Table II. Estimates of Upper Limits of pK_a's for Some Acetylenes in Aqueous Solution at 25 °C

acetylene	$\leq pK_a$	acetylene	$\leq pK_a$
$CF_3C{\equiv}CH$	18.5[a]	$CH{\equiv}CH$	21.7[a]
$CH_3OCOC{\equiv}CH$	18.8[a]	$CH_3(CH_2)_2CH(OH)C{\equiv}CH$	21.9[a]
$C_6H_5COC{\equiv}CH$	19.1[b]	$(CH_3)_3CC{\equiv}CH$	22.2[a]
$CH_3(CH_2)_2COC{\equiv}CH$	20.3[a]	$CH_3CH_2C{\equiv}CH$	22.5[a]
$C_6H_5{}^+(CH_3)_2C_2C{\equiv}CH$	20.3[b]	$CH_3(CH_2)_2C{\equiv}CH$	22.5[a]
$4\text{-}NO_2C_6H_4C{\equiv}CH$	20.7[b]	$CH_3(CH_2)_3C{\equiv}CH$	22.5[a]
$(CH_3)_3SiC{\equiv}CH$	21.1[b]	$CH_3C{\equiv}CH$	22.7[a]
$CH_2FC{\equiv}CH$	21.1[a]	$CH_3(CH_2)_5C{\equiv}CH$	22.7[b]
$C_6H_5C{\equiv}CH$	21.2[b]		

[a] Obtained using the correlation of Figure 3. [b] Obtained via eq 7.

for benzoylacetylene and $pK_a \leq 21.1$ for (trimethylsilyl)-acetylene.

General-base catalytic coefficients for the detritiation of three other acetylenes in aqueous solution are available,[4d] and these, when treated as described above for benzoyl- and (trimethylsilyl)acetylene, give the estimates $pK_a \leq 20.3$ for [(phenyldimethylamonio)methyl]acetylene, $pK_a \leq 20.7$ for (4-nitrophenyl)acetylene, and $pK_a \leq 22.7$ for *n*-hexylacetylene. An estimate made in the same way is also available for phenylacetylene, $pK_a \leq 21.2$.[4a,21]

These six pK_a estimates were found to correlate well with hydroxide-ion catalytic coefficients for detritiation of these acetylenes. The relationship is shown in Figure 3; least-squares analysis gives $pK_a = 23.98 \pm 0.13 - (1.114 \pm 0.045) \log (k_{HO^-}/M^{-1}\ s^{-1})$. On the assumption that this correlation applies also to other terminal acetylenes whose hydroxide ion catalytic coefficients fall into the range encompassed, upper limits of pK_a's for other acetylenes for which such catalytic coefficients are available[4c] may be calculated. The results so obtained are listed in Table II, together with the pK_a estimates upon which this correlation is based.

It may be seen that, on the basis of these estimates, benzoylacetylene is a fairly strongly acidic acetylene: of the entries in Table II, only (trifluoromethyl)acetylene and carbomethoxyacetylene appear to be stronger. The three acetylenes of Table II with carbonyl groups attached directly to acetylenic carbon, moreover, fall in a sensible order, with acidity increasing in accord to the electron-withdrawing ability of the substituent attached to the other side of the carbonyl group.

(Trimethylsilyl)acetylene appears to be a notably acidic substance as well. Silicon is less electronegative than either carbon or hydrogen,[22] and, as has been pointed out before,[2] (trimethylsilyl)acetylene might therefore be expected to be less acidic than either *tert*-butylacetylene or acetylene itself. The estimates of Table II indicate otherwise.

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Supplementary Material Available: Table S1 of rate data (2 pages). Ordering information is given on any current masthead page.

(21) The original estimate, $pK_a \leq 20.0$,[4a] did not take into account the difference in hydrogen-bond strength, $\delta\Delta G°_{HB}$; when this is included that estimate rises to $pK_a \leq 21.2$.

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A Novel Friedel–Crafts Reaction: Synthesis of 4-Phenylnaphthalen-1-ols

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Gossypol (1, Chart I), a complicated dimer of sesquiterpene with multiple biological activities, was isolated from certain species of the cotton plant. The chemical structure was first proposed by Adams[1] in 1938 and was confirmed by total synthesis in 1958.[2] Venuti[3] completed a formal total synthesis of gossypol. Manmade et al.[4] reported the synthesis of some O-methylated hemigossypol derivatives, which exhibited in vitro spermicidal activity as effective as that of gossypol. Meltzer et al.[5] converted gossypol into the 5,5′-dideisopropyl-5,5′-diethyl analogue.

During the course of our studies on the synthesis of gossypol analogues, we discovered a novel Friedel–Crafts reaction leading to the synthesis of 1-phenylnaphthalenes. We attempted to synthesize derivatives of 1,4-diphenylbutane-1,4-diol **2** (Chart I), which may be considered the simplest analogue of gossypol, lacking both the B rings, by reaction of veratrole (**3b**) with succinyl chloride.

In 1955 Buchta et al.[6] obtained lactone **5a** in 13–16% yield from the Friedel–Crafts reaction of anisole (**3a**) with succinyl chloride (**4**) at low temperature (between −10 and −5 °C) using carbon disulfide as the solvent, while at higher temperature (60 °C), both lactone **5a** (13%) and diketone **6a** (18–21%) were obtained. It was shown that succinyl chloride exists in acyclic and cyclic forms (**4a** and **4b**), the former prevailing at low temperature. It is interesting to note that, after repeating the Buchta reaction,[6] we isolated, in addition to **5a** (33%), diketone **6e** (8%) and traces of its isomer **6f** (2%) in CS_2 as well as in dichloroethane ($ClCH_2CH_2Cl$) at −5 °C. This reaction was then applied to the construction of **2**. We found that the Friedel–Crafts reaction of veratrole (**3b**) with succinyl chloride at 60 °C using $ClCH_2CH_2Cl$ as the solvent afforded diketone **6b** albeit in a very low yield (0.6%). The same reaction at low temperature (−10 to −5 °C) gave lactone **5b** (Scheme I) in 23% yield as the major product.

Attempts to remove the methyl functions from the phenyl moiety of **5b** by prolonged treatment (overnight) with boron tribromide (BBr_3) caused an intramolecular Friedel–Crafts acylation, giving 4-phenylnaphthalen-1-ol (**7b**, $R_1 = R_2 = OH$) in 53% yield, Scheme II). After brief treatment of **5b** with BBr_3, a small amount of the de-O-methylated compound **8** was obtained. There are several approaches to the synthesis of α-phenylnaphthalenes.[7-9] To our best knowledge, there is little literature that deals with the synthesis of 4-phenylnaphthalen-1-ol derivatives. We, therefore, studied our new reaction for the synthesis

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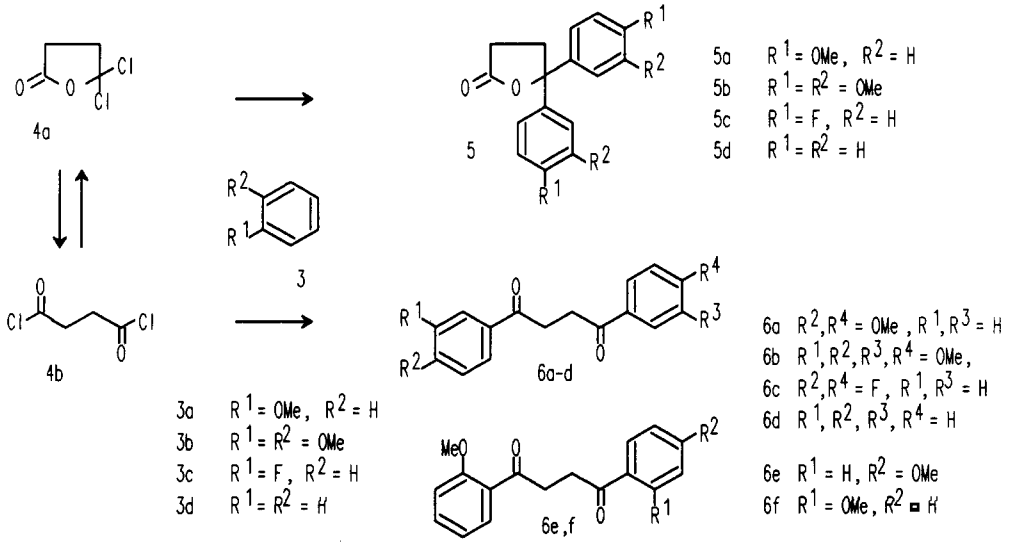
0022-3263/91/1956-4811$02.50/0

Scheme I



Scheme II

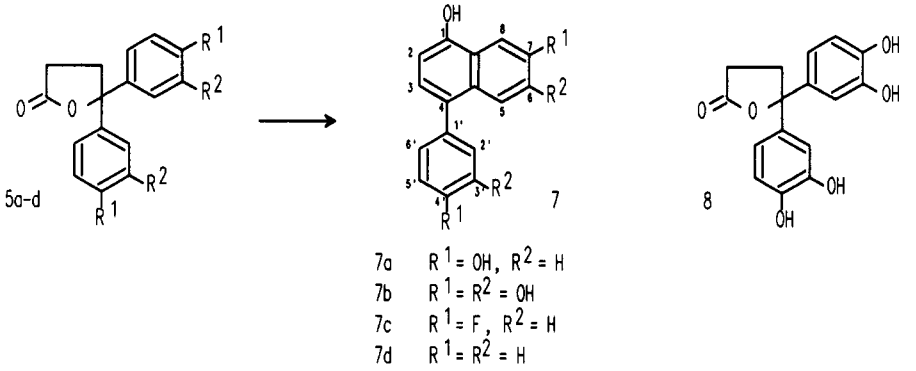
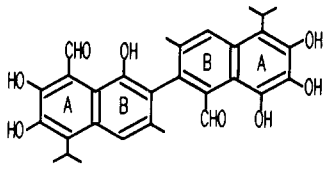
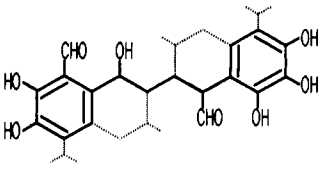


Chart I



1 Gossypol



2

of a variety of 4-phenylnaphthalen-1-ols, which we report herein.

Reaction of several benzene derivatives (**3b–d**) with succinyl chloride (Scheme I) at low temperature afforded the corresponding lactones (**5b–d**, 17–50%) as the major product, along with small amounts of 1,2-bis(benzoyl)-ethanes (**6b–f**, 0.6–9%). It should be noted that we isolated **5b** as a major product (50%) along with **6d** (8%) when the same reaction was carried out at −5 °C. Under very similar conditions (only difference was the temperature, which was 0 °C). Baker et al.[10] obtained **6d** in 23% yield; however, the formation of lactone **5d** was not mentioned. The structural assignment of lactones **5** and 1,2-bis(benzoyl)ethanes **6** is based on their IR and ^{1}H NMR spectra. The IR absorption for the carbonyl function in lactone **5** appears at ca. 1760 cm^{-1}, while it appears in 1,2-bis(benzoyl)ethanes at 1645–1650 cm^{-1}. The ^{1}H NMR ($CDCl_3$) spectra of the lactones **5** show that the two methylene groups appear at δ 2.47–2.66 (2 H, multiplet) and δ 2.77–2.96 (2 H, m). The two methylene functions in 1,2-dibenzoylethanes **6** appear as a 4-H singlet due to the symmetric structure of the dione at δ ~3.40.

After prolonged reaction of lactones **5a–d**, the corresponding 4-phenylnaphthalen-1-ols **7a–d** were obtained (Scheme II). It has been reported that cyclopentenones and cyclohexenones were synthesized by the intramolecular acylation of lactones via unsaturated acids as intermediate upon treatment with polyphosphoric acid or phosphorus pentoxide.[11,12] Formation of 1-phenylnaphthalenes **7** from the lactones **5** through a similar ring-opening–ring-closure mechanism is thus possible. The intramolecular acylation of the lactones **5** is thought to involve electrophilic attack by the lactone–BBr_3 complex [A] on the bromide anion (Scheme III). Elimination of hydrogen bromide from [A] gives the unsaturated acid [B], which is then readily cyclized to form [C], and thus **7**.

As described earlier, compound **6b**, a key intermediate for the synthesis of the simplest analogue of gossypol, **2**, was synthesized by condensation of veratrole (**3b**) and succinyl chloride. The yield was low due to the formation

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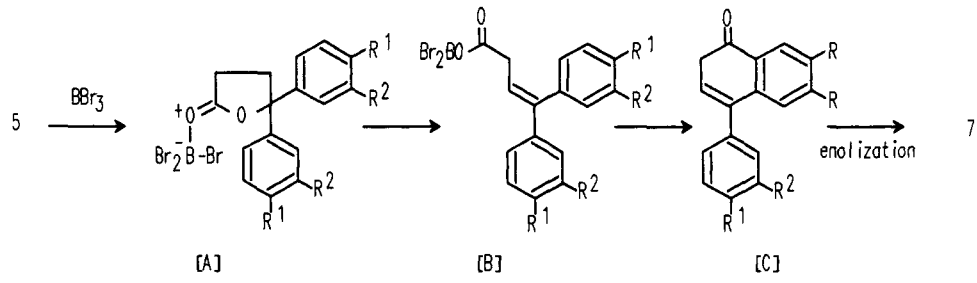
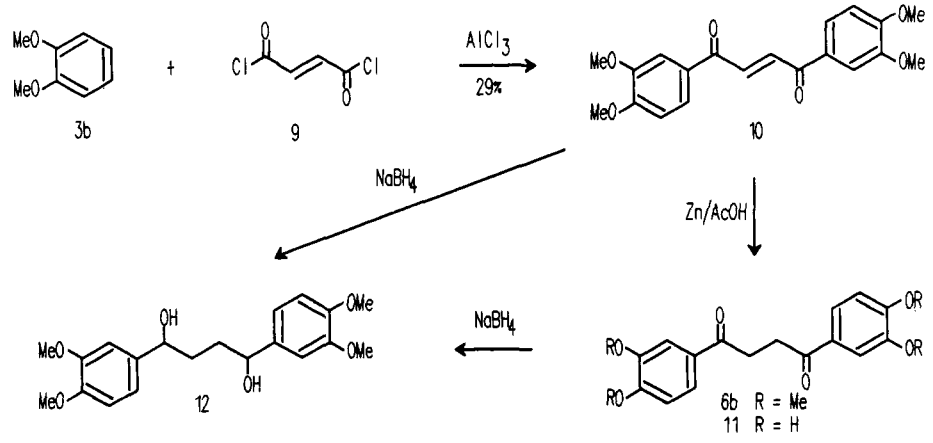
Scheme III



Scheme IV



of lactone **5b**. Lactone formation can be prevented if fumaryl chloride (**9**) is used instead of succinyl chloride, since the two acyl carbonyl groups of fumaryl chloride are in trans configuration and cannot exist in a cyclic form. Actually, we found that condensation of **3b** with fumaryl chloride gave 1,2-bis(3,4-dimethoxybenzoyl)ethene (**10**) in relatively good yield (Scheme IV). Reduction of **10** with zinc dust in acetic acid yielded **6b**, which was then de-O-methylated with BBR_3 in methylene chloride at −78 °C to give the acetophenone dimer **11**. Reduction of **6b** by treatment with $NaBH_4$ afforded the 1,4-diphenylbutane-1,4-diol **12**, which can also be prepared more readily by the same procedure directly from **10**. Compound **12** appears to be a 1:1 mixture of diastereomers of judged by its ^1H NMR spectrum. Both compounds **11** and **12** are unstable and readily decomposed to a dark tar in a few days at room temperature. Attempts at conversion of **11** by reduction with $NaBH_4$, or of **12** by treatment with BBr_3, into 1,4-bis(3,4-dihydroxyphenyl)butane-1,4-diol (**13**) gave a crystalline product, which gave a molecular ion peak (m/z 306) upon mass spectrometry and correct elemental analyses corresponding to **13**. However, it was extremely unstable in solution and decomposed during ^1H NMR measurement in D_2O and DMSO-d_6, and we could not obtain a clear spectrum.

Experimental Section

Melting points are uncorrected. Column chromatography was performed on silica gel G60 (70–230 mesh, ASTM, Merck). TLC was carried out on Analtech Uniplates with short-wavelength UV light for visualization. ^1H NMR spectra were recorded at 90 MHz in $CDCl_3$ or in DMSO-d_6.

Synthesis of 5,5-Bis(phenyl)butyrolactones 5a–d and 1,2-Bis(benzoyl)ethanes 6b–f. General Methods. Succinyl chloride (8.06 g, 0.052 mol) was added to a mixture of **3a–d** (0.159 mol) and $AlCl_3$ (7.0 g, 0.052 mol) in solvent [all reactions were run in $ClCH_2CH_2Cl$ (200 mL), except for **3d** in which benzene was used] with vigorous stirring overnight at −5 °C (reaction for the synthesis of **6b** was proceeded at 60 °C for 4 h). The reaction was then quenched by addition of a mixture of ice (100 g) and concentrated HCl (10 mL). The organic layer was separated, washed successively with H_2O, 10% $NaHCO_3$ aqueous solution, and H_2O, and dried over Na_2SO_4. The solvent was removed in vacuo and the residue (TLC [SiO_2, Hexane/EtOAc, 4:1 v/v] showed two major spots with other impurities) was chromatographed on a silica gel column using hexane/EtOAc (9:1 v/v) as the eluent. The fractions with the same higher R_f were eluted first and combined to give 1,2-bis(benzoyl)ethanes **6b–f**. The slow-moving fractions with the same lower R_f were collected to yield 5,5-bis(phenyl)butyrolactones **5a–d**.

The following products were obtained from the reaction of anisole (**3a**) with **4**.

5,5-Bis(4-methoxyphenyl)butyrolactone (5a): yield 5.11 g (33%); mp 104–7 °C (lit.[6] mp 108–9 °C); IR (KBr) 1710 cm^{-1} (C=O); ^1H NMR ($CDCl_3$) δ 2,48–2.76 and 2.77–2.96 (each 2 H, m, 2 × CH_2), 3.86 (6 H, s, 2 × OMe), 6.75–6.99 (8 H, m, Ar H). Anal. Calcd for $C_{18}H_{18}O_4$: C, 72.45; H, 6.08. Found: C, 72.55; H, 6.04.

1-(3-Methoxybenzoyl)-2-(4-methoxybenzoyl)ethane (6e): yield 1.24 g (8%); mp 89–90 °C; ^1H NMR ($CDCl_3$) δ 3.40 (4 H, t, 2 × CH_2), 3.86 and 3.91 (each 3 H, s, OMe), 6.79 (1 H, dd, $J_{3',5'}$ = 1.09, $J_{5',6'}$ = 7.95 Hz, H5′), 6.93 (2 H, d, J = 9.06 Hz), 7.04 (1 H, $J_{3',5'}$ = 1.09, $J_{3',4'}$, = 8.23 Hz, H3′), 7.47 (1 H, dd, $J_{4',6'}$ = 1.92, $J_{3',4'}$ = 8.23 Hz, H4′), 7.76 (1 H, dd, $J_{5',6'}$ = 7.93, $J_{4',6'}$ = 1.92 Hz, H6′), 8.02 (2 H, d, J = 9.06 Hz). Anal. Calcd for $C_{18}H_{18}O_4$: C, 72.45; H, 6.08. Found: C, 72.64; H, 6.06.

1,2-Bis(2-methoxybenzoyl)ethane (6f): yield 0.31 g (2%); mp 102–4 °C; ^1H NMR ($CDCl_3$) δ 3.40 (4 H, s, 2 × CH_2), 3.90 (6 H, s, 2 × OMe), 6.95 (2 H, dd, $J_{3',5'}$ = 1.10, $J_{5',6'}$ = 7.95 Hz, 2 × H5′), 7.03 (2 H, dd, $J_{3',5'}$ = 1.10, $J_{3',4'}$ = 8.45 Hz, 2 × H3′), 7.45 (2 H, m, $J_{4',6'}$ = 1.92, $J_{4',5'}$ = 7.13, $J_{3',4'}$ = 8.45 Hz, 2 × H4′), 7.74 (2 H, dd, $J_{4',6'}$ = 1.92, $J_{5',6'}$ = 7.95 Hz, 2 × H6′). Anal. Calcd for $C_{18}H_{18}O_4$: C, 72.45; H, 6.08. Found: C, 72.54; H, 6.27.

Reaction of **3b** and **4** at −5 °C gave compound **5b**, whereas at 60 °C **6c** was obtained.

5,5-Bis(3,4-dimethoxyphenyl)butyrolactone (5b): yield 4.28 g (23%); mp 106–7 °C; IR (KBr) 1785 cm^{-1} (C=O); ^1H NMR ($CDCl_3$) δ 3.85 (12 H, s, 4 × OMe), 2.48–2.65 and 2.66–2.96 (each 2 H, m, 2 × CH_2), 6.88 (6 H, m, Ar H). Anal. Calcd for $C_{20}H_{22}O_6$: C, 67.03; H, 6.19. Found: C, 67.17; H, 6.40.

1,2-Bis(3,4-dimethoxybenzoyl)ethane (6b): yield 0.112 g (0.6%); mp 154–6 °C; IR (KBr) 1665 cm^{-1} (C=O); ^1H NMR ($CDCl_3$) δ 3.42 (4 H, s, 2 × CH_2), 3.94 and 3.96 (each 6 H, s, 4 × OMe), 6.91 (2 H, d, J = 8.23 Hz, 2 × H3′), 7.57 (2 H, d, J = 1.93 Hz, 2 × H6′), 7.71 (2 H, dd, J = 1.93, J= 8.23 Hz, 2 × H2′). Anal.

Calcd for $C_{20}H_{22}O_6$: C, 67.03; H, 6.19. Found: C, 66.97; H, 6.32.

Reaction of **3c** and **4** yielded **5c** and **6c**.

5,5-Bis(4-fluorophenyl)butyrolactone (5c): yield 2.26 g (17%); mp 68–70 °C; IR (KBr) 1785 cm^{-1} (C=O); ^1H NMR ($CDCl_3$) δ 2.47–2.66 and 2.79–2.98 (each 2 H, m, 2 × CH_2), 6.90–7.48 (8 H, m, Ar H). Anal. Calcd for $C_{16}H_{12}F_2O_2$: C, 70.07; H, 4.41; F, 13.85. Found: C, 70.22; H, 4.54; F, 13.79.

1,2-Bis(4-fluorobenzoyl)ethane (6c): yield 1.19 g (9%); mp 126–9 °C; IR (KBr) 1675 cm^{-1} (C=O); ^1H NMR ($CDCl_3$) δ 3.34 (4 H, s, 2 × CH_2), 7.24 and 8.06 (each 4 H, dd, $J_{2',3'}$ = 9.09, $J_{3',F}$ = 8.51 Hz, Ar H). Anal. Calcd for $C_{16}H_{12}F_2O_2$: C, 70.07; H, 4.41; F, 13.85. Found: C, 70.00; H, 4.47; F, 13.90.

Reaction of **3d** and **4** afforded **5d** and **6d**.

5,5-Diphenylbutyrolactone (5d): yield 6.19 g (50%); mp 79–82 °C; IR (KBr) 1780 cm^{-1} (C=O); ^1H NMR ($CDCl_3$) δ 2.47–2.66 and 2.83–3.01 (each 2 H, m, 2 × CH_2), 7.15–7.50 (10 H, m, Ar H). Anal. Calcd for $C_{16}H_{14}O_2$: C, 80.65; H, 5.92. Found: C, 80.85; H, 5.97.

1,2-Dibenzoylethane (6d): yield 0.99 g (8%); mp 142–6 °C; IR (KBr) 1675 cm^{-1} (C=O); ^1H NMR ($CDCl_3$) δ 3.46 (4 H, s, 2 × CH_2), 7.35–7.60 (6 H, m, AR H), 7.98–8.09 (4 H, m, Ar H). Anal. Calcd for $C_{16}H_{14}O_2$: C, 80.65; H, 5.92. Found: C, 80.92; H, 5.91.

4-(3,4-Dihydroxyphenyl)naphthalene-1,6,7-triol (7b). A solution of BBr_3 (20 g, 79.8 mmol) in dry CH_2Cl_2 (20 mL) was added slowly to a vigorously stirring solution of **5b** (10 g, 27.9 mmol) in dry CH_2Cl_2 (200 mL) at −78 °C. Stirring was continued for 3 h at −78 °C and then at rt overnight. Ice (100 g) was added to the mixture, and the organic layer was separated. The aqueous layer was extracted with CH_2Cl_2 (300 mL × 5). The combined organic solutions were washed with H_2O and dried (Na_2SO_4) and concentrated in vacuo. The residue was chromatographed over a silica gel column ($CHCl_3$/MeOH, 98:2 v/v) to give **7b** (4.5 g, 53%) as gray crystals ($CHCl_3$/Me_2CO): mp 224–6 °C; ^1H NMR (DMSO-d_6) δ 6.58 (1 H, d, $J_{2,3}$ = 7.80 Hz, H3), 6.59 (1 H, dd, J = 2.10, J = 8.00 Hz, H6'), 6.74 (1 H, d, J = 2.10 Hz, H2'), 6.79 (1 H, d, J = 8.00 Hz, H5'), 6.80 (1 H, d, $J_{2,3}$ = 7.80 Hz, H2), 7.10 (1 H, s, H5), 7.39 (1 H, s, H8). Anal. Calcd. for $C_{16}H_{12}O_5 \cdot {}^3/_4H_2O$: C, 64.54; H, 4.57. Found: C, 64.17; H, 4.37.

By following a similar procedure but using the corresponding butyrolactones **5a,c,d**, the following 4-phenylnaphthalen-1-ols **7a,c,d** are prepared.

4-(4-Hydroxyphenyl)naphthalene-1,7-diol (7a): yield 6.19 g (88%); mp 210–3 °C; ^1H NMR (DMSO-d_6) δ 6.78 (1 H, $J_{2,3}$ = 7.41 Hz, H3), 6.84 (2 H, d, J = 8.51 Hz), 6.92 (1 H, d, $J_{2,3}$ = 7.41 Hz, H2), 6.99 (1 H, dd, J = 2.47, J = 9.09 Hz, H6), 7.18 (2 H, d, J = 8.51 Hz), 7.43 (1 H, s, H8), 7.62 (1 H, d, J = 9.05 Hz, H5). Anal. Calcd for $C_{16}H_{12}O_3 \cdot {}^1/_4H_2O$: C, 74.84; H, 4.91. Found: C, 74.82; H, 4.98.

7-Fluoro-4-(4-fluorophenyl)naphthalen-1-ol (7c): yield 2.14 g (30%); mp 123–4 °C; ^1H NMR (DMSO-d_6) δ 6.98 (1 H, d, $J_{2,3}$ = 7.68 Hz, H3), 7.22 (1 H, $J_{2,3}$ = 7.68 Hz, H2), 7.20–7.91 (7 H, m, Ar H). Anal. Calcd for $C_{16}H_{10}F_2O$: C, 74.99; H, 3.93; F, 14.83. Found: C, 74.91; H, 3.87; F, 14.86.

4-Phenylnaphthalen-1-ol (7d): yield 3.01 g (49%); mp 136–8 °C; ^1H NMR (DMSO-d_6) δ 6.94 (1 H, D, $J_{2,3}$ = 7.68 Hz, H3), 7.22 (1 H, d, $J_{2,3}$ = 7.68 Hz, H2), 7.36–8.22 (10 H, m, Ar H). Anal. Calcd for $C_{16}H_{12}O \cdot {}^1/_8H_2O$: C, 86.36.; H, 5.55. Found: C, 86.11; H, 5.51.

5,5-Bis(3,4-dihydroxyphenyl)butyrolactone (8). A solution of BBr_3 (5 mL) in dry CH_2CL_2 (5 mL) was added to a solution of **5b** (3.0 g, 8.37 mmol) in dry CH_2Cl_2 (50 mL) at −78 °C over a period of 20 min with vigorous stirring. The reaction mixture was allowed to stir at rt for 1 h. TLC (SiO_2, $CHCl_3$/MeOH, 9:1 v/v) of the mixture indicated that two major products were formed. The mixture was poured into ice water (50 mL) and extracted with CH_2Cl_2 (50 mL × 4). The organic extracts were washed with H_2O, dried (Na_2SO_4), and concentrated in vacuo to dryness. The residue was chromatographed over a silica gel column (3 × 40 cm) using $CHCl_3$/MeOH (9:1 v/v) as the eluent. Compound **8** was eluted first, 0.3 g (12%) with mp 168–70 °C: ^1H NMR (DMSO-d_6) δ 2.46, 2.52 (2 h, m, CH_2), 2.64–2.82 (2 H, m, CH_2), 6.54–6.76 (6 H, m, 6 × Ar H), 8.94 (4 H, b, exchangeable, 4 × OH). Anal. Calcd for $C_{16}H_{14}O_6$: C, 63.57; H, 4.67. Found: C, 63.34; H, 4.69.

The second product eluted by the same solvent was identical with **7b**, 1.3 g (55%).

1,2-Bis(3,4-dimethoxybenzoyl)ethene (10). Veratrole (**3b**, 40.0 g, 0.29 mol) was added to a mixture of $AlCl_3$ (40 g, 0.3 mol) in dry benzene (100 mL) at 55 °C with vigorous stirring. This was followed by dropwise addition of fumaryl chloride (**9**, 20.0 g, 0.13 mol) and then an additional amount of **3b** (10.0 g, 0.072 mol). The mixture was heated at reflux for 1 h, cooled to rt, and then poured onto ice–water (500 mL) containing concentrated HCl (5 mL). The benzene layer was separated, washed with water, dried (Na_2SO_4), and then concentrated in vacuo. The residue was triturated with MeOH, and the solid was collected by filtration and recrystallized from EtOH to give **10**: 13.5 g (29%); mp 178–9 °C; ^1H NMR (DMSO-d_6) δ 3.98 (12 H, s, 4 × OMe), 6.95 (2 H, d, $J_{5',6'}$ = 8.22 Hz, 2 × Ar H5'), 7.44 (2 H, d, $J_{1',6'}$ = 2.19 Hz, 2 × Ar H1'), 7.77 (2 H, dd, $J_{1',6'}$ = 2.19 Hz, $J_{5',6'}$ = 8.22 Hz, 2 × Ar H6'), 7.81 (2 H, s, -*CH*=*CH*-). Anal. Calcd for $C_{20}H_{20}O_6$: C, 67.41; H, 5.66. Found: C, 67.34; H, 5.46.

1,2-Bis(3,4-dimethoxybenzoyl)ethane (6b). To a solution of **10** (10.5 g, 29.5 mmol) in HOAc (150 mL) was added portion-wise Zn dust (15 g). The mixture was heated at 80 °C for 1 h and then filtered through a Celite pad. The filtrate was concentrated to about 30 mL in vacuo, and crystallized product was collected by filtration (4.1 g, 39%). The product was identical with **6b**, prepared as described earlier, with respect to mixture mp, IR (KBr), and ^1H NMR.

1,2-Bis(3,4-dihydroxybenzoyl)ethane (11). BBr_3 (2 mL) was added dropwise to a solution of **6b** (1.6 mg, 4.5 mmol) in dry CH_2Cl_2 (60 mL) at −78 °C. The resulting mixture was allowed to warm slowly to rt and was stirred for an additional 1.5 h and then poured into ice–water (200 mL). The mixture was extracted with CH_2Cl_2 (50 mL × 4), and the combined extracts were washed with water, dried (Na_2SO_4), and concentrated in vacuo to dryness. The residue was chromatographed over a silica gel column (3 × 40 cm) using $CHCl_3$/MeOH/HCO_2H (10:1.5:0.1 v/v/v) as the eluent to give **11**: 1.05 g (74%); mp 280–3 °C (MeOH); IR (KBr) 1660 cm^{-1} (C=O); ^1H NMR (DMSO-d_6) δ 3.34 (4 H, b, 2 × CH_2), 6.82 (2 H, d, J = 8.24 Hz, 2 × Ar H5'), 7.37 (2 H, s, 2 × Ar H1'), 7.41 (2 H, d, J = 8.24 Hz, 2 × Ar H6'). Anal. Calcd for $C_{16}H_{14}O_6$: C, 63.57; H, 4.67. Found: C, 63.11; H, 4.64. Due to instability of **11**, the carbon analysis fell outside the 0.4% limit.

1,4-Bis(3,4-dimethoxyphenyl)butane-1,4-diol (12). To a solution of **6b** (5.5 g, 15.4 mmol) in THF (150 mL) was added a solution of $NaBH_4$ (4.66 g, 0.123 mol) in H_2O (15 mL). The mixture was stirred at rt overnight. The organic layer was separated and the aqueous layer was extracted with EtOAc (50 mL × 4). The combined organic solutions were washed with H_2O, dried (Na_2SO_4), and concentrated in vacuo, and the residue was crystallized from H_2O to give **12** (3.5 g): mp 132–3 °C; ^1H NMR (DMSO-d_6) δ 1.56 (4 H, b, 2 × CH_2), 3.71 (12 H, s, 4 × OMe), 4.37–4.43 (2 H, b, 2 × CH), 4.99 (2 H, d, J = 4.40 Hz, exchangeable, 2 × OH), 6.70–6.91 (6 H, m, 6 × Ar H). Anal. Calcd for $C_{20}H_{26}O_6$: C, 66.28; H, 7.23. Found: C, 66.08; H, 7.30.

By following the same procedure, compound **10** can be directly converted into **12**.

1,4-Bis(3,4-dihydroxyphenyl)butane-1,4-diol (13). To a solution of **12** (1.0 g, 2.76 mmol) in dry CH_2Cl_2 (200 mL) at −78 °C under argon was added slowly BBr_3 (6.9 g, 27.6 mmol). The mixture, after being stirred for 2 days at rt was diluted with MeOH (200 mL) at 0 °C over a 1-h period and then concentrated in vacuo. The residue was triturated with ice–H_2O (200 mL), and the mixture was extracted with EtOAc (200 mL × 3). The combined extracts were washed (H_2O, 40 mL × 4), dried (Na_2SO_4), and concentrated to a dark red-brown solid, which was dissolved in Me_2CO (3 mL). The solution was diluted with $CHCl_3$ (5 mL). Compound **13** (250 mg, 29%) precipitated was collected by filtration: mp 170–3 °C; MS, m/z 306. Anal. Calcd for $C_{16}H_{18}O_6$: C, 62.74; H, 5.92. Found: C, 62.51; H, 5.80.

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Registry No. **3a**, 100-66-3; **3b**, 91-16-7; **3c**, 462-06-6; **3d**, 71-43-2; **4b**, 543-20-4; **5a**, 109393-95-5; **5b**, 114914-84-0; **5c**, 63295-11-4; **5d**, 7746-94-3; **6a**, 15982-64-6; **6b**, 4650-71-9; **6c**, 108791-65-7; **6d**,

495-71-6; **6e**, 134179-54-7; **6f**, 134179-55-8; **7a**, 134179-56-9; **7b**, 114815-06-4; **7c**, 134179-57-0; **7d**, 36159-76-9; **8**, 134179-58-1; **9**, 627-63-4; **10**, 114914-88-4; **11**, 114914-89-5; **12**, 102454-96-6; **13**, 134179-59-2.

Synthesis of 4′-Vinyl-2,2′:6′,2″-terpyridine

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In several recent papers, we described the synthesis of 4′-vinyl-2,2′:6′,2″-terpyridine,[1] its homo- and copolymerization behavior,[2] and the electropolymerization of its transition-metal coordination complexes in chemically modified electrode studies.[1,3] Interest in the coordination chemistry of vinyl-substituted bipyridines (bpy) and terpyridines (terpy) continues unabated, with applications in polymer chemistry,[2,4] chemically modified electrodes,[5] and in solar energy conversion.[6] Synthetic sequences developed[1,5a,7] to date for the introduction of a vinyl substituent into ligands of this type are often relatively cumbersome, utilizing multistep reactions with accompanying low overall yields. By applying a combination of triflate, vinyltin, and Pd^0 chemistry,[8] we have resolved this problem in the terpyridine series, and a convenient synthesis of 4′-vinylterpy from ethyl 2-pyridinecarboxylate in a reasonable overall yield is described in this paper.

The use of Pd-catalyzed reactions in the formation of C–C bonds has been shown in recent years to provide an excellent alternative to more classical bond-formation reactions.[8a-f] The recent report that trifluoromethanesulfonates (triflates) undergo palladium-catalyzed coupling with organostannanes with the formation of a new C–C bond and the elimination of the triflate group,[8f] especially the palladium-catalyzed coupling of 2-quinolyl triflate with 5-(trimethylstannyl)-1,3-benzodioxole to afford[9] dubamine (79%), suggested this present application. The overall reaction sequence utilized in our synthesis is shown in Figure 1.

The requisite 2,6-di-2-pyridyl-4(1*H*)-pyridone (**3**) was prepared in two ways. 2,6-Di-2-pyridyl-4-(methylsulfonyl)pyridine (**2**), obtained from the corresponding methylthio compound **1** by peracid oxidation,[10] was hydrolyzed with 20% aqueous potassium hydroxide in dimethoxyethane with a catalytic amount of dibenzo-18-crown-6. An alternative procedure (80% yield) involved the reaction of 1,5-di-2-pyridylpentane-1,3,5-trione (**4**) with hot ammonium acetate, the trione itself being obtained (80% yield) from the Claisen condensation of ethyl 2-pyridinecarboxylate and acetone.[11] The triflate **5** was readily prepared (76% yield) from **3** and triflic anhydride in the presence of pyridine. Reaction of the triflate with vinyltributyltin using the general procedure described by Stille[9] gave 4′-vinyl-2,2′:6′,2″-terpyridine in up to 50% yield. However, use of the preformed catalyst bis(triphenylphosphine)palladium dichloride in DMF/Et_3N solution under the reaction conditions described in the Experimental Section increased the yield of the 4′-vinylterpy to 86%. An interesting feature of these experimental conditions was the absence of added lithium chloride in the reaction mixture. Others have also observed that added chloride is not necessary for vinylation to occur with aryl halides,[12,13] vinyl triflates,[14] or with pyrimidyl triflates.[15] An alternative reaction procedure for this type of coupling described by Chen[12] resulted in slightly reduced yields of the vinyl compound.

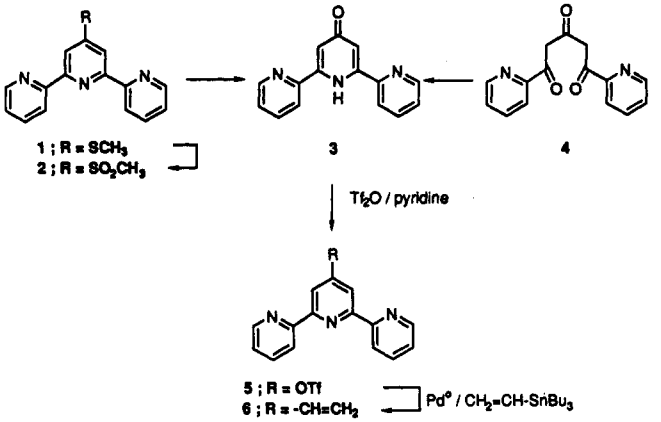

Figure 1. Reaction sequence for the formation of 4′-vinyl-2,2′:6′,2″-terpyridine.

Experimental Section[16]

2,6-Di-2-pyridyl-4(1*H*)-pyridone (3). A: From 2,6-Di-2-pyridyl-4-(methylsulfonyl)pyridine (2). A mixture of the (methylsulfonyl)pyridine **2** (0.30 g, 0.096 mmol) and aqueous potassium hydroxide (20 mL of 20% solution), DME (20 mL), and a catalytic amount of dibenzo-18-crown-6 (50 mg) was refluxed for 48 h. The resultant homogeneous mixture was cooled to room temperature and diluted with water. The organic layer was distilled off and the residual solution neutralized with acetic acid, giving a white solid (mp >400 °C) that was removed. The filtrate was extracted with $CHCl_3$, and after drying (Na_2SO_4) and evaporation of the extract, a residue containing starting material and pyridone was obtained. This residue was boiled in water while ethanol was added slowly until homogeneity was achieved and, on cooling of the solution, the starting material separated. Reduction of the filtrate to a small volume resulted in white microneedles of the pyridone separating from solution: 0.05 g (32 %), mp 165 °C; IR (KBr) ν_{NH} 3300, ν_{CO} 1630 cm^{-1}; ^1H NMR

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