of silica eluted with methanol/chloroform/ammonia solvents (93:7:0.04). The solute was concentrated in vacuo, affording colorless, crude 4 (1.8 g), which was crystallized from isopropyl ether to afford colorless, crystalline 4 (1.65 g): ^{1}H NMR ($CDCl_3$) δ 0.91 (t), 1.10–1.50 (m), 1.60–2.00 (m), 2.30 (s), 2.40–2.70 (m), 2.85 (dd), 3.08 (t), 3.35 (s), 3.50–3.60 (m), 3.70 (br s), 3.95 (br t), 4.00 (m), 4.65 (d), 4.95–5.05 (m); ^{13}C NMR ($CDCl_3$) δ 176.5 (off-resonance, s), 101.8 (d), 94.8 (d), 84.1 (d), 77.5, 77.3, 76.6, 73.3, 72.7, 70.4, 70.3, 69.3, 65.8 (d), 65.1 (d), 54.8 (d), 49.1 (q), 44.0, 43.7, 40.2 (q), 39.9, 36.0, 34.4, 32.0, 28.6, 22.7, 22.1, 21.4, 21.0, 17.9, 16.7, 15.3, 12.5, 11.3, 9.1.

Anal. Calcd for $C_{37}H_{69}O_{12}NS$: C, 59.90; H, 9.25; N, 1.86. Found: C, 59.51; H, 9.27; N, 2.01.

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Secondary Enamide and Thioenamide Photochemistry. A New Spiroannelation Method

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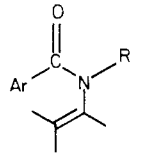
Owing to mesomerism, which confers to the amide group a partial double bond character, aromatic enamides, a class of compounds in which this chromophore connects two unsaturated systems, possess a marked degree of hexatrienic character. This property induces most of their photochemical reactions and thus irradiation of a great number of these compounds, particularly type a (R ≠ H),

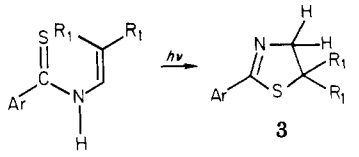


type a, R ≠ H
type b, R = H

results in stilbene–phenanthrene-like photoconversion, providing a general approach toward a wide variety of six-membered lactams.[1] To our knowledge the only exceptions concern some of these models in which the double bond is acyclic. Their irradiation leads mainly to aromatic enamino ketones,[2,3] products of photo-Fries rearrangement.

Surprisingly, few reports have dealt with the photochemical properties of type b (R = H) secondary enamides. Ninomiya[4] only reported recently an elegant synthesis of haemanthidine that proceeds via photocyclization of a secondary enamide in which the double bond α to the nitrogen atom is further conjugated with a carbonyl group. Within the framework of our systematic studies of the photochemistry of conjugated hexatrienic systems[3,5] we have therefore investigated the photochemical behavior of a number of these heteroatomic systems. The results obtained led us to undertake a comparative study of their sulfur analogues.

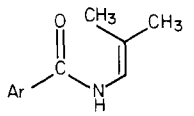
Scheme I



2

a, Ar = Ph; R_1 = CH_3
b, Ar = α-naphthyl; R_1 = CH_3
c, Ar = *o*-biphenylyl; R_1 = CH_3
d, Ar = Ph; R_1,R_1 = $(CH_2)_5$
e, Ar = α-naphthyl; R_1,R_1 = $(CH_2)_5$
f, Ar = β-naphthyl; R_1,R_1 = $(CH_2)_5$
g, Ar = *o*-biphenylyl; R_1,R_1 = $(CH_2)_5$
h, Ar = CH_2Ph; R_1,R_1 = $(CH_2)_5$

Enamides **1a–c** are readily accessible by direct condensation of the appropriate aromatic amide (phenyl-, α-naphthyl-, and *o*-biphenylylcarboxamide) with isobutyraldehyde. Although many problems may apparently arise from the use of aliphatic aldehydes,[6] the desired enamides were obtained exclusively when the α,β-disubstituted aldehyde was used.



1a, Ar = phenyl
b, Ar = α-naphthyl
c, Ar = *o*-biphenylyl

Irradiation of secondary enamides **1a–c** in neutral solvent and under various conditions left the starting compounds unchanged. Long-time irradiation (3 days) resulted mainly in degradation products and polymeric material. This absence of photoreactivity has been recently observed for rather similar systems,[7] and it was then thought that it might be of interest to investigate the photochemical behavior of the sulfur analogues of **1a–c**. There are indeed many examples of dramatic differences in the photochemical reactions of carbonyl and thiocarbonyl compounds. For example, while benzanilide is photoconverted into phenanthridinone,[8] irradiation of thiobenzanilide has been reported to yield 2-phenylbenzo[*b*]thiazole.[9] We have also recently observed that some acyclic aromatic enamides give rise photochemically to Fries rearrangement products whereas their thio analogues photocyclize normally to yield isoquinolinethione derivatives.[3] On the other hand the thioenamide group has been reported to add easily carbon–carbon double bonds inter-[10,11] and intramolecularly[12] and this aptitude could be interesting for our models.

The synthesis of thioenamides **2a–c** could be accomplished by treating the amide with P_2S_5 under a variety of conditions,[13,14] but the best sulfurating agent with re-

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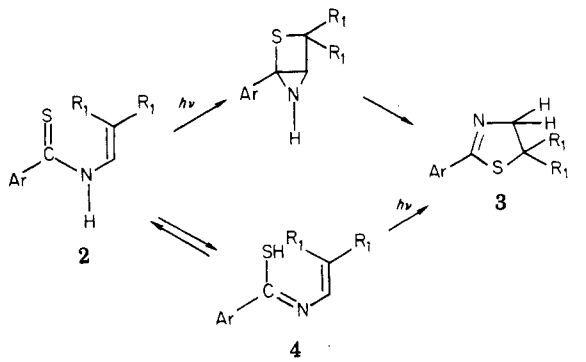
Scheme II



spect to the ease of manipulation and yields of conversion was undoubtedly Lawesson reagent[15] (Aldrich).

Irradiation of thioenamides **2a–c** in hexane (10^{-3} M, Rayonet RPR 208, 3000-Å lamps) led to the formation of 5,5-dimethylthiazolines **3a–c** with fairly good yields (75–80%) (Scheme I).

The starting solutions were carefully degassed by passing argon through the solution before and during irradiation to avoid any photooxidation reaction.[16]

Since these reactions give rise to new heterocycles possessing a quaternary carbon center α to the sulfur atom, we speculated that it might be possible to elaborate a strategy for the construction of a spiro heterocyclic framework, one of the most restricted processes in organic synthesis.[17] To this end thioenamides **2d–g** in which the double bond α to the nitrogen atom was exocyclic were synthesized by reacting the appropriate arylcarboxamide with cyclohexanecarboxaldehyde and subsequent sulfuration with Lawesson reagent. Irradiation of thioenamides **2d–g** under the conditions described previously furnished the expected spirocyclohexanethiazolines **3d–g** with good yields (78–82%). Spectroscopic data confirmed the formation of the spiro structure: in particular the NMR spectra were simple on account of the symmetry of these molecules and the methylene group α to the nitrogen atom gave a singlet at δ ca. 4.1. The hexatrienic character is not a prerequisite to the formation of these compounds since thioenamide **2h** is readily photoconverted into the corresponding spirocyclohexanethiazoline **3h**.

The absence of photocyclization reactions for the enamides and thioenamides remains unclear. Literature reports show that for similar systems photocyclization only occurs when an anilide,[8,18] a pyridylenamide,[19] or an enamide in which the double bond is conjugated with a carbonyl group[4] is used.

The formation of the five-membered heterocyclic compounds **3a–h** may be explained according to the mechanisms depicted in Scheme II, which take into account the specific properties of the thiocarbonyl entity. Although not identified, the presence of the thioenol form **4** cannot be ruled out since the existence of a few percent of this alternative structure has been sometimes reported for rather similar models in dilute solutions.[20,21] The fact that 2-phenylbenzo[*b*]thiazole can be variously obtained by photolysis of thiobenzanilide and/or 2-mercapto-*N*-benzylideneaniline[9] supports the hypothesis of an intramolecular addition[22] of the thiol **4** on the double bond.

The photoreaction reported here represents, therefore, a fast, efficient, and novel method for preparing a wide variety of spirothiazolines from easily available starting materials. In particular it provides a solution to a problem often encountered in organic synthesis since it creates a spiro carbon center in one step. Such compounds can indeed be prepared by only a few limited methods.[17]

Experimental Section

General Techniques. ^{1}H NMR spectra were run in $CDCl_3$ (unless otherwise noted) on either a Bruker WP 60 or WP 80 spectrophotometer. The chemical shifts are reported in δ values relative to tetramethylsilane, which was used as internal standard. UV spectra were measured on a Jobin Yvon spectrophotometer. For accurate mass determination, the samples were analyzed on a Varian MAT 311 A. IR spectra were recorded on a Perkin-Elmer 157G instrument. For column chromatography, neutral alumina (Merck Al_2O_3 90, 70–230 mesh) was used with ethyl acetate–petroleum ether mixture as eluant. Purification of the products by thin-layer chromatography was effected on Merck silical gel 60 GF_{254}. Elemental analyses were performed at the CNRS microanalysis center. Melting points are uncorrected.

The following abbreviations are employed: (s) singlet, (d) doublet, (t) triplet, and (m) multiplet.

Photolyses were carried out in water-cooled quartz reactors equipped with dry argon inlets and magnetic stirrers. Solutions containing the enamides and the thioenamides were purged by bubbling argon through them for 2 h and then subsequent irradiation with eight Rul 3000-Å or 2537-Å lamps in a Rayonet RPR photochemical reactor. Enamides were also irradiated with a Hanovia 450-W medium-pressure mercury lamp.

The solvents were removed under vacuum, and the crude photoreaction product was treated by column chromatography and/or by TLC.

Preparation of Enamides. All the enamides **1a–h** were prepared by following the same procedure. A mixture of the appropriate arylcarboxamide (0.1 mol) and aldehyde (0.2 mol) in benzene (500 mL) was refluxed in presence of a catalytic amount of β-naphthalenesulfonic acid (0.5 g). A Dean–Stark apparatus was used in order to remove the water formed by azeotropic distillation. When isobutyraldehyde was used the mixture was refluxed for 2 h, while with cyclohexanecarboxaldehyde a 16-h reflux was necessary for a complete reaction.

Except for benzamide, the different arylcarboxamides were prepared in the usual manner by treatment of the corresponding acid with thionyl chloride and subsequently with ammoniac in aqueous solution.

The enamides were recrystallized from toluene–hexane.

***N*-(1-Isobutenyl)benzamide (1a):** mp 71 °C (lit.[6] mp 70–71 °C); NMR ($CDCl_3$) δ 1.35 (3 H, s, CH_3), 1.65 (3 H, s, CH_3), 6.7 (1 H, d, C=CH), 7.3–8 (6 H, m, Ar), 8.1 (1 H, br m, NH); IR ($CDCl_3$, cm^{-1}, inter alia) 3450, 1570 (both NH), 1670 (CON); UV (EtOH) λ_{max} 268 (ϵ 8250), 225 (9700).

***N*-(1-Isobutenyl)-α-naphthoic acid amide (1b):** mp 88 °C; NMR ($CDCl_3$) δ 1.38 (3 H, s, CH_3), 1.65 (3 H, s, CH_3), 6.8 (1 H, d, C=CH), 7.2–8.5 (8 H, m, Ar and NH); IR ($CDCl_3$, cm^{-1}) 3440, 1660, 1570; UV (EtOH) λ_{max} 280 nm (ϵ 7200), 225 (18800). Anal. Calcd for $C_{15}H_{15}ON$: C, 79.97; H, 6.71; 0, 7.1; N, 6.22. Found: C, 79.84; H, 6.65; O, 6.75; N, 6.18.

***N*-(1-Isobutenyl)-*o*-phenylbenzamide (1c):** mp 121 °C; NMR ($CDCl_3$) δ 1.35 (3 H, s, CH_3), 1.65 (3 H, s, CH_3), 6.8 (1 H, d, C=CH), 7.2–8.1 (9 H, m, Ar), 8.4 (1 H, br m, NH); IR ($CDCl_3$,

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cm^{-1}) 3445, 1655, 1570; UV (EtOH) λ_{max} 260 nm (ϵ 13 800). Anal. Calcd for $C_{17}H_{17}ON$: C, 81.24; H, 6.82; O, 6.37; N, 5.57. Found: C, 81.12; H, 6.65; O, 6.21; N, 5.43.

***N*-(Cyclohexylidenemethyl)benzamide (1d)**: mp 138–139 °C; NMR ($CDCl_3$) δ 1.3–1.9 (6 H, m, CH_2), 1.9–2.3 (4 H, m, CH_2), 6.65 (1 H, d, C=CH), 7.2–8 (6 H, m, Ar), 8.1 (1 H, br m, NH); IR ($CDCl_3$, cm^{-1}) 3445, 1570, 1665; UV (EtOH) λ_{max} 270 nm (ϵ 10 400), 225 (10 700). Anal. Calcd for $C_{14}H_{17}ON$: C, 78.10; H, 7.96; O, 7.43; N, 6.51. Found: C, 77.98; H, 7.77; O, 7.35; N, 6.41.

***N*-(Cyclohexylidenemethyl)-α-naphthoic acid amide (1e)**: mp 148–149 °C; NMR ($CDCl_3$) δ 1.3–1.9 (6 H, m, CH_2), 1.9–2.3 (4 H, m, CH_2), 6.7 (1 H, d, C=CH), 7.2–8.3 (8 H, m, Ar and NH); IR ($CDCl_3$, cm^{-1}) 3440, 1570, 1670, 1300; UV (EtOH) λ_{max} 285 nm (ϵ 6300), 225 (18800). Anal. Calcd for $C_{18}H_{19}ON$: C, 81.47; H, 7.22; O, 6.03; N, 5.28. Found: C, 81.35; H, 7.11; O, 5.96; N, 5.14.

***N*-(Cyclohexylidenemethyl)-β-naphthoic acid amide (1f)**: mp 165 °C; NMR ($CDCl_3$) δ 1.25–1.9 (6 H, m, CH_2), 1.9–2.3 (4 H, m, CH_2), 6.7 (1 H, d, C=CH), 7.2–8.3 (8 H, m, Ar and NH); IR ($CDCl_3$, cm^{-1}) 3445, 1565, 1670, 1290. Anal. Calcd for $C_{18}H_{19}ON$: C, 81.47; H, 7.22; O, 6.03; N. 5.28. Found: C, 81.32; H, 7.19; O, 5.88; N, 5.12.

***N*-(Cyclohexylidenemethyl)-*o*-phenylbenzamide (1g)**: mp 89–90 °C; NMR ($CDCl_3$) δ 1.25–1.9 (6 H, m, CH_2), 2–2.3 (4 H, m, CH_2), 6.6 (1 H, d, C=CH), 7.2–8.1 (9 H, m, Ar), 8.3 (1 H, br m, NH); IR ($CDCl_3$, cm^{-1}) 3445, 1655, 1570; UV (EtOH) λ_{max} 278 nm (ϵ 12 600). Anal. Calcd for $C_{20}H_{21}ON$: C, 82.44; H, 7.26; O, 5.49; N, 4.81. Found: C, 82.32; H, 7.13; O, 5.35; N, 4.82.

***N*-(Cyclohexylidenemethyl)phenylacetamide (1h)**: mp 249 °C; NMR (CD_2Cl_2) δ 1.3–1.9 (6 H, m, CH_2), 2–2.3 (4 H, m, CH_2), 3.6 (2 H, s, CH_2Ph), 6.45 (1 H, d, C=CH), 7.2 (5 H, m, Ar), 7.3 (1 H, br, NH); IR ($CDCl_3$, cm^{-1}) 3460, 1660, 1580; UV (EtOH) λ_{max} 237 nm (ϵ 10 800) Anal. Calcd for $C_{15}H_{19}ON$: C, 78.56; H, 8.35; O, 6.98; N, 6.11. Found: C, 78.46; H, 8.21; O, 6.54; N, 5.99.

Photolysis of the Enamides 1a–h. Solutions (10^{-3} M) of the enamides **1a–h** in hexane or ethanol have been irradiated with eight Rul 3000- or 2537-Å lamps for different times (from 8 to 72 h). No trace of isolable products could be detected in the photoreaction mixture.

A 10^{-3} M solution of **1a** and **1d** in hexane was also irradiated with a Hanovia 450-W mercury lamp. After several days, TLC of the photoreaction product indicated only the presence of small amounts of degradation products.

Preparation of Thioenamides 2a–h. The thioenamides **2a–h** were prepared by treating the parent enamides **1a–h** with the dimer of (*p*-methoxyphenyl)thionophosphine, called Lawesson reagent, in toluene[15] (85–110 °C, 3–5 h). This reagent was consistently superior to P_4S_{10} in pyridine[13] or diglyme.[14] A typical experimental procedure for the preparation of thioamides **2a–h** follows. A mixture of *N*-cyclohexylidenebenzamide (**1d**) (860 mg, 4.00 mmol), $Ar_2P_2S_4$ (984 mg, 2.4 mmol), and dry toluene (10 mL) was heated at 100 °C for 4 h in an atmosphere of argon. TLC indicated that all the amide **1d** had been consumed. The toluene was removed in vacuo, and the residue was purified by flash chromatography on alumina with ethyl acetate–petroleum ether (2:8) as eluant. A total of 885 mg of almost pure *N*-cyclohexylidenethiobenzamide (**2d**) was obtained (yield 96%). The amount of products and the yields indicated are those obtained by sulfuration of 4 mmol of enamides **2a–h** as described above.

***N*-(1-Isobutenyl)thiobenzamide (2a)**: 718 mg, 94%; NMR ($CDCl_3$) δ 1.37 (3 H, s, CH_3), 1.68 (3 H, s, CH_3), 6.9 (1 H, d, C=CH), 7.2–7.9 (5 H, m, Ar), 8.5 (1 H, br m, NH); IR ($CDCl_3$) 3430, 1565, 1525, 1150, 780; UV (EtOH) λ_{max} 385 nm (ϵ 570), 305 (2200), 225 (40 000). Anal. Calcd for $C_{11}H_{13}SN$: C, 69.09; H, 6.85; S, 16.73; N, 7.33. Found: C, 68.81; H, 6.66; S, 16.54; N, 7.10.

***N*-(1-Isobutenyl)-α-naphthoic acid thioamide (2b)**: 906 mg, 94%; NMR ($CDCl_3$) δ 1.4 (3 H, s, CH_3), 1.68 (3 H, s, CH_3), 6.92 (1 H, d, C=CH), 7.2–8.6 (8 H, m, Ar and NH); IR ($CDCl_3$; cm^{-1}) 3425, 1560, 1510, 1145, 775; UV (EtOH) λ_{max} 385 nm (ϵ 550), 305 (17 600), 210 (35 600); precise mass d eternination calcd for $C_{15}H_{15}NS$ 241.103374, found 241.1027.

***N*-(1-Isobutenyl)-*o*-phenylthiobenzamide (2c)**: 972 mg, 91%; NMR ($CDCl_3$) δ 1.41 (3 H, s, CH_3), 1.70 (3 H, s, CH_3), 6.9 (1 H, d, C=CH), 7.2–7.9 (9 H, m, Ar), 8.5 (1 H, m, NH); IR ($CDCl_3$; cm^{-1}) 3430, 1565, 1530, 1155, 790; UV (EtOH) λ_{max} 390 nm (ϵ 430), 319 (9200), 264 (sh, 10 200), 233 (17 500); precise mass determination calcd for $C_{17}H_{17}SN$ 267.141614, found 267.1412.

***N*-(Cyclohexylidenemethyl)thiobenzamide (2d)**: 885 mg, 96%; NMR ($CDCl_3$) δ 1.35–1.9 (6 H, m, CH_2), 1.9–2.4 (4 H, m, CH_2), 6.88 (1 H, d, C=CH), 7.2–8 (5 H, m, Ar), 8.6 (1 H, br m, NH); IR ($CDCl_3$, cm^{-1}) 3435, 1560, 1510, 1150, 780; UV (EtOH) λ_{max} 388 nm (ϵ 385), 312 (19 800), 223 (35 000); precise mass determination calcd for $C_{14}H_{17}NS$ 231.1081614, found 231.1079.

***N*-(Cyclohexylidenemethyl)-α-naphthoic acid thioamide (2e)**: 1.10 g, 98%; NMR ($CDCl_3$) δ 1.35–1.9 (6 H, m, CH_2), 1.9–2.4 (4 H, m, CH_2), 6.87 (1 H, d, C=CH), 7.2–8.5 (8 H, m, NH and Ar); IR ($CDCl_3$, cm^{-1}) 3430, 1620, 1565, 1150, 795; UV (EtOH) λ_{max} 380 nm (sh, ϵ 550), 305 (17 600), 210 (35 600); precise mass determination calcd for $C_{18}H_{19}NS$ 281.123814, found 281.1235.

***N*-(Cyclohexylidenemethyl)-β-naphthoic acid thioamide (2f)**: 1.03 g, 96%; NMR ($CDCl_3$) δ 1.35–1.9 (6 H, m, CH_2), 1.9–2.4 (4 H, m, CH_2), 6.88 (1 H, d, C=CH), 7.2–8.6 (8 H, m, NH and Ar); IR ($CDCl_3$, cm^{-1}) 3430, 1620, 1560, 1150, 800; UV (EtOH) λ_{max} 392 (ϵ 206), 311 (19 700), 220 (31 000); precise mass determination calcd for $C_{18}H_{19}NS$ 281.123814, found 281.1231.

***N*-(Cyclohexylidenemethyl)-*o*-phenylthiobenzamide (2g)**: 1.24 g, 90%; NMR ($CDCl_3$) δ 1.35–1.9 (6 H, m, CH_2), 1.9–2.5 (4 H, m, CH_2), 6.9 (1 H, d, C=CH), 7.2–7.9 (9 H, m, Ar), 8.55 (1 H, m, NH); IR ($CDCl_3$, cm^{-1}) 3430, 1620, 1565, 1150, 790; UV (EtOH) λ_{max} 385 (ϵ 320), 316 (9200), 265 (sh, 11 000), 235 (18 000); precise mass determination calcd for $C_{20}H_{21}NS$ 307.139463, found 307.1384.

***N*-(Cyclohexylidenemethyl)phenylthioacetamide (2h)**: 892 mg, 91%; NMR ($CDCl_3$) δ 1.35–1.9 (6 H, m, CH_2), 1.9–2.5 (4 H, m, CH_2), 4.32 (2 H, s, CH_2Ph), 7.25 (5 H, m, Ar), 8.6 (1 H, m, NH); IR ($CDCl_3$, cm^{-1}) 3430, 1620, 1565, 1150, 790; UV (EtOH) λ_{max} 380 (ϵ 570), 305 (22 000), 225 (40 000); precise mass determination calcd for $C_{15}H_{19}NS$ 245.139463, found 245.1389.

Photolysis of Thioenamides 2a–h. A 10^{-3} M solution of the thioenamides **2a–h** in hexane is placed in a quartz cylinder equipped with dry argon inlet and a magnetic stirrer. Argon is passed through the solution 2 h before irradiation. The different solutions were irradiated with eight Rul 3000-Å lamps for 7 h. The reaction mixtures were evaporated to dryness at reduced pressure in a rotatory evaporator. The photoreaction products were initially separated by elution chromatography using ethyl acetate–petroleum ether (2:8) as eluant, and the main product was finally purified by TLC on silica with the same eluant.

The amounts of photoreaction products and the yields indicated correspond to irradiation carried out on 2 mmol of starting thioenamides.

5,5-Dimethyl-2-phenylthiazoline (3a): 286 mg, 75%; NMR ($CDCl_3$) δ 1.6 (6 H, s, CH_3), 4.15 (2 H, s, CH_2), 7.2–7.6 (3 H, m, Ar), 7.7–8.1 (2 H, m, Ar); IR ($CDCl_3$, cm^{-1}) 2960, 2870, 1640, 1320; precise mass determination for $C_{11}H_{13}NS$ 191.076866, found 191.0778. Anal. Calcd for $C_{11}H_{13}NS$: C, 69.09; H, 6.85; N, 7.33; S, 16.73. Found: C, 68.82; H, 6.72; N, 7.11; S, 16.54.

5,5-Dimethyl-2-(α-naphthyl)thiazoline (3b): 385 mg, 80%; NMR ($CDCl_3$) δ 1.65 (6 H, s, CH_3), 4.2 (2 H, s, CH_2), 7.5–8.7 (7 H, m, Ar); IR ($CDCl_3$, cm^{-1}) 1640, 1320, 680; precise mass determination for $C_{15}H_{15}NS$ 241.103374, found 241.1029. Anal. Calcd for $C_{15}H_{15}NS$: C, 74.66; H, 6.27; N, 5.81; S, 13.26. Found: C, 74.55; H, 6.10; S, 13.01; N, 5.72.

5,5-Dimethyl-2-*o*-biphenylylthiazoline (3c): 416 mg, 78%; NMR ($CDCl_3$) δ 1.65 (6 H, s, CH_3), 4.2 (2 H, s, CH_2), 7.1–7.8 (9 H, m, Ar); IR ($CDCl_3$, cm^{-1}) 1650, 1320, 680; precise mass determination for $C_{17}H_{17}NS$ 267.141614, found 267.1411. Anal. Calcd for $C_{17}H_{17}NS$: C, 76.38; H, 6.41, N, 5.24; S, 11.97. Found: C, 76.26; H, 6.28; N, 5.19; S, 12.01.

Cyclohexanespiro-5′-(2′-phenylthiazoline) (3d): 378 mg, 82%; NMR ($CDCl_3$) δ 1.2–2 (10 H, m, cyclohexyl), 4.1 (2 H, s, CH_2), 7–7.25 (3 H, m, Ar), 7.3–7.7 (2 H, m, Ar); IR ($CDCl_3$, cm^{-1}) 2800, 1640, 1320. Anal. Calcd for $C_{14}H_{17}NS$: C, 72.7; H, 7.41; N, 6.06; S, 13.83. Found: C, 72.41; H, 7.19; N, 5.85; S, 13.62.

Cyclohexanespiro-5′-(2′-α-naphthylthiazoline) (3e): 449 mg, 80%; NMR ($CDCl_3$) δ 1.2–2 (10 H, m, cyclohexyl), 4.15 (2 H, s, CH_2), 7.45–8.55 (7 H, m, Ar); IR ($CDCl_3$, cm^{-1}) 2810, 16435, 1320, 980. Anal. Calcd for $C_{18}H_{19}NS$: C, 76.84; H, 6.81; N, 4.98; S, 11.37. Found: C, 76.61; H, 6.60; N, 4.65; S, 10.98.

Cyclohexanespiro-5′-(2′-β-naphthylthiazoline) (3f): 435 mg, 78%; NMR ($CDCl_3$) δ 1.2–2.1 (10 H, m, cyclohexyl), 4.17 (2 H, s, CH_2), 7.5–8.6 (7 H, m, Ar); IR ($CDCl_3$, cm^{-1}) 2810, 1650, 1315, 960. Anal. Calcd for $C_{18}H_{19}NS$: C, 76.84; H, 6.81; N, 4.98; S, 11.37.

Found: C, 76.57; H, 6.67; N, 4.58; S, 11.02.

Cyclohexanespiro-5′-(2′-*o*-biphenylylthiazoline) (3g): 484 mg, 79%; mp 121–122 °C (toluene–hexane); NMR ($CDCl_3$) δ 1.2–2.2 (10 H, m, cyclohexyl), 4.05 (2 H, s, CH_2), 7.2–8.1 (9 H, m, Ar); IR ($CDCl_3$, cm^{-1}) 2845, 1650, 1320, 980. Anal. Calcd for $C_{20}H_{21}NS$: C, 78.14; H, 6.89; N, 4.56; S, 10.41. Found: C, 77.88; H, 6.62; N, 4.31; S, 10.25.

Cyclohexanespiro-5′-(2′-benzylthiazoline) (3h): 395 mg, 81%; mp 146 °C (toluene–heptane); NMR ($CDCl_3$) δ 1.1–2.1 (10 H, m, cyclohexyl), 3.7 (2 H, s, CH_2Ph), 4.16 (2 H, s, CH_2), 7.4 (5 H, m, Ar); IR ($CDCl_3$, cm^{-1}) 3010, 2800, 1640, 1320. Anal. Calcd for $C_{15}H_{19}NS$: C, 73.44; H, 7.81; N, 5.71; S, 13.04. Found: C, 73.11; H, 7.63; N, 5.55; S, 12.86.

Registry No. **1a**, 5202-81-3; **1b**, 88425-11-0; **1c**, 88413-28-9; **1d**, 88413-29-0; **1e**, 88413-30-3; **1f**, 88413-31-4; **1g**, 88413-32-5; **1h**, 88413-33-6; **2a**, 88413-34-7; **2b**, 88413-35-8; **2c**, 88413-36-9; **2d**, 88413-37-0; **2e**, 88413-38-1; **2f**, 88413-39-2; **2g**, 88413-40-5; **2h**, 88413-41-6; **3a**, 37950-61-1; **3b**, 88413-42-7; **3c**, 88413-43-8; **3d**, 88413-44-9; **3e**, 88413-45-0; **3f**, 88413-46-1; **3g**, 88413-47-2; **3h**, 88413-48-3; phenylcarboxamide, 55-21-0; α-naphthylcarboxamide, 2243-81-4; *o*-biphenylylcarboxamide, 13234-79-2; β-naphthylcarboxamide, 2243-82-5; phenylacetamide, 103-81-1; isobutyraldehyde, 78-84-2; cyclohexanecarboxaldehyde, 2043-61-0.

Use of [2,3]-Sigmatropic Rearrangements in a One-Step Conversion of Tetrahydroquinoline to Substituted 1,2,5,6-Tetrahydro-4*H*-pyrrolo[3,2,1-*ij*]quinolin-2-one and 5,6-Dihydro-4*H*-pyrrolo[3,2,1-*ij*]quinoline

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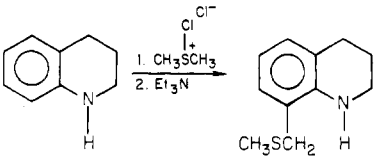
The 1,2,5,6-tetrahydro-4*H*-pyrrolo[3,2,1-*ij*]quinoline ring system has been of interest to a variety of investigators[2] because of the physiological effects of certain of its derivatives[3] and because it represents the basic ring system of the lilolidines.[4] The synthetic paths into this system have relied heavily on the Fischer indole synthesis or on Friedel–Crafts-type substitution of the aromatic ring. Since these reactions have limited applicability to systems bearing a wide variety of electron-withdrawing substituents, we decided to apply our oxindole[5] and indole[6] syntheses to the preparation of the 1,2,5,6-tetrahydro-4*H*-pyrrolo[3,2,1-*ij*]quinolin-2-one and 5,6-dihydro-4*H*-pyrrolo[3,2,1-*ij*]quinoline skeletons. Our process, which involves a [2,3]-sigmatropic rearrangement of intermediate azasulfonium ylides, results in negligible charge buildup on the aromatic ring, and as a result, proceeds readily in the presence of a wide range of electron-donating and electron-withdrawing groups.[7]

In order to test our approach for the use of [2,3]-sigmatropic rearrangements for the specific functionalization of the 8-position of tetrahydroquinoline (1), we first examined the (methylthio)methylation of this position.[7] Treatment of 1 with dimethylchlorosulfonium chloride[7] at −78 °C, followed by addition of triethylamine and workup, gave a 46% yield of 8-[(methylthio)methyl]-tetrahydroquinoline (2). In a similar fashion, chlorine was added to ethyl methylthioacetate to give the corresponding chlorosulfonium chloride, 3, which was added dropwise to



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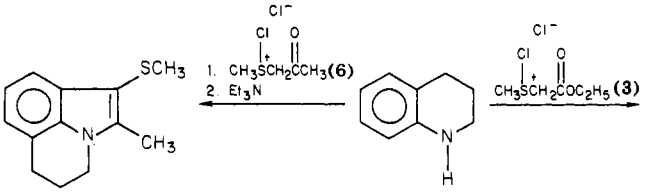

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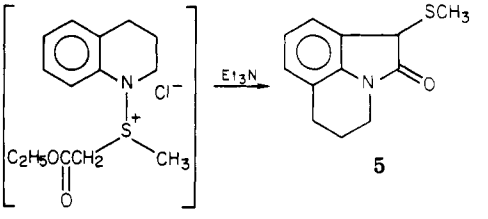

4 5

1 at −78 °C. Treatment of the intermediate azasulfonium salt 4 with triethylamine gave **5** in 53% yield. When 1 was treated with the chlorosulfonium chloride salt **6**, derived from 1-(methylthio)propan-2-one, and subsequently with triethylamine at −70 °C, a 39% yield of 1-(methylthio)-2-methyl-5,6-dihydro-4*H*-pyrrolo[3,2,1-*ij*]quinoline (**7**) was obtained.

Overall, we have demonstrated that the use of [2,3]-sigmatropic rearrangements of ylides generated from tetrahydroquinoline-derived azasulfonium salts provides a one-pot procedure for the synthesis of derivatives of the 5,6-dihydro-4*H*-pyrrolo[3,2,1-*ij*]quinoline system.

Experimental Section

8-[(Methylthio)methyl]tetrahydroquinoline (2). Chlorine (2.0 mL, 44 mmol) was condensed into a dry ice–acetone-cooled (jacketed) addition funnel at −78 °C. The chlorine was added dropwise to 120 mL of dry methylene chloride at −78 °C. To the resultant pale yellow solution, under a static nitrogen pressure,

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