Photochemical Isomerization of N-Monosubstituted α,β-Unsaturated Thioamides to Iminothietanes

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Photochemical isomerization of thiomethacryl-, thiotiglyl-, and thiocrotonamides gives iminothietanes, *N*-(2-thietanylidene)amines, in good yields. The iminothietanes reverted quantitatively to the starting materials on heating. Use of Michler's ketone or thioxanthone as sensitizers indicates that the photoelectric cyclization proceeds from the triplet excited state. Irradiation of *N*-benzylthiocinnamamide does not give an iminothietane, but only cis–trans isomerization that reached the photostationary state at cis/trans = 1.7.

Introduction

Photochemical studies of thiocarbonyl compounds have received much attention from both mechanistic and synthetic points of view; in particular, [2 + 2] cycloadditions, hydrogen abstraction, and dimerization have been studied.[1] Several groups have reported on photochemical reactions of α,β-unsaturated thiones, primarily their intermolecular addition with olefins across the C=S linkage.[1b,2] In connection with our studies on photoreactions of nitrogen-containing thiocarbonyl compounds,[3] we now report that photolysis of N-monosubstituted α,β-unsaturated thioamides gives iminothietanes via intramolecular cyclization.

Results and Discussion

Irradiation of *N*-isopropylthiomethacrylamide (**1a**) with a high-pressure mercury lamp in benzene under argon gave *N*-(3-methyl-2-thietanylidene)isopropylamine (**2a**) in 55% yield. The structure of **2a** was determined from spectral data. The IR spectrum exhibited the characteristic absorption of the C=N bond at 1660 cm^{-1}. The ^1H NMR spectrum showed two double doublets at δ 2.70 and 3.25 assignable to 4-CH_2, a multiplet at δ 4.0–4.1 for 3-CH, and the absence of olefinic protons. The ^{13}C NMR spectrum exhibited new triplet and doublet peaks derived from C-4 and C-3 at δ 27.3 and 53.8, respectively. In the low-field region, a new singlet signal for imino carbon appeared at δ 161.2, and there was no signal for thiocarbonyl carbon. This structure was further supported by the fact that **2a** reverted quantitatively to **1a** on heating.[4] Photolysis of thioamides **1b–h** gave the corresponding iminothietanes **2b–h**. Iminothietanes **2d–g**, synthesized from tiglylamides **1d–g**, were obtained as mixtures of stereoisomers, and the cis/trans ratios are given in Table I. The cis/trans ratios were determined from ^1H NMR coupling constants: J_{3-4} (trans) = 4.4 Hz and J_{3-4} (cis) = 8.1 Hz.

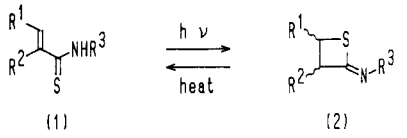
Irradiation of either *trans*- or *cis*-benzylcinnamamide (**1i**) produced only isomerization at the double bond, reaching the photostationary state at the cis/trans ratio 1.7 in both cases. Extended irradiation did not form any iminothietane **1i**.

Table I. Photochemical Isomerization of α,β-Unsaturated Thioamides 1

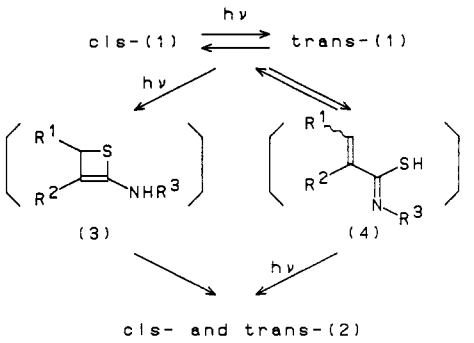
1	R^1	R^2	R^3	yields of 2 (trans/cis)
a	H	Me	*i*-Pr	55
b	H	Me	CH_2Ph	85
c	H	Me	CH(Me)Ph	50
d	Me	Me	*i*-Pr	52 (4.1)[a]
e	Me	Me	CH_2Ph	86 (3.2)[a]
f	Me	Me	CH(Me)Ph	73 (2.3)[a]
g	Me	Me	Ph	76 (1.9)[a]
h	Me	H	CH(Me)Ph	70
i	Ph	H	CH_2Ph	0[b]

[a] Determined on the basis of ^1H NMR spectra. [b] Cis–trans isomerization proceeded and the photostationary state was reached at trans/cis = 1.7.

Scheme I



Scheme II



Irradiation of tiglylthioamides **1d–g** involved cis/trans isomerization initially, but further irradiation led to the iminothietanes *trans*- and *cis*-**2d–g**. The time-course for consumption of **1e** and formation of **2e** is shown in Figure 1. In the initial stage, the photostationary state is reached in 10 min at trans/cis = 2.2. The yield of **2e** increases roughly linearly at the expense of **1e** up to 60 min. The ratio *trans*-**2e**/*cis*-**2e** is constant at ~3.2 even after all **1e** is consumed. The difference in the cis/trans ratios of **1e** and **2e** indicates that *trans*-**2e** and *cis*-**2e** are formed from the same intermediate in which thermodynamically controlled proton transfer occurs. A mechanism for the formation of **2** is suggested in Scheme II. Although an electrocyclization involving aminothiete **3** is plausible, photochemical addition from a tautomer of the thioamide cannot be excluded. The fact that 2-phenylbenzothiazole is obtained by photolysis of thiobenzanilide supports the

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(2) (a) Okazaki, R.; Ishii, F.; Ogawa, K.; Inamoto, N. *J. Chem. Soc., Perkin Trans. 1*, **1975**, 270 and references cited therein. (b) de Mayo, P.; Ng, H. Y. *Tetrahedron Lett.* **1973**, 1561. (c) Jouin, P.; Fourrey, J. L. *Tetrahedron Lett.* **1975**, 1329 and references cited therein.

(3) (a) Sakamoto, M.; Watanabe, S.; Fujita, T.; Tohnish, M.; Aoyama, H.; Omote, Y. *J. Chem. Soc., Perkin Trans. 1* **1988**, 2203. (b) Sakamoto, M.; Watanabe, S.; Fujita, T.; Yanase, T. *J. Org. Chem.* **1990**, *55*, 2986. (c) Sakamoto, M.; Tohnishi, M.; Fujita, T.; Watanabe, S. *J. Chem. Soc., Perkin Trans. 1*, **1991**, 347 and 403 and references cited therein.

(4) When the iminothietane **2a** was heated under nitrogen at 100 °C for 1 h, thioamide **1a** was obtained quantitatively.

0022-3263/92/1957-2419$03.00/0

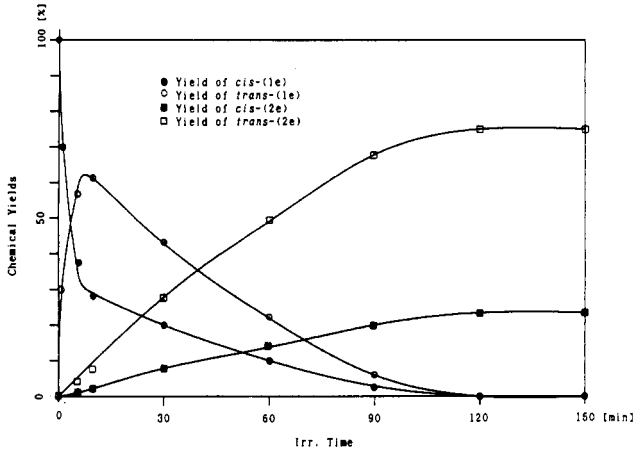

Figure 1. Correlation diagram for the photolysis of **1e**.

hypothesis of an intramolecular addition of thiol **4** to the double bond.[5]

The use of different solvents (benzene, Et_2O, MeCN, and MeOH) for the photoreaction of **1e** did not affect chemical yields or the ratio of recovered **1e** to products.

The photoreaction **1b** was sensitized by Michler's ketone and by thioxanthone; quenching by stilbene or ferrocene was quite inefficient.[6] This reaction is presumed to involve a triplet state by direct irradiation.

We recently reported that the photolysis of *N,N*-dibenzyl-α,β-unsaturated thioamides gave thioxo-β-lactams (Norrish type II cyclization)[7] as the main products in yields that depended on the nature of the substituents. In the present reaction, the nonrotation about the C(=S)-N bonds of **1** apparently prevents the Norrish type II reaction at the C=C bond.

The photochemical isomerization of *cis*-α-phenylcinnamamide and anilide results in cyclization, involving the nitrogen, to both *cis*- and *trans*-β-lactams, the cis isomers being the principal products.[8] In the present reaction of **1** to **2**, sulfur is involved in the cyclization, and trans isomers predominate.

Few syntheses of iminothietanes have been reported. They have been prepared by [2 + 2] cycloaddition of ketenimine to thioketones,[9] reaction of a vinyl ether with a sulfonyl isothiocyanate,[10] and recyclization of β-lactones.[11] The present reaction provides a useful synthetic route since the starting materials are easily obtained from the corresponding amides with Lawesson's reagent[12] or phosphorus pentasulfide.

Experimental Section

^1H and ^{13}C NMR spectra were recorded at 400 MHz using tetramethylsilane as an internal standard, and $CDCl_3$ was used as a solvent unless otherwise stated. An Eikohsya 500-W high-pressure mercury lamp was used as an irradiation source. Silica gel (Merck, Kieselgel 60, 230–400 mesh) was used for flash column chromatography.

α,β-Unsaturated Thioamides. Thioamides **1a–1i** were prepared by the reaction of corresponding amides with Lawesson's reagent. To a dry benzene solution of amide (3.0 mmol) was added Lawesson's reagent (1.5 mmol), and the mixture was refluxed for 2 h. After the solvent was removed in vacuo, the resulting mixture was separated by flash column chromatography on silica gel (eluant: benzene–ethyl acetate mixture). Crystalline thioamides were recrystallized from chloroform–hexane mixture, and the liquid thioamides were purified by molecular distillation.

***N*-Isopropylthiomethacrylamide (1a)**: bp 22–25 °C/1 mmHg; UV (C_6H_{12}) 223 (ϵ 5600), 289 (4600), and 392 (70); IR ($CHCl_3$) 3360, 3250, and 1615 cm^{-1}; ^1H NMR ($CDCl_3$) δ 1.31 (d, J = 6.6 Hz, 6 H, $NCMe_2$), 2.1 (m, 3 H, 2-Me), 4.70 (sep, J = 6.6 Hz, 1 H, N-CH), 5.1 (m, 1 H, 3-CH), 5.4 (m, 1 H, 3-CH) and 7.24 (br, 1 H, NH); ^{13}C NMR ($CDCl_3$) δ 21.2 (q, $NCMe_2$), 21.4 (q, 2-Me), 46.9 (d, N-C), 114.9 (t, 3-C), 147.8 (s, 2-C), 199.1 (s, C=S). Anal. Calcd for $C_7H_{13}NS$: C, 58.69; H, 9.14; N, 9.77. Found: C, 58.81; H, 9.20; N, 9.72.

***N*-Benzylthiomethacrylamide (1b)**: mp 49–51 °C; UV (C_6H_{12}) 230 (ϵ 10700), 287 (6700), and 388 (100); IR ($CHCl_3$) 3350, 3250, and 1610 cm^{-1}; ^1H NMR ($CDCl_3$) δ 2.15 (dd, J = 1.5 and 0.7 Hz, 3 H, 2-Me), 4.86 (d, J = 5.3 Hz, 2 H, NCH_2), 5.2 (m, 1 H, 3-CH), 5.5 (m, 1 H, 3-CH), 7.3–7.4 (m, 5 H, Ph) and 7.24 (br, 1 H, NH); ^{13}C NMR ($CDCl_3$) δ 21.5 (q, 2-Me), 50.0 (t, NC), 115.7 (t, 3-C), 128.1 (d, Ph), 128.2 (d, Ph), 128.9 (d, Ph), 136.1 (s, Ph), 147.1 (s, 2-C), and 200.3 (s, C=S). Anal. Calcd for $C_{11}H_{13}NS$: C, 69.06; H, 6.84; N, 7.32. Found: C, 68.88; H, 6.80; N, 7.29.

***N*-(α-Phenylethyl)thiomethacrylamide (1c)**: bp 48–50 °C/2 mmHg; UV (C_6H_{12}) 231 (ϵ 9500), 288 (6400), and 398 (90); IR ($CHCl_3$) 3380, 3250, and 1635 cm^{-1}; ^1H NMR ($CDCl_3$) δ 1.63 (d, J = 6.9 Hz, 3 H, NCMe), 2.13 (dd, J = 1.7 and 0.8 Hz, 3 H, 2-Me), 5.2 (m, 1 H, 3-CH), 5.4 (m, 1 H, 3-CH), 5.7–5.8 (m, 1 H, NCH), 7.3–7.4 (m, 5 H, Ph) and 7.5 (br, 1 H, NH); ^{13}C NMR ($CDCl_3$) δ 20.0 (q, NCMe), 21.5 (q, 2-Me), 54.0 (d, N-C), 115.2 (t, 3-C), 126.4 (d, Ph), 127.8 (d, Ph), 128.8 (d, Ph), 141.3 (s, Ph), 147.7 (s, 2-C), and 199.3 (s, C=S). Anal. Calcd for $C_{12}H_{15}NS$: C, 70.19; H, 7.36; N, 6.82. Found: C, 69.96; H, 7.28; N, 6.75.

***N*-Isopropylthiotiglylamide (1d)**: bp 27–30 °C/1 mmHg; UV (C_6H_{12}) 233 (ϵ 9300), 287 (7900), and 384 (130); IR ($CHCl_3$) 3380, 3250, and 1630 cm^{-1}; ^1H NMR ($CDCl_3$) δ 1.29 (d, J = 6.6 Hz, 6 H, $NCMe_2$), 1.74 (d, q, J = 6.7 and 1.1 Hz, 3 H, 3-Me), 2.0 (m, 3 H, 2-Me), 4.73 (sep, J = 6.6 Hz, 1 H, N-CH), 6.1–6.2 (m, 1 H, 3-CH) and 7.2 (br, 1 H, NH); ^{13}C NMR ($CDCl_3$) δ 14.1 (q, 3-Me), 15.3 (q, 2-Me), 21.3 (q, $NCMe_2$), 47.0 (d, NC), 127.1 (d, 3-C), 140.2 (s, 2-C), and 200.5 (s, C=S). Anal. Calcd for $C_8H_{15}NS$: C, 61.09; H, 9.61; N, 8.90. Found: C, 60.81; H, 9.44; N, 8.81.

***N*-Benzylthiotiglylamide (1e)**: bp 50–55 °C/1 mmHg; UV (C_6H_{12}) 234 (ϵ 11300), 286 (7300), and 385 (120); IR ($CHCl_3$) 3380, 3250, and 1630 cm^{-1}; ^1H NMR ($CDCl_3$) δ 1.74 (dq, J = 7.0 and 1.1 Hz, 3 H, 3-Me), 2.04 (m, 3 H, 2-Me), 4.87 (d, J = 5.3 Hz, 2 H, NCH_2), 6.2–6.3 (m, 1 H, 3-CH), 7.3–7.4 (m, 5 H, Ph), and 7.48 (br, 1 H, NH); ^{13}C NMR ($CDCl_3$) δ 14.2 (q, 3-Me), 15.4 (q, 2-Me), 50.1 (t, N-C), 128.0 (d, Ph), 128.2 (d, Ph), 128.2 (d, 3-C), 128.9 (d, Ph), 136.3 (s, Ph), 140.0 (s, 2-C), and 201.8 (s, C=S). Anal. Calcd for $C_{12}H_{15}NS$: C, 70.19; H, 7.36; N, 6.82. Found: C, 70.25; H, 7.34; N, 6.77.

***N*-(α-Phenylethyl)thiotiglylamide (1f)**: bp 48–50 °C/2 mmHg; UV (C_6H_{12}) 234 (ϵ 8900), 287 (6400), and 385 (110); IR ($CHCl_3$) 3380, 3250, and 1625 cm^{-1}; ^1H NMR ($CDCl_3$) δ 1.62 (d, J = 6.9 Hz, 3 H, NCMe), 1.74 (dq, J = 6.1 and 1.1 Hz, 3 H, 3-Me), 2.02 (m, 3 H, 2-Me), 5.8–5.9 (m, 1 H, NCH), 6.1–6.2 (m, 1 H, 3-CH), 7.3–7.4 (m, 5 H, Ph) and 7.4 (br, 1 H, NH); ^{13}C NMR ($CDCl_3$) δ 14.2 (q, 3-Me), 15.4 (q, 2-Me), 20.0 (q, NCMe), 54.0 (d, NC), 126.4 (d, Ph), 127.4 (d, Ph), 127.7 (d, 3-CH), 128.8 (d, Ph), 140.1 (s, 2-C), 141.5 (s, Ph), and 200.7 (s, C=S). Anal. Calcd for $C_{13}H_{17}NS$: C, 71.18; H, 7.81; N, 6.38. Found: C, 70.99; H, 7.77; N, 6.34.

Thiotiglylanilide (1g): mp 59–62 °C; UV (C_6H_{12}) 234 (ϵ 11500), 252 (9400), 268 (8200), 316 (6500), and 423 (170); IR ($CHCl_3$) 3360, 3250, and 1625 cm^{-1}; ^1H NMR ($CDCl_3$) δ 1.78 (d, J = 6.8 Hz, 3 H, 3-Me), 2.02 (s, 3 H, 2-Me), 6.2–6.3 (m, 1 H, 3-CH), 7.2–7.7 (m, 5 H, Ph), and 8.8 (br, 1 H, NH); ^{13}C NMR ($CDCl_3$)

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δ 14.3 (q, 3-Me), 15.7 (q, 2-Me), 123.8 (d, Ph), 126.8 (d, Ph), 127.7 (d, 3-CH), 128.8 (d, Ph), 138.7 (s, Ph), 141.1 (s, 2-C), and 201.5 (s, C=S). Anal. Calcd for $C_{11}H_{13}NS$: C, 69.06; H, 6.84; N, 7.32. Found: C, 68.76; H, 6.75; N, 7.26.

***N*-(α-Phenylethyl)thiocrotonamide (1h)**: mp 99–101 °C; UV (C_6H_{12}) 233 (ε 15100), 304 (5400), and 403 (140); IR ($CHCl_3$) 3360, 3230, and 1650 cm^{-1}; ^1H NMR ($CDCl_3$) δ 1.62 (d, J = 6.8 Hz, 3 H, NCMe), 1.84 (dq, J = 7.0 and 1.7 Hz, 3 H, 3-Me), 5.8–5.9 (m, 1 H, N-CH), 6.21 (dq, J = 14.8 and 1.7 Hz, 1 H, 2-CH), 6.96 (dq, J = 14.8 and 7.0 Hz, 3-CH), and 7.3–7.4 (m, 6 H, Ph and NH); ^{13}C NMR ($CDCl_3$) δ 17.9 (q, 3-Me), 20.0 (q, NCMe), 53.9 (d, NC), 126.5 (d, Ph), 127.7 (d, 3-C), 128.7 (d, Ph), 132.5 (d, Ph), 140.4 (d, 2-C), 141.4 (s, Ph), and 194.0 (s, C=S). Anal. Calcd for $C_{12}H_{15}NS$: C, 70.19; H, 7.36; N, 6.82. Found: C, 69.90; H, 7.21; N, 6.77.

***trans*-*N*-Benzylthiocinnamamide (*trans*-1i)**: mp 114–116 °C; UV (C_6H_{12}) 223 (ε 18000), 288 (19700), 296 (19000), 310 (13700), and 334 (5700); IR ($CHCl_3$) 3380, 3230, and 1625 cm^{-1}; ^1H NMR ($CDCl_3$) δ 4.95 (d, J = 5.2 Hz, 2 H, NCH_2), 6.82 (d, J = 15.1 Hz, 1 H, 2-CH), 7.2–7.5 (m, 11 H, 2 Ph and NH) and 7.81 (d, J = 15.1 Hz, 1 H, 3-CH); ^{13}C NMR ($CDCl_3$) δ 50.2 (t, NC), 127.3 (d), 128.0 (d), 128.1 (d), 128.4 (d), 128.8 (d), 129.0 (d), 130.0 (d), 134.8 (s), 136.2 (s), 142.0 (d), and 194.6 (s, C=S). Anal. Calcd for $C_{16}H_{15}NS$: C, 75.85; H, 5.96; N, 5.52. Found: C, 75.66; H, 5.90; N, 5.52.

General Procedure for the Photochemical Reaction of α,β-Unsaturated Thioamides (1a–1i). A benzene solution of the thioamide was irradiated with a 500-W high-pressure mercury lamp under argon at room temperature until the starting material had disappeared. After evaporation of the solvent, the filtrate was subjected to chromatography on silica gel, using benzene–ethyl acetate or benzene–hexane mixture as eluant.

***N*-(3-Methyl-2-thientanylidene)isopropylamine (2a)**: bp 35–40 °C/13 mmHg; UV (C_6H_{12}) 230 (ε 1400) and 267 (700); IR ($CHCl_3$) 1660 cm^{-1}; ^1H NMR ($CDCl_3$) δ 1.14 (d, J = 6.3 Hz, 3 H, NCMe), 1.15 (d, J = 6.3 Hz, 3 H, NCMe), 1.37 (d, J = 7.4 Hz, 3 H, 3-Me), 2.70 (dd, J = 8.5 and 4.4 Hz, 1 H, 4-CH), 3.14 (sep, J = 6.3 Hz, 1 H, NCH), 3.25 (dd, J = 8.5 and 8.0 Hz, 1 H, 4-CH) and 4.0–4.1 (m, 1 H, 3-CH); ^{13}C NMR ($CDCl_3$) δ 18.4 (q, 3-Me), 22.8 (q, NCHMe), 22.9 (q, NCHMe), 27.3 (t, 4-C), 53.7 (d, NC), 53.8 (d, 3-CH), and 161.2 (s, C=N). Anal. Calcd for $C_7H_{13}NS$: C, 58.69; H, 9.14; N, 9.77. Found: C, 58.75; H, 9.22; N, 9.72.

***N*-(3-Methyl-2-thietanylidene)benzylamine (2b)**: bp 38–42 °C/3 mmHg; UV (C_6H_{12}) 233 (ε 4000) and 268 (2100); IR ($CHCl_3$) 1680 cm^{-1}; ^1H NMR ($CDCl_3$) δ 1.40 (d, J = 7.2 Hz, 3 H, 3-Me), 2.75 (dd, J = 8.5 and 4.4 Hz, 1 H, 4-CH), 3.29 (dd, J = 8.5 and 7.7 Hz, 1 H, 4-CH), 4.0–4.1 (m, 1 H, 3-CH), 4.29 (d, J = 1.1 Hz, 1 H, N=CH), 4.31 (d, J = 1.1 Hz, 1 H, NCH), and 7.2–7.3 (m, 5 H, Ph); ^{13}C NMR ($CDCl_3$) δ 18.4 (q, 3-Me), 27.3 (t, 4-C), 53.8 (d, 3-C), 56.7 (t, NC), 126.9 (d, Ph), 127.9 (d, Ph), 128.4 (d, Ph), 138.8 (s, Ph), and 165.2 (s, C=N). Anal. Calcd for $C_{11}H_{13}NS$: C, 69.06; H, 6.84; N, 7.32. Found: C, 69.24; H, 6.92; N, 7.30.

***N*-(3-Methyl-2-thietanylidene)-α-phenylethylamine (2c).** This material was obtained as a mixture of two diastereomers in a ratio of 1:1 as determined from the ^1H NMR spectrum: bp 44–49 °C/3 mmHg; UV (C_6H_{12}) 233 (ε 1700) and 265 (900); IR ($CHCl_3$) 1670 cm^{-1}; ^1H NMR ($CDCl_3$) δ 1.36 (d, J = 7.2 Hz) and 1.41 (d, J = 7.1 Hz) (total 3 H, 3-Me), 1.47 (d, J = 6.6 Hz) and 1.48 (d, J = 6.9 Hz) (total 3 H, NCMe), 2.65–2.75 (m, 1 H, 4-CH), 3.2–3.3 (m, 1 H, 4-CH), 4.0–4.2 (m, 2 H, 3-CH and NCH) and 7.2–7.4 (m, 5 H, Ph); ^{13}C NMR ($CDCl_3$) δ 18.4 (q, 3-Me), 18.5 (q, 3-Me), 23.2 (q, NCMe), 23.6 (q, NCHMe), 27.4 (t, 4-C), 53.8 (d, 3-C), 53.9 (d, 3-C), 61.7 (d, NC), 62.2 (d, NC), 126.5 (d, Ph), 126.7 (d, Ph), 126.7 (d, Ph), 126.9 (d, Ph), 128.3 (d, Ph), 128.3 (d, Ph), 144.2 (s, Ph), 144.5 (s, Ph), 163.2 (s, C=N). Anal. Calcd for $C_{12}H_{15}NS$: C, 70.19; H, 7.36; N, 6.82. Found: C, 69.95; H, 7.25; N, 6.71.

***N*-(3,4-Dimethyl-2-thientanylidene)isopropylamine (2d).** Obtained as a mixture of two stereoisomers which with a trans/cis ratio of 4.1 as determined by the ^1H NMR spectrum: bp 27–32 °C/4 mmHg; UV (C_6H_{12}) 229 (ε 2600); IR ($CHCl_3$) 1670 cm^{-1}. Anal. Calcd for $C_8H_{15}NS$: C, 61.09; H, 9.61; N, 8.90. Found: C, 60.88; H, 9.51; N, 8.80.

Trans isomer: ^1H NMR ($CDCl_3$) δ 1.13 (d, J = 6.2 Hz, NCMe), 1.15 (d, J = 6.4 Hz, 3 H, NCMe), 1.32 (d, J = 7.1 Hz, 3 H, 3-Me), 1.56 (d, J = 6.6 Hz, 3 H, 4-Me), 3.0–3.2 (m, 1 H, NCH), 3.30 (dq, J = 4.4 and 6.6 Hz, 1 H, 4-CH), and 3.50 (dq, J = 4.4 and 7.1 Hz, 1 H, 3-CH); ^{13}C NMR ($CDCl_3$) δ 17.1 (q, 3-Me), 22.8 (q, NCMe), 22.9 (q, NCMe), 23.1 (q, 4-Me), 40.3 (d, 4-C), 54.1 (d, NC), 60.6 (d, 3-C) and 159.1 (s, C=N).

Cis isomer: ^1H NMR ($CDCl_3$) δ 1.14 (d, J = 6.3 Hz, NCHMe), 1.15 (d, J = 6.3 Hz, 3 H, NCMe), 1.25 (d, J = 7.5 Hz, 3 H, 3-Me), 1.46 (d, J = 7.0 Hz, 3 H, 4-Me), 3.0–3.2 (m, 1 H, NCH), 3.81 (dq, J = 8.1 and 7.0 Hz, 1 H, 4-CH) and 4.09 (dq, J = 8.0 and 7.5 Hz, 1 H, 3-CH); ^{13}C NMR ($CDCl_3$) δ 12.7 (q, 3-Me), 18.1 (q, NCMe), 22.7 (q, NCMe), 22.9 (q, 4-Me), 35.3 (d, 4-C), 54.0 (d, NC), 54.9 (d, 3-C), and 160.5 (s, C=N).

***N*-(3,4-Dimethyl-2-thientanylidene)benzylamine (2e).** Obtained as a mixture of two stereoisomers which with a trans/cis ratio of 3.2 as determined by the ^1H NMR spectrum: bp 38–42 °C/1 mmHg; UV (C_6H_{12}) 231 (ε 4000) and 258 (900); IR ($CHCl_3$) 1670 cm^{-1}. Anal. Calcd for $C_{12}H_{15}NS$: C, 70.19; H, 7.36; N, 6.82. Found: C, 70.01; H, 7.26; N, 6.73.

Trans isomer: ^1H NMR ($CDCl_3$) δ 1.36 (d, J = 7.2 Hz, 3 H, 3-Me), 1.58 (d, J = 6.6 Hz, 3 H, 4-Me), 3.36 (dq, J = 4.4 and 6.6 Hz, 1 H, 4-CH), 3.57 (dq, J = 4.4 and 7.2 Hz, 1 H, 3-CH), 4.30 (brs, 2 H, NCH_2), and 7.2–7.4 (m, 5 H, Ph); ^{13}C NMR ($CDCl_3$) δ 17.0 (q, 3-Me), 23.0 (q, 4-Me), 40.4 (d, 4-C), 57.0 (t, N-C), 60.7 (d, 3-C), 126.8 (d, Ph), 127.9 (d, Ph), 128.3 (d, Ph), 138.9 (s, Ph) and 163.0 (s, C=N).

Cis isomer: ^1H NMR ($CDCl_3$) δ 1.29 (d, J = 7.5 Hz, 3 H, 3-Me), 1.49 (d, J = 7.0 Hz, 3 H, 4-Me), 3.85 (dq, J = 8.1 and 7.0 Hz, 1 H, 4-CH), 4.16 (dq, J = 8.1 and 7.5 Hz, 1 H, 3-CH), 4.30 (brs, 2 H, NCH_2) and 7.2–7.4 (m, 5 H, Ph); ^{13}C NMR ($CDCl_3$) δ 12.7 (q, 3-Me), 18.2 (q, 4-Me), 35.3 (d, 4-C), 55.0 (d, 3-C), 56.9 (t, N-C), 126.8 (d, Ph), 127.9 (d, Ph), 128.3 (d, Ph), 138.9 (s, Ph), and 164.6 (s, C=N).

***N*-(3,4-Dimethyl-2-thietanylidene)-α-phenylethylamine (2f).** Obtained as a mixture of two stereoisomers which with a trans/cis ratio of 2.3; each stereoisomer comprised two diastereomers in equal ratio as determined by the ^1H NMR spectrum: bp 40–45 °C/1 mmHg; UV (C_6H_{12}) 231 (ε 3800) and 258 (700); IR ($CHCl_3$) 1665 cm^{-1}. Anal. Calcd for $C_{13}H_{17}NS$: C, 71.18; H, 7.81; N, 6.38. Found: C, 69.95; H, 7.75; N, 6.26.

Trans isomer: ^1H NMR ($CDCl_3$) δ 1.32 (d, J = 7.1 Hz) and 1.37 (d, J = 7.1 Hz) (3 H, 3-Me), 1.46 (d, J = 6.6 Hz) and 1.48 (d, J = 6.6 Hz) (3 H, NCMe), 1.53 (d, J = 6.6 Hz) and 1.58 (d, J = 6.6 Hz), (3 H, 4-Me), 3.2–3.35 (m, 1 H, 4-CH), 3.5–3.6 (m, 1 H, 3-CH), 4.0–4.2 (m, 1 H, N-CH), and 7.2–7.4 (m, 5 H, Ph); ^{13}C NMR ($CDCl_3$) δ 17.1 (q, 3-Me), 17.1 (q, 3-Me), 23.1 (q, 4-Me), 23.1 (q, N-CMe), 23.5 (q, 4-Me), 23.6 (q, N-CMe), 40.5 (d, 4-C), 40.5 (d, 4-C), 60.6 (d, 3-C), 60.7 (d, 3-C), 61.9 (d, NC), 62.4 (d, NC), 126.5 (d, Ph), 126.7 (d, Ph), 126.8 (d, Ph), 126.8 (d, Ph), 128.3 (d, Ph), 128.3 (d, Ph), 144.6 (d, Ph), 144.3 (s, Ph), 160.9 (s, C=N) and 161.1 (s, C=N).

Cis isomer: ^1H NMR ($CDCl)_3$ δ 1.25 (d, J = 7.5 Hz) and 1.30 (d, J = 7.5 Hz) (3 H, 3-Me), 1.43 (d, J = 7.0 Hz) and 1.48 (d, J = 6.6 Hz) (3 H, 4-Me), 1.46 (d, J = 6.8 Hz) and 1.47 (d, J = 7.0 Hz) (3 H, NCMe), 3.75–3.9 (m, 1 H, 4-CH), 4.0–4.2 (m, 2 H, 3-CH and NCH), and 7.2–7.4 (m, 5 H, Ph); ^{13}C NMR ($CDCl_3$) δ 12.7 (q, 3-Me), 12.8 (q, 3-Me), 18.0 (q, 4-Me), 18.1 (q, 4-Me), 23.0 (q, N-CMe), 23.2 (q, N-CMe), 35.5 (d, 4-C), 35.6 (d, 4-C), 55.0 (d, 3-C), 55.0 (d, 3-C), 61.9 (d, N-C), 62.3 (d, N-C) and 162.2 (s, C=N).

***N*-(3,4-Dimethyl-2-thietanylidene)aniline (2g).** Obtained as a mixture of two stereoisomers which with a trans/cis ratio of 1.9 as determined by the ^1H NMR spectrum: bp 35–40 °C/1 mmHg; UV (C_6H_{12}) 250 (ε 3700), 274 (3900), 284 (3500), and 296 (2600); IR ($CHCl_3$) 1665 cm^{-1}. Anal. Calcd for $C_{11}H_{13}NS$: C, 69.06; H, 6.84; N, 7.32. Found: C, 68.80; H, 6.72; N, 7.24.

Trans isomer: ^1H NMR ($CDCl_3$) δ 1.45 (d, J = 7.2 Hz, 3 H, 3-Me), 1.61 (d, J = 6.6 Hz, 3 H, 4-Me), 3.43 (dq, J = 4.4 and 6.6 Hz, 1 H, 4-CH), 3.68 (dq, J = 4.4 and 7.2 Hz, 1 H, 3-CH) 7.2–7.4 (m, 5 H, Ph); ^{13}C NMR ($CDCl_3$) δ 17.1 (q, 3-Me), 22.9 (q, 4-Me), 41.5 (d, 4-C), 61.4 (d, 3-C), 121.0 (d, Ph), 124.9 (d, Ph), 129.1 (d, Ph), 147.8 (s, Ph) and 164.8 (s, C=N).

Cis isomer: ^1H NMR ($CDCl_3$) δ 1.37 (d, J = 7.4 Hz, 3 H, 3-Me), 1.51 (d, J = 6.9 Hz, 3 H, 4-Me), 3.93 (m, 1 H, 4-CH), 4.27 (m, 1 H, 3-CH), 7.2–7.4 (m, 5 H, Ph); ^{13}C NMR ($CDCl_3$) δ 12.8 (q, 3-Me), 18.0 (q, 4-Me), 36.6 (d, 4-C), 55.7 (d, 3-C), 121.0 (d, Ph), 124.9 (d, Ph), 129.1 (d, Ph), 147.8 (s, Ph) and 165.2 (s, C=N).

***N*-(4-Methyl-2-thietanylidene)-α-phenylethylamine (2h).** Obtained as a mixture of two diastereomers in a ratio of 1:1 as determined from the ^1H NMR spectrum: bp 37–42 °C/2 mmHg;

UV (C_6H_{12}) 234 (ϵ 3200) and 257 (800); IR ($CHCl_3$) 1675 cm^{-1}; ^1H NMR ($CDCl_3$) δ 1.46 (d, J = 6.6 Hz) and 1.49 (d, J = 6.6 Hz) (total 3 H, NCMe), 1.56 (d, J = 6.4 Hz) and 1.62 (d, J = 6.6 Hz) (total 3 H, 4-Me), 3.3-3.4 (m, 1 H, 3-CH), 3.8-3.9 (m, 1 H, 4-CH), 3.9-4.0 (m, 1 H, 3-CH), 4.0-4.1 (q, J = 6.6 Hz, 1 H, NCH) and 7.2-7.4 (m, 5 H, Ph); ^{13}C NMR ($CDCl_3$) δ 23.3 (q, NCMe), 23.3 (q, NCMe), 24.3 (q, 4-Me), 24.4 (q, 4-Me), 32.3 (d, 4-C), 32.4 (d, 4-C), 52.3 (t, 3-C), 62.8 (d, N-C), 62.9 (d, N-C), 126.7 (d, Ph), 126.9 (d, Ph), 128.3 (d, Ph), 144.2 (s, Ph), 144.3 (s, Ph), 155.6 (s, C=N) and 155.7 (s, C=N). Anal. Calcd for $C_{12}H_{15}NS$: C, 70.19; H, 7.36; N, 6.82. Found: C, 69.88; H, 7.28; N, 6.75.

***cis*-*N*-Benzylthiocinnamamide (cis-1i)**: mp 74-76 °C; UV (C_6H_{12}) 220 (ϵ 16500), 284 (15000), 296 (13700) and 310 (10000); IR ($CHCl_3$) 3350 and 1610 cm^{-1}; ^1H NMR ($CDCl_3$) δ 4.72 (d, J = 5.5 Hz, 2 H, N-CH_2), 6.41 (d, J = 12.1 Hz, 1 H, 2-CH), 6.53 (d, J = 12.1 Hz, 1 H, 3-CH) and 7.2-7.4 (m, 11 H, 2 Ph and NH); ^{13}C NMR ($CDCl_3$) δ 49.9 (t, NC), 128.0 (d), 128.4 (d), 128.6 (d), 128.7 (d), 128.8 (d), 130.0 (d), 132.0 (d), 134.7 (s), 135.3 (s), 141.9 (d), and 196.5 (s, C=S). Anal. Calcd for $C_{16}H_{15}NS$: C, 75.85; H, 5.96; N, 5.52. Found: C, 75.61; H, 5.88; N, 5.49.

An Unusual Doubly Substituted Product from the Phase-Transfer-Catalyzed Heck Reactions of *o*-Bromobenzaldehydes with Methyl Acrylate

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The reactions of *o*-bromobenzaldehydes with methyl acrylate under Heck conditions and with phase-transfer catalysis to yield significant amounts of doubly substituted deformylated products **1A-E** in addition to the expected *o*-formyl cinnamates **2A-E** are reported. X-ray crystallography of one such product (**4**) established that the bromine was replaced by a propionate and the formyl group by an acrylate residue. Employment of deuterium-labeled substrates showed that the hydrogen atom of the formyl group of the substrate was transferred intramolecularly and regiospecifically to the benzylic carbon of the propionate substituent of the product. A tentative hypothesis is advanced to explain these and other experimental findings.

The Heck reaction[1] of aryl bromides and various alkenes is a versatile and valuable synthetic process. A recent popular modification[2] that gives better results with thermally labile substrates involves the addition of a phase-transfer catalyst. In attempting to employ these new conditions in the reaction of 6-bromoveratraldehyde with methyl acrylate in DMF and with tetrabutylammonium chloride as the phase-transfer reagent, we observed the formation of a significant amount of an anomalous product (**1C**) in addition to the expected cinnamate (**2C**) (Table I). We have investigated the reaction with several *o*-bromoaryl aldehydes to establish its generality and now report our results.

The reactions between ten bromoaldehydes and methyl acrylate were carried out under the general conditions described in the Experimental Section, with the results indicated in Table I. Total yields were moderate and very little of the bromoaldehyde substrate was recovered under these conditions. Polymerization of the methyl acrylate (employed in 5-fold excess) always took place and thin layer chromatograms of the reaction mixtures showed much streaking. The structures of the anomalous products were easily established by ^1H NMR, mass, and infrared data and confirmed in one instance (vide infra) by X-ray crystallography. The formation of **1** to any extent at all required (1) the aldehyde and bromine substituents to be ortho related (entry 10) and (2) the absence of a methoxy group ortho to the bromine (entries 8 and 9). The production of **1** was favored by an increase in the proportion of methyl acrylate used and by running the reaction in concentrated solution. Products **1** and **2** were not separable by TLC directly but could be separated by preparative TLC only after conversion of the aldehydes **2** to their dimethyl acetals by treating the reaction mixtures with trimethyl orthoformate, Dowex, and methanol under reflux. Decarbonylation of aromatic aldehydes[3] by Pd^0 catalysts does not usually occur under the mild conditions employed in these reactions and veratraldehyde itself was unaffected under such conditions. The normal Heck product **2** was also inert if re-subjected to the reaction after isolation, thus indicating that **2** is not an intermediate in the formation of **1**.

The question of relating the positions of the three-carbon substituents of the products **1** to the positions of the bromine and aldehyde of the starting material was investigated by examining the 500-MHz ^1H NMR of the nonsymmetric product **1E** (Entry 5). The aromatic signal at 8.3 (meta-coupled, J = 2.4 Hz) was the most downfield and assigned to H-6′ while the other two protons H-4′ and H-3′ were at 8.14 (dd, J = 8.5, 2.4 Hz) and 7.43 ppm (d, J = 8.5 Hz), respectively. The alkene protons at δ 7.95 and 6.51 were trans coupled (J = 16 Hz) doublets assigned to H-β and H-α, respectively, while the two methylene groups were triplets at δ 2.63 and 3.17 (J = 8 Hz). A difference NOE experiment with **1E** provoked an 8.3% enhancement of the olefinic proton at 6.51 ppm when H-6′ (δ 8.3) was irradiated. No other signal appeared in the difference spectrum. This compound unfortunately did not provide crystals good enough for an X-ray structure. We therefore synthesized 2-bromo-5-nitroanisaldehyde (**3**) and repeated the reaction with this substrate to obtain crystals of **4** suitable for an X-ray structure. The molecular plot diagram (Figure 1) confirms the results of the NOE experiment and unequivocally establishes that the bromine is

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