Photochemistry of Epoxyquinone. 4. Primary Dimers in the Photochemical Reaction of 2,3-Dimethyl-2,3-epoxy-2,3-dihydro-1,4-naphthoquinone

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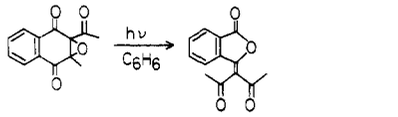
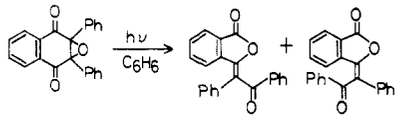
Photolysis of a benzene solution of 2,3-dimethyl-2,3-epoxy-2,3-dihydro-1,4-naphthoquinone (1) (0.1 M) gave the primary dimers **2a** and **2b** in 65 and 20% yields, respectively. Upon further irradiation, the primary dimers underwent photoisomerization to give alkylidenephthalide dimers **3a** and **3b** quantitatively. On the other hand, photolysis of an extremely dilute solution of 1 (<0.1 mM in benzene) gave different phthalides, **4a** and **4b**, and triketone **5**. Reversible inner C–C bond opening of the oxirane ring was suggested on the basis of a product distribution change dependent upon the concentration of **1**.

In striking contrast to the extensive investigation of the photochemistry of α,β-epoxy ketones,[1] only scattered reports have appeared on the photochemistry of epoxyquinones. Recently, various types of photochemical reactions of epoxyquinones have been developed.[2] Our recent work in this area has revealed that photoinduced cycloadditions of epoxynaphthoquinones to olefins were highly dependent upon the substitution pattern of the C-2 and C-3 positions of epoxynaphthoquinones[2a] and that 2-acetyl-3-methyl-2,3-epoxy-2,3-dihydro-1,4-naphthoquinone underwent photoisomerization leading to alkylidene phthalide (eq 1).[2a] 2,3-Diphenyl-2,3-epoxy-2,3-dihydro-1,4-naphthoquinone was also reported to undergo similar photoisomerization (eq 2).[2b] Photochemical dimerization of 2,3-dimethyl-2,3-epoxy-2,3-dihydro-1,4-naphthoquinone (**1**) was reported by Jiménez et al. in 1974.[2c] However, these workers only isolated alkylidenephthalide-type dimers (**3a** and **3b**) and determined neither the stereochemistry of the dimers nor the reaction course. In the course of our study on the photochemistry of epoxynaphthoquinone, we found that the primary dimers **2a** and **2b** were initially formed from the photolysis of 1 (0.1 M in benzene) and that the primary dimers subsequently underwent photoisomerization to give the secondary dimers quantitatively; these were the same as those reported by Jiménez et al.



(1)

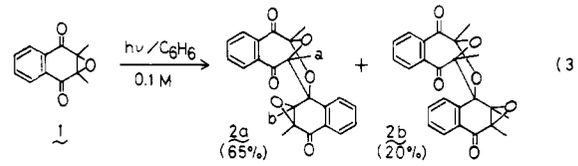


(2)

We report here the stereospecific dimerization of **1** leading to the primary dimers and present evidence for the reversible opening of the inner C–C bond of the oxirane ring in **1**.

Results and Discussion

Product Analysis. A benzene solution of 1 (0.1 M) was irradiated for 2 h in a Pyrex tube with a 300-W high-pressure Hg lamp. Separation of the products by column chromatography gave **2a** and **2b** (eq 3) in 65 and 20% yields, respectively. Upon further irradiation in a benzene or acetone solution, **2a** isomerized to give alkylidenephthalide-type dimers **3a** and **3b** in 42 and 50% yields, respectively (eq 4). Similarly, **2b** was irradiated to give **3a** (40%) and **3b** (49%). Secondary dimers **3a** and **3b** attained a photoequilibrium to give a 1:1.2 mixture of **3a** to **3b**. However, the photoisomerization of **2a** and **2b** to **3a** and **3b** proceeded much more readily than the photoequilibration (**3a** ⇌ **3b**); therefore, it could be concluded that **3a** and **3b** were produced in the same ratio from either **2a** or **2b**.



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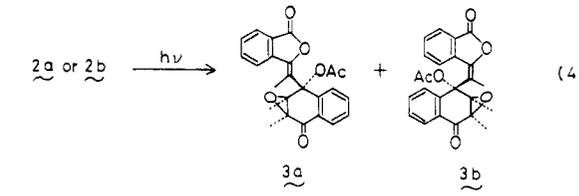

(4)

The structures of these dimers were determined by their IR, ^{1}H NMR, and ^{13}C NMR spectra, elemental analyses, and chemical reactions. Both **3a** and **3b** show characteristic IR bands due to a strained five-membered lactone and a conjugated ketone at 1770 and 1690 cm^{-1}, respectively. The ^{1}H NMR spectrum of **3a** shows signals at δ 1.68 (s, 3 H), 1.69 (s, 3 H), 1.70 (s, 3 H), 2.32 (s, 3 H), and 7.1–8.0 (m, 8 H), and that of **3b** shows signals at δ 1.60 (s, 3 H), 1.81 (s, 3 H), 2.20 (s, 3 H), 2.32 (s, 3 H), and 7.18–7.90 (m, 8 H), in agreement with the structures of **3a** and **3b**. The allylic methyl protons of **3b** are deshielded at δ 2.20 relative to those of **3a** at δ 1.70, since the allylic methyl group is cis to the benzene ring in **3b**. Ozonolysis of **3a** and **3b** in methylene chloride or methanol was unsuccessful, but treatment of **3a** and **3b** with an excess amount of $NaIO_4$ and a catalytic amount of $KMnO_4$ in acetone and water[3] gave phthalic anhydride (**6**) (80%) and epoxy ketone **7** (57%) (eq 5), presenting unambiguous evidence for the alkylidenephthalide structures of **3a** and **3b**. The identity of the oxidized products from **3a** and **3b** indicates that the stereochemistry around the benzocyclohexanone ring in **3a** and **3b** is the same and, therefore, that **3a** and **3b** are *E* and *Z* isomers about the double bond. Epoxy ketone **7** was hydrolyzed to give **8** in 62% yield (eq 6). The upfield shift of the a-methyl protons in **8** relative to **7** can be ascribed to the lack of the deshielding effect of the ester carbonyl. On the basis of the above observation, it was

(1) (a) For a review see: Bertonier, N. R.; Griffin, J. M. *Org. Photochem.* **1973**, *3*, Chapter 2. (b) Johnson, C. K.; Doming, B.; Reush, W. *J. Am. Chem. Soc.* **1963**, *85*, 3894. (c) Markos, C. S.; Reush, W. *Ibid.* **1967**, *89*, 3363.

(2) (a) Arakawa, S. *J. Org. Chem.* **1977**, *42*, 3800. (b) Kato, H.; Tezuka, H.; Yamaguchi, K.; Nowada, K.; Nakamura, Y. *J. Chem. Soc., Perkin Trans. 1* **1978**, 1029. (c) Jiménez, M.; Rodrriguez-Hahn, L.; Romo, J. *Rev. Latinoam. Quim.* **1974**, *5*, 184. (d) Giles, R. G. F.; Green, I. R.; Mitchell, P. R. K.; Raston, C. L.; White, A. H. *J. Chem. Soc., Perkin Trans. 1* **1979**, 719.

(3) Lemieux, R. L.; von Rudloff, E. *Can. J. Chem.* **1955**, *33*, 1701, 1770.

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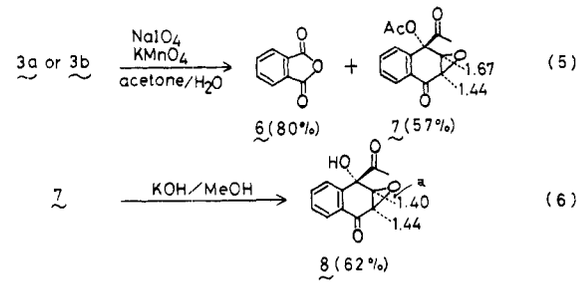


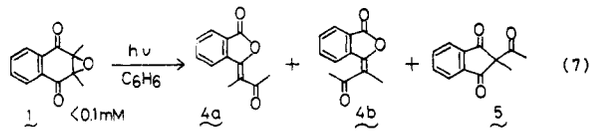
(5)

(6)

determined that the acetoxy group and the dimethyl groups are on the same side in **7**. The IR spectra of the primary dimers **2a** and **2b** show characteristic bands due to conjugated ketones at 1688 and 1689 cm^{-1}, respectively. The ^1H NMR spectrum of **2a** shows signals at δ 0.71 (s, 3 H), 1.20 (s, 3 H), 1.63 (s, 3 H), 2.05 (s, 3 H), and 6.90–7.96 (m, 8 H) and that of **2b** shows signals at δ 1.56 (s, 3 H), 1.74 (s, 3 H), 1.85 (s, 3 H), 2.05 (s, 3 H), and 6.90–7.96 (m, 8 H). It is reasonable to assume on the basis of the structure of the secondary dimers **3a** and **3b** that the stereochemistry around the benzocyclohexanone ring in **2a** and **2b** is the same, i.e., trans,[4a] presumably because the secondary dimers are derived from the photolysis of the primary dimers via radical rearrangement which leaves intact the stereochemical relationship around the benzocyclohexanone ring. From the marked upfield shift for a- and b-methyl protons in **2a** (designated in eq 3) due to the shielding effect of the aromatic ring, **2a** was assigned as the antidimer.

Further support for the structure of the primary dimer **2a** comes from its ^{13}C NMR spectrum which reveals 3 ketone carbonyls at δ 196.412, 201.786, and 205.280, 1,3-dioxolane ring carbons at δ 91.382, 94.171, and 109.845, and 2 oxirane ring carbons at δ 61.322 and 64.081, besides 4 methyl carbons and 12 sp^2 carbons. On the other hand, the ^{13}C NMR spectrum of the secondary dimer **3a** reveals only 1 ketone carbonyl at δ 193.651, 2 ester carbonyls at δ 165.681 and 166.644, and two oxirane ring carbons at δ 63.552 and 65.227, besides 4 methyl carbons and 14 sp^2 carbons.

The photochemical dimerization of **1** was a fairly clean reaction in a rather high concentration range of **1** (>0.1 M). But yields of the dimers decreased as the concentration of **1** became low. The dimerization was practically suppressed when the concentration of **1** was lower than 0.1 mM, under which conditions thorough irradiation of **1** in a degassed benzene solution gave a mixture of alkylidenephthalides **4a** and **4b** in 21 and 18% yields, respectively. Controlled irradiation of **1** under the above conditions gave triketone **5** (7%) together with **4a** (16%) and **4b** (14%) (eq 7). The triketone **5** was photochemically converted to **4a** and **4b** almost quantitatively.

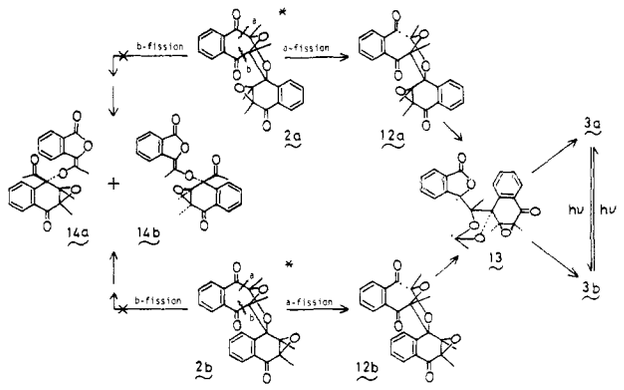


(7)

Alkylidenephthalides **4a** and **4b** show IR bands at 1778 and 1696 cm^{-1} and at 1781 and 1665 cm^{-1}, respectively,

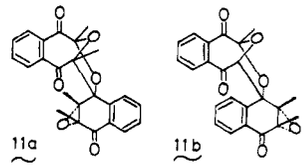
(4) (a) Ullman, E. F.; Milks, J. E. *J. Am. Chem. Soc.* **1964**, *86*, 3814. 2,3-Diphenyl-2,3-epoxyindenone was reported to undergo closely related thermal dimerization which also proceeded stereospecifically at the side with the oxirane ring. Ullman and Milks determined the stereochemistry of the dimers elegantly by treating them with hydrochloric acid in moist acetonitrile. The primary dimers **2a** and/or **2b** were treated with hydrochloric acid in moist acetonitrile but were recovered. (b) Huisgen, R. *J. Org. Chem.* **1976**, *41*, 3.

Scheme I



assignable to a strained five-membered lactone and a conjugated ketone. In the ^1H NMR spectra, the allylic methyl protons of **4a** appear at lower field (δ 2.32) than those of **4b** (δ 2.20), and the acetyl protons appear vice versa (see Experimental Section). The ^{13}C NMR spectrum of **4a** reveals eight sp^2 carbons, one ketone (δ 192.1), one ester (δ 170.4), and two methyl carbons. Further, the structures of **4a** and **4b** were confirmed by independent synthesis.

Reaction Mechanism. Formation of the primary dimers can be explained in terms of inner C–C bond fission of the oxirane ring and trapping of carbonyl ylide **9** or 1,3-diradical **10** with the carbonyl group of **1** in a ground state. It is interesting to note that dimers with cis configurations in the benzocyclohexanone ring (**11a** and **11b**)



were not formed at all as the primary dimers. In other words, the dimerization occurred stereospecifically at the same side as the oxirane ring in **1**. We believe that the lone-pair electrons of the oxirane oxygen atom play some role through so-called secondary π-orbital overlap in addition to the critical steric hindrance of dimethyl groups in the transition state.[4]

The photoisomerization of the primary dimers to the secondary dimers could proceed according to Scheme I. After photoexcitation and successive Norrish type I cleavage, the resulting aroyl radical attacks the carbonyl oxygen atom intramolecularly, leading to the diradical **13** which rearranges to the secondary dimers **3a** and **3b**. As indicated in Scheme I, the proposed mechanism leaves the stereochemistry of the benzocyclohexanone ring intact. It should be stressed here that predominant formation of **3a** and **3b** over enol ketone type dimers (**14a** and **14b** in Scheme I) required the pronounced preference of a-fission over b-fission (designated in Scheme I) from the excited state of the primary dimers. The preference of a-fission over b-fission is consistent with the proposed stepwise radical mechanism since radical intermediates **12a** and **12b** may be better stabilized by two ethereal oxygen atoms adjacent to the radical center than corresponding radical intermediates derived from b-fission.

A plausible mechanism for the photoisomerization of **1** to **4a**, **4b**, and **5** is shown in Scheme II. Path A begins with Norrish type I cleavage followed by lactonization to give **4a** and **4b** or by radical rearrangement of oxirane ring to give **5**. However, an alternative explanation is also possible for the photoisomerization of **1** to **4a**, **4b**, and **5**,

Scheme II

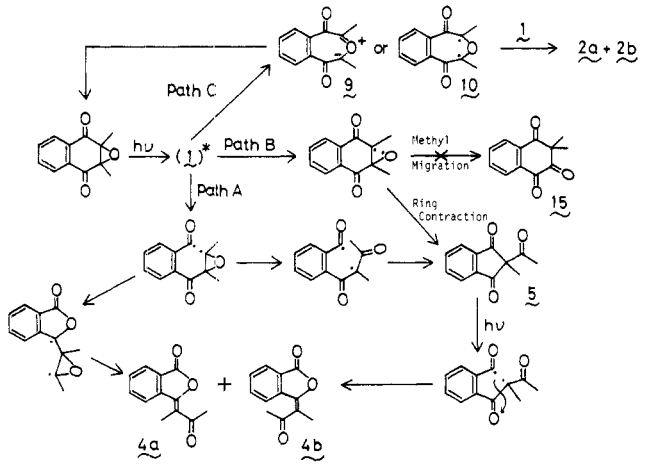


Table I. Effect of Concentration of 1 on Product Distribution[a,b]

concn, mM	% dimers[c]: % isomers[d]	total yield, %	dimers/ isomers
0.40	2:98	40	0.02
0.82	9:91	45	0.10
1.65	12:88	50	0.14
8.25	74:26	68	2.8
16.5	95:5	83	19
82.5	99:1	85	99

[a] Degassed benzene solutions of 1 were irradiated in a Pyrex tube with a 300-W high-pressure Hg lamp. [b] Product ratios were determined by high-pressure liquid chromatography. [c] Sum of 2a + 2b + 3a + 3b. [d] Sum of 4a + 4b + 5.

if the triketone 5 is assumed to be the primary product (path B). The formation of 5 from 1 can be achieved by C–O bond cleavage followed by ring contraction. Preferred ring contraction (to give 5) over methyl migration (to give 15) is consistent with the usual migratory aptitudes in the photorearrangement of α,β-epoxy ketones to β-diketones.[1b,c] Photoisomerization of 2,2-disubstituted 1,3-indandione to alkylidenephthalides is a well-established process.[5] Indeed, the conversion of 5 to 4a and 4b does occur photochemically. At present we cannot distinguish between the two paths.[6]

The effect of the concentration of 1 on the product distribution was examined (Table I). The ratio of dimers to isomerized products decreased dramatically from 99 to 0.02 as the concentration of 1 decreased from 0.82 to 4.0 × 10^{-4} M. It is evident from Table I that carbonyl ylide 9 or 1,3-diradical 10 largely cyclizes to reproduce the starting epoxyquinone 1 if it is not trapped by dipolarophiles.[7]

The predominant reaction path from the excited state of 1 is the reversible inner C–C bond cleavage of the oxirane ring (path C in Scheme II). Norrish type I cleavage (path A) or C–O bond cleavage of oxirane ring (path B) is usually of less importance in this system. However, the latter process becomes predominant in the photolysis of a extremely dilute solution of 1 in the absence of dipolarophiles.

In summary, in the photolysis of 1 we have found the primary dimers 2a and 2b and the isomerized products 4a, 4b, and 5, besides the secondary dimers 3a and 3b, and propose plausible mechanisms for these reactions. We are continuing to investigate structural effects on these reactions.

(5) Rigaudy, J.; Derible, P. *Bull. Soc. Chim. Fr.* **1965**, 3045, 3055, 3061.
(6) Kitamura, T.; Imagawa, T.; Kawanishi, M. *Tetrahedron Lett.* **1978**, 3443.
(7) Ishikawa, K.; Griffin, G. W.; Lev, I. J. *J. Org. Chem.* **1976**, *41*, 3747.

Experimental Section

Apparatus. Melting points were measured on a Yanagimoto micro melting point apparatus and are uncorrected. Infrared spectra were taken on a JASCO-402G spectrometer. ^{1}H NMR spectra were recorded on a JEOL PS-100 spectrometer and chemical shifts are reported in parts per million on the δ scale from internal tetramethylsilane. ^{13}C NMR spectra were recorded on a JEOL FX-100 spectrometer. Elemental analyses were performed at the Microanalytical Laboratory of Kyoto University. Mass spectra were recorded on a Hitachi M-52 mass spectrometer. UV irradiations were carried out in a Pyrex tube at room temperature with an Eikosha 300-W high-pressure Hg lamp. High-pressure liquid chromatography was run with a Waters compact type column (μ-Porasil, 4 mm × 30 cm, 50 psi) with methylene chloride as the eluant.

Photochemical Reaction of 1 in a Concentrated Benzene Solution. A solution of 1 (1 g) in 50 mL of benzene was irradiated in a Pyrex tube for 4 h with a 300-W high-pressure Hg lamp. After removal of the solvent, the products were separated by column chromatography (Wakogel C-200) by using 3% ether/hexane as the eluant to give *anti*-1,6-dimethyl-3,4-benzo-7,9-dioxabicyclo-[4.2.1]nonene-2,5-dione-8-spiro-*r*-1-*t*-2′,*t*-3′-epoxy-*c*-2′,*c*-3′-dimethyl-1′,2′,3′,4′-tetrahydronaphthalen-4-one (**2a**, 650 mg, 65%) and *syn*-1,6-dimethyl-3,4-benzo-7,9-dioxabicyclo[4.2.1]nonene-2,5-dione-8-spiro-*r*-1′-*t*-2′,*t*-3′-epoxy-*c*-2′,*c*-3′-dimethyl-1′,2′,3′,4′-tetrahydronaphthalene-4-one (**2b**, 203 mg, 20%).

2a: mp 244–244.5 °C; IR (KBr) 1688 cm^{-1}; ^{13}C NMR ($CDCl_3$) δ 10.743 (q), 15.792 (q), 22.221 (q), 23.865 (q), 61.322 (s), 64.081 (s), 91.382 (s), 94.171 (s), 109.845 (s), 124.522 (d), 126.547 (d), 129.045 (d), 128.895 (d), 129.454 (d), 131.333 (s), 132.948 (d), 133.799 (d), 134.033 (d), 134.329 (s), 135.118 (s), 138.204 (s), 196.412 (s), 201.786 (s), and 205.280 (s); mass spectrum, *m/e* 404 (M^+), 361, 344, and 319. Anal. Calcd for $C_{24}H_{20}O_6$: C, 71.28; H, 4.99. Found: C, 70.99; H, 5.09.

2b: mp 278–280 °C (sealed); IR (KBr) 1693 cm^{-1}; mass spectrum, *m/e* 404 (M^+), 361, 344, and 319. Anal. Calcd for $C_{24}H_{20}O_6$: C, 71.28; H, 4.99. Found: C, 71.14; H, 5.13.

A solution of **2a** and **2b** (total 850 mg) in 600 mL of acetone was irradiated for 8 h. Removal of the solvent afforded a yellow oil. Separation of the products by column chromatography (Wakogel C-200) by using methylene chloride as the eluant gave (*Z*)-*r*-1-acetoxy-*c*-2,*c*-3-dimethyl-*t*-2,*t*-3-epoxy-1-(2-phthalidenyl)ethyl-1,2,3,4-tetrahydronaphthalen-4-one (**3a**, 357 mg, 42%) and (*E*)-*r*-1-acetoxy-*c*-2,*c*-3-dimethyl-*t*-2,*t*-3-epoxy-(2-phthalidenyl)ethyl-1,2,3,4-tetrahydronaphthalen-4-one (**3b**, 420 mg, 50%). A solution of **2a** (200 mg) in 200 mL of benzene was irradiated for 6 h. Separation over silica gel gave **3a** (83 mg, 42%) and **3b** (100 mg, 50%). Similarly **2b** (200 mg) gave **3a** (80 mg, 40%) and **3b** (98 mg, 49%).

3a: mp 230–232 °C; ^{13}C NMR ($CDCl_3$) δ 11.007 (q), 14.736 (q), 16.057 (q), 22.770 (q), 63.552 (s), 65.227 (s), 122.615 (s), 124.668 (d), 125.814 (d), 126.491 (d), 127.340 (s), 128.106 (d), 128.693 (d), 129.280 (s), 130.130 (d), 133.888 (d), 134.033 (d), 137.232 (s), 139.055 (s), 144.691 (s), 165.681 (s), 166.644 (s), and 196.651 (s); mass spectrum, *m/e* 404 (M^+), 361, 344, and 319. Anal. Calcd for $C_{24}H_{20}O_6$: C, 71.28; H, 4.99. Found: C, 71.30; H, 4.77.

3b: mp 224.5–225 °C; mass spectrum, *m/e* 404 (M^+), 361, 344, and 319. Anal. Calcd for $C_{24}H_{20}L_6$: C, 71.28; H, 4.99. Found: C, 71.22; H, 4.76.

Oxidation of Secondary Dimers 3a and 3b with $NaIO_4$ in the Presence of a Catalytic Amount of $KMnO_4$. The secondary dimers **3a** and **3b** (357 mg; **3a**/**3b** = 1), dissolved in 70 mL of water and 30 mL of acetone, were oxidized with $NaIO_4$ (1 g) and $KMnO_4$ (35 mg). The mixture was stirred for 3 days at room temperature, poured into 300 mL of water, and extracted with chloroform, and the organic layer was washed with $NaHSO_3$ solution and dried over Na_2SO_4. Formation of phthalic anhydride (6) (80%) was confirmed by comparison with an authentic sample on GLC (2-m column packed with 5% SE-30 on Celite 545 AW) and GC–mass spectroscopy. Purification by short-column chromatography afforded *r*-1-acetoxy-1-acetyl-*c*-2,*c*-3-dimethyl-

t-2,*t*-3-epoxy-1,2,3,4-tetrahydronaphthalen-4-one (**7**, 144 mg, 57%).

7: colorless oil; IR (KBr) 1750 (ester C=O), 1700 (ketone C=O), and 1675 cm^{-1} (an unconjugated ketone); ^1H NMR ($CDCl_3$) δ 1.44 (s, 3 H), 1.67 (s, 3 H), 2.22 (s, 3 H), 2.40 (s, 3 H), and 7.20–7.94 (m, 4 H). Anal. Calcd for $C_{16}H_{16}O_5$: C, 66.66; H, 5.59. Found: C, 66.78; H, 5.43.

A solution of **7** (100 mg) in methanol was treated with 0.1 N KOH methanol solution for 10 min at room temperature. The mixture was poured into water and extracted with ether. The organic layer was washed with dilute HCl solution and brine and dried over Na_2SO_4. *r*-1-Hydroxy-1-acetyl-*c*-2,*c*-3-dimethyl-*t*-2,*t*-3-epoxy-1,2,3,4-tetrahydronaphthalen-4-one (**8**) was obtained by preparative TLC in 62% yield.

8: colorless oil; IR (CCl_4) 3400 (OH), 1695 (C=O), and 1680 (C=O) cm^{-1}; ^1H NMR ($CDCl_3$) δ 1.40 (s, 3 H), 1.44 (s, 3 H), 2.20 (s, 3 H), 6.00 (mobile, 1 H), and 7.35–7.90 (m, 4 H). Anal. Calcd for $C_{14}H_{14}O_4$: C, 68.28; H, 5.73. Found: C, 68.32; H, 5.91.

Photochemical Reaction of 1 in Extremely Dilute Benzene Solution. A degassed benzene solution of **1** (200 mg/600 mL of benzene) was irradiated for 4 h. Separation of the products by column chromatography gave (*Z*)-1-(2-acetyl)ethylidenephthalide (**4a**, 42 mg, 21%) and (*E*)-1-(2-acetyl)ethylidenephthalide (**4b**, 35 mg, 18%).

4a: mp 104–105 °C; IR (KBr) 1781 and 1696 cm^{-1}; ^1H NMR ($CDCl_3$) δ 2.32 (C=CCH_3), 2.40 ($COCH_3$), and 7.60–8.00 (m, 4 H); ^{13}C NMR ($CDCl_3$) δ 192.1 (ketone), 170.4 (ester), 161.3 (s), 142.8 (s), 138.2 (s), 135.0 (d), 133.4 (s), 131.2 (d), 126.3 (d), 125.4 (d), 123.2 (s), 32.5 (q), and 12.7 (q). Anal. Calcd for $C_{12}H_{10}O_3$: C, 71.28; H, 4.99. Found: C, 71.38; H, 5.03.

4b: mp 115–120 °C; IR (KBr) 1781 and 1665 cm^{-1}; ^1H NMR ($CDCl_3$) δ 2.20 (C=CH_3), 2.62 ($COCH_3$), and 7.60–8.00 (m, 4 H). Anal. Calcd for $C_{12}H_{10}O_3$: C, 71.28; H, 4.99. Found: C, 71.05; H, 4.78.

Under the above conditions, irradiation was stopped after 1 h. Separation of the products by column chromatography gave 2-acetyl-2-methyl-1,3-indandione (**5**, 14 mg, 7%) together with **4a** (32 mg, 16%) and **4b** (29 mg, 14%).

5: mp 96–99 °C; IR (KBr) 1748 and 1720 cm^{-1}; ^1H NMR ($CDCl_3$) δ 1.80 (s, 3 H), 2.12 (s, 3 H), and 7.4–7.9 (m, 4 H); ^{13}C NMR ($CDCl_3$) δ 202.8 (ketone), 196.5 (ketone), 142.3 (s), 137.0 (d), 128.6 (d), 63.0 (s), 26.3 (q), and 21.1 (q). Anal. Calcd for $C_{12}H_{10}O_3$: C, 71.28; H, 4.99. Found: C, 71.53; H, 5.12.

Independent Synthesis of 4a and 4b. A solution of phthaloyl chloride (1 g) in 10 mL of ether was added to a mixture of ethyl methyl ketone and 50% sodium hydride (0.5 g) in 20 mL of ether. The mixture was stirred for 2 days at room temperature, poured into ice water, and extracted with ether, and the organic layer was dried over Na_2SO_4. Separation of the products over silica gel by using 5% ether/hexane as the eluant gave **4a** (170 mg, 17%) and **4b** (142 mg, 14%).

Registry No. **1**, 53948-58-6; **2a**, 73198-12-6; **2b**, 73245-74-6; **3a**, 73245-75-7; **3b**, 73245-76-8; **4a**, 73198-13-7; **4b**, 73198-14-8; **5**, 73198-15-9; **6**, 85-44-9; **7**, 73198-16-0; **8**, 73198-17-1.

Studies in the (+)-Morphinan Series. 7.[1] Unusual Crystallographic and Tautomeric Properties of (+)-4-Hydroxy-7-oxo-3-methoxy-17-methyl-5,6-dehydromorphinan: An Interlacing Double Helix

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(+)-4-Hydroxy-7-oxo-3-methoxy-17-methyl-5,6-dehydromorphinan (**3a**) was found, by IR and NMR (^1H and ^{13}C) spectroscopy and X-ray crystallography, to be a byproduct in the cyclization of dihydrosinomenine to dihydrocodeinone. In solution, it was in equilibrium with its tautomeric Michael addition product, (+)-4,5-epoxy-7-oxo-3-methoxy-17-methylmorphinan (**4a**). The 5,6-dehydromorphinan **3a** was observed to have infinite, hydrogen-bonded, interlacing double helices of molecules in the solid state by X-ray crystallography. The tautomeric mixture (**3a** + **4a**) was converted to (+)-4-hydroxy-7-oxo-3-methoxy-17-methylmorphinan (**6a**), the structure of which was proven by the synthesis of its enantiomer (**6b**) from thebaine.

The essential step in our preparation of unnatural enantiomers of biologically important opioids is the cyclization of dihydrosinomenine to dihydrocodeinone[2-5] by a modification of the method of Goto et al.[6] In this cyclization a byproduct which could easily be detected by TLC analysis was consistently observed. The structure of this interesting byproduct is discussed in this paper.

Results and Discussion

Cyclization of dihydrosinomenine (**1a**)[6,7] with PPA at 65–70 °C afforded, in addition to dihydrocodeinone (**2a**) as the major reaction product, a 10% yield of ketonic material, mp 104–106 °C, separated by preparative chromatography. Recrystallization of this ketone, which proved to be a mixture of **3a** and **4a**, from ethyl acetate gave colorless needles, mp 156–157 °C (**3a**). The higher and

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