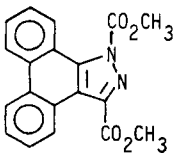
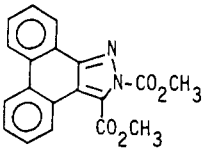
(8-1) or its tautomer, dimethyl 3*H*-phenanthro[9,10-*c*]-



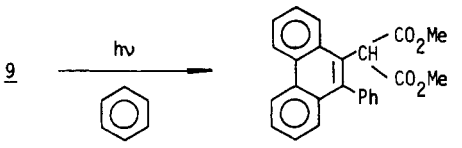
8-1



8-2

pyrazole-2,3-dicarboxylate (8-2), for **8** and as dimethyl 3*H*-phenanthro[9,10-*c*]pyrazole-3,3-dicarboxylate for **9**. The final structural assignment of **8** cannot yet be made.

It was reported[8] that benzocyclopropenes (**12**) are formed when the corresponding polyphenyl-substituted spiro-3*H*-pyrazoles (**13**) are photolyzed in benzene by using a high-pressure mercury lamp. The reaction pathway shown in Scheme III was proposed, though **14** was not isolated. Therefore, we carried out the photolysis of **9** in benzene using a high-pressure mercury lamp and obtained the phenanthrene derivative **15** in 18% yield with no



15

formation of the expected phenanthrocyclopropene. The pathway of the formation of the products is shown in Scheme IV. Cyclopropene is formed in the pyrolysis in benzene (path a) while the Van Alphen–Hüttel rearrangment followed by the migration of an ester phenyl group is the favorable reaction pathway in the pyrolysis in polar solvents (path b), affording phenanthropyrazoles **8** and **9**. Though the pathway of the formation of **3** is not known, **3** might be formed via **8** and **9** or directly from the intermediate A.

Experimental Section

Melting points were determined on a Yanagimoto micro-melting-point apparatus and were uncorrected. IR, NMR, and mass spectra were obtained on a Nippon Bunko IR-A spectrometer, Hitachi R-40 and Nippon Denshi JEOL FT-100 spectrometers, and a Nippon Denshi JMS-01SG-2 spectrometer, respectively. IR spectra were taken of KBr disks, and mass spectra were obtained at 75 eV.

Pyrolysis of 1. A solution of **1a** (500 mg) in a solvent (5 mL) was refluxed, and the solvent was evaporated in vacuo. The residue was triturated with benzene (2 mL) to afford the 2:1 complex of **8** and benzene, which on recrystallization from benzene gave colorless prisms: mp 155–156 °C dec; IR 1735 (C=O) cm^{-1}; ^1H NMR (CD_3CN) δ 3.96 (s, 3 H), 3.98 (s, 3 H), 7.35 (s, 3 H), 7.5–7.8 (m, 4 H), 8.4–8.6 (m, 4 H). Anal. Calcd for ($C_{19}H_{14}N_2O_4 \cdot 1/2C_6H_6$): C, 70.77; H, 4.59; N, 7.50. Found: C, 70.74; H, 4.58; N, 7.45. Recrystallization of the complex from methanol gave **8**: mp 156–157 °C; colorless needles; IR 1725 (C=O) cm^{-1}. Anal. Calcd for $C_{19}H_{14}N_2O_4$: C, 68.25; H, 4.22; N, 8.38. Found: C, 68.40; H, 4.37; N, 8.24. The benzene filtrate was chromatographed on silica gel (Wako gel, C-300). From the fractions with benzene and chloroform as eluents were isolated compounds **4**[5] and **7** and compounds **9** and **3**[4] were isolated, respectively. Compound **7** was recrystallized from hexane to give yellow prisms: mp 134–135 °C; IR 1740, 1700 cm^{-1} (C=O); ^1H NMR ($CDCl_3$) δ 3.76, 3.99 (each s, 3 H), 5.33 (s, 1 H), 7.2–7.9 (m, 6 H). Anal. Calcd for $C_{19}H_{14}O_4$: C, 74.45; H, 4.60. Found: C, 74.25; H, 4.59. Recrystallization of **9** from methanol afforded pale yellow needles: mp 168–169 °C; IR (C=O) 1760, 1740 cm^{-1}. Anal. Calcd for $C_{19}H_{14}N_2O_4$: C, 68.25; H, 4.22; N, 8.38. Found: C, 68.07; H, 4.30; N, 8.44.

(8) Dürr, H.; Schrader, L. *Chem. Ber.* **1970**, *103*, 1334.

Thermolysis of 4. A solution of **4** (100 mg) in toluene (3 mL) was refluxed for 4 h. The solvent was evaporated in vacuo, and the residue was chromatographed on silica gel (Wako gel, C-300) with benzene as an eluent to give 48 mg (48%) of **7**.

Hydrolysis of 8. A solution of **8** (100 mg) in a mixture of concentrated hydrochloric acid (1 mL) and ethanol (4 mL) was heated at reflux for 1 h. The reaction mixture was poured into water (100 mL) and extracted with chloroform (2 × 20 mL). The extract was dried over sodium sulfate, and the solvent was evaporated in vacuo to leave the residue which was triturated with ether to give 12 mg (15%) of **3**. The ether filtrate was evaporated, and the residue was recrystallized from methanol to give 19 mg (19%) of unchanged **8**.

Hydrolysis of 9. A solution of **9** (50 mg) in a mixture of concentrated hydrochloric acid (1 mL) and ethanol (4 mL) was heated at reflux for 1 h. The solvent was evaporated in vacuo, and the residue was washed with methanol to give 22 mg (54%) of **3**.

Photolysis of 9. A solution of **9** (100 mg) in benzene (50 mL) was irradiated at room temperature with Pyrex-filtered light from a 100-W, high-pressure mercury lamp for 1 h. The solvent was evaporated in vacuo, and the residue was column chromatographed on silica gel with benzene as an eluent to give white solids, which on recrystallization from ethanol gave 18 mg (16%) of dimethyl (10-phenylphenanthren-9-yl)malonate (**15**): mp 142–144 °C; colorless prisms; IR (C=O) 1740, 1725 cm^{-1}; ^1H NMR ($CDCl_3$) δ 3.63 (s, 6 H), 5.12 (s, 1 H), 7.2–7.7 (m, 10 H), 8.0–8.2 (m, 1 H), 8.65–8.85 (m, 2 H); mass spectrum, *m/e* (relative intensity) 384 (M^+, 57), 266 (26), 265 ($M^+ - CH_3CO_2H - CH_3CO_2$, 100). Anal. Calcd for $C_{25}H_{20}O_4$: C, 78.11; H, 5.24. Found: C, 78.01; H, 5.33.

Registry No. **1**, 53313-99-8; **3**, 76600-21-0; **4**, 39500-48-6; **7**, 76600-24-3; **8**, 76600-23-2; **9**, 76600-25-4; **15**, 76600-26-5.

Supplementary Material Available: Spectral data on phenanthropyrazoles **8** and **9** (Table II, ^1H and ^{13}C NMR; Table III, mass spectra) (2 pages). Ordering information is given on any current masterhead page.

Selected Reactions of 1,8-Divinylnaphthalene

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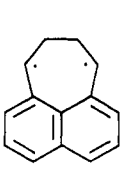
Received October 24, 1980

In connection with our work on the chemistry of the 1,8-naphthoquinodimethane biradical (**1**),[1] it was desirable



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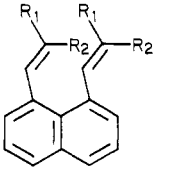


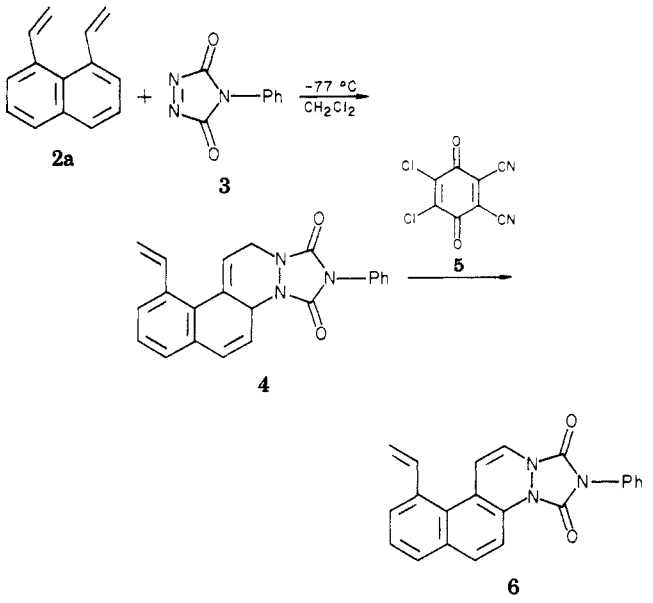
2a, $R_1 = R_2 = H$
b, $R_1 = D$; $R_2 = H$
c, $R_1 = H$; $R_2 = D$

to find a reaction of 1,8-divinylnaphthalene (**2a**) that brought the two vinyl groups together stereospecifically. For accomplishment of this end, it became necessary to look at a series of reactions of **2a** which a priori could bring the vinyl groups together. Once such a reaction was found, it was hoped that its stereospecificity could be ascertained by repeating the reaction on deuterium-labeled **2b** or **2c**,

(1) (a) Gisin, M.; Rommel, E.; Wirz, J.; Burnett, M. N.; Pagni, R. M. *J. Am. Chem. Soc.* **1979**, *101*, 2216. (b) Watson, C. R., Jr.; Pagni, R. M.; Dodd, J. R.; Bloor, J. E. *Ibid.* **1978**, *98*, 2551 and references cited therein.

0022-3263/81/1946-1931$01.25/0

Scheme I

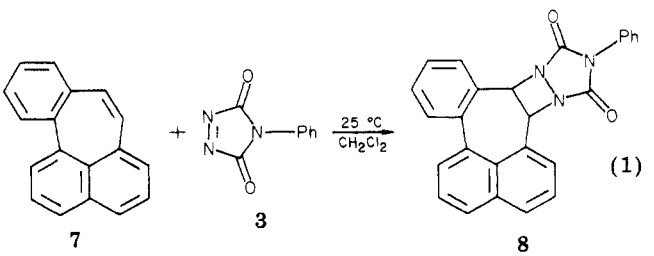


which, of course, would also have to be synthesized. Although our overall objectives were not accomplished, we did find a few interesting chemical transformations which we describe at this time.

Results and Discussion

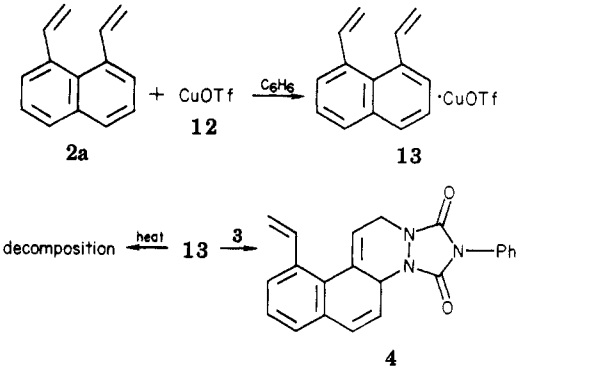
When a solution of **2a** in methylene chloride was treated with 1 equiv of the highly reactive *N*-phenyltriazolinedione (**3**) at −77 °C, an instantaneous reaction occurred (Scheme I). The structure of the 1:1 adduct **4** (mass spectrometry) could not be deduced unambiguously from its complex NMR spectrum. Because 1-vinylnaphthalene is known to undergo Diels–Alder reactions by using a double bond from the naphthalene ring as part of the diene unit,[2] **4** seemed a likely structure for the 1:1 adduct in this case. This was confirmed when **4** was dehydrogenated with 2,3-dichloro-5,6-dicyanobenzoquinone (**5**). The product of this reaction was unambiguously identified as the benzo[*f*]cinnoline derivative **6** from its spectral properties. When **2a** was treated with the less reactive diethyl azodicarboxylate in refluxing benzene, an adduct similar in structure to **4** was produced. It is obvious from these reactions that the vinyl groups of **2a** are not properly oriented for a [2 + 2 + 2] cycloaddition to occur, or, if they are, the Diels–Alder reaction is more facile.

That orientation of the vinyl group(s) is a critical feature of the cycloaddition reactions of 1-vinylnaphthalenes can be seen in the reaction of **7**, "a 1-vinylnaphthalene derivative", with **3** (eq 1). Although not fully characterized, spectral properties indicate that the product is the [2 + 2] cycloadduct **8**. Here, of course, a Diels–Alder reaction is geometrically impossible.

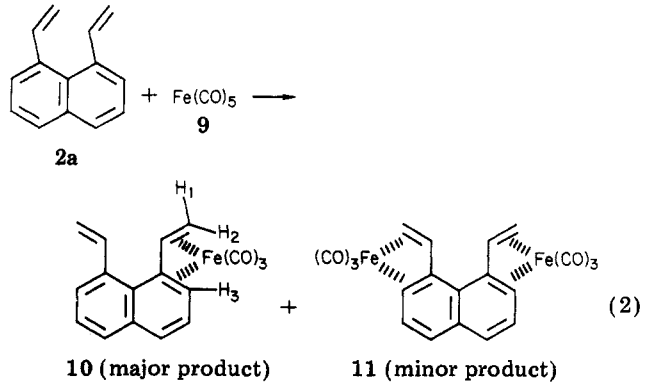


(1)

Scheme II



The reaction of **2a** with $Fe(CO)_5$ (**9**) under photolytic conditions was also investigated (eq 2). Under these

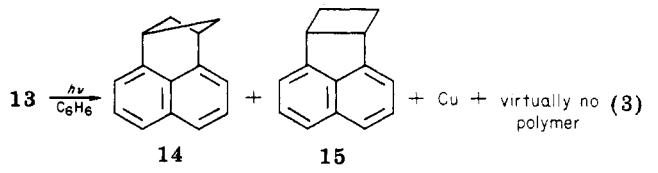


(2)

conditions the iron tricarbonyl adduct **10** and the bis(iron tricarbonyl) adduct **11** were synthesized; no carbon monoxide inserted or vinyl–vinyl-coupled products were detected in this reaction. These results are not totally surprising because 1-vinylnaphthalene is known to undergo a similar reaction with $Fe(CO)_5$ (**9**).[3]

We discovered one other interesting set of transformations. When **2a** is treated with copper trifluoromethanesulfonate (copper triflate, CuOTf, **12**), a 1:1 complex (**13**) is produced (Scheme II) in which both vinyl groups appear to be complexed to the Cu(I) ion. As evidenced by the melting point with decomposition for this material and the inability to obtain a mass spectrum of it, thermolysis of the complex **13** resulted in its decomposition before intramolecular [2 + 2] cycloaddition of the vinyl groups could occur. Treating this complex (**13**) with *N*-phenyltriazolinedione (**3**) surprisingly yielded the adduct **4** which was also formed in the reaction of divinylnaphthalene **2a** itself with **4**. From this it is not clear if *N*-phenyltriazolinedione (**3**) reacts directly with the complex or with a small equilibrium concentration of uncomplexed **2a**.

Photolysis of **13** in benzene yielded results remarkably different from those for photolysis of **2a** in any solvent. (See the paragraph at the end of the paper about supplementary material!) First of all, the cyclobutane **15** became the major photoproduct and the cyclobutane **14** became the minor product, whereas photolysis of **2a** in benzene yielded predominantly **14**.[4] Second, virtually no



(3)

(2) (a) Nagata, J.; Shirota, Y.; Nogami, T.; Mikawa, H. *Chem Lett.* **1973**, 1087. (b) Matsumoto, M.; Kondo, K. *Tetrahedron Lett.* **1975**, 3935.

(3) Manuel, T. A. *Inorg Chem.* **1964**, *3*, 1794.

polymer was formed in this reaction, unlike all the other photolyses of **2a** observed in these laboratories. Third, copper metal was plated out onto the photolysis vessel. This last result is the first example where the photolysis of an alkene–copper triflate complex yielded copper metal.[5] This undoubtedly can be attributed in some way to the presence of the naphthalene ring in **13**.[6]

Experimental Section

General Techniques. Nuclear magnetic resonance (NMR) spectra were recorded on Varian A-60 and HA-100 spectrometers using tetramethylsilane as an internal standard. Infrared (IR) spectra were obtained on a Perkin-Elmer IR-5A spectrometer. Mass spectra were recorded on a Perkin-Elmer RMU-6E spectrometer with ionization energies of 20 and 70 eV, unless otherwise stated.

All photolysis reactions were performed with degassed solutions. Degassing of solutions was accomplished by the freeze–pump–thaw method or by bubbling deoxygenated nitrogen through a solution contained in a Hanovia immersion apparatus.

All reactions with air-sensitive materials were carried out under an inert atmosphere of dry nitrogen. Air-sensitive compounds were stored in vacuum-sealed ampules under an argon atmosphere.

Reaction products were purified by column chromatography with alumina or silica gel as the adsorbent. Further purification was accomplished by recrystallization. Melting points were obtained on a Thomas-Hoover capillary-tube melting point apparatus and are uncorrected. Elemental analysis and molecular weight determinations were performed by Galbraith Laboratories.

1,8-Divinylnaphthalene. This was prepared according to the procedure of Mitchell and Sondheimer.[7]

Reaction of 1,8-Divinylnaphthalene (2a) with *N*-Phenyltriazolinedione (3). A solution of 0.350 g (2 mmol) of *N*-phenyltriazolinedione (PTAD)[8] in 75 mL of methylene chloride was added dropwise over a period of 1 h to a methylene chloride solution of 0.360 g (2 mmol) of 1,8-divinylnaphthalene (**2a**) cooled to dry ice/acetone temperature. The red color of the PTAD disappeared immediately upon addition to **2a**. The solvent was removed in vacuo, and recrystallization from a 1:1 mixture of pentane–methylene chloride afforded 0.547 g of adduct **4**: mp 155–161 °C; NMR ($CDCl_3$) δ 6.60–7.75 (m, 11 H, 8 aromatic, 2 vinyl, 1 methine), 5.2–6.1 (m, 4 H, 4 β-vinyl), 4.3 (t, 2 H, 2 methylene); IR ($CHCl_3$) 1749 cm^{-1} (C=O), 1675 (C=C); mass spectrum, m/e 355 (M^+), 354 (M – H), 200, 180 (M – PTAD), 179, 178.

Anal. Calcd for $C_{22}H_{17}N_3O_2$: C, 74.56; H, 4.55; N, 11.73. Found: C, 74.11; H, 4.80; N, 11.73.

Dehydrogenation of Adduct 4. After refluxing a solution of adduct **4** (0.625 g, 1.8 mmol) and 2,3-dichloro-5,6-dicyanobenzoquinone (**5**) in 50 mL of benzene for 3 h, the solution was cooled, filtered, and washed with 3 N potassium hydroxide and water. The dried extract was evaporated under reduced pressure. Crystallization from chloroform afforded 0.450 g of **6**: mp 190–192 °C; NMR ($CDCl_3$) δ 6.65–8.4 (m, 13 H, 12 aromatic, 1 vinyl), 5.2–5.8 (m, 2 H, 2 β-vinyl); IR ($CHCl_3$) 1750 (C=O), 1675 (C=C) cm^{-1}; mass spectrum, m/e 353 (M^+), 352 (M – H). The product was not characterized further.

Reaction of 1,8-Divinylnaphthalene (2a) with Diethyl Azodicarboxylate. A solution of **2a** (0.180 g, 1 mmol) and diethyl azodicarboxylate (0.174 g, 1 mmol) in 25 mL of benzene was refluxed under nitrogen for 24 h. The solvent was removed in vacuo, and the resulting viscous oil was chromatographed on silica gel. Elution with 1 L of 40% chloroform–ligroin afforded a viscous oil: NMR ($CDCl_3$) δ 6.8–7.8 (m, 5 H, 3 aromatic, 2 α-vinyl), 5.00–6.4 (m, 5 H, 4 β-vinyl, 1 methylene), 1.25 (t, 6 H, methyl); IR ($CHCl_3$) 1750 cm^{-1} (C=O). This material was not characterized further.

Synthesis of the Iron Tricarbonyl Complexes 10 and 11. Compound **2a** (0.270 g, 1.5 mmol) and 0.295 g (1.5 mmol) of iron pentacarbonyl (**9**) were dissolved in 30 mL of cyclohexane, and the mixture was placed in a photolysis tube, degassed by the freeze–pump–thaw method, and sealed in vacuo. The solution was then photolyzed at a wavelength of 350 nm for 19 h. The sealed tube was broken, the contents were filtered, and the solvent was removed. The residue was chromatographed on silica gel. Elution with 1 L of ligroin and recrystallization from chloroform afforded 0.250 g (47%) of **10**: orange needles; mp 139 °C; NMR ($CDCl_3$) δ 6.80–8.0 (m, 7 H, 5 aromatic, 2 α-vinyl), 5.2–5.95 (dd, 2 H, 2 β-vinyl), 2.35–2.45 (d, J = 4 Hz, 1 H, H_3), 1.8–2.0 (dd, J = 7, 2 Hz, 1 H, H_1), 0.20–0.43 (dd, J = 8, 2 Hz, 1 H, H_2); IR ($CHCl_3$) 2048, 1950, 1800, 1670, 1500 cm^{-1}; mass spectrum, m/e 320 (M^+), 292, 264, 236.

Anal. Calcd for $C_{17}H_{12}FeO_3$: C, 63.77, H, 3.70; Fe, 17.44. Found: C, 63.50; H, 3.78; Fe, 17.25.

Elution with an additional 750 mL of ligroin and recrystallization from $CHCl_3$ gave 80 mg (12%) of **11**: orange needles; mp 120 °C; NMR ($CDCl_3$) δ 6.8–7.2 (m, 6 H, 4 aromatic, 2 α-vinyl), 2.75–3.0 (d, J = 5 Hz, 2 H, H_3), 1.85–2.10 (dd, J = 7, 2 Hz, 2 H, H_1), 0.5 (dd, J = 9, 2 Hz, 2 H, H_2); IR ($CHCl_3$) 2025, 1955, 1250 cm^{-1}; mass spectrum, m/e 460 (M^+), 432 (M – CO), 405, 347, 320.

Reaction of 1,8-Divinylnaphthalene 2a with Copper Triflate (12). Compound **2a** (100 mg) was dissolved in 10 mL of 2-butanone and deoxygenated by bubbling dry nitrogen through the solution for a period of 5 min. A sealed vial of compound **12**[5a] (110 mg) was opened under an inverted funnel with a vigorous stream of nitrogen, and the contents were poured into the solution. The solution was stirred for an additional 15 min under a nitrogen atmosphere, and then pentane was added until the solution turned partially cloudy. The contents of the flask were placed in a refrigerator until precipitation was complete. The resulting white crystals upon recrystallization from chloroform afforded 100 mg of **13**: mp 155 °C dec; NMR (CD_3CN) δ 7.0–7.6 (m, 8 H, 6 aromatic, 2 α-vinyl), 5.1 (m, 4 H, β-vinyl); IR (KBr) 1528, 1523 cm^{-1}; mol wt (by osmometry, acetone) 300 (calcd 392).

Anal. Calcd for $C_{15}H_{12}CuF_3O_3S$: Cu, 16.17. Found: Cu, 15.42.

Reaction of the 1,8-Divinylnaphthalene–Copper Triflate Complex with *N*-Phenyltriazolinedione (3). To a solution of 30 mg of **13** in 2-butanone at −77 °C was added dropwise a solution of 15 mg of *N*-phenyltriazolinedione (**3**) in the solvent. After removal of most of the solvent, the NMR showed in addition to solvent peaks those due to adduct **4**.

Reaction of 4,5-Benzocyclohepta[1,2,3-*de*]naphthalene (7) with *N*-Phenyltriazolinedione (3). To a solution of 100 mg (0.44 mmol) of 4,5-benzocyclohepta[1,2,3-*de*]naphthalene (**7**)[9] in 40 mL of methylene chloride cooled to dry ice/acetone temperature was added dropwise 76.6 mg (0.44 mmol) of *N*-phenyltriazolinedione (**3**). The cooling bath was removed since the red color of the PTAD persisted. The red color disappeared at 30 °C. Removal of solvent in vacuo and recrystallization from methylene chloride gave **8**: mp 190–192 °C; NMR ($CDCl_3$) δ 6.7–8.0 (m, 15 H, aromatic), 5.2 (s, 2 H, benzylic); IR ($CHCl_3$) 1760 cm^{-1} (C=O); mass spectrum, m/e 228 (M – PTAD).

Acknowledgment. H.M.H. thanks the Egyptian government for support.

Registry No. 2a, 17935-66-9; **2b**, 76630-92-7; **3**, 4233-33-4; **4**, 76630-93-8; **6**, 76630-94-9; **7**, 198-73-2; **8**, 76630-95-0; **9**, 13463-40-6; **10**, 76631-36-2; **11**, 76631-37-3; **12**, 42152-44-3; **13**, 76631-38-4; **14**, 30736-77-7; **15**, 32624-91-2; **16a**, 18067-44-2; **16b**, 76630-96-1.

(4) Fleming, R. H.; Quina, F. H.; Hammond, G. S. *J. Am. Chem. Soc.* **1974**, *96*, 7738.

(5) (a) Salomon, R. G.; Kochi, J. K. *J. Am. Chem. Soc.* **1973**, *95*, 1889. (b) Salomon, R. G.; Kochi, J. K. *Tetrahedron Lett.* **1973**, 2529. (c) Salomon, R. G.; Kochi, J, K. *J. Am. Chem. Soc.* **1974**, *96*, 1137. (d) Salomon, R. G.; Folting, K.; Streib, W. E.; Kochi, J. K. *Ibid.* **1974**, *96*, 1145. (e) Salomon, R. G.; Salomon, M. F. *Ibid.* **1976**, *98*, 7454. (f) Salomon, R. G.; Sinha, A.; Salomon, M. F. *Ibid.* **1978**, *100*, 520. (g) Evers, J. T. M.; Mackor, A. *Tetrahedron Lett.* **1978**, 821. (h) Salomon, R. G.; Sinha, A. *Ibid.* **1978**, 1367. (i) Evers, J. T. M.; Mackor, A. *Ibid.* **1978**, 2317, 2321. (j) Salomon, R. G.; Caughlin, D. J.; Easler, E. M. *J. Am. Chem. Soc.* **1979**, *101*, 3961. (k) Evers, J. T. M.; Mackor, A. *Tetrahedron Lett.* **1980**, 415. (l) McMurray, J. E.; Choy, W. *Ibid.* **1980**, 2477.

(6) Our attempts to explore the mechanism and stereospecificity of this unusual reaction were thwarted by our inability to prepare either **2b** or **2c** on a large enough scale. (See paragraph at the end of the paper about supplementary material describing our numerous attempts to prepare these compounds.)

(7) Mitchell, R. H.; Sondheimer, F. *Tetrahedron* **1968**, *24*, 1397.

(8) Cookson, R. C.; Gupte, S. S. *Org. Synth.* **1971**, *51*, 123.

(9) Pagni, R. M.; Burnett, M.; Hazell, A. C. *J. Org. Chem.* **1978**, *43*, 2750.

Supplementary Material Available: A tabulation of our and other workers' results on the thermal and photochemical isomerization of **2a** plus experimental details (and tabulation) of our attempts to prepare **2b** and **2c** (6 pages). Ordering information is given on any current masthead page.

Dehydrogenation of the Azetidinone Sulfenic Acid Generated from Penicillin Sulfoxide[1]

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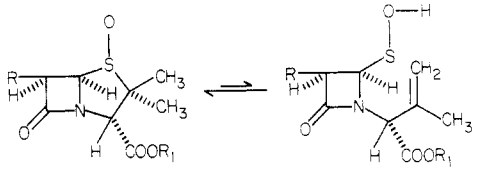
Received December 30, 1980

The beauty and unlimited opportunities of penicillin chemistry lie in the fact that many functional groups are brought into combination in a relatively small molecule. In addition, some of these groups can be transformed into new, reactive functionalities which give a special challenge to the chemistry of the penicillin molecule. A typical example of a transformation which creates a highly reactive functionality is the thermal equilibrium of penicillin sulfoxide **1** and the azetidinone sulfenic acid **2** (eq 1).



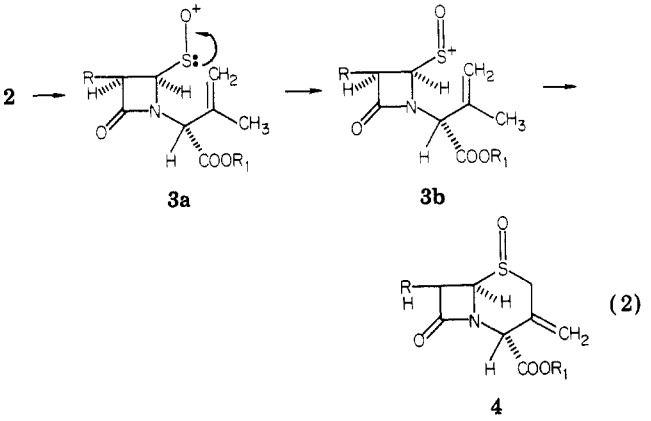
(1)

1 **2**

Although the sulfenic acid group in **2** consists of only three atoms, i.e., S, O, and H, many different and distinct reactions have been successfully performed on each of these atoms in spite of the fact that the S–O–H group is attached to the very sensitive four-membered azetidinone ring.[2] Our interest in finding a new way to form the sulfinium cation **3b**, which is a proposed intermediate in the preparation of 3-methylenecepham sulfoxide (**4**),[3] led us to study the dehydrogenation of the azetidinone sulfenic acid **2**, and our results are reported here.

We hoped that the hydrogen atom of the sulfenic acid group in **2** could be abstracted as the hydride ion H^-, forming the intermediate **3a** and that the resonance form **3b** might then ring close to the *exo*-methylene sulfoxide **4** (eq 2).

To test this idea the sulfenic acid **2**, prepared by thermolysis of penicillin sulfoxide **1**, was treated with *p*-benzoquinone or chloranil (1 equiv, refluxing toluene, 2 h). A mixture of five compounds was obtained which was separated by chromatography over silica gel. From the first fraction, the crystalline deacetoxycephem **9** (mp 189–190 °C), was isolated in 3.4% yield (Scheme I). The structure was established by comparison with an authentic sample. The second fraction provided a mixture of 2-(sulfinoxymethyl)penams **5** and **6** and the 3-sulfinoxycepham **7** (total yield 48.5%).



3a **3b**

(2)

4

By repeated chromatography these isomers were separated and isolated as colorless amorphous solids. From the third fraction was isolated the 3-sulfinoxycepham ester **8** in 13.3% yield.

Elemental analyses for **5–8** were correct for empirical formula $C_{46}H_{44}N_6O_{16}S_2$, consistent with the conclusion that these compounds are isomeric and also dimers of the original penicillin molecule. The dimeric nature of these compounds can be clearly seen by examination of the NMR spectra.

The structure of the azetidinone sulfinic acid portion of esters **5–8** was established by IR, NMR, and mass spectra. The IR spectra of these esters display an absorption band at 1780 cm^{-1}, indicating the presence of the azetidinone carbonyl. The NMR spectra show characteristic quartets and doublets for azetidinone portions with coupling constants J = 4.5 and 9.0 Hz. In addition, all these esters have a singlet at δ 1.9–2.0 for methyl protons and typical allylic signals between δ 5.0 and 5.3, which when the compound is treated with triethylamine for 10 min changed to two 3-proton singlets at δ 2.21 and 2.27 due to the presence of the isopropylidene group.[4] The major fragmentation peaks at m/e 451, 483, and 501 indicate the presence of the azetidinone sulfinate fragment and the penam and cepham moiety in these molecules.

Treatment of a mixture of **5–8** with methanesulfonic acid afforded after chromatography 3-methylenecepham sulfoxide **4**. This results provides chemical support for the sulfinic acid ester portion of compounds **5–8**.[3]

The structures of 3β-hydroxycephams and 2β-hydroxymethylpenams, fragments of esters **5–8**, were also ascertained by NMR spectra and chemical reactions. Thus the 3β-hydroxy-3-methylcepham fragment in **7** was easily recognized by the characteristic AB quartet at δ 2.85 and 3.48 (J = 15 Hz), the saturated methyl singlet at δ 1.4, and the H-4 singlet at δ 4.78. Similarly, the diastereoisomer **8** displays the AB quartet at δ 2.15 and 3.24 (J = 15 Hz), the methyl protons at δ 1.48, and the H-4 proton at δ 4.35.[5]

The isomeric 2α-oxymethylpenam part of **5** was deduced from the NMR spectrum in which the 2β-methyl protons show chemical shift at δ 1.31, the 2-methylene AB quartet at δ 3.75 and 3.89 (J = 11.0 Hz), and the H-3 singlet at δ 4.75. These signals for the methyl and methylene protons were shifted significantly upon oxidation of the penam sulfur to the corresponding sulfoxide. Thus in the sulfoxide the 2β-methyl group has an upfield chemical shift to δ 1.25 and the methylene protons a downfield shift to δ 4.48. Similar chemical shifts between the sulfide and

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