[4] Crystal structure analysis data: **1**: Dark red needles; $0.01 \times 0.01 \times 0.15$ mm^3; tetragonal; $P4_2/mnm$ (No. 136); $Z = 2$; $T = 293(2)$ K; $a = 1452.32(16)$, $c = 360.83(6)$ pm (powder data: $a = 1452.9(2)$, $c = 360.9(1)$ pm); $V = 761.1 \times 10^6$ pm^3; $2\theta_{max} = 44°$, $Mo_{K\alpha}$ ($\lambda = 71.073$ pm); graphite monochromator, Bruker Smart CCD (ω-scan); 1777 measured reflections, 292 reflections unique; $R_{int} = 0.099$; LP correction; no other absorption correction applied; SHELXTL-5.03 (structure solution: direct methods; structure refinement: full-matrix least-squares on $|F^2|$); 39 parameters (all atoms refined anisotropically except N4 and C); max./min. residual electron density: $0.77/-0.73$ e Å^{-3}; $R1 = 0.061/0.088$, $wR2 = 0.123/0.136$, GooF = 1.21/1.16 (for $233\ F_o > 4\sigma(F_o)$/all 292 unique reflections). **2**: Yellow-green transparent needles; $0.03 \times 0.03 \times 0.15$ mm^3; orthorhombic; $Pnma$ (No. 62); $Z = 4$; $T = 293(2)$ K; $a = 1143.9(2)$, $b = 357.72(7)$, $c = 1384.4(3)$ pm (powder data: $a = 1145.8(2)$, $b = 358.5(1)$, $c = 1386.4(3)$ pm); $V = 566.5 \times 10^6$ pm^3; $2\theta_{max} = 46.7°$, $Mo_{K\alpha}$ ($\lambda = 71.073$ pm); graphite monochromator, Bruker Smart CCD (ω-scan); 2271 measured reflections, 478 unique reflections; $R_{int} = 0.085$; LP correction; no other absorption correction applied; SHELXTL-5.03 (structure solution: direct methods; structure refinement: full-matrix least-squares on F^2); 47 parameters (all atoms except C refined anisotropically); max./min. residual electron density: $0.88/-0.72$ e Å^{-3}, $R1 = 0.056/0.085$, $wR2 = 0.115/0.126$, GooF = 1.23/1.12 (for $344\ F_o > 4\sigma(F_o)$/all 478 unique reflections). Further details of the crystal structure investigations may be obtained from the Fachinformationszentrum Karlsruhe, D-76344 Eggenstein-Leopoldshafen, Germany (fax: (+49) 7247-808-666; e-mail: crysdata@fiz-karlsruhe.de), on quoting the depository numbers CSD-410825 ($Ca_4N_2(CN_2)$) and CSD-410862 ($Ca_{11}N_6(CN_2)_2$).
[5] U. Berger, W. Schnick, *J. Alloys Compd.* **1994**, *206*, 179–184.
[6] N.-G. Vannerberg, *Acta Chem. Scand.* **1962**, *16*, 2263–2266.
[7] While preparing the revised version of this text, we were informed of work by P. Hoehn, R. Niewa, M. Ludwig and R. Kniep. Their research on $Ca_4N_2(CN_2)$ and some other phases was presented as Poster P148 at the 7th European Conference on Solid State Chemistry (ECSSC'99), Sept. 15–18, 1999, Universidad Complutende, Madrid (Spain).

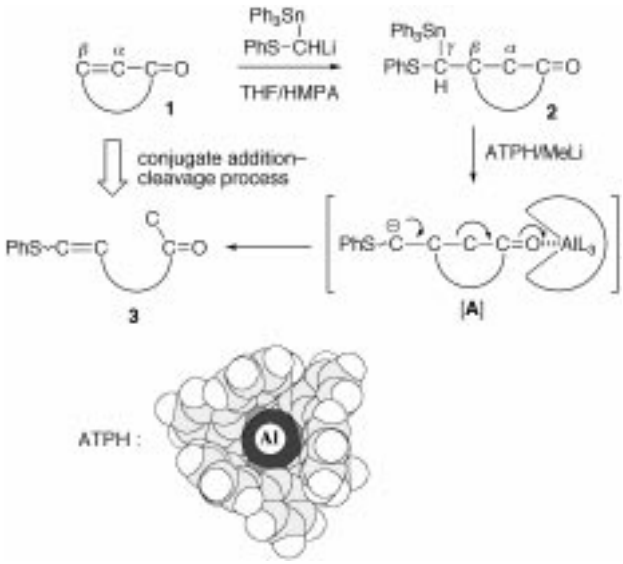
"Amphiphilic" Cleavage of γ-Stannyl Ketones with ATPH/RLi: Application to Enone Fragmentation by the Conjugate Addition–Cleavage Sequence**

Yuichiro Kondo, Kana Kon-i, Atsuko Iwasaki, Takashi Ooi, and Keiji Maruoka*

Despite the availability of many carbon–carbon bond forming reactions, including ring closures in organic synthesis, less attention has been paid so far to the corresponding reverse processes, that is, the selective ring cleavage of carbon–carbon bonds.[1, 2] Although it is not of synthetic importance, the McLafferty rearrangement of the C_α–C_β bond of aliphatic carbonyl compounds, as determined by mass spectrometry, is a typical example of such a reaction.[3]

The previously known ring-cleavage reactions can be divided into two classes depending on the mode of activation.[1] Most involve base- or acid-promoted fragmentation by activating either electrofugal or nucleofugal moieties, respectively.[4] The other, less general type of fragmentation is realized by the intramolecular push–pull effect of the electrofugal and nucleofugal parts,[2c] as exemplified by retro-aldol reactions.

Here we report a conceptually new, "amphiphilic" cleavage reaction of the C_α–C_β bonds of γ-stannyl ketones **2**, leading to compounds of type **3** (Scheme 1). In combination with the



Scheme 1. Conjugate addition and amphiphilic cleavage of enone **1** with ATPH/MeLi leading to ketone **3**. L = 2,6-diphenylphenoxy.

conjugate addition of α-stannyl carbanion to enone **1**, this approach constitutes a novel two-step conjugate addition–cleavage sequence. The new fragmentation is interpretable as the nucleophilic attack of the electrofugal carbanion part to an electrophilically activated carbonyl moiety (in this respect, "amphiphilic" means electrophilically activated nucleophilic), and it should be categorized into a third, yet unexplored class of fragmentation. The success of this amphiphilic cleavage highly relies on the effective use of a combined Lewis acid/base system consisting of aluminum tris(2,6-diphenylphenoxide) (ATPH) and MeLi,[5] thereby allowing the appropriate push–pull relay of the electrofugal and nucleofugal moieties in the key intermediate [**A**].

The requisite conjugate adduct, 3-[triphenylstannyl(phenylsulfanyl)methyl]cyclohexanone (**4**) can be readily prepared by treatment of cyclohexenone with triphenylstannyl(phenylsulfanyl)methyllithium—generated from triphenylstannyl(phenylsulfanyl)methane with lithium diisopropylamide (LDA) in THF[6]—in the presence of hexamethyl phosphoramide (HMPA) at −78 °C. Complexation of **4** with ATPH (1.1 equiv) in toluene/diethyl ether at −78 °C and subsequent addition of MeLi (3 equiv) afforded cleanly 7-phenylsulfanyl-6-hepten-2-one (**5**) as a product of C_α–C_β bond cleavage in 96% yield (Z:E = 1.3:1; Table 1, entry 1). The push–pull effect of γ-lithio ketones by complexation with Lewis acidic ATPH is crucial for effecting the smooth C_α–C_β

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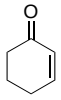
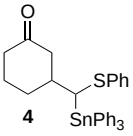
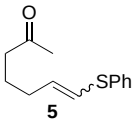
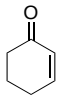
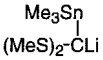
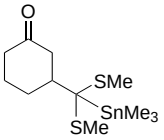
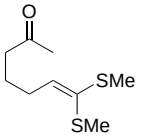
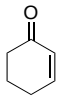
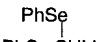
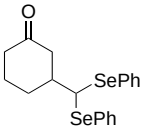
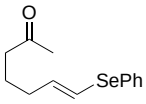
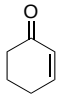
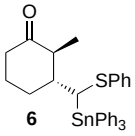
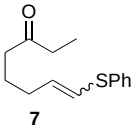
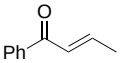
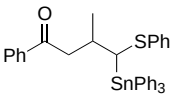
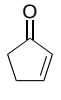
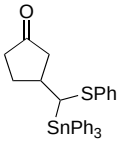
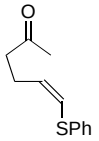
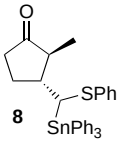
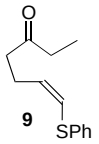
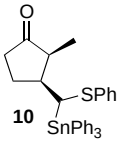
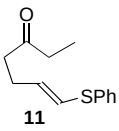
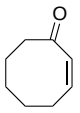
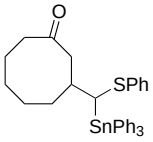
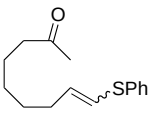
Table 1. Selected results of the conjugate addition–cleavage sequence of enones.[a] See the Experimental Section for details.

Entry	Enone	Reagent	Solvent	Conjugate adduct	yield [%][b,c]	Reagent	Solvent	Cleavage product	yield [%][b] (ratio)[d]
1			HMPA/THF		93	ATPH/MeLi	PhMe/Et_2O		96 (1.3:1)
2			HMPA/THF		77	ATPH/MeLi	PhMe/THF		85
3			ATPH/THF		73	ATPH/BuLi	PhMe/THF		63
4		 HMPA/THF, then MeI			77	ATPH/MeLi	PhMe/Et_2O		76 (6:1)
5			HMPA/THF		64	ATPH/MeLi	PhMe/Et_2O		92
6			HMPA/THF		93	ATPH/MeLi	PhMe/Et_2O		56
7		 HMPA/THF, then MeI			83	ATPH/MeLi	PhMe/Et_2O		87
8			HMPA/THF		82	ATPH/MeLi	PhMe/Et_2O		89
9			ATPH/THF		57	ATPH/MeLi	PhMe/THF		85 (1.2:1)

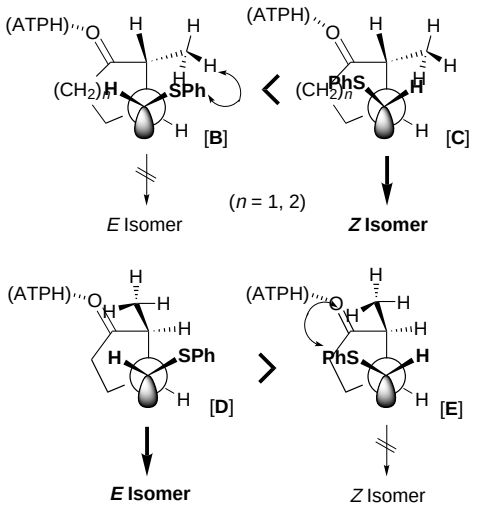
[a] The reaction was carried out with ATPH (1.1 equiv) and RLi (3 equiv; R = Me or Bu) in toluene/diethyl ether at $-20\,^{\circ}C$ or toluene/THF (1/1) at $-78\,^{\circ}C$ for 20 min. [b] Yield of isolated compound. [c] The diastereomeric ratio of the newly created C–C bond is ≈1:1 (entries 1, 4–9). [d] The *Z*:*E* ratios of the cleavage products were determined by ^1H NMR analysis.

bond cleavage reaction. Indeed, without ATPH, treatment of **4** with MeLi gave deteriorated reaction products without formation of the desired **5**. Use of ordinary Lewis acids such as $BF_3 \cdot OEt_2$ and $TiCl_4$ in place of ATPH gave unsatisfactory results, mainly due to the facile attack of MeLi on the Lewis acids.

Other selected examples (Table 1) concerning the novel conjugate addition/fragmentation reaction of enones clearly indicate the effectiveness of our approach. In addition to triphenylstannyl(phenylsulfanyl)methyllithium, bis(methylsulfanyl)(trimethylstannyl)methyllithium and bis(phenylselanyl)methyllithium are also employable as conjugate addition agents (entries 2 and 3), thereby enhancing the synthetic potential for further manipulation of the cleavage products. The conjugate addition/alkylation sequence further expands the synthetic utility of our approach.

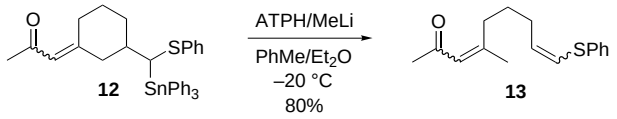
The stereochemical outcome of the newly formed double bonds in the present amphiphilic cleavage is worthy of

comment. The *trans*-conjugate adducts **6** and **8** afforded cleavage products **7** and **9**, respectively, with high *Z* selectivity (Table 1, entries 4 and 7). Since the diastereomeric ratio of the newly created C–C bond in the conjugate adducts **6** and **8** is about 1:1, the conformations of intermediate carbanions should be responsible for the stereochemisty of the cleavage process. The conformer [**C**] (Scheme 2, $n = 1, 2$) is preferred over [**B**] ($n = 1, 2$) due to the steric repulsion between the PhS and CH_3 groups. Such a steric effect is also predominant in the amphiphilic cleavage of *cis*-conjugate adduct **10**, giving the *E* isomer **11** (Table 1, entry 8) by way of the preferred conformer [**D**] rather than [**E**] (Scheme 2).



Scheme 2. The stereochemical outcome of the amphiphilic cleavage of ketones **6**, **8**, and **10** with ATPH/MeLi, leading to ketones **7**, **9**, and **11**, respectively.

The new amphiphilic cleavage of γ-stannyl enones described herein serves as a highly efficient and general route to functionalized ketones from commercially available enones, and therefore should find considerable utility in selective organic synthesis. Furthermore, this process has been extended to the selective C_γ–C_δ bond cleavage of $\alpha\beta$-enone **12** ($E:Z \approx 1:1$), giving $\alpha\beta$-enone **13** in 80% yield (Scheme 3, (3*E*,8*E*):(3*E*,8*Z*):(3*Z*,8*E*):(3*Z*,8*Z*) = 45:30:15:10).



Scheme 3. Selective C_γ–C_δ bond cleavage of enone **12**.

Experimental Section

The conjugate addition/cleavage sequence of cyclohexenone (Table 1, entry 1): To a solution of LDA—prepared by treatment of diisopropylamine (231 μL, 1.65 mmol) with BuLi (1.6 M solution in hexane, 0.94 mL, 1.5 mmol) in THF at 0 °C for 30 min—was added a solution of phenylsulfanyl(triphenylstannyl)methane (710 mg, 1.5 mmol) in THF at −78 °C. The mixture was allowed to warm to −20 °C, and then stirred for 30 min to furnish a pale yellow solution. After the mixture was recooled to −78 °C, HMPA (287 μL, 1.65 mmol) and 2-cyclohexen-1-one (96 μL, 1 mmol) were added. The solution was stirred at −78 °C for 1 h and poured into water. After extraction with diethyl ether, the organic extracts were dried over Na_2SO_4. Evaporation of solvents and purification of the residue by column chromatography on silica gel (ethyl acetate/hexane (1/4) as eluant) gave **4** as a white solid (529 mg, 0.93 mmol; 93% yield): ^{1}H NMR (300 MHz, $CDCl_3$, 25 °C, TMS): $\delta = 7.16-7.77$ (m, 20H; Ph), 3.72 (d, $^3J(H,H) = 2.4$ Hz, 1H for a diastereomer; CH(SPh)($SnPh_3$)), 3.67 (d, $^3J(H,H) = 1.8$ Hz, 1H for a diastereomer; CH(SPh)($SnPh_3$)), 1.43–2.50 (m, 9H; $COCH_2$, CH_2, and CH).

A solution of 2,6-diphenylphenol (406 mg, 1.65 mmol) in toluene (4.5 mL) was carefully degassed, and Me_3Al (1.0 M solution in hexane, 0.55 mL, 0.55 mmol) was added at room temperature under argon. Methane gas evolved immediately. The resulting yellow solution was stirred for 30 min and used without purification. After the addition of **4** (285 mg, 0.5 mmol) in toluene (0.5 mL) and diethyl ether (5 mL) at −78 °C, the solution was allowed to warm to −20 °C, and MeLi (1.0 M solution in diethyl ether, 1.5 mL, 1.5 mmol) was added dropwise. The solution was stirred at −20 °C for 20 min and then poured into 1 N HCl. The mixture was extracted with diethyl ether, and the organic extracts were dried over Na_2SO_4. Evaporation of solvents and purification of the residue by column chromatography on silica gel (dichloromethane/hexane (1/3) to ethyl acetate/hexane (1/9) as eluant) gave **5** as a colorless oil (106 mg, 0.479 mmol; 96% yield). The *Z*:*E* ratio of **5** was determined to be 1.3:1 by ^{1}H NMR spectroscopy: *Z* isomer: ^{1}H NMR (300 MHz, $CDCl_3$, 25 °C, TMS): $\delta = 7.17-7.42$ (m, 5H; Ph), 6.25 (dt, $^3J(H,H) = 9.4$, 1.3 Hz, 1H; C=CHSPh), 5.78 (dt, $^3J(H,H) = 9.4$, 7.2 Hz, 1H; CH=C), 2.49 (t, $^3J(H,H) = 7.3$ Hz, 2H; $COCH_2$), 2.27 (dq, $^3J(H,H) = 7.3$, 1.3 Hz, 2H; CH_2C=C), 2.15 (s, 3H; $COCH_3$), 1.74 (quint, $^3J(H,H) = 7.3$ Hz, 2H; CH_2); *E* isomer: ^{1}H NMR (300 MHz, $CDCl_3$, 25 °C, TMS): $\delta = 7.17-7.42$ (m, 5H; Ph), 6.17 (dt, $^3J(H,H) = 15.0$, 1.3 Hz, 1H; C=CHSPh), 5.91 (dt, $^3J(H,H) = 9.4$, 15.0 Hz, 1H; CH=C), 2.47 (t, $^3J(H,H) = 7.3$ Hz, 2H; $COCH_2$), 2.18 (dq, $^3J(H,H) = 7.3$, 1.3 Hz, 2H; CH_2C=C), 2.15 (s, 3H; $COCH_3$), 1.72 (quint, $^3J(H,H) = 7.3$ Hz, 2H; CH_2).

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