Registry No.—**4g,** 68186-11-8; **5q,** 68186-12-9; **6,** 68186-13-0; **7,** 26257-70-5; trimethylchlorosilane, 75-77-4.

References and Notes

(1) From the Thèse d'Etat of J.-P. Picard, Université de Bordeaux I, 1976.
(2) J.-P. Picard, R. Calas, J. Dunoguès, and N. Duffaut, *J. Organomet. Chem.*, **26,** 183 (1971).
(3) Ketals **2e, 2k,** and **2l** are very sensitive to hydrolysis and give directly the corresponding acylsilanes.
(4) A. G. Brook and P. J. Dillon, *Can. J. Chem.*, **47,** 4347 (1969).
(5) This procedure has been successfully applied to the synthesis of ^{13}C labeled **4a:** W. Ando, A. Sekiguchi, A. J. Rothschild, R. R. Gallucci, M. Jones, Jr., T. J. Barton, and J. A. Kilgour, *J. Am. Chem. Soc.*, **99,** 6995 (1977).
(6) A. G. Brook, *Adv. Organomet. Chem.*, **7,** 85 (1968).
(7) Benzoic acid **1n** and its anhydride **1o** are precursors of **1m,** since they react with $Me_3SiCl/Mg/HMPT$ to form **1m** and respectively hydrogen and benzoyltrimethylsilane **3a,** which reacts further.[2]
(8) Upon hydrolysis, **4** gives the corresponding carbinol which easily oxidizes in air into benzoic acid and hexamethyldisiloxane.[2]
(9) H. Bock, H. Alt, and H. Seidl, *J. Am. Chem. Soc.*, **91,** 357 (1969).
(10) Formation of such compounds involves the aromatization of **5: 5q** leads to *p*-trimethylsilylbenzaldehyde and **5r** to trimethylsilyl *p*-trimethylsilylbenzoate (with evolution of isobutene), both of which are silylated further.
(11) A. Luttringhaus and H. W. Diritsen, *Angew. Chem.*, 260 (1964).
(12) H. Normant, *Bull. Soc. Chim. Fr.*, 791 (1968); *Angew. Chem., Int. Ed. Engl.*, **6,** 1046 (1967).
(13) M. T. Reetz, *Adv. Organomet. Chem.*, **16,** 33 (1977).
(14) R. West, P. Nowakowski, and P. Boudjouk, *J. Am. Chem. Soc.*, **98,** 5620 (1976).
(15) J. A. Zapp, Jr., *Science*, 190 (1975).
(16) C. Eaborn and P. M. Jackson, *J. Chem. Soc. B*, 21 (1969).
(17) J. F. Norris and G. W. Rigby, *J. Am. Chem. Soc.*, **54,** 2098 (1932).
(18) H. H. Anderson, *J. Am. Chem. Soc.*, **74,** 2371 (1952).
(19) M. Biensan, Thèse d'Etat, Bordeaux, 1959.
(20) B. N. Dolgov, N. P. Kharitonov, and M. G. Voronkov, *Zh. Obshch. Khim.*, **24,** 861 (1954), *J. Gen. Chem. USSR (Engl. Transl.)*, **24,** 859 (1954).
(21) E. Frainnet and M. Paul, *C. R. Hebd. Seances Acad. Sci., Ser. C,* **265,** 1185 (1967).
(22) $MgCl_2$·$(HMPT)_2$ has been previously isolated and identified.[2]
(23) J. Dunoguès, E. Jousseaume, and R. Calas, *J. Organomet. Chem.*, **71,** 377 (1974).

Reactions of Lithio Derivatives of Carboxylic Acids. 2. Alkylations and Cyclizations of Substituted Acrylic Acids

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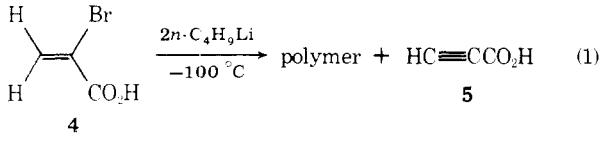
2-Substituted 3-phenylcinnamic acids are obtained in good yields by effecting bromine–lithium exchange with 2-bromo-3-phenylcinnamic acid and 2 molar equiv of *n*-butyllithium at −100 °C and subsequent reaction with electrophiles (e.g., CH_3I, Ph_2CO, PhS_2Ph). Oxiranes afford γ-butyrolactones in modest yields. In contrast, 2-bromoacrylic acid polymerizes under such conditions and (*Z*)-2-bromocinnamic acid dehydrobrominates at −140 °C. Friedel–Crafts cyclization of 2-alkyl-3-phenylcinnamic acids affords 2-alkyl-3-phenylinden-1(1*H*)-ones in good yields.

Bromine–lithium exchange at low temperature allows the preparation of organolithium compounds which contain electrophilic functionality or which are otherwise thermolabile.[2,3] For example, it was shown that techniques used for such exchange at −100 °C with bromoarylcarboxylic acids[2c] were applicable to an aliphatic bromo acid.[2b] The objectives of the present study were to establish more clearly the scope of this reaction in vinylic bromides[4] and to demonstrate its utility for introducing cyclic units.

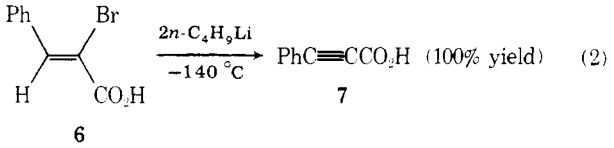
2-Substituted 3-Phenylcinnamic Acids. Bromine–lithium exchange with 2-bromo-3-phenylcinnamic acid (**1**) and 2 molar equiv of *n*-butyllithium in THF at −100 °C was efficient, and good yields of 2-alkylated acids (**3,** Table I) were obtained with most electrophilic reagents tested. In contrast, attempts to condense the dilithio derivative of **1** (i.e., **2**) with phenyl isothiocyanate or *tert*-butyl acrylate yielded polymeric material, and only **3a** was obtained with allyl *p*-toluenesulfonate. Metalation of the 2 position of **3a** was not effected by *n*-butyllithium in THF at −100 °C, even in the presence of Dabco (1,4-diazabicyclo[2.2.2]octane), although evidence for analogous metalation of the benzyl ester of **3a** (by lithium 2,2,6,6-tetramethylpiperidide) has been described.[7]

2-Bromo Acids with 3-Hydrogen. All attempts to effect bromine–lithium exchange with 2-bromoacrylic acid (**4**) were unsuccessful. Lithiation of **4** at −100 °C (eq 1) rapidly gave



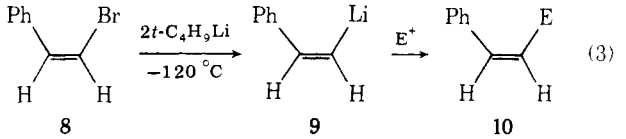
4 5 (1)

a polymeric mixture (whose NMR spectrum exhibited evidence for **5**), and only phenylpropynoic acid (**7**) was obtained from the reaction of **6** with 2 molar equiv of *n*-butyllithium, even at −140 °C (eq 2) (Köbrich obtained similar results at



6 7 (2)

−115 °C[4c]). These results were not unexpected in view of the observation by Seebach that the vinyllithium compound **9,** prepared as shown in eq 3, and others prepared analogously



8 9 10 (3)

were stable at −120 °C but at −110 °C dehydrobromination occurred rapidly.[3] In a related study, Köbrich found that bromine–lithium exchange could be effected with (*E*)-2-bromocinnamic acid (**11**) and *n*-butyllithium in a Trapp mixture at −115 °C, but protonation yielded a mixture of (*E*)- and (*Z*)-cinnamic acids.[4b,c]

It is improbable that the carboxylate anion renders the 3-proton of **6** more acidic, relative to the 3-proton of **8,** by either inductive (weak for CO_2^-) or resonance (without invoking carbonium ion structures) effects. More attractive is the hypothesis that this difference in reactivity results from carboxylate-directed lithiation, through an arrangement such

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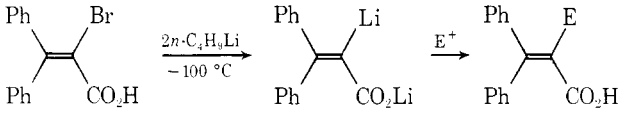
Table I. Carboxylic Acids Obtained from Reaction of Lithio Derivative 2 with Electrophiles

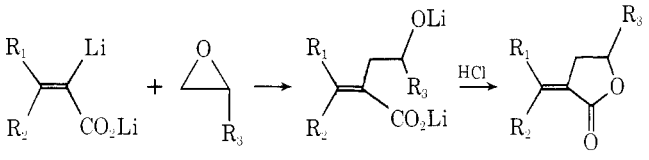


1 2 3

acid	electrophile	registry no.	E	isolated yield, %	mp, °C	IR ($\nu_{C=O}$), cm^{-1}
3a	H_2O	7732-18-5	H	74	157–158.5[a]	1690[b]
3b	CH_3I	74-88-4	CH_3	73[c]	151.5–155[d]	1690[b]
3c		108-94-1		62[c]	152.5–154.5 dec	1690[b]
3d	$(C_6H_5)_2C{=}O$	119-61-9	$C(OH)(C_6H_5)_2$	47	162.5–164.5	1690[b]
3e	$(C_6H_5S)_2$	882-33-7	SC_6H_5	68	214–215	1680[e]
3f	$(C_6H_5CH_2S)_2$	150-60-7	$SCH_2C_6H_5$	61	140–142	1685[b]

[a] Lit.[5] mp 157–159 °C. [b] $CHCl_3$ solution. [c] Contained a trace of **3a**. [d] Lit.[6] mp 163 °C. [e] Mineral oil mull.

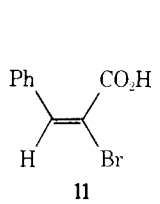
Table II. γ-Butyrolactones Obtained from Reaction of Lithium 2-Lithiocarboxylates with Oxiranes



14

2-lithio derivative	lactone	yield, %	mp, °C	IR ($\nu_{C=O}$), cm^{-1}
2	**14a**, $R_1 = R_2 = Ph$; $R_3 = H$	48[a]	167.5–169.5[b]	1755[c]
2	**14b**, $R_1 = R_2 = Ph$; $R_3 = CH_3$	21[a]	116–117	1755[c]
2	**14c**, $R_1 = R_2 = R_3 = Ph$	6[a]	170.5	1755[c]
13	**15**, $R_1 = R_2 = CH_3$; $R_3 = H$	10[d,e]		1745[f]
13	**16**	16[e]		1760[f]
13	**17**	4[e]		1760[f]

[a] Isolated. [b] Lit.[8] mp 178–179 °C (EtOH). [c] $CHCl_3$ solution. [d] See ref 9. [e] By GLC analysis. [f] Thin film.



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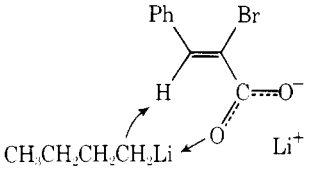
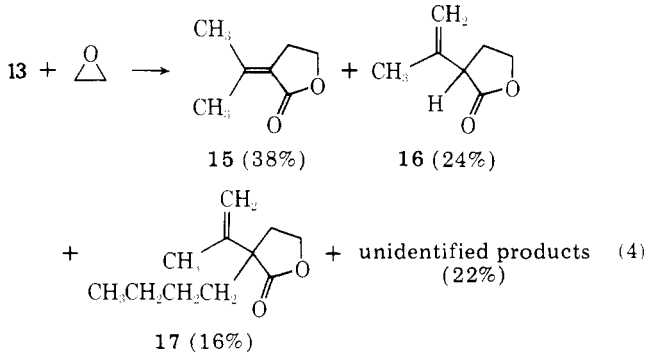


12

as **12**. Such an orientation is not possible for either **8** or **11** (which, it is noted, do undergo Br–Li exchange at −115 °C[4c]).

γ-Butyrolactones. Reaction of the vinyllithium compound **2** or lithium 2-lithio-3-methyl-2-butenoate (**13**)[2b] with an oxirane afforded the salt of an intermediate hydroxy acid. This was not isolated but directly cyclized with HCl in 1,2-dimethoxyethane to afford substituted γ-butyrolactones (**14–17**, Table II). Because the yield of lactone decreases with the increasing ability of the alkyl group from the oxirane (R_3 in Table II) to stabilize a carbonium ion, it is believed that dehydration to dienes is a major competing reaction. α-Methylene-γ-butyrolactone could not be prepared by this method because the required vinyllithium precursor could not be obtained (eq 1). The reaction of **13** with oxirane afforded a mixture from which lactones **15, 16,** and **17** were isolated by GLC (eq 4). The processes by which isopropenyl compounds such as **16** and **17** are formed from **13** have been discussed.[2b] The intramolecular condensation of aryllithiooxiranes has been recently investigated in these laboratories.[2e]

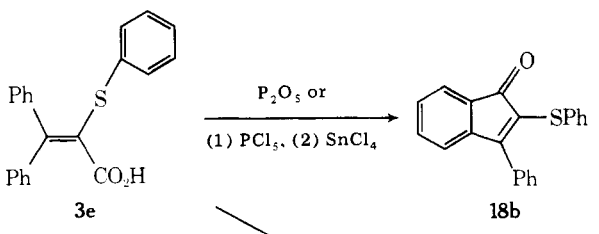


15 (38%) 16 (24%)

17 (16%)

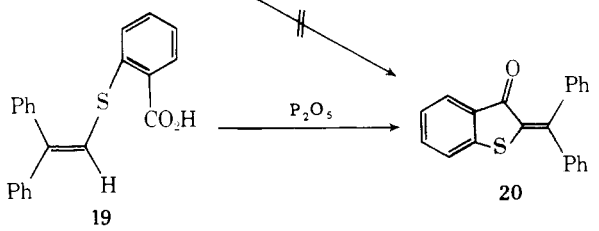
(4)

Indenones. Some of the 3-phenylcinnamic acids obtained from **2** were cyclized by Friedel–Crafts procedures to afford



3e 18b

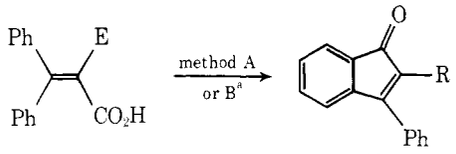
(5)



19 20

(6)

Table III. 3-Phenylinden-1(1*H*)-ones Obtained from Friedel–Crafts Cyclizations

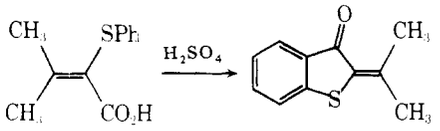


3 18

indenone	obtained from	isolated yield, %	mp, °C	UV, nm (ε), solvent
18a, R = CH_3	**3b** by A	19	75–77.5[b]	*b*
18b, R = SC_6H_5	**3e** by A	78	141.5–142[c]	253.5 (23 000), hexane
	3e by B	70		
18c, R = $SCH_2C_6H_5$	**3f** by A	54	72–73[c]	244.0 (17 000); 269.5 (21 000), hexane
18d, R = $SO_2C_6H_5$	**18b** + H_2O_2	23	174.5–176.5[c,d]	251.5 (25 000), CH_3OH
18e, R = $S^+(CH_3)C_6H_5\ BF_4^-$	**18b** + CH_3I + $AgBF_4$	60	55–130 dec[c]	

[a] Method A: (1) $SOCl_2$ or PCl_5, (2) $SnCl_4$. Method B: P_2O_5 in benzene. [b] Lit.[10] mp 91 °C. Vis spectrum appears in ref 10. [c] IR ($\nu_{C=O}$): 1710 cm^{-1} for **18b** and **18c** (films from CCl_4), **18d** (mineral oil mull), and **18e** (thin film). [d] IR ($\nu_{S=O}$): 1150, 1325 cm^{-1}.

3-phenylinden-1(1*H*)-ones (**18**, Table III). It is of interest to compare the cyclization of **3e** by phosphorus pentoxide (eq 5) with that of the isomeric **19** in a similar reaction described by Awad and Abdul-Malik (eq 6).[11] Although it was anticipated that cyclization would occur at the presumably more reactive phenylthio group, this study found that reaction at the neighboring β-phenyl group afforded the indenone **18b** in good yield. Similarly, cyclization of **3f** afforded indenone **18c** and not a sulfur heterocycle. Where cyclization to a β-phenyl group was not possible, as for **21**,[2b] a benzo[*b*]thiophen-3(2*H*)-one (**22**)[12] was obtained (eq 7).



21 22 (7)

With the exceptions of acids with 3-hydrogen, bromine–lithium exchange provides a useful means for the 2-alkylation of 2-bromo-2-alkenoic acids. For the exceptions, a number of synthesis alternatives are available. The methyl esters of (*Z*)-2-bromocrotonic acid and **11** afford copper(I) derivatives with lithium dimethylcuprate(I) at −80 °C.[13] The direct 2-arylation of **11** with phenyllithium, albeit in poor yield, has been reported, and no accounting of starting material is made.[14] Various organometallic species which are synthetically related to lithium 2-lithioacrylate have been described by Marino[15] and Ficini.[16]

Experimental Section

The general procedures have been previously described.[2b] Infrared and ultraviolet spectral data were obtained with Perkin-Elmer Model 297 and Model 576 spectrophotometers, respectively. GLC analyses were performed on a column of 20% SE-30 on 60–80 mesh Chromosorb W (4 ft × 0.25 in., 160 °C, 60 mL/min He) with a Varian Model 910 gas chromatograph. All melting points were determined on a Mel-Temp heating block apparatus and are corrected.

2-Bromo-3-phenylcinnamic acid (1) was prepared by bromination of 3-phenylcinnamic acid[5] in CH_2Cl_2 (HBr is readily eliminated) in 66% yield: mp 148.5–151 °C (lit.[17] mp 148–150 °C); mass spectrum (70 eV), *m/e* 304 (M^+), 302, 233 (M^+ − Br).

Lithiation of 2-Bromo-3-phenylcinnamic Acid. Detailed procedures for low temperature lithiation are described elsewhere.[2] A solution of **1** in dry tetrahydrofuran (10 mL of THF/mmol of **1**) was cooled to −100 °C, and 2 molar equiv of *n*-butyllithium (hexane solution) was added to afford the lithio derivative **2**. After the reaction mixture had been stirred for 15 min at −100 °C, a solution of the electrophile in tetrahydrofuran (25 mL) was added. The reaction mixture was allowed to warm to room temperature (an additional 12 h was allowed for the oxirane reactions) and was processed as previously described.

γ-Butyrolactones (2(3*H*)-Furanones). The hydroxy acids obtained from treatment of the aqueous solution of reaction products with concentrated hydrochloric acid were extracted with diethyl ether, concentrated, and dissolved in dry 1,2-dimethoxyethane (150 mL). These solutions were saturated with dry hydrogen chloride and stirred at room temperature for 18 h. The solvent was removed (rotary evaporator), and the residues were purified as described herein.

A. 2-(Diphenylmethylidene)-γ-butyrolactone (14a)[8] was obtained from **2** (0.010 mol) and oxirane (0.75 g, 0.017 mol). Recrystallization from ligroin afforded fine yellow needles: 1.22 g (48% yield); NMR ($CDCl_3$) δ 3.11 (t, *J* = 7 Hz, 2, OCH_2CH_2), 4.32 (t, *J* = 7 Hz, 2, OCH_2CH_2), 7.0–7.6 (m, 10, ArH).

Anal. Calcd for $C_{17}H_{14}O_2$: C, 81.58; H, 5.64. Found: C, 81.29; H, 5.50.

B. 2-(Diphenylmethylidene)-4-methyl-γ-butyrolactone (14b) was obtained from **2** (0.010 mol) and methyloxirane (0.64 g, 0.011 mol). Column chromatography (activity 1 alumina, 2.5 × 25 cm column) using a mixture of dichloromethane and acetone (19:1) as the eluent afforded semicrystalline lactone which was recrystallized from a mixture of hexane and dichloromethane (99:1) to afford yellowish prisms: 0.57 g (21% yield); NMR ($CDCl_3$) ($AMNX_3$) δ 1.39 (d, $^3J_{AX}$ = 7 Hz, 3, CH_3), 2.69 (calcd, dd, $^2J_{MN}$ = 16 Hz, $^3J_{NX}$ = 7 Hz, 1, H_N), 3.10 (calcd, dd, $^2J_{MN}$ = 16 Hz, $^3J_{MX}$ = 7 Hz, 1, H_M), 4.91 (sextet, 1, methine H_A), 7.0–7.4 (m, 15, ArH).

Anal. Calcd for $C_{18}H_{16}O_2$: C, 81.79; H, 6.10. Found: C, 81.87; H, 6.20.

C. 2-(Diphenylmethylidene)-4-phenyl-γ-butyrolactone (14c) was obtained from **2** (0.010 mol) and phenyloxirane (1.32 g, 0.011 mol). Three recrystallizations from a mixture of hexane and dichloromethane (19:1) afforded fine yellowish needles: 0.22 g (6% yield); NMR ($CDCl_3$) (AXY) δ 3.16 (calcd, dd, $^2J_{XY}$ = 16 Hz, $^3J_{AY}$ = 7 Hz, 1, H_Y), 3.47 (calcd, dd, $^2J_{XY}$ = 16 Hz, $^3J_{AX}$ = 7 Hz, 1, H_X), 5.50 (t, 1, methine H_A), 7.0–7.4 (m, 15, ArH).

Anal. Calcd for $C_{23}H_{18}O_2$: C, 84.64; H, 5.56. Found: C, 84.57; H, 5.50.

Reaction of **13** (prepared from 0.050 mol of 2-bromo-3-methyl-2-butenoic aicd)[2b] with oxirane (2.64 g, 0.060 mol) afforded 2.72 g of yellowish liquid, found by GLC analysis to be a mixture of at least seven components. The three major components were isolated (listed in order of their elution).

D. 2-Isopropenyl-γ-butyrolactone (16) (24%, 10% yield) was obtained as a colorless liquid: NMR ($CDCl_3$) δ 1.84 (s, 3, CH_3), 2.2–2.5 (m, 2, CH_2CH_2O), 3.1–3.4 (m, 1, methine H), 4.1–4.4 (m, 2, CH_2CH_2O), 4.90 (d, 2, CH_2=C).

Anal. Calcd for $C_7H_{10}O_2$: C, 66.64; H, 7.99. Found: C, 66.72; H, 8.32.

E. 2-Isopropylidene-γ-butyrolactone (15) (38%, 16% yield) yielded IR and NMR data which agreed with that obtained by Turro.[9]

F. 2-Isopropenyl-2-*n*-butyl-γ-butyrolactone (17) (16%, 4% yield) was obtained as a colorless liquid: NMR ($CDCl_3$) δ 0.90 (t, 3, $CH_2CH_2CH_2CH_3$), 1.1–1.8 (m, 6, $CH_2CH_2CH_2CH_3$), 1.81 (s, 3, CH_2=CCH_3), 2.1–2.5 (m, 2, CH_2CH_2O), 4.1–4.3 (m, 2, CH_2CH_2O),

4.96 (d, 2, CH_2=CCH_3).

Anal. Calcd for $C_{11}H_{18}O_2$: C, 72.49; H, 9.96. Found: C, 72.37; H, 10.15.

2-Substituted 3-Phenylcinnamic Acids. Processing details may be found in ref 2b.

A. 3-Phenylcinnamic acid (3a)[5] was obtained by quenching the lithio derivative **2** (0.010 mol) in water after 15 min. The precipitate (2.17 g) obtained upon acidification of the alkaline solution was recrystallized from a mixture of ligroin and toluene (3:1) to afford **3a** as white prisms, 1.66 g (74% yield).

B. 2-Methyl-3-phenylcinnamic acid (3b)[6] was obtained from **2** (0.010 mol) and methyl iodide (7.10 g, 0.050 mol). The precipitated oily solid was extracted with diethyl ether, and the extracts were washed with aqueous sodium thiosulfate and concentrated. The residue was recrystallized from a mixture of petroleum ether and toluene (1:3) to afford **3b** as yellowish prisms: 1.76 g (73% yield); mp 151–152.5 °C [raised to 151.5–155 °C by an additional recrystallization, but still contained a trace of **3a** (by NMR)]; NMR ($CDCl_3$) δ 2.04 (s, 3, CH_3), 7.1–7.5 (m, 10, ArH), 9.8 (s, 1, CO_2H) [δ 6.34 (s, **3a** impurity)].

Anal. Calcd for $C_{16}H_{14}O_2$: C, 80.64; H, 5.92. Found: C, 80.55; H, 5.92.

C. 2-(1-Hydroxycyclohexyl)-3-phenylcinnamic acid (3c) was obtained from **2** (0.010 mol) and cyclohexanone (1.08 g, 0.011 mol). The crude acid (3.05 g) was recrystallized from a mixture of ligroin and toluene (3:1) to afford fine white needles of **3c:** 2.00 g (62% yield); mp 138–143 °C dec (sealed capillary) [raised by an additional recrystallization to 152.5–154.5 °C dec (sealed capillary), but still contained a trace of **3a** (by NMR)]; NMR ($CDCl_3$) δ 0.9–2.0 (m, 8, methylene H), 6.80 (broad s, 2, OH's), 7.1–7.6 (m, 10, ArH) [δ 6.32 (s, **3a** impurity)].

Anal. Calcd for $C_{21}H_{22}O_3$: C, 78.23; H, 6.88. Found: C, 78.41; H, 6.81.

D. 2-(Hydroxydiphenylmethyl)-3-phenylcinnamic acid (3d) was obtained from **2** (0.010 mol) and benzophenone (2.00 g, 0.011 mol). The precipitated gum was crystallized twice from a mixture of ligroin and toluene (3:1) to afford finely divided white crystals of **3d:** 1.53 g (47% yield); NMR ($CDCl_3$) δ 3.9 (broad s, 2, OH's), 6.6–7.5 (m, 20, ArH).

Anal. Calcd for $C_{28}H_{22}O_3$: C, 82.73; H, 5.45. Found: C, 82.58; H, 5.46.

E. 2-(Phenylthio)-3-phenylcinnamic acid (3e) was obtained from **2** (0.050 mol) and diphenyl disulfide (11.57 g, 0.053 mol). The yellowish precipitate (20 g) was recrystallized from a mixture of ligroin and 2-propanol (10:1) to afford fine yellowish needles of **3e:** 11.46 g (68% yield); mp 209–213 °C (raised by an additional recrystallization to 214–215 °C); NMR ($CDCl_3$–Me_2SO-d_6) δ 7.2–7.8 (m, 15, ArH), 12.0 (s, 1, CO_2H).

Anal. Calcd for $C_{21}H_{16}O_2S$: C, 75.87; H, 4.85; S, 9.64. Found: C, 75.73; H, 4.79; S, 9.69.

F. 2-(Benzylthio)-3-phenylcinnamic acid (3f) was obtained from **2** (0.010 mol) and dibenzyl disulfide (2.71 g, 0.011 mol). The oily precipitate was extracted with diethyl ether and concentrated. The semicrystalline residue (3 g) was recrystallized twice from a mixture of ligroin and toluene (1:1) to afford fine yellow needles of **3f:** 2.13 g (61% yield); NMR ($CDCl_3$) δ 3.88 (s, 2, CH_2), 6.5–7.2 (m, 15, ArH), 8.5 (s, 1, CO_2H).

Anal. Calcd for $C_{22}H_{18}O_2S$: C, 76.27; H, 5.24; S, 9.25. Found: C, 76.54; H, 5.23; S, 9.26.

Cyclizations of Acids to Inden-1(1*H*)-ones. A. 2-Methyl-3-phenylinden-1(1*H*)-one (18a).[10] A mixture of benzene (4 mL), **3b** (0.95 g, 4.0 mmol), and powdered phosphorus pentachloride (0.84 g, 4.0 mmol) was placed in a flask protected from moisture and warmed with a water bath until a clear yellow solution was obtained. It was then cooled to 5 °C, and a solution of anhydrous stannic chloride (2.08 g, 8.0 mmol) in benzene (3 mL) was added slowly. The mixture was stirred for 1 h at 0–10 °C and then hydrolyzed by adding ice (5 g) and concentrated hydrochloric acid (5 mL) and heating at reflux for 30 min. The mixture was poured into dilute hydrochloric acid (25 mL), and the benzene phase was separated. The aqueous phase was extracted with benzene, and the extracts were washed successively with water, 10% sodium carbonate, water, and a saturated sodium chloride solution. Concentration of the extracts afforded 0.90 g of orange crystals. Four recrystallizations from ligroin (with cooling to −70 °C) afforded yellow-orange crystals of **18a:** 0.17 g (19% yield); NMR ($CDCl_3$) δ 1.96 (s, 3, CH_3), 6.9–7.5 (m, 9, ArH).

Anal. Calcd for $C_{22}H_{12}O$: C, 87.24; H, 5.49. Found: C, 86.97; H, 5.43.

B. 2-(Phenylthio)-3-phenylinden-1(1*H*)-one (18b). Method A. A mixture of **3e** (3.32 g, 0.010 mol) and PCl_5 (2.08 g, 0.010 mol) was allowed to react in benzene (4 mL) and subsequently with $SnCl_4$ (5.55 g, 0.0213 mol) as described for the cyclization of **3b.** Concentration of the benzene extracts afforded 2.94 g of red powder, mp 120–129 °C, which was recrystallized from ligroin to afford bright red prisms of **18b,** 2.46 g (78% yield).

Method B. A mixture of **3e** (0.50 g, 0.0015 mol) and phosphorus pentoxide (2.5 g, 0.018 mol) in benzene (25 mL) was heated at reflux for 5 h. The red solution was cooled, and ice (50 g) and diethyl ether (25 mL) were added. The aqueous phase was separated and extracted with diethyl ether. The ether phases were washed (method A) and afforded 0.48 g of red-orange powder, which was recrystallized from ligroin to yield analytically pure **18b:** 0.33 g (70% yield); mp 139–141 °C; NMR ($CDCl_3$) δ 7.3–8.0 (m, ArH). An admixture of this material with that obtained by method A showed no depression of the melting point.

Anal. Calcd for $C_{21}H_{14}OS$: C, 80.22; H, 4.49; S, 10.20. Found: C, 80.45; H, 4.47; S, 10.15.

C. 2-(Benzylthio)-3-phenylinden-1(1*H*)-one (18c). The acid chloride of **3f** was prepared from thionyl chloride, but PCl_5 appears to be equally satisfactory for these cyclizations. A mixture of $SOCl_2$ (3.2 g, 0.026 mol) and **3f** (1.73 g, 0.0050 mol) was heated gently until gas evolution ceased and a clear solution was obtained (20 min). The excess $SOCl_2$ was distilled under vacuum, and the reddish acid chloride of **3f** thus obtained was diluted with benzene (3 mL), cooled, and allowed to react with $SnCl_4$ (2.87 g, 0.011 mol). Isolation of the crude product afforded 1.76 g of dark red syrup which could not be crystallized. Column chromatography on silica gel (2.5 × 60 cm) with a mixture of petroleum ether and dichloromethane (1:2) used as the eluent afforded a syrup which crystallized from petroleum ether to yield maroon prisms of **18c:** 0.89 g (54% yield); NMR ($CDCl_3$) δ 4.16 (s, 2, CH_2), 6.9–7.6 (m, 14, ArH).

Anal. Calcd for $C_{22}H_{16}OS$: C, 80.45; H, 4.91; S, 9.76. Found: C, 80.43; H, 4.88; S, 9.89.

D. 2-(Phenylsulfonyl)-3-phenylinden-1(1*H*)-one (18d) was obtained by oxidation of **18c** (0.314 g, 0.0010 mol) in glacial acetic acid (50 mL) with 30% hydrogen peroxide (5 mL) and a catalytic amount of 1% H_2SO_4 at 50 °C for 2 h.[18] The yellow solution was cooled and cautiously neutralized with solid sodium carbonate (foaming). The yellow precipitate (0.29 g) was filtered and recrystallized from ligroin to afford **18d** as finely divided yellow crystals, 0.08 g (23% yield).

Anal. Calcd for $C_{21}H_{14}O_3S$: C, 72.81; H, 4.07; S, 9.26. Found: C, 73.06; H, 4.05; S, 9.05.

E. *S*-Methyl-2-(phenylthio)-3-phenylinden-1(1*H*)-one tetrafluoroborate (18e) was obtained through Acheson's procedure[19] by treating **18b** (0.150 g, 0.50 mmol) with silver tetrafluoroborate (0.100 g, 0.50 mmol) and methyl iodide (0.50 g, 3.5 mmol) in dichloromethane (20 mL) at room temperature with stirring for 48 h. The precipitated silver iodide was filtered, and concentration of the filtrate gave 0.30 g of orange gum. Recrystallization from a mixture of dichloromethane and hexane afforded finely divided yellow crystals of **18e:** 0.125 g (60% yield); NMR ($CDCl_3$) δ 3.74 (s, 3, CH_3), 5.04 (s, H_2O), 7.1–7.9 (m, 14, ArH).

Anal. Calcd for $C_{22}H_{17}BF_4OS{\cdot}0.5H_2O$: C, 62.14; H, 4.27; S, 7.54. Found: C, 61.96; H, 4.34; S, 7.34.

2-Isopropylidenebenzo[*b*]thiophen-3(2*H*)-one (22) was obtained by adding 2-(phenylthio)-3-methyl-2-butenoic acid (**21**)[2b] (0.26 g, 1.2 mmol) to concentrated sulfuric acid (5 mL) at 0 °C and stirring at 0 °C for 4 h. The dark red solution was poured into ice water (50 mL), and the yellow precipitate was filtered. Column chromatography (1.5 × 40 cm) on silica gel with a mixture of dichloromethane and petroleum ether (1:4) used as the eluent afforded 0.055 g (11% yield) of **22** as yellowish crystals: mp 101–102.5 °C (lit.[12] mp 103–105 °C); NMR data have been reported elsewhere;[12] IR ($CHCl_3$) 1660 cm^{-1} ($\nu_{C=O}$). This compound decomposed in a few days when exposed to air.

Anal. Calcd for $C_{11}H_{10}OS$: C, 69.43; H, 5.30; S, 16.85. Found: C, 69.63; H, 5.34; S, 16.62.

Reaction of 2-bromoacrylic acid (4) with *n*-butyllithium at −100 °C as described for **1** afforded a gum of acidic products, which NMR analysis showed to be polymeric, indicated by the intense, broad absorptions centered at δ 0.90 and 1.30 and weak, complex signals in the region δ 5.0–7.5 from vinylic protons. A sharp singlet at δ 3.00 strongly suggested the presence of propargylic acid (**5**), but **5** could not be isolated by chromatography. Analysis of the lithium salts of the reaction products (by NMR) indicated that polymerization was taking place during the lithiation experiment and did not result from the acid used in subsequent processing. **4** was made according to a literature procedure.[20]

Reaction of (*Z*)-2-bromocinnamic acid (6) with *n*-butyllithium at −140 °C was effected by first placing **6**[21] (2.27 g, 0.010 mol) in a solution of diethyl ether (60 mL) and 2-methylbutane (120 mL) in the usual apparatus.[2b] The solution was cooled to −150 °C (liquid

nitrogen bath), and *n*-butyllithium (0.020 mol) was added at a rate such that the temperature of the mixture did not exceed −140 °C. A yellowish slurry resulted, indicating that elimination rather than efficient bromine–lithium exchange (which produces brightly colored dianion solutions) was taking place. The mixture was stirred for 5 min at −140 °C and 15 min at −100 °C, at which temperature the turbidity almost completely disappeared. Methanol (5 mL) was added to quench the mixture. The yellow color was discharged, and the mixture was poured into water and processed as described for reactions of **1**. NMR analysis of the crude acidic product (2.08 g of yellowish crystals) showed no cinnamic acid, only phenylpropynoic acid (**7**): NMR ($CDCl_3$) δ 7.3–8.0 (m, 5, ArH), 10.0 (s, 1, CO_2H). Recrystallization from ligroin afforded 1.48 g (100% yield) of yellowish needles of **7**: mp 106–124 °C (lit.[22] mp 136–137 °C); IR ($\nu_{C\equiv C}$, mineral oil) 2200 cm^{-1}. In a separate experiment, white needles of **7** of mp 134–136 °C were obtained by recrystallization from water.

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Registry No.—**1**, 4541-91-7; **2**, 68344-90-1; **3a**, 606-84-8; **3b**, 17684-12-7; **3c**, 68344-86-5; **3d**, 68344-87-6; **3e**, 68344-88-7; **3f**, 68344-89-8; **3f** acid chloride, 68345-01-7; **4**, 10443-65-9; **5**, 471-25-0; **6**, 15813-24-8; **7**, 637-44-5; **13**, 68344-91-2; **14a**, 21690-34-6; **14b**, 68344-92-3; **14c**, 68344-93-4; **15**, 24186-31-0; **16**, 68344-94-5; **17**, 68344-95-6; **18a**, 13304-52-4; **18b**, 68344-96-7; **18c**, 68344-97-8; **18d**, 68344-98-9; **18e**, 68345-00-6; **21**, 60582-26-5; **22**, 23086-31-9; oxirane, 75-21-8; methyloxirane, 75-56-9; phenyloxirane, 96-09-3; 2-bromo-3-methyl-2-butenoic acid, 1578-14-9.

References and Notes

(1) (a) Charles R. Hauser Fellow, Duke University, 1977. (b) Deceased.
(2) (a) W. E. Parham, L. D. Jones, and Y. Sayed, *J. Org. Chem.*, **40**, 2394 (1975); (b) W. E. Parham and D. W. Boykin, *ibid.*, **42**, 260 (1977); (c) Lawrence D. Jones, Ph.D. Dissertation, Duke University, 1976; (d) David Wayne Boykin, Ph.D. Dissertation, Duke University, 1978; (e) C. K. Bradsher and D. C. Reames, *J. Org. Chem.*, **43**, 3800 (1978).
(3) H. Neumann and D. Seebach, *Tetrahedron Lett.*, 4839 (1976).
(4) G. Köbrich, H. Trapp, and A. Akhtar, *Chem. Ber.*, **101**, 2644 (1968); (b) H. L. Elbe and G. Köbrich, *ibid.*, **107**, 1654 (1974); (c) *Tetrahedron Lett.*, 2557 (1974).
(5) R. Heilmann and R. Glenat, *Bull. Soc. Chim. Fr.*, **22**, 1586 (1955).
(6) H. Rupe, H. Steiger, and F. Fiedler, *Ber. Dtsch. Chem. Ges.*, **47**, 63 (1914).
(7) C. J. Upton and P. Beak, *J. Org. Chem.*, **40**, 1094 (1975).
(8) H. Matsuda, N. Ozawa, and S. Ohki, *Yakugaku Zasshi*, **95**, 190 (1975).
(9) D. R. Morton, E. Lee-Ruff, R. M. Southam, and N. J. Turro, *J. Am. Chem. Soc.*, **92**, 4349 (1970).
(10) (a) A. Müller and A. Richl, *Ber. Dtsch. Chem. Ges. A*, **76**, 1119 (1943). (b) Cyclization is reported to occur in H_2SO_4: S. A. Goshchinskii and A. I. Kucherenko, *Vest. Khar'k. Politekh. Inst.*, **76**, 17 (1973); *Chem. Abstr.*, **81**, 151826 (1974).
(11) S. B. Awad and N. F. Abdul-Malik, *Aust. J. Chem.*, **28**, 601 (1975).
(12) R. B. Morin, D. O. Spry, and R. A. Mueller, *Tetrahedron Lett.*, 849 (1969).
(13) (a) J. Klein and P. Levine, *J. Am. Chem. Soc.*, **94**, 2520 (1972); (b) *J. Chem. Soc., Perkin Trans. 2*, 1971 (1973).
(14) A. K. Plisov and Y. P. Ram'yalg, *Zh. Obshch. Khim.*, **5**, 990 (1969).
(15) (a) J. P. Marino and D. M. Floyd, *J. Am. Chem. Soc.*, **96**, 7138 (1974); (b) J. P. Marino and J. S. Farina, *Tetrahedron Lett.*, 3901 (1975).
(16) J. Ficini and J. C. Depezay, *Tetrahedron Lett.*, 4797 (1969).
(17) D. D. E. Newman and L. N. Owen, *J. Chem. Soc.*, 4722 (1952).
(18) Similar reaction conditions with related compounds afford sulfoxides: K. Buggle and D. O'Sullivan, *J. Chem. Soc., Perkin Trans. 1*, 818 (1976).
(19) R. M. Acheson and D. R. Harrison, *J. Chem. Soc. C*, 1764 (1970).
(20) C. S. Marvel, J. Dec, H. G. Cooke, Jr., and J. C. Cowan, *J. Am. Chem. Soc.*, **62**, 3495 (1940).
(21) H. Moureu, P. Chovin, M. Garein, and J. Ventrillard, *Bull. Soc. Chim. Fr.*, **19**, 296 (1952).
(22) C. Glaser, *Justus Liebigs Ann. Chem.*, **154**, 140 (1870).

Oxidation of Sterically Hindered Phenols by Periodic Acid

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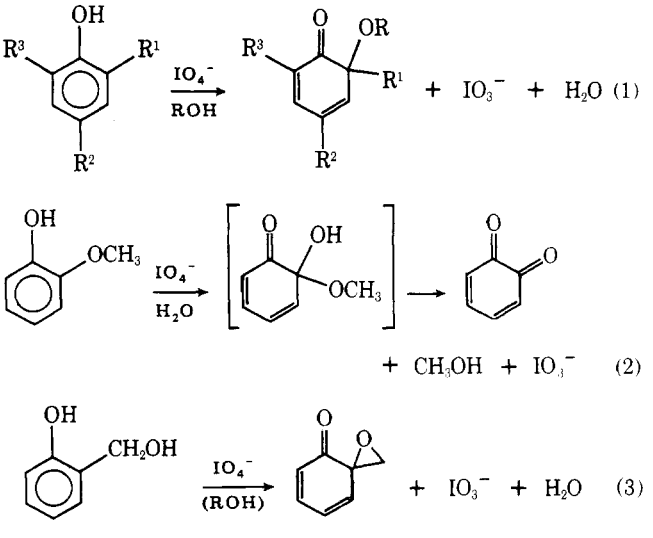
Sterically hindered phenols react smoothly with periodic acid in methanol to give, dependent on the nature of the substituents, diphenoquinones, benzoquinones, or cyclohexadienones as major products. The formation of the various types of quinonoid compounds may be rationalized by a mechanism involving initial electrophilic substitution of the phenol by periodic acid.

The oxidation of methyl-, methoxy-, and hydroxymethyl-substituted phenols by periodic acid or its sodium salt has been the subject of detailed investigations.[1-8] The overall reaction, corresponding to a two-electron oxidation of the phenol, involves either intermolecular or intramolecular participation of nucleophiles to give 2,4-cyclohexadienones as main products (cf. reactions 1–3). Characteristic features of these reactions are the following: (a) intramolecular nucleophilic reaction is favored over intermolecular participation of nucleophiles, (b) cross-conjugated cyclohexadienones are formed as minor products only, and (c) oxidative coupling reactions typical of one-electron transfer are negligible.

The mechanism proposed for the oxidation of phenols by periodate involves the aryl periodate **1** and its heterolytic decomposition into iodate and phenoxonium ions (reaction 4).[9] Consequently, bulky R substituents conceivably might impair the formation of **1**. In order to study the potential effect of steric hindrance on the course of the reaction, we investi-



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