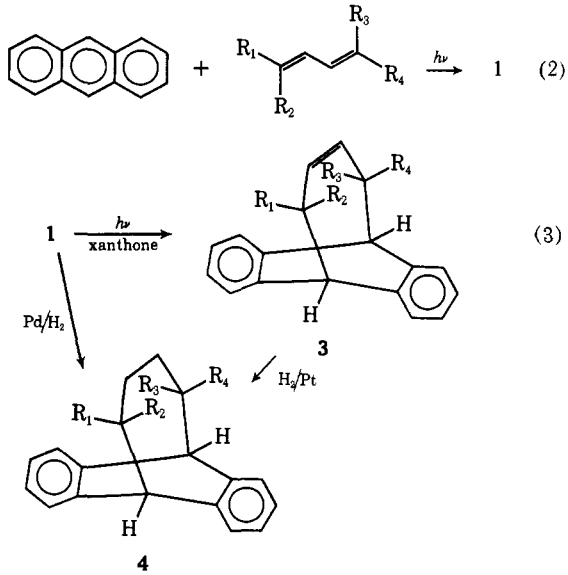
δ 1.04 (s, 6, CH_3), 1.37 (s, 6, CH_3), 3.26 (s, 2, ArC*H*Ar), 5.30 (s, 2, C*H*=C*H*), and 7.12 ppm (broad s, 8, Ar*H*). Under the influence of light and xanthone as the sensitizer, the adduct was rapidly converted into a stable isomer **3a**: mp 139–141° (petroleum ether–methanol); uv max (cyclohexane) 272 (ϵ 1190), 266 (ϵ 1020), and 248 nm (ϵ 690, shoulder); ir (KBr) 709 cm^{-1}; nmr (CCl_4) δ 1.20 (s, 12, CH_3), 3.68 (s, 2, ArC*H*Ar), 4.45 (s, 2, C*H*=C*H*), and 7.12 ppm (m, 8, Ar*H*). Both isomers upon hydrogenation gave the same dihydro derivative **4a**, mp 156–158°, which exhibited spectral properties in accordance with its structure. The results suggest the labile adduct to be **1a** ($R_1 = R_2 = R_3 = R_4 = CH_3$) with the newly formed double bond in the strained trans configuration which may be isomerized to the more stable cis isomer **3a** by photosensitization (reaction 3).



Similarly, upon irradiation with *trans,trans*-2,4-hexadiene, anthracene gave the metastable 1,4 adduct (**1b**, $R_1 = R_4 = CH_3$; $R_2 = R_3 = H$) in excellent yield, which failed thus far to crystallize: uv max (cyclohexane) 260, 267, and 275 nm; ir (CCl_4) 1005 cm^{-1}; nmr (CCl_4) δ 1.28 (d, 6, J = 7 Hz, $CHCH_3$), 2.45 (m, 2, $CHCH_3$), 3.56 (s, 2, ArC*H*Ar), 4.93 (sextet, 2, C*H*=C*H*),[12] and 7.12 ppm (s, 8, Ar*H*). The compound was isomerized to a more stable isomer **3b** by photosensitization: mp 110–113°; uv max (cyclohexane) 270 (ϵ 1255), 263 (ϵ 1160), and 255 nm (ϵ 775); ir (KBr) 720 cm^{-1}; nmr (CCl_4) δ 1.18 (d, 6, J = 7.5 Hz, $CHCH_3$), 2.92 (m, 2, $CHCH_3$), 3.82 (d, 2, J = 3.0 Hz, ArC*H*Ar), 4.68 (d, 2, J = 1.2 Hz, C*H*=C*H*), and 7.12 ppm (m, 8, Ar*H*). Both isomers **1b** and **3b** upon hydrogenation gave the same dihydro derivative **4b**, mp 78–80°, which exhibited spectral properties in accordance with the structure. These results indicate that the addition proceeds in a stereospecific manner.

The light-induced addition of 1,3-dienes to anthracene may be visualized as a photochemical electrocyclic $4_\pi + 4_\pi$ addition reaction.[13] The stereospecificity of the addition suggests that the reaction proceeds in a concerted manner and that the diene assumes the s-trans conformation in the transition state. Since the trans adduct **1** may be isomerized by photosensitization to give the more stable cis adduct **3**, it is probable that the various products from the benzene–1,3-diene photoreactions may be formed from the bicyclo[4.2.2]deca-7,9-*trans*-3-trienes as the intermediate.[4]

It is known that 1,3-cyclohexadiene quenches the fluorescence of anthracene efficiently with a rate approximately equal to one-half of that of a diffusion-controlled process,[2] and we have found that the quantum yield of consumption of anthracene in the presence of 1 *M* 1,3-cyclohexadiene is comparable to that of anthracene fluorescence. Traces of anthracene dimer were detected in the reaction mixture; however, the dimer was formed in 10–15% yield at higher anthracene concentrations. If the mechanism of fluorescence quenching of anthracene by cyclohexadiene involves exciplex formation, the principal mode of decay of the exciplex is the formation of the adduct **2**. It is not certain at this moment whether the exciplex would dissociate appreciably back to the excited state of anthracene once it is formed.

The formation of cyclohexadiene dimers from the irradiation of anthracene in the presence of cyclohexadiene may be due to energy transfer from the upper triplet state of anthracene to cyclohexadiene,[14] but the quantum efficiency for the dimer formation is much higher than that for the anthracene-sensitized cis–trans isomerization of 1,3-pentadiene. The mechanism of cyclohexadiene dimer formation in this reaction is being examined.

Acknowledgment. The authors wish to acknowledge the National Institutes of Health, Grant No. AM-11,676, and the National Science Foundation, Grant No. GP-16,347, for the support of this work.

(12) The sextet was analyzed to be a characteristic A_2X_2 pattern, and the first-order analysis (ref 8) gives the following coupling constants: $J_{CH=CH}$ = 8.8 Hz, $J_{CHCH=CH}$ = 7.8 Hz, and $J_{CHCH=CH}$ = 0.9 Hz.

(13) R. B. Woodward and R. Hoffmann, "Conservation of Orbital Symmetry," Academic Press, New York, N. Y. 1971.

(14) R. S. H. Liu, *J. Amer. Chem. Soc.*, **90**, 1899 (1968); R. S. H. Liu and J. Erdman, *ibid.*, **90**, 213 (1968); **91**, 1492 (1969); R. S. H. Liu and R. E. Kellogg, *ibid.*, **91**, 250 (1969).

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Photochemical Addition of Acyclic 1,3-Dienes to 9-Cyanoanthracene and 9-Anthraldehyde, a $4_\pi + 2_\pi$ Stereospecific Photochemical Cycloaddition

Sir:

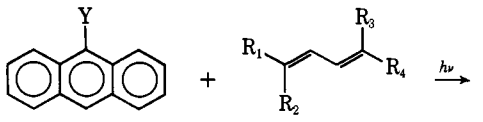
In the accompanying communication,[1] we reported the 1,4 photocycloaddition of 1,3-dienes to anthracene. Since the diene may act as an electron donor in its interaction with the excited anthracene,[2] we investigated the effect of electron-withdrawing substituents on anthracene in this reaction. This communication deals with the stereospecific 1,2 photocycloaddition of acyclic 1,3-dienes to 9-cyanoanthracene (**1a**) and 9-anthraldehyde (**1b**) to give 9,10-ethanoanthracene derivatives **2** (reaction 1). This result suggests that the course of a photochemical addition reaction may be controlled by the configuration of the two components in the exciplex intermediate.

(1) N. C. Yang and J. Libman, *J. Amer. Chem. Soc.*, **94**, 1405 (1972).
(2) T. R. Evans, *ibid.*, **93**, 2081 (1971).

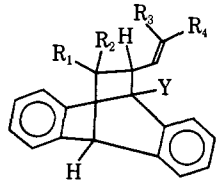
Table I

Olefin	9-Cyanoanthracene Yield, % Adduct	9-Cyanoanthracene Yield, % Dimer	$k_q\tau_s$ M^{-1} [a]	ϕ_{-1a} [b]	9-Anthraldehyde Yield, % Adduct	9-Anthraldehyde Yield, % Dimer
cis-1,3-Pentadiene	31 (151–152°)	10	6.53	0.38	20 (oil)	26
trans-1,3-Pentadiene	35 (126–128°)	13	6.52		20 (oil)	17
trans,trans-2,4-Hexadiene	85 (111–112°)	3				
cis,cis-2,4-Hexadiene	93 (101–103°)	4				
2,5-Dimethyl-2,4-hexadiene	84 (117–118°)	5	129	0.56		
2,3-Dimethyl-1,3-butadiene					45 (oil)	*c*
2,3-Dimethyl-2-butene	10 (oil)[d]	73	0.042			

[a] The slope of the Stern–Volmer plot of fluorescence quenching of **1a** by olefins in benzene. [b] The quantum yield of consumption of **1a** in the presence of 1 *M* olefin in benzene. [c] Not determined. [d] The adduct is 9-cyano-10-[1,1,2-trimethyl-2-propenyl]-9,10-dihydroanthracene.



1a, Y = CN
1b, Y = CHO



(1)

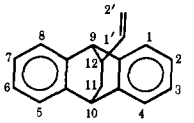
2a, Y = CN; $R_1 = R_4 = CH_3$; $R_2 = R_3 = H$
2b, Y = CN; $R_1 = R_4 = H$; $R_2 = R_3 = CH_3$
2c, $R_1 = R_2 = R_4 = H$; $R_3 = CH_3$
2d, $R_1 = R_2 = R_3 = H$; $R_4 = CH_3$

9-Cyanoanthracene (**1a**) reacts with *trans,trans*-2,4-hexadiene under the influence of ultraviolet light (>300 nm) to give a crystalline adduct in 85% yield after purification, mp 111–112°, with the dimer of **1a** as the only detectable by-product (3%). The structure and stereochemistry of this adduct were established unambiguously to be *trans*-11-(*trans*-1-propenyl)-12-methyl-9-cyano-10-hydro-9,10-ethanoanthracene (**2a**) by its spectroscopic properties: uv max (cyclohexane) 257 (ε 652), 263 (ε 925), and 270 nm (ε 1030); ir max (KBr) 210, 970, and 757 cm^{-1}; nmr ($CDCl_3$) δ 0.82 (d, 3, J = 7 Hz, $C^{12}CH_3$), 1.32–1.82 (m, 1, $C^{12}H$), 1.60 (2 d, 3, $J_{3'-2'}$ = 6.0 Hz, $J_{3'-1'}$ = 1.5 Hz, $C^{3'}H_3$), 2.00 (2 d, 1, $J_{11-1'}$ = 9 Hz, $J_{11-12(trans)}$ = 4.5 Hz,[3] $C^{11}H$), 3.98 (d, 1, J_{10-12} = 2.0 Hz, $C^{10}H$), 4.72 (4 q, 1, $J_{1'-2'(trans)}$ = 15.0 Hz,[4] $J_{1'-11}$ = 9.0 Hz, $J_{1'-3'}$ = 1.5 Hz, $C^{1'}H$), 5.60 (2 q, $J_{2'-1'(trans)}$ = 15.0 Hz, $J_{2'-3'}$ = 6.0 Hz, $C^{2'}H$), 7.25 (m, 6, ArH), and 7.60 ppm (m, 2, C^1H and C^8H). The photoaddition of *cis,cis*-2,4-hexadiene to **1a** also proceeded stereospecifically to give the ethanoanthracene **2b** in 93% yield, mp 101–103°, and the nmr of **2b** exhibited $J_{11-12(cis)}$ = 10.5 Hz,[3] and $J_{1'-2'(cis)}$ = 11.0 Hz.[4] Under similar conditions, 2,5-dimethyl-2,4-hexadiene and *cis*- and *trans*-1,3-pentadiene reacted with **1a**, 2,3-dimethyl-1,3-butadiene and *cis*- and *trans*-1,3-pentadiene reacted with **1b** to give ethanoanthracenes (**2**) as the only detectable adduct. The results are tabulated in Table I, the yields recorded are for crystalline or chromatographically homogeneous material, and all products gave satisfactory elemental analyses and exhibited spectra in agreement with the structure. Once again the addition of *cis*- or *trans*-1,3-pentadiene proceeded stereospecifically to give the corresponding 11-propenylethanoanthracenes (**2c–d**). No 1,4 adduct was detected in any of these reactions during the course of the irradiation.

The quantum yields of consumption of **1a** in the presence of 1 mol of dienes are high, and the fluorescence of **1a** was quenched by olefins (Table I). Taking the fluorescence quantum yield of **1a** to be 0.80 in benzene,[5] the major portion of excited **1a** quenched by dienes did lead to the formation of the adduct. The qualitative correlation between the efficiency of various dienes on the quenching of fluorescence of **1a** and on the adduct formation suggests that the addition proceeds *via* the singlet excited state of **1a**. Our attempts to detect an exciplex emission under a variety of experimental conditions including those at −80 and −196° were not successful.

The overall reaction of **1** with acyclic 1,3-dienes may be formulated as a $4_\pi + 2_\pi$ photocycloaddition which is forbidden as a concerted process according to the conservation of orbital symmetry.[6] Since **1a** undergoes a $4_\pi + 4_\pi$ photocycloaddition with 1,3-cyclohexadiene and anthracene undergoes a $4_\pi + 4_\pi$ photocycloaddition with both acyclic and cyclic conjugated dienes,[1] the exclusive $4_\pi + 2_\pi$ photocycloaddition of acyclic 1,3-dienes to **1** must be attributed not only to the presence of an electron-withdrawing group at the 9 position of anthracene but also to the geometry of acyclic dienes. The 9 substituent in the excited singlet state of **1** may interact with one double bond of the diene in the s-trans conformation during the exciplex formation such that the two components in the exciplex are aligned in an orientation favorable for 1,2 addition, **3**. The exciplex then collapses to give a singlet biradical **4** which will undergo ring closure faster than bond rotation to give stereospecific addition products.[7–9] For unsymmetrical 1,3-dienes such as 1,3-

(3) S. J. Cristol, T. W. Russell, J. R. Mohrig, and D. E. Pforde, *J. Org. Chem.*, 31, 581 (1966), but the numbering system used in this communication differs from the system used in this reference, *i.e.*



(4) L. M. Jackman and S. Sterhell, "Applications of Nuclear Magnetic Resonance Spectroscopy in Organic Chemistry," Pergamon Press, New York, N. Y., 1969, p 218, 301.

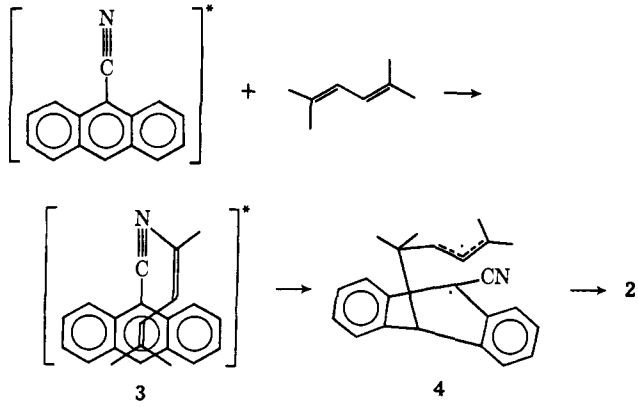
(5) W. Melhuish, *J. Phys. Chem.*, 65, 229 (1961).

(6) R. B. Woodward and R. Hoffmann, "Conservation of Orbital Symmetry," Academic Press, New York, N. Y., 1971. A $4_\pi + 2_\pi$ supra–antara addition is considered to be unlikely in this case.

(7) P. D. Bartlett and N. A. Porter, *J. Amer. Chem. Soc.*, 90, 5317 (1968).

(8) N. C. Yang and S. P. Elliott, *ibid.*, 91, 7550 (1969).

(9) N. C. Yang and W. Eisenhardt, *ibid.*, 93, 1277 (1971).



3 4

pentadienes, the structure of the adducts seems to be determined by the stability of the biradical **4** formed. Our results strongly suggest that the reaction pathway of a photochemical addition may be controlled by the configuration of two components in the exciplex intermediate.

The thermal $4_\pi + 2_\pi$ cycloaddition reactions including the Diels–Alder reaction are widely used in the organic synthesis, and this reaction, a $4_\pi + 2_\pi$ stereospecific photocycloaddition, may be complementary to the Diels–Alder reaction in the organic synthesis. The scope and limitation of this reaction are being investigated.

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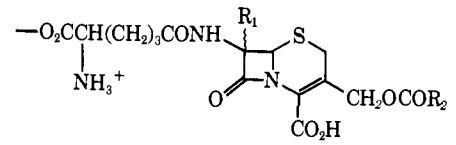
Substituted Penicillin and Cephalosporin Derivatives. I. Stereospecific Introduction of the C-6(7) Methoxy Group

Sir:

It has been suggested that an α-methyl group at C-6 of the penicillin nucleus would enhance antibacterial activity.[1] Several groups have attempted modifications at this position.[2] Recently we have developed synthetic routes to 6-methoxypenicillins and 7-methoxycephalosporins. Our interest in these compounds also arises from the discovery of four members of the cephamycin[3] class (**1a–d**), each of which contains a 7-methoxyl substituent.[4] Like cephalosporin C (**1e**), these new cephalosporins contain an α-aminoadipoyl side chain and its interchange to other acyl side chains was presumed necessary in order to obtain medicinally useful antibacterials.[5] We report here the partial synthesis of such compounds as well as a general method for the stereospecific introduction of a methoxy group adjacent to the β-lactam group in both the penicillin and cephalosporin series.



1a, $R_1 = OCH_3$; $R_2 = NH_2$
b, $R_1 = OCH_3$; $R_2 = CH_3$
c, $R_1 = OCH_3$; $R_2 = -C(OCH_3)=CHC_6H_4OH\text{-}p$
d, $R_1 = OCH_3$; $R_2 = -C(OCH_3)=CHC_6H_4OSO_3^-\text{-}p$
e, $R_1 = H$; $R_2 = CH_3$

Although the reactions of aliphatic diazocarbonyl compounds with halogens and pseudohalogens[6] are well known, their reaction with bromine azide has not been reported. Treatment of benzyl 6-diazopenicillanate[7] with bromine azide and excess triethylammonium azide in methylene chloride at $-15°$ resulted in a mixture of epimeric 6-bromo-6-azidopenicillanates **2a** and **b** (see Scheme I): ir (film) 2120 cm^{-1} (azide). The isomers could be separated by crystallization of **2a** (mp 62–63°) out of the mixture. Both isomers gave the same benzyl 6β-azido-6-methoxypenicillanate (**3a**): mp 60–61°; ir (CH_2Cl_2) 2125, 1785, 1750 cm^{-1}, upon treatment with $AgBF_4$ in methanol at room tempera-

Table I. Nmr Data of Penicillins ($CDCl_3$)

Compd	Chemical shift, τ (TMS) H_5	H_3	2-CH_3	OCH_3
2a	4.68	5.47	8.40, 8.62	
2b	4.29	5.47	8.42, 8.62	
3a	4.61	5.49	8.42, 8.59	6.37
3b	4.75	5.52	8.48, 8.64	6.45
4a	4.63	5.51	8.45, 8.60	6.53
4b	4.80	5.53	8.44, 8.51	6.57
5a	4.40	5.59	*8.70*	6.59
5b	4.32	5.54	8.44, 8.62	6.62
5c[a]	4.49	5.74	8.59, 8.61	6.51
5d[a]	4.53	5.72	8.45, 8.49	6.58
6a	4.55	5.48	8.40, 8.62	6.34
6b	4.26	5.48	8.47, 8.60	6.38
Benzyl 6,6-dibromopenicillanate[b]	4.20	5.44	8.41, 8.62	

[a] D_2O was the solvent used with **5c** and **5d**. [b] Obtained as a by-product in the formation of **2a** and **2b**.

(1) J. L. Strominger and D. J. Tipper, *Amer. J. Med.*, **39**, 708 (1965).
(2) R. Reiner and P. Zeller, *Helv. Chim. Acta*, **51**, 1905 (1968); G. V. Kaiser, C. W. Ashbrook, and J. E. Baldwin, *J. Amer. Chem. Soc.*, **93**, 2342 (1971); M. R. Bell, R. Oesterlin, S. D. Clemans, and J. A. Carlson, Abstracts, XXIIIrd IUPAC Meeting, Boston, Mass., 1971, p 74; E. H. W. Böhme, H. E. Applegate, B. Toeplitz, J. E. Dolfini, and J. Z. Gougoutas, *J. Amer. Chem. Soc.*, **93**, 4324 (1971).
(3) The name cephamycin has been proposed for 7-methoxy substituted cephalosporins.[4a] The excellent bioactivity of these compounds suggests the 7a configuration. **1b** has been prepared using the methods of this paper (R. W. Ratcliffe and B. G. Christensen, manuscript in preparation) and is identical with the natural product, confirming this assignment.
(4) (a) E. O. Stapley, D. Hendlin, S. Hernandez, M. Jackson, J. M. Mata, A. K. Miller, H. B. Woodruff, T. W. Miller, G. Albers-Schonberg, B. H. Arison, and J. L. Smith, Abstracts, XIth Interscience Conference on Antimicrobial Agents and Chemotherapy, Atlantic City, N.J., 1971, p 8; (b) R. Nagarajan, L. D. Boeck, M. Gorman, R. L. Hamill, C. E. Higgens, M. M. Hoehn, W. M. Stark, and J. G. Whitney, *J. Amer. Chem. Soc.*, **93**, 2308 (1971).
(5) For an excellent recent review on structure–activity relationships, see M. L. Sassiver and A. Lewis, *Advan. Appl. Microbiol.*, **13**, 163 (1970). An alternate synthesis of 7-methoxy cephalosporins from the naturally occurring cephamycins is reported in an accompanying communication: S. Karady, S. H. Pines, L. M. Weinstock, G. S. Brenner, A. M. Hoinowski, T. Y. Cheng, and M. Sletzinger, *J. Amer. Chem. Soc.*, **94**, 1410 (1972).
(6) C. Rappe, *Acta Chem. Scand.*, 17, 2140 (1963); J. P. Clayton, *J. Chem. Soc. C*, 2123 (1969); H. Baganz and H. May, *Chem. Ber.*, **99**, 3766 (1966); F. Weygand, H. J. Bestmann, and H. Fritsche, *ibid.*, **93**, 2340 (1960).
(7) D. Hauser and H. P. Sigg, *Helv. Chim. Acta*, **50**, 1327 (1967).