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**Chemistry of 2-Methoxy-2,5-cyclohexadienone. V.¹⁾ Photochemical
Rearrangement and Oxidation of 2-Methoxy-4-methyl-4-phenyl-
2-cyclohexenone and 2-Methoxy-4-methyl-4-phenyl-
2,5-cyclohexadienone²⁾**

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A methanolic solution of 2-methoxy-4-methyl-4-phenyl-2-cyclohexenone (I) was irradiated with a 100 W mercury lamp to give 4-methyl-4-phenyl-2-cyclohexenone (III) and 1-methoxy-5-methyl-6-phenylbicyclo[3.1.0]hexan-2-one (IV). When a benzene solution of I was irradiated, only IV was obtained. On the other hand, 2-methoxy-4-methyl-4-phenyl-2,5-cyclohexadienone (II) gave 2,2-dimethoxy-6-methyl-6-phenylbicyclo[3.1.0]hexan-3-one (V) and 6,6-dimethoxy-5-methyl-5-phenyl-3-cyclohexenone (VI) on photoirradiation in methanol. In benzene, 6-methoxy-6-methyl-5-phenyl-2,4-cyclohexadienone (XI) was obtained.

Compound II was treated with *m*-chloroperbenzoic acid in a bilayer system of methylene chloride-aqueous disodium orthophosphate at room temperature to give 5,6-epoxy-6-methoxy-4-methyl-4-phenyl-2-cyclohexenone (XVI) and its stereoisomer (XVI'). 5,6-Epoxy-2-methoxy-4-methyl-4-phenyl-2-cyclohexenone (XVIII) was obtained by treatment of II with hydrogen peroxide in a basic medium. 2,3:5,6-Diepoxy-6-methoxy-4-methyl-4-phenyl-6-hexanolide (XVII) rather than the expected diepoxide (XII) was obtained by the alternative oxidation of XVI or XVIII.

Keywords—photochemical rearrangement; epoxidation; 2,5-cyclohexadienone; 2-methoxy-2,5-cyclohexadienone; 2-methoxy-4-methyl-4-phenyl-2,5-cyclohexadienone; Baeyer-Villiger oxidation

The intermediacy of the 4,4-disubstituted 2-methoxy-2,5-cyclohexadienone structure, which occurs in natural alkaloids such as sinoactine, in the biosynthesis of sinomenine from reticuline, has prompted us to investigate chemical reactivity of this particular structure.³⁾ Previously, we have examined photochemical and oxidative reactions of a series of 4,4-disubstituted 2-methoxycyclohexenones and cyclohexadienones.^{1,4)} In this paper, we report the results obtained by photochemical and oxidative reactions of 2-methoxy-4-methyl-4-phenyl-2-cyclohexenone (I) and 2-methoxy-4-methyl-4-phenyl-2,5-cyclohexadienone (II) to clarify the effect of C₄-substituents on the reaction course.

First, we investigated the reactivity of the cyclohexenone (I) not only as a basic study but also for comparison with the reactivity of other cyclohexenones and cyclohexadienones. When a methanolic solution of I was irradiated with a high-pressure 100 W mercury lamp for 5 h, 4-methyl-4-phenyl-2-cyclohexenone (III), a demethoxylated compound, and 1-methoxy-5-methyl-6-phenylbicyclo[3.1.0]hexan-2-one (IV) were obtained in yields of 30.0 and 66.8%, respectively, together with a 2.9% recovery of I. The structure of III was suggested on the basis of the physical data and confirmed by comparison with an authentic sample prepared by the known method.⁵⁾ Compound IV exhibited in the nuclear magnetic resonance (NMR) spectrum a multiplet signal at δ 0.8–1.1 and a singlet peak at δ 2.80 due to the C₃-*endo*- and C₆-protons, respectively. The high-field shift of the C₃-*endo* proton could be explained in

terms of anisotropy induced by the cyclopropane ring system. The stereochemical structure of IV was deduced from the mechanism proposed in Chart 1, that is, the phenyl group migrates with retention of the configuration and is on the opposite side to the C₅-methyl group. On the other hand, a benzene solution of I was irradiated to give only IV in the yield of 44.6%. From these results, it would be suggested that methanol as a solvent might play a role in the reduction of I to III.

Then, we examined the photochemical behavior of the dienone, II. When a methanolic solution of II was irradiated with a high-pressure 100 W mercury lamp for 30 min, two products, 2,2-dimethoxy-6-methyl-6-phenylbicyclo[3.1.0]hexan-3-one (V) and 6,6-dimethoxy-5-methyl-5-phenyl-3-cyclohexenone (VI), were obtained in 45.9 and 15.9% yields, respectively. Compound V exhibited an infrared (IR) absorption at 1760 cm^{-1} due to the carbonyl group and NMR signals at δ 2.36 and 2.80 (double doublet and broad doublet, respectively) due to the methylene protons at the C₄-position. Compound VI exhibited an absorption at 1730 cm^{-1} in the IR spectrum due to the unconjugated carbonyl group and NMR signals at δ 3.06, 3.29 due to the methylene protons and at δ 5.61, 5.77 due to two protons of the unconjugated double bond. The α -keto dimethylketal structures in these products (V and VI) were suggested by the formation of the adducts with *o*-phenylenediamine as shown in Chart 2. Although compound V readily reacted with this reagent in the presence of acid to give the corresponding adduct, 10-methyl-10-phenyl-2,3-dihydro-1,2-methano-1*H*-

Chart 1

Chart 2

Chart 3

cyclopenta[*b*]quinoxaline (VII), compound VI was found to be inert under the same conditions. However, 2-hydroxy-6-methyl-6-phenyl-2-cyclohexenone (IX), which was obtained by catalytic hydrogenation of VI followed by hydrolysis with 10% hydrochloric acid, gave an adduct, 1-methyl-1-phenyl-1,2,3,4-tetrahydrophenazine (X), with *o*-phenylenediamine.

Then, compound II was irradiated in benzene with a high-pressure 100 W mercury lamp in order to examine the solvent effect. The only product obtained (in poor yield) was 6-methoxy-6-methyl-5-phenyl-2,4-cyclohexadienone (XI), which exhibited a singlet at δ 1.72 due to the C_6 -methyl proton in the NMR spectrum, supporting the structure of XI as shown.

A possible mechanism for the photochemical transformation of II to V, VI, and XI is shown in Chart 3, that is, it was considered that compound V was formed *via* the zwitterion (A), and VI and XI *via* bicyclo[3.1.0]hexenone (B) and dienolate (C) intermediates.⁶⁾ Thus, the photochemical products from I and II were characteristic ones compared with those obtained from 5,5-dimethyl or diphenyl analogues.^{1,4c)} In particular, the isolation of unconjugated ketone, VI, was surprising.

In view of the suggestion that the biosynthesis of acutumine possibly involves a diepoxide (see Chart 4),³⁾ studies on the oxidation of the cyclohexadienone (II) with hydrogen peroxide (HPO) or *m*-chloroperbenzoic acid (mCPBA) were carried out in order to obtain the diepoxide (XII). Prior to the study on the oxidation of cyclohexadienone (II), the oxidative behavior of the cyclohexenone (I) was examined to establish the optimal conditions, which might be applied to the preparation of XII, for the synthesis of a monoepoxide of I, 2,3-epoxy-2-methoxy-4-methyl-4-phenylcyclohexanone (XIII). When I was treated with HPO in trifluoroacetic acid (TFA) at 40°C, a monomethyl ester of 3-methyl-3-phenyladipic acid (XIVa) was obtained in 97.1% yield. The structure of XIVa was suggested from the physical data and a consideration of its formation from I. Compound XIVa was treated with diazomethane to give the diester (XIVb) which was then hydrolyzed with sodium hydroxide to give the known 3-methyl-3-phenyladipic acid (XIVc).⁷⁾ When compound I was allowed to react with mCPBA at room temperature overnight, a lactone, 5,6-epoxy-6-methoxy-4-methyl-4-phenyl-6-hexanolide (XV), was obtained in 74.1% yield. The doublet signal at δ 4.95 ($J=2$ Hz) in the NMR spectrum of XV is attributable to the C_5 -proton coupling through four σ bonds with one of the C_3 -protons (*W* rule). From an examination of a molecular model, the C_5 -proton must be quasi-equatorial. When compound I was then allowed to react with mCPBA in a bilayer system of methylene chloride–aqueous disodium orthophosphate at 4°C for 136.6 h, the epoxy ketone (XIII) and lactone (XV) were obtained in 8.6 and 64.3% yields, respectively, along with recovery of I (18.9%). Compound XIII exhibited a singlet signal at δ

Chart 4

a: R = Me, R' = H b: R = R' = Me c: R = R' = H

Chart 5

3.74 due to the C₃-proton. Thus, the expected monoepoxide, XIII, was obtained by the oxidation of the cyclohexenone (I) with mCPBA in a bilayer system at low temperature.

On the other hand, when II was treated with mCPBA in the bilayer system at 4°C, a large amount of the starting material was recovered. When this oxidation was carried out at room temperature, the expected epoxides, 5,6-epoxy-6-methoxy-4-methyl-4-phenyl-2-cyclohexenone (XVI) and its stereoisomer (XVI'), were obtained in yields of 43.5 and 5.9%, respectively, along with recovery of II (26.0%). In the NMR spectra of XVI and XVI', the signals due to the C₅-protons appeared at δ 3.77 and 3.79, respectively, as a doublet ($J=4$ Hz) coupled with the C₃-protons. In the IR spectrum of XVI, a carbonyl band was observed at 1685 cm⁻¹. When XVI was treated with HPO in basic medium at room temperature, 2,3:5,6-diepoxo-6-methoxy-4-methyl-4-phenyl-6-hexanolide (XVII) was obtained in poor yield instead of the expected product, XII. In the NMR spectrum of XVII, signals due to the C₃-, C₂-, and C₅-protons were observed at δ 3.61 (d, $J=4$ Hz), 3.96 (d, $J=4$ Hz), and 5.02 (s), respectively. Thus the attempts to obtain XII *via* XVI were unsuccessful.

When, compound II was treated with HPO at room temperature, 5,6-epoxy-2-methoxy-4-methyl-4-phenyl-2-cyclohexenone (XVIII) was obtained in 52.6% yield accompanied with recovery of II (37.7%). Absorptions due to the carbonyl and enol ether at 1685 and 1620 cm⁻¹ in the IR spectrum of XVIII, and NMR signals due to two protons at the epoxy carbons and the C₃-proton at δ 3.54, 3.58, and 5.31 were observed. To convert XVIII into XII, XVIII was treated with mCPBA at 4°C in the bilayer system. Unfortunately the product (obtained in 46.8% yield) was XVII.

Thus all the attempts to obtain the corresponding diepoxides from 2-methoxy-2,5-cyclohexadienones were unsuccessful. Further study is necessary to obtain these diepoxides.

Experimental

All melting points (taken on a Kofler block) and boiling points are uncorrected. IR spectra were determined by using a JASCO A 102 diffraction grating spectrophotometer; absorption data are given in cm^{-1} . Ultraviolet (UV) spectra were obtained in MeOH with a Hitachi 220 spectrometer, and absorption maxima are given in nm. Gas chromatography (GC) was carried out on a Shimadzu GC-6AM instrument with a stainless steel column (3 mm $\times$ 2 m) packed with 5% SE-30. The N_2 gas flow was 40 ml/min. NMR spectra were recorded on a Varian EM-360, JEOL PMX-60, or Varian XL-200 spectrometer with tetramethylsilane as an internal standard. The chemical shifts and coupling constants (J) are given in δ and Hz, respectively. Mass spectra (MS) were measured with a JEOL D-200 or D-300 (70 eV, direct inlet system) spectrometer. All solvents were removed by evaporation under reduced pressure after drying the solution over anhyd. MgSO_4 or Na_2SO_4 .

2-Methoxy-4-methyl-4-phenyl-2-cyclohexenone (I)⁸—A methanolic solution of 2-phenylpropionaldehyde (8.04 g, 60 mmol), Triton B (40% in MeOH, 6.00 g, 14 mmol), and 1,4-dimethoxybutan-2-one (7.49 g, 60 mmol) was refluxed overnight under an Ar atmosphere. The reaction mixture was diluted with water and extracted with Et_2O . The organic layer was washed with brine and dried. The residue obtained after removal of the solvent was distilled to give a pale yellow oil. bp 148–150 $^\circ\text{C}$ (2 mmHg). Yield: 8.41 g (64.9%). IR (neat): $\nu_{\text{C=O}}$ 1690, $\nu_{\text{C=C}}$ 1620. UV λ_{max} (ϵ): 205 (9600), 258 (8200), 263 (sh. 8000). GC (200 $^\circ\text{C}$): t_{R} 2.8 min. NMR (CDCl_3): 1.58 (3H, s, $\text{C}_4\text{-Me}$), 2.0–2.3 and 2.3–2.6 (each 2H, m, $\text{C}_5\text{-}$ and $\text{C}_6\text{-H}$), 3.69 (3H, s, OMe), 5.80 (1H, s, $\text{C}_3\text{-H}$), 7.2–7.5 (5H, m, aromatic H). MS m/z (%): 216 (M^+ , 91), 201 ($\text{M}^+ - \text{Me}$, 91), 173 ($\text{M}^+ - \text{CH}_3\text{CO}$, 100), 142 (m/z 173–OMe, 50), 115 (54), 91 (44). Anal. Calcd for $\text{C}_{14}\text{H}_{16}\text{O}_2$: C, 77.75; H, 7.46. Found: C, 77.69; H, 7.19.

2-Methoxy-4-methyl-4-phenyl-2,5-cyclohexadienone (II)⁸—a) With 2,3-Dichloro-5,6-dicyanobenzoquinone (DDQ): A solution of I (0.55 g, 2.6 mmol) and DDQ (96%, 0.73 g, 3.2 mmol) in dioxane (14.6 ml) was refluxed with stirring for 22 h, and then filtered. The filtrate was concentrated. The residue was rinsed with Et_2O and the Et_2O layer was washed with 10% NaOH and brine. The deep yellow oil obtained after removal of the solvent was distilled to give a colorless oil, bp 104–106 $^\circ\text{C}$ (0.5 mmHg). Yield: 0.43 g (78.8%). IR (neat): $\nu_{\text{C=O}}$ 1670, $\nu_{\text{C=C}}$ 1640, 1610. UV λ_{max} (ϵ): 212 (17500), 240 (9300), 318 (2200). GC (200 $^\circ\text{C}$): t_{R} 3.7 min. NMR (CCl_4): 1.79 (3H, s, $\text{C}_4\text{-Me}$), 3.63 (3H, s, OMe), 5.75 (1H, d, $J=3$, $\text{C}_3\text{-H}$), 6.13 (1H, d, $J=10$, $\text{C}_6\text{-H}$), 6.80 (1H, dd, $J=10$, 3, $\text{C}_5\text{-H}$), 7.1–7.5 (5H, m, aromatic H). MS m/z (%): 214 (M^+ , 100), 199 ($\text{M}^+ - \text{Me}$, 33), 171 ($\text{M}^+ - \text{CH}_3\text{CO}$, 33), 128 (24), 105 (13), 77 (14). Anal. Calcd for $\text{C}_{14}\text{H}_{14}\text{O}_2 + 1/5\text{H}_2\text{O}$: C, 77.12; H, 6.61. Found: C, 77.01; H, 6.58.

b) With SeO_2 : A mixture of I (6.96 g, 32.2 mmol), SeO_2 (95%, 3.9 g every 13 h, total 31.2 g, 267 mmol), AcOH (41 ml), and anhyd. *tert*-amyl alcohol (138 ml) was refluxed with stirring and the reaction was monitored by GC during the course of 104 h. The residue obtained after evaporation of the filtrate was rinsed with CH_2Cl_2 , and the organic layer was washed with 5% NaOH and brine. The oil obtained after removal of the solvent was distilled to give a mixture of I and II (3.28 g, 1:5). bp 144–162 $^\circ\text{C}$ (3 mmHg).

General Procedure for Photochemical Experiments—A methanolic or benzene solution of the starting material in a Pyrex vessel equipped with a thermometer, N_2 -gas inlet system and a drying tube was well stirred and agitated for 1 h with N_2 which had been dried with anhyd. CaCl_2 and deoxygenated with a Badische Anilin und Soda Fabrik (BASF) catalyst. The solution was cooled and irradiated with a high-pressure mercury lamp. The irradiation was continued with monitoring of the reaction products by GC.

Irradiation of I in MeOH—A solution of I (121.8 mg, 0.56 mmol) in MeOH (240 ml) was irradiated with a high pressure 100 W mercury lamp at 5–20 $^\circ\text{C}$ for 5 h. After removal of MeOH, the residue (0.25 g) was fractionated through an SiO_2 column. I (3.6 mg, 2.9%), 4-methyl-4-phenyl-2-cyclohexenone (III, 31.4 mg, 30.0%), and 1-methoxy-5-methyl-6-phenylbicyclo[3.1.0]hexan-2-one (IV, 81.6 mg, 66.8%) were eluted successively with 3% AcOEt in hexane. III: bp < 120 $^\circ\text{C}$ (1 mmHg), GC (170 $^\circ\text{C}$), t_{R} : 4.0 min. NMR (CDCl_3): 1.58 (3H, s, Me), 2.1–2.5 (each 2H, m, $\text{C}_5\text{-}$ and $\text{C}_6\text{-H}$), 6.16 (1H, d, $J=10$, $\text{C}_2\text{-H}$), 6.97 (1H, d, $J=10$, $\text{C}_3\text{-H}$), 7.2–7.5 (5H, m, aromatic H). MS m/z (%): 186 (M^+ , 100), 171 ($\text{M}^+ - \text{Me}$, 17), 158 ($\text{M}^+ - \text{CO}$, 48), 144 ($\text{M}^+ - \text{CH}_2 = \text{C} = \text{O}$, 97), 129 (97), 115 (31). III was also prepared according to the known method⁵) from 2-phenylpropionaldehyde and methyl vinyl ketone; the product was identical with that obtained in this experiment. IV: bp < 120 $^\circ\text{C}$ (1 mmHg). IR (neat): $\nu_{\text{C=O}}$ 1720. GC (170 $^\circ\text{C}$): t_{R} 4.5 min. NMR (CDCl_3): 0.8–1.1 (1H, m, $\text{C}_3\text{-endo H}$), 1.56 (3H, s, $\text{C}_5\text{-Me}$), 1.7–1.9 (1H, m), 1.9–2.1 (2H, m), 2.80 (1H, s, $\text{C}_6\text{-H}$), 3.71 (3H, s, OMe), 7.2–7.5 (5H, m, aromatic H). MS m/z (%): 216 (M^+ , 100), 201 ($\text{M}^+ - \text{Me}$, 46), 184 ($\text{M}^+ - \text{MeOH}$, 16), 173 ($\text{M}^+ - \text{CH}_3\text{CO}$, 59), 142 (57), 128 (36), 114 (29), 90 (30). High-resolution MS Calcd for $\text{C}_{14}\text{H}_{16}\text{O}_2$: 216.1149. Found: 216.1149. Anal. Calcd for $\text{C}_{14}\text{H}_{16}\text{O}_2$: C, 77.75; H, 7.46. Found: C, 77.52; H, 7.30.

Irradiation of I in Benzene—A benzene solution (240 ml) of I (200.8 mg, 0.94 mmol) was irradiated with a 100 W mercury lamp at 7–23 $^\circ\text{C}$ for 10 h. GC (170 $^\circ\text{C}$): t_{R} 4.5 min. Compound III could not be detected. An oily substance obtained after removal of the solvent was microdistilled to give a colorless oil. bp < 150 $^\circ\text{C}$ (3 mmHg). The NMR spectrum was superimposable on that of IV and exhibited no signal due to III. Yield: 89.5 mg (44.6%).

Irradiation of II in MeOH—A methanolic solution (240 ml) of II (196.4 mg, 0.92 mmol) was irradiated with a 100 W mercury lamp at 2–9 $^\circ\text{C}$ for 30 min. The residue (212.9 mg) obtained after removal of the solvent was fractionated through a medium-pressure SiO_2 column. 6,6-Dimethoxy-5-methyl-5-phenyl-3-cyclohexenone (VI) and 2,2-dimethoxy-6-methyl-6-phenylbicyclo[3.1.0]hexan-3-one (V) were eluted with 2% AcOEt–hexane and 3–5%

AcOEt-hexane, respectively. V: mp 91–94 °C (white prisms from hexane), yield 98.2 mg (43.5%). IR (CHCl₃): $\nu_{C=O}$ 1760, δ_{C-O} 1100. GC (170 °C): t_R 6.3 min. NMR (CDCl₃): 1.59 (3H, s, C₆-Me), 1.8–2.0 (2H, m, C₁- and C₅-H), 2.36 (1H, d, $J=18$, C₄-endo H), 2.80 (1H, dd, $J=18$, 5, C₄-exo H), 3.14 and 3.65 (each 3H, s, OMe), 7.2–7.4 (5H, m, aromatic H). MS m/z (%): 246 (M⁺, 0.2), 218 (M⁺ – CO, 100), 203 (M⁺ – 1 – MeOH, 45), 187 (27), 171 (24), 155 (13), 143 (M⁺ – 1 – (MeO)₂C = C = O, 48), 129 (85). Anal. Calcd for C₁₅H₁₈O₃: C, 73.14; H, 7.37. Found: C, 73.30; H, 7.40. VI: Oil, yield 42.6 mg (18.9%). IR (CHCl₃): $\nu_{C=O}$ 1730. UV, only end absorption. GC (200 °C): t_R 2.6 min. NMR (CDCl₃): 1.50 (3H, s, C₅-Me), 3.06 (1H, dm, $J=20$, C₂-H), 3.00 and 3.14 (each 3H, s, OMe), 3.29 (1H, dt, $J=20$, 4, C₂-H), 5.61 (1H, dm, $J=10$, C₄-H), 5.77 (1H, dt, $J=10$, 4, C₃-H), 7.2–7.6 (5H, m, aromatic H). MS m/z (%): 246 (M⁺, 26), 218 (M⁺ – CO, 43), 203 (M⁺ – MeCO, 31), 143 (M⁺ – (MeO)₂C = C = O, 29), 129 (100), 117 (33). High-resolution MS Calcd for C₁₅H₁₈O₃: 246.1255. Found: 246.1232.

10-Methyl-10-phenyl-2,3-dihydro-1,2-methano-1H-cyclopenta[b]quinoxaline (VII)—A solution of *o*-phenylenediamine (8.9 mg, 0.08 mmol) and V (19.5 mg, 0.08 mmol) in MeOH (5 ml) was added to an aqueous solution of AcONa·3H₂O (13.0 mg, 0.10 mmol) and AcOH (5 drops). The mixture was stirred overnight at room temperature, and then diluted with water followed by extraction with CH₂Cl₂. The residue obtained after removal of the solvent was fractionated through an SiO₂ column. Compounds V and VII were successively eluted with CH₂Cl₂. The yields of V and VII were 10.0 mg (51.3%) and 4.7 mg (21.0%), respectively. VII: mp 147–150 °C (from hexane). NMR (CDCl₃): 1.56 (3H, s, Me), 2.40 (1H, dd, $J=6$, 6, C₂-H), 2.97 (1H, d, $J=6$, C₁-H), 3.06 (1H, d, $J=20$, C₃-H), 3.37 (1H, dd, $J=20$, 6, C₃-H), 6.9–7.2 (5H, m, C₁₀-phenyl-H), 7.5–7.7 (2H, m, C₆-, C₇-H), 7.77 (1H, dm, $J=8$, C₅-H), 8.02 (1H, dd, $J=8$, 1.5, C₈-H). MS m/z (%): 272 (M⁺, 100), 257 (M⁺ – Me, 79), 128 (26), 105 (28), 77 (12). High-resolution MS Calcd for C₁₉H₁₆N₂: 272.1313. Found: 272.1315.

2,2-Dimethoxy-3-methyl-3-phenylcyclohexanone (VIII)—A methanolic solution of VI (23.2 mg, 0.09 mmol) was shaken under an ordinary pressure of H₂ in the presence of PtO₂ (100 mg, 0.4 mmol) at room temperature for 3 h. The residue obtained after concentration of the filtrate was dissolved in CH₂Cl₂. Crude VIII obtained after removal of the organic solvent was purified through an SiO₂ column (CH₂Cl₂ as the eluent). VIII: mp 76–81 °C (from hexane). Yield: 14.7 mg (62.8%). IR (CHCl₃): $\nu_{C=O}$ 1720. NMR (CDCl₃): 1.36 (3H, s, C₃-Me), 1.5–1.8 and 1.8–2.1 (each 2H, m), 2.49 (1H, dm, $J=12$, C₆-H), 2.6–2.8 (1H, m, C₆-H), 2.81 and 3.11 (each 3H, s, OMe), 7.2–7.5 (3H, m, aromatic H), 7.64 (2H, dm, $J=8$, aromatic H). MS m/z (%): 248 (M⁺, 5), 220 (M⁺ – CO, 6), 214 (24), 199 (10), 131 (28), 117 (100), 101 (67), 91 (47), 57 (45). Anal. Calcd for C₁₅H₂₀O₃: C, 72.55; H, 8.12. Found: C, 72.82; H, 8.06.

2-Hydroxy-6-methyl-6-phenyl-2-cyclohexenone (IX)—Three drops of 10% HCl were added to an acetone solution of VIII (6.8 mg). The mixture was refluxed for 3 h on a water bath, then concentrated and extracted with CH₂Cl₂. The organic layer was washed with brine and concentrated to give crude IX (6.0 mg). GC (200 °C), t_R 2.5 min (single peak). NMR (CDCl₃): 1.20 (3H, s, Me), 1.8–2.5 (4H, m), 5.95 (1H, t, $J=5$, C₃-H), 7.1–7.4 (5H, m, aromatic H). MS m/z (%): 202 (M⁺, 48), 187 (M⁺ – Me, 26), 119 (PhCMe, 26), 108 (M⁺ – MeH – PhH, 100), 91 (38), 80 (56), 56 (60). High-resolution MS Calcd for C₁₃H₁₄O₂: 202.0993. Found: 202.1016.

1-Methyl-1-phenyl-1,2,3,4-tetrahydrophenazine (X)—An aqueous solution of AcONa·3H₂O (2.5 mg, 0.018 mmol) was added to a mixture of IX (1.8 mg, 0.009 mmol) and *o*-phenylenediamine (0.9 mg, 0.08 mmol). After being stirred overnight, the mixture was concentrated. The residue was dissolved in CH₂Cl₂ and the organic layer was washed with brine and evaporated to give crude X (1.9 mg). MS m/z (%): 274 (M⁺, 100), 259 (M⁺ – Me, 55), 245 (18), 231 (33), 149 (77), 57 (80). High-resolution MS Calcd for C₁₉H₁₈N₂: 274.1469. Found: 274.1454.

Irradiation of II in Benzene—A benzene solution of II (208.4 mg, 0.97 mmol) was irradiated with a 100 W mercury lamp at 20 °C for 30 min. The residue obtained after removal of the solvent was fractionated through an SiO₂ column. 6-Methoxy-6-methyl-5-phenyl-2,4-cyclohexadienone (XI, 5.1 mg, 2.4%) and II (14.2 mg, 6.8%) were eluted with 2% AcOEt-hexane and 5% AcOEt-hexane, respectively. XI: GC (200 °C): t_R 3.2 min. NMR (CDCl₃): 1.72 (3H, s, Me), 3.66 (3H, s, OMe), 5.48 (1H, d, $J=6$, C₂-H), 5.82 (1H, d, $J=10$, C₄-H), 7.1–7.4 (6H, m, C₃- and aromatic H). MS m/z (%): 214 (M⁺, 100), 199 (M⁺ – Me, 16), 171 (39), 128 (34). High resolution MS Calcd for C₁₅H₁₈O₃: 246.1255. Found: 246.1232.

Treatment of I with HPO—HPO (31%, 0.27 ml, 2.37 mmol) was gradually added to a mixture of I (513 mg, 2.38 mmol) and TFA (1.95 ml) at room temperature with stirring (exothermic!). After being stirred at 40 °C for 3 h, the mixture was diluted with ice-water and extracted with CH₂Cl₂. The organic layer was washed with sat. NaHCO₃, 1% NaHSO₃, and brine. The residue (129 mg) obtained after removal of the solvent showed an NMR spectrum consistent with that of I. The basic layer was acidified with 5% HCl and extracted with AcOEt. The organic layer was dried and evaporated to give 4-methoxycarbonylmethyl-4-phenylpentanoic acid (XIVa, 431 mg, conversion yield was 97.1%). XIVa: IR (film): $\nu_{C=O}$ 1700–1740. NMR (CDCl₃): 1.48 (3H, s, CH₃), 2.0–2.3 (4H, m, 2 × CH₂), 2.62 and 2.70 (each 1H, d, $J=14$, CH₂COOMe), 3.53 (3H, s, OMe), 7.2–7.4 (5H, m, aromatic H). MS m/z (%): 250 (M⁺, 0.6), 191 (M⁺ – COOMe, 0.8), 84 (100). Compound XIVa was esterified with an excess of CH₂N₂ to give dimethyl 3-methyl-3-phenyladipate (XIVb) quantitatively. XIVb: bp < 120 °C (0.3 mmHg). IR (film): $\nu_{C=O}$ 1735. NMR (CDCl₃): 1.48 (3H, s, CH₃), 2.0–2.3 (4H, m, 2 × CH₂), 2.61 and 2.71 (each 1H, d, $J=14$, C₂-H), 3.52 and 3.59 (each 3H, s, OMe), 7.1–7.4 (5H, m, aromatic H). MS m/z (%): 264 (M⁺, 1.5), 177 (Ph(Me)C⁺ – CH₂COOMe, 100). Anal. Calcd for C₁₅H₂₀O₄: C, 68.16; H, 7.63. Found: C, 68.26; H, 7.68. NaOH (0.26 g) in aq. MeOH (1 ml) was added to a solution of

XIVa (412 mg) in MeOH (3 ml), and the mixture was refluxed for 1 h. The resulting mixture was diluted with ice-water, acidified with 5% HCl, and then extracted with AcOEt. The crystalline compound obtained after removal of the solvent was recrystallized from water to give 3-methyl-3-phenyladipic acid (XIVc). Yield: 362 mg (93.0%). mp 153—156 °C (Lit.⁷⁾ mp 153—155 °C).

Treatment of I with mCPBA—a) At Room Temperature in CH₂Cl₂: mCPBA (130 mg, 0.53 mmol) was added to a solution of I (99 mg, 0.46 mmol) under ice-cooling with stirring. After being stirred for 66.5 h at room temperature, the mixture was washed with sat. NaHCO₃ and brine. The residue obtained after removal of the solvent was purified through an SiO₂ column. 5,6-Epoxy-6-methoxy-4-methyl-4-phenyl-6-hexanolide (XV) was eluted with AcOEt. XV: bp < 200 °C (4 mmHg). 84.3 mg (74.1%). NMR (CDCl₃): 1.60 (3H, s, C₄-CH₃), 2.5—2.7 and 2.7—3.0 (each 2H, m, C₃- and C₂-H, respectively), 3.34 (3H, s, OMe), 4.95 (1H, d, *J* = 2, C₅-H), 7.1—7.5 (5H, m, aromatic H). MS *m/z* (%): 248 (M⁺, 2.4), 118 (Ph(Me)C=CH₂, 100). Anal. Calcd for C₁₄H₁₆O₄ + 1/10 H₂O: C, 67.25; H, 6.49. Found: C, 67.26; H, 6.47.

b) At 4 °C in a Bilayer System: mCPBA (70%, 138 mg, 0.56 mmol) was added to a solution of I (105 mg, 0.49 mmol) and Na₂HPO₄·12H₂O (0.97 g, 2.71 mmol) in CH₂Cl₂ (20 ml) and water (10 ml) under ice-cooling. The mixture was stirred at 4 °C for ca. 140 h and the organic layer was washed with sat. NaHCO₃ and brine. The residue obtained after removal of the solvent was fractionated through an SiO₂ column. 2,3-Epoxy-2-methoxy-4-methyl-4-phenylcyclohexanone (XIII, 9.7 mg, 8.6%), I (20.4 mg, 18.9%), and XV (77.6 mg, 64.3%) were eluted with 2% AcOEt-hexane, 5% AcOEt-hexane and AcOEt, successively. XIII: bp < 130 °C (3 mmHg). NMR (CDCl₃): 1.58 (3H, s, C₄-CH₃), 1.6—2.4 (4H, m, 2 × CH₂), 3.68 (3H, s, OMe), 3.74 (1H, s, C₃-H), 7.2—7.5 (5H, m, aromatic H). MS *m/z* (%): 232 (M⁺, 9.8), 131 (Ph(Me)C-CH=CH₂, 67), 105 (PhCHCH₃, 51), 91 (PhCH₂⁺, 100).

5,6-Epoxy-6-methoxy-4-methyl-4-phenyl-2-cyclohexenone (XVI)—mCPBA (1.62 g, 6.6 mmol) was added to a solution of II (522 mg, 2.4 mmol) and Na₂HPO₄·12H₂O (5.17 g) in CH₂Cl₂ (76 ml) and water (53 ml) under ice-cooling. The mixture was stirred at room temperature for ca. 86 h. The organic layer was washed with 10% NaOH and brine, and then evaporated. The residue (613 mg) was fractionated through an SiO₂ column. Compound XVI and its isomer (XVI') were successively eluted with 2% AcOEt-hexane. II (136 mg, 26.0%) was recovered from the fraction eluted with 20% AcOEt-hexane. XVI: 244 mg (43.5%). bp < 110 °C (0.5 mmHg). IR (film): ν_{C=O} 1685. NMR (CDCl₃): 1.72 (3H, s, C₄-CH₃), 3.59 (3H, s, OMe), 3.77 (1H, d, *J* = 4, C₅-H), 6.05 (1H, d, *J* = 10, C₂-H), 6.37 (1H, dd, *J* = 10, 4, C₃-H), 7.3—7.5 (5H, m, aromatic H). MS *m/z* (%): 230 (M⁺, 1.1), 215 (M⁺ - CH₃, 14), 201 (1.5), 187 (1.3), 171 (100). Anal. Calcd for C₁₄H₁₄O₃: C, 73.02; H, 6.13. Found: C, 73.11; H, 6.18. XVI': 33 mg (5.9%). NMR (CDCl₃): 1.66 (3H, s, C₄-CH₃), 3.60 (3H, s, OMe), 3.79 (1H, d, *J* = 4, C₅-H), 6.09 (1H, d, *J* = 10, C₂-H), 6.62 (1H, dd, *J* = 10, 4, C₃-H), 7.40 (5H, s, aromatic H). MS *m/z* (%): 230 (M⁺, 1), 215 (M⁺ - CH₃, 28), 201 (1.7), 187 (1.7), 171 (100).

5,6-Epoxy-2-methoxy-4-methyl-4-phenyl-2-cyclohexenone (XVIII)—HPO (31%, 0.4 ml, 3.0 mmol) was added to a solution of II (214 mg, 1.0 mmol) in MeOH (2.8 ml). Then 6N NaOH solution was added to the mixture (exothermic!). After being stirred at room temperature for 2.7 h, the mixture was diluted with water and extracted with CH₂Cl₂. The organic layer was washed with brine and evaporated. The residue (191 mg) was fractionated through an SiO₂ column. XVIII (121 mg, 52.6%) and II (81 mg, 37.7%) were eluted with 5% and 10% AcOEt-hexane, successively. XVIII: bp < 110 °C (0.4 mmHg). IR (film): ν_{C=O} 1685, ν_{C=C} 1620. NMR (CDCl₃): 1.78 (3H, s, C₄-CH₃), 3.5—3.7 (2H, m, C₅- and C₆-H), 3.60 (3H, s, OMe), 5.31 (1H, d, *J* = 4, C₃-H), 7.2—7.6 (5H, m, aromatic H). MS *m/z* (%): 230 (M⁺, 24), 215 (M⁺ - CH₃, 26), 202 (M⁺ - CO, 29), 187 (100), 171 (24). Anal. Calcd for C₁₄H₁₄O₃: C, 73.02; H, 6.13. Found: C, 72.91; H, 6.21.

2,3:5,6-Diepoxy-6-methoxy-4-methyl-4-phenyl-6-hexanolide (XVII)—a) From XVI by Oxidation with HPO: HPO (31%, 0.11 ml, 1.47 mmol) and 6N NaOH (0.03 ml, 0.18 mmol) were added to a methanolic solution (1.1 ml) of XVI (71.4 mg, 0.31 mmol). The mixture was stirred at room temperature for 23.7 h and extracted with CH₂Cl₂. The organic layer was washed with brine and evaporated to give an oily residue (22.7 mg), which was fractionated through an SiO₂ column. XVII: bp < 110 °C (0.3 mmHg). NMR (CDCl₃): 1.91 (3H, s, C₄-CH₃), 3.52 (3H, s, OMe), 3.61 and 3.96 (each 1H, d, *J* = 4, C₃- and C₂-H, respectively), 5.02 (1H, s, C₅-H), 7.2—7.4 (5H, m, aromatic H). MS *m/z* (%): 262 (M⁺, 26), 145[Ph(Me)C-CH₂CHO, 100], 117 (M⁺ - 145, 51). Anal. Calcd for C₁₄H₁₄O₅: C, 64.11; H, 5.38. Found: C, 64.17; H, 5.44.

b) From XVIII by Oxidation of mCPBA: mCPBA (785 mg, 3.18 mmol) was added to a solution of XVIII (54.0 mg, 0.24 mmol) and Na₂HPO₄ (3.78 g, 10.6 mmol) in CH₂Cl₂ (7.3 ml) and water (5.2 ml) under ice-cooling. The mixture was stirred at 4 °C for 21.7 h. The crude product after the usual work-up was fractionated through an SiO₂ column. XVIII (14.8 mg, 21.8%) and XVII (28.8 mg, 46.8%) were successively eluted with benzene. The physical data of XVII were identical with those of XVII obtained in the above experiment a).

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References and Notes

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