

Photoinduced Intramolecular Cyclization Reaction of 2-(2-Alkenoyl)-3-isopropylthio-1,4-benzoquinones to Heterocyclic Compounds

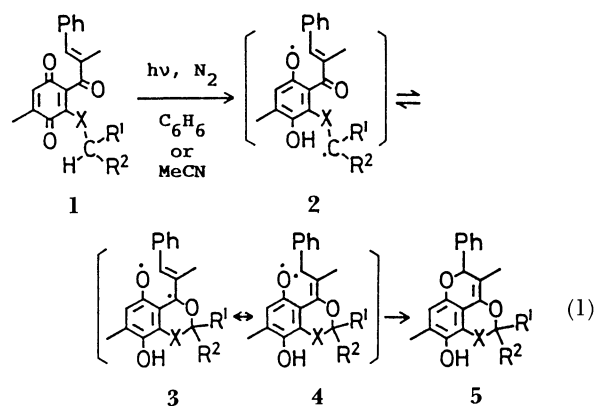
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(Received October 8, 1990)

Synopsis. Irradiation of 2-acryloyl- and 2-(1-cycloalkenylcarbonyl)-3-isopropylthio-1,4-benzoquinones in benzene gave tricyclic and tetracyclic compounds in good yields, respectively.

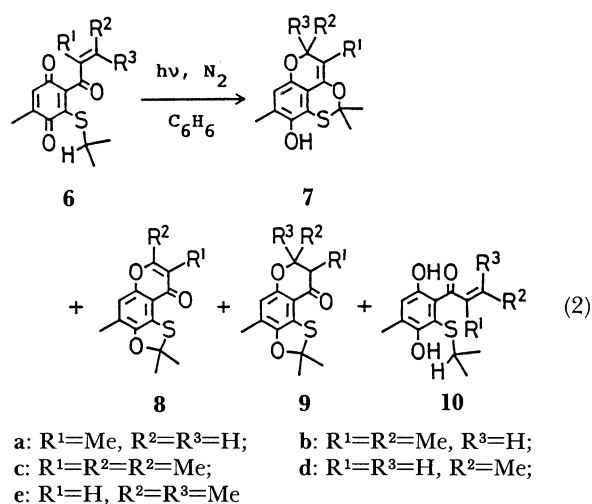
We recently reported that photochemical reactions of 3-alkoxy- (**1**, X=O)¹ and 3-alkylthio-2-cinnamoyl-1,4-benzoquinones (**1**, X=S)² give tricyclic compounds (**5**, X=O or S) in good yields together with other minor secondary products.^{2,3} In these reactions, the biradical intermediate **2** generated by an intramolecular hydrogen abstraction of **1** easily cyclizes with the carbonyl oxygen of the cinnamoyl group to give another cyclic intermediate **3**; it finally yields the tricyclic product **5** (Eq. 1).^{1,2} For an extension of this cyclization reaction, we examined the photochemical reaction of 2-acryloyl- (**6**) and 2-(1-cycloalkenylcarbonyl)-3-isopropylthio-1,4-benzoquinones (**11**).

X=O or S; R¹=R²=H, R¹=Me, R²=H, R¹=R²=Me

Results and Discussion

Irradiation of a benzene solution of **6** (0.01 mol dm⁻³) with light of wavelength longer than 410 nm under a nitrogen atmosphere for 1 h afforded a mixture of **7**,

8, **9**, and/or **10** (Eq. 2, Table 1), which were separated by column chromatography on silica gel. The tricyclic product **7** was a major product. A structural identification of these products was elucidated by spectral analyses and a chemical transformation. For example, the IR spectrum of **7** showed the presence of a hydroxyl group at ca. 3500 cm⁻¹ and the absence of a carbonyl group. The ¹H NMR spectrum of **7** showed the presence of two methyl groups arising from the isopropylthio group at δ ca. 1.69 (6H, s), and also suggested a change in the alkenoyl group to the corresponding enol type, as shown in the Experimental section. The ¹H NMR spectra of **8** and **9** also agreed with the proposed structures (Experimental section).



On the basis of the following results and a comparison with the reaction of **1**,^{2,3} products **8** would be oxidation products of **7**, and **9** would be an isomerization product of **7**. As shown in Table 1, the formation of **8** was always accompanied by hydroquinone **10** (Runs 1, 2, and 4). These results indicate that the quinone **6** oxidized product **7** to give **8**, together with

Table 1. Photochemical Reaction of **6**

Run	Quinone	Substituents			Yields of products/% ^{a)}			
		R ¹	R ²	R ³	7	8	9	10
1	6a	Me	H	H	80	11	0	6
2	6b	Me	Me	H	82	10	0	5
3	6c ^{b)}	Me	Me	Me	79	0	0	0
4	6d ^{b)}	H	Me	H	49	17	11	14
5	6e ^{b)}	H	Me	Me	77	0	8	0

a) Isolated yields based on the quinone used. b) The starting quinones **6c**, **6d**, and **6e** were recovered in 9%, 4%, and 12% yields, respectively.

10. The amount of **8** is always greater than that of hydroquinone **10** (Runs 1, 2, and 4), suggesting that product **7** can also be oxidized with air.

Since hydrogen at the R³-position of **7a**, **b**, or **d** is situated in both the allylic and α -alkoxyl positions, it should easily be abstracted by the quinone.⁴ This idea is supported by the fact that **7c** and **e**, which have no hydrogen at R³-position, afforded neither **8** nor **10** (Runs 3 and 5).

Product **9** was observed only in the reactions of **6d** and **e** (Runs 4 and 5). Therefore, products **7d** and **e**, which have a hydrogen at the R¹-position, may be less stable than **7a**, **b**, and **c**, which have a methyl group (Runs 1, 2, and 3).⁵

Irradiation of **11** under the same conditions gave the corresponding tetracyclic product **12** in good yield together with **13** and **15** (Eq. 3, Table 2). Since the structures of **11a–c** agreed with the type of **6b**, the isomerization product **14** was not obtained.⁵ The amounts of the oxidation products, **13b** and **c**, were larger than that of **13a**. This result indicates that products **12b** and **c**, which have a six- or seven-membered ring, are more reactive than **12a**, which has a five-membered ring.⁶

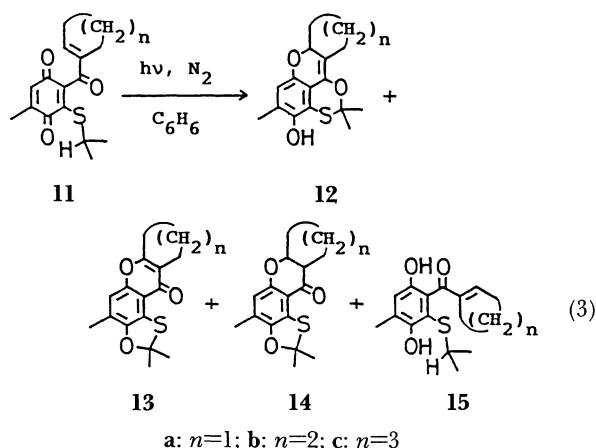


Table 2. Photochemical Reaction of **11**

Run	Quinone	(CH ₂) _n n	Yields of products/% ^a			
			12	13	14	15
6	11a	1	90	5	0	4
7	11b	2	63	21	0	14
8	11c	3	69	20	0	10

a) Isolated yields based on the quinone used.

In any event, these cyclization paths can be consistently explained by a modification of Eq. 1, and the irradiation of 2-(2-alkenoyl)-3-isopropylthio-1,4-benzoquinones which have an α,β -unsaturated carbonyl group as an alkenoyl side chain, should generally give the corresponding cyclization product in good yield.

Experimental

All of the melting points are uncorrected. The ¹H NMR spectra were measured using a JEOL JNM-GX 270 spectrometer in CDCl₃ using TMS. The IR (CCl₄) spectra were

recorded on a Hitachi 260-50 spectrometer. Elemental analyses (C and H) were agreed within $\pm 0.3\%$.

Quinones **6** and **11** were prepared by modified methods of Farina and Valderrama⁷ and Jacob et al.,⁸ as described in a previous paper.² The characteristic physical properties of **6** and **11** are described.

3-Isopropylthio-3-methacryloyl-5-methyl-1,4-benzoquinone (6a): Red oil; IR (CCl₄) 1660 cm⁻¹; ¹H NMR (270 MHz, CDCl₃) δ =1.24 (6H, d, J =6.8 Hz, SCHMe₂), 2.01 (3H, dd, J =1.5 and 0.7 Hz, COCMe=CH₂), 2.12 (3H, d, J =1.7 Hz, CH=CMe), 3.96 (1H, m, J =6.8 Hz, SCHMe₂), 5.74 (1H, m, J =0.7 Hz, COCMe=CHH), 6.02 (1H, m, J =1.5 Hz, COCMe=CHH), 6.61 (1H, q, J =1.7 Hz, CH=CMe). Anal. (C₁₄H₁₆O₃S) C, H.

6b: Red oil; IR 1675 cm⁻¹; ¹H NMR δ =1.89 (3H, d, J =7.3 Hz), 1.90 (3H, d, J =1.7 Hz), 6.47 (1H, mq, J =7.3 and 1.7 Hz). Anal. (C₁₅H₁₈O₃S) C, H.

6c: Red oil; IR 1665 cm⁻¹; ¹H NMR δ =1.85 (3H, d-like, J =1.2 Hz), 1.91 (3H, s), 2.11 (3H, d-like, J =1.2 Hz). Anal. (C₁₆H₂₀O₃S) C, H.

6d: Orange prisms, mp 70–72 °C; IR 1670 cm⁻¹; ¹H NMR δ =1.96 (3H, dd, J =6.8 and 1.5 Hz), 6.28 (1H, dq, J =15.9 and 1.5 Hz), 6.71 (1H, dq, J =15.9 and 6.8 Hz). Anal. (C₁₄H₁₆O₃S) C, H.

6e: Orange prisms, mp 55–56 °C; IR 1650 cm⁻¹; ¹H NMR δ =1.95 (3H, d, J =1.2 Hz), 2.25 (3H, d, J =1.0 Hz), 6.11 (1H, m). Anal. (C₁₅H₁₈O₃S) C, H.

2-(1-Cyclopentenylcarbonyl)-3-isopropylthio-5-methyl-1,4-benzoquinone (11a): Orange needles, mp 87–89 °C; IR 1660 cm⁻¹; ¹H NMR δ =1.95–2.10 (2H, m, J =7.6 Hz), 2.50–2.75 (4H, m), 6.54 (1H, ms). Anal. (C₁₆H₁₈O₃S) C, H.

11b: Orange prisms, mp 78–80 °C; IR 1670 cm⁻¹; ¹H NMR δ =1.6–1.75 (4H, m), 2.23 (2H, bs), 2.36 (2H, bs), 6.63 (1H, ms). Anal. (C₁₇H₂₀O₃S) C, H.

11c: Orange prisms, mp 67–69 °C; IR 1660 cm⁻¹; ¹H NMR δ =1.52–1.62 (4H, m), 1.75–1.85 (2H, m), 2.30–2.40 (2H, m), 2.60–2.65 (2H, m), 6.79 (1H, t, J =6.6 Hz). Anal. (C₁₈H₂₂O₃S) C, H.

Photochemical Reaction of 6. A solution of **6** (0.3 mmol) in 30 cm³ of benzene was degassed under reduced pressure and replaced with N₂, and then irradiated with a 300-W halogen lamp through a yellow glass filter (<410 nm cut off) at room temperature for 1 h. After irradiation, the solvent was removed in vacuo and the resulting oil chromatographed on a silica-gel column with benzene as the eluent. The first yellow component was **7** and/or **9**, the second was **8**, and the third was **10**. The yields of products **7**, **8**, **9**, and **10** are summarized in Table 1.

2,2,4,8-Tetramethyl-5H-pyrano[4,3,2-de][3,1]benzo-xathiin-9-ol (7a): Oil; IR 3500, 1670 (w), 1180 cm⁻¹; ¹H NMR δ =1.69 (6H, s, 2-Me₂), 1.70 (3H, d, J =1.2 Hz, 4-Me), 2.18 (3H, s, 8-Me), 4.65 (1H, bs, 9-OH), 4.70 (2H, bs, 5-H₂), 6.41 (1H, s, 7-H).

2,2,4,8-Tetramethyl-9H-oxathiolo[4,5-f][1]benzopyran-9-one (8a): Pale yellow prisms, mp 131–132 °C; IR 1650, 1430 cm⁻¹; ¹H NMR δ =1.85 (6H, s, 2-Me₂), 1.99 (3H, d, J =1.0 Hz, 8-Me), 2.29 (3H, s, 4-Me), 6.86 (1H, s, 5-H), 7.67 (1H, q, J =1.0 Hz, 7-H). Anal. (C₁₄H₁₄O₃S) C, H.

7b: Oil; IR 3510, 1665 (w), 1180 cm⁻¹; ¹H NMR δ =1.34 (3H, d, J =6.6 Hz), 1.62 (3H, s), 4.65 (1H, s), 4.82 (1H, q, J =6.6 Hz).

8b: Pale yellow needles, mp 182–183 °C; IR 1635, 1430 cm⁻¹; ¹H NMR δ =2.01 (3H, s), 2.35 (3H, s). Anal. (C₁₅H₁₆O₃S) C, H.

7c: Oil; IR 3510, 1650 (w), 1185 cm⁻¹; ¹H NMR δ =1.40 (6H, s), 1.74 (3H, s), 4.47 (1H, s).

9c: Pale yellow oil; IR 1680, 1610, 1420 cm⁻¹; ¹H NMR δ =1.19 (3H, d, J =7.1 Hz), 1.27 (3H, s), 1.46 (3H, s), 2.67 (1H, q, J =7.1 Hz). Anal. (C₁₆H₂₀O₃S) C, H.

7d: Oil; IR 3500, 1670 (w), 1185 cm^{-1} ; $^1\text{H NMR}$ $\delta=1.42$ (3H, d, $J=6.3$ Hz), 4.73 (1H, bs), 5.00 (1H, d, $J=3.2$ Hz), 5.00–5.10 (1H, m, 5-H).

8d: Pale yellow needles, mp 140–141 $^{\circ}\text{C}$; IR 1650, 1420 cm^{-1} ; $^1\text{H NMR}$ $\delta=2.31$ (3H, s), 6.05 (1H, s). Anal. ($\text{C}_{14}\text{H}_{14}\text{O}_3\text{S}$) C, H.

2,2,4,7-Tetramethyl-7H-oxathiol[4,5-f][1]benzopyran-9(8H)-one (9d): Pale yellow prisms, mp 94–95 $^{\circ}\text{C}$; IR 1685, 1615, 1415 cm^{-1} ; $^1\text{H NMR}$ $\delta=1.47$ (3H, d, $J=6.3$ Hz, 7-Me), 1.81 (6H, s, 2-Me₂), 2.19 (3H, d, $J=0.7$ Hz, 4-Me), 2.55–2.70 (2H, m, 8-H₂), 4.40–4.55 (1H, m, 7-H), 6.43 (1H, q, $J=0.7$ Hz, 5-H).

7e: Oil, IR 3500, 1645 (w), 1185 cm^{-1} ; $^1\text{H NMR}$ $\delta=1.42$ and 1.43 (6H, each s), 4.55 (1H, s), 4.99 (1H, s).

9e: Pale yellow prisms, mp 118–119 $^{\circ}\text{C}$; IR 1680, 1615, 1415 cm^{-1} ; $^1\text{H NMR}$ $\delta=1.41$ (6H, s), 2.55 (2H, s). Anal. ($\text{C}_{15}\text{H}_{18}\text{O}_3\text{S}$) C, H.

A photochemical reaction of **11** was similarly carried out for **6** described above. On the column, the first yellow component was **12**, the second was **13**, and the third was **15**. The yields of products **12**, **13**, and **15** are summarized in Table 2.

2,2,5-Trimethyl-7a,8,9,10-tetrahydrocyclopenta[5,6]pyrano[4,3,2-de][3,1]benzoxathiin-4-ol (12a): Oil; IR 3500, 1680 (w), 1180 cm^{-1} ; $^1\text{H NMR}$ $\delta=1.55$ –2.0 (4H, m), 2.25–2.60 (2H, m), 4.75 (1H, bs), 5.07 (1H, t-like).

2,2,4-Trimethyl-7,8,9,10-tetrahydrocyclopenta[b][3,1]oxathiol[4,5-f][1]benzopyran-10-one (13a): Yellow needles, mp 236–238 $^{\circ}\text{C}$; IR 1630, 1440 cm^{-1} ; $^1\text{H NMR}$ $\delta=2.09$ (2H, m, 7.5 Hz), 2.81 (2H, t-like, $J=7.5$ Hz), 2.92 (2H, t-like, $J=7.5$ Hz). Anal. ($\text{C}_{16}\text{H}_{16}\text{O}_3\text{S}$) C, H.

12b: Oil; IR 3500, 1665 (w), 1185 cm^{-1} ; $^1\text{H NMR}$ $\delta=1.15$ –1.45 (2H, m), 1.55–1.90 (4H, m), 2.15–2.25 (1H, m), 2.95 (1H, bd, $J=14.0$ Hz), 4.55 (1H, s), 4.92 (1H, dd, $J=11.0$ and 5.4 Hz).

13b: Pale yellow needles, mp 149–151 $^{\circ}\text{C}$; IR 1630, 1430 cm^{-1} ; $^1\text{H NMR}$ $\delta=1.65$ –1.9 (4H, m), 2.51 (2H, t-like, $J=6.3$ Hz), 2.59 (2H, t-like, $J=6.3$ Hz). Anal. ($\text{C}_{17}\text{H}_{18}\text{O}_3\text{S}$) C, H.

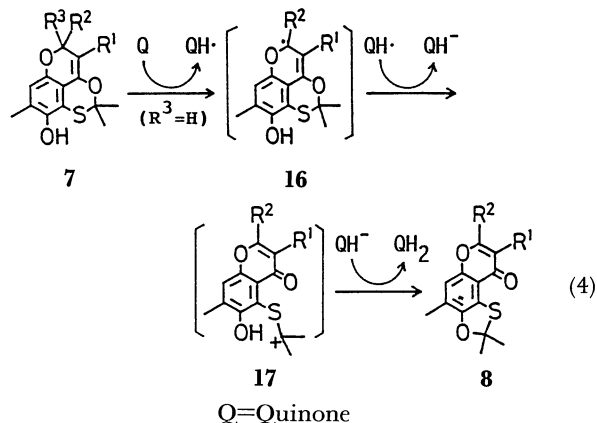
12c: Oil; IR 3500, 1645 (w), 1190 cm^{-1} ; $^1\text{H NMR}$ $\delta=1.5$ –2.1 (7H, m), 2.65–2.75 (1H, m), 4.70 (1H, s), 4.92 (1H, dd, $J=6.5$ and 3.5 Hz).

13c: Pale yellow prisms, mp 173–174 $^{\circ}\text{C}$; IR 1615, 1420, 1205 cm^{-1} ; $^1\text{H NMR}$ $\delta=1.55$ –1.9 (6H, m), 2.70–2.80 (4H,

m). Anal. ($\text{C}_{18}\text{H}_{20}\text{O}_3\text{S}$) C, H.

References

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- 2) H. Iwamoto, *Bull. Chem. Soc. Jpn.*, **62**, 3479 (1989).
- 3) The minor product corresponds to **8** in Eq. 2. H. Iwamoto, *Chem. Express*, **4**, 145 (1989).
- 4) The oxidation reaction of **5S** with quinone has been examined, and the possible reaction mechanism for **7** can be proposed to Eq. 4 as described in previous paper.³⁾



5) The isomerization of **7** to **9** was accelerated by the presence of a weak acid as described in previous paper.²⁾ The other **7a–c** and **12a–c**, of course, can be respectively converted into **9a–c** and **14a–c** in the presence of a weak acid.

6) Probably, the radical intermediate of type **16** from **12b** must be more stable than that from **12a**, because the former having six-membered ring is more flexible than the latter having five-membered ring. c.f. R. Srinivasan and F. I. Sonntag, *J. Am. Chem. Soc.*, **89**, 407 (1967).

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