L. The Ise unit was determined to be *R*-form by HPLC analysis of the *N*-benzoyl-derivatized hydrolysate of 1 on chiral columns (SUMIPAX). Therefore, the total structure of keramamide F was concluded to be 1.

Keramamide F (1) is a peptide having unique structural features containing some unusual amino acids such as isoserine, Δ-Trp, and (*O*-methylseryl)thiazole. (*R*)-Isoserine[15] and (*O*-methylseryl)thiazole have not been previously found in any naturally-occurring peptide. A few peptides containing Δ-Trp[16] have been reported as metabolites of terrestrial microorganisms. Keramamide F (1) showed cytotoxicity against human epidermoid carcinoma KB cells and murine lymphoma L1210 cells with IC_{50} values of 1.4 and 2.0 μg/mL, respectively.

Experimental Section

General Methods. FAB mass spectra were obtained using *m*-nitrobenzyl alcohol as a matrix [bombarding ions (Cs), acceleration (8 kV), and collison gas (He)].

Collection, Extraction, and Separation. The sponge *Theonella* sp. was collected off Kerama Island, Okinawa, and was kept frozen until used. The MeOH/toluene (3:1) extract (1 L × 2) of the sponge (4.0 kg, wet weight) was suspended in 1 M NaCl (1 L) and was extracted with toluene (600 mL × 2). The aqueous layer was subsequently extracted with $CHCl_3$ (800 mL × 2). The $CHCl_3$ soluble fraction (2.1 g) was subjected to flash silica gel column chromatography (4.5 × 36 cm) with gradient elution of MeOH (2–50%) in $CHCl_3$. The fraction eluted with 15% MeOH in $CHCl_3$ was then separated by gel filtration on Sephadex LH-20 (2 × 93 cm) with MeOH to give a crude peptide fraction in the 120–175-mL fraction, which was further purified by reversed-phase HPLC [YMC-Pack AM-324 ODS, Yamamura Chemical, 10 × 250 mm; flow rate 2.5 mL/min; eluent, CH_3CN/H_2O, 40:60] to yield keramamide F (1, 5.1 mg, t_R 23.4 min).

Keramamide F (1): colorless solid; mp 187 °C dec; $[\alpha]^{21}_D$ −25° (*c* 0.86, MeOH); IR (KBr) ν_{max} 3400, 1650, and 1520 cm^{-1}; UV (MeOH) 209 (ε 30 800), 220 (30 800), 275 (23 200), and 339 (9800) nm; ^1H and ^{13}C NMR (Table I); $^1J_{C-H}$ values (Hz) by INEPT experiments (DMSO-d_6) formamide 195 (CHO); Δ-Trp residue 151 (β), 187 (2′), 158 (4′), 160 (5′), and 164 (7′); 2 residue 158 (2), 155 (3), and 189 (5); FABMS (positive) *m/z* 921 $(M + H)^+$; exact mass found *m/z* 921.3912, calcd for $C_{43}H_{57}O_{11}N_{10}S$ 921.3895.

Hydrogenation and Mild Acid Hydrolysis of 1. A solution of compound 1 (100 μg) in MeOH (500 μL) was stirred in the presence of a catalytic amount of 10% Pd–C under H_2 for 1 h at room temperature. The reaction mixture was hydrolyzed with 4 N methanesulfonic acid (100 μL) at 115 °C for 24 h and subjected to amino acid analysis to detect tryptophan. Amino acid analysis indicated that Ala, Ise, Ile, Dpr, and Trp were present in the ratio of 1:1:1:1:0.2.

Amino Acid Analysis by Chiral GC. Compound 1 (100 μg) was hydrolyzed with 6 N HCl (1 mL) at 110 °C for 24 h. The reaction mixture was treated with 9% HCl/MeOH (1 mL) at 100 °C for 30 min and was then treated with trifluoroacetic anhydride (TFAA)/CH_2Cl_2 (1:1, 1 mL) at 100 °C for 5 min. Capillary GC analyses were carried out using a Chirasil-Val column (Alltech, 0.32 mm × 25 m; N_2 as a carrier gas; the program rate: 50–200 °C at 4 °C/min) to show peaks at t_R 3.9, 7.5, and 22.2 min. Standard amino acids were also converted to the TFA/Me derivatives by the same procedure. Retention times (minutes) were as follows: D-Ala (3.6), L-Ala (3.9), D-Ile (7.2), L-Ile (7.5), D-Dpr (21.6), and L-Dpr (22.2).

Determination of the Stereochemistry of the (*O*-Methylseryl)thiazole. A stream of O_3 was bubbled into a 1-mL MeOH solution of compound 1 (200 μg) at room temperature for 8 min. The reaction mixture was subjected to hydrolysis and TFA/Me derivatization. The chiral GC analysis of the TFA/Me derivatized hydrolysate was carried out as above and established the presence of L-*O*-methylserine [t_R: L-*O*-methylserine (6.8 min) and D-*O*-methylserine (6.6 min)].

Determination of the Stereochemistry of the C-11–C-14 Moiety in Segment 2. To a stirred solution of compound 1 (100 μg) in 5% NaOH (300 μL) was added dropwise 30% H_2O_2 (50 μL). After stirring at 65 °C for 20 min the reaction mixture was subjected to hydrolysis and TFA/Me derivatization. Only the L-form of Ile (t_R 7.5 min) was observed by the chiral GC analysis as above, and the peak area for Ile was nearly doubled compared to 1.

Determination of the Stereochemistry of the Isoserine. Compound 1 (100 μg) was hydrolyzed with 6 N HCl (500 μL) at 110 °C for 24 h. The reaction mixture was treated with 9% HCl/MeOH (1 mL) at 100 °C for 30 min and was then treated with benzoyl chloride/Et_3N/CH_2Cl_2 (1 μmol/1 μmol/0.5 mL) at room temperature for 2 h. Evaporation under reduced pressure afforded a residue, which was subjected to the chiral HPLC analysis using SUMIPAX OA-1000 (Sumitomo Chemical Industry, 4 × 150 mm) and two SUMIPAX OA-4100 (4 × 250 mm) columns connected in tandem [37 °C; flow rate: 0.7 mL/min; eluent: *n*-hexane/1,2-dichloroethane/ethanol (15:5:1); detection: UV at 240 nm]. Retention times of (*S*)- and (*R*)-*N*-benzoylisoserine were 35.5 and 36.6 min, respectively. The retention time of the *N*-benzoylisoserine derived from the hydrolysate of 1 was found to be 36.6 min.

Acknowledgment. We thank Mr. Z. Nagahama for his help in collecting the sponge, Dr. T. Iwasaki, Tanabe Seiyaku Co., Ltd., for the generous gift of (*S*)-isoserine, and Prof. T. Hayashi, Hokkaido University, for help with chiral HPLC determination. This work was partly supported by a Grand-in-Aid for Scientific Research from the Ministry of Education, Science, and Culture, Japan.

Supplementary Material Available: All spectra of keramamide F (11 pages). This material is contained in many libraries on microfiche, immediately follows this article in the microfilm version of the journal, and can be ordered from the ACS; see any current masthead page for ordering information.

(15) Maeda, H.; Suzuki, M.; Sugano, H.; Matsumoto, K. *Synthesis* **1988**, 401–402.

(16) Sheehan, J. C.; Mania, D.; Nakamura, S.; Stock, J. A.; Maeda, K. *J. Am. Chem. Soc.* **1968**, *90*, 462–470.

Stereoselective Synthesis of *N,N*-Divinylureas by Diiron Enneacarbonyl-Catalyzed Isomerization of N,N-Diallylic or N-Allylic *N*-Vinylureas

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In contrast to the well-developed chemistry of enamines and enamides,[1] the chemistry of amines with two vinyl groups attached to nitrogen has not been explored, in spite of its potential utility.[2] There are as yet no general methods available for the preparation of *N,N*-divinylamides. Although some *N,N*-divinylamides[3] have been

(1) (a) Hickmott, P. W. *Tetrahedron* **1982**, *38*, 1975, 3363. (b) Whitesell, J. K.; Whitesell, M. A. *Synthesis* **1983**, 517. (c) *Enamines: Synthesis, Structure and Reactions*, 2nd ed.; Cook, A. G., Ed; Marcel Dekker: New York, 1987.

(2) Adler, B.; Burtzlaff, C.; Duschek, C.; Ohl, J.; Schmidt, H.; Zech, W. *J. Prakt. Chem.* **1978**, *320*, 904.

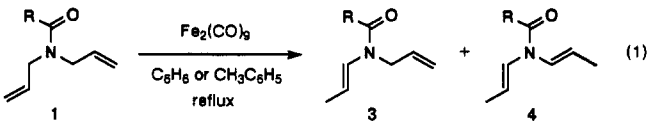
(3) (a) Chupp, J. P.; Weiss, E. R. *J. Org. Chem.* **1968**, *33*, 2357. (b) Meyers, A. I.; Takaya, T. *Tetrahedron Lett.* **1971**, 2609. (c) Hasegawa, H.; Suzuki, M.; Arai, N.; Fujita, M.; Watanabe, K. *Rep. Asahi Glass Found. Ind. Technol.* **1980**, *37*, 296. (d) Duschek, C.; Höbold, W.; Naick, R.; Schmidtu, H.; Yen, N. T. *J. Prakt. Chem.* **1975**, *317*, 491. (e) Adler, B.; Burtzlaff, C.; Duschek, C.; Ohl, J.; Schmidt, H.; Zech. W. *J. Prakt. Chem.* **1978**, *320*, 904. (f) Medici, A.; Fogagnolo, M.; Pedrini, P.; Dondori, A. *J. Org. Chem.* **1982**, *47*, 3844. (g) Barlenga, J.; Joglar, J.; Fustero, S.; Gotor, V. *J. Chem. Soc., Chem. Commun.* **1986**, 361.

0022-3263/92/1957-5542$03.00/0

obtained by the acylation of azadienes[3a] or by thermal rearrangement of sulfolenes[3b] and vinylaziridines,[3c] several steps are required to prepare the starting materials. In this paper, we describe a versatile new synthetic method to prepare *N,N*-divinylureas via diiron enneacarbonyl-catalyzed isomerization of N,N-diallylic or N-allylic *N*-vinylureas.

Transition metal-catalyzed isomerization reactions[4] of N-allylic amines and amides[5] have been extensively studied from the synthetic as well as the mechanistic point of view. However, examples of the application of transition metals to the isomerization of N-allylic amines bearing allylic or vinyl groups are very scarce.[6] For example, it has been briefly noted that the Rh-catalyzed isomerization of N,N-diallylic amines required much higher temperature than the isomerization of N-allylic amines.[4b]

The isomerization of some *N,N*-diallylamides **1** in the presence of $Fe_2(CO)_9$ was examined (eq 1). Diallylamide



(1)

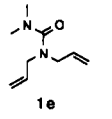
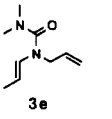
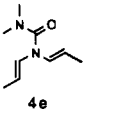
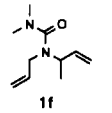
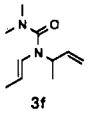
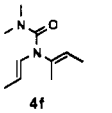
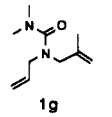
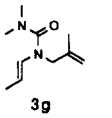
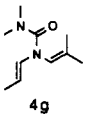
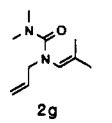
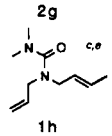
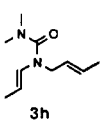
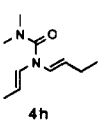
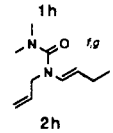
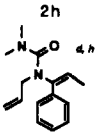
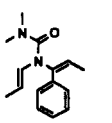
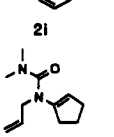
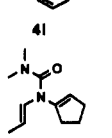
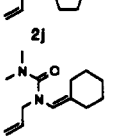
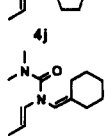
1a : R = CH_3	$Fe_2(CO)_9$ (20 mol%)	30 h	**3a** + **4a** : 90 % (**3a** / **4a** = 20 / 80)
1b : R = C_6H_5	$Fe_2(CO)_9$ (40 mol%)	46 h	**3b** + **4b** : 35 % (**3b** / **4b** = 13 / 87)
1c : R = 4-$CH_3C_6H_4$	$Fe_2(CO)_9$ (40 mol%)	45 h	**3c** + **4c** : 78 % (**3c** / **4c** = 6 / 94)
1d : R = 4-$CH_3OC_6H_4$	$Fe_2(CO)_9$ (40 mol%)	45 h	**3d** + **4d** : 86 % (**3d** / **4d** = 3 / 97)
1e : R = $(CH_3)_2N$	$Fe_2(CO)_9$ (10 mol%)	3 h	**3e** + **4e** : 82 % (**3e** / **4e** = 7 / 93)

1a gave a mixture of *N*-allyl-*N*-vinylamide **3a** and *N,N*-divinylamide **4a**. The reaction of aromatic amides **1b–1d** gave predominantly **4**, but the reaction required more than 30 h. Interestingly, when a dimethylcarbamoyl group was attached to the nitrogen of the *N,N*-diallylamine and 10 mol % of the catalyst was used, the reaction was complete within 3 h at 110 °C in toluene and gave **4e** in 82% yield with an *E,E* to *E,Z* ratio of 54:46.[7]

The results of the $Fe_2(CO)_9$-catalyzed isomerization of a variety of N,N-diallylic and N-allylic *N*-vinylureas are summarized in Table I. The use of THF improved the stereoselectivity of the reaction compared with the reaction in toluene, and the *E,E* isomer of **4e** was the predominant product (entry 1).[8] Both double bonds in **1f** migrated smoothly, and the *E,E* and *E,Z* isomers of **4f** were formed in a ratio of 61:39 with high selectivity although there are eight possible regio- and stereoisomers.[10] N-Allylic *N*-vinylureas **3g** and **3h** were the predominant product in the isomerization of **1g** and **1h** (entries 3 and 5). Attempts to improve their conversion to **4g** and **4h** failed even at prolonged reaction times and/or at higher temperatures. Instead, **4g** and **4h** were synthesized from N-allylic *N*-vinylureas **2g** and **2h** (entries 4 and 6). The 3-aza-Cope rearrangement that takes place in the Pd-catalyzed reaction of *N*-allylenamines[11] did not take place with **2g** and **2h**. The $Fe_2(CO)_9$-catalyzed isomerization approach was also successful in the synthesis of *N,N*-divinylureas having a phenyl, cyclopentenyl, or cyclohexylidene group, in spite of the steric congestion around the nitrogen atom of the products, **4i**, **4j**, and **4k** (entries 7–9).

From the results in Table I, it is apparent that the isomerization of an allyl group occurs more rapidly than that of methallyl and crotyl groups (eq 2). This tendency

Table I. $Fe_2(CO)_9$-Catalyzed Isomerization of N-Allylic Ureas[a]

entry	substrate	products	yield,[b] %
1	 **1e**	 **3e**  **4e**	85, **3e** / **4e** = 3 / 97 *E,E* / *E,Z* (**4e**) = 86 / 14 [c]
2	 **1f**	 **3f**  **4f**	87, **3f** / **4f** = <1 / >99 *E,E* / *E,Z* (**4f**) = 61 / 39 [c,d]
3	 **1g**	 **3g**  **4g**	83, **3g** / **4g** = 60 / 40 *E* / *Z* (**4g**) = <1 / >99 [c]
4	 **2g**		64, **2g** / **4g** = <1 / >99
5	 [c,e] **1h**	 **3h**  **4h**	94, **3h** / **4h** = 67 / 33 *E* / *Z* (**3h**) = <1 / >99 [c] *E,E* / *E,Z* (**4h**) = 82/18 [f]
6	 [f,g] **2h**		57, **2h** / **4h** = 3 / 97 *E,E* / *E,Z* (**4h**) = 93 / 7 [f]
7	 [d,h] **2i**	 **4i**	67, **2i** / **4i** = <1 / >99 *E,E* / *E,Z* (**4i**) = 13 / 87 [d]
8	 **2j**	 **4j**	84, **2j** / **4j** = <1 / >99 *E* / *Z* (**4j**) = >99 / <1 [e]
9	 **2k**	 **4k**	91, **2k** / **4k** = <1 / >99 *E* / *Z* = >99 / <1 [e]

[a] Reaction conditions: N,N-diallylic or N-allylic *N*-vinylureas (1.0 mmol), $Fe_2(CO)_9$ (0.25 mmol), THF (10 mL), 67 °C, 3 h. [b] Isolated yield. [c] Ratios determined by ^{1}H-NMR. [d] Stereochemistry estimated by NOE experiment. [e] *E*/*Z* = 75/25. [f] Determined by capillary GC analysis. [g] *E*/*Z* = 75/25. [h] *E*/*Z* = 11/89.

(4) For reviews, see: (a) Tani, K. *Pure Appl. Chem.* **1985**, *57*, 1845. (b) Otuka, S.; Tani, K. *Synthesis* **1991**, 665.

(5) Iron carbonyl-catalyzed isomerization of N-allylic amides usually requires more than 10 h: (a) Rossi, P.; Barola, P. F. *Ann. Chem. (Rome)* **1969**, *59*, 268, 762. (b) Hubert, A. J.; Moniotte, P.; Goebbels, G.; Warin, R.; Teyssi'e, P. *J. Chem. Soc., Perkin Trans. 2* **1973**, 1954. (c) Stille, J. K.; Becker, Y. *J. Org. Chem.* **1980**, *45*, 2139. (d) Corriu, R. J. P.; Huynh, V.; Moreau, J. J. E.; Patand-Sat, M. *J. Organomet. Chem.* **1983**, *255*, 359.

(6) Diiron enneacarbonyl-catalyzed reaction of *N*-triallylamine has been noted to give *N*-trivinylamine, but the details of the reaction have not been available: Kiji, J.; Nishimura, S.; Yamamoto, K.; Furukawa, J. *Bull. Chem. Soc. Jpn.* **1975**, *48*, 3417.

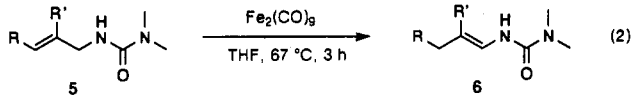
(7) Although iron carbonyl has been known to form stable diene complexes,[8] the *N,N*-divinylurea was purified by the usual bulb-to-bulb distillation.

(8) (a) Pearson, A. J. *In Advances in Metal–Organic Chemistry*; Liebeskind, L. S., Ed.; JAI: Greenwich, 1989; Vol. 1, p 1. (b) Alper, H.; Brandes, D. A. *Organometallics* **1991**, *10*, 2457.

(9) The isomer ratio of the product did not change even when the reaction continued for a prolonged reaction time.

(10) The other possible isomers are the *E* and *Z* isomers of *N*-allylic *N*-vinylureas and the *E,E*, *E,Z*, *Z,E*, and *Z,Z* isomers of *N,N*-divinylureas.

(11) Murahashi, S. I.; Makabe, Y.; Kuniya, K. *J. Org. Chem.* **1988**, *53*, 4489.



(2)

5a : R = R' = H	$Fe_2(CO)_9$ (0.5 mol%)	6a : 79 % (*E*/*Z* = 92 / 8)
5b : R = H, R' = CH_3	$Fe_2(CO)_9$ (5 mol%)	6b : 82 %
5c : R = CH_3, R' = H	$Fe_2(CO)_9$ (10 mol%)	6c : 79 % (*E*/*Z* = 71 / 29)

was also observed in the reaction of N-allylic ureas **5**. Only 0.5 mol % of $Fe_2(CO)_9$ was necessary to attain the isomerization of **5a**,[12] but 5 and 10 mol % of the catalyst were required for the complete conversion of **5b** and **5c**. Although the details of the mechanism of the reaction are still being elucidated, the *N*,*N*-dimethylcarbamoyl group appears to play an important role in facilitating the isomerization reaction. When *N*-allyl-*N'*,*N'*-diethylurea was treated with 0.5 mol % of $Fe_2(CO)_9$ in THF, the isomerization did not proceed at all.

In summary, N,N-diallylic or N-allylic *N*-vinylureas can be efficiently converted to *N*,*N*-divinylureas in the presence of $Fe_2(CO)_9$. This reaction is the most practical method for the synthesis of *N*,*N*-divinylureas. Furthermore, the $Fe_2(CO)_9$-catalyzed double bond migration of N-allylic *N*-vinylureas proceeds with *E* selectivity.

Experimental Section

General. Unless otherwise noted, materials were obtained from commercial suppliers and were used without further purification. Tetrahydrofuran (THF) was distilled from sodium metal prior to use. Toluene was distilled from sodium–lead alloy. Diiron enneacarbonyl purchased from Kanto Kagaku, and Strem was washed with acetic acid, water, ethanol, and *n*-hexane and dried prior to use. N-Allylic ureas **1e**, **1f**, **1g**, and **2i** were prepared either by the *N*,*N*-dimethylcarbamoylation of diallylamine or by the allylation of the corresponding N-monoallylic ureas. N-Allylic *N*-vinylureas **2g** and **2h** were prepared by the allylation of the corresponding *N*-vinylureas. N-Allylic *N*-vinylureas **2j** and **2k** were prepared by modified literature methods.[14] The IR spectra were measured on a JASCO grating IR spectrometer IR-G and a Perkin-Elmer FT-IR 1640. The ^{1}H-NMR spectra were recorded on JEOL-JNM-GX-270 (270 MHz) and Hitachi R-1500 (60 MHz) spectrometers with tetramethylsilane as an internal standard. The ^{13}C-NMR spectra were obtained on a JEOL JNM-GX-270 (67.8 MHz). The mass spectra were recorded on Shimadzu GCMS-QP1000 (A) (EI/CI, mode) and GCMS 9020DF high-resolution mass spectrometers. Analytical gas chromatography (GLC) was carried out on a Shimadzu GC-8A equipped with a flame ionization detector and a 0.5-mm i.d. × 25-m capillary column packed with (+) CBP 20-M25-0.25. Bulb-to-bulb distillation was carried out with a Kugelrohr apparatus (SHIBATA's Glass Tube Oven GTO-250).

Typical Procedure for Isomerization of N-Allylic *N'*,*N'*-Dimethylureas. In a 20-mL two-necked flask fitted with a reflux condenser were placed *N*,*N*-diallyl-*N'*,*N'*-dimethylurea (**1e**) (0.17 g, 1.0 mmol) and THF (10 mL) under nitrogen atmosphere. Diiron enneacarbonyl (0.09 g, 0.25 mmol) was added, and the solution was stirred under reflux. After 3 h, the reaction mixture was cooled and filtered. The filtrate was concentrated in vacuo and purified by bulb-to-bulb distillation under reduced pressure (150 °C (3 Torr)) to give a mixture of *N*,*N*-di(1-propenyl)-*N'*,*N'*-dimethylurea (**4e**) and *N*-(1-propenyl)-*N*-(2-propenyl)-*N'*,*N*-dimethylurea (**3e**) (0.14 g, 85% yield, **3e**/**4e** = 3/97, *E*,*E*/*E*,*Z* of **4e** = 86/14 (capillary GLC ((+) CBP-M-0.25, 0.5-mm i.d. × 25 m), 130–170 °C)): IR (neat) 2925, 1655, 1480, 1440, 1385, 1375, 1240, 1200, 1110, 1055, 965, 930, 770 cm^{-1}; ^{1}H-NMR ($CDCl_3$) δ 1.44 (dd, *J* = 7.0, 1.7 Hz, 0.4 H), 1.68 (dd, *J* = 6.7, 1.5 Hz, 0.4 H), 1.71 (dd, *J* = 6.6, 1.5 Hz, 5.2 H), 2.85 (s, 5.2 H), 2.86 (s, 0.8 H), 4.84 (dq, *J* = 14.0, 6.6 Hz, 0.1 H), 5.08 (dq, *J* = 14.0, 6.8 Hz, 1.8 H), 5.34 (dq, *J* = 7.9, 7.4 Hz, 0.1 H), 5.80 (dq, *J* = 8.0, 1.7 Hz, 0.1 H), 6.14 (dq, *J* = 14.0, 1.5 Hz, 1.8 H), 6.49 (dq, *J* = 14.0, 1.5 Hz, 0.1 H); ^{13}C-NMR ($CDCl_3$) δ 11.9, 15.1 (CH_3), 38.3 ($N(CH_3)_2$), 105.1, 111.6, 119.6, 126.7, 129.2, 130.1 (C=C), 159.7 (C=O); CI-MS (*m*/*e*) 169 (M^+ + 1), 157, 141, 129, 93; HRMS calcd for $C_9H_{16}N_2O$ 168.126 18, found 168.125 21.

***N*-(1-Methyl-1-propenyl)-*N*-(1-propenyl)-*N'*,*N'*-dimethylurea (4f)**: bp 150 °C (oven) (3 Torr) (0.16 g, 89% yield, *E*,*E*/*E*,*Z* = 61/39); IR (neat) 2922, 1651, 1489, 1446, 1374, 1253, 1213, 942 cm^{-1}; ^{1}H-NMR ($CDCl_3$) δ 1.45 (dq, *J* = 6.8, 1.5 Hz, 1.2 H), 1.66–1.69 (m, 4.8 H), 1.79–1.81 (m, 3 H), 2.84 (s, 3.6 H), 2.85 (s, 2.4), 4.77 (dq, *J* = 13.3, 6.6 Hz, 0.6 H), 4.96 (dq, *J* = 13.3, 6.6 Hz, 0.4 H), 5.25 (qq, *J* = 7.1, 1.1 Hz, 0.6 H), 5.38 (qq, *J* = 6.8, 1.1 Hz, 0.4 H), 6.24 (dq, *J* = 13.9, 1.5 Hz, 0.6 H), 6.41 (dq, *J* = 14.1, 1.5 Hz, 0.4 H) [the stereochemistry was supported by an NOE measurement conducted on a JEOL-GX 270 (270 MHz) instrument as follows: irradiation of the CH_3 at δ 1.79–1.81 enhanced the intensity of δ 5.38 by 17%]; ^{13}C-NMR ($CDCl_3$) δ 13.0, 14.9, 15.1, 19.6 (CH_3), 38.1, 38.2 ($N(CH_3)_2$), 105.1, 106.9, 120.8, 121.9, 128.2, 130.0 (C=C), 160.1 (C=O); CI-MS (*m*/*e*) 183 (M^+ + 1), 129; HRMS calcd for $C_{10}H_{18}N_2O$ 182.141 82, found 182.140 95.

***N*-(2-Methyl-1-propenyl)-*N*-(1-propenyl)-*N'*,*N'*-dimethylurea (4g)**: bp 140 °C (oven) (5 Torr) (0.07 g, 64% yield); IR (neat) 3400, 2925, 1650, 1480, 1440, 1390, 1370, 1255, 1190, 1100, 935, 855, 775 cm^{-1}; ^{1}H-NMR ($CDCl_3$) δ 1.47 (s, 3 H), 1.67 (dd, *J* = 6.6, 1.5 Hz, 3 H), 1.77 (s, 3 H), 2.84 (s, 6 H), 4.71–4.84 (dd, *J* = 13.8, 6.9 Hz, 1 H), 5.60–5.63 (m, 1 H), 6.54 (dq, *J* = 13.8, 1.5 Hz, 1 H); ^{13}C-NMR (67.8 MHz, $CDCl_3$) δ 14.7, 16.8, 21.5 (CH_3), 37.8 ($N(CH_3)_2$), 103.6, 121.4, 130.0, 130.3 (C=C), 159.5 (C=O); CI-MS (*m*/*e*) 183 (M^+ + 1), 142, 72; HRMS calcd for $C_{10}H_{18}N_2O$ 182.141 82, found 182.140 32.

A mixture of *N*-(1-butenyl)-*N*-(1-propenyl)-*N'*,*N'*-dimethylurea (4h) and *N*-(1-butenyl)-*N*-(2-propenyl)-*N'*,*N'*-dimethylurea (2h): bp 150 °C (oven) (3 Torr) (0.13 g, 57% yield, **2h**/**4h** = 3/97, *E*,*E*/*E*,*Z* = 93/7 (capillary GLC ((+)CBP-M-0.25, 0.5-mm i.d. × 25 m), 130–170 °C)) as a yellow oil; IR (neat) 2950, 1655, 1480, 1440, 1380, 1250, 1205, 1125, 1160, 930, 775 cm^{-1}; ^{1}H-NMR ($CDCl_3$) δ 0.95 (t, *J* = 7.4 Hz, 3 H), 1.65 (dd, *J* = 6.7, 1.6 Hz, 3 H), 2.01 (quintet, *J* = 7.2 Hz, 2 H), 2.78 (s, 6 H), 4.97–5.09 (m, 2 H), 6.07 (d, *J* = 13.9 Hz, 2 H); ^{13}C-NMR ($CDCl_3$) δ 0.9, 15.1 (CH_3), 23.3 (CH_2), 38.2 ($N(CH_3)_2$), 117.7, 118.3, 127.7, 129.1 (C=C), 159.6 (C=O); CI-MS (*m*/*e*) 183 (M^+ + 1), 143; HRMS calcd for $C_{10}H_{18}N_2O$ 182.141 82, found 182.144 16.

***N*-(1-Phenyl-1-propenyl)-*N*-(1-propenyl)-*N'*,*N'*-dimethylurea (4i)**: bp 150 °C (oven) (3 Torr) (0.20 g, 67% yield, *E*,*E*/*E*,*Z* = 13/87); IR (neat) 2920, 1651, 1489, 1443, 1389, 1223, 1107, 1064, 941, 778, 697 cm^{-1}; ^{1}H-NMR ($CDCl_3$) δ 1.62 (dd, *J* = 6.7, 1.6 Hz, 3 H), 1.69 (d, *J* = 7.0 Hz, 2.6 H), 1.88 (d, *J* = 7.3 Hz, 0.4 H), 2.73 (s, 5.2 H), 2.80 (s, 0.8 H), 4.73 (dq, *J* = 13.8, 6.9, Hz, 0.9 H), 4.93 (dq, *J* = 13.8, 6.9 Hz, 0.1 H), 5.62 (q, *J* = 7.0 Hz, 0.1 H), 6.08 (q, *J* = 7.0 Hz, 0.9 H), 6.37 (dq, *J* = 14.1, 1.5 Hz, 0.1 H), 6.71 (dq, *J* = 14.1, 1.5 Hz, 0.9 H), 7.23–7.40 (m, 5 H) [the stereochemistry was supported by an NOE measurement conducted on a JEOL-GX 270 (270 MHz) instrument as follows: irradiation of the Ph at δ 7.28–7.40 enhanced the intensity of δ 6.08 by 18%]; ^{13}C-NMR ($CDCl_3$) δ 14.0, 15.1 (CH_3), 38.0 ($N(CH_3)_2$), 105.9, 122.0, 125.3, 127.6, 128.0, 128.4, 128.7, 129.0, 137.5, 138.5 (C=C, Ph), 159.8 (C=O); HRMS calcd for $C_{15}H_{20}N_2O$ 244.157 46, found 244.157 10.

***N*-(1-Cyclopentenyl)-*N*-(1-propenyl)-*N'*,*N'*-dimethylurea (4j)**: bp 140 °C (oven) (2 Torr) (0.16 g, 84% yield, *E*/*Z* = >99/<1); IR (neat) 3412, 2935, 1655, 1490, 1388, 1204, 1133, 1061, 950, 788 cm^{-1}; ^{1}H-NMR (270 MHz, $CDCl_3$) δ 1.69 (dd, *J* = 6.7, 1.6 Hz, 3 H), 1.93 (quintet, *J* = 7.4 Hz, 2 H), 2.37–2.45 (m, 4 H), 2.87 (s, 6 H), 4.93 (dq, *J* = 13.8, 6.8 Hz, 1 H), 5.17 (br s, 1 H), 6.15 (dq, *J* = 13.8, 1.6 Hz, 1 H); ^{13}C-NMR (67.8 MHz, $CDCl_3$) δ 15.0 (CH_3), 22.5, 30.1, 31.3 (CH_2), 37.7 ($N(CH_3)_2$), 108.9, 115.9, 129.5, 142.7 (C=C), 159.0 (C=O); CI-MS (*m*/*e*) 195 (M^+ + 1), 167, 149; HRMS calcd for $C_{11}H_{18}N_2O$ 194.141 82, found 194.140 90.

***N*-(Cyclohexylidenemethyl)-*N*-(1-propenyl)-*N'*,*N'*-dimethylurea (4k)**: bp 140 °C (2 Torr) (0.20 g, 91% yield, *E*/*Z* = >99/<1); IR (neat) 2928, 1651, 1486, 1444, 1393, 1274, 1226,

(12) This reaction represents a catalytic reaction using a small amount of iron carbonyl. In the previous isomerizations using iron carbonyl, more than 10 mol % of the catalyst is necessary.[5,13]

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1189, 1107, 1066, 966, 942, 869, 777 cm^{-1}; ^1H-NMR (270 MHz, $CDCl_3$) δ 1.44–1.57 (m, 6 H), 1.67 (dd, J = 6.6, 1.6 Hz, 3 H), 1.91 (t, J = 5.8 Hz, 2 H), 2.17 (t, J = 5.8 Hz, 2 H), 2.84 (s, 6 H), 4.80 (dq, J = 13.8, 6.8 Hz, 1 H), 5.58 (s, 1 H), 6.57 (dq, J = 13.8, 1.6 Hz, 1 H); ^{13}C-NMR (67.8 MHz, $CDCl_3$) δ 15.0 (CH_3), 26.3, 26.4, 27.6, 28.1, 32.9 (CH_2), 38.3 ($N(CH_3)_2$), 103.9, 118.6, 130.5, 138.0 (C=C), 160.1 (C=O); CI-MS (m/e) 223 (M^+ + 1), 150; HRMS calcd for $C_{13}H_{22}N_2O$ 222.173 10, found 222.174 22.

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Supplementary Material Available: Preparative methods, IR, MS, ^1H NMR, ^{13}C NMR, and HRMS spectral data, and actual ^1H NMR spectra of **1e–1h, 2g–2k, 4e–k 5a–5c, 6a–6c** (36 pages). This material is contained in many libraries on microfiche, immediately follows this article in the microfilm version of the journal, and can be ordered from the ACS; see any current masthead page for ordering information.

Trityl Tetrakis(3,5-bis(trifluoromethyl)phenyl)-borate: A New Hydride Abstraction Reagent

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Introduction

Trityl tetraphenylborate, $Ph_3C^+BPh_4^-$, was recently shown to be a useful hydride or methyl anion abstraction reagent for organic and organometallic compounds.[1] Although the tetraphenylborate anion is less reactive toward some electrophilic cationic compounds than other widely used trityl cation counterions (i.e. ClO_4^-, BF_4^-, PF_6^-),[2] it still suffers from facile degradation and a tendency to π-coordinate through one of its phenyl groups.[3]

It is well-known that fluoro-substituted tetraarylborate derivatives have increased stability in acidic media relative to BPh_4^-.[4] This is possibly attributed to lower electron density in the vicinity of the boron–carbon bonds which reduces the susceptibility toward electrophilic attack. Indeed, the tetraarylborate derivatives $[B(C_6F_5)_4]^-$ and $[B(4\text{-}FC_6H_4)_4]^-$ have been used to stabilize highly reactive base-free cationic group 4 metallocene complexes.[5] B-$[3,5\text{-}(CF_3)C_6H_3]_4^-$ was also found to be a highly stable counterion in combination with electrophilic cobalt complexes.[6] We have long had an interest in using hydride abstractions to generate highly electrophilic, cationic compounds through use of trityl salts which contain potentially less reactive anions than the derivatives so far reported. Here we report the synthesis of trityl tetrakis-(3,5-bis(trifluoromethyl)phenyl)borate (trityl TFPB)[7] and its utility in hydride and methyl anion abstractions on organic or organometallic compounds.

Experimental Section

Materials and General Procedures. Trityl triflate,[1] Cp_2ZrMe_2,[8] and $CpFe(CO)_2Pr$[9] were synthesized according to literature procedures. Ph_3CCl was synthesized from Ph_3COH and acetyl chloride.[10] Tetrahydrofuran (THF) and diethyl ether were distilled from sodium/benzophenone ketyl just prior to use. CH_2Cl_2 was distilled from P_2O_5 immediately before use. Hexane was stirred over H_2SO_4 and distilled. Benzene was shaken with H_2SO_4, dried by azeotropic removal of water, and distilled into a storage bottle with 4A molecular sieves. All experiments were performed under a dry-nitrogen atmosphere, and air-sensitive compounds were transferred in an argon-filled glovebox. The ^1H (270.17 or 399.78 MHz) and ^{13}C (67.94 or 100.53 MHz) NMR spectra were obtained on a JEOL GSX270 or a JEOL GSX400 spectrometer. ^{11}B (128.3 MHz) and ^{19}F (376.1 MHz) NMR spectra were obtained on a JEOL GSX400 spectrometer with chemical shifts reported relative to $BF_3{\cdot}OEt_2$ in $CDCl_3$ (0 ppm) and $CFCl_3$ in $CDCl_3$ (0 ppm), respectively. Elemental analyses were performed by Desert Analytics in Tucson, AZ. Mass spectra were obtained on a Hewlett-Packard 5988A mass spectrometer at 70 eV. Melting points were taken on a Thomas Hoover capillary melting point apparatus and are uncorrected.

Sodium Tetrakis(3,5-bis(trifluoromethyl)phenyl)borate (Sodium TFPB). Sodium TFPB was synthesized using a similar procedure to one previously described.[11] Mg turnings (0.92 g, 38 mmol) and 10 mL of ether were placed in a 250-mL 3-necked flask fitted with a condenser/N_2 inlet and 50-mL addition funnel. 3,5-Bis(trifluoromethyl)-1-bromobenzene (6.2 mL, 36 mmol) and 40 mL of ether were placed in the addition funnel and added dropwise to the flask over a period of 1 h so as to maintain a moderate reflux. The mixture was stirred for 4 h, giving a dark brown solution. $NaBF_4$ (0.93 g, 8.5 mmol), dried at 110 °C for 1 h under vacuum, was quickly added and the mixture stirred for another 12 h, producing a light tan suspension. This was slowly poured into 50 mL of water and saturated with NaCl, and the brown ether layer separated. After extraction of the water layer with an additional 50-mL portion of ether, the two portions were combined and the ether was removed by vacuum giving a thick, dark brown oil. The oil was shaken with 20 mL of benzene followed by decanting off the benzene and drying leaving a light brown solid. The solid was rinsed with 5 mL of CH_2Cl_2 and dried at 110 °C for 6 h, yielding 4.6 g of sodium TFPB. An additional 0.16 g was isolated from the CH_2Cl_2 rinse and dried giving a total yield of 4.76 g (60% yield) of sodium TFPB: ^1H NMR (400 MHz, CD_3CN) δ 7.69 (s, 4 H, H_p), 7.72 (s, 8 H, H_o); ^{13}C NMR (100.5 MHz, CD_3CN) δ 118.7 (C_p), 125.5 (q, J_{CF} = 273 Hz, CF_3), 129.9 (m, C_m), 135.7 (C_o), 162.6 (q, J_{BC} = 50.3 Hz, C_{ipso}); ^{11}B NMR (CD_3CN) δ –6.06; ^{19}F NMR (CD_3CN) δ –62.68.

Triphenylmethylium Tetrakis(3,5-bis(trifluoromethyl)-phenyl)borate (Trityl TFPB). In a dry box, a 50-mL Schlenk tube equipped with a filter frit and a 50-mL round-bottomed flask was charged with trityl triflate (235 mg, 0.60 mmol) and sodium tetrakis(3,5-bis(trifluoromethyl)phenyl)borate (530 mg, 0.60 mmol). After the apparatus was removed from the dry box, 15

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