

The Photochemical Synthesis of Novel Heterocyclic Compounds
from *s*-Triazolo[4,3-*b*]pyridazine, III

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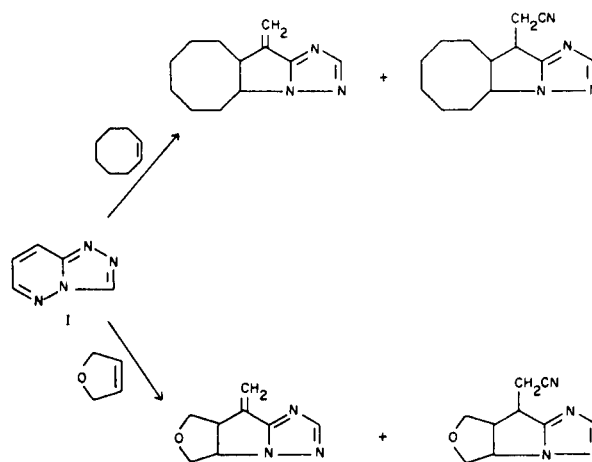
s-Triazolo[4,3-*b*]pyridazine (I) reacted photochemically with bicyclo[2.2.1]hepta-2,5-diene, 1,5-cyclooctadiene, 1,3-cyclooctadiene, methylene cyclohexane, diethyl *cis*-1,2,3,6-tetrahydrophthalate and ethyl 2-cyclopentene-1-acetate to give the following products: the *endo* and *exo* isomers of 4a,5,8a,9-tetrahydro-9-methylene-5,8-methano-8*H*-*s*-triazolo[1,5-*a*]indole (II) and the *endo* and *exo*-9-cyanomethyl products (III and IV) from bicyclo[2.2.1]hepta-2,5-diene; 4a,5,9,10,10a,11-hexahydro-11-methylene-6*H*-cycloocta[4,5]pyrrolo[1,2-*b*]-*s*-triazole (V) and the 11-cyanomethyl product VI from 1,5-cyclooctadiene; 4a,7,8,9,10,10a-hexahydro-11-methylene-11*H*-cycloocta[4,5]pyrrolo[1,2-*b*]-*s*-triazole (VII), 4a,5,7,8,10a,11-hexahydro-11-methylene-6*H*-cycloocta[4,5]pyrrolo[1,2-*b*]-*s*-triazole (VIII) and their respective 9-cyanomethyl products (X and IX) from 1,3-cyclooctadiene; 6',7'-dihydro-7'-methylenspiro[cyclohexane-1,5'-[5*H*]pyrrolo[1,2-*b*]-*s*-triazole] (XI), 6',7'-dihydro-7'-methylenspiro[cyclohexane-1,6'-[5*H*]pyrrolo[1,2-*b*]-*s*-triazole] (XII) and their respective 7'-cyanomethyl products (XIII and XIV) from methylene cyclohexane; 6,7-dicarbethoxy-9-cyanomethyl-4a,5,7,8,8a,9-hexahydro-6*H*-*s*-triazolo[1,5-*a*]indole (XV) from diethyl *cis*-1,2,3,6-tetrahydrophthalate; and 5-carbethoxymethyl-8-cyanomethyl-4a,5,6,7,7a,8-hexahydrocyclopenta[4,5]pyrrolo[1,2-*b*]-*s*-triazole (XVI) from ethyl 2,2-cyclopentene-1-acetate. Many other alkenes, particularly the phenyl ethylenes, did not react with compound I. In general, more than one product was isolated for each reaction except in the case of the two ester alkenes where a single cyanomethyl product was observed.

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We have previously reported the preparation of a variety of new heterocyclic ring systems by the photoaddition of various alkenes to *s*-triazolo[4,3-*b*]pyridazine (2-6). The products of those reactions resulted from the addition of the alkene to the 1 and 8 positions of compound I with a concurrent opening of the pyridazine ring. The products of the reaction with cyclooctene (5) and 2,5-dihydrofuran (6) are shown below.

This paper describes the further reactions of compound I with three cyclic dienes, an exocyclic alkene and two cyclic alkenes containing functional groups. The following compounds were prepared: the *endo* and *exo* isomers of 4a,5,8a,9-tetrahydro-9-methylene-5,8-methano-8*H*-*s*-triazolo[1,5-*a*]indole (II) and the *endo* and *exo*-9-cyanomethyl products (III and IV) from bicyclo[2.2.1]hepta-2,5-diene; 4a,5,9,10,10a,11-hexahydro-11-methylene-6*H*-cycloocta[4,5]pyrrolo[1,2-*b*]-*s*-triazole (V) and the 11-cyanomethyl product VI from 1,5-cyclooctadiene; 4a,7,-

8,9,10,10a-hexahydro-11-methylene-11*H*-cycloocta[4,5]pyrrolo[1,2-*b*]-*s*-triazole (VII), 4a,5,7,8,10a,11-hexahydro-11-methylene-6*H*-cycloocta[4,5]pyrrolo[1,2-*b*]-*s*-triazole



VIII and IX, then, have the double bond next to carbon 10a as postulated. An additional methylene compound was isolated but not fully characterized. The nmr of this compound showed a triazole hydrogen at 8.05 δ and H_{4a} at 5.12 δ . This indicates that this compound is an isomer of VII much the same as the two isomers of VI.

1,3-Cyclohexadiene was also irradiated in the presence of I. The products could not be isolated and purified; however, the nmr spectra of mixtures of peaks clearly showed the triazole and methylene hydrogens typical of these photoadducts. We are not sure if only 1,2-addition to the diene occurred.

Photoaddition of methylene cyclohexane gave four isolatable products. The structures are clearly shown by the fact that the nmr spectra for compounds XI and XIII did not contain a peak at 4.0 ± 0.2 indicative of H_{5'}, while the spectra of XII and XIV did have the peak at 4.1 ± 0.1 . The structures for XV and XVI are consistent with their spectra although the carbethoxymethyl substituent could be in position 7.

Many other alkenes were reacted without success. These include vinyl acetate, sulfolene, phenanthrene, α -benzylstyrene, 3-butenic acid, tetraphenylethylene, ethyl cinnamate, *trans*-cinnamaldehyde, dimethyl acetylenedicarboxylate and 1,10-phenanthroline. The reason for the nonreaction of these compounds is not understood.

The photoaddition mechanism has been previously postulated (5). The majority of the products of the methylene cyclohexane reaction are a result of addition of the least substituted vinyl carbon to the nitrogen of compound I. This is in keeping with our postulated mechanism (5).

EXPERIMENTAL

All ir spectra were obtained on a Hilger and Watts H1200 infra-graph. The nmr spectra were obtained on a Varian EM-390 spectrometer. Varian model 202B and 1700 vapor phase chromatographs were used to isolate all products. A 6' x 1/4" copper tube packed with 10% SE-30 on 60/100 mesh chromasorb G/AW was used. The mass spectra (MS) were obtained on a CEC-20-110C high resolution mass spectrometer. The starting alkenes were used as purchased from Aldrich Chemical Company. Diethyl-*cis*-1,2,3,6-tetrahydrophthalate and ethyl 2-cyclopentene-1-acetate were prepared from the anhydride and carboxylic acid, respectively.

Bicyclo[2.2.1]hepta-2,5-diene Photoproducts.

Three peaks amounting to 92% of the total peak area were isolated on the vpc. Peak 1 (70% of the total) proved to be a mixture of *endo* and *exo* isomers. Compound II exhibited the following nmr spectrum (δ): 8.05 (s, 2/3H, H₂), 7.94 (s, 1/3H, H₂), 6.42 (m, 2/3H, H₆ or H₇), 6.28 (m, 2/3H, H₆ or H₇), 6.09 (m, 1/3H, H₆ or H₇), 5.94 (d, 2/3H, J = 2 Hz, methylene H), 5.85 (d, 1/3H, J = 2 Hz, methylene H), 5.60 (m, 1/3H, H₆ or H₇), 5.39 (d, 2/3H, J = 2 Hz, methylene H), 5.30 (d, 1/3H, J = 2 Hz, methylene H), 4.95 (dd, 1/3H, H_{4a}), 4.40 (d, 2/3H, H_{4a}), 3.95 (m, 1/3H, H_{8a}), 2.9-3.3 (m, ~3H, H₅, H₈ and H_{8a}) and 1.1-1.8 (m, 2H, H₁₀). The molecular weight of total compound II was:

Calcd. for C₁₁H₁₁N₃: 185.09512. Found: 185.09529.

Peak 2 (14%, compound III) exhibited the following spectra: ir: 2250 cm⁻¹ (CN); nmr (δ): 8.02 (s, 1H, H₂), 6.36 (m, 2H, H₆ and H₇), 4.48 (d, 1H, H_{4a}), 2.8-3.4 (m, 6H), 1.72 (d, 1H, H₁₀) and 1.14 (d, 1H, H₁₀); molecular weight: Calcd. for C₁₂H₁₂N₄: 212.10619. Found: 212.10502.

Peak 3 (9%) proved to be a mixture of compounds III and IV. Compound IV exhibited the following spectra: ir: 2230 cm⁻¹ (CN); nmr (δ): 7.93 (s, 1H, H₂), 6.32 (m, 1H, H₆ or H₇), 5.76 (m, 1H, H₆ or H₇), 5.02 (dd, 1H, H_{4a}), 2.8-3.5 (m, 6H), 1.7 (m, 2H, C₁₀); molecular weight was not taken.

1,5-Cyclooctadiene Photoproducts.

Three product peaks were isolated from the vpc. Peak 1 (67%, compound V) exhibited the following nmr (δ): 8.01 (s, 1H, H₂), 5.90 (d, 1H, J = 1.0 Hz, methylene H), 5.77 (s, 2H, H₇ and H₈), 5.21 (d, 1H, J = 1.0 Hz, methylene H), 4.55 (m, 1H, H_{4a}), 3.63 (m, 1H, H_{10a}) and 1.6-2.8 (m, 8H); molecular weight: Calcd. for C₁₂H₁₅N₃: 201.12659. Found: 201.1268.

Peak 2 (23%) proved to be compound VI; ir: 2230 cm⁻¹ (CN); nmr (δ): 7.95 (s, 1H, H₂), 5.80 (m, 2H, H₇ and H₈), 4.27 (m, 1H, H_{4a}) and 1.5-3.2 (m, 12H); molecular weight: Calcd. for C₁₃H₁₆N₄: 228.13749. Found: 228.1380.

Peak 3 (10%) proved to be an isomer of VI; ir: 2230 cm⁻¹ (CN); nmr (δ): 7.94 (s, 1H, H₂), 5.71 (m, 2H, H₇ and H₈), 4.77 (m, 1H, H_{4a}) and 1.8-3.2 (m, 12H); molecular weight: Calcd. for C₁₃H₁₆N₄: 228.13749. Found: 228.1380.

1,3-Cyclooctadiene Photoproducts.

Six peaks were isolated from the vpc. Peak 1 (4%) was a dimer of 1,3-cyclooctadiene; nmr (δ): 5.55 (m, 4H), 2.32 (m, 4H) and 1.0-1.8 (m, 16H). Peak 2 (25%, compound VII) exhibited the following nmr spectrum (δ): 7.92 (s, 1H, H₂), 6.32 (m, 1H, H₅ or H₆), 6.25 (d, 1H, J = 0.5 Hz, methylene H), 6.00 (m, 1H, H₅ or H₆), 5.37 (d, 1H, J = 0.5 Hz, methylene H), 5.28 (m, 1H, H_{4a}), 3.60 (m, 1H, H_{10a}) and 1.0-2.3 (m, 7H); molecular weight: Calcd. for C₁₂H₁₅N₃: 201.12659. Found: 201.1267.

Peak 3 (23%, compound VIII) exhibited the following nmr spectrum (δ): 7.98 (s, 1H, H₂), 5.93 (m, 2H, H₉ and H₁₀), 5.86 (d, 1H, J = 1 Hz, methylene H), 5.27 (d, 1H, J = 1 Hz, methylene H), 4.22 (m, 1H, H_{4a}), 3.77 (m, 1H, H_{10a}) and 1.2-3.0 (m, 8H); molecular weight: Calcd. for C₁₂H₁₅N₃: 201.12659. Found: 201.1269.

Peak 4 (16%) probably was an isomer of compound VII; nmr (δ): 8.05 (s, 1H, H₂), 5.99 (m, 1H, H₅ or H₆), 5.86 (d, 1H, J = 1.5 Hz, methylene H), 5.60 (m, 1H, H₅ or H₆), 5.27 (d, 1H, J = 1.5 Hz, methylene H), 5.12 (m, 1H, H_{4a}), 3.65 (m, 1H, H_{10a}) and 1.3-2.3 (m, 8H); molecular weight was not obtained.

Peak 5 (23%, compound IX) exhibited the following spectra: ir: 2210 cm⁻¹ (CN); nmr (δ): 7.96 (s, 1H, H₂), 5.90 (m, 2H, H₉ and H₁₀), 3.75 (m, 1H, H_{4a}), 3.42 (m, 1H, H_{10a}), 2.95 (d, 2H, CH₂CN and m, 1H, H₁₁), 2.30 (m, 2H, H₈) and 1.3-2.0 (m, 6H); molecular weight: Calcd. for C₁₃H₁₆N₄: 228.13749. Found: 128.1376.

Peak 6 (8%) proved to be compound X; ir: 2210 cm⁻¹ (CN); nmr (δ): 7.87 (s, 1H, H₂), 5.80 (m, 2H, H₅ and H₆), 4.95 (m, 1H, H_{4a}), 2.90 (m, 3H, CH₂CN and other), 1.2-2.4 (m, 9H); molecular weight: Calcd. for C₁₃H₁₆N₄: 228.13749. Found: 228.1375.

1,3-Cyclohexadiene Photoproducts.

More than six peaks were observed on the vpc. Three types of peaks were isolated. First, a high yield of the 1,3-cyclohexadiene photodimer (octahydrobiphenylene) was isolated. Second, a group of 3 or 4 inseparable peaks were observed. The isolated peaks all

exhibited the methylene hydrogens at 5-6 δ with $J = 0.5-2$. Third, two or three addition peaks were isolated. Each compound exhibited an ir peak at 2240 cm^{-1} indicative of a cyano group. No definitive spectra could be obtained on any of these compounds because no pure material could be isolated.

Methylene Cyclohexane Photoproducts.

Four peaks were isolated from the vpc. Peak 1 (10%) contained mainly starting I with a small amount of XI, nmr (δ): 8.02 (s, 1H, H_2'), 5.91 (d, 1H, methylene H), 5.32 (d, 1H, methylene H), 3.27 (m, 2H, H_6') and 1.3-2.1 (m, 10H). No molecular weight could be obtained.

Peak 2 (57%) proved to be compound XII; nmr (δ): 8.06 (s, 1H, H_2'), 5.92 (s, 1H, methylene H), 5.28 (s, 1H, methylene H), 4.09 (s, 2H, H_5') and 1.3-2.0 (m, 10H); molecular weight: Calcd. for $C_{11}H_{15}N_3$: 189.12659. Found: 189.1267.

Peak 3 (6%, compound XIII) exhibited the following spectra; ir: 2230 cm^{-1} (CN); nmr (δ): 8.01 (s, 1H, H_2'), 3.56 (m, 1H, H_7'), 2.8-3.2 (m, 4H, H_6' , and CH_2CN) and 1.3-2.4 (m, 10H); molecular weight: Calcd. for $C_{12}H_{16}N_4$: 216.13749. Found: 216.1382.

Peak 4 (26%) proved to be compound XIV; ir: 2240 cm^{-1} (CN); nmr (δ): 8.02 (s, 1H, H_2'), 4.12 (dd, 2H, H_5'), 3.17 (t, 1H, H_7'), 2.72 (d, 2H, CH_2CN) and 1.3-1.9 (m, 10H); molecular weight: Calcd. for $C_{12}H_{16}N_4$: 216.13749. Found: 216.1378.

Diethyl cis-1,2,3,6-Tetrahydrophthalate Photoproducts.

Only one product peak (compound XV) was isolated; ir: 2240 cm^{-1} (CN); nmr (δ): 7.80 (m, 1H, H_2), 4.1 (m, 6H), 2.0-3.2 (m, 9H) and 0.9-1.5 (m, 6H); molecular weight: Calcd. for $C_{17}H_{22}N_4O_4$: 346.16409. Found: 346.16379.

Ethyl 2-Cyclopentene-1-Acetate Photoproducts.

Only one product peak (compound XVI) was isolated; ir:

2250 cm^{-1} (CN); nmr (δ): 7.94 (s, 1H, H_2), 4.90 (m, 1H, H_{4a}), 4.15 (q, 2H), 3.35 (m, 2H), 2.85 (m, 2H), 2.65 (m, 3H), 1.7-2.3 (m, 4H) and 1.28 (t, 3H); molecular weight: Calcd. for $C_{14}H_{18}N_4O_2$: 274.14296. Found: 274.14263.

Other Photochemical Reactions.

The following alkenes were irradiated in the presence of compound I: vinyl acetate, sulfolene, phenanthrene, α -benzylstyrene, 3-butenic acid, tetraphenylethylene, ethyl cinnamate, *trans*-cinnamaldehyde, dimethyl acetelynedicarboxylate and 1,10-phenanthroline. No reaction took place.

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