

Spirolactones of Xanthene. III. Formation and Molecular Structure of Novel Spirolactones of Xanthene and Dibenzo[*c,h*]xanthene [1]

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The reaction of 1-naphthol or phenol derivatives with oxalic and sulfuric acids yielded novel spirolactones. Eight examples (**2a-h**) were synthesized by this reaction. The structures of the spirolactones were established from spectral evidence and the X-ray diffraction studies. Some of the spirolactones form the solvates with the aromatic solvent molecules, such as toluene, xylene and nitrobenzene, and the structure of the nitrobenzene solvate of **2a** was determined by the X-ray analysis.

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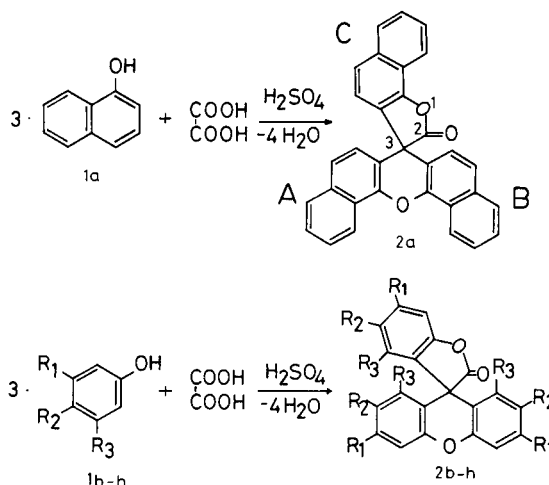
Previous papers [1,2] from our laboratory have described that the reaction of 1-naphthol (**1a**) with oxalic and sulfuric acids gives a novel spirolactone **2a** of dibenzo[*c,h*]xanthene in one step process. This novel reaction forms **2a** in an excellent yield (70-75%) with the accompanying loss of four molecules of water. As the molecular structure of **2a** could not be well established on the basis of the chemical and spectroscopic data, it has been determined by the X-ray diffraction method as shown in Figure 1. An extension of the study to the reaction has been attempted in order to increase the examples of the novel spirolactones related to **2a** and to learn more about the scope of the reaction. It was found that analogous spirolactones **2b-h** of xanthene are formed when this reaction is carried out by utilizing the substituted phenols **1b-h** in place of 1-naphthol. That is, the reaction appears to have some generality for 1-naphthol and phenol derivatives. In addition, these spirolactones possess the interesting properties that they form solvates with the aromatic solvent molecules used for recrystallization. This paper is concerned with synthesis of the novel spirolactones of xanthene and dibenzo[*c,h*]xanthene utilizing 1-naphthol (**1a**) or phenol derivatives **1b-h** with oxalic and sulfuric acids, and also the crystal and molecular structures of the nitrobenzene solvate of **2a** was established by the X-ray diffraction method.

Results and Discussion

Synthesis.

The spirolactones **2a-h** prepared in this study are summarized in Table 1 and their syntheses are outlined in Scheme 1. In this condensation reaction, a Friedel-Crafts type reaction between 1-naphthol or substituted phenols and oxalic acid may be included initially to form the oxalophenols **3** as described in Scheme 2. The reaction was carried out by treating 1 mole of 1-naphthol (**1a**) or a substituted phenol **1b-h** with a 2.6 mole excess of oxalic acid in the presence of 1 mole of sulfuric acid at 130-145°

for 3-5 hours. The reaction was also successfully carried out by using mesitylene or xylene as solvents, but generally these solvents did not produce good yields of the desired spirolactones **2a-b**. The spirolactones were detected easily by tlc after the reaction, because of the high R_f values as mentioned in the experimental. The resulting reaction mixtures were purified by column chromatography on silica gel using chloroform or ethyl acetate as the eluent, or by preparative tlc (silica gel with chloroform as the eluent) and then recrystallized from xylene, toluene, or nitrobenzene. Regarding the formation of **2b-h**, the yields were high except for some cases of sterically hindered substituents or halides on the phenol ring. The methyl groups attached to the 3- or the 4-position of the phenol ring did not have any particular influences on the formation of **2b-h**. However, the desired spirolactone was not obtained if the unsubstituted phenol was used, because the sulfonation reaction of phenol pro-



Scheme 1

The numbering system of **2a** is different from that of ORTEP drawing.

Table 1
Physical Data for Spirolactones **2a-h**

Spirolactone	R ₁	R ₂	R ₃	mp (°C)	IR (cm ⁻¹) C=O	¹³ C nmr (δ) Spiro carbon atom	C=O	Yield (%)
2a		naphthalene		296-298	1790	53.42	177.09	75
2b	H	CH ₃	H	164-166	1810	51.91	175.90	62
2c	CH ₃	H	H	205-208	1810	51.13	176.55	65
2d	H	Cl	H	236-238	1800	51.69	174.51	23
2e	H	Br	H	227-229	1810	51.60	175.10	11
2f	CH ₃	Cl	H	> 300	1800	51.08	174.99	45
2g	CH ₃	CH ₃	H	273-275	1800	51.20	176.23	75
2h	CH ₃	H	CH ₃	294-296	1800	49.72	177.50	36

Table 2
Crystallographic Data for Spirolactones

	Nitrobenzene solvate of 2a C ₃₂ H ₁₈ O ₃ ·C ₆ H ₅ NO ₂	<i>p</i> -Xylene solvate of 2a C ₃₂ H ₁₈ O ₃ ·C ₈ H ₁₀	<i>p</i> -Xylene solvate of 2b C ₂₃ H ₁₈ O ₃ ·C ₈ H ₁₀	2d [1] C ₂₀ H ₅ Cl ₃ O ₃
Recrystallization solvent	nitrobenzene	xylene [a]	xylene [a]	xylene [a]
mp/°C	312	297	165	237
Crystal system	triclinic	triclinic	monoclinic	monoclinic
Space group	P1	P1	C2/c	C2/c
a/Å	11.296(1)	11.760(4)	21.736(4)	21.316(9)
b	13.050(2)	13.064(9)	17.387(1)	17.267(4)
c	11.138(1)	11.239(4)	9.211(3)	9.158(6)
α/°	113.43(1)	69.59(4)		
β	94.18(1)	106.14(3)	95.13(2)	94.05(5)
γ	107.95(1)	111.94(4)		
Z	2	2	8	8
V/Å ³	1397(1)	1479(1)	3467(1)	3362(3)
Dc/gcm ⁻³	1.363	1.250	1.718	1.594
Do [b]	1.364	1.252	1.716	1.593

[a] Purchased xylene of boiling range 138.5-141.5°. [b] Flotation in aqueous potassium iodide.

ceeded initially. In addition, bulky substituents in phenol ring, such as ethyl, propyl, *t*-butyl, trimethylene, and phenyl groups prevent the formation of the desired spiro-lactones. In contrast, electron-withdrawing groups (such as Cl and Br) decrease the yield of the formation of the spiro-lactones. Some of the compounds **2a-h** have interesting properties resulting in the formation of solvates with the aromatic solvent molecules from which **2a-h** were recrystallized (for example, toluene, xylene and nitrobenzene, etc.). Three isolated solvates of **2a** and **2b** are summarized in Table 2.

The structures of **2a-h** were confirmed by ir, ¹H, and ¹³C nmr spectroscopy as well as mass spectrometry after isolation of the products. The ir spectra of **2a-h** showed the strong absorption (1790-1810 cm⁻¹) which characterizes the lactone moiety. In the ¹H nmr spectra, the presence of sharp singlet signals in the range δ 2.0-2.5 confirmed the methyl groups on the benzene rings. For the aromatic ring protons of **2b-h** a singlet or a doublet at

about δ 7-9 was observed, which are indicative of one or two substituents on the benzene rings. Even though the substituent R₁ is different from R₃ as in compounds **2c**, **2f**, and **2g**, the molecular structures could be established unambiguously by means of these ¹H nmr spectra. That is, the methyl groups of R₁ in **2c**, **2f**, and **2g** were observed in the range δ 2.32-2.49, which could be clearly distinguished from other methyl groups on the xanthene moiety. On the other hand, the protons of R₃ could be assigned as singlet signals in the range δ 7.05-7.09. Accordingly, ring formation by this reaction proceeds to give the spiro-lactones which possess less sterically hindered substituents for R₃. The ¹³C nmr spectra contain three types of signals: the aromatic carbons appear at ca. δ 105-150, the spiro carbon (C-3) is observed at ca. δ 51, and the carbonyl carbon is observed at ca. δ 175. With regard to mass spectrometry, all the compounds exhibited common fragmentation corresponding to the molecular ion (M⁺), M⁺-CO, and M⁺-CO-OH which assisted in confirming the structures. The

Table 3

Final Atomic Parameters of Non-hydrogen Atoms with
Estimated Standard Deviations in Parentheses

$$\text{Beq} = \frac{1}{3} (U_{11} + U_{22} + U_{33}) \text{ (defined as } U_{11} = \frac{B_{11}}{8\pi^2 a^2}, \text{ etc.)}$$

Atoms	x	y	z	Biso/Beq
O1	0.0144(2)	0.1413(2)	0.0764(2)	4.29
C2	0.0527(3)	0.1768(3)	-0.0205(3)	3.59
C3	0.1854(3)	0.2058(3)	-0.0169(3)	3.68
C4	0.2696(3)	0.2000(3)	0.0789(3)	4.36
C5	0.3971(3)	0.2325(3)	0.0801(4)	5.59
C6	0.4458(3)	0.2712(4)	-0.0140(4)	6.35
C7	0.3663(3)	0.2755(3)	-0.1088(4)	5.95
C8	0.2336(3)	0.2430(3)	-0.1130(3)	4.54
C9	0.1485(3)	0.2487(3)	-0.2083(3)	5.24
C10	0.0222(3)	0.2224(3)	-0.2049(3)	4.69
C11	-0.0280(3)	0.1855(3)	-0.1098(3)	3.66
C12	-0.1687(3)	0.1572(3)	-0.1085(3)	3.66
C13	-0.1987(3)	0.1309(3)	0.0101(3)	3.61
C14	-0.3225(3)	0.1115(3)	0.0354(4)	4.63
C15	-0.3529(3)	0.0841(3)	0.1380(4)	5.27
C16	-0.2608(3)	0.0747(3)	0.2223(3)	4.54
C17	-0.2895(4)	0.0458(4)	0.3300(4)	6.40
C18	-0.1975(4)	0.0403(4)	0.4106(4)	7.41
C19	-0.0719(4)	0.0642(4)	0.3900(4)	6.37
C20	-0.0416(3)	0.0902(3)	0.2859(3)	4.72
C21	-0.1357(3)	0.0963(3)	0.2009(3)	3.76
C22	-0.1089(3)	0.1232(3)	0.0912(3)	3.39
O23	-0.2516(3)	-0.0541(2)	-0.2830(3)	5.38
C24	-0.2513(3)	0.0449(3)	-0.2399(3)	4.05
O25	-0.3321(2)	0.0746(2)	-0.3080(2)	3.97
C26	-0.3060(3)	0.1982(3)	-0.2351(3)	3.66
C27	-0.3649(3)	0.2592(3)	-0.2825(3)	3.92
C28	-0.4561(3)	0.2056(3)	-0.4049(3)	4.79
C29	-0.5025(4)	0.2751(4)	-0.4443(4)	6.01
C30	-0.4611(4)	0.4000(4)	-0.3624(4)	6.83
C31	-0.3755(3)	0.4542(3)	-0.2418(4)	5.67
C32	-0.3240(3)	0.3850(3)	-0.1982(3)	4.28
C33	-0.2311(3)	0.4396(3)	-0.0757(3)	4.47
C34	-0.1767(3)	0.3742(3)	-0.0364(3)	4.17
C35	-0.2157(3)	0.2507(3)	-0.1197(3)	3.67
C36	0.0701(4)	0.6083(4)	0.3463(4)	13.96
O37	0.0414(4)	0.4230(3)	0.2186(3)	10.06
N38	0.0802(3)	0.5145(4)	0.3267(4)	8.38
C39	0.1460(3)	0.5069(4)	0.4415(4)	5.74
C40	0.1601(4)	0.4006(4)	0.4176(4)	6.47
C41	0.2195(5)	0.3928(4)	0.5265(5)	8.55
C42	0.2603(5)	0.4875(5)	0.6504(5)	8.54
C44	0.1868(4)	0.6047(4)	0.5645(4)	6.84
HC4	0.236(3)	0.172(3)	0.147(4)	2.74
HC5	0.457(4)	0.228(3)	0.153(4)	3.76
HC6	0.547(4)	0.298(4)	-0.012(4)	3.96
HC7	0.403(4)	0.304(4)	-0.181(4)	4.40
HC9	0.182(4)	0.273(3)	-0.282(4)	3.25
HC10	-0.043(4)	0.228(3)	-0.271(4)	3.42
HC14	-0.390(3)	0.120(3)	-0.028(4)	2.76
HC15	-0.448(4)	0.070(3)	0.158(4)	3.59
HC17	-0.385(4)	0.029(4)	0.346(4)	3.85
HC18	-0.221(4)	0.018(4)	0.490(4)	4.16

Table 3 (continued)

Atoms	x	y	z	Biso/Beq
HC19	0.003(4)	0.066(4)	0.455(4)	4.03
HC20	0.051(4)	0.104(3)	0.270(4)	3.26
HC28	-0.487(4)	0.115(3)	-0.463(4)	3.36
HC29	-0.569(4)	0.233(3)	-0.537(4)	3.74
HC30	-0.497(4)	0.454(3)	-0.394(4)	3.70
HC31	-0.345(4)	0.551(3)	-0.177(4)	3.55
HC33	-0.203(4)	0.535(3)	-0.014(4)	3.31
HC34	-0.106(4)	0.413(3)	0.050(4)	2.98
HC40	0.126(4)	0.325(4)	0.319(4)	4.42
HC41	0.231(4)	0.311(4)	0.513(4)	4.39
HC42	0.303(4)	0.482(4)	0.737(4)	5.08
HC43	0.277(4)	0.669(4)	0.772(4)	5.80
HC44	0.173(4)	0.688(4)	0.578(4)	5.59

elemental analyses and high resolution mass spectra of the spirolactones **2a-h** were in good agreement with the calculated values.

Molecular Structure.

The molecular structure (ORTEP drawing [7]) of **2a** with atom labeling is presented in Figure 1. The bond lengths and angles are schematically shown in Figure 2. Compound **2a** possess a ψ -like shape composed of three naphthalene rings fused by the spirolactone, the most interesting point of which may be the dihedral angles of the

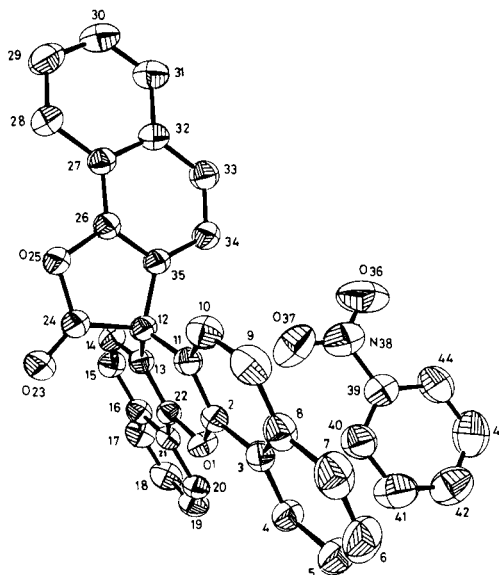


Figure 1. Molecular structure (ORTEP [7] drawing) of the nitrobenzene solvate of **2a**. Non-hydrogen atoms are drawn as thermal ellipsoids with 50% probability level.

planar naphthalene rings; 5.9° between rings A and B, 86.9° between rings A and C, and 81.4° between rings B and C, respectively. These dihedral angles may be compared with the corresponding values in the reported

molecular structure of 2',5,7'-trichlorospiro[benzofuran-3(2*H*)-9'-(9*H*)xanthen]-2-one (**2d**) [1]; 22.8, 83.6, and 73.6° in order, respectively. The great difference in the butterfly angles of the benzoxanthen ring of **2a** and **2d** (5.9 and 22.8°) seems to be caused by electron-withdrawing effects of the chloride atoms and the lesser steric hindrance of the phenyl ring of **2d** in comparison with the bulky naphthalene ring of **2a**. The average C-C-C angle is 120.0° for each of rings A, B, and C. The carbonyl group has the normal bond length (1.18 Å). The average C-C bond lengths in rings A, B, and C are normal, 1.398 and 1.397 Å, respectively. The C-O bonds in dibenzo[*c,h*]xanthen ring have the values of 1.373 and 1.382 Å, which are comparable to the same bond of the lactone moiety (1.407 Å).

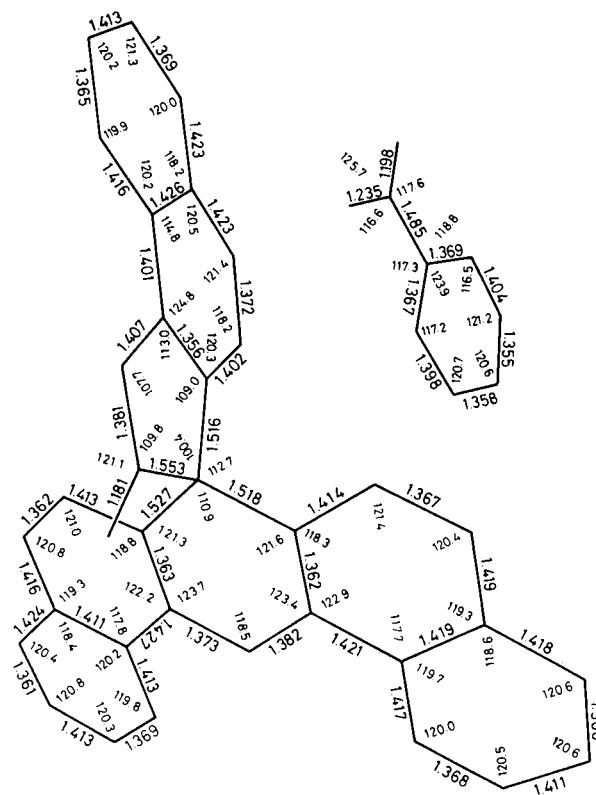


Figure 2. Bond lengths (Å) and angles (°). Estimated standard deviations ranged between 0.004 and 0.005 Å, and between 0.2 and 0.4°, respectively.

Crystal Structure.

The crystal structure is shown in Figure 3. Nitrobenzene molecules are packed by van der Waals contacts in the unit cell, whose intermolecular distances are more than 3.275 Å. The nitrobenzene ring exists in the space composed of two adjacent molecules of **2a** in the unit cell. The nitrobenzene molecules are also stacked parallel to the lactone moiety of **2a** and perpendicular to the dibenzo[*c,h*]xanthen plane. All other intermolecular contacts correspond to normal van der Waals interactions.

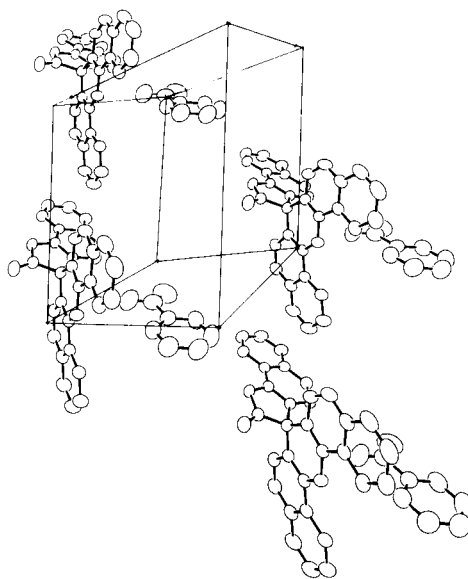
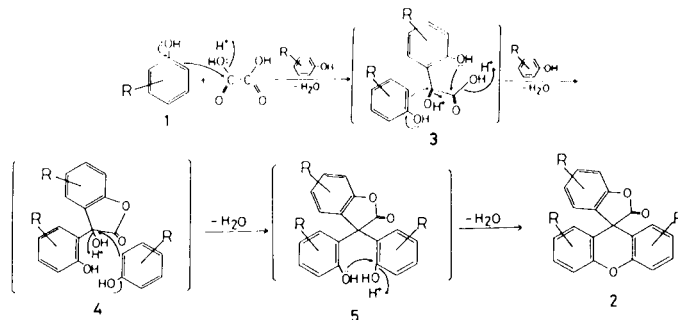


Figure 3. Molecular packing arrangement (ORTEP drawing).

Reaction Mechanism.

As for the details of the mechanism of assembly of **2a-h** including the structures **2a** and **2d** established by the X-ray analysis, some reasonable speculations are possible. As shown in Scheme 2, it is surmised that the initial step probably involves a Friedel-Crafts type reaction between phenol **1** and oxalic acid to form the oxalophenol **3**. Subsequently, nucleophilic attack of two other phenol molecules to the protonated carbonyl carbon atom of **3** forms the intermediates **5** with three phenol rings connected by the lactone moiety. Further, the intermediates **5** proceed by the intramolecular cyclization to the xanthen ring accompanying the loss of one molecule of water to yield the ultimate product **2**.

Scheme 2



*R is shown in Table 1

EXPERIMENTAL

Spectroscopy.

The ¹H nmr, totally decoupled and off-resonance decoupled ¹³C nmr spectra were measured in deuteriochloroform solution in 5 mm tubes on a JEOL FX-200 spectrometer. Chemical shifts are relative to tetramethyl-

silane (δ 0.0). The ir spectra were measured on a JASCO A-3 spectrometer. The EI mass spectra were obtained from a Hitachi-MU-7MG mass spectrometer.

Chromatography.

The tlc was performed on Merck Kieselgel 60 F₂₅₄ strips, 9.5 x 3.5 cm, and thickness, 0.25 mm with chloroform or ethyl acetate (EtOAc). The preparative tlc was carried out on Merck Kieselgel 60 F₂₅₄ plates, 20 x 20 cm, and 2 mm thickness with chloroform as the eluent.

The melting points were measured on a Yanagimoto micro-melting point apparatus and are uncorrected.

Spiro[7H-dibenzo[*c,h*]xanthen-7,3'(2'H)-naphtho[1,2-*b*]furan]-2'-one (**2a**).

A suspension of 7 g of 1-naphthol (0.049 mole), 3.5 g of oxalic acid (0.039 mole) and 4.4 g of concentrated sulfuric acid (0.046 mole) was heated for 4 hours at 135-140° in an oil bath. The reaction mixture was cooled to room temperature, and poured into hot water. A precipitate was collected, washed with water and a little ethanol, and dried, yielding 16.5 g of **2a** (75%), which could be recrystallized from xylene or nitrobenzene, mp 296-298°; ir (potassium bromide): 3050, 1790 (C=O), 1600, 1560, 1500, 1460, 1400, 1360, 1340, 1240, 1200, 1120, 1100, 1040, 1020, 950, 880, 800, 790, 660 cm⁻¹; pmr (deuteriochloroform): δ 6.68 (d), 7.10 (d), 7.25 (s), 7.42 (d), 7.46-7.91 (m), 8.22 (d), 8.74 (d) (for aromatic ring protons); cmr (deuteriochloroform): δ 53.42 (C-3), 112.97, 119.78, 121.53, 121.60, 122.04, 124.08, 124.59, 125.71, 126.78, 127.32, 127.44, 127.80, 128.46, 134.32, 134.69, 146.12, 148.94, 177.09 (C=O); ms: m/z (relative intensity, %) 450 (1.2, M⁺), 422 (1.0, M⁺-CO), 421 (0.9), 405 (0.9, M⁺-CO-OH), 275 (100), 184 (43), 139 (38); high-resolution mass spectra (hr-ms): m/z 450.1269, Calcd. for C₃₂H₁₈O₃ 450.1255; tlc (chloroform): R_f 0.70.

Anal. Calcd. for C₃₂H₁₈O₃: C, 85.29; H, 4.03. Found: C, 85.21; H, 4.28.

2',5,7'-Trimethylspiro[benzofuran-3(2H)-9'-[9H]xanthen]-2-one (**2b**).

To a mixture of 11 g of 4-methylphenol (0.1 mole) and 8 g of oxalic acid (0.09 mole), 8 g of concentrated sulfuric acid (0.08 mole) was added cautiously, and the resulting mixture was heated gently for 4 hours at 140-145° in an oil bath. After cooling, the reaction mixture was poured into water and extracted with chloroform (150 ml). The organic layer was separated, washed with 5% sodium hydroxide and water, dried over anhydrous sodium sulfate, and concentrated under vacuum. The crude oily products were chromatographed over 300 mg of silica gel (using chloroform as an eluent) to give 21.2 g of **2b** (62%), mp 164-166°; ir (potassium bromide): 2920, 1810 (C=O), 1620, 1510, 1480, 1300, 1280, 1260, 1220, 1140, 1130, 1120, 1060, 960, 900, 820, 810, 790, 660 cm⁻¹; pmr (deuteriochloroform): δ 2.17 (s, 6H), 2.28 (s, 3H), 6.47 (s, 2H), 6.82 (s, 1H), 7.09 (s, 4H), 7.18 (s, 1H), 7.23 (s, 1H); cmr (deuteriochloroform): δ 20.60, 21.11, 51.91 (C-3), 110.44, 117.13, 119.41, 125.76, 127.58, 130.28, 130.48, 133.08, 133.28, 135.25, 148.89, 151.30, 175.90 (C=O); ms: m/z (relative intensity, %) 342 (30, M⁺), 313 (42, M⁺-CO + 1), 299 (100), 141 (15), 28 (17); hr-ms: m/z 342.1261, Calcd. for C₂₃H₁₈O₃ 342.1255; tlc (ethyl acetate) R_f 0.67.

Anal. Calcd. for C₂₃H₁₈O₃: C, 80.68; H, 5.30. Found: C, 80.56; H, 5.53.

3',6,6'-Trimethylspiro[benzofuran-3(2H)-9'-[9H]xanthen]-2-one (**2c**).

From 11 g of 3-methylphenol (0.1 mole) and 8 g of oxalic acid (0.09 mole) with 8 g of concentrated sulfuric acid (0.08 mole) there was obtained by the same procedure, except isolating by the preparative tlc using chloroform as eluate, 23.3 g of **2c** (65%), mp 205-208°; ir (potassium bromide): 2920, 1810 (C=O), 1620, 1600, 1500, 1410, 1320, 1250, 1170, 1130, 1060, 1010, 970, 880, 790 cm⁻¹; pmr (deuteriochloroform): δ 2.31 (s, 6H), 2.42 (s, 3H), 6.50 (d, 2H), 6.72 (d, 2H), 6.84-7.40 (m, 5H); cmr (deuteriochloroform): δ 21.09, 21.75, 51.13 (C-3), 108.17, 111.26, 117.20, 117.68, 117.76, 124.59, 124.71, 125.05, 126.15, 126.68, 126.83, 127.20, 129.73, 140.01, 140.11, 140.43, 150.89, 153.86, 176.55 (C=O); ms: m/z (relative intensity, %) 342 (35, M⁺), 314 (97, M⁺-CO), 299 (100), 269 (5); hr-ms: m/z 342.1241; Calcd. for C₂₃H₁₈O₃ 342.1254; tlc (chloroform) R_f 0.72.

Anal. Calcd. for C₂₃H₁₈O₃: C, 80.68; H, 5.30. Found: C, 80.51; H, 5.18.

2',5,7'-Trichlorospiro[benzofuran-3(2H)-9'-[9H]xanthen]-2-one (**2d**).

From 22 g of 4-chlorophenol (0.17 mole) and 16 g of oxalic acid (0.18 mole) with 16 g of concentrated sulfuric acid (0.16 mole) there was obtained by the same procedure 15.8 g of **2d** (23%), mp 236-238°; ir (potassium bromide): 3300, 3150, 1800 (C=O), 1580, 1460, 1410, 1270, 1240, 1110, 1060, 880, 820, 810, 700, 680 cm⁻¹; pmr (deuteriochloroform): δ 6.50 (d, 1H), 6.75 (d, 1H), 6.80-7.50 (m, 7H) (for aromatic ring protons); cmr (deuteriochloroform): δ 51.69 (C-3), 112.67, 116.64, 118.22, 119.14, 119.58, 120.07, 125.66, 126.90, 128.56, 129.02, 129.21, 129.31, 129.43, 129.82, 130.38, 130.63, 131.14, 149.16, 174.51 (C=O); ms: m/z (relative intensity, %) 402 (17, M⁺), 374 (32, M⁺-CO), 339 (100, M⁺-CO-OH₂O), 276 (15), 162 (30), 112 (22), 57 (15); tlc (ethyl acetate): R_f 0.76.

Anal. Calcd. C₂₀H₈Cl₃O₃: C, 59.51; H, 2.25; Cl, 26.35. Found: C, 59.20; H, 2.32; Cl, 26.35.

2',5,7'-Tribromospiro[benzofuran-3(2H)-9'-[9H]xanthen]-2-one (**2e**).

From 10 g of 4-bromophenol (0.058 mole) and 5.2 g of oxalic acid (0.058 mole) with 5.7 g of concentrated sulfuric acid (0.058 mole) there was obtained by the same procedure 3.4 g of **2e** (11%), mp 227-229°; ir (potassium bromide): 3010, 2850, 1810 (C=O), 1460, 1400, 1270, 1220, 1060, 960, 940, 820, 730 cm⁻¹; pmr (deuteriochloroform): δ 6.48 (d, 1H), 6.73 (d, 1H), 7.00-7.50 (m, 7H) (for aromatic ring protons); cmr (deuteriochloroform): δ 51.60 (C-3), 113.14, 116.54, 119.53, 120.46, 128.53, 129.90, 133.54, 134.06, 149.65, 175.10 (C=O); ms: m/z (relative intensity, %) 534 (25, M⁺), 508 (76), 429 (10), 353 (5), 328 (30), 149 (13), 97 (26), 70 (37), 57 (98), 43 (100); tlc (chloroform): R_f 0.67.

Anal. Calcd. for C₂₀H₈Br₃O₃: C, 44.73; H, 1.69; Br, 44.64. Found: C, 44.65; H, 1.53; Br, 44.25.

2',5,7'-Trichloro-3',6,6'-trimethylspiro[benzofuran-3(2H)-9'-[9H]xanthen]-2-one (**2f**).

From 10 g of 4-chloro-3-methylphenol (0.07 mole) and 6.3 g of oxalic acid (0.07 mole) with 6.8 g of sulfuric acid (0.07 mole) there was obtained by the same procedure 14 g of **2f** (45%), mp >300°; ir (potassium bromide): 3500, 2950, 1800 (C=O), 1750, 1620, 1480, 1440, 1390, 1380, 1310, 1250, 1170, 1090, 1060, 940, 870, 780 cm⁻¹; pmr (deuteriochloroform): δ 2.35 (s, 6H), 2.49 (s, 3H), 6.63 (s, 2H), 7.05 (s, 1H), 7.11 (s, 1H), 7.20 (s, 1H), 7.25 (s, 1H); cmr (deuteriochloroform): δ 19.97, 20.85, 51.08 (C-3), 109.92, 113.45, 117.88, 119.68, 119.80, 125.76, 126.68, 127.27, 129.36, 130.28, 131.26, 138.68, 138.82, 139.38, 149.16, 152.10, 174.99 (C=O); ms: m/z (relative intensity, %) 444 (37, M⁺), 416 (95, M⁺-CO), 381 (100), 317 (15), 229 (5), 182 (30), 165 (43), 119 (20), 69 (17); tlc (chloroform): R_f 0.73.

Anal. Calcd. for C₂₃H₁₅Cl₃O₃: C, 61.98; H, 3.39; Cl, 23.86. Found: C, 61.69; H, 3.60; Cl, 23.61.

2',3',5,6,6',7'-Hexamethylspiro[benzofuran-3(2H)-9'-[9H]xanthen]-2-one (**2g**).

From 5 g of 3,4-dimethylphenol (0.041 mole) and 3.7 g of oxalic acid (0.041 mole) with 3 g of concentrated sulfuric acid (0.031 mole) there was obtained by the same procedure 11.8 g of **2g** (75%), mp 273-275°; ir (potassium bromide): 2910, 1800 (C=O), 1620, 1500, 1450, 1400, 1320, 1260, 1200, 1130, 1120, 1080, 1050, 1020, 950, 910, 880, 860, 800, 740 cm⁻¹; pmr (deuteriochloroform): δ 2.06 (s, 6H), 2.15 (s, 3H), 2.21 (s, 6H), 2.25 (s, 3H), 6.41 (d, 1H), 6.78 (s, 1H), 6.98 (s, 2H), 7.06 (s, 1H), 7.23 (s, 1H); cmr (deuteriochloroform): δ 18.95, 19.51, 19.61, 20.36, 51.20 (C-3), 107.11, 111.55, 115.93, 117.05, 118.00, 125.93, 127.51, 128.02, 130.60, 130.89, 131.79, 133.67, 138.43, 148.94, 151.69, 176.23 (C=O); ms: m/z (relative intensity, %) 384 (10, M⁺), 356 (27, M⁺-CO), 341 (100, M⁺-CO-OH + 2); hr-ms: m/z 384.1696, Calcd. for C₂₅H₂₄O₃ 384.1723; tlc (chloroform): R_f 0.59.

Anal. Calcd. for C₂₅H₂₄O₃: C, 81.22; H, 6.29. Found: C, 81.02; H, 6.10.

1',3',4,6,6',8'-Hexamethylspiro[benzofuran-3(2H)-9'-[9H]xanthen]-2-one (**2h**).

From 5 g of 3,5-dimethylphenol (0.041 mole) and 3.7 g of oxalic acid (0.041 mole) with 4 g of concentrated sulfuric acid (0.041 mole) there was obtained by the same procedure 5.7 g of **2h** (36%), mp 294-296°; ir

(potassium bromide): 2970, 2920, 1800 (C=O), 1790, 1620, 1610, 1600, 1560, 1480, 1440, 1400, 1330, 1190, 1150, 1120, 1080, 1030, 970, 900, 850, 700 cm^{-1} ; pmr (deuteriochloroform): δ 1.69 (s, 3H), 1.91 (s, 6H), 2.25 (s, 6H), 2.33 (s, 3H), 6.5-6.7 (m, 3H), 6.82 (s, 2H), 7.24 (s, 1H); cmr (deuteriochloroform): δ 19.29, 20.68, 20.92, 21.28, 21.60, 49.72 (C-3), 108.12, 109.34, 109.49, 114.45, 115.25, 124.08, 125.35, 126.95, 127.78, 128.44, 135.51, 136.51, 136.17, 137.17, 139.09, 139.84, 141.33, 150.74, 153.20, 177.50 (C=O); ms: m/z (relative intensity, %) 384 (2.5, M⁺), 342 (5.5), 306 (2), 226 (13), 122 (100), 90 (73), 77 (20); hr-ms: m/z 384.1734, Calcd. for $\text{C}_{26}\text{H}_{24}\text{O}_3$, 384.1724; tlc (chloroform): R_f 0.58.

Anal. Calcd. for $\text{C}_{26}\text{H}_{24}\text{O}_3$: C, 81.22; H, 6.29. Found: C, 81.05; H, 6.11.

X-Ray Crystal Structure Analysis.

Preliminary crystallographic information was obtained on several of the novel spirolactones or their solvates with aromatic solvents used on crystallization. Comparison of the crystal data in Table 2 strongly suggests that crystals examined in this way appear to have a similar packing scheme in the unit cell between the nitrobenzene and *p*-xylene solvates of **2a**, and between the *p*-xylene solvate of **2b** and **2d**. With respect to the unit cell, in the case of the *p*-xylene solvate of **2b** and **2d**, the values of *a*-axis is approximately 2 times those of the nitrobenzene and *p*-xylene solvates of **2a** depending upon the *z*-values. In addition, the space groups are related to each other among the nitrobenzene and *p*-xylene solvates of **2a**, or the *p*-xylene solvate of **2b** and **2d**. These facts suggest that crystals composed of spirolactone molecules have similar packing schemes, regardless of the occupied aromatic solvents in the unit cell. That is, it shows that the solvent molecules are inserted into the space composed of the spirolactones possessing the rigid and bulky molecular conformation. Crystals of the 1:1 nitrobenzene solvate of **2a** chosen for detailed studies were obtained from nitrobenzene in the triclinic system (Table 2), because the *p*-xylene solvates were gradually decomposed by the X-ray.

A crystal with approximate dimensions of 0.2 x 0.3 x 0.35 mm was used for the X-ray experiment. The unit cell dimensions and other crystal data were obtained by a least-squares fit of 24 medium-angle reflections as in Table 2. Intensity data for $2\theta < 120^\circ$ were collected on a Rigaku AFC-5 four-circle diffractometer equipped with rotating anode by the θ - 2θ scan technique using a nickel-filtered $\text{Cu K}\alpha$ radiation ($\lambda = 1.54178 \text{ \AA}$). The scan speed was $4^\circ/\text{minute}$ in θ and the scan range in θ was varied by $1.2^\circ + 0.15^\circ \tan \theta$. Backgrounds were counted for 5 s at both ends of a scan with an offset of 50% of the scan range from the calculated position of the $\text{K}\alpha$ peak. Three periodically monitored reflections showed no significant crystal deterioration. Of the 4654 independent reflections measured, 3753 reflections had intensities greater than $3\sigma(I)$ where $\sigma(I)$ was estimated from counting statistics. Lorentz and polarization corrections were applied, but no absorption correction was made. The structure (Figure 1) was solved by the direct method (MULTAN78 [3]) and refined

anisotropically by the block-diagonal least-squares procedure [4,5]. The function minimized was $\Sigma w(|F_o| - |F_c|)^2$ where $w = 1/\sigma(F_o)^2$. Hydrogen atoms were located on a difference Fourier map, which were refined isotropically at the final stages of the refinement [5]. The final R value was 0.049 for 3753 observed reflections where $R = \Sigma ||F_o| - |F_c|| / \Sigma |F_o|$, and a weighted $R_w = (\Sigma w(|F_o| - |F_c|)^2 / w |F_o|^2)^{1/2}$ was 0.050 with a GOF of 0.612 (quality of fit = $[\Sigma w(|F_o| - |F_c|)^2 / (N_{\text{obs}} - N_{\text{para}})]^{1/2}$) [6]. All parameter shifts during the final cycles were less than 0.1σ and a final difference Fourier map showed no peak larger than 0.24 e/\AA^3 .

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