This material was resuspended in acidified water (1 mL of 0.1 N HCl in 100 mL of distilled water) and allowed to stand at 4 °C for 16 h. The crystalline S-alkylated derivative was collected by filtration, washed with cold distilled water, and air-dried. These derivatives were of sufficient purity for elemental analyses but could be recrystallized as indicated in Table I.

A similar set of conditions was employed for the methylation of **3**. Like **4a**, **5** remained in solution. When the reaction was complete, the solvent was evaporated under diminished pressure, and the residue was crystallized from 95% ethanol to furnish **5**.

5,6-Diamino-*as*-triazine-3-one (6a). Method A. 6-Amino-5-(methylthio)-*as*-triazine-3-one (**4a**, 4.75 g, 30 mmol) was suspended in methanolic ammonia (30 mL, saturated at −5 °C) and kept at room temperature for 24 h in a pressure bottle. During this time, **4a** dissolved, and **6a** gradually began to precipitate out of solution. The excess gases were vented, and the solvent was removed under diminished pressure. The residual off-white solid was recrystallized from distilled water to afford a quantitative yield (3.81 g) of **6a**: mp 268 °C (slow decomposition); MS (EI, 70 eV, probe 300 °C, source 200 °C), 127 (M^+); ^1H NMR δ 5.88 (br s, 2, 6-NH_2), 7.0–8.40 (v br s, 2, 5-NH_2), 10.77 (v br, s, 1, N2H).

Anal. Calcd for $C_3H_5N_5O$: C, 28.35; H, 3.97; N, 55.10. Found: C, 28.57; H, 4.08; N, 55.26.

Method B. 6-Amino-3-oxo-*as*-triazine-5-thione (**2**, 720 mg, 4.99 mmol) and liquid ammonia (ca. 15 mL) were heated (oil bath) and stirred in a glass-lined stainless steel reaction vessel at 90 °C for 5 h. The vessel was cooled to room temperature, and the excess ammonia was vented off to provide a yellow residue, which was dissolved in hot methanol (30 mL) and filtered through Celite, and the solvent was removed under diminished pressure. Recrystallization from water furnished 520 mg (82%) of **6a**, identical (UV, IR, chromatographic mobilities, and a mixture melting point) with **6a** prepared by method A.

5,6-Diamino-3-(methylthio)-*as*-triazine (7a). 6-Amino-3,5-bis(methylthio)-*as*-triazine (**5**, 1.88 g, 10 mmol) and liquid ammonia (20 mL) were heated in a glass-lined stainless steel reaction vessel at 50 °C for 24 h. The reaction vessel was allowed to cool to room temperature, and the excess gases were vented off. Crystallization of the resulting residue from distilled water furnished **7a**: 1.52 g (97%); mp 200–202 °C, ^1H NMR δ 2.38 (s, 3, SCH_3), 5.96 (s, 2, 6-NH_2), 7.12 (br, s, 2, 5-NH_2).

General Procedure for the Preparation of 5-(Alkylamino)- and 5-(Arylalkylamino)-6-amino-3-substituted-*as*-triazines. Either **4a** or **5** was stirred with the appropriate alkylamine or arylalkylamine at room temperature to furnish the corresponding 5-alkylamino or 5-arylalkylamino derivatives (Table II). For the preparation of **6c**, liquid dimethylamine was used, and the reaction was run in a glass-lined stainless steel bomb. Compounds **6d** and **6e** were synthesized by suspending **4a** in 100 mL of absolute ethanol and adding 1.5 equiv of benzylamine and furfurylamine, respectively. With the exceptions of **6c** and **7c**, the workups were similar. The excess solvent was removed in vacuo or under diminished pressure and the resulting solid recrystallized as indicated in Table II. In the case of **6c**, the excess gases were vented off, and the residue was crystallized form AR methanol. For **7c**, the reaction mixture was poured into ethyl ether and washed with three portions of water. The ether layer was then allowed to evaporate overnight and the crystalline residue recrystallized from ethyl acetate.

Acknowledgment. We thank Prof. Elie Abushanab for many helpful discussions and Ms. Sylvia Stoner for technical assistance.

Registry No. **1**, 18802-38-5; **2**, 84582-84-3; **3**, 84582-85-4; **4a**, 84582-86-5; **4b**, 84582-87-6; **4c**, 84582-88-7; **4d**, 84582-89-8; **5**, 84582-90-1; **6a**, 84582-91-2; **6b**, 84582-92-3; **6c**, 84582-93-4; **6d**, 84602-16-4; **6e**, 84602-17-5; **7a**, 84582-94-5; **7b**, 84582-95-6; **7c**, 84582-96-7; 6-bromo-*as*-triazine-3,5-dione, 4956-05-2; methyl iodide, 74-88-4; allyl bromide, 106-95-6; benzyl bromide, 100-39-0; *p*-nitrobenzyl bromide, 100-11-8; methylamine, 74-89-5; dimethylamine, 124-40-3; benzylamine, 100-46-9; furfurylamine, 617-89-0.

Supplementary Material Available: Additional UV absorption data (3 pages). Ordering information is given on any current masthead page.

Photocycloaddition Reactions of 3-Phenyl-1,2-benzisothiazole and Alkynes

M. Sindler-Kulyk and D. C. Neckers*

Department of Chemistry, Bowling Green State University, Bowling Green, Ohio 43403

Received July 26, 1982

Photocycloaddition reactions of 3-phenyl-1,2-benzisothiazole (**1**) and the electron-rich alkynes ethoxyacetylene (**2a**), ethoxypropyne (**2b**), and (diethylamino)propyne (**2c**) gave substituted 3,4-benzo-2,6-thiazabicyclo[3.2.3]-hepta-3,6-dienes (**3a**, **3b**, **6**) in one-step processes presumably via the 1,4-benzothiazepines **13** and **14**.

In continuation of our work[1,2] on photocycloaddition reactions of fused heterocyclic compounds, we report herein a one-step photochemical synthesis of substituted 3,4-benzo-2,6-thiazabicyclo[3.2.0]hepta-3,6-dienes by irradiating 3-phenyl-1,2-benzisothiazole (**1**) in the presence of electron-rich alkynes. Previous results from our laboratory, as well as others,[3] have indicated the viability of $_\pi2_s + _\pi2_s$ cycloadditions with the 2,3-bond of fused heterocyclic compounds such as benzo[*b*]thiophene, benzo[*b*]-furan, and indole, followed by a thermal cyclobutene–butadiene rearrangement, in generating benzo[*b*]thiepines, benzo[*b*]oxepines, and benzo[*b*]azepines.

On the basis of these observations, we postulated that irradiation of fused heteroaromatic compounds such as benzothiazole or benzisothiazole with alkynes might provide the pharmacologically interesting benzothiazepines. Contrary to our expectation, initial attempted photocycloadditions in the presence of both alkynes and alkenes

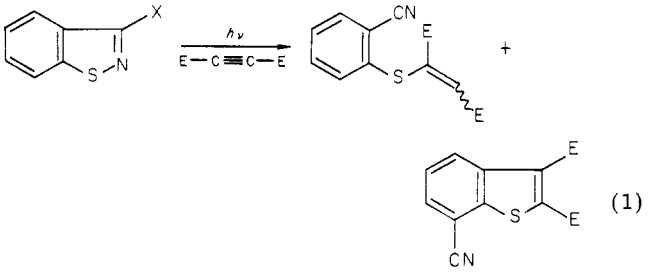
(1) (a) Neckers, D. C.; Dopper, J. H.; Wynberg, H. *J. Org. Chem.* **1970**, *35*, 1582. (b) Dopper, J. H.; Neckers, D. C. *Ibid.* **1971**, *36*, 3755. (c) Tinnemans, A. H. A.; Neckers, D. C. *Ibid.* **1977**, *42*, 2374. (d) Tinnemans, A. H. A.; Neckers, D. C. *Ibid.* **1978**, *43*, 2493. (e) Ditto, S. R.; Davis, P. D.; Neckers, D. C. *Tetrahedron Lett.* **1981**, *22*, 521. (f) Davis, P. D.; Neckers, D. C. *J. Org. Chem.* **1980**, *45*, 456. (g) Davis, P. D.; Neckers, D. C.; Blount, J. R. *Ibid.* **1980**, *45*, 462. (h) Davis, P. D.; Neckers, D. C. *Tetrahedron Lett.* **1978**, 2979.

(2) (a) Sindler-Kulyk, M.; Neckers, D. C. *Tetrahedron Lett.* **1981**, *22*, 525, 259. (b) Sindler-Kulyk, M.; Neckers, D. C.; Blount, J. R. *Tetrahedron* **1981**, 3377.

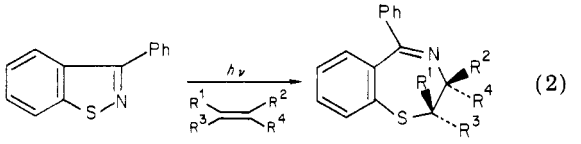
(3) Reinhoudt, D. N.; Kouwenhoven, C. G. *Tetrahedron* **1974**, *30*, 2431.

0022-3263/83/1948-1275$01.50/0

provided alternative products (eq 1, X = H or Cl, E = $COOCH_3$). Thus irradiation of certain benzisothiazoles with deactivated alkynes such as dimethyl acetylenedicarboxylate (DMAD) led to linear products as well as benzo[*b*]thiophenes (eq 1). Benzisothiazole with the 3-position blocked with a nondissociable functional group produced cyclic adducts in regio- and stereospecific reactions, occurring by the trapping of the intermediate deriving from sulfur–nitrogen bond cleavage (eq 2). 2-

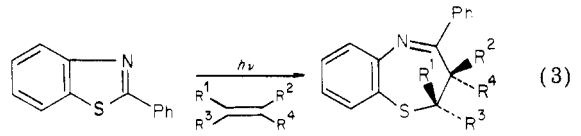


(1)



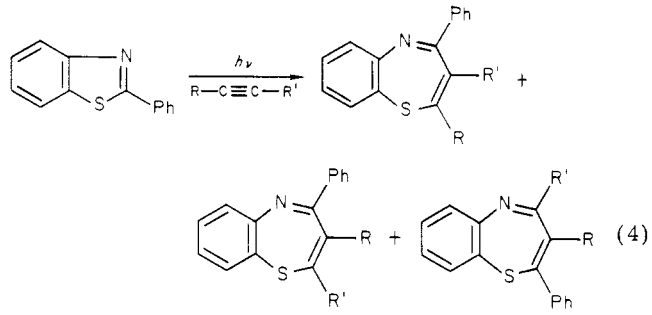
(2)

Phenylbenzothiazole, when irradiated under similar conditions, gave 2,3-dihydro-1,5-benzothiazepine (eq 3).



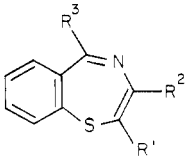
(3)

Recent experiments tested the photocycloaddition of 2-phenylbenzothiazole to electron-rich alkynes. These reactions gave substituted 1,5-benzothiazepines (eq 4) in one step.



(4)

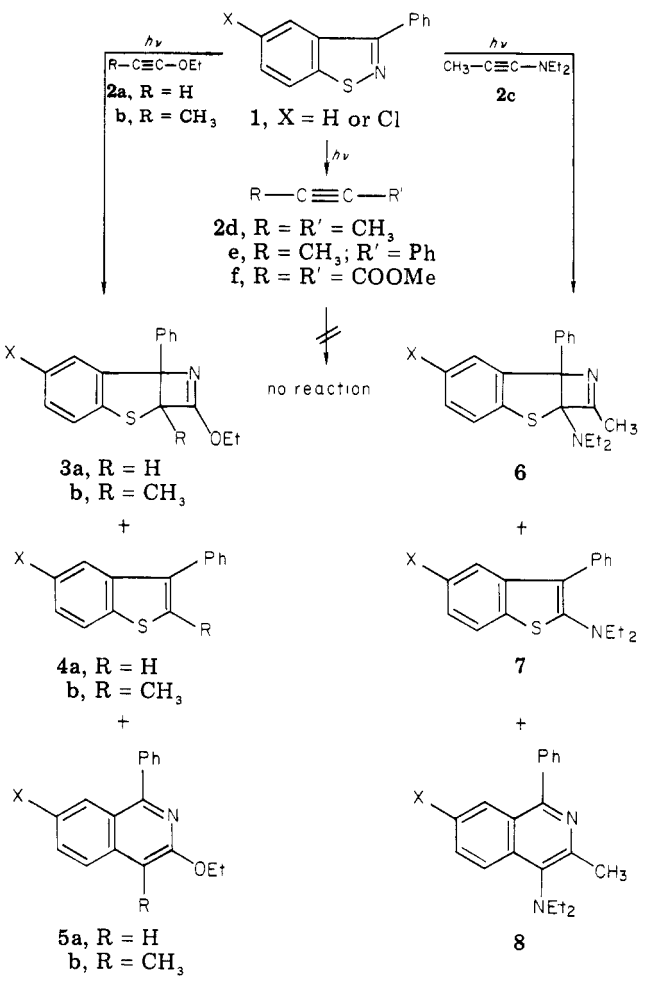
On the basis of these previous observations, we anticipated that the photocycloaddition reaction of 3-phenylbenzisothiazole or other 3-substituted aryl derivatives with electron-rich alkynes such as ethoxypropyne, ethoxyacetylene, and (diethylamino)propyne, might provide a direct route to the heretofore unknown 1,4-benzothiazepine system.



Results

Direct irradiation for 108 h of a 0.02 M degassed solution of **1** in 1-ethoxy-1-propyne (**2b**) at 15 °C with a 450-W medium-pressure mercury arc lamp led to the formation of 1-methyl-5-phenyl-7-ethoxy-3,4-benzo-2,6-thiazabicyclo[3.2.0]hepta-3,6-diene (**3b**) in 67% yield, as well as 7% 2-methyl-3-phenylbenzo[*b*]thiophene (**4b**) and 3% 3-ethoxy-4-methyl-1-phenylisoquinoline (**5b**). In a similar manner irradiation of **1** in the presence of ethoxyacetylene in a Rayonet reactor (λ_{max} 300 mm) for 30 h (the reaction mixture gradually darkens so that prolonged irradiation does not increase the conversion) gave 15% 5-phenyl-7-ethoxy-3,4-benzo-2,6-thiazabicyclo[3.2.0]hepta-3,6-diene (**3a**), 33% 3-phenylbenzothiophene (**4a**) and 15% 3-ethoxy-1-phenylisoquinoline (**5a**; Scheme I). Two other compounds, **9a** and **10a**, were isolated, but these were shown to be formed during the workup procedure by hydrolysis of **3a** (see eq 5).

Scheme I



Irradiation of a 0.02 M benzene solution of 3-phenyl-1,2-benzisothiazole (**1**) in the presence of 0.1 M 1-(diethylamino)propyne (**2c**) resulted in the formation of **6**–**8**. On the other hand, 3-phenyl-1,2-benzisothiazole, when irradiated in the presence of 2-butyne (**2d**), 1-phenylpropyne (**2e**), or DMAD (**2f**) gave no products.

The structures of all photoproducts were confirmed spectroscopically as well as by chemical degradation. The major product **3a** shows, in the ^1H NMR spectrum, a one-proton singlet at δ 4.76 assigned to the bridgehead hydrogen on C-1. When the hydrogen on C-1 is replaced by a methyl group, as in compound **3b**, a three-proton singlet appears at δ 1.23. Both compounds **3a** and **3b** show a triplet and a split quartet centered at δ 1.37 and 4.34, respectively, for the ethoxy group on C-7. The magnetic nonequivalence[4] of the methylene hydrogens of the ethoxy

(4) Günther, H. "NMR Spectroscopy, An Introduction"; Wiley: New York, 1980; p 200.

Table I. ^{13}C NMR (δ)

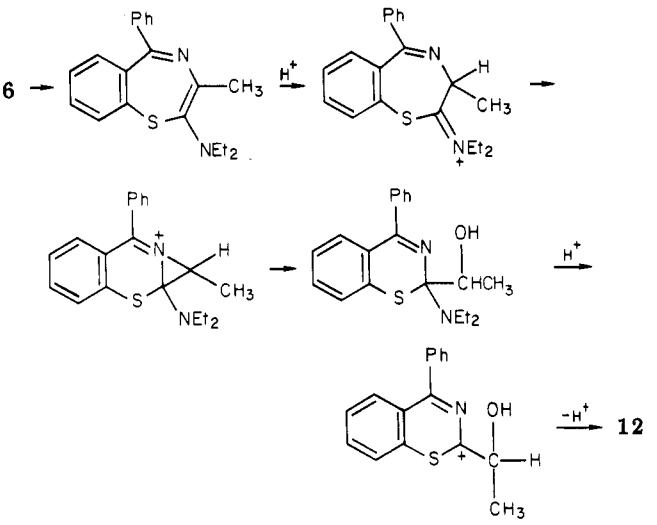
compd	C=N/C=O	C_{sp^3}	$-CH_2CH_3$	$-CH_3$
3a	170.34	56.62 (1), 77.39 (5)	63.30, 14.16	
3b, X = H	173.67	63.92 (1), 80.38 (5)	63.04, 14.12	18.02
3b, X = Cl	173.67	64.70 (1), 80.08 (5)	63.18, 14.11	17.97
6	182.72	95.38 (1), 80.42 (5)	43.19, 12.37	17.60
9a, X = H	169.41	63.37 (3, d), 71.76 (2, 5)	61.32, 14.05	
9b, X = Cl	172.01	73.84 (2), 70.14 (3)	61.66, 13.90	22.30
10b, X = Cl	169.21	77.71 (1), 72.99 (5)		17.62
12	189.57	68.43 (5)		22.39

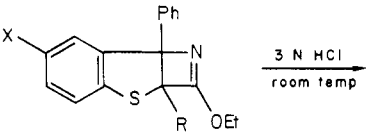
group can be explained by the presence of the asymmetric carbon atom C-1. The methyl group on C-7 in compound **6** appears at δ 2.34, in the chemical shift region for allylic methyl groups. The split quartet of the methylene portion of the diethylamino group as well as the triplet of the methyl group are shifted upfield and centered at δ 2.51 and 0.56, respectively. The physical properties of 2-methyl-3-phenylbenzothiophene (**4b**) as well as its sulfone are in accord with literature data.[5] Isoquinoline **5a** has hydrogen (C-4) at δ 6.97 and the ethoxy group as a quartet (δ 4.44) and triplet (δ 1.47) with a coupling constant of J = 7 Hz. **5b** shows methylene and methyl protons at almost the same position (δ 4.55 and 1.43). The methyl group on C-4 is located at δ 2.54. Isoquinoline **8** with the diethylamino group on C-4 shows the signal of the methyl group on C-3 at δ 2.71. The two ethyl groups on nitrogen are equivalent, and the methylene protons appear as a four-proton quartet at δ 3.32 and the methyl group as a six-proton triplet at δ 1.07.

In the mass spectrum of **3a** and **3b** the major fragment is at m/e 210 and 224, respectively, indicating loss of 71 mass units, the equivalent of N≡C—OEt. The cyclobutenes derived from the cycloaddition of acetylene compounds to benzo[*b*]thiophene and benzo[*b*]furan characteristically lose an acetylenic fragment as the major fragmentation.[1d] Contrary to this trend the cycloadduct **6** loses m/e 32 followed by m/e 15 as the major fragmentation. This provides additional evidence, along with the data from ^1H NMR, that in the photoproduct **6**, the diethylamino group does not occupy the same position (C-7) as the ethoxy group does in photoproduct **3**. The easy loss of sulfur (M − 32) might provide evidence for a 1,4-benzothiazepine structure in accord with our previous results in 1,5-benzothiazepines.[6] This possibility was excluded, however, by ^{13}C NMR investigations. The photoproduct **6** clearly shows in the ^{13}C NMR spectrum two C_{sp^3} resonances at δ 95.38 and 88.42 for C-1 and C-5, which would not be present if the compound had a 1,4-benzothiazepine structure. This is in accord with ^{13}C NMR data we have collected for 1,5-benzothiazepine systems[6] as well as with literature reports of ^{13}C spectra of benzodiazepines.[7] The downfield resonance signal at δ 95.38 is assigned to C-1 bearing the NEt_2 group, and it is lower than the resonances of the same carbon of similar compounds (see Table I). This is in accord with the general observation that *N*-alkyl substituents cause a downfield shift at the carbon of attachment.[8]

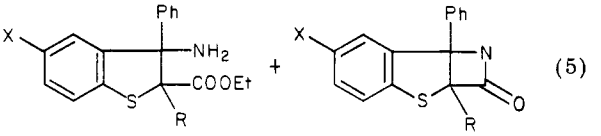
To further confirm the structure of compounds **3** and **6**, each was subjected to acidic hydrolysis under mild conditions as well as thermal and photochemical decomposition. When **3b** was treated with 3 N HCl for 2 h at 60 °C, the 2,3-dihydrobenzo[*b*]thiophene **9b** was isolated as the main product accompanied by a small quantity of the lactam **10b** (eq 5). Compound **3a** is even more sensitive to acid and also hydrolyzes, in the same way, during the workup procedure. The structure of the products **9** and **10** was evident from spectroscopic data. The presence of the amino group in **9b** is obvious from the IR (λ_{NH_2} 3340 and 3275 cm^{-1}) and the ^1H NMR spectrum (broad singlet at δ 2.2). A very weak stretching frequency at 3205 cm^{-1} is due to λ_{NH} of the lactam **10**. The carbonyl ester absorption of **9b** at 1725 cm^{-1} in the IR together with a two-proton quartet a δ 4.18 in the ^1H NMR confirm the presence of the carbethoxy group. A three-proton singlet at δ 1.32 is assigned to the methyl substituent on C-2. **10b** shows a carbonyl at 1765 cm^{-1}, which corresponds to a β-lactam absorption.[9] The loss of m/e 43 in the mass spectrum, corresponding to the loss of an NHCO fragment,

Scheme II





3a, R = H
b, R = CH_3



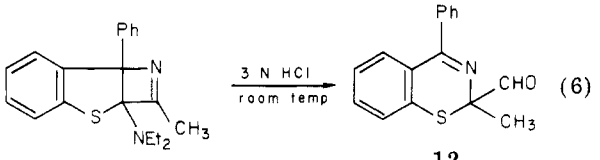
(5)

9a, R = H
b, R = CH_3

10a, R = H
b, R = CH_3

(5) Murthy, T. S.; Tilak, B. D. *J. Sci. Ind. Res. Sect. B* **1960**, *19*, 395.
(6) Sindler-Kulyk, M.; Neckers, D. C. *J. Org. Chem.* **1982**, *47*, 4914.
(7) See for example: Kovar, K.-A.; Linden, D. *Arch. Pharm. (Weinheim Ger.)* **1981**, *314*, 186. Haran, R.; Tuchagues, J. P. *J. Heterocycl. Chem.* **1980**, *17*, 1483. Singh, S. P.; Parmar, S. S.; Farnum, S. A.; Stenberg, V. I. *Ibid.* **1978**, *15*, 1083.
(8) Levy, G. C. "Carbon-13 Nuclear Magnetic Resonance Spectroscopy"; Wiley: New York 1980.
(9) Rao, C. N. R. "Chemical Applications of Infrared Spectroscopy"; Academic Press: New York, 1963; p 261.

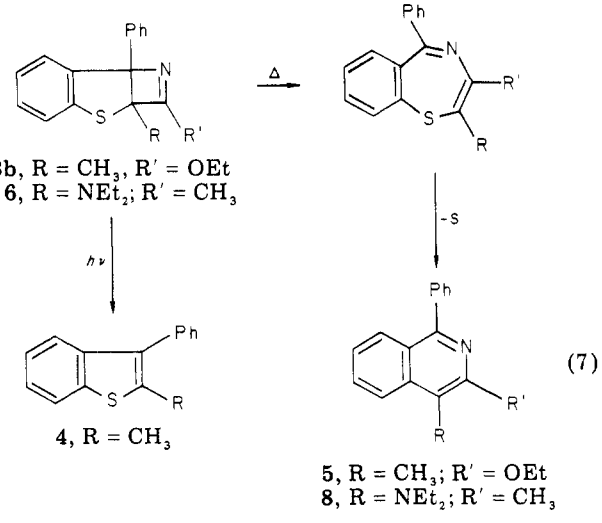
confirms structure **10b**. Finally, the 2,3-dihydrobenzo[*b*]thiophene structure of the compounds **9** and **10** was evident from the ^{13}C NMR spectra. When the bicyclic adduct **6** (X = H) was treated with 3 N HCl for 2 h at room temperature, the aldehyde **12** was isolated as a major product (eq 6). In **12** a strong carbonyl absorption was



6 12 (6)

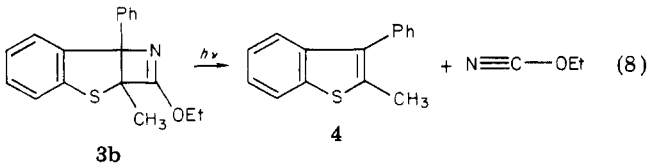
observed at 1725 cm^{-1}, indicating the presence of an unconjugated aldehyde group. The compound **12** showed, in the mass spectrum, loss of *m/e* 29 (CHO) followed by loss of *m/e* 41 ($CH_3C{\equiv}N$) and finally loss of *m/e* 32 (sulfur). The ^1H NMR spectrum shows a very simple and narrow aromatic pattern, the aldehyde singlet at δ 9.32 and the methyl singlet at δ 1.85. The ^{13}C NMR spectrum confirmed the presence of a carbonyl group bearing a proton at δ 189.57 and showed a quaternary carbon at δ 68.43. The structure that best accommodates these data is structure **12**. One possible mechanism for its formation is outlined in Scheme II.

It should be mentioned that thiazabicyclo[3.2.0]heptadienes **3** and **6** undergo electrocyclic thermal ring opening like the cyclobutene analogues in the benzo[*b*]thiophene series.[1d] While **6** undergoes thermal decomposition at 130–160 °C almost quantitatively to give isoquinoline **8**, **3** thermolyzes to **4** and **5** only upon prolonged heating (2 h at 210 °C; see eq 7). In contrast, irradiation of photo-



(7)

product **3** gave only substituted benzo[*b*]thiophene **4** through elimination of the rather unusual fragment ethyl cyanate (eq 8). Ethyl cyanate isomerizes easily to ethyl



3b 4 (8)

isocyanate,[10] which can be confirmed in the distillate after photolysis.

Discussion

Photoaddition of the electron-rich acetylenes (**2a–c**) to 3-phenyl-1,2-benzisothiazole (**1**, X = H or Cl) leads to the formation of substituted 3,4-benzo-2,6-thiazabicyclo[3.2.0]hepta-3,6-dienes (**3** and **6**, Scheme III). The other products (**4**, **5**, **7–10**) found in the reaction mixture are secondary products formed either photochemically or thermally. There are several ways to explain the formation of the isolated compounds. One mechanism involves cycloaddition to the carbon–nitrogen double bond to give bicyclic adducts **15** and **16**, which upon photochemical rearrangement would give **3** and **6**. Another pathway, which seems to us more reasonable, proceeds via formation of 1,4-benzothiazepines **13** and **14**. Benzothiazepines (**13** and **14**) were formed by trapping the intermediate obtained by photoinduced bond cleavage[2,11] of the 3-phenyl-1,2-benzisothiazole sulfur–nitrogen bond. Substituted isoquinolines (**5** and **8**) present in the reaction mixture after irradiation are obtained by extrusion of sulfur from the initially formed 1,4-benzothiazepines **13** and **14**, and their presence supports the proposed pathway. It is unlikely that the isoquinolines **5** and **8** are secondary photoproducts of **3** and **6**, since only benzothiophenes (**4** and **7**) are formed on photolysis of the photoproducts (**3** and **6**).

Although bicyclic compounds **3** and **6** are both formed by regiospecific addition, the regiochemistry of the addition is opposite in the two cases. In the photoreaction of 3-phenyl-1,2-benzisothiazole (**1**) with ethoxypropyne (**2b**), photoproduct **3** has the methyl substituent on C-1, while in the photoreaction with (diethylamino)propyne (**2c**), photoproduct **6** has the methyl substituent on C-7. Assuming that the mechanism of the photoreaction involves trapping the intermediate resulting form S–N cleavage, the possible mechanism for the addition of ethoxyacetylenes might be as presented in Scheme IV.

The reaction with (diethylamino)propyne is more efficient than is the reaction with ethoxypropyne. When 0.02 M benzene solutions of 3-phenyl-1,2-benzisothiazole were simultaneously irradiated for 10 h in the Rayonet reactor (λ_{max} 300 nm) one with 0.2 M ethoxypropyne, the other with 0.2 M (diethylamino)propyne, no reaction was observed with ethoxypropyne, while with (diethylamino)propyne, 3-phenylbenzisothiazole was almost completely consumed and the main photoproduct 3-phenyl-2-(diethylamino)benzo[*b*]thiophene (**7**) was obtained. In (diethylamino)propyne (**2c**) the nitrogen atom is directly bonded to the C≡C triplet bond, and the material, which is an ynamine,[12] is more nucleophilic than is the oxygen analogue. The different direction of addition could result because of the formation of a different intermediate **18** such as outlined in Scheme V. In both cases, the ethoxypropyne and (diethylamino)propyne, the photoreaction proceeds via the 1,4-benzothiazepines **13** and **14**. The presence of isoquinolines **5** and **8** in the reaction mixture is due to the thermal instability of the 1,4-benzothiazepines **13** and **14**. The yields of isoquinolines depend on both the rate of ring closure and the rate of sulfur extrusion in 1,4-benzothiazepines.

Experimental Section

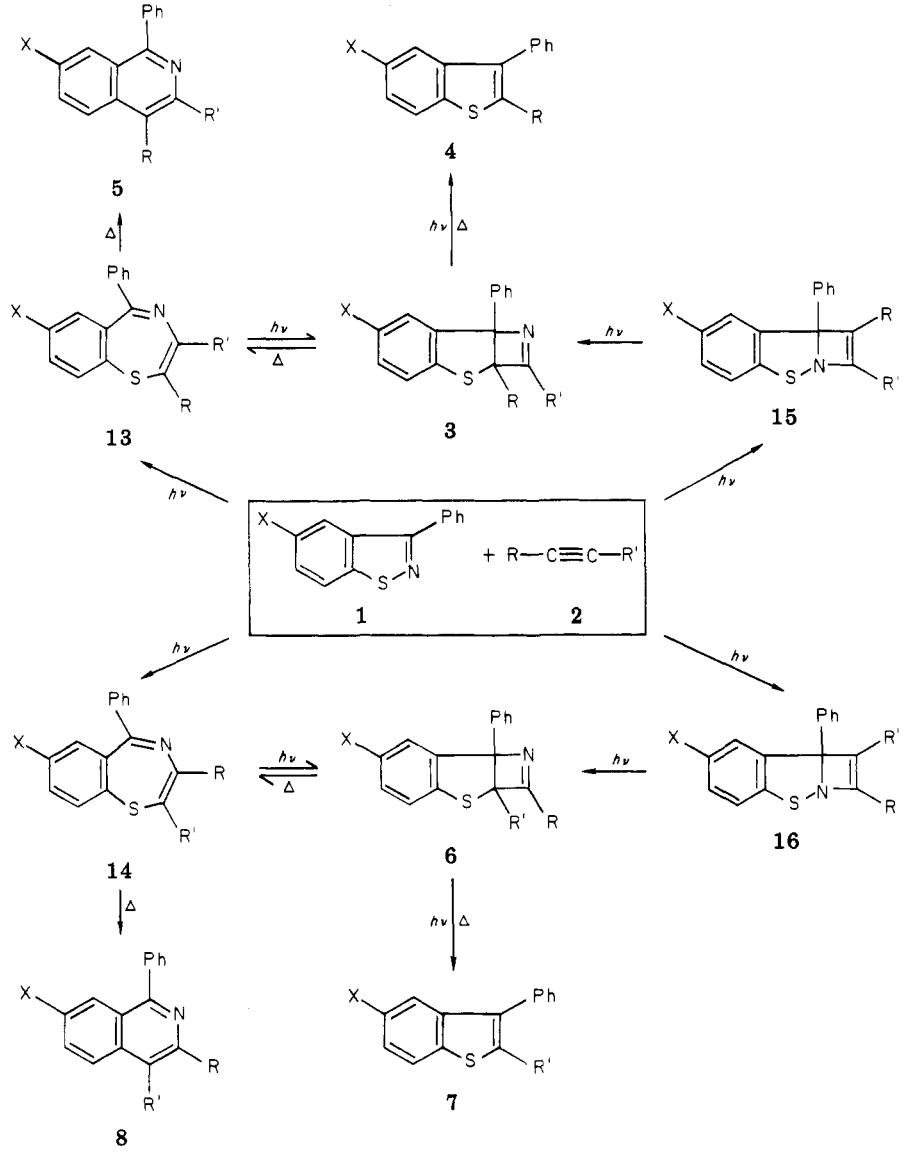
General Procedures. ^1H and ^{13}C NMR spectra were recorded on Varian EM-360 and CFT-20 spectrometers. Unless otherwise indicated, $CDCl_3$ was used as the solvent with Me_4Si as the internal standard. IR spectra were obtained on a Perkin-Elmer 337 spectrophotometer, UV spectra on a Varian/Cary 219 spectro-

(10) For ethyl cyanate see: (a) Martin, D.; Mucke, W. *Chem. Ber.* **1965**, *98*, 2059. (b) Jensen, K. A.; Due, M.; Holm, A. *Acta Chem. Scand.* **1965**, *19*, 438.

(11) Ohashi, M. *J. Chem. Soc., Chem. Commun.* **1974**, 617.

(12) Ficini, J. *Tetrahedron* **1976**, *32*, 1449.

Scheme III



photometer in EtOH, and mass spectra on a Varian MAT CH7 spectrometer. Melting points were taken on a Thomas-Hoover capillary melting point apparatus and are uncorrected. Ethoxyacetylene, 1-ethoxy-1-propyne, and 2-butyne were purchased from Farchan Chemical Co., 1-(diethylamino)propyne from Fluka, and 1-phenylpropyne and DMAD from Aldrich Chemical Co. 3-Phenyl-1,2-benzisothiazole (1, X = H)[13] and 5-chloro-3-phenyl-1,2-benzisothiazole (1, X = Cl)[2b] were prepared as previously described. The irradiations were performed in a Rayonet reactor (λ_{max} 300 nm) as well as with a medium-pressure mercury lamp. The source of light did not effect the formation of the products.

Irradiation of 3-Phenyl-1,2-benzisothiazole (1, X = H) in the Presence of Ethoxyacetylene (2a). A 0.02 M solution of 3-phenyl-1,2-benzisothiazole (1, X = H) in ethoxyacetylene (**2a**), degassed by several freeze–thaw cycles, was irradiated in a sealed Pyrex tube for 30 h. The irradiation was performed in the Rayonet reactor (λ_{max} 300 nm) and in a cold room, so that the temperature in the reactor did not exceed 18 °C. The dark reaction mixture, after removal of the excess ethoxyacetylene by distillation on a high vacuum line, was chromatographed. Preparative thick-layer chromatography on a silica gel plate with a mixed solvent of 93% hexane–7% ether as eluent gave the main photoproduct **3a** (X = H), which was not isolated because it hydrolyzed during the workup procedure to **9a** (X = H). Column chromatography gave both products **3a** and **9a** as well as others that we report herein in the order of increasing retention time. Unreacted starting material (1, X = H), was also isolated (11%).

3-Phenylbenzothiophene (4a, X = H: 33% yield) was identical with the compound obtained by unambigous synthesis.[14]

3-Ethoxy-1-phenylisoquinoline (5a, X = H): 15% yield; mp 41–42 °C (EtOH); IR (mineral oil) 1620, 1580, 1540 cm^{-1}; UV (λ_{max} nm (ϵ)) 279 (6410), 348 (8550); mass spectrum, *m/e* 249 (M^+, 47), 234 (M – 15, 100); ^1H NMR δ 7.0–8.07 (m, 9 H, Ar), 6.97 (s, 1 H, Ar), 4.44 (q, 2 H, J = 7.0 Hz), 1.47 (t, 3 H, J = 7.0Hz). Anal. Calcd for $C_{17}H_{15}NO$: C, 81.90; H, 6.07; N, 5.62. Found: C, 81.71; H, 6.01; N, 5.69.

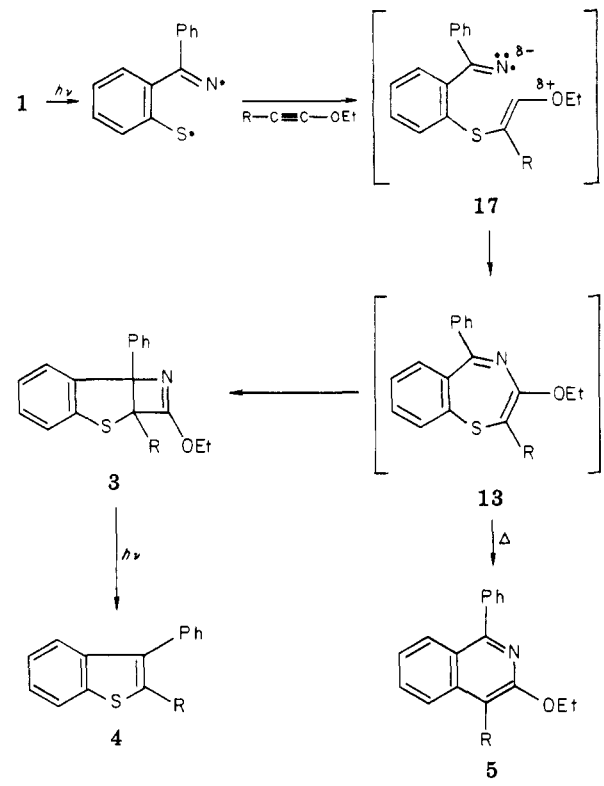
7-Ethoxy-5-phenyl-3,4-benzo-2,6-thiazabicyclo[3.2.0]hepta-3,6-diene (3a, X = H): 15% yield; mp 132–133 °C (from EtOH); IR (mineral oil) 1590 cm^{-1}; UV (λ_{max} nm (ϵ)) 251 (8440), 291 (1400), 300 (1200); mass spectrum, *m/e* 281 (M^+, 9), 210 (M – 71, 100); ^1H NMR δ 7.0–7.5 (m, 9 H, Ar), 4.76 (s, 1 H), 4.34 (dq, 2 H, J = 7.1 Hz), 1.37 (t, 3 H, J = 7.1 Hz); ^{13}C NMR δ 170.34, 142.53, 141.06, 140.28, 129.30, 128.32, 127.68, 126.81, 126.60, 125.14, 122.89, 77.39 (d), 63.3 (t), 56.62 (d), 14.16 (t). Anal. Calcd for $C_{17}H_{15}NOS$: C, 72.56; H, 5.37; N, 4.98. Found: C, 72.46; H, 5.29; N, 4.86.

Ethyl 2,3-dihydro-3-amino-3-phenylbenzothiophenyl-2-carboxylate (9a, X = H): 16% yield; mp 81–82 °C (EtOH); IR (mineral oil) 3360, 3300, 1725 cm^{-1}; UV (λ_{max} nm (ϵ)) 249 (5700), 278 (1870), 288 (1680), 296 (1120); mass spectrum, *m/e* 299 (M^+,

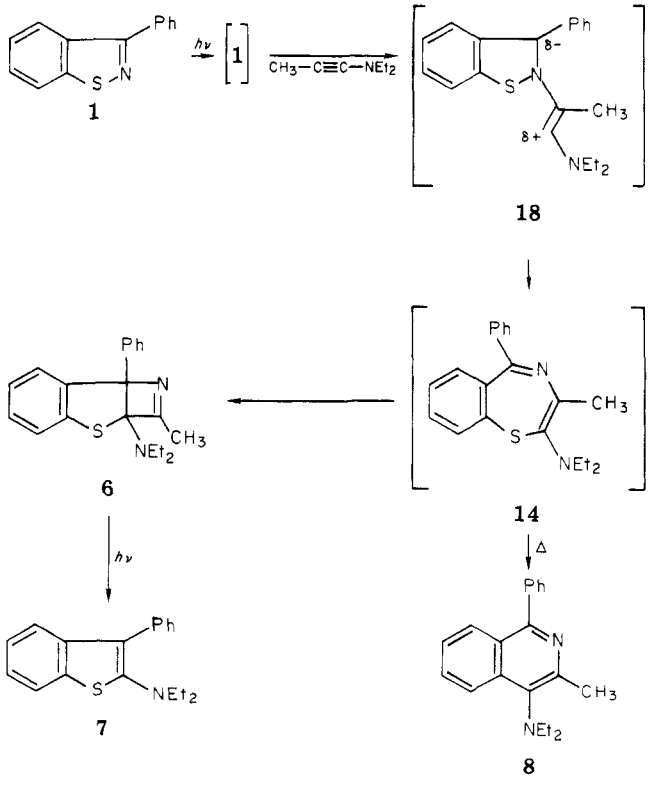
(13) Fries, K.; Eishold, D.; Vahlberg, B. *Justus Liebigs Ann. Chem.* **1927**, *454*, 264.

(14) Rao, D. S.; Tilak, B. D. *J. Sci. Ind. Res., Sect. B* **1959**, *18*, 77.

Scheme IV



Scheme V



65), 210 (100); ^{1}H NMR δ 6.85–7.5 (m, 9 H), 4.66 (s, 1 H), 4.16 (q, 2 H, J = 7.1 Hz), 2.21 (br s, 2 H), 1.20 (t, 3 H, J = 7.1 Hz); ^{13}C NMR δ 169.41, 145.88, 144.35, 138.79, 128.75, 128.10, 127.54, 126.87, 125.51, 125.19, 122.55, 71.76 (s), 63.37 (d), 61.32 (t), 14.05 (q). Anal. Calcd for $C_{17}H_{17}NO_2S$: C, 68.20; H, 5.73; N, 4.68; S, 10.71. Found: C, 68.22; H, 5.66; N, 4.64; S, 10.71.

5-Phenyl-3,4-benzo-2,6-thiazabicyclo[3.2.0]hept-3-en-7-one (10a, X = H): ~2% yield; mp 202–203 °C (EtOH); IR (mineral oil) 3190, 1725 cm^{-1}; UV (λ_{max} nm (ϵ)) 250 (9020), 290 (950), 300 (790); mass spectrum, m/e 253 (M^+), 210 (100); ^{1}H NMR δ 6.98–7.5 (m, 9 H), 4.73 (s, 1 H). Anal. Calcd for $C_{15}H_{11}NOS$: N, 5.53; S, 12.66. Found: N, 5.53; S, 12.55.

Irradiation of 3-Phenyl-1,2-benzisothiazole (1, X = H) in the Presence of 1-Ethoxypropyne (2b). A 0.29 M solution of 3-phenyl-1,2-benzisothiazole (1, X = H) in 1-ethoxypropyne (**2b**) was degassed by several freeze–thaw cycles and irradiated in a sealed Pyrex tube at 15 °C with a medium-pressure mercury lamp for 108 h. Excess ethoxypropyne was distilled under diminished pressure and the residue chromatographed on a silica gel column using hexane–ether as the eluent. Besides 21% of the unreacted starting material the following compounds were isolated:

2-Methyl-3-phenylbenzo[*b*]thiophene (4b, X = H): 7% yield. It appears in the first fractions and it was identical with a known sample[5] in all respects.

3-Ethoxy-4-methyl-1-phenylisoquinoline (5b, X = H): 3.6% yield; mp 70–71 °C (EtOH); mass spectrum, m/e 263 (M^+, 83), 248 (M – 15, 100), 235 (M – 28, 47), 234 (M – 29, 53), 207 (M – 56, 53), 206 (M – 57, 77); ^{1}H NMR δ 7.16–8.03 (m, 9 H), 2.54 (s, 3 H), 4.55 (q, 2 H, J = 7 Hz), 1.43 (t, 3 H). Anal. Calcd for $C_{18}H_{17}NO$: C, 82.10; H, 6.51; N, 5.32. Found: C, 82.03; H, 6.46; N, 5.29.

7-Ethoxy-1-methyl-5-phenyl-3,4-benzo-2,6-thiazabicyclo-[3.2.0]hepta-3,6-diene (3b, X = H): 67.5% yield; mp 101–102 °C (EtOH); IR (mineral oil) 1620 cm^{-1}; UV (λ_{max} nm (ϵ)) 249 (9440), 290 (1475), 299 (1280); mass spectrum, m/e 295 (M^+, 25), 224 (M – 71, M – $NCOC_2H_5$, 100); ^{1}H NMR δ 6.97–7.34 (9 H, Ar), 4.34 (dq, 2 H), 1.37 (t, 3 H, J = 7 Hz); ^{13}C NMR δ 173.67, 142.14, 141.46, 138.96, 129.15, 128.09, 127.74, 127.44, 124.91, 122.41, 80.38, 63.92, 63.04, 18.02, 14.12. Anal. Calcd for $C_{18}H_{17}NOS$: C, 73.19; H, 5.80; N, 4.74; S, 10.86. Found: C, 73.04; H, 5.84; N, 4.80; S, 10.88.

Irradiation of 5-Chloro-3-phenyl-1,2-benzisothiazole (1, X = Cl) in the Presence of 1-Ethoxypropyne (2b). A degassed solution of 220 mg of 1 (X = Cl) in 15 mL of **2b** was irradiated in a sealed Pyrex tube with filtered light (313 nm; 0.2 g of $K_2Cr_2O_4$ in 1 L of 0.1% NaOH solution) for 300 h at 5 °C. Unreacted ethoxypropyne was distilled off on a high vacuum line and the residue chromatographed on a silica gel column eluting with hexane–ether solution. Increasing the polarity of the eluent gave the following compounds as well as 18% of unreacted starting material:

5-Chloro-2-methyl-3-phenylbenzo[*b*]thiophene (4b, X = Cl): 13% yield; mp 53–55 °C (EtOH); IR (mineral oil) 1580 cm^{-1}; UV (λ_{max} nm (ϵ)) 239 (39 800), 262 (9560), 298 (4200), 308 (3940); mass spectrum, m/e 224 (M^+, 100), 147 (M – 77, 45); ^{1}H NMR δ 7.1–7.7 (8 H, Ar), 2.45 (s, 3 H). Anal. Calcd for $C_{15}H_{11}ClS$: C, 69.62; H, 4.29; Cl, 13.70; S, 12.39. Found: C, 69.21; H, 4.35; Cl, 13.77; S, 12.45.

7-Chloro-3-ethoxy-4-methyl-1-phenylisoquinoline (5b, X = Cl): 8% yield; mp 80–81 °C (EtOH); IR (mineral oil) 1540 cm^{-1}; UV (λ_{max} nm (ϵ)) 239 (52 650), 279 (7660), 289 (9220), 299 (8400), 364 (9520); mass spectrum, m/e 297 (M^+, 83), 282 (M – 15, 100), 268 (M – 29, 49); ^{1}H NMR δ 7.1–8.0 (8 H, Ar), 2.51 (s, 3 H), 4.54 (q, 2 H, J = 7 Hz), 1.42 (t, 3 H, J = 7 Hz). Anal. Calcd for $C_{18}H_{16}NOCl$: C, 72.60; H, 5.42; N, 4.70; Cl, 11.91. Found: C, 72.61; H, 5.46; N, 4.62; Cl, 11.84.

7-Ethoxy-1-methyl-5-phenyl-3,4-(6-chlorobenzo)-2,6-thiazabicyclo[3.2.0]hepta-3,6-diene (3b, X = Cl): 61% yield; mp 120–121 °C (EtOH); IR (mineral oil) 1620 cm^{-1}; UV (λ_{max} nm (ϵ)) 256 (12 350), 300 (1850), 310 (16450); mass spectrum, m/e 329 (M^+), 258 (M – 71, base peak); ^{1}H NMR δ 6.9–7.4 (8 H, Ar), 4.3 (dq, 2 H, J = 7 Hz), 1.22 (s, 3 H), 1.38 (t, 3 H, J = 7 Hz); ^{13}C NMR δ 173.67, 143.31, 140.51, 138.23, 130.67, 129.38, 128.31, 128.06, 127.58, 123.37, 80.08, 64.70, 63.18, 17.97, 14.11. Anal. Calcd for $C_{18}H_{16}NOClS$: C, 65.54; H, 4.89; N, 4.25; Cl, 10.75; S, 9.72. Found: C, 65.65; H, 4.93; N, 4.24; Cl, 10:72; S, 9.65.

Reaction in the Dark. The reaction mixture of 1 (X = H; 25 mg) and **2b** was kept in a sealed tube in the dark under the same conditions as the irridation mixture. Similar experiments were performed with **2a**. GC analysis indicated no product formation.

Photolysis of 3b (X = H). Photolysis of the bicyclic product **3b** (X = H) was carried out in a Pyrex tube in benzene-d_6 to which an NMR tube was connected. The whole system was degassed by several freeze–thaw cycles and sealed. After 19 h of irradiaiton with a 450-W Hanovia medium-pressure mercury lamp the ir-

radiated mixture in the Pyrex tube was concentrated into the NMR tube by warming slightly the reaction mixture and cooling the receiver with liquid nitrogen. The NMR spectrum of the residue showed 2-methyl-3-phenylbenzo[*b*]thiophene (**4b**, X = H)[5] [δ (C_6D_6) 2.19 (s, 3 H)] and in the NMR spectrum of the distillate a quartet (δ 3.21) and triplet (δ 0.54) assigned to ethyl isocyanate.[10]

Hydrolysis of 3b (X = H). Compound **3b** (X = H; 50 mg) was treated with 5 mL of 3 N HCl and the suspension warmed to 60 °C and kept for 2 h at these conditions. After neutralization with Na_2CO_3 and extraction with ether the reaction mixture was purified on a TLC silica gel plate. The products were isolated and identified by spectroscopic data.

Ethyl 2,3-dihydro-3-amino-2-methyl-3-phenylbenzo[*b*]-thiophenyl-2-carboxylate (9b, X = H): 49% yield; mp 81–82 °C (EtOH); IR (mineral oil) 3340, 3275, 1725 cm^{-1}; UV (λ_{max} nm (ϵ)) 250 (4700), 284 (1960); mass spectrum, *m/e* 313 (M^+); ^1H NMR δ 6.90–7.40 (9 H, Ar), 4.18 (q, 2 H, *J* = 7.1 Hz), 2.22 (s, 2 H), 1.21 (t, 3 H, *J* = 7.1 Hz), 1.32 (s, 3 H). Anal. Calcd for $C_{18}H_{19}NO_2S$: C, 68.98; H, 6.11; N, 4.47; S, 10.23. Found: C, 68.95; H, 6.07; N, 4.48; S, 10.20.

1-Methyl-5-phenyl-3,4-benzo-2,6-thiazabicyclo[3.2.0]-hept-3-en-7-one (10b, X = H): 35% yield; mp 190–192 °C (EtOH); IR (mineral oil) 3205, 1765 cm^{-1}; mass spectrum, *m/e* 267 (M^+), 224 (M – 43, base peak); ^1H NMR δ 6.42–7.4 (9 H, Ar), 1.27 (s, 3 H).

Hydrolysis of 3b (X = Cl). Compound **3b** (X = Cl; 200 mg) was treated with 20 mL of 3 N HCl for 3 h at 60–80 °C. The reaction mixture, with some sticky material, was neutralized with Na_2CO_3 and extracted with ether. Ether was evaporated and the residue chromatographed on TLC eluting four times with 10% ether in hexane. Two products were isolated.

Ethyl 3-amino-5-chloro-2-methyl-3-phenyl-2,3-dihydro-benzo[*b*]thiophenyl-2-carboxylate (9b, X = Cl): 57% yield; mp 82–83 °C (EtOH); IR (mineral oil) 3390, 3320, 1720 cm^{-1}; UV (λ_{max} nm (ϵ)) 258 (10 310), 296 (4970); mass spectrum, *m/e* 347 (M^+), 274 (M –73, base peak); ^1H NMR δ 6.90–7.40 (8 H, Ar), 4.18 (q, 2 H, *J* = 7.1 Hz), 2.28 (s, 2 H), 1.31 (s, 3 H), 1.22 (t, 3 H, *J* = 7.1 Hz); ^{13}C NMR δ 172.01, 149.66, 144.25, 139.59, 131.34, 128.53, 128.10, 127.81, 125.30, 123.54, 73.84, 70.14, 61.66, 13.90. Anal. Calcd for $C_{18}H_{18}NO_2ClS$: C, 62.15; H, 5.22; N, 4.03; Cl, 10.19; S, 9.22. Found: C, 62.23; H, 5.21; N, 3.95; Cl, 10.23; S, 9.25.

1-Methyl-3,4-(6-chlorobenzo)-2,6-thiazabicyclo[3.2.0]-hept-3-en-7-one (10b, X = Cl): 29% yield; mp 216–217 °C (EtOH); IR (mineral oil) 3150, 1760 cm^{-1}; mass spectrum, *m/e* 301 (M^+), 258 (M – 43, base peak); ^1H NMR δ 6.85–7.40 (8 H, Ar), 1.25 (s, 3 H); ^{13}C NMR δ 169.21, 142.26, 141.09, 136.45, 130.64, 130.14, 128.78, 127.81, 127.03, 125.31, 123.72, 71.71, 72.99, 17.62. Anal. Calcd for $C_{16}H_{12}NOClS$: C, 63.67; H, 4.01; N, 4.64; Cl, 11.75; S, 10.63. Found: C, 63.53; H, 4.16; N, 4.75; Cl, 11.63; S, 10.65.

Thermal Decomposition of 3b (X = H). A small quantity of **3b** (X = H) in an NMR tube was heated at 210 °C for 2 h. Chloroform-*d* was added, and **4b** and **5b** were detected in the NMR spectrum.

Irradiation of 3-Phenyl-1,2-benzisothiazole (1, X = H) in the Presence of (Diethylamino)propyne (2c). A solution of 1 (X = H; 260 mg, 1.23 mmol) and 690 mg (6.22 mmol) of **2c** in 50 mL of benzene (dried over sodium) was purged with nitrogen and irradiated in the Rayonet reactor (λ_{max} 300 nm) at 18 °C for 43 h. The solvent was evaporated on a rotor evaporator and unreacted **2c** on a high vacuum line at room temperature. The dark brown residue was chromatographed on a silica gel column eluting with hexane–ether solution. Starting material (37%) was recovered and the following compounds were isolated:

2-(Diethylamino)-3-phenylbenzo[*b*]thiophene (7, X = H;[15] 5% yield) was identical with the known compound.

4-(Diethylamino)-3-methyl-1-phenylisoquinoline (8, X = H): 30% yield; mp 56.5–57 °C (EtOH); IR (mineral oil) 1560 cm^{-1}; UV (λ_{max} nm (ϵ)) 331 (6220), 289 (7260), 280 (6640), 230 (23 230); mass spectrum, *m/e* 290 (M^+), 275 (M – 15, base peak); ^1H NMR δ 7.24–7.35 (9 H, Ar), 2.71 (s, 3 H), 3.32 (q, 4 H, *J* = 7.0 Hz), 1.07 (t, 6 H, *J* = 7.0 Hz); ^{13}C NMR δ 157.00, 150.14, 139.97, 138.24, 137.21, 129.96, 129.10, 128.17, 127.68, 126.33, 125.56, 124.15, 48.29, 22.24, 14.82. Anal. Calcd for $C_{20}H_{22}N_2$: C, 82.71; H, 7.64; N, 9.65. Found: C, 82.79; H, 7.54; N, 9.68.

1-(Diethylamino)-7-methyl-5-phenyl-3,4-benzo-2,6-thiazabicyclo[3.2.0]hepta-3,6-diene (6): 26% yield; mp 86–87 °C (EtOH); IR (neat) 1590 cm^{-1}; UV (λ_{max} nm (ϵ)) 244 (13 300), 290 (3430), 302 (2820); mass spectrum, *m/e* 322 (M^+), 290 (M – 32, 50), 281 (M – 41, 43), 275 (M – 47, 100), 235 (M – 87, 59), 207 (M – 115, 54); ^1H NMR δ 7.1–7.35 (9 H, Ar), 2.51 (dq, 4 H, *J* = 7.1 Hz), 2.34 (s, 3 H), 0.56 (t, 6 H, *J* = 7.1 Hz); ^{13}C NMR δ 182.72, 143.29, 137.55, 136.46, 129.49, 128.90, 127.82, 127.72, 127.39, 124.05, 123.39, 95.38, 88.42, 43.19, 17.60, 12.37. Anal. Calcd for $C_{20}H_{22}N_2S$: C, 74.49; H, 6.88; N, 8.69; S, 9.94. Found: C, 74.09; H, 6.86; N, 8.46; S, 9.95.

Hydrolysis of 6 (X = H). Compound **6** (X = H; 260 mg) was treated with 20 mL of 3 N HCl for 2 h at room temperature. The reaction mixture was neutralized with Na_2CO_3 and extracted with ether. Ether was evaporated and the residue chromatographed on silica gel TLC eluting two times with 10% ether in hexane. 2-Formyl-2-methyl-4-phenyl-2*H*-1,3-benzothiazine (**12**) was isolated in 51% yield as an oil: IR (neat) 1725 cm^{-1}; mass spectrum, *m/e* 267 (M^+), 252, 238 (base peak), 197, 165; ^1H NMR δ 9.32 (s, 1 H), 7.20–7.45 (9 H, Ar), 1.85 (s, 3 H).

Thermal Decomposition of 6 (X = H). A small quantity of the isolated compound **6** (X = H) was heated at 130–160 °C for 2 h. The NMR spectrum of the reaction mixture showed almost complete conversion to isoquinoline **8**.

Irradiation of 5-Chloro-3-phenyl-1,2-benzisothiazole (1, X = Cl) in the Presence of 1-(Diethylamino)propyne (2c). A solution of 1 (X = Cl; 440 mg, 1.81 mmol) and 728 mg (7.05 mmol) of **2c** in 90 mL of benzene (dried over sodium) was irradiated and worked up with the same conditions as was used for the reaction mixture of 1 (X = H). The following compounds were isolated, and 62% of starting material was recovered.

5-Chloro-2-(diethylamino)-3-phenylbenzothiophene (7, X = Cl): 2% yield; mp 55–57 °C (EtOH); IR (mineral oil) 1550 cm^{-1}; UV (λ_{max} nm (ϵ)) 223 (23 460), 240 (27 520), 258 (14 660), 312 (12 740); mass spectrum, *m/e* 315 (M^+, base peak), 300; ^1H NMR δ 7.08–7.61 (m, 8 H), 3.02 (q, 4 H, *J* = 7.0 Hz), 1.01 (t, 6 H, *J* = 7.0 Hz). Anal. Calcd for $C_{18}H_{18}NClS$: C, 68.44; H, 5.74; N, 4.44. Found: C, 68.38; H, 5.89; N, 4.21.

7-Chloro-4-(diethylamino)-3-methylisoquinoline (8, X = Cl): 23% yield; mp 106–107 °C; IR (mineral oil) 1560 cm^{-1}; UV (λ_{max} nm (ϵ)) 230 (40 600), 282 (6220), 294 (6900), 342 (5410); mass spectrum, *m/e* 324 (M^+), 309 (M – 15, base peak); ^1H NMR δ 7.32–8.32 (m, 8 H), 2.71 (s, 3 H), 3.26 (q, 4 H, *J* = 7.0 Hz), 1.05 (t, 6 H, *J* = 7.0 Hz); ^{13}C NMR δ 156.14, 150.58, 139.40, 137.26, 136.84, 131.65, 130.12, 129.89, 128.47, 126.91, 126.31, 48.28, 22.26, 14.75. Anal. Calcd for $C_{20}H_{21}N_2Cl$: C, 73.94; H, 6.52; N, 8.63. Found: C, 74.07; H, 6.47; N, 8.58.

1-(Diethylamino)-7-methyl-3,4-(6-chlorobenzo)-2,6-thiazabicyclo[3.2.0]hepta-3,6-diene (6, X = Cl): 12% yield; mp 97–99 °C (EtOH); IR (mineral oil) 1610 cm^{-1}; UV (λ_{max} nm (ϵ)) 258 (13 000), 302 (2670), 314 (2170); mass spectrum, *m/e* 356 (M^+, 11), 324 (M – 32, 52), 315 (M – 41, 23), 309 (M – 47, 100), 269 (M – 87, 77), 241 (M – 115, 59); ^1H NMR δ 7.25–7.47 (m, 8 H, Ar), 2.34 (s, 3 H), 2.50 (m, 4 H), 0.55 (t, 6 H, *J* = 7.1 Hz); ^{13}C NMR δ 183.02, 141.84, 138.25, 136.91, 129.71, 129.34, 129.10, 128.06, 127.80, 127.63, 124.45, 96.32, 88.23, 43.16, 17.66, 12.34. Anal. Calcd for $C_{20}H_{21}N_2ClS$: C, 67.30; H, 5.93. Found: C, 67.19; H, 6.27.

Acknowledgment. This work was supported by the National Institutes of Health (NS 14883) and we greatfully acknowledge this support. We also appreciate many useful discussions with Prof. J. C. Dalton.

Registry No. 1 (X = H), 70132-76-2; 1 (X = Cl), 78134-69-7; **2a**, 927-80-0; **2b**, 14273-06-4; **2c**, 4231-35-0; **3a** (X = H), 84538-73-8; **3b** (X = H), 84538-74-9; **3b** (X = Cl), 84538-75-0; **4a** (X = H), 14315-12-9; **4b** (X = H), 57642-62-3; **4b** (X = Cl), 84538-76-1; **5a** (X = H), 84538-77-2; **5b** (X = H), 84538-78-3; **5b** (X = Cl), 84538-79-4; **6** (X = H), 84538-80-7; **6** (X = Cl), 84538-81-8; **7** (X = H), 38210-55-8; **7** (X = Cl), 84538-82-9; **8** (X = H), 84538-83-0; **8** (X = Cl), 84538-84-1; **9a** (X = H), 84538-85-2; **9b** (X = H), 84538-86-3; **9b** (X = Cl), 84538-87-4; **10a** (X = H), 84538-88-5; **10b** (X = H), 84538-89-6; **10b** (X = Cl), 84538-90-9; **12**, 84538-91-0.

(15) Chippendale, K. E.; Iddon, B.; Suschitzky, H. *J. Chem. Soc. Perkin Trans. 1* **1972**, 2023.