

THERMAL CYCLOADDITION OF AROYLKETENE TO
1-ARYL-1-TRIMETHYLSILOXYETHYLENE:
A SIMPLE SYNTHESIS OF 2,6-DIARYL-4H-PYRAN-4-ONE

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Abstract - Aroylketene (2) generated by pyrolytic decarbonylation of 5-aryl-2,3-dihydro-2,3-furandione (1) reacted with 1-aryl-1-trimethylsilyloxyethylene (3) in a regioselective manner to give 2,6-diaryl-4H-pyran-4-one (5) and/or 1,5-diarylpentane-1,3,5-trione (6). This reaction provides a simple synthetic method of 2,6-diaryl-4H-pyran-4-one with various substituents in the aryl group.

Acylketenes readily react with a variety of hetero-olefins including imine,^{1,2} cyanide,^{1,3,4} diimine,^{1,4} ketone,^{1,5,6} thioamide,⁷ and isocyanate^{1,3,5,8} as a heterodiene, in the [4 + 2] cycloaddition reaction. Furthermore, it has been demonstrated that acylketenes undergo [4 + 2] cycloaddition to electron-rich olefins such as enol ethers^{9~11} and ketene acetals^{9,10} which provide a versatile synthetic method of 2-alkoxy-2,3-dihydro-4H-pyran-4-one and of 4H-pyran-4-one. In this paper, we describe a potentially versatile approach to the 2,6-diaryl-4H-pyran-4-ones, based on the reaction in which aroylketene (2) and 1-aryl-1-trimethylsilyloxyethylene (3) undergo [4 + 2] cycloaddition.

Benzoylketene (2a) and *p*-nitrobenzoylketene (2b) used for the reaction were thermally generated *in situ* from the 5-phenyl-2,3-dihydro-2,3-furandione (1a)¹² and 5-*p*-nitrophenyl derivative (1b), respectively. The reactions with 1-aryl-1-trimethylsilyloxyethylene (3) were performed simply by heating a mixture of the precursor (1) and the olefin (3) in dry toluene at 100°C for 1 h in a sealed tube. The reaction mixture was purified by silica gel column chromatography to afford 2,6-diaryl-4H-pyran-4-one (5) and/or 1,5-

diarylpentane-1,3,5-trione (6). The structures of the products were confirmed by their mass, ir, uv, ^1H - and ^{13}C -nmr spectral data. The 1,5-diarylpentane-1,3,5-trione existed exclusively as the keto-enol tautomers, as evidenced from the ^1H -nmr spectrum of (6a) (CDCl_3). The results are summarized in the table.

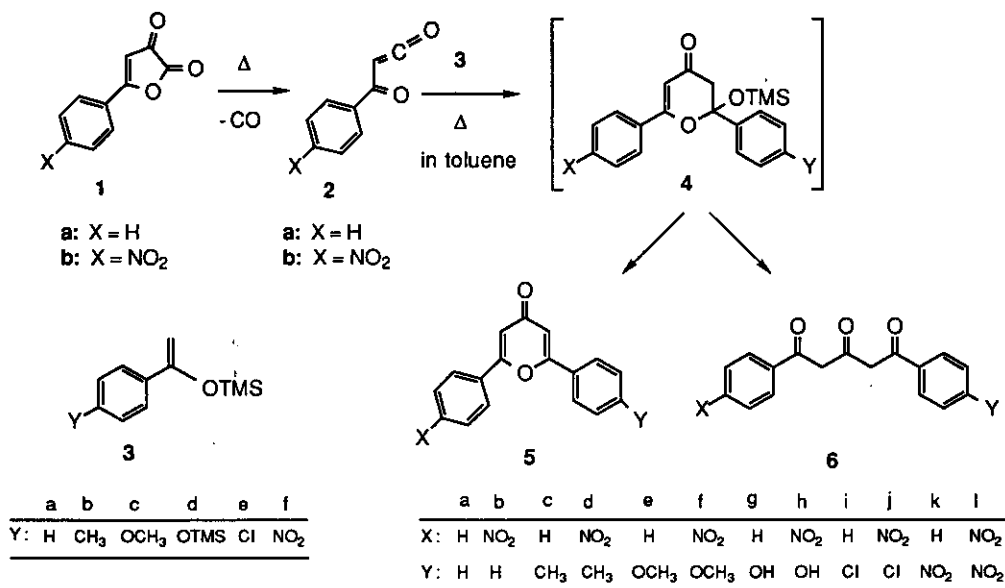


Table Cycloaddition of Arylketene (2) to 1-Aryl-1-trimethylsilyloxyethylene (3)

Arylketene (2)		Olefin (3)		Yield (%)	
X		Y		Pyran-4-one (5)	Triketone (6)
H (2a)		H (3a)		27 (5a)	5 (6a)
NO ₂ (2b)		H (3a)		51 (5b)	5 (6b)
H (2a)		CH ₃ (3b)		--	2 (6c)
NO ₂ (2b)		CH ₃ (3b)		26 (5d)	10 (6d)
H (2a)		OCH ₃ (3c)		19 (5e)	8 (6e)
NO ₂ (2b)		OCH ₃ (3c)		61 (5f)	5 (6f)
H (2a)		OTMS (3d)		37 (5g)	--
NO ₂ (2b)		OTMS (3d)		63 (5h)	--
H (2a)		Cl (3e)		--	23 (6i)
NO ₂ (2b)		Cl (3e)		7 (5j)	20 (6j)
H (2a)		NO ₂ (3f)		--	3 (6k)*
NO ₂ (2b)		NO ₂ (3f)		--	3 (6l)

*6k was identical with 6b

Substituents introduced at the *para*-position of the phenyl group in the trimethylsilyloxyethylene (3) affected this reaction. In the reaction of benzoylketene (2a) with the olefin (3), the trimethylsilyloxy substituted 3d gave the pyran-4-one (5g) in slightly higher yield (37%) than the non-substituted 3a which

gave the pyran-4-one (5a) (27%) and (6a) (5%). The methoxy substituted 3c little affected the reaction (19% for 5e and 8% for 6e). The chlorine derivative (3e) gave only the triketone (6i) as a characterizable product in 23% yield. The methyl derivative (3b), in contrast to the expectation inferred from its electron releasing property, showed poor reactivity for 2a, giving the triketone (6c) in only 2% yield as a characterizable product. The result is similar to that of the nitro derivative (3f) (6k: 3%) which is predictable from the electron-withdrawing property of the nitro group.

As shown in the table, the *p*-nitrobenzoylketene (2b) was evidenced to have higher reactivity for this cycloaddition reaction. The olefins (3c) and (3d) with electron-releasing substituents (OMe and OTMS) gave the pyran-4-ones (5f) and (5h) in the yield of 61% and 63%, respectively. Although the methyl derivative (3b) showed the poor result in the reaction with 2a as described above, the reaction with 2b was appreciably improved, thus giving the pyran-4-one (5d) in 26% yield and the triketone (6d) in 10% yield. However, in the reaction with the chlorine derivative (3e) the nitro substituted 2b introduced into the aryl group of the aroylketene did not improve the reaction as expected, giving the triketone (6j) (20%) as a major product together with the pyran-4-one (5j) (7%). The nitro derivative (3f), as predicted, gave a poor result, yielding the triketone (6l) in only 3% yield.

The formation of such products is rationalized when it is assumed that aroylketene (2) generated by pyrolytic decarbonylation of 5-aryl-2,3-dihydro-2,3-furandione (1) undergoes cycloaddition in terms of the inverse Diels-Alder reaction. In this [4 + 2] cycloaddition reaction the aroylketene behaves as an electron-deficient diene and 1-aryl-1-trimethylsilyloxyethylene as an electron-rich olefin, which is evidenced by the fact that this cycloaddition reaction is facilitated either by the electron-withdrawing group (X) in the 5-aryl-2,3-dihydro-2,3-furandione or by the electron-releasing group (Y) in the 1-aryl-1-trimethylsilyloxyethylene. The cycloaddition proceeds in a highly regioselective manner to afford the dihydropyran-4-one (4) which then undergoes either pyrolytic desilyloxylation or ring opening with concomitant desilylation to yield the pyran-4-one (5) or the triketone (6). Since the pyran-4-one (5) is obtainable from the triketone (6) by acid catalysed ring closure,^{13,14} this approach provides a potentially versatile synthetic method of 2,6-diaryl-4H-pyran-4-ones with various substituents in the aryl group.

EXPERIMENTAL

Unless otherwise stated, following procedures were adopted. Melting points were determined with Yanagimoto MP-S1 melting point apparatus and are uncorrected. Infrared spectra were measured with JASCO FT/IR-5000 Fourier transform infrared spectrophotometer using KBr and are given as cm⁻¹.

Ultraviolet spectra were measured with Hitachi U-3200 spectrophotometer in dioxane and are given as $\lambda_{\max}$ nm (ϵ). ^1H - and ^{13}C -Nmr spectra were measured in CDCl_3 using tetramethylsilane as an internal standard with a JEOL JNM-EX90 (^1H : 90 MHz; ^{13}C : 22.5 MHz). High-resolution mass (HRms) and low-resolution mass (LRms) spectra were obtained on JEOL JMS-D300 at 30 eV by the direct inlet system.

Synthesis of 1-Aryl-1-trimethylsilyloxyethylenes (3)

The olefins (**3a-f**) were prepared by trimethylsilylation of acetophenone derivatives according to the known procedure.¹⁵

3a: ^1H -Nmr: 0.27 (9H, s), 4.43 (1H, d, $J=2$ Hz), 4.91 (1H, d, $J=2$ Hz), 7.2-7.4 (3H, m), 7.5-7.7 (2H, m). **3b**: ^1H -Nmr: 0.26 (9H, s), 2.34 (3H, s), 4.37 (1H, d, $J=2$ Hz), 4.86 (1H, d, $J=2$ Hz), 7.11 (2H, d, $J=8$ Hz), 7.48 (2H, d, $J=8$ Hz). **3c**: ^1H -Nmr: 0.26 (9H, s), 3.81 (3H, s), 4.33 (1H, d, $J=2$ Hz), 4.79 (1H, d, $J=2$ Hz), 6.7-6.9 (2H, m), 7.4-7.6 (2H, m). **3d**: ^1H -Nmr: 0.26 (18H, s), 4.32 (1H, d, $J=2$ Hz), 4.78 (1H, d, $J=2$ Hz), 6.7-6.9 (2H, m), 7.4-7.6 (2H, m). **3e**: ^1H -Nmr: 0.26 (9H, s), 4.43 (1H, d, $J=2$ Hz), 4.88 (1H, d, $J=2$ Hz), 7.2-7.6 (4H, m). **3f**: ^1H -Nmr: 0.28 (9H, s), 4.60 (1H, d, $J=2$ Hz), 5.06 (1H, d, $J=2$ Hz), 7.6-7.8 (2H, m), 8.0-8.3 (2H, m).

Synthesis of 5-Aryl-2,3-dihydro-2,3-furandiones (1)

The 5-phenyl-(**1a**) and 5-(*p*-nitrophenyl)-2,3-dihydro-2,3-furandione (**1b**) were prepared by condensation of oxalyl chloride with **3a** and **3f** according to the known procedure.¹²

1a: Yield 76%. mp 124-127°C [lit.,¹² mp 130-132°C]. Ir: 1823, 1717. Uv: 348 (9000). ^1H -Nmr: 4.41 (1H, s), 7.5-8.0 (5H, m). LRms m/z 174 (M^+).

1b: Yield 70%. mp 141-142°C. Ir: 1829, 1734. Uv: 349 (8100). ^1H -Nmr: 6.55 (1H, s), 8.0-8.5 (4H, m). LRms m/z 219 (M^+).

General Procedure for Thermal Cycloaddition of Benzoylketene (2a) to 1-Aryl-1-trimethylsilyloxyethylene (3)

A mixture of **1a** (500 mg, 2.87 mmol) and **3** (2 mol eq.) in toluene (10 ml) was heated at 100°C for 1 h in a sealed tube. After the reaction mixture was concentrated to dryness *in vacuo*, the residue was chromatographed over SiO_2 . Elution with benzene- CH_2Cl_2 (1:1) and recrystallizations of the eluate from appropriate solvents gave the pyran-4-one (**5**) and the triketone (**6**).

1) Reaction with 3a

5a: 191 mg (27%). Colorless needles from CH_2Cl_2 -benzene, mp 136-140°C [lit.,^{13,16} mp 138-140°C]. Ir: 1649, 1618. Uv: 283 (26200). ^1H -Nmr: 6.82 (2H, s), 7.5-7.9 (10H, m). ^{13}C -Nmr: 111.4 (sx2), 125.9 (dx4),

129.1 (dx4), 131.4 (sx2, dx2), 163.3 (sx2), 180.1 (s). HRms Calcd for $C_{17}H_{12}O_2$ (M^+): 248.0834. Found: 248.0832.

6a: 35 mg (5%). Yellow plates from ether, mp 103-106°C [lit.,^{13,17,18} mp 105-109°C]. Ir: 1601, 1570. Uv: 382 (30800). HRms Calcd for $C_{17}H_{14}O_3$ (M^+): 266.0942. Found: 266.0957.

2) Reaction with 3b.

6c: 15 mg (2%). Yellow needles from ether-hexane, mp 80-81°C. Ir: 1593, 1562, 1512, 1493. Uv: 386 (26400). HRms Calcd for $C_{18}H_{16}O_3$ (M^+): 280.1054. Found: 280.1104.

3) Reaction with 3c.

5e: 150 mg (19%). Colorless needles from CH_2Cl_2 , mp 158-160°C [lit.,^{13,19,20} mp 160-161°C]. Ir: 1644, 1601, 1570, 1512. Uv: 266 (25700), 297 (26000). 1H -Nmr: 3.89 (3H, s), 6.78 (1H, d, $J=2$ Hz), 6.83 (1H, d, $J=2$ Hz), 7.0-7.1 (2H, m), 7.5-7.6 (2H, m), 7.8-8.0 (5H, m). ^{13}C -Nmr: 55.5 (q), 109.8 (d), 111.1 (d), 114.5 (dx2), 123.6 (s), 125.8 (dx2), 127.5 (d), 129.0 (dx3), 131.2 (s), 131.5 (d), 162.2 (s), 162.9 (s), 163.2 (s), 180.1 (s). HRms Calcd for $C_{18}H_{14}O_3$ (M^+): 278.0942. Found: 278.0942.

6e: 70 mg (8%). Yellow needles from ether, mp 79-81°C [lit.,¹³ recrystallized from benzene, mp 121-122°C]. Ir: 1595, 1564, 1512, 1493. Uv: 384 (31100).

4) Reaction with 3d.

5g: 278 mg (37%). Pale brown needles from $CHCl_3$ -MeOH, mp 260-262°C. Ir: 1647, 1615, 1582, 1572, 1547, 1516. Uv: 265 (25400), 297 (24600). 1H -Nmr (acetone- d_6): 6.68 (1H, d, $J=2$ Hz), 6.78 (1H, d, $J=2$ Hz), 7.6-7.7 (4H, m), 7.9-8.1 (5H, m). ^{13}C -Nmr (acetone- d_6): 109.9 (d), 111.6 (d), 116.9 (dx2), 123.7 (s), 126.8 (dx2), 128.8 (d), 130.0 (dx3), 132.1 (d), 132.7 (s), 161.4 (s), 163.4 (s), 164.1 (s), 179.7 (s). HRms Calcd for $C_{17}H_{12}O_3$ (M^+): 264.0784. Found: 264.0799.

5) Reaction with 3e.

6i: 200 mg (23%). Yellow needles from CH_2Cl_2 -ether, mp 104-105°C [lit.,¹³ mp 106-107.5°C]. Ir: 1605, 1562, 1493. Uv: 384 (33400). HRms Calcd for $C_{17}H_{13}O_3Cl$ (M^+): 300.0550. Found: 300.0537.

6) Reaction with 3f.

6k: 23 mg (3%). Yellow prisms from ether, mp 100-102°C. Ir: 1597, 1562, 1510, 1493. HRms Calcd for $C_{17}H_{13}NO_5$ (M^+): 311.0791. Found: 311.0776.

General Procedure for Thermal Cycloaddition of *p*-Nitrobenzoylketene (2b) to 1-Aryl-1-trimethylsilyloxyethylene (3).

A mixture of **1b** (500 mg, 2.28 mmol) and **3** (2 mol eq.) in toluene (10 ml) was heated at 100°C for 1 h in a sealed tube. After the reaction mixture was concentrated to dryness *in vacuo*, the residue was purified by recrystallizations from appropriate solvents to afford the pyran-4-one (**5**). The mother liquor was chromatographed on SiO₂ and elution with benzene:hexane (1:1) gave the triketone (**6**).

1) Reaction with 3a.

5b: 340 mg (51%). Pale brown needles from CH₂Cl₂-benzene, mp 235-236°C. Ir: 1667, 1552. Uv: 301 (18500). ¹H-Nmr: 6.68 (1H, d, *J*=2 Hz), 6.92 (1H, d, *J*=2 Hz), 7.5-7.6 (3H, m), 7.8-8.1 (4H, m), 8.4-8.5 (2H, m). ¹³C-Nmr: 111.6 (d), 113.3 (d), 124.5 (dx2), 126.2 (dx2), 127.2 (d), 129.5 (dx3), 130.9 (s), 132.1 (d), 137.1 (s), 149.5 (s), 161.3 (s), 164.5 (s), 180.4 (s). HRms Calcd for C₁₇H₁₁NO₄ (M⁺): 293.0687. Found: 293.0547.

6b: 34 mg (5%). This was identical with the triketone (**6k**) described above.

2) Reaction with 3b.

5d: 180 mg (26%). Pale brown needles from CH₂Cl₂, mp 275-277°C. Ir: 1642, 1613, 1520. Uv: 278 (22900), 304 (22600). ¹H-Nmr: 2.47 (3H, s), 6.90 (1H, d, *J*=2 Hz), 7.00 (1H, d, *J*=2 Hz), 7.3-7.4 (2H, m), 7.8-7.9 (2H, m), 8.1-8.2 (2H, m), 8.4-8.5 (2H, m). HRms Calcd for C₁₈H₁₃NO₄ (M⁺): 307.0845. Found: 307.0870.

6d: 75 mg (10%). Yellow needles from CH₂Cl₂-ether, mp 168°C. Ir: 1599, 1522. Uv: 398 (32500). HRms Calcd for C₁₈H₁₅NO₅ (M⁺): 325.0950. Found: 325.0965.

3) Reaction with 3c.

5f: 450 mg (61%). Pale yellow needles from CH₂Cl₂, mp 257-258°C. Ir: 1649, 1605, 1514. Uv: 290 (32600). ¹H-Nmr (acetone-d₆): 3.92 (3H, s), 6.78 (1H, d, *J*=2 Hz), 6.98 (1H, d, *J*=2 Hz), 7.1-7.2 (2H, m), 8.0-8.4 (6H, m). HRms Calcd for C₁₈H₁₃NO₅ (M⁺): 323.0791. Found: 323.0780.

6f: 39 mg (5%). Yellow needles from AcOEt-hexane, mp 178-180°C. Ir: 1609, 1572, 1514. Uv: 407 (26800). HRms Calcd for C₁₈H₁₅NO₆ (M⁺): 341.0897. Found: 341.0890.

4) Reaction with 3d.

5h: 463 mg (63%). Orange needles from CHCl₃-MeOH, mp > 300°C. Ir: 1638, 1615, 1551, 1516. Uv: 291 (12600). HRms Calcd for C₁₇H₁₁NO₅ (M⁺): 309.0635. Found: 309.0624.

5) Reaction with 3e.

5j: 56 mg (7%). Colorless needles from CH₂Cl₂, mp 236-239°C. Ir: 1649, 1591, 1491. Uv: 263 (29300). ¹H-Nmr: 6.81 (1H, s), 6.83 (1H, s), 7.4-7.9 (8H, m). LRms : 316, 318 (peak, M-11).

6j: 156 mg (20%). Yellow needles from benzene, mp 149-150°C. Ir: 1603, 1562, 1491. Uv: 386 (35600). LRms (CI): 335 (peak, M-12).

6) Reaction with 3f.

6l: 21 mg (3%). Orange needles from CH₂Cl₂, mp 233-236°C. Ir: 1624, 1589, 1516. Uv: 400 (35300). HRms Calcd for C₁₇H₁₂N₂O₇ (M⁺): 356.0624. Found: 356.0639.

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