KOH (85% assay, 120 mg, 1.82 mmol) was added, and the mixture was distilled until the bath temperature reached 205 °C, the distillate being collected. Heating under reflux was further continued for 6 h. The cooled solution was combined with the distillate, the mixture was poured into ice–water, and the product was extracted with ether. The extract was washed with water and saturated brine and dried. Evaporation left an oil which was purified by silica gel column chromatography [ether–petroleum ether (1:5) as solvent] to give **29**: 98 mg (88%); ^{1}H NMR 0.84 (s, 3 H), 0.86 (d, 3 H, J = 6), 3.67–4.0 (m, 4 H). Anal. Calcd for $C_{14}H_{24}O_2$: C, 74.95; H, 10.78. Found: C, 74.70; H, 10.57.

A solution of the above ketal (84 mg, 0.38 mmol) in 70% aqueous acetic acid (1.2 mL) was stirred at 90 °C for 1 h. The cooled solution was neutralized by aqueous $NaHCO_3$ at 0 °C, and the product was extracted with ether. The extract was washed with water and saturated brine and dried. After evaporation, the residual oil was purified by TLC [ether–petroleum ether (1:10) as solvent] to give **30**: 62 mg (91%); IR (liquid) 1700 cm^{-1}; ^{1}H NMR 0.62 (d, 3 H, J = 6), 1.0 (s, 3 H). An analytical sample was prepared by distillation; bp 70–75 °C (bath temperature; 35 mmHg). Anal. Calcd for $C_{12}H_{20}O$: C, 79.94; H, 11.18. Found: C, 80.09; H, 11.41.

***cis*-8β,8aβ-Dimethyl-4,4a,5,6,7,8-hexahydronaphthalen-1(8a*H*)-one (31).** To a solution of **30** (472 mg, 2.6 mmol) in dry THF (15 mL) was added dropwise at 5 °C under Ar a solution of phenyltrimethylammonium tribromide (1.075 g, 2.86 mmol) in dry THF (20 mL) over 15 min. After completion of the addition, the mixture was stirred at 5 °C for an additional 2 h and poured into cold water, and the product was thoroughly extracted with ether. The extract was washed twice with water, and the aqueous washings were reextracted with ether. The combined organic layers were washed with aqueous $NaHCO_3$, water, and saturated brine and dried. Evaporation gave a solid bromo ketone (986 mg), which was immediately subjected to the next reaction. A mixture of the bromo ketone obtained and Li_2CO_3 (1.92 g, 26 mmol) in *N*,*N*-dimethylacetamide (16 mL) was stirred at 135 °C for 2.5 h, and the cooled reaction mixture was poured into cold water and extracted with CH_2Cl_2. The extract was washed with water and saturated brine and dried. After filtration, the crude product (676 mg) was obtained by removal of the solvent. This was purified by TLC [petroleum ether–ether (8:1) as solvent] to give **31**: 405 mg (88%); IR (liquid) 3030, 1672, 1640 (sh) cm^{-1}; ^{1}H NMR 0.78 (d, 3 H, J = 7), 1.03 (s, 3 H), 5.78 (dt, 1 H, J = 10, 2), 6.65 (dt, 1 H, J = 10, 4). An analytical sample was prepared by distillation: bp 65–70 °C (bath temperature; 35 mmHg). Anal. Calcd for $C_{12}H_{18}O$: C, 80.85; H, 10.18. Found: C, 81.17; H, 10.55.

8β,8aβ-Dimethyl-2,3-epoxy-3,4,4aβ,5,6,7,8,8a-octahydronaphthalen-1(2*H*)-one (32). To a solution of **31** (280 mg, 1.6 mmol) and 30% H_2O_2 (0.45 mL, 4.7 mmol) in methanol (8 mL) was added dropwise at 15 °C 6 N aqueous NaOH (0.13 mL, 0.78 mmol) over 5 min. After being stirred an additional 2.5 h, the mixture was poured into water (10 mL) and extracted with ether. The extract was washed with water and saturated brine and dried. Evaporation gave an oil (288 mg) which was purified by TLC [petroleum ether–ether (8:1) as solvent] to afford **32** (257 mg, 84%) as an epimeric mixture: IR (liquid) 1700 cm^{-1}; ^{1}H NMR 0.72 (d, 3 H, J = 6.5), 1.07 (s, 3 H), 2.98 (d, 1 H, J = 4), 3.41 (m, 1 H). An analytical sample was prepared by distillation: bp 70–80 °C (bath temperature; 34 mmHg). Anal. Calcd for $C_{12}H_{18}O_2$: C, 74.19; H, 9.34. Found: C, 73.92; H, 9.38.

***cis*-Decahydro-8β,8aβ-dimethylnaphthalene-1,3-diol (33).** A solution of **32** (90 mg, 0.46 mmol) in dry THF (5 mL) was added to liquid ammonia (10 mL) at −78 °C. The cold bath was removed, Li (22.5 mg, 3.22 mmol) was added, and the resulting purple solution was stirred for 5 min. NH_4Cl (207 mg, 3.86 mmol) was then slowly added, and the mixture was allowed to stand to allow evaporation of the liquid ammonia. The residue was poured into water and thoroughly extracted with ether, and the extract was washed with aqueous NH_4Cl, water, and saturated brine and then dried. Evaporation gave **33** (85 mg, 93%) as a diastereomeric mixture. The major isomer crystallized when the mixture was allowed to stand: mp 116–117 °C (recrystallized from CCl_4); IR (KBr) 3340 cm^{-1}; ^{1}H NMR ($CDCl_3$) 0.75 (d, 3 H, J = 6), 1.02 (s, 3 H), 2.88 (br s, 2 H), 3.88 (m, 1 H), 4.16 (m, 1 H). Anal. Calcd for $C_{12}H_{22}O_2$: C, 72.68; H, 11.18. Found: C, 72.87; H, 11.19.

***cis*-4aβ,5,6,7,8,8a-Hexahydro-8β,8aβ-dimethylnaphthalen-1,3(2*H*,4*H*)-dione (34).** A solution of the crude diol **33** (206 mg, 1.0 mmol) in acetone (10 mL) was submitted to oxidation with a slight excess of Jones reagent at −10 to 0 °C for 1 h. Workup gave a crystalline product which was purified by TLC [CH_2Cl_2–ether (5:3) as solvent] to afford **34**: 145 mg (72%); mp 130.5–131 °C (recrystallized from CCl_4); IR (KBr) 3600–2400, 1610, 1542 cm^{-1}; ^{1}H NMR ($CDCl_3$) 0.87 (d, 3 H, J = 7), 1.13 and 1.18 (2 s, 3 H total), 3.43 (br s, 1 H). Anal. Calcd for $C_{12}H_{18}O_2$: C, 74.19; H, 9.34. Found: C, 74.46; H, 9.73.

(±)-Ligularone (25) and (±)-Isoligularone (26). A mixture of **34** (70 mg, 0.36 mmol), **9** (79 μL, 0.47 mmol), KF (4 mg, 0.07 mmol), and dry DME (2 mL) was stirred at 50 °C for 6 h under N_2. The cooled reaction mixture was passed through a short silica gel column with ether. Evaporation of the eluate gave crude product (IR 3600–2500, 1620, 1555, 1385 cm^{-1}), which was stirred with KF (4 mg) in dry benzene (2 mL) at 80 °C for 7 h under N_2. After filtration of the mixture through a short silica gel column, the eluate was evaporated to leave an oil. The residue was separated by TLC [petroleum ether–ether (2:1) as solvent] to give **35** (27 mg, 22%) and **36** (49 mg, 40%) as polar and less polar fractions. For **35**: IR (CCl_4) 3050, 1645, 1584, 1550, 1390 cm^{-1}; ^{1}H NMR 0.78 (d, 3 H, J = 7), 1.01 (s, 3 H), 1.31 (d, 3 H, J = 7), 3.17–3.60 (m, 1 H), 5.93 (d, 1 H, J = 9), 6.83–7.60 (m, 5 H). **36**: IR (CCl_4) 3050, 1653, 1582, 1390 cm^{-1}; ^{1}H NMR 3.00–3.90 (m, 1 H), 5.42 and 5.83 (d, J = 5 each, 0.3 H total), 5.95 and 6.00 (d, J = 9 each, 0.7 H total), 7.0–7.6 (m, 5 H).

A solution of **35** (34 mg, 0.1 mmol) and $NaIO_4$ (26 mg, 0.12 mmol) in 60% aqueous methanol (2.3 mL) was stirred at room temperature for 72 h. The mixture was diluted with water and extracted throughly with CH_2Cl_2. The extract was washed with water and saturated brine and dried. Crude product obtained on evaporation of the solvent was dissolved in dry benzene (2.5 mL) containing pyridine (30 μL) and active alumina (0.4 g), and the mixture was stirred at 100 °C for 3 h under N_2. After filtration, the solvent was removed in vacuo, and the residue was purified by TLC [petroleum ether–ether (2:1) as solvent] to give **25**: 11 mg (47%); mp 70.5–71 °C; IR (KBr) 1660 cm^{-1}; ^{1}H NMR ($CDCl_3$) 0.88 (d, 3 H, J = 7), 1.11 (s, 3 H), 2.20 (d, 3 H, J = 1.2), 7.10 (br s, 1 H).

Compound **26** was obtained from **36** (68 mg, 0.2 mmol) by the same sequence: 25 mg (54%); mp 111–114 °C; IR (KBr) 3050, 3100, 1665, 1547 cm^{-1}; ^{1}H NMR ($CDCl_3$) 0.92 (d, 3 H, J = 7), 1.30 (s, 3 H), 2.20 (d, 3 H, J = 1.5), 7.05 (q, 1 H, J = 1.5).

The synthetic products obtained were identified by spectral (IR and ^{1}H NMR) and chromatographic (silica gel, thin layer) comparison with (+)-ligularone[16] and (+)-isoligularone.[17]

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Registry No. 1, 126-81-8; 2, 17082-05-2; 4, 73805-32-0; 6, 103-04-8; 7, 60595-16-6; 8, 67808-90-6; 9, 67808-91-7; 10a, 67808-93-9; 10b, 67808-92-8; 11, 67808-94-0; 12, 69477-90-3; 13, 67808-95-1; 18, 67808-99-5; 19, 67808-98-4; 20, 32933-07-6; 20 2,4-dinitrophenylhydrazone, 67809-00-1; 21, 4341-24-6; 22a, 73805-33-1; 22b, 73805-34-2; 23, 67808-97-3; 24, 65349-85-1; 25, 65378-28-1; 26, 69501-09-3; 27, 54584-41-7; 28, 73805-35-3; 29, 73836-89-2; 30, 22645-04-1; 30 bromo ketone, 73816-19-0; 31, 73805-36-4; 32 (isomer 1), 73836-90-5; 32 (isomer 2), 73836-91-6; 33, 69478-11-1; 34, 73805-37-5; 35, 69478-12-2; 36, 69478-13-3; acetaldehyde, 75-07-0; acetylacetone, 123-54-6.