Available online at www.sciencedirect.com
SCIENCE DIRECT®
Journal of Photochemistry and Photobiology A: Chemistry 163 (2004) 241–247
Journal of Photochemistry and Photobiology A:Chemistry
www.elsevier.com/locate/jphotochem

Synthesis of benzo[1,2-*b*:4,5-*b*′]difuran derivatives utilizing concomitant photocyclization and photo-Fries rearrangement reactions

Kwanghee Koh Park [a,*], Sun-Hyuk Kim [a], Joon Woo Park [b]

[a] *Department of Chemistry, Chungnam National University, Taejon 305-764, South Korea*
[b] *Department of Chemistry, Ewha Womans University, Seoul 120-750, South Korea*

Received 22 September 2003; received in revised form 9 November 2003; accepted 5 December 2003

Abstract

A synthetic route for 2,6-dialkyl-3,7-diphenylbenzo[1,2-*b*:4,5-*b*′]difurans **1a–c** (**a**: alkyl = *n*-C_7H_{15}; **b**: alkyl = CH_3; **c**: alkyl = $-(CH_2)_7Br$) from *p*-dimethoxybenzene utilizing photocyclization and photo-Fries rearrangement reactions is described. Dimethoxybenzene was reacted with benzoyl chloride to obtain 3-benzoyl-4-hydroxyphenyl benzoate **5**, and the reaction of **5** with alkyl halides gave 4-alkoxy-3-benzoylphenyl benzoates **6a–c**. Photoirradiation of **6a–c** followed by dehydration afforded 2-alkyl-6-benzoyl-5-hydroxy-3-phenylbenzofurans **7a–c** via concomitant photocyclization and photo-Fries rearrangement. Etherification of **7a–c** with alkyl halides gave 5-alkoxy-2-alkyl-6-benzoyl-3-phenylbenzofurans **11a–c**, and photocyclization/dehydration reaction of **11a–c** provided 2,6-dialkyl-3,7-diphenylbenzo[1,2-*b*:4,5-*b*′]difuran compounds **1a–c**. A cyclophane containing both benzo[1,2-*b*:4,5-*b*′]difuran and naphthalene rings was also prepared by the coupling of **1c** with 2,7-dihydroxynaphthalene.

Keywords: Photocyclization; Photo-Fries rearrangement; Benzo[1,2-*b*:4,5-*b*′]difuran

1. Introduction

Benzo[1,2-*b*:4,5-*b*′]difuran derivatives are known to exhibit interesting chemical and physiological properties [1–3]. However, there is a paucity of reports on the synthetic methods for the benzodifuran derivatives: they were prepared via the condensation of 5-hydroxybenzo[*b*]furan with appropriate α-halocarbonyl compound [1], from the reaction of *p*-benzoquinone with acetoacetic ester [4], or via aromatization of tetrahydrobenzo[1,2-*b*:4,5-*b*′]difuran [3]. The reported methods have limited scope, and the development of new synthetic methodology for benzo[1,2-*b*:4,5-*b*′]difuran derivatives having various substituents is highly desirable.

Photocyclization of *o*-alkoxybenzophenones has been utilized for the synthesis of various furan ring derivatives [5–7]. Recently, we reported that the double photocyclization of 1,5-dibenzoyl-2,4-dialkoxybenzene **4** followed by dehydration provides facile access to 2,6-dialkyl-3,5-diphenylbenzo[1,2-*b*:5,4-*b*′]difurans **2** [8]. However, the similar reaction with 1,4-dibenzoyl-2,5-dialkoxybenzenes **3** gave only trace amount of 2,6-dialkyl-3,7-diphenylbenzo[1,2-*b*:4,5-*b*′]difurans **1** (Scheme 1). Photo-Fries rearrangement of aryl esters and amides is another class of important photochemical reactions and has been utilized to obtain variously substituted aromatic compounds [9–11]. Here, we report a synthetic route for the synthesis of **1** via photochemical reaction involving concomitant photocyclization and photo-Fries rearrangement.

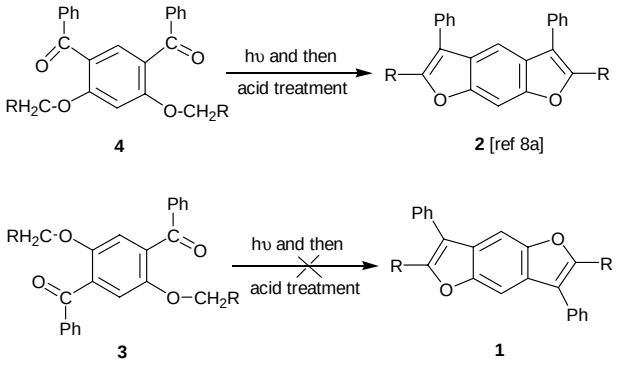
2. Results and discussion

To synthesize 2,6-dialkyl-3,7-diphenylbenzo[1,2-*b*:4,5-*b*′]difurans **1**, we first attempted the photocyclization reaction of 1,4-dibenzoyl-2,5-dialkoxybenzenes **3** (R = CH_3, $(CH_2)_6CH_3$)[1] followed by acid treatment as applied for the synthesis of 2,6-dialkyl-3,5-diphenylbenzo[1,2-*b*:5,4-*b*′]difurans **2** from **4** (Scheme 1) [8]. However, the reactions gave only trace amount of the corresponding benzo[1,2-*b*:4,5-*b*′]difuran derivatives with the irradiation of either 350 nm or 254 nm light. The unsuccessful result led us to design an alternate route to **1** involving two separate steps for the formation of two benzo-fused furan rings. We

* Corresponding author. Tel.: +82-42-821-5479; fax: +82-42-823-1360.
E-mail address: khkoh@cnu.ac.kr (K.K. Park).

[1] The compounds **3a** and **3b** were obtained by reacting 1,4-dibenzoyl-2,5-dihydroxybenzene [11] with octyl bromide and ethyl iodide in 88 and 91% yield, respectively.

1010-6030/$ – see front matter © 2004 Elsevier B.V. All rights reserved.
doi:10.1016/j.jphotochem.2003.12.004

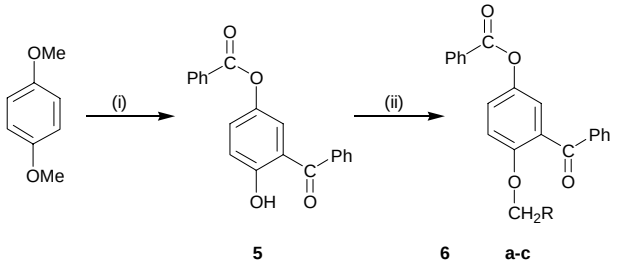


Scheme 1. The synthesis of **2** from **4** and the attempted synthesis of **1** from **3**.

chose 4-alkoxy-3-benzoylphenyl benzoates **6a**–**c** as intermediates for the synthesis. The compounds **6** have both functionalities for concurrent photocyclization and photo-Fries rearrangement, i.e. *o*-alkoxybenzoyl moiety for the former and aryl ester moiety for the latter reaction. Photoirradiation of **6**, followed by dehydration is expected to give 6-benzoyl-5-hydroxybenzo[*b*]furan derivatives **7**. The compound **7** has suitable substituents for the formation of another benzo-fused furan ring to provide **1** via alkylation and then photocyclization/dehydration procedure.

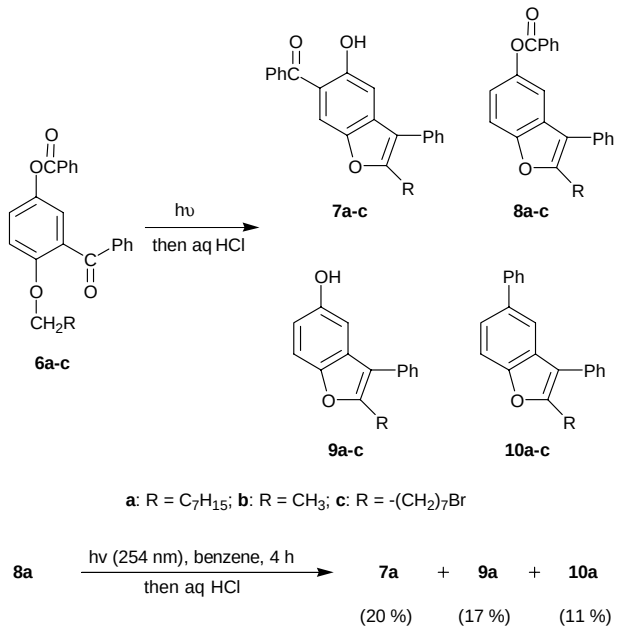
3-Benzoyl-4-hydroxyphenyl benzoate **5** is obtained in 93% yield from *p*-dimethoxybenzene [11]. The reaction of **5** with alkyl halides in the presence of potassium carbonate gave the corresponding 4-alkoxy-3-benzoylphenyl benzoates **6a**–**c** with 81–86% yields (Scheme 2).

We first carried out the photoirradiation of 1 mM solution of **6** with 254 nm light, with which photo-Fries rearrangement is usually carried out [9–11]. When the reaction mixture showed virtually no starting material remaining, dehydration reaction was carried out, without attempting the separation of dihydrobenzofuranol intermediates, by treating the concentrated photoreaction mixture with a few drops of 1 M HCl in acetone. Separation by silica gel column chromatography gave the products **7**, **9**, and **10** (Scheme 3). Clearly, the product **7** is formed via concurrent photocyclization/dehydration and Fries rearrangement reaction of **6**.



reagents and conditions: (i) $PhCOCl$, $AlCl_3$, CH_2Cl_2, reflux, 26 h (93 %);
(ii) RCH_2X, K_2CO_3, acetone, reflux, 20-30 h (**6a**, 83 %; **6b**,86 %; **6c**, 81 %)

Scheme 2. Synthesis of the intermediates **6a**–**c**.



Scheme 3. Photoreactions followed by dehydration reactions of **6a**–**c** and **8a**. Products **8a**–**c** were not detected after irradiation of **6a**–**c** with 254 nm light.

The compounds **9** and **10** are from deacylation and decarboxylation reaction of the ester moiety, respectively, which are usually accompanied in the photo-Fries reaction of aryl esters [9a].

As both photocyclization and photo-Fries reactions are solvent-dependent [6d,12], we carried out the photoreaction of **6a** with 254 nm in benzene, methanol, and acetonitrile and compared the results (entries 1–3 of Table 1). The overall yield of the photocyclized products **7a**, **9a**, and **10a** as well as the yield of **7a**, which is the desired precursor for benzo[1,2-*b*:4,5-*b*′]difuran derivative **1a**, is highest in benzene solvent.[2] The observation of no detectable amount of **8a**–**c** from the above reactions of **6a**–**c** with 254 nm light indicates extensive occurrence of photo-Fries rearrangement with accompanying side reactions. However, the overall yield of the photocyclized products is rather low. This might be due to inefficiency in photocyclization reaction of the rearranged product with 254 nm light.

It is well known that photo-Fries rearrangement of aryl esters is a singlet excited state reaction that occurs through homolytic cleavage of the carbonyl–oxygen bond, to give a caged radical pair of which in-cage recombination gives the acyl migration products [9]. Contrary to this, the photocyclization reaction of *o*-alkoxybenzophenones involves (n, π^*) triplet-state δ-hydrogen abstraction to give 1,5-biradical [6]: the reaction is readily quenched by typical triplet quenchers [6a,6b]. As the absorption maximum of the (n, π^*) band is near 350 nm [6a], the photocyclization reaction proceeds effectively using about 350 nm light [6–8]. Thus,

[2] Benzene is a toxic solvent and should be handled with appropriate care.

Table 1
Yields and product distribution of photochemical reactions of **6a–c** followed by dehydration

Entry	Starting material	*hν* (nm)	Solvent	Reaction time (h)	Product yields (%)			
					7 **7a**	**8** **8a**	**9** **9a**	**10** **10a**
1	**6a**	254	Benzene	5	15	nd[a]	16	15
2	**6a**	254	MeOH	8	6	nd[a]	15	nd[a]
3	**6a**	254	CH_3CN	8	12	nd[a]	17	5
4	**6a**	350	Benzene	20	16	24	12	7
5	**6a**	350 and then 254	Benzene	20 and then 4	21	nd[a]	19	10
					7b	**8b**	**9b**	**10b**
6	**6b**	254	Benzene	4	15	nd[a]	15	12
7	**6b**	350	Benzene	15	14	28	13	2
8	**6b**	350 and then 254	Benzene	15 and then 3	21	nd[a]	15	7
					7c	**8c**	**9c**	**10c**
9	**6c**	254	Benzene	5	15	nd[a]	15	15
10	**6c**	350	Benzene	12	13	25	15	5
11	**6c**	350 and then 254	Benzene	12 and then 4	20	nd[a]	17	7

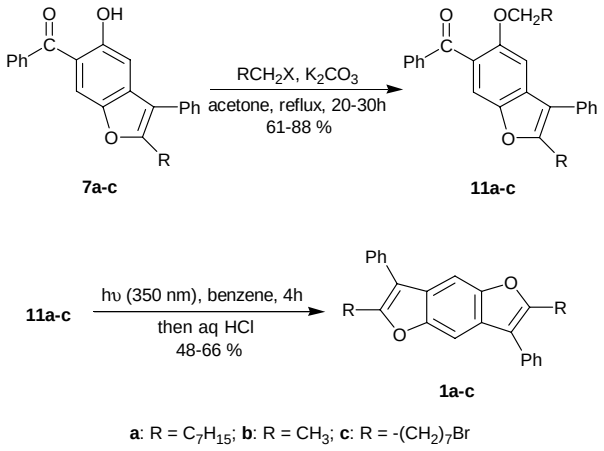
[a] Not detected.

we irradiated **6a–c** using 350 nm light instead of 254 nm (entries 4, 7, and 10 of Table 1). The photoirradiation gave the photocyclized but not Fries-rearranged products **8a–c**, in addition to **7a–c**, **9a–c**, and **10a–c**: the yields of **7a–c** were comparable with those obtained with 254 nm lamp and the overall yields of **7–10** were much higher than those of 254 nm. To check the photo-Fries rearrangement of the photocyclized but not Fries-rearranged product **8**, we irradiated 1 mM benzene solution of **8a** with 254 nm light and obtained the compounds **7a**, **9a**, and **10a** with 20, 17, and 11% yields, respectively (Scheme 3). Based on these results, sequential irradiation of **6a–c** with 350 nm and then 254 nm lamps was carried out in one pot. This gave the higher yields of **7a–c** than the one-step photoreaction with either 254 or 350 nm light. The yields and product distributions obtained from the photochemical reactions of **6a–c** are summarized in Table 1.

Etherification of **7a–c** with alkyl halides gave corresponding 5-alkoxy-2-alkyl-6-benzoyl-3-phenylbenzofurans **11a–c** in 76, 88, and 61% yields, respectively. Gratifyingly, photoirradiation of **11a–c** with 350 nm light followed by dehydration with acid resulted in the formation of another benzo-fused furan ring to provide benzo[1,2-*b*:4,5-*b*′]difuran derivatives **1a–c** with 48–66% yields (Scheme 4).

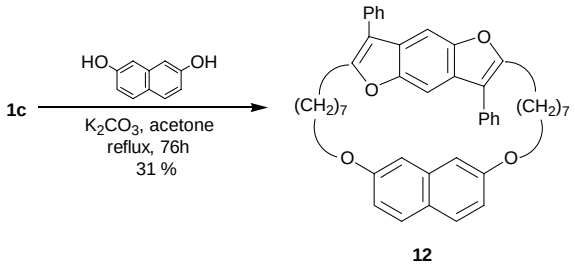
Synthesis of the compound **1c** prompted us to utilize it in the preparation of the cyclophane containing both benzo[1,2-*b*:4,5-*b*′]difuran and naphthalene rings.[3] Ether-forming reaction of 2,7-dihydroxynaphthalene with **1c** provided the cyclophane **12** in 31% yield (Scheme 5).

The structures of the compounds prepared in this work were fully characterized by spectroscopic data and elemental analysis. Particularly, the number of ^1H and ^{13}C NMR peaks confirmed the symmetrical nature of the compounds **1a–c**



Scheme 4. The synthesis of 2,6-dialkyl-3,7-diphenylbenzo[1,2-*b*:4,5-*b*′]difuran compounds **1a–c** from **7a–c**.

and **12**. The observed numbers of peaks in the ^{13}C NMR spectra exactly match the expected numbers based on the symmetry of the compounds, which are 16 for **1a** and **1c**, 10 for **1b**, and 22 for **12**. The actual carbon numbers present in the compounds are 36 for **1a** and **1c**, 24 for **1b**, and 46 for **12**.



Scheme 5. The synthesis of the cyclophane **12** from **1c**.

[3] We reported the synthesis of the cyclophanes containing benzo[1,2-*b*:5,4-*b*′]difuran and naphthalene rings via similar strategy [8a].

In summary, we have developed a synthetic route for 2,6-dialkyl-3,7-diphenylbenzo[1,2-*b*:4,5-*b*′]difurans utilizing concomitant occurrence of photocyclization and photo-Fries rearrangement reactions. These compounds are interesting not only due to their useful chemical and physiological properties [1–3], but also due to their further applicabilities such as precursors for the synthesis of benzo[1,2-*b*:4,5-*b*′]difuran ring-containing cyclophanes which are potentially useful synthetic receptors.

3. Experimental

3.1. General

Photoreaction was carried out with 1 mM solution of a substrate in appropriate solvent contained in pyrex (for 350 nm irradiation) or quartz vessel (for 254 nm and sequential 350/254 nm irradiation). The solution was purged with nitrogen gas for 1 h and irradiated under nitrogen atmosphere using RPR-100 photochemical reactor (Southern New England Ultraviolet Company). ^{1}H NMR and ^{13}C NMR spectra were obtained using tetramethylsilane as an internal standard in $CDCl_3$ and coupling constants (*J*) are given in Hz. Melting points are uncorrected.

3.2. General procedure for the synthesis of 4-alkoxy-3-benzoylphenyl benzoates *6a–c*

An acetone solution (50 ml) of a haloalkane (7.54 mmol; 1-bromooctane, iodoethane, or 1,8-dibromooctane) was added slowly to a mixture of 3-benzoyl-4-hydroxyphenyl benzoate **5** [11] (2.00 g, 6.28 mmol) and potassium carbonate (5.21 g, 37.7 mmol) in 200 ml of acetone, and the reaction mixture was heated at reflux for 20–30 h. After the reaction was complete, potassium carbonate was removed by filtration. To the concentrated reaction mixture dichloromethane was added and washed with water. The organic layer was dried with sodium sulfate and then concentrated. Washing the residue with hexane afforded analytically pure **6a**–**c**. The residual product washed out in hexane was recovered by silica gel column chromatography eluting with 5:1 hexane/ethyl acetate (**6a** and **6c**) or 3:1 hexane/ethyl acetate (**6b**).

3-Benzoyl-4-octyloxyphenyl benzoate **6a** (2.24 g, 83%). mp 86–88 °C. ^{1}H NMR (300 MHz) δ 0.87 (3H, t, $J = 7$), 0.95–1.34 (10H, m), 1.43 (2H, quintet, $J = 7$), 3.88 (2H, t, $J = 6$), 6.99 (1H, d, $J = 9$), 7.28–7.65 (8H, m), 7.82 (2H, dd, $J = 8$ and 1), 8.19 (2H, dd, $J = 8$ and 1). IR (KBr): 1741, 1661, 1492, 1449, 1417, 1247, 1193, 1052, 1025, 715 cm^{-1}. UV (CH_3Cl): λ_{max} (ε) 246 nm (21,100). Anal. Calcd. for $C_{28}H_{30}O_4$: C, 78.11; H, 7.02. Found: C, 78.42; H, 7.25.

3-Benzoyl-4-ethoxyphenyl benzoate **6b** (1.87 g, 86%). mp 75–76 °C. ^{1}H NMR (300 MHz) δ 1.09 (3H, t, $J = 7$), 3.97 (2H, q, $J = 7$), 7.01 (1H, d, $J = 9$), 7.26–7.35 (2H, m), 7.41–7.65 (6H, m), 7.83 (2H, dd, $J = 8$ and 1), 8.19 (2H, dd, $J = 8$ and 1). IR (KBr): 1745, 1661, 1495, 1472, 1452, 1285, 1241, 1192, 1060, 1023, 706 cm^{-1}. UV (CH_3Cl): λ_{max} (ε) 247 nm (19,500). Anal. Calcd. for $C_{22}H_{18}O_4$: C, 76.29; H, 5.24. Found: C, 76.35; H, 5.38.

3-Benzoyl-4-(8-bromo-octyloxy)phenyl benzoate **6c** (2.59 g, 81%). mp 114–116 °C. ^{1}H NMR (300 MHz) δ 0.97–1.24 (6H, m), 1.25–1.50 (4H, m), 1.81 (2H, quintet, $J = 7$), 3.39 (2H, t, $J = 7$), 3.88 (2H, t, $J = 6$), 6.99 (1H, d, $J = 9$), 7.27–7.66 (8H, m), 7.82 (2H, d, $J = 8$), 8.19 (2H, d, $J = 8$). IR (KBr): 1740, 1658, 1492, 1448, 1417, 1249, 1193, 1057, 1025, 715 cm^{-1}. UV (CH_3Cl): λ_{max} (ε) 247 nm (18,700). Anal. Calcd. for $C_{28}H_{29}BrO_4$: C, 66.01; H, 5.74. Found: C, 65.83; H, 5.89.

3.3. Photoreactions of 4-alkoxy-3-benzoylphenyl benzoates *6a–c* with 254 nm light

1 mM Solution (700 ml) of **6a**–**c** (0.700 mmol) was irradiated with 254 nm lamp. After the reaction was complete, the solvent was removed under reduced pressure and the residue was dissolved in 5 ml of acetone. The acetone solution was treated with a few drops of 1 M HCl, stirred for 2 h, and then water (10 ml) was added and extracted with dichloromethane (3 × 15 ml). The organic layer was dried with sodium sulfate and then concentrated. Separation of the residue by silica gel column chromatography (eluent, 1:1 CH_2Cl_2/hexane) gave the products **7a**–**c**, **9a**–**c**, and **10a**–**c** with the yields shown in Table 1.

7a. Oil. ^{1}H NMR (400 MHz) δ 0.85 (3H, t, $J = 7$), 1.2–1.4 (8H, m), 1.75 (2H, quintet, $J = 8$), 2.83 (2H, t, $J = 8$), 7.15 (1H, s), 7.39 (1H, t, $J = 8$), 7.44–7.62 (7H, m), 7.64 (1H, s), 7.72 (2H, dd, $J = 8$ and 1), 11.98 (1H, s). ^{13}C NMR (125 MHz) δ 14.05, 22.57, 27.09, 27.96, 28.89, 29.22, 31.63, 106.49, 114.78, 115.20, 117.30, 127.46, 128.36, 128.87, 128.89, 129.05, 131.63, 131.65, 136.71, 138.35, 146.82, 159.35, 161.75, 201.27. IR (neat): 1639, 1611, 1591, 1446, 1337, 700 cm^{-1}. Anal. Calcd. for $C_{28}H_{28}O_3$: C, 81.52; H, 6.84. Found: C, 81.62; H, 7.00.

7b. mp 189–192 °C. ^{1}H NMR (300 MHz) δ 2.52 (3H, s), 7.18 (1H, s), 7.35–7.41 (1H, m), 7.45–7.60 (7H, m), 7.62 (1H, s), 7.71 (2H, dd, $J = 8$ and 1), 11.98 (1H, s). ^{13}C NMR (125 MHz) δ 13.29, 106.47, 114.68, 115.21, 117.45, 127.44, 128.35, 128.74, 128.89, 129.08, 131.60, 131.67, 136.53, 138.31, 146.81, 157.75, 159.36, 201.22. IR (KBr): 1641, 1606, 1591, 1421, 1339, 1271, 1224, 701 cm^{-1}. Anal. Calcd. for $C_{22}H_{16}O_3$: C, 80.47; H, 4.91. Found: C, 80.25; H, 5.07.

7c. Oil. ^{1}H NMR (500 MHz) δ 1.25–1.45 (6H, m), 1.74–1.85 (4H, m), 2.86 (2H, t, $J = 7.5$), 3.38 (2H, t, $J = 6.8$), 7.17 (1H, s), 7.41 (1H, t, $J = 7.2$), 7.45–7.57 (6H, m), 7.62 (1H, t, $J = 7.3$), 7.66 (1H, s), 7.73 (2H, d, $J = 7.4$), 12.01 (1H, s). ^{13}C NMR (125 MHz) δ 26.95, 27.75, 27.88, 28.29, 28.95, 32.61, 33.88, 106.51, 114.78, 115.23, 117.40, 127.49, 128.35, 128.88 (two C), 129.03, 131.58, 131.628, 136.633, 138.31, 146.80, 159.34, 161.44, 201.25. IR (neat):

1639, 1611, 1591, 1446, 1337, 701 cm^{-1}. Anal. Calcd. for $C_{28}H_{27}BrO_3$: C, 68.43; H, 5.54. Found: C, 68.72; H, 5.86.

9a. Oil. ^{1}H NMR (500 MHz) δ 0.88 (3H, t, J = 6.9), 1.20–1.40 (8H, m), 1.77 (2H, quintet, J = 7.5), 2.83 (2H, t, J = 7.7), 4.75 (1H, s), 6.78 (1H, dd, J = 8.7 and 2.6), 6.98 (1H, d, J = 2.5), 7.32 (1H, d, J = 8.7), 7.35–7.39 (1H, m), 7.45–7.48 (4H, m). ^{13}C NMR (125 MHz) δ 14.07, 22.60, 26.83, 28.33, 28.95, 29.26, 31.70, 104.67, 111.17, 111.78, 116.67, 126.96, 128.70, 128.92, 129.73, 132.79, 148.98, 151.42, 156.52. IR (neat): 3361, 1615, 1456, 1189, 1146, 701 cm^{-1}. Anal. Calcd. for $C_{21}H_{24}O_2$: C, 81.78; H, 7.84. Found: C, 81.56; H, 7.70.

9b. mp 131–133 °C. 1H NMR (300 MHz) δ 2.50 (3H, s), 4.91 (1H, br s), 6.75 (1H, dd, J = 8 and 2), 6.98 (1H, d, J = 2), 7.28 (1H, d, J = 8), 7.30–7.38 (1H, m), 7.43–7.46 (4H, m). ^{13}C NMR (125 MHz) δ 12.89, 104.67, 111.10, 111.83, 116.80, 126.90, 128.71, 128.73, 129.56, 132.69, 148.97, 151.38, 152.44. IR (KBr): 3335, 1616, 1497, 1467, 1238, 700 cm^{-1}. Anal. Calcd. for $C_{15}H_{12}O_2$: C, 80.34; H, 5.39. Found: C, 80.57; H, 5.34.

9c. Oil. ^{1}H NMR (500 MHz) δ 1.20–1.45 (6H, m), 1.73–1.83 (4H, m), 2.82 (2H, t, J = 7.6), 3.37 (2H, t, J = 6.8), 4.80 (1H, s), 6.77 (1H, dd, J = 8.7 and 2.5), 6.96 (1H, d, J = 2.5), 7.30 (1H, d, J = 8.7), 7.35 (1H, t, J = 6.9), 7.42–7.48 (4H, m). ^{13}C NMR (125 MHz) δ 26.69, 27.97, 28.12, 28.36, 28.97, 32.69, 33.98, 104.68, 111.18, 111.86, 116.81, 127.01, 128.74, 128.92, 129.69, 132.74, 148.97, 151.48, 156.23. IR (neat): 3378, 1612, 1457, 1186, 1146, 701 cm^{-1}. Anal. Calcd. for $C_{21}H_{23}BrO_2$: C, 65.12; H, 5.99. Found: C, 65.18; H, 5.64.

10a. Oil. ^{1}H NMR (400 MHz) δ 0.86 (3H, t, J = 7), 1.20–1.40 (8H, m), 1.79 (2H, quintet, J = 8), 2.86 (2H, t, J = 8), 7.30 (1H, t, J = 8), 7.35–7.52 (9H, m), 7.58 (2H, dd, J = 8 and 1), 7.72 (1H, d, J = 1). ^{13}C NMR (100 MHz) δ 14.06, 22.62, 26.78, 28.36, 28.97, 29.26, 31.72, 110.93, 117.01, 118.02, 123.19, 126.74, 127.06, 127.47, 128.65, 128.78, 129.13, 129.43, 132.79, 136.38, 141.90, 153.65, 156.09. IR (neat): 1464, 1376, 763, 699 cm^{-1}. HR MS (positive ion FAB). Calcd. for $C_{27}H_{29}O^+$ (MH^+): 369.2218; found: 369.2215. Anal. Calcd. for $C_{27}H_{28}O$: C, 88.00; H, 7.66. Found: C, 88.17; H, 7.55.

10b. mp 88–90 °C. ^{1}H NMR (300 MHz) δ 2.55 (3H, s), 7.31 (1H, t, J = 7), 7.38–7.55 (9H, m), 7.59 (2H, dd, J = 8 and 1), 7.75 (1H, s). ^{13}C NMR (125 MHz) δ 12.88, 110.84, 117.09, 117.92, 123.19, 126.76, 127.02, 127.45, 128.65, 128.80, 128.95, 129.23, 132.68, 136.38, 141.82, 152.02, 153.61. IR (KBr): 1465, 1428, 1200, 766, 705 cm^{-1}. Anal. Calcd. for $C_{21}H_{16}O$: C, 88.70; H, 5.67. Found: C, 88.63; H, 5.47.

10c. Oil. ^{1}H NMR (300 MHz) δ 1.23–1.45 (6H, m), 1.74–1.87 (4H, m), 2.87 (2H, t, J = 7), 3.37 (2H, t, J = 7), 7.31 (1H, t, J = 7), 7.35–7.55 (9H, m), 7.59 (2H, dd, J = 8 and 1), 7.72 (1H, s). ^{13}C NMR (125 MHz) δ 26.63, 27.99, 28.15, 28.38, 28.96, 32.71, 33.92, 110.93, 117.12, 118.03, 123.24, 126.76, 127.10, 127.46, 128.65, 128.81, 129.11, 129.36, 132.70, 136.40, 141.84, 153.62, 155.81. IR (neat): 1464, 763, 700 cm^{-1}. Anal. Calcd. for $C_{27}H_{27}BrO$: C, 72.48; H, 6.08. Found: C, 72.74; H, 5.94.

*3.4. Photoreactions of 4-alkoxy-3-benzoylphenyl benzoates **6a–c** with 350 nm light*

The reaction was carried out in the same manner as described in Section 3.3. Silica gel column chromatography (eluent, 1:1 CH_2Cl_2/hexane) of the reaction mixture provided **8a–c** in addition to **7a–c**, **9a–c**, and **10a–c**, with the yields shown in Table 1.

8a. Oil. ^{1}H NMR (300 MHz) δ 0.87 (3H, t, J = 8), 1.18–1.40 (m, 8H), 1.78 (2H, quintet, J = 8), 2.86 (2H, t, J = 8), 7.09 (1H, dd, J = 8 and 2), 7.32–7.38 (2H, m), 7.42–7.53 (7H, m), 7.62 (1H, t, J = 8), 8.20 (2H, d, J = 9). ^{13}C NMR (125 MHz) δ 14.07, 22.61, 26.79, 28.30, 28.95, 29.22, 31.70, 111.26, 112.24, 117.14, 117.30, 127.13, 128.51, 128.76, 128.99, 129.63, 129.74, 130.12, 132.39, 133.48, 146.56, 151.68, 156.85, 165.77. IR (neat): 1739, 1465, 1451, 1268, 1247, 1176, 1140, 1060, 702 cm^{-1}. UV (CH_3Cl): λ_{max} (ε) 260 nm (17,700). Anal. Calcd. for $C_{28}H_{28}O_3$: C, 81.52; H, 6.84. Found: C, 81.36; H, 6.98.

8b. mp 104–106 °C. ^{1}H NMR (300 MHz) δ 2.54 (3H, s), 7.09 (1H, dd, J = 8 and 2), 7.33–7.36 (1H, m), 7.39 (1H, d, J = 2), 7.42–7.52 (7H, m), 7.61 (1H, t, J = 8), 8.20 (2H, dd, J = 8 and 1). ^{13}C NMR (125 MHz) δ 12.91, 111.18, 112.18, 117.27, 117.32, 127.11, 128.52, 128.79, 128.83, 129.60, 129.64, 130.12, 132.33, 133.49, 146.63, 151.67, 152.82, 165.73. IR (KBr): 1730, 1465, 1452, 1271, 1255, 1213, 1173, 1137, 1061, 701 cm^{-1}. UV (CH_3Cl): λ_{max} (ε) 258 nm (18,500). Anal. Calcd. for $C_{22}H_{16}O_3$: C, 80.47; H, 4.91. Found: C, 80.49; H, 5.05.

8c. Oil. ^{1}H NMR (500 MHz) δ 1.25–1.44 (6H, m), 1.76–1.85 (4H, m), 2.87 (2H, t, J = 7.5), 3.38 (2H, t, J = 6.8), 7.10 (1H, dd, J = 8.7 and 2.4), 7.33–7.39 (2H, m), 7.45–7.53 (7H, m), 7.63 (1H, t, J = 7.4), 8.21 (2H, dd, J = 8.4 and 1.2). ^{13}C NMR (125 MHz) δ 26.66, 27.98, 28.11, 28.37, 28.95, 32.69, 33.95, 111.28, 112.27, 117.28, 117.38, 127.18, 128.52, 128.80, 128.99, 129.61, 129.71, 130.12, 132.33, 133.51, 146.58, 151.67, 156.58, 165.78. IR (neat): 1738, 1464, 1451, 1248, 1176, 1140, 1060, 703 cm^{-1}. UV (CH_3Cl): λ_{max} (ε) 258 nm (15,900). Anal. Calcd. for $C_{28}H_{27}BrO_3$: C, 68.43; H, 5.54. Found: C, 68.09; H, 5.68.

*3.5. Photoreactions of 4-alkoxy-3-benzoylphenyl benzoates **6a–c** with 350 nm and then 254 nm light*

The reaction was carried out and worked up similarly as described in Section 3.3 using 350 nm and then 254 nm lamps. The yields of **7a–c**, **9a–c**, and **10a–c** are listed in Table 1.

3.6. General procedure for the synthesis of 2-alkyl-5-alkoxy-6-benzoyl-3-phenylbenzofurans **11a–c**

The etherification reactions of **7a–c** (0.70 mmol) with alkyl halide (0.84 mmol) were carried out in the same way as described for the synthesis of 4-alkoxy-3-benzoylphenyl benzoates **6a–c** in 3.2. Silica gel column chromatography eluting with 1:9 ethyl acetate/hexane (for **11a** and **11c**) or 1:1 ethyl acetate/hexane (for **11b**) afforded the analytically pure products.

11a (0.28 g, 76%). Oil. ^{1}H NMR (300 MHz) δ 0.86 (6H, t, $J = 7$), 0.90–1.40 (20H, m), 1.77 (2H, q, $J = 7$), 2.84 (2H, t, $J = 8$), 3.79 (2H, t, $J = 6$), 6.99 (1H, s), 7.37–7.43 (3H, m), 7.46–7.54 (5H, m), 7.56 (1H, s), 7.79 (2H, d, J 8). ^{13}C NMR (125 MHz) δ 14.07, 22.61, 25.61, 26.88, 28.23, 28.89, 28.92, 29.03, 29.16, 29.22, 31.69, 31.72, 68.97, 102.00, 112.15, 117.14, 125.48, 127.20, 127.97, 128.87, 129.01, 129.45, 132.02, 132.28, 132.50, 139.05, 148.16, 153.95, 158.41, 196.75. IR (neat): 1662, 1622, 1449, 1436, 1243, 700 cm^{-1}. UV (CH_3Cl): λ_{max} (ε) 258 nm (25,000), 314 nm (11,400). Anal. Calcd. for $C_{36}H_{44}O_3$: C, 82.40; H, 8.45. Found: C, 82.05; H, 8.69.

11b (0.22 g, 88%). mp 103–104 °C. ^{1}H NMR (500 MHz) δ 0.98 (3H, t, $J = 6.9$), 2.54 (3H, s), 3.89 (2H, q, $J = 6.9$), 7.05 (1H, s), 7.37–7.43 (3H, m), 7.48–7.54 (5H, m), 7.56 (1H, s), 7.79 (2H, d, $J = 7.4$). ^{13}C NMR (125 MHz) δ 13.03, 14.20, 64.82, 102.49, 112.12, 117.29, 125.49, 127.20, 127.94, 128.84, 128.90, 129.46, 131.92, 132.30, 132.37, 138.97, 148.18, 153.90, 154.46, 196.53. IR (KBr): 1653, 1620, 1452, 1433, 1255, 702 cm^{-1}. UV (CH_3Cl): λ_{max} (ε) 258 nm (21,800), 313 nm (10,300). Anal. Calcd. for $C_{24}H_{20}O_3$: C, 80.88; H, 5.66. Found: C, 80.95; H, 5.85.

11c (0.30 g, 61%). Oil. ^{1}H NMR (500 MHz) δ 0.90–1.00 (2H, m), 1.03–1.17 (4H, m), 1.23–1.43 (10H, m), 1.72–1.83 (6H, m), 2.85 (2H, t, $J = 7.5$), 3.33–3.41 (4H, m), 3.80 (2H, t, $J = 6.2$), 6.99 (1H, s), 7.37–7.43 (3H, m), 7.45–7.54 (5H, m), 7.56 (1H, s), 7.79 (2H, d, $J = 7.7$). ^{13}C NMR (125 MHz) δ 25.52, 26.77, 27.99 (two C), 28.04, 28.36, 28.47, 28.86, 28.96 (two C), 32.70, 32.74, 33.93, 33.99, 68.92, 102.08, 112.17, 117.31, 125.58, 127.28, 128.01, 128.93, 129.04, 129.50, 132.00, 132.34, 132.46, 139.03, 148.20, 153.93, 158.17, 196.67. IR (neat): 1653, 1622, 1449, 1436, 1243, 701 cm^{-1}. UV (CH_3Cl): λ_{max} (ε) 259 nm (21,700), 313 nm (9100). Anal. Calcd. for $C_{36}H_{42}Br_2O_4$: C, 61.90; H, 6.06. Found: C, 61.78; H, 6.20.

3.7. Photoreactions of 2-alkyl-5-alkoxy-6-benzoyl-3-phenylbenzofurans **11a–c**

1 mM Benzene solution of **11a–c** (350 ml) was irradiated with 350 nm lamp for 4 h. Dehydration reaction and work-up were carried out as described in Section 3.3. The residues were purified either by silica gel column chromatography (eluents: 19:1 hexane/ethyl acetate for **1a**; 1:1 hexane/dichloromethane for **1b**) or recrystallization from hexane (for **1c**).

1a (85 mg, 48%). mp 118–119 °C. ^{1}H NMR (400 MHz) δ 0.85 (6H, t, $J = 7$), 1.20–1.40 (16H, m), 1.77 (4H, quintet, $J = 7$), 2.85 (4H, t, $J = 7$), 7.38 (2H, tt, $J = 7$ and 2), 7.47–7.54 (8H, m), 7.56 (2H, s). ^{13}C NMR (100 MHz) δ 14.05, 22.61, 26.94, 28.34, 28.97, 29.24, 31.72, 100.10, 116.86, 126.29, 126.95, 128.73, 129.04, 133.10, 151.17, 155.78. IR (KBr): 1620, 1437, 968, 770, 703 cm^{-1}. Anal. Calcd. for $C_{36}H_{42}O_2$: C, 85.33; H, 8.35. Found: C, 85.18; H, 8.58.

1b (78 mg, 66%). mp 265 °C. ^{1}H NMR (400 MHz, 40 °C) δ 2.54 (6H, s), 7.37 (2H, t, $J = 7$), 7.49 (4H, t, $J = 8$), 7.54 (4H, d, $J = 8$), 7.55 (2H, s). ^{13}C NMR (100 MHz, 40 °C) δ 13.12, 100.01, 117.03, 126.19, 126.91, 128.73, 128.86, 133.05, 151.21, 151.68. IR (KBr): 1618, 1430, 959, 770, 703 cm^{-1}. Anal. Calcd. for $C_{24}H_{18}O_2$: C, 85.18; H, 5.36. Found: C, 85.39; H, 5.61.

1c (118 mg, 51%). mp 99–100 °C. ^{1}H NMR (400 MHz) δ 1.25–1.43 (12H, m), 1.73–1.85 (8H, m), 2.86 (4H, t, $J = 8$), 3.37 (4H, t, $J = 7$), 7.38 (2H, tt, $J = 7$ and 2), 7.47–7.54 (8H, m), 7.56 (2H, s). ^{13}C NMR (100 MHz) δ 26.81, 28.02, 28.15, 28.40, 28.96, 32.74, 33.94, 100.16, 117.02, 126.32, 127.04, 128.80, 129.05, 133.03, 151.18, 155.55. IR (KBr): 1617, 1437, 964, 769, 701 cm^{-1}. Anal. Calcd. for $C_{36}H_{40}Br_2O_2$: C, 65.07; H, 6.07. Found: C, 65.37; H, 6.15.

3.8. Synthesis of the cyclophane **12**

A solution of 2,7-dihydroxynaphthalene (29 mg, 0.18 mmol) in acetone (10 ml) was added slowly to a reaction mixture of the compound **1c** (100 mg, 0.15 mmol) and K_2CO_3 (210 mg, 1.5 mmol) in acetone (50 ml), heated at reflux for 76 h and worked-up as described for the synthesis of **6a–c**. Silica gel column chromatography eluting with 1:1 hexane/dichloromethane afforded **12** (31 mg, 31% yield). mp 166–168 °C. ^{1}H NMR (400 MHz) δ 1.15–1.40 (12H, m), 1.60–1.72 (6H, m), 1.78–1.90 (2H, m), 2.85–3.00 (4H, m), 3.94 (4H, t, $J = 7$), 6.94 (2H, dd, $J = 9$ and 2), 7.00 (2H, d, $J = 2$), 7.32 (2H, t, $J = 8$), 7.39 (4H, t, $J = 8$), 7.50 (4H, d, $J = 8$), 7.58 (2H, s), 7.63 (2H, d, $J = 9$). ^{13}C NMR (100 MHz) δ 25.69, 26.10, 27.56, 28.29, 28.34, 28.43, 67.96, 100.21, 106.95, 115.78, 117.66, 124.16, 126.43, 127.00, 128.76, 128.95, 129.02, 132.92, 135.91, 151.16, 155.72, 157.39. IR (KBr): 1630, 1514, 1436, 1207, 704 cm^{-1}. Anal. Calcd. for $C_{46}H_{46}O_4$: C, 83.35; H, 6.99. Found: C, 83.21; H, 7.01.

Acknowledgements

This work was supported by grant No. R05-2003-000-10459-0 from the Basic Research Program of the Korea Science and Engineering Foundation (KKP) and by CRM/KOSEF, Korea University (JWP).

References

[1] (a) L. Rene, J.P. Buisson, R. Royer, D. Averbeck, Eur. J. Med. Chem. Chim. Ther. 12 (1977) 31–34;
(b) R. Royer, E. Bisagni, C. Hudry, A. Cheutin, M.L. Desvoye, Bull. Soc. Chim. Fr. (1963) 1003–1007.

[2] T. Takahashi, M. Oota, T. Oonuma, H. Sakon, T. Yamaguchi, Jpn. Kokai Tokkyo Koho, JP 05109485 (1993).

[3] J.J. Chambers, D.M. Kurrasch-Orbaugh, M.A. Parker, D.E. Nichols, J. Med. Chem. 44 (2001) 1003–1010.

[4] A.P. Terent'ev, A.N. Grinev, P. Bon-Khvar, Zh. Obshch. Khim. 24 (1954) 2050–2051.

[5] (a) P.J. Wagner, Acc. Chem. Res. 22 (1989) 83–91;
(b) T. Sumathi, K.K. Balasubramanian, Tetraheron. Lett. 33 (1992) 2213–2216;
(c) M. Abdul-Aziz, J.V. Auping, M.A. Meador, J. Org. Chem. 60 (1995) 1303–1308.

[6] (a) G.R. Lappin, J.S. Zannucci, J. Org. Chem. 36 (1971) 1808–1811;
(b) P.J. Wagner, M.A. Meador, J.C. Scaiano, J. Am. Chem. Soc. 106 (1984) 7988–7989;
(c) E.M. Sharshira, M. Okamura, E. Hasegawa, T. Horaguchi, J. Heterocyclic Chem. 34 (1997) 861–869;
(d) E.M. Sharshira, T. Horaguchi, J. Heterocyclic Chem. 34 (1997) 1837–1849.

[7] (a) K.K. Park, H. Seo, J.-G. Kim, I.-H. Suh, Tetrahedron Lett. 41 (2000) 1393–1396;
(b) K.K. Park, I.K. Han, J.W. Park, J. Org. Chem. 66 (2001) 6800–6802.

[8] (a) K.K. Park, H. Lim, S.-H. Kim, D.H. Bae, J. Chem. Soc., Perkin Trans. 1 (2002) 310–314;
(b) K.K. Park, H. Lim, Heterocycles 57 (2002) 657–664.

[9] (a) D. Bellus, Adv. Photochem. 8 (1971) 109–159;
(b) M.A. Miranda, in: W.M. Horspool (Ed.), CRC Handbook of Organic Photochemistry and Photobiology, CRC Press, 1994, pp. 570–578.

[10] K.K. Park, J.J. Lee, J. Ryu, Tetrahedron 59 (2003) 7651–7659.

[11] K.K. Park, H.J. Lee, E.H. Kim, S.K. Kang, J. Photochem. Photobiol. A: Chem. 159 (2003) 17–21.

[12] (a) D.A. Plank, Tetrahedron Lett. (1968) 5423–5426;
(b) K. Pitchumani, M. Warrier, V. Ramamurthy, J. Am. Chem. Soc. 118 (1996) 9428–9429.