mass spectrum, m/z 334 $(M + 1)^+$. Anal. Calcd for $C_{17}H_{16}NO_3SF$: C, 61.24; H, 4.84; N, 4.20; F, 5.67; S, 9.62. Found: C, 61.42; H, 4.83; N, 4.15, F, 5.34, S, 9.68.

D-(−)-***threo*-1-(4-(Methylsulfonyl)phenyl)-2-amino-3-chloro-1-propanol (10).** To a suspension of **7** (0.5 g, 1.51 mmol) in 10 mL of CH_2Cl_2 was added 0.70 mL (0.83 g, 4.6 mmol) of Yarovenko reagent at room temperature under nitrogen. The reaction was enclosed in a pressure reactor and heated at 100 °C for 5 h. After cooling to near 0 °C, the vessel was opened and the solution was concentrated to a residue. The residue was dissolved in MeOH and chromatographed on silica gel eluted with 16:4:0.75:0.25 toluene–CH_2Cl_2–MeOH–MeOH saturated with NH_3 gas. Concentration of the appropriate fractions yielded **10** as a colorless oil: ^1H NMR (300 MHz, DMSO-d_6) δ 3.23 (s, 1 H), 3.93–4.03 (m, 1 H), 4.08–4.15 (m, 1 H), 4.45–4.5 (m, 1 H), 5.73 (d, 1 H, J = 7.5 Hz), 7.51–7.71 (m, 5 H), 7.95–8.03 (m, 4 H); ^{13}C NMR (300 MHz, DMSO-d_6) δ 43.4, 47.2, 75.1, 81.8, 126.4, 126.5, 127.5, 128.1, 128.8, 132.1, 140.6, 145.9, 163.1; HRMS m/z calcd 350.0618, obsd 350.0646.

D-(−)-***threo*-1-(4-(Methylsulfonyl)phenyl)-2-amino-3-fluoro-1-propanol (11).** The CH_2Cl_2 solution of **9** was added over 0.5 h to 300 mL of 6 N HCl heated at near reflux, allowing the CH_2Cl_2 to distill from the reaction vessel. After removal of the CH_2Cl_2, the reaction mixture was heated at 100–105 °C for 12 h. The solution was cooled and extracted twice with dichloroethane. The aqueous layer was adjusted to pH 12, and the product was extracted into CH_2Cl_2. The CH_2Cl_2 solution was dried over Mg_2SO_4, filtered, and concentrated to a residual solid of 24.0 g (HPLC 85%, 0.0826 mol) (HPLC parameters: column, Zorbax C-8; mobile phase, 20:1 0.05 M pH3 phosphate buffer: CH_3CN; flow rate, 1 mL/min; detection, 254 nm). An analytical sample was prepared by crystallization from CH_2Cl_2: mp 111–113 °C; ^1H NMR (300 MHz, DMSO-d_6) δ 1.54 (br s, 2 H), 2.9–3.1 (m, 1 H), 3.2 (s, 3 H), 4.05–4.5 (m, 2 H), 4.69 (d, 1 H, J = 6 Hz), 5.69 (br s, 1 H), 7.61 (d, 2 H, J = 9 Hz), 7.88 (d, 2 H, J = 9 Hz); ^{13}C NMR (300 MHz, DMSO-d_6) δ 43.0, 55.7, 55.9, 70.6, 83.2, 85.4, 125.9, 126.9, 138.6, 149.1; mass spectrum, m/z 248 $(M + 1)^+$; rotation (MeOH) $[\alpha]^{26} = -36.5°$. Anal. Calcd for $C_{10}H_{14}NO_3SF$: C, 48.56; H, 5.71; N, 5.67; F, 7.68; S, 12.97. Found: C, 48.22; H, 5.48; N, 5.58; F, 7.93; S, 13.08.

D-(−)-***threo*-1-(4-(Methylsulfonyl)phenyl)-2-amino-3-chloro-1-propanol Hydrochloride (12).** A solution of **9** (3.0 g, 9.0 mmol) in 15 mL of 12 N HCl was heated at 130 °C for 22 h. After cooling, the solution was concentrated to a residue, which was triturated with 2-propanol, filtered, and dried, yielding 2.61 g of **12**·HCl as a white solid: mp 189–192 °C; NMR (200 MHz, DMSO-d_6) δ 3.21 (s, 3 H), 3.35–3.5 (m, 1 H) 3.6–3.75 (m, 1 H), 3.87 (dd, 1 H, J = 8, 4 Hz), 4.83–4.95 (m, 1 H), 6.69 (d, 1 H, J = 6 Hz), 7.68 (d, 2 H, J = 9 Hz), 7.95 (d, 2 H, J = 9 Hz), 8.48 (br s, 2 H); ^{13}C NMR (300 MHz, DMSO-d_6) δ 42.6, 43.4, 56.2, 70.0, 127.1, 127.9, 140.5, 145.9; HRMS m/z calcd 264.0461, obsd 264.0451; rotation (MeOH) $[\alpha]_D = 4.1°$.

D-(−)-***threo*-1-(4-(Methylsulfonyl)phenyl)-2-(dichloroacetamido)-3-fluoro-1-propanol (1).** A solution of 11.1 g (HPLC purity 97%, 43.9 mmol) of **11**, 6.12 mL (4.44 g, 43.9 mmol) of Et_3N, and 22.7 mL (31.4 g, 0.220 mol) of methyl dichloroacetate in 110 mL of dry methanol was stirred at room temperature for 18 h. The HPLC analysis of the solution gave 15.4 g (43.0 mmol, 98% yield) of **11**. The reaction mixture was concentrated to a low volume and precipitated by the addition of toluene and H_2O. The product was collected by filtration, washed with H_2O, and dried under vacuum to afford 16.8 g (HPLC purity 90%, 42.2 mmol, 96% yield) of crude **1**. The precipitate was recrystallized from 2-propanol/H_2O and dried under vacuum to yield 13.4 g (HPLC purity 98%, 36.7 mmol, 84% yield) (HPLC parameters: column, Zorbax C-8; mobile phase, 2:1 H_2O–CH_3CN; flow rate, 1 mL/min; detection, 254 nm) of **1** as a white solid: mp 152–154 °C (lit.[1] mp 153–154 °C); NMR (400 MHz, DMSO-d_6) δ 3.17 (s, 3 H), 4.2–4.5 (m, 2 H), 4.55–4.75 (m, 1 H), 5.00 (m, 1 H), 6.17 (d, 1 H, J = 9 Hz), 6.46 (s, 1 H), 7.62 (d, 2 H, J = 9 Hz), 7.87 (d, 2 H, J = 9 Hz), 8.62 (d, 1 H, J = 9 Hz); ^{13}C NMR (300 MHz, DMSO-d_6) δ 43.5, 54.4, 54.7, 66.1, 69.2, 81.1, 83.4, 126.4, 127.0, 139.4, 147.8, 163.6, mass spectrum, m/e 360 $(M + 1)^+$, 358, 342, 340; rotation (DMF) $[\alpha]^{26} = 17.9°$. Anal. Calcd for $C_{12}H_{14}NO_4Cl_2SF$: C, 40.23; H, 3.94; N, 3.91; Cl, 19.80; F, 5.30; S, 8.95. Found: C, 40.48; H, 3.93; N, 3.86; Cl, 19.76; F, 5.39; S, 8.95.

Acknowledgment. We thank the staff of the Physical–Analytical Departments for spectra and microanalyses and Professor Ronald Breslow for helpful discussions. We also thank the personnel of the Pilot Plant for the successful scale up of this process.

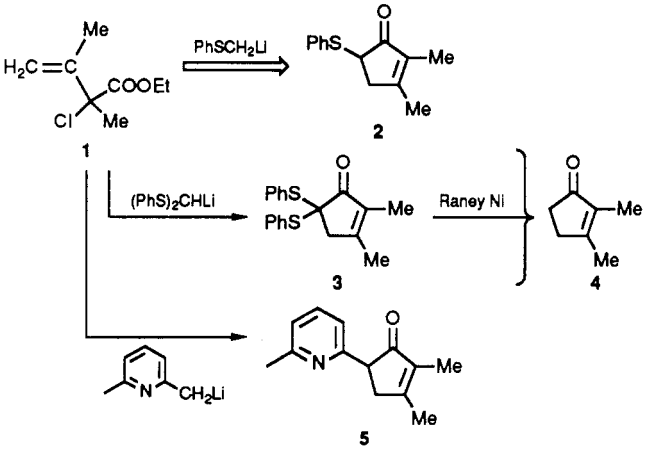
Synthesis and Reactions of α-Chloro β,γ-Unsaturated Esters. 2. Application to the Synthesis of Dihydrojasmone, *cis*-Jasmone, Desoxyallethrolone, and Novel Cyclopentenones

Jacob Mathew†

Mallinckrodt Specialty Chemicals Company, P.O. Box 5439, Mallinckrodt & Second Sts., St. Louis, Missouri 63147

Received March 26, 1990

In the preceding paper in this series, we described the syntheses and reactions of four new α-chloro β,γ-unsaturated esters.[1] It was shown that a substituted cyclopentenone can be synthesized by the reaction of 2-lithio-1,3-dithiane with ethyl 2-chloro-2,3-dimethyl-3-butenoate (**1**). As an extension of this novel reaction, we were interested in applying this route for the synthesis of several substituted cyclopentenones. We have now found that other sulfur and nitrogen stabilized carbanions undergo this reaction with allylic halide **1**. Thus (bis(phenylthio)methyl)lithium,[2] ((phenylthio)methyl)lithium,[3] and 2-(lithiomethyl)-6-methylpyridine[4] can be used as the nucleophile in this reaction. Cyclopentenones **2** and **3** undergo desulfurization with Raney nickel at room temperature almost instantaneously and quantitatively. ((Phenylthio)methyl)lithium is the preferred reagent for this transformation due to the ease of removal of sulfur.



In order to extend this reaction to other fully substituted allylic halides similar to **1**, the ene–ester enolate of ethyl 2-chloro-3-methyl-3-butenoate[1] was alkylated with allyl/alkyl halides to give the desired allylic halides:[5]

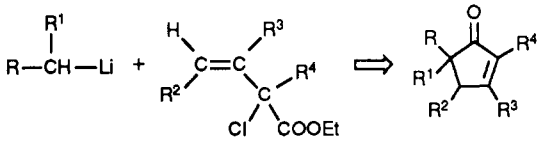
1, R = Me, yield 76%; **6**, R = $PhCH_2$, yield 63%; **7**, R = CH_2=$CHCH_2$, yield 68%; **8**, R = $(Me)_2C$=$CHCH_2$, yield 56%; **9**, R = EtCH=$CHCH_2$, yield 78%; **10**, R = $CH_3(CH_2)_4$, yield 70%

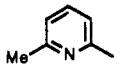
Two more highly substituted 2-chloro-2-methyl-3-butenoates were prepared by the reaction of hypochlorous

†This work was completed at Petrolite Corp., St. Louis, MO, and is covered by a pending U.S. patent assigned to Petrolite Corp.

0022-3263/90/1955-5294$02.50/0

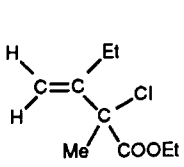
Table I. Reaction of Sulfur- and Nitrogen-Stabilized Carbanions with Allylic Halides



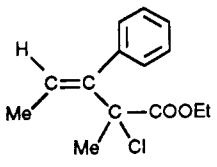
R	R^1	R^2	R^3	R^4	product	yield,[a] %
PhS	H	H	Me	$CH_2CH{=}CH_2$	13	54
PhS	H	H	Me	$CH_2CH{=}C(Me)_2$	14	34
PhS	H	H	Me	CH_2Ph	15	44
PhS	H	H	Me	$(CH_2)_4Me$	16	46
PhS	H	H	Me	$CH_2CH{=}CHEt$ (cis)	17	42
PhS	H	H	Et	Me	18	38
PhS	H	Me	Ph	Me	19[b]	49
$-S(CH_2)_3S-$		H	Et	Me	20	51
$-S(CH_2)_3S-$		Me	Ph	Me	21[b]	58
	H	H	Me	Me	22	60
	H	Me	Ph	Me	23[b]	76
	H	H	Et	Me	24	62

[a] Isolated yield after flash column chromatography. [b] Proton NMR indicated the presence of only one isomer (trans).

acid[1] with isomeric ethyl 2,3-dimethyl-2-pentenoate[6] (*E*:*Z* ratio of 51:42) and ethyl 2-methyl-3-phenyl-2-pentenoate[7] (*E*:*Z* ratio of 65:35). Allylic halides **11** and **12** were the exclusive products from this reaction. All of the above



11



12

allylic halides reacted with sulfur and nitrogen stabilized carbanions to give 2,3,5- and 2,3,4,5-substituted cyclopentenones (Table I). As is evident from the table, the product yield is not affected by the size of the substituent R^4 or when R^2 is a methyl group. Despite only modest yields in some cases, the reaction appears to be of a general scope. It is proposed that the reaction proceeds via a nitrogen- or sulfur-assisted abnormal S_N2 reaction of the initially formed keto enolate.[8] Furthermore, it is imperative to point out that while 2-(lithiomethyl)pyridine reacted with **1** to give the cyclopentenone **22**, similar reaction of 4-(lithiomethyl)pyridine with **1** gave no trace of cyclopentenone.

The desulfurization of compounds **13–19** listed in Table I proceeded in high yield (85–92%) to give compounds of some general interest. For example, **17** gave *cis*-jasmone[9] and **16** gave dihydrojasmone,[10] both of which are important in the perfumery industry.[11] Compound **13** gave deoxyallethrolone,[12] which is an important intermediate for the synthesis of allethrolone[13] and pyrethrins.[14]

Compounds **22–24** represent the first reported example of 5-(2-pyridyl)-2-cyclopenten-1-ones. A literature survey, however, revealed that the corresponding 2-(2-pyridyl)-cyclopentanones[15] have indeed been synthesized.

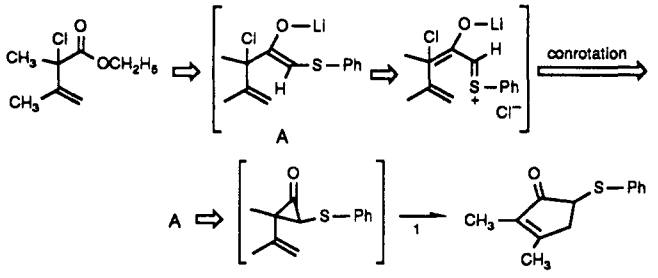
Conclusions

We have shown that α-chloro β,γ-unsaturated esters are readily available intermediates useful for the synthesis of substituted cyclopentenones. The versatility of these reagents is amply demonstrated by its application to the facile synthesis of *cis*-jasmone, dihydrojasmone, and desoxyallethrolone.

Experimental Section

Melting points were determined in open capillaries with a Mel-Temp Laboratory Devices apparatus and are uncorrected. Elemental analyses were performed by Galbraith Laboratories, Knoxville, TN, and Petrolite Corp., Analytical Section. The ^{13}C NMR spectra were obtained on a JEOL FX-60 spectrometer operating at 15.04 MHz. Proton NMR spectra were obtained on a Perkin-Elmer R-32 90-MHz spectrometer and a Gemini XL-300 spectrometer. The chemical shifts (+) are downfield from tetramethylsilane, and all NMR data were obtained in $CDCl_3$ solution. IR spectra were obtained on a Beckman AccuLab 8

(1) Mathew, J.; Alink, B. *J. Org. Chem.* **1990**, *55*, 3880.
(2) Corey, E. J.; Seebach, D. *J. Org. Chem.* **1966**, *31*, 4097.
(3) (a) Ager, D. J.; Cookson, R. C. *Tetrahedron Lett.* **1980**, *21*, 1677. (b) Ager, D. J. *J. Chem. Soc., Perkin Trans. 1* **1983**, 1131.
(4) (a) Kaiser, E. M.; Bartling, G. J.; Thomas, W. R.; Nichols, S. B.; Nash, D. R. *J. Org. Chem.* **1973**, *38*, 71. (b) Kofron, W. G.; Baclawski, L. M. *Org. Synth.* **1973**, *52*, 75. (c) Bohme, R.; Breitmaier, E. *Chem. Ber.* **1986**, *119*, 2062.
(5) (a) Ha, B.; Hart, D. J.; Yang, T. K. *J. Am. Chem. Soc.* **1984**, *106*, 4819. (b) Herrmann, J. L.; Schlessinger, R. H. *Tetrahedron Lett.* **1973**, 2433.
(6) Tanaka, K.; Uneme, H.; Ono, N.; Kaji, A. *Chem. Lett.* **1979**, *9*, 1039.
(7) McGreer, D. E.; McKinley, J. W. *Can. J. Chem.* **1971**, *49*, 105.
(8) Another plausible mechanism can invoke a Favorski type process where sulfur helps stabilize the zwitterion, i.e.



(1) vinyl cyclopropane rearrangement.

(9) (a) Büchi, G.; Egger, B. *J. Org. Chem.* **1971**, *36*, 202. (b) Wiegers, W. J.; Hall, J. B. (International Flavors & Fragrances Inc.), US 4 045 489, 1976; *Chem. Abstr.* **1978**, *88* 6418f.
(10) Hosomi, A.; Shirahata, A.; Sakurai, H. *J. Org. Chem.* **1981**, *46*, 4631.
(11) Bedoukian, P. Z. *Perfumery and Flavoring Synthetics*, 1986, 3rd ed.; Allied Publishing: Wheaton, IL, 1986; pp 248–253.
(12) Welch, S. C.; Assereg, J. H.; Glase, S. A. *J. Org. Chem.* **1987**, *52*, 1440.
(13) Sasaki, M.; Okada, K.; Matsui, M. *Agric. Biol. Chem.* **1979**, *43*, 379.
(14) Piers, E.; Cheng, K. F.; Nagakura, I. *Can. J. Chem.* **1982**, *60*, 1256.
(15) Houminer, Y. *J. Org. Chem.* **1985**, *50*, 786.

spectrometer. Mass spectra were obtained on a DuPont instruments DP-1 mass spectrometer system. Flash column chromatography[16] was performed with silica gel 60 (230–440 mesh) purchased from Merck. THF was either distilled from $LiAlH_4$ or Gold Label anhydrous THF supplied by Aldrich Chemical Co. Reagent grade CH_2Cl_2, EtOAc, hexane, and ether were used. All reactions were done under nitrogen.

2,3-Dimethyl-5-(phenylthio)-2-cyclopenten-1-one (2). To a solution of thioanisole (0.5 g, 4.1 mmol) in dry THF (10 mL) was added TMEDA (0.6 mL, 4 mmol), and then the reaction mixture was cooled to 0 °C. The solution was stirred while 2.5 M *n*-BuLi (1.7 mL, 4 mmol) was added dropwise. The cloudy solution was then warmed to room temperature and after 45 min cooled to −70 °C, while allylic halide 1 (0.45 g, 3 mmol) was added rapidly. The yellow solution warmed to room temperature, quenched with 1 N NH_4Cl (5 mL) and extracted with ether (2 × 10 mL). Usual processing and flash column chromatography gave the cyclopentenone **2** (0.35 g, 54%), eluting in 10% EtOAc/hexane. ^{13}C NMR: δ 205.76, 167.56, 131.20, 128.98, 127.45, 47.65, 40.52, 17.02, and 8.18. ^1H NMR ($CDCl_3$): δ 7.55 (m, 5 H), 3.90 (d of d, 1 H), 2.70–3.10 (m, 2 H), 2.00 (s, 3 H), and 1.70 (s, 3 H). Mass spectrum: *m/e* 218, 203, 135, and 110 (base peak). Anal. Calcd for $C_{13}H_{14}OS$: C, 71.55; H, 6.40; S, 14.67. Found: C, 71.20; H, 6.50; S, 14.82.

2,3-Dimethyl-2-cyclopenten-1-one[1] (4). To a stirred solution of **2** (1.1 g, 5 mmol) in acetone (40 mL) was added excess Raney nickel (3 mL) at room temperature. After 15 min (TLC indicated disappearance of **2**) the mixture was filtered over Celite, and solvents were evaporated to give a pale yellow oil. This was taken up in ether (20 mL), washed with water (2 × 5 mL), dried, and evaporated to give crude **4**. Flash column chromatography gave pure enone **4** (0.52 g, 92%), eluting in 25% EtOAc/hexane. IR (neat): 1735, 1695, 1650 cm^{-1}. ^1H NMR ($CDCl_3$): δ 2.38 (m, 4 H), 2.10 (s, 3 H), and 1.68 (s, 3 H). ^{13}C NMR: δ 209.14, 169.30, 135.80, 33.60, 30.96, 16.10, and 7.30. Mass spectrum: *m/e* 110, 67 (base peak).

5-(6-Methylpyridin-2-yl)-2,3-dimethyl-2-cyclopenten-1-one (5). To a stirred solution of 2,6-dimethylpyridine (1.1 g, 10 mmol) and TMEDA (1.2 g, 10 mmol) in THF (20 mL) at −70 °C was added via syringe 2.5 M *n*-BuLi (4 mL, 10 mmol). The orange red solution was stirred at this temperature for 20 min, and then a solution of the allylic halide **1** (1.4 g, 8 mmol) in THF (4 mL) was added rapidly. The yellow solution warmed to room temperature and then quenched with 1 N NH_4Cl (5 mL) and ether (20 mL). The organic layer washed with water (10 mL), dried, and evaporated. Flash column chromatography gave a yellow viscous mass (1.1 g), eluting in 25% EtOAc/$CHCl_3$. Trituration with hexane (1 mL) gave pure enone **5** as a yellow powder (0.95 g, 64%). Mp: 91 °C. IR (KBr): 3450, 1700, 1650, and 1600 cm^{-1}. ^1H NMR ($CDCl_3$): δ 7.60 (t, 1 H), 7.10 (t, 2 H), 3.80 (m, 1 H), 3.10 (m, 2 H), 2.50 (s, 3 H), 2.20 (s, 3 H), and 1.80 (s, 3 H). ^{13}C NMR: δ 207.78, 169.58, 158.54, 134.60, 136.21, 121.88, 120.21, 53.14, 39.11, 25.62, 17.14, and 8.80. Mass spectrum: *m/e* 201, 186, 172, 158. Anal. Calcd for $C_{13}H_{15}NO$: C, 77.61; H, 7.46; N, 6.96. Found: C, 77.69; H, 7.56; N, 6.90.

2-(3-Methyl-2-butenyl)-3-methyl-5-(phenylthio)-2-cyclopenten-1-one (14). ^1H NMR: δ 7.60–7.20 (m, 5 H), 5.10 (m, 1 H)8 3.85 (dd, 1 H), 3.30 (d, 2 H), 2.65–2.30 (m, 2 H), 2.1 (s, 3 H), and 1.80 (s, 6 H). ^{13}C NMR: δ 205.16, 168.17, 138.95, 133.49, 132.16, 128.69, 127.39, 120.12, 47.65, 40.38, 25.58, 22.33, 17.79, and 17.14. Mass spectrum: *m/e* 272, 163. Anal. Calcd for $C_{17}H_{20}OS$: C, 75.00; H, 7.35; S, 11.76. Found: C, 74.89; H, 7.16; S, 12.02.

2-Pentyl-3-methyl-5-(phenylthio)-2-cyclopenten-1-one (16). ^1H NMR: δ 7.50 (m, 5 H), 3.90 (dd, 1 H), 2.70–3.30 (m, 2 H), 2.30 (m, 2 H), 2.15 (s, 3 H), 1.40 (m, 6 H), 1.00 (t, 3 H). ^{13}C NMR: δ 205.20, 168.04, 139.73, 132.06, 128.69, 127.39, 47.65, 40.34, 31.68, 27.78, 23.29, 22.44, 17.01, 14.02. Anal. Calcd for $C_{17}H_{22}OS$: C, 74.45; H, 8.03; S, 11.67. Found: C, 74.27; H, 8.14; S, 11.93.

2-(2-*cis*-Pentenyl)-3-methyl-5-(phenylthio)-2-cyclopenten-1-one (17). ^1H NMR: δ 7.30 (m, 5 H), 5.30 (m, 2 H), 3.70 (dd, 1 H), 2.90 (d, 2 H), 2.40–2.60 (m, 2 H), 2.10 (q, 2 H), 2.00 (s, 3 H), 1.00 (t, 3 H). ^{13}C NMR: δ 204.14, 168.43, 138.43, 132.58, 131.93, 128.69, 127.43, 124.40, 47.52, 40.51, 21.42, 20.51, 17.01, 14.15. IR (neat): 2950, 1700, 1650 cm^{-1}. Mass spectrum: *m/e* 272, 257, and 110 (base peak). Anal. Calcd for $C_{17}H_{20}OS$: C, 75.00; H, 7.35; S, 11.76. Found: C, 74.85; H, 6.94; S, 11.81.

2-Allyl-3-methyl-2-cyclopenten-1-one (Desoxyallethrolone,[12] 25). IR (neat): 1700, 910 cm^{-1}. ^1H NMR ($CDCl_3$): δ 6.10–5.40 (m, 1 H), 5.20–4.90 (m, 2 H), 3.00 (d, 2 H, *J* = 5.4 Hz), 2.80–2.30 (m, 4 H), and 2.10 (s, 3 H). ^{13}C NMR: δ 208.20, 172.10, 137.70, 134.30, 115.18, 33.90, 31.68, 27.27, and 17.28. Mass spectrum: *m/e* 136, 121.

2-(3-Methyl-2-butenyl)-3-methyl-2-cyclopenten-1-one (26). Mass spectrum: *m/e* 164, 149, and 131. ^{13}C NMR: δ 208.10, 174.30, 139.54, 135.60, 120.77, 34.78, 31.55, 25.98, 22.17, and 17.27. ^1H NMR ($CDCl_3$): δ 5.10 (m, 1 H), 3.00 (d, 2 H, *J* = 5.9 Hz), 2.40–2.70 (m, 4 H), 2.10 (s, 3 H), 1.80 (s, 6 H). Anal. Calcd for $C_{11}H_{16}O$: C, 80.48; H, 9.75. Found: C, 80.31; H, 9.64.

5-(Pyridin-2-yl)-2,3-dimethyl-2-cyclopenten-1-one (22). Via the general procedure, enone **22** was obtained as a yellow viscous oil (58%). ^1H NMR ($CDCl_3$): δ 8.50 (m, 1 H), 7.70 (m, 1 H), 7.30 (m, 2 H), 3.80 (m, 1 H), 3.10 (m, 2 H), 2.20 (s, 3 H), and 1.80 (s, 3 H). ^{13}C NMR: δ 207.56, 170.30, 158.74, 136.40, 149.39, 123.81, 121.73, 134.50, 52.90, 38.76, 17.32, and 8.23. Mass spectrum: *m/e* 187, 172, 158. Anal. Calcd for $C_{12}H_{13}NO$: C, 77.01; H, 6.95; N, 7.48. Found: C, 77.14; H, 6.82; N, 7.31.

5-(Pyridin-2-yl)-2,4-dimethyl-3-phenyl-2-cyclopenten-1-one (23). ^1H NMR ($CDCl_3$): δ 8.70 (m, 1 H), 7.10–7.90 (m, 3 H), 7.55 (s, 5 H), 3.80 (m, 1 H), 3.60 (m, 1 H), 1.90 (d, 3 H, *J* = 1 Hz), and 1.05 (d, 3 H). ^{13}C NMR: δ 206.72, 172.02, 149.62, 136.46, 129.42, 128.80, 128.09, 124.87, 121.89, 62.89, 42.96, 18.86, and 9.80. Anal. Calcd for $C_{18}H_{16}ON$: C, 82.44; H, 6.11; N, 5.34. Found: C, 82.21; H, 5.89; N, 5.20.

5-(Phenylthio)-2,4-dimethyl-3-phenyl-2-cyclopenten-1-one (19). ^1H NMR ($CDCl_3$): δ 7.40–7.20 (m, 10 H), 3.38 (d, 1 H), 3.20 (m, 1 H), 1.82 (d, 3 H, *J* = 2 Hz), and 1.10 (d, 3 H, *J* = 7 Hz). ^{13}C NMR: δ 204.56, 170.48, 134.67, 133.26, 132.98, 129.26, 128.81, 128.56, 128.06, 127.85, 127.69, 56.28, 44.53, 18.78, and 9.75. IR (neat): 1700, 1340, and 701 cm^{-1}. Anal. Calcd for $C_{19}H_{18}OS$: C, 77.55; H, 6.12; S, 10.88. Found: C, 77.28; H, 6.26; S, 10.69.

2,4-Dimethyl-3-phenyl-6,10-dithiaspiro[4.5]dec-2-en-1-one (21). ^{13}C NMR ($CDCl_3$): δ 203.37, 165.39, 134.51, 131.80, 129.09, 128.61, 127.74, 51.19, 49.13, 26.76, 25.72, 25.29, 14.57, and 9.69. ^1H NMR: δ 7.35 (m, 5 H), 3.90 (dq, 2 H, *J* = 14, 2.5 Hz, 7 and 9 axial H's), 3.20 (m, 1 H, 4-CH), 2.60 (m, 2 H, 7 and 9 equatorial H's), 2.15 (m, 2 H, 8 CH_2's), 1.87 (d, 3 H, *J* = 2.5 Hz), 1.20 (d, 3 H, *J* = 7 Hz). Anal. Calcd for $C_{16}H_{18}OS_2$: C, 66.20; H, 6.20; S, 22.06. Found: C, 66.05; H, 6.45; S, 22.31.

2,4-Dimethyl-3-phenyl-2-cyclopenten-1-one[17] (31). From enone **19** following the standard Raney nickel desulfurization procedure described for compound **2**, there was obtained after flash column chromatography pure **31** (90%), eluting in 25% EtOAc/hexane. Mass spectrum: *m/e* 186, 171, 157, and 143. IR (neat): 1700, 1342, and 700 cm^{-1}. ^1H NMR ($CDCl_3$): δ 7.40 (s, 5 H), 3.30 (m, 1 H), 2.80 (dd, 1 H, 5 axial H's), 2.15 (dd, 1 H, 5 equatorial H's), 1.85 (s, 3 H), and 1.05 (d, 3 H, *J* = 7 Hz). ^{13}C NMR: δ 208.78, 172.54, 136.19, 135.38, 128.98, 128.55, 127.74, 42.96, 35.53, 19.99, 9.48. Anal. Calcd for $C_{13}H_{14}O$: C, 83.87; H, 7.52. Found: C, 83.65; H, 7.59.

Acknowledgment. I wish to thank Prof. Barry Trost (Stanford University) for communicating to me the mechanism mentioned in ref 8. I also wish to thank Dr. Ben Alink for showing an interest in this project and Petrolite Corp. for funding this research.

Registry No. **1**, 127229-64-5; **2**, 128191-87-7; **3**, 128191-88-8; **4**, 1121-05-7; **5**, 128191-89-9; **6**, 128191-90-2; **7**, 128191-91-3; **8**, 128191-92-4; **9**, 128191-93-5; **10**, 128191-94-6; **11**, 128191-95-7; **12**, 128191-96-8; **13**, 128191-97-9; **14**, 128191-98-0; **15**, 128191-99-1; **16**, 128192-00-7; **17**, 128192-01-8; **18**, 128192-02-9; **19**, 128192-03-0; **20**, 128192-04-1; **21**, 128192-05-2; **22**, 128192-06-3; **23**, 128192-08-5; **24**, 128192-08-5; **25**, 3569-36-6; **26**, 61900-44-5; **27**, 13380-80-8; **28**, 1128-08-1; **29**, 488-10-8; **30**, 41496-77-9; **31**, 128192-10-9; (phe-

(16) Still, W. C.; Kahn, H.; Mitra, A. *J. Org. Chem.* **1978**, *43*, 2923.

(17) For other routes to 4-substituted cyclopentenones, see: Jackson, D. A.; Rey, M.; Dreiding, A. S. *Tetrahedron Lett.* **1983**, *24*, 4817.

(18) Antczak, K.; Kingston, J. F.; Fallis, A. G. *Can. J. Chem.* **1984**, *62*, 829.

nylthiomethyl)lithium, 13307-75-0; bis(phenylthio)methyllithium, 13307-76-1.

Supplementary Material Available: Preparative, spectroscopic, and analytical data on compounds **3**, **6–13**, **15**, **18**, **20**, **24**, and **27–30** (6 pages). Ordering information is given on any current masthead page.

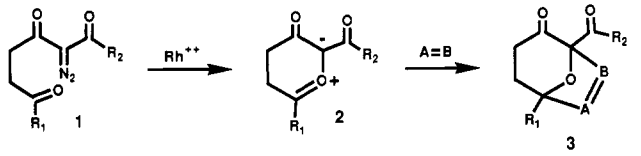
Synthesis of 1,3-Diketones Using α-Diazo Ketones and Aldehydes in the Presence of Tin(II) Chloride

Albert Padwa,* Susan F. Hornbuckle, Zhijia Zhang, and Lin Zhi

Department of Chemistry, Emory University, Atlanta, Georgia 30322

Received April 9, 1990

Recent publications from our laboratory have introduced a new general strategy for oxapolycyclic ring synthesis in which a rhodium(II)-catalyzed tandem cyclization–cycloaddition reaction represents the central element.[1] For ongoing studies to further implement and develop this strategy, we required a general route to α-diazo 1,3-diketones, which serve as the precursors for carbonyl ylide dipoles of type **2**. Highly stabilized β-dicarbonyl enolates



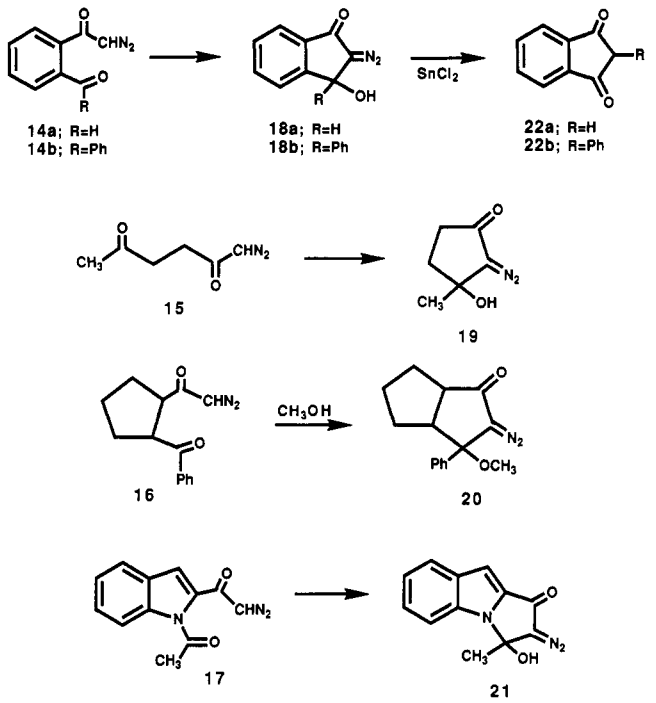
1 2 3

are known to readily react with sulfonyl azide reagents to give the desired diazo compounds in good yield.[2-6] Thus, for the subsequent development of our fundamental strategy, we needed an efficient method to prepare 1,3-diketones. A wide variety of procedures have been described in the literature for the synthesis of β-dicarbonyl compounds, including the reaction of metal enolates with acid chlorides[7] and acyl cyanides,[8] the acylation of enamines,[9] the direct acid-catalyzed acylation of ketones with acid anhydrides,[10] and the acylation of ketone silyl enol ethers.[11] A two-step method for the conversion of aldehydes into 1,3-diketones has also been reported, which involves the reaction with 1-diazo-1-lithioacetone followed by an acid-induced rearrangement of the initially formed α-diazo β-hydroxy keto derivative.[12-14] However, under these conditions the α-diazo alcohol also undergoes a retro-aldol reaction, leading to variable amounts of the starting aldehyde and diazo ketone. This approach is unsuitable for 1,3-diketones that have acid-labile groups incorporated into the side chain. Herein we report that the reaction of α-diazo ketones with aldehydes in the presence of Lewis acids is an effective method for the synthesis of a variety of 1,3-diketones.[15]

Table I

diazo ketone R_1COCHN_2, R_1 =	aldehyde R_2CHO, R_2 =	diketone (% yield) $R_1COCH_2COR_2$
Ph	C_2H_5	**4** (88)
Ph	$PhCH_2$	**5** (90)
Ph	C_4H_9	**6** (73)
$CH_3COCH_2CH_2$	C_2H_5	**7** (83)
$PhCH_2CH_2$	C_4H_9	**8** (80)
$PhCH_2CH_2$	$PhCH_2$	**9** (90)
$PhCOCH_2CH_2$	$CH_2=CH(CH_2)_2$	**10** (42)
$PhCOCH_2CH_2$	$CH_2=CH(CH_2)_3$	**11** (49)

Scheme I



A series of unsymmetrical 1,3-diketones were readily prepared by treating various α-diazo ketones with the appropriate aldehyde in the presence of a Lewis acid using methylene chloride as the solvent (Table I). The reaction is catalyzed by several different Lewis acids but the best results were obtained with $SnCl_2$ or BF_3. Methylene chloride was the solvent of choice since it gave the highest yields and was the easiest to remove. No reaction occurred in the absence of a catalyst and the formation of product appears to be relatively insensitive to the atmosphere.

The mild conditions of this reaction are illustrated by the facility with which 4-pentenal and 5-hexenal react with 1-diazo-5-phenyl-2,5-pentanedione to give the labile triones **10** (42%) and **11** (49%). Other aspects of the reaction were briefly probed. Yields and relative rate of reaction were

(1) Padwa, A.; Carter, S. P.; Nimmesgern, H. *J. Org. Chem.* **1986**, *51*, 1157. Padwa, A.; Carter, S. P.; Nimmesgern, H.; Stull, P. *J. Am. Chem. Soc.* **1988**, *110*, 2894. Padwa, A.; Fryxell, G. E.; Zhi, L. *J. Org. Chem.* **1988**, *53*, 2975. Padwa, A.; Hertzog, D. L.; Chinn, R. L. *Tetrahedron Lett.* **1989**, 4077. Padwa, A.; Zhi, L. *J. Am. Chem. Soc.* **1990**, *112*, 2037.

(2) Regitz, M. *Angew. Chem., Int. Ed. Engl.* **1967**, *6*, 733. Regitz, M.; Menz, F. *Chem. Ber.* **1968**, *101*, 2622.

(3) Adams, J. L.; Metcalf, B. W. *Tetrahedron Lett.* **1964**, 919.

(4) Taber, D. F.; Schuchardt, J. L. *J. Am. Chem. Soc.* **1985**, *107*, 5289.

(5) Baum, J. S.; Shook, D. A.; Davies, H. M. L.; Smith, H. D. *Synth. Commun.* **1987**, *17*, 1709.

(6) Chen, E. Y. *J. Org. Chem.* **1984**, *49*, 3245.

(7) Beck, A. K.; Hoekstra, M. S.; Seebach, D. *Tetrahedron Lett.* **1977**, 1187.

(8) Howard, H. S.; Meerholz, C. A.; Michael, J. P. *Tetrahedron Lett.* **1979**, 1339.

(9) House, H. O. *Modern Synthetic Reactions*, 2nd ed.; W. A. Benjamin: New York, 1972; Chapter 11.

(10) House, H. O.; Czuba, L. J.; Gall, M.; Olmstead, H. D. *J. Org. Chem.* **1969**, *34*, 2324.

(11) Kopka, I.; Rathke, M. W. *J. Org. Chem.* **1981**, *46*, 3771.

(12) Wenkert, E.; McPherson, C. A. *J. Am. Chem. Soc.* **1972**, *94*, 8084.

(13) Schollkopf, U.; Banhidai, B.; Frasnelli, H.; Meyer, R.; Beckhaus, H. *Liebigs Ann. Chem.* **1974**, 1767.

(14) Pellicciari, R.; Castagnino, E.; Corsano, S. *J. Chem. Res., Synop.* **1979**, 76. Pellicciari, R.; Fringuelli, R.; Sisani, E.; Curini, M. *J. Chem. Soc., Perkin Trans. I* **1981**, 2566.

(15) While our work was in progress, Holmquist and Roskamp reported that aldehydes are efficiently converted into β-keto esters by reaction with ethyl diazoacetate in the presence of tin(II) chloride, see: Holmquist, C. R.; Roskamp, E. J. *J. Org. Chem.* **1989**, *54*, 3258.

0022-3263/90/1955-5297$02.50/0