Heterocyclic Studies. 29. Photoisomerization of 2,3-Dihydro-1,2-diazepine Ketones and Carbinols to 1,2-Diazabicyclo[3.2.0]-6-heptenes[1]

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Irradiation of the 2,3-dihydrodiazepinones (**1**) and the carbinols (**3**) gives in high yields the 1,2-diazabicyclo-[3.2.0]-6-hepten-4-ones (**2**) and -4-ols (**4** and **5**), respectively. The major photoalcohols in each case were shown by nmr analysis to be the *exo* isomers. The *endo* alcohols were the minor photoproducts of **3** and were obtained exclusively on reduction of the ketones (**2**) with $NaBH_4$. The alcohols and tosylates are thermally stable, and elimination reactions have not been observed. Hydrogenation of derivatives of the *endo* alcohols gives mainly the *endo*-phenyldiazabicyclo[3.2.0]heptanols; in the *exo* alcohol series, equal amounts of *exo*- and *endo*-phenyl compounds are obtained. The rates of the photocyclization of the diazepinones (**1**) at 313 or 390 mμ decrease in the order R = $CH_3 \cong CH_2CH_2CN > H \gg COC_6H_5 \cong COCH_3$. Under the same conditions at 313 mμ, the reverse order of substituent effects is obtained with the diazepinols **3**: R = $COCH_3 \cong COC_6H_5 > CH_3 \cong H$.

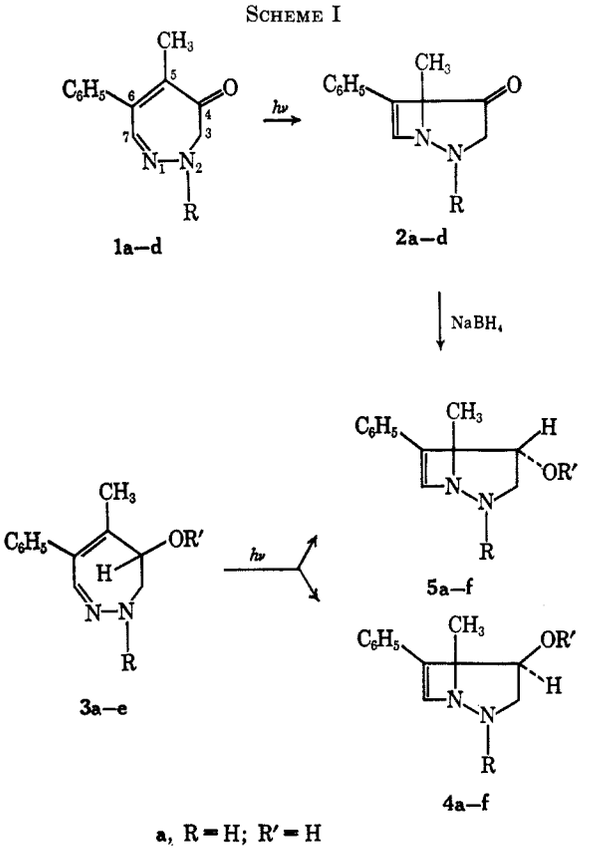
The photocyclization of seven-membered cyclic dienes and dienones to bicyclo[3.2.0]heptene derivatives is a generally useful reaction and has been applied to a variety of carbocyclic[3] and heterocyclic[4] systems. As noted previously,[5] the diazepine ketones **1** and carbinols **3** readily undergo this photocyclization to give the bicyclic ketones **2** and alcohols **4** and **5** (Scheme I). We now report the results of a study of several aspects of this cyclization and the novel bicyclic products.

For preparative purposes, exposure of the ketones **1**, which absorb strongly in the 400-mμ region, to sunlight in Pyrex vessels is the most satisfactory procedure for photocyclization. Cyclization of the colorless carbinols **3** requires higher frequency radiation and these reactions were carried out with a 200-W medium-pressure arc in a quartz envelope, usually with a Corex filter.

Under optimum conditions, essentially complete conversion into the photoisomers was achieved with small amounts of impurities. In kinetic experiments described in a later section, good isosbestic points were observed when the photocyclization was followed spectrophotometrically. From the acetyl ketone **1c**, the crystalline bicyclic ketone **2c** was isolated in yields of 80–90% in gram-scale runs. Ketones **2a** and **b** were obtained as unstable oils; a crystalline hydrochloride was obtained from **2a**.

The structure of the photoketones **2** was apparent from spectral data and several interconversions. All of the compounds showed singlet methyl peaks at δ 1.63–1.72, AB methylene patterns with $|J_{gem}| = 18$ Hz, and a singlet one-proton peak at 6.73–6.78. The ketone carbonyl band in **2c** appeared at 1767 cm^{-1} (CCl_4). The acetyl ketone **2c** was obtained both by cyclization of **1c** and by acetylation of **2a**. The semicarbazone of **1a** also underwent cyclization, and subsequent acetylation gave the N-acetyl bicyclic semicarbazone, also obtained from **2c**. Finally, isomerization of the photoketones **2a** and **b** on warming regenerated the respective diazepinones.

SCHEME I



a, R = H; R′ = H
b, R = CH_3; R′ = H
c, R = $COCH_3$; R′ = H
d, R = COC_6H_5; R′ = H
e, R = $COCH_3$; R′ = $COCH_3$
f, R = $COCH_3$; R′ = $SO_2C_7H_7$

With the bicyclic alcohols **4a–e**, the possibility of stereoisomers arises, and two isomeric alcohols were in fact obtained in unequal amounts by photocyclization of the diazepinols. These mixtures could be separated by crystallization or chromatography, and, as discussed below, the major cyclization product in each case was shown to be the *exo* alcohol and the minor product the *endo* isomer. Reduction of the bicyclic ketones **2a–d** with sodium borohydride gave cleanly single products which were identical with the minor photocyclization products, providing a convenient source of the *endo* alcohols.

The bicyclic alcohols **4a** and **5a** were stable, high-

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(3) (a) O. L. Chapman, *Advan. Photochem.*, **1**, 323 (1963); (b) R. N. Warrener and J. B. Bremner, *Rev. Pure Appl. Chem.*, **16**, 117 (1966).

(4) (a) L. A. Paquette and J. H. Barrett, *J. Amer. Chem. Soc.*, **88**, 1718 (1966); (b) O. L. Chapman and E. D. Hoganson, *ibid.*, **86**, 498 (1964); (c) L. A. Paquette, *ibid.*, **86**, 500 (1964); (d) J. M. Holovka and P. D. Gardner, *ibid.*, **89**, 6390 (1967).

(5) A preliminary note of some of this work has appeared: *Chem. Commun.*, 468 (1965).

TABLE I

NMR DATA FOR BICYCLIC ALCOHOLS AND KETONES

Compd	R	R′	δ, ppm (CDCl₃) 3ex	3en	4en	J, Hz 3ex-3en[a]	3ex-4en	3en-4en	CH_3	H-7
			exo Alcohols (Major Photoisomers)							
4a	H	H	3.23	3.86	4.48	−13.5	0	3.0		
4b	CH_3	H	3.17	3.80	4.52	−12.5	0	4.1	1.78	6.50
4c	Ac	H	4.58	3.82	4.58	−13.5	0	3.6	1.72	6.40
4d	Bz	H	4.71	4.00	4.58	−13.5	0	4.0	1.64	6.45
4e	Ac	Ac	4.69	3.85	5.66	−14	0	4.5	1.59	6.45
4f	Ac	Tos	4.54	3.73	5.25	−15	0	4.5	1.70	6.40
			endo-Alcohols (Hydride Series)							
5a[b]	H	H								
5b	CH_3	H	3.46	3.07	4.45	−11.5	8.7	10.3	1.79	6.70
5c	Ac	H	4.59	3.46	4.00	−11.3	6.3	8.5	1.69	6.57
5d	Bz	H	4.79	3.67	4.09	−10.7	6.5	9.0	1.62	6.64
5e	Ac	Ac	4.91	3.47	5.01	−11.7	7.4	8.75	1.77	6.66
5f	Ac	Tos	4.55	3.45	4.66	−11.7	7.1	8.7	1.66	6.56
			Ketones							
2b	CH_3		3.13	4.33		−18			1.70	6.78
2a	H		3.53	4.35		−18			1.63	6.73
2c	Ac		4.71	4.39		−18.5			1.72	6.78

[a] Negative value assumed for all J_{gem}; opposite sign from J_{vic} shown by calculation in **5e** and **5f**. [b] Compound insoluble in $CDCl_3$. [c] Spin decoupling of the spectrum of the N-acetyl alcohol **5c** with an irradiating frequency of −74 Hz caused the upfield multiplet to collapse to a doublet, δ 3.46, J = 8.5 Hz.

melting solids. The nmr spectra of the alcohols and several derivatives (Table I) contained methyl, phenyl and vinyl singlets very similar in position to those in the ketone spectra and three-proton ABX or ABC multiplets for the $-CH_2CHOR$ protons. Acetylation of the alcohols **4a** and **5a** or the N-acetyl alcohols **4c** and **5c** gave diacetyl derivatives also obtained by cyclization of the N-acetyl-4-acetoxydiazepine, and tosylates were also prepared from **4c** and **5c** in the usual way. The interconversions of individual isomers in each series established configurational correlation of the major photocyclization products and hydride reduction products.

Preliminary study of the chemical properties of these compounds revealed no obvious differences in reactivity of the two isomeric series and no notable instability or susceptibility to rearrangement or elimination. The alcohols were unchanged on prolonged refluxing in ethanol; some decomposition of **4a** occurred in refluxing butanol but the diazepinol **3a** was not detected. Alkaline hydrolysis of the diacetyl derivative **4e** gave first the N-acetyl alcohol **4c** and then **4a**. The N-acetyl tosylates in both series were unaffected by treatment with aqueous acetone or acetic acid–sodium acetate at 50°; higher temperatures did lead to decomposition. An attempt to methylate **4a** by the Clarke–Eschweiler method ($HCHO$–HCO_2H, 90°) caused extensive decomposition, and correlation of configuration of the N-methyl alcohol **4b** with the other *exo* alcohols rests on nmr data.

The isomer distributions in the photocyclization of several of the diazepinols were determined by area measurement of the C-7 (vinyl) proton peaks and other well-separated peaks for the two isomers in the nmr spectra of the total photolysis product mixtures (Table II). The relatively minor differences in amounts of the

TABLE II

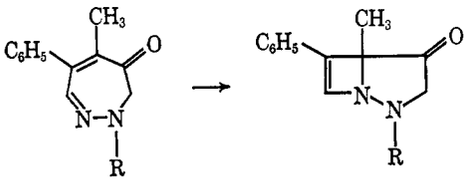
ISOMER DISTRIBUTION IN PHOTOCYCLIZATION OF DIAZEPINOLS

Compd	Diazepinol R	R′	Per cent isomer: Major (*exo*)	Minor (*endo*)
3a	H	H	78	22
3b	CH_3	H	80	20
3c	$COCH_3$	H	65	35
3d	COC_6H_5	H	60	40
3e	$COCH_3$	$COCH_3$	65	35

TABLE III

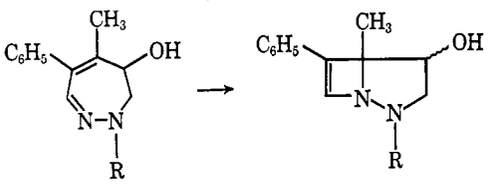
CYCLIZATION OF DIAZEPINES AT 313 mμ

Ketones



R	R′	Methanol solution: Absorption maxima of diazepinone, λ, mμ (ε)	Concn × 10⁴, mol/l.	k_1 × 10⁵, min⁻¹	$t_{1/2}$, min	n × 10⁸, mol min⁻¹ l.⁻¹	% diazepine at equilibrium	Hexane solution: Absorption maxima of diazepinone, λ, mμ (ε)	Concn × 10⁴, mol/l.	k_1 × 10⁵, min⁻¹	$t_{1/2}$, min	n × 10⁸, mol min⁻¹ l.⁻¹	% diazepine at equilibrium
CH_3		410 (4400) 315 (5000)	1.46	38	18	410	18	406 (3480) 321 (4220)	1.70	35	19	450	27
$(CH_2)_2CN$[a]		406 (3900) 315 (5150)	1.40	39	17	410	13	402 (3040) 316 (4640)	1.55	30	23	340	25
H		398 (2900) 312 (5020)	1.43	28	25	280	6	388 (2050) 310 (4530)	1.59	17	40	200	47
COC_6H_5		393 (2860) 298 (7160)	1.00	9.6	72	69	9	399 (2700) 330, 297 (5330, 6770)	1.20	6.9	100	60	37
$COCH_3$		393 (2240) 315 (5520)	1.30	8.7	80	81	5	399 (2100) 326, 314 (5000, 4940)	1.43	7.3	95	75	50
Semicarbazone, R = H		345 (6700) 305 (7300)	0.99	5.8	120	41							
Semicarbazone, R = $COCH_3$		360 (8300) 298 7100)	0.74	3.6	190								

Carbinols

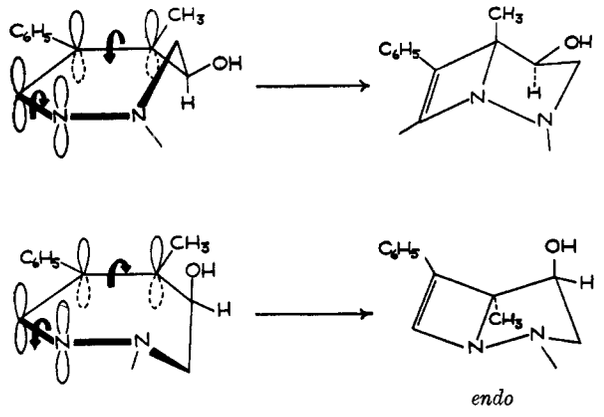


CH_3	H	320 (6150)	1.17	2.1	330		17	316 (5300)	1.36	2.6	270		25
H	H	306 (4650)	1.55	1.1	660		13	299 (4380)	1.64	0.8	840		10
COC_6H_5	H	313 (8240)	0.87	41	17		250	316 (8620)	0.83	41	17		240
$COCH_3$	H	308 (5820)	1.23	44	16		390	309 (4610)	1.56	32	22		350
$COCH_3$	$COCH_3$	312 (7160)	1.00	35	20		250	316 (7220)	1.00	33	21		240

[a] W. J. Theuer and J. A. Moore, *J. Org. Chem.*, **32**, 1602 (1967). The bicyclic product from this diazepinone was not characterized.

two isomers reflect very small energy differences in the transition states for the two modes of cyclization, which must arise by disrotatory movement of the C-5–C-6 and C-7–N-1 bonds from opposite faces of the ring, as shown in Scheme II. The cyclizations are arbitrarily represented in these drawings as proceeding from two different nonplanar conformations of the diazepinol. As discussed below (*cf.* Table III), cyclization of the NH and NCH_3 alcohols **3a** and **3b**, which give the highest *exo*/*endo* ratio (4:1), is slower by a factor of 20–40 than the photocyclization of the N-acyl alcohols **3c–e** which give more nearly equal amounts of the two isomers. Thus the degree of stereoselectivity in these cyclizations seems clearly to be inversely related to the rate or efficiency of the photocyclization process. The significance of this relationship, and the extent to which the ground-state geometry of **3** determines the product structure, cannot be assessed until more is known about the photochemical mechanism.

SCHEME II



endo

It should be mentioned that, in representing the (racemic) *exo* and *endo* alcohols formed in the photocyclization by the single projection structures **4** and **5**, and in naming these compounds, the same configuration of the ring junction at C-5 is implied for both epimers. This cannot be the case, however, since the configuration at C-4 does not change during the cyclization. As illustrated in Scheme II for the (4*S*) enantiomer, the *exo*-bicyclic alcohol has the (4*S*,5*R*) configuration, while the *endo* epimer is (4*S*,5*S*).

In assigning the configuration of the hydride reduction products and the major photoisomers, the direction of attack of hydride on the ketones **2a–d** was first considered. The same alcohol (**5c**) was also obtained exclusively on reduction of **2c** with diisocampheylborane, confirming that the highly selective isomer formation in these reductions stems from steric approach ("steric strain") control.[6,7] The question then depends upon the relative steric importance of the ethylenic bridge and the adjacent axial methyl group.

The parent bicyclo[3.2.0]heptanone is reduced by hydride reagents to the *endo* alcohol,[8] but information about the stereochemistry of substituted bicyclo[3.2.0]-6-heptenols is rather sketchy. Photocyclization of 2,4-cycloheptadienol[9] and the 2,6,6-trimethyl derivative (eucarvol)[10] have been reported to proceed in good yield, but the stereochemistry of the bicyclic alcohols was not specified. Several dimethylbicyclo[3.2.0]-6-hepten-2-ones have been reduced with lithium aluminum hydride to give sterically homogeneous alcohols, but again the configuration has not been definitely established.[11] Reduction of bicyclo[3.2.0]-3,6-heptadien-2-one with $LiAlH_4$ gives nearly equal amounts of the *exo*- and *endo*-dienols. With a more bulky reagent, conjugated addition of hydride predominates, but *endo*-bicyclo[3.2.0]-6-hepten-2-ol was isolated as a minor product.[12] In view of these limited data, assignment of stereochemistry from the course of reduction of the ketones **2**, containing two substituents and two heteroatoms, seemed unjustified.

Stereochemistry of Alcohols.—A firm basis for the hydroxyl configurations was provided by analysis of the C-3 and C-4 protons in the nmr spectra of **4a–f** and **5a–f** (Table I). In the spectra of the major photoisomers (**4**), one of the coupling constants was zero in each case, and all values of δ and J could be measured directly from the spectra. In the hydride isomers **5** the signals for these protons contained three spin–spin interactions; exact values of δ_{3ex}, δ_{3en}, and J_{gem} for the hydride isomers were obtained from the AX spectra of the 4-deuterio compounds prepared from **2a–d** with $NaBD_4$. In the spectra of the N-acetyl esters **5e** and **5f**, one proton was sufficiently deshielded to permit analysis by the standard calculation for ABX spectra,[13] but the A and B lines overlapped heavily because of the very small value of $(\delta_A - \delta_B)$ and required reference to 100-MHz spectra.[14]

Identification of peaks due to the 3-*exo*,3-*endo* and 4 protons in the N-acetyl photoisomers (**4c–f**) follows the assignments $J|_{gem}$ = 12–14 Hz and J_{cis} = 3.6–4.5 > J_{trans} = 0 Hz. On the basis that **4** represents the *exo* series, H_{3en} is then upfield from H_{3ex} in **4c–f**, as usually found with *exo* and *endo* protons at C-5 and C-6 in norbornenes.[15–19] However, the reverse chemical-shift relationship of H_{3en} and H_{3ex} is seen in the NH and $N-CH_3$ derivatives **4a** and **b**. The chemical shifts of these protons are influenced by three factors: (a) the diamagnetic anisotropy of the double bond (as noted above, H_{3en} should experience positive shielding because of its position above the plane of the double bond),[19] (b) proximity to OH or OR at C-4, and (c) the effect of N-acyl or N-methyl at N-2.

In these folded molecules, the N-2 substituent must assume an *exo* configuration to avoid nonbonding interactions with the C-6–C-7 bridge,[20] and any difference due to proximity of the carbonyl group in the N-acyl derivatives *vs.* $N-CH_3$ would therefore be reflected more strongly in H_{3ex} than in H_{3en}. This conclusion is borne out by the relatively small differences in δ_{3en} in N-acyl and N-methyl derivatives in both series. In each pair of epimeric alcohols, the H_{3en} signal in the *endo* isomer, *i.e.*, the proton *cis* to the hydroxyl group, is at 0.33–0.6-ppm higher field than H_{3en} in the *exo* isomer. In the epimeric 2-norbornenols, the corresponding difference in H_{3en} in the *endo* and *exo* alcohols is 0.45 ppm, with the signal in the *endo* isomer again at higher field.[17]

The signals of the 3-*exo* protons in the diazabicyclo[3.2.0] alcohols, however, are strongly dependent on the substituent at N-2, and the $N-CH_3$ group in both hydride and photoisomers is seen to cause a large diamagnetic shielding of H_{3ex} in **4b** and **5b** which outweighs the influence of the 6,7 double bond and causes H_{3ex} to resonate at higher field than H_{3en} in the NH and $N-CH_3$ *exo* alcohols. In the N-acetyl and N-benzoyl compounds, the deshielding of H_{3ex} by the adjacent carbonyl and the shielding of H_{3en} by the double bond are mutually reinforcing, leading to a difference $\delta_{3ex} - \delta_{3en}$ of 1.1 ppm in the *endo* alcohols and 0.7 ppm in the *exo* epimers. These differences between *exo* and *endo* C-3 protons in the two series may be compared to differences of 1.1 and 0.5 ppm in the *exo* and *endo* C-3 protons in *endo*- and *exo*-2-norbornenol, respectively.[17]

A similar effect of the N-2 substituent is observed also in one of the H-3 chemical shifts of the ketones **2a–c**, whereas the other signal remains practically unchanged throughout the three compounds. The *exo* and *endo* assignments of these protons is of necessity based entirely on this parallel behavior to the alcohols, in the absence of additional data from coupling constants.

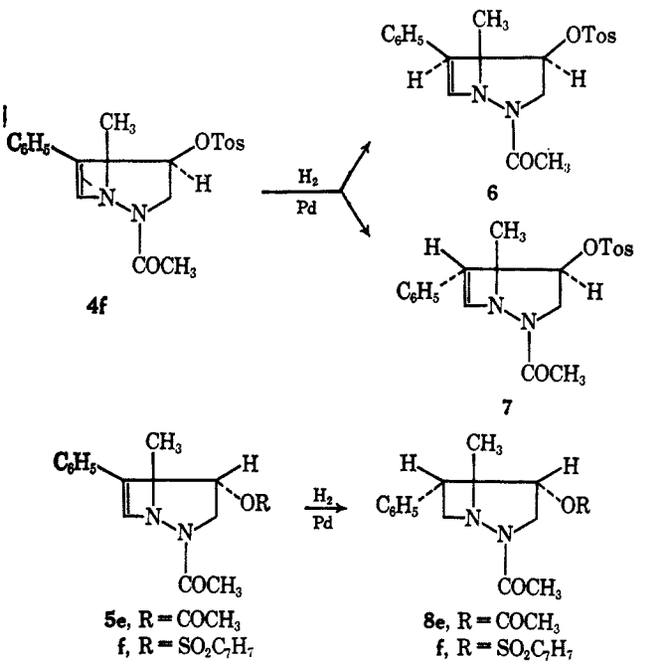
Final confirmation of the alcohol configurations was achieved in the hydrogenation of the epimeric N-acetyl tosylates and acetates. Catalytic reduction of the *exo*-tosylate **4f** gave a mixture of two dihydro compounds **16** and **7**. The nmr spectrum of the total product showed no vinyl protons. The signals due to the six secondary and tertiary protons were hopelessly mixed in four overlapping ABC patterns, but there were two clear methyl singlets at δ 0.91 and 1.55 ppm with an area ratio of 55:45. These isomers were not separated, but analysis corresponded to **6** or **7**. The higher field signal is assigned to the methyl group of the *exo*-phenyl

(6) H. C. Brown and H. R. Deck, *J. Amer. Chem. Soc.*, **87**, 5620 (1965).
(7) H. C. Brown and V. Varma, *ibid.*, **88**, 2871 (1966).
(8) S. Winstein, F. Gadient, E. T. Stafford, and P. E. Klinedinst, *ibid.*, **80**, 5895 (1958).
(9) O. L. Chapman, D. J. Pasto, G. W. Borden, and A. A. Griswold, *ibid.*, **84**, 1220 (1962).
(10) O. L. Chapman, *Advan. Photochem.*, **1**, 323 (1963).
(11) R. L. Cargill, M. E. Beckham, A. E. Siebert, and J. Dorn, *J. Org. Chem.*, **30**, 3647 (1965); R. L. Cargill and D. M. Pond, *ibid.*, **31**, 2414 (1966).
(12) P. R. Story and S. R. Fahrenholz, *J. Amer. Chem. Soc.*, **87**, 1624 (1965).
(13) J. A. Pople, W. G. Schneider, and H. J. Bernstein, "High Resolution Nuclear Magnetic Resonance," McGraw-Hill Book Co., Inc., New York, N. Y., 1959, p 132.
(14) We are indebted to Dr. G. Reddy, Central Research Department, E. I. du Pont de Nemours and Co., Inc., for the 100-MHz spectra and for helpful discussions.
(15) K. L. Williamson, *J. Amer. Chem. Soc.*, **85**, 516 (1963).
(16) P. Laszlo and P. R. Schleyer, *ibid.*, **86**, 1171 (1964).
(17) J. C. Davis, Jr., and T. V. Van Auken, *ibid.*, **87**, 3900 (1965).
(18) F. A. L. Anet, H. H. Lee, and J. L. Sudmeier, *ibid.*, **89**, 4431 (1967).
(19) R. R. Fraser, *Can. J. Chem.*, **40**, 78 (1962).
(20) There was no indication of splitting in the $N-COCH_3$ methyl peaks arising from population of two "invertomers."

isomer **6**, in which methyl and phenyl groups are eclipsed and the methyl group is strongly shielded by the aromatic ring. This result shows that in hydrogenation of the *exo*-tosylate there is negligible discrimination of the two sides of the 6 7 double bond.

Hydrogenation of either the *endo*-tosylate or *endo*-acetate, on the other hand, led to greater than 90% one isomer, in which the C-5 methyl peak appeared at 1.50 and 1.18, respectively. These products must be the *endo*-phenyl compounds **8e** and **8f** (Scheme III).

SCHEME III



The spectrum of the dihydro acetate **8e** contained acetyl peaks at 1.61 and 2.16 ppm which are assigned to the *endo*-$OCOCH_3$ and $-N-COCH_3$, respectively, the acetoxy methyl group evidently experiencing considerable shielding from the juxtaposed *endo*-phenyl ring. In the hydrogenation of the *endo* alcohol derivatives, therefore, approach to the catalyst surface occurs exclusively on the *outer* face of the four-membered ring because of crowding on the inside of the bicyclic system.

Rates of Photocyclization.—In the initial experiments on solar photocyclization of the diazepine ketones, it was noted that the reaction was appreciably faster with the 2-methyl derivative **1b** than with the 2-acetyldiazepinone **1c**. These diazepinones and diazepinols comprise a fairly extensive series of compounds in which the reacting cyclic diene chromophore is modified by a variety of substituents. This situation is one that cannot readily be achieved with carbocyclic compounds, and prompted us to study the effect of substituents on the photoreaction in somewhat more detail.

The electronic spectra of the ketones and carbinols are quite similar in the ultraviolet, with maxima at 230–240 and 300–315 mμ. The ketone spectra also contain a third maximum at 390–410 mμ, and it is presumably this latter band which enables photocyclization of the ketones to proceed rapidly in Pyrex vessels in ordinary daylight. In order to compare directly the effect of substituents in the carbinols and ketones, the relative rates of photocyclization were measured in a simple apparatus in which solutions of the diazepines of the same initial transmittance at the 300–315-mμ absorption maximum were irradiated under standardized conditions. The source was a 100-W medium-pressure mercury arc with glass and solution filters which provided irradiation primarily by the 3126–3132-Å band, and prevented absorption of the ketones at the longer wavelength maximum.[21]

Data on the disappearance of the diazepines with time were plotted as first-order reactions (Table III). Since the transmittance of the solutions increased during the reaction, these plots became nonlinear after about one half-life; rate constants were measured from the initial slopes. For convenience in measurement, the irradiations were carried out with a fixed initial optical density of 0.72–0.74 at the wavelength of the main absorption maximum in the 300–315-mμ region. Because of variations in the extinction coefficient of these maxima, the initial diazepine concentrations differed from compound to compound; in order to compare the number of moles of diazepine reacting in a given time, the quantity n mol/l. min was derived by dividing one-half of the initial concentration by $t_{1/2}$.

Cyclization of the diazepinols **3a–e** was complete under these irradiation conditions, but an equilibrium was reached with 8–18% of the diazepine in the case of the ketones **1** in methanol; in hexane solution cyclization was even less complete, and proceeded only to the extent of 50% with the N-acetyl ketone **1c**. The same equilibrium compositions were reached when solutions of the bicyclic ketones, obtained by unfiltered irradiation, were exposed to the 313-mμ source. The rate of the reverse reaction was measured directly for the crystalline bicyclic ketones **2c** and **2d** in hexane and the values of k_{-1}, 72×10^{-4} min^{-1} for **1c** and 42×10^{-4} min^{-1} for **1d**, agreed very well with those calculated, 73×10^{-4} and 41×10^{-4}, respectively, from the rate k_1 of the forward reaction and the measured equilibrium concentrations.

$$\text{diazepine} \underset{k_{-1}}{\overset{k_1}{\rightleftharpoons}} \text{bicyclic ketone};\ k_{-1} = K_{eq}/k_1$$

The concentrations of diazepinones given in Table III thus represent a true photoequilibrium due to excitation of the bicyclic ketones. It is not surprising that a significant reverse reaction occurs, since these ketones possess strong end absorption at 315 mμ (*e.g.*, **2a**, ϵ_{315} 2400; **2c**, ϵ_{315} 900). With the N-methyl bicyclic ketone **2b**, but not the other compounds, the reverse reaction occurs at a measurable rate in the dark at 25°; the rate of the dark reaction in methanol ($k_1 = 21 \times 10^{-3}$ sec^{-1}) was about one-fourth that of the photoreaction. In hexane, the dark reaction of **2b** was 30-fold slower, indicating a polar transition state. The lability of the bicyclic system in **2b**, which appears to stem from the presence of an electron-releasing N-2 alkyl group, invites comparison with the rapid cleavage of 5-methoxybicyclo[3.2.0]-6-hepten-2-one in alcohol solution, attributed to the bridgehead methoxy group.[9]

Although the rate of the reverse photoisomerization of the bicyclic ketones is considerably enhanced in hexane, as seen in Table III, the solvent polarity has a

(21) K. R. Kopecky, G. S. Hammond, and P. A. Leermakers, *J. Amer. Chem. Soc.*, **84**, 1016 (1962).

negligible effect on the rate of the diazepine cyclizations. A significant decrease in the photocyclization rate of the ketone was observed, however, in 10^{-2} *M* methanolic HCl. The rates of the –NH and NCH_3 diazepinones **1a** and **1b** were reduced to 12 and 23%, respectively, of the values in methanol; a somewhat smaller decrease to 40 and 25% of the methanol rate was observed with the acyl ketones **1c** and **1d**. The larger effect of acid on **1a** and **b** is in line with the higher basicity of the latter.

A similar comparison of the rates of cyclization of the three ketones **1a**, **b**, and **c** was also made by irradiation at the long wavelength maximum (393–408 mμ) using the same source with a narrow band-pass filter (T_{max} 390 mμ); the light intensity was about one-tenth that available in the 313-mμ runs. Rates and values of *n* mol/l. min are given in Table IV. In this series, the maxima and extinction coefficients differ considerably, and there is a correspondingly large difference in the ratios of k_1 and *n*.

TABLE IV

CYCLIZATION OF DIAZEPINONES AT 390 mμ

Ketone	λ_{max}, mμ (ε)	Concn × k_1 × 10^3, 10^4, mol/l.	k_1 × 10^3, min^{-1}	$t_{1/2}$, min	n × 10^8, mol min^{-1} $l.^{-1}$
1b (R = CH_3)[a]	410 (4400)	1.60	3.6	190	42
1b (R = CH_3)[b]	406 (3480)	2.10	3.1	220	47
1a (R = H)[a]	398 (2860)	2.46	2.0	340	36
1c (R = Ac)[a]	393 (2240)	3.08	0.35	1980	7.8

[a] Methanol solution. [b] Hexane solution.

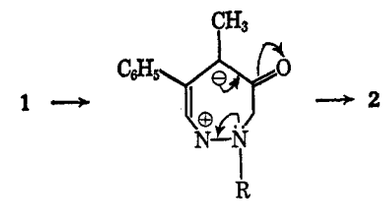
As shown in Table V, the ratios of *n* mol/l. min for three diazepinones in methanol at the two wavelengths correspond tolerably well, considering the limitations of the photolysis procedure. This correspondence and the fact that the rates of disappearance of the diazepinones at 390 and 313 mμ were proportional to the source intensity lead us to feel that the variation in values of *n* mol/l. sec for the differently substituted diazepines reflects, at least approximately, the relative quantum efficiencies.

TABLE V

COMPARISON OF DIAZEPINONE CYCLIZATIONS AT 313 and 390 mμ

Ratio of *n*	313 mμ	390 mμ
1b/**1a**	1.42	1.17
1b/**1c**	5.0	5.4
1a/**1c**	3.5	4.6

Perhaps the most striking result in these comparisons of photochemical reactivity is the opposite effect of substitution at N-2 in the ketones and carbinols. It is evident from the rate-retarding effect of acyl substitution and of acid that electron release by N-2 in the ketone series enhances the photochemical efficiency. The facilitation of photocyclizations of this type by methoxyl groups situated at the terminus of the reacting diene system is familiar in the photochemistry of cycloheptadienones,[9] cycloheptatrienones (tropolone α- and γ-methyl ethers),[3a] and cycloheptatrienes.[22] The role of an electron-donating group at N-2 in these cyclizations can be viewed in terms of a polar excited state as shown in **9**.



9

The opposite effect of acyl substitution at N-2 in the diazepine carbinols **3** was unexpected, and cannot be explained with the data now available. If excitation of the alcohols at 313 mμ involves an n → π* transition of the C=N group, cyclization *via* an excited state having a *reverse* polarity from that depicted in **11** could conceivably benefit by electron withdrawal at N-2. It is entirely possible, however, and perhaps more likely that the differences in photochemical efficiency in the acyldiazepinols arises from the operation of different excitation processes in the acyl derivatives and the nonacylated compounds **3a** and **b**.

Experimental Section[23,24]

2-Acetyl-5-methyl-6-phenyl-1,2-diazabicyclo[3.2.0]-6-hepten-4-one (2c).—A solution of 0.60 g of the 2-acetyldiazepinone **1c**[25] in 600 ml of methanol was placed in a 2-l. shallow wide-bottomed Brewster fermentation flask (Pyrex), and the flask was placed in direct October sunlight for 3 hr. The nearly colorless solution was evaporated and the solid residue was crystallized from ether–hexane to give 0.53 g (88%) of colorless prisms of **2c**: mp 122–123°; ν^{KBr} 1767, 1678 cm^{-1}; nmr, see Table I.

Anal. Calcd for $C_{14}H_{14}O_2N_2$: C, 69.40; H, 5.82; N, 11.56. Found: C, 69.22; H, 5.89; N, 11.29.

A solution of 73 mg of the unsubstituted diazepinone **1a** in 10 ml of methanol was exposed to sunlight in a Pyrex erlenmeyer flask for 2 hr and then evaporated to give **5-methyl-6-phenyl-1,2-diazabicyclo[3.2.0]-6-hepten-4-one** (**2a**) as a yellow oil. This oil was treated with acetic anhydride and pyridine and the resulting product (**2c**) was crystallized to give pale yellow crystals, mp 119–120°, identical (ir) with material obtained by irradiation of **1c** (above).

The **semicarbazone** of the acetyl bicyclic ketone **2c** was prepared in the usual way[25] and recrystallized from methanol to give white prisms: mp 189–191°; λ_{max}^{MeOH} 250, 278 mμ.

Anal. Calcd for $C_{15}H_{17}O_2N_5$: C, 60.19; H, 5.72; N, 23.40. Found: C, 60.01; H, 5.78; N, 23.21.

Hydrochloride of 1a.—To an 87-mg sample of the unsubstituted bicyclic ketone **2a** was added 1.8 ml of 6 *N* HCl and then 0.5 ml of concentrated HCl. Tan crystals separated which were collected and washed with a small volume of cold water to give 93 mg of the hydrochloride, mp 136–137 dec. Recrystallization from methanol containing a trace of HCl gave tan prisms: mp 139–140°; λ^{KBr} 1760 cm^{-1}.

Anal. Calcd for $C_{21}H_{13}ON_2Cl$: C, 60.88; H, 5.53; N, 11.84. Found: C, 60.48; H, 5.36; N, 11.58.

Semicarbazone of 1a.—A solution of 30 mg of the semicarbazone of diazepinone **1a** in 36 ml of methanol was irradiated in a cylindrical Pyrex cuvette (1 cm thick × 5 cm diameter) for 2.5 hr with a Hanovia 510C1 xenon arc. Evaporation of the solution gave 28 mg of white prisms of **2a semicarbazone**: mp 136–137° (to yellow melt); λ_{max}^{MeOH} 253, 281 mμ. On crystallizing the melt or recrystallization of the product from methanol, the diazepinone semicarbazone, mp and mmp 188–190°, λ_{max}^{MeOH} 305, 350 mμ, was obtained. The bicyclic semicarbazone, mp 136°, was also ob-

(22) G. W. Borden, O. L. Chapman, R. Swindell, and T. Tezuka, *J. Amer. Chem. Soc.*, **89**, 2979 (1967).

(23) General procedures are given in paper XXII of this series.[24]

(24) J. A. Moore, R. W. Medeiros, and R. L. Williams, *J. Org. Chem.*, **31**, 52 (1966).

(25) J. A. Moore and J. Binkert, *J. Amer. Chem. Soc.*, **81**, 6029 (1959).

tained by irradiation of **1a** followed by treatment with semicarbazide acetate. Acetylation gave the acetyl bicyclic semicarbazone, mp 189–190°, identical with that prepared from **2c**.

2-Benzoyl-5-methyl-6-phenyl-1,2-diazabicyclo[3.2.0]-6-hepten-4-one (2d).—A solution of 300 mg of the 2-benzoyldiazepinone **1d** in 300 ml of methanol was irradiated in sunlight for 2 hr and evaporated. The light yellow solid was recrystallized to give 150 mg of nearly colorless crystals, mp 112–114°. Repeated crystallization caused some yellow color to appear; this compound appeared to be significantly more sensitive to heat than the acetyl derivative.

Anal. Calcd for $C_{19}H_{16}O_2N_2$: C, 74.98; H, 5.30; N, 9.21. Found: C, 74.77; H, 5.26; N, 9.12.

5-Methyl-6-phenyl-1,2-diazabicyclo[3.2.0]-6-hepten-4-*endo*-ol (5a).—A solution of 65 mg of diazepinone **1a** in 20 ml of methanol was irradiated (xenon lamp) until nearly colorless and evaporated to an oil. The oil was dissolved in 4 ml of ethanol, and a solution of 38 mg of $NaBH_4$ in 2 ml of water–ethanol (1:2) was added. The solution became turbid and a white precipitate separated. After stirring for 1 hr, several drops of glacial acetic acid was added and the mixture was diluted with water. The colorless solid was collected in two crops to give a total of 60 mg of **5a**, mp 208–214°. Recrystallization from ethanol gave glistening white plates, mp 215–220° dec.

Anal. Calcd for $C_{12}H_{14}N_2O$: C, 71.26; H, 6.98; N, 13.85. Found: C, 71.20; H, 6.95; N, 13.72.

Acetylation gave the **N,O-diacetyl** derivative, **5e**, mp 124–125°, identical mixture melting point and ir) with that obtained by acetylation of the N-acetyl *endo* alcohol (*vide infra*).

5-Methyl-6-phenyl-1,2-diazabicyclo[3.2.0]-6-hepten-4-*exo*-ol (4a).—A solution of 250 mg of the diazepinol **3a**[25] in 250 ml of methanol was placed in two semicylindrical quartz cuvettes and irradiated at room temperature, with a slow stream of nitrogen, using a 200-W Hanovia medium-pressure arc with Corex filter. The uv spectrum of the original solution had λ_{min} 280 mμ, λ_{max} 306 mμ (ε 5000); after 260 min the spectrum had λ_{max} 273 mμ (14,000), λ 306 mμ (ε 1200), and the irradiation was discontinued and the solution evaporated.

Crystallization of the residue gave a first crop of 23 mg of the *endo* alcohol, **5a**, mp 217–221° dec (one spot, tlc), and as a second crop, 106 mg of the *exo* isomer, mp 167–170° dec. The tlc of the second crop showed the presence of a slower spot representing about 10–20% *endo* alcohol. The oily mother liquor from the second crop showed a major tlc spot corresponding to *exo* alcohol and three smaller spots corresponding to the diazepinol **1a**, *endo* isomer and one other compound. Recrystallization of the first crop from methanol gave large prisms of *endo* alcohol **5a**, mp 220–225° dec; the ir spectrum contained 29 bands at the same position and relative intensities as those in the spectrum of **5a** obtained by reduction of the ketone. Recrystallization of the second crop from methanol gave 8 mg of **5a**, mp 210–213°, and then 60 mg of *exo* alcohol, **4a**, mp 166–169° (one spot, tlc). Further crystallization from methanol–ether gave rhombs, mp 168–171°. A sample was sublimed for analysis.

Anal. Calcd for $C_{12}H_{14}N_2O$: C, 71.26; H, 6.98; N, 13.85. Found: C, 70.79; H, 7.00; N, 13.93.

Acetylation of 40 mg of the *exo* alcohol (0.3 ml of Ac_2O, 0.3 ml of C_5H_5N, 16 hr, 20°) gave 48 mg of the ***exo*-O,N-diacetyl** derivative **4e**: mp 145–146°; ν^{KBr} 1740, 1665 cm^{-1}.

Anal. Calcd for $C_{16}H_{18}N_2O_3$: C, 67.11; H, 6.34; N, 9.78. Found: C, 66.79; H, 5.98; N, 9.66.

2-Acetyl-5-methyl-6-phenyl-1,2-diazabicyclo[3.2.0]-6-hepten-4-*endo*-ol (5c).—A solution of 114 mg of the 2-acetyl bicyclic ketone **2c** in 9 ml of ethanol was treated with 56 mg of $NaBH_4$ dissolved in 1 ml of water. After 1 hr, 1 ml of acetic acid was added and the solution was evaporated, treated with water, and extracted with ether; evaporation of the washed ($NaHCO_3$) and dried ether solution gave 93 mg of **5c** as a colorless oil which showed one spot on tlc: ν^{CCl_4} 3400, 1670 cm^{-1}. Material prepared in this way was used for nmr. On one occasion, crystals, mp 75–80° dec, were obtained on evaporation of a carbon tetrachloride solution; this sample contained chlorine, and analysis indicated a solvate.

Anal. Calcd for $(C_{14}H_{16}N_2O_2)_3 \cdot CCl_4$: C, 58.24; H, 5.45; N, 9.48. Found: C, 58.39; H, 5.52; N, 9.53.

Acetylation of the oil (Ac_2O, pyridine) gave an oil which crystallized from ether, giving the ***endo*-N,O-diacetyl** derivative **5e**: mp 124–125°; ν^{KBr} 1770, 1675 cm^{-1}.

Anal. Calcd for $C_{16}H_{18}N_2O_3$: C, 67.11; H, 6.34; N, 9.78. Found: C, 66.92; H, 6.33; N, 9.87.

The ***endo*-N-acetyl tosylate 5f** was obtained by treatment of 130 mg of **5c** with 130 mg of *p*-toluenesulfonyl chloride in 1 ml of pyridine for 24 hr. After pouring into ice, 125 mg of beige solid, mp 165–170° dec, was collected and recrystallized from benzene and then ethanol to give 100 mg of **5f**, mp 170° dec.

Anal. Calcd for $C_{21}H_{22}N_2O_4S$: C, 63.31; H, 5.57; N, 7.03. Found: C, 63.39; H, 5.66; N, 7.03.

2-Acetyl-5-methyl-6-phenyl-1,2-diazabicyclo[3.2.0]-6-hepten-4-*exo*-ol (4c).—A solution of 250 mg of the 2-acetyldiazepinol in 200 ml of methanol was irradiated at 0° using a 200-W Hanovia medium-pressure mercury arc with Pyrex filter. After 30 min, the uv spectrum showed no further change, and the solution was evaporated and the residue was crystallized from benzene, giving 100 mg of white crystals, mp 158–165°. Several recrystallizations from benzene gave white prisms of **4c**, mp 167–168°.

Anal. Calcd for $C_{14}H_{16}N_2O_2$: C, 68.83; H, 6.60; N, 11.47. Found: C, 69.27; H, 6.79; N, 11.43.

The mother liquor from the first crop of **4c** was evaporated to an oily residue (130 mg) which showed two spots on tlc (alumina coating, ether solvent). The slower moving spot corresponded to the crystals from the first crop (*exo* isomer). The two zones containing the separate spots [as shown by a control plate (I_2) and subsequent separate spotting of the zones] were scraped from the plate and eluted with methanol. After dilution to equal volumes, the eluates from the upper and lower zones showed A_{270} 1.07 and 0.50, respectively, corresponding to 68% *endo* and 32% *exo* alcohol. Nmr examination of this mother liquor mixture gave values of 72 and 28%, respectively. Assuming that the first crop of crystals was 90% *exo* isomer, the ratio of *exo*/*endo* in the total reaction mixture would be *ca.* 60:40. The value of 65:35 determined by nmr analysis of the total mixture (Table II) is undoubtedly more accurate because of mechanical losses in the above isolation.

Acetylation of the N-acetyl-*exo* alcohol gave the **O,N-diacetyl** derivative, mp 146–147°, identical with that obtained by acetylation of the *exo* alcohol **4a**.

The ***exo*-N-acetyl tosylate 4f** was obtained as described for **5f** as a viscous oil which crystallized after several days. Recrystallization from benzene–hexane and then methanol–water gave **4f** as white crystals, mp 144–145°.

Anal. Calcd for $C_{21}H_{22}N_2O_4S$: C, 63.31; H, 5.57; N, 7.03. Found: C, 63.67; H, 5.93; N, 6.94.

2,5-Dimethyl-6-phenyl-2,3-dihydro-4H-1,2-diazepin-4-ol (3b).—A solution of 700 mg of the 2-methyldiazepinone (**1b**) in 70 ml of ethanol was treated with 140 mg of sodium borohydrides and allowed to stand 2 hr. Acetic acid was added and the solution was evaporated. The ether solution of the residue was washed, dried and concentrated to give 320 mg of white crystals of **3b**, mp 110°; recrystallization from methanol–water gave needles, mp 114–116°.

Anal. Calcd for $C_{13}H_{16}N_2O$: C, 72.19; H, 7.46; N, 12.95. Found: C, 72.12; H, 7.50; N, 13.29.

2,5-Dimethyl-6-phenyl-1,2-diazabicyclo[3.2.0]-6-hepten-4-ol. *endo* Isomer (5b).—A solution of 0.37 g of 2-methyldiazepinone **1b** in 650 ml of ethanol was irradiated in sunlight for 30 min. The nearly colorless solution was then treated with 0.1 g of $NaBH_4$ and the solution kept in the sunlight for 2 more hr to avoid reverse reaction. After adding a few drops of acetic acid, the solution was evaporated to a solid residue. Addition of 10 ml of water gave a clear solution. At pH 7 some turbidity developed, but the compound remained dissolved. The aqueous solution was evaporated and the residue was extracted with hot benzene. The dried benzene solution was concentrated to give a white crystalline solid, mp 153–158°. Recrystallization from benzene gave 290 mg of **5b**, mp 158°.

Anal. Calcd for $C_{13}H_{16}N_2O$: C, 72.19; H, 7.46; N, 12.95. Found: C, 72.40; H, 7.19; N, 12.77.

***exo* Isomer (4b).**—A methanol solution of 0.26 g of the 2-methyldiazepinol **3b** was irradiated with a 450-W Hanovia medium-pressure lamp for 65 min and then evaporated to dryness. Tlc (silica, ether–methanol 1%) showed two spots; the larger spot (*exo* alcohol) was faster moving. The slower, small spot corresponded to the *endo* alcohol. The composition of the mixture was determined by nmr and the material was then chromatographed on 6 g of silicic acid. Initial fractions eluted with ether contained brown oil; fractions eluted with ether–2% methanol contained exclusively *exo* alcohol; the nmr spectrum of material from these fractions was used for detailed analysis. Evaporation gave a solid residue; recrystallization from carbon tetrachloride gave crystals, mp 145–147°; analytical data were not obtained.

2-Benzoyl-5-methyl-6-phenyl-1,2-diazabicyclo[3.2.0]-6-hepten-4-ol (4d and 5d).—A solution of 306 mg of the 2-benzoyldiazepinol (**3d**) was irradiated as described for the N-acetyl derivative. After evaporation and nmr analysis of the crystalline residue, the mixture was triturated with ether and the insoluble material (85 mg), together with the first crop of crystals from the ether (25 mg), was recrystallized from benzene to give 98 mg of the *exo* isomer (major product by nmr), mp 174–176°. Recrystallization from ethanol gave colorless crystals of **4d**, mp 174–175°; a satisfactory analysis was not obtained.

Anal. Calcd for $C_{19}H_{18}N_2O_2$: C, 74.49; H, 5.92; N, 9.15. Found: C, 73.57; H, 6.55; N, 8.75.

The 200 mg of solid remaining after removal of 25 mg of **4d** from the ether-soluble fraction was crystallized several times from ethanol to give 67 mg of the *endo*-N-benzoyl alcohol **5d**, mp 188–189°.

Anal. Calcd for $C_{19}H_{18}N_2O_2$: C, 74.49; H, 5.92; N, 9.15. Found: C, 74.75; H, 5.93; N, 9.02.

Photocyclization of 4-Acetoxy-2-acetyl-5-methyl-6-phenyl-2,3-dihydro-4H-1,2-diazepine (3e).—A solution of 286 mg of **3e**[24] in 200 ml of methanol was irradiated as described for **3c** and after removal of solvent and nmr analysis, the solid mixture was crystallized from ether–hexane. The first crop of crystals, 130 mg, mp 145–150°, was recrystallized from ether to give the *exo*-**acetate 4e**, mp 149–150° (major product). From the more soluble fractions, a sample of the *endo*-**acetate 5e**, mp 125–126°, was isolated.

4-Acetoxy-2-benzoyl-5-methyl-6-phenyl-2,3-dihydro-4H-1,2-diazepine was prepared in 83% yield by acetylation of the N-benzoyl alcohol **3d** (acetic anhydide, pyridine, 90°, 2 hr) and crystallized from ethanol, mp 162–163°.

Anal. Calcd for $C_{21}H_{20}N_2O_3$: C, 72.39; H, 5.79; N, 8.04. Found: C, 72.32; H, 5.85; N, 7.89.

Irradiation of this compound was qualitatively similar to that of **3e**; the bicyclic products were not isolated.

2-Acetyl-5-methyl-6-*endo*-phenyl-1,2-diazabicyclo[3.2.0]-heptan-4-*endo*-yl Acetate (8e).—A solution of 130 mg of N-acetyl *endo*-acetate **5e** in 10 ml of ethanol was injected into a flask containing 20 ml of ethanol and 30 mg of 10% palladium on charcoal serving as the hydrogenation vessel in an Brown hydrogenation apparatus (Delmar Scientific Co.). After passing in hydrogen generated from $NaBH_4$ until uptake ceased, the solution was filtered and concentrated to a solid residue. Recrystallization from ether–hexane gave 120 mg of crystals, mp 100°. Further recrystallization gave 80 mg of **8e**, mp 107°.

Anal. Calcd for $C_{16}H_{20}N_2O_3$: C, 66.64; H, 6.99; N, 9.72. Found: C, 66.88; H, 7.30; N, 9.60.

2-Acetyl-5-methyl-6-*endo*-phenyl-1,2-diazabicyclo[3.2.0]heptan-4-*endo*-yl *p*-toluenesulfonate (8f) was obtained by hydrogenation of **5f** as described above. The nmr spectrum of the crude product contained peaks corresponding to about 10% the *exo*-phenyl isomer. Several recrystallizations from benzene–hexane gave pure **8f**, mp 166–167°.

Anal. Calcd for $C_{21}H_{24}N_2O_4S$: C, 62.99; H, 6.04. Found: C, 63.28; H, 5.84.

A mixture of 6-*endo* and 6-*exo* isomers of **2-acetyl-5-methyl-6-phenyl-1,2-diazabicyclo[3.2.0]heptan-4-*exo*-yl *p*-toluenesulfonate** was prepared by similar hydrogenation of the *exo*-tosylate **4f**. Evaporation of the filtered solution gave a colorless oil whose nmr spectrum showed methyl peaks corresponding to two isomers in a ratio of 55:45. A hexane solution of the oil crystallized on scratching to give a white solid, mp 105–108°; the nmr spectrum resembled that of the oil. Further crystallization gave a mixture of the *exo*- and *endo*-phenyl-4-*exo* tosylates **6** and **7**, mp 111–119°.

Anal. Calcd for $C_{21}H_{24}N_2O_4S$: C, 62.99; H, 6.04. Found: C, 63.60; H, 6.31.

Determination of Isomer Ratios in Diazepinol Cyclizations.—Solutions of 200-300 mg of the diazepinols **3a–e** in 250 ml of Spectrograde methanol were irradiated with a 200- or 400-W medium-pressure lamp until A_{315} was constant; the time required varied from 10 min for **3e** to 100 min for **3a** (*cf.* Table III). The solutions were then evaporated to an oily or solid residue; after removal of all solvent at 0.1 mm, the residues, except for that from **3a**, were dissolved completely in 1.5–2.0 ml of $CDCl_3$. The mixture from **3a** was dissolved in acetic acid.

The nmr spectra of these mixtures contained negligible peaks for the diazepinols. The scans were made at 250 sweep width over a 27-Hz region containing the H-7 signals of the photoalcohols (6.4–6.8 ppm). Areas of the peaks from each isomer were calculated from height and $W_{1/2}$ (about 2 Hz) for each scan, and the average values were used to derive the ratios given in Table I. The same procedure was applied also to the $N-CH_3$ or $N-COCH_3$ peaks in the mixtures from **3b**, **3c** and **3e**. The ratios from these measurements differed by less than 2% from those calculated from the H-7 peaks.

4-*exo*-*d*-4-*endo* Alcohols.—Reductions of the bicyclic ketones **2b**, **2c**, and **2d** were carried out using 400-mg samples of **2** and 80 mg of $NaBD_4$ (Merck Sharp and Dohme) by the procedures described for the $NaBH_4$ reductions. The ir spectra of these 4-*d* alcohols showed several distinct differences from those of the 4-^{1}H compounds in the 800–1200-cm^{-1} region. The spectra (KBr) contain about eight to ten strong or medium bands in this region, and most of these differed in position and relative intensity. In the spectra of the 4-*d* derivatives of **4b**, **4c**, and **4d**, there were strong bands at 1120–1150 and 820–860 cm^{-1} which were either extremely weak or shifted by as much as 50 cm^{-1} in the spectra of the 4-^{1}H compounds.

Photocyclization Rate Comparison. Apparatus.—A Hanovia 100-W utility lamp with U-shaped quartz arc tube 616A-13 was mounted horizontally. Directly in front of the lamp were placed in sequence a Pyrex heat shield, a 1-cm Pyrex cuvette with circulating water, a 7-54 Corning glass filter, and a 1-cm Pyrex cuvette containing a filter solution of 145 g/l. of $NiSO_4$ and 44.5 g/l. of $CoSO_4$. The uncollimated beam was passed through a 1.3 × 1 cm shuttered aperture in a box with a removable lid. The solution to be irradiated was placed in a standard 1-cm quartz cuvette mounted about 1 cm from the aperture. A stirring bar was placed in the cell and positioned over a rotating magnetic stirrer. The temperature inside the box was maintained at 24–25° by means of a circulating air stream. The lamp output with this filter system was measured by the standard potassium ferrioxalate system[26] to be $I_0^i = 7.6 \times 10^{14}$ quanta/sec.

For irradiation at the long wavelength maximum of the ketones (Table IV), the same lamp was used with heat shield and water-cooled cuvette and a narrow band pass (CS-5-62) filter with 30% transmittance at 390 mμ. The intensity I_0^i was 9.8×10^{13} quanta/sec.

Procedure.—A solution of the diazepine was diluted in the quartz cuvette with the appropriate solvent (Spectrograde methanol or hexane) to a measured optical density of 0.72–0.75. The cuvette was then placed in the holder and irradiated for appropriate time intervals; optical density was measured with a Cary Model 14 spectrophotometer. In general, ten readings were made during the first half-life time. For all ketones except the 2-acetyldiazepinone **1c**, the reaction was followed using the 390–410-mμ maximum, and concentrations were derived directly. For the 2-acetyl ketone **1c** and the 2-unsubstituted and 2-methyldiazepinols **3a** and **3b**, the concentrations were calculated by measurements of the maxima of the diazepine at 300–315 mμ and of the bicyclic product at 260–270 mμ. For the remaining diazepinols **3c**, **d**, and **e**, the bicyclic alcohol absorption at 315 mμ was neglected.

Registry No.—**1a**, 1706-26-9; **1a**·HCl, 17838-72-1; **1a** semicarbazone, 17827-16-6; **1b**, 4084-21-3; **1c**, 4134-95-6; **1c** semicarbazone, 17827-19-9; **1d**, 17827-20-2; **2a**, 17827-21-3; **2a** semicarbazone, 17827-22-4; **2b**, 17827-23-5; **2c**, 3988-19-0; **2c** semicarbazone, 17827-25-7; **2d**, 17827-26-8; **3a** (*exo*), 17827-63-3; **3a** (*endo*), 17827-64-4; **3b** (*exo*), 17827-65-5; **3b** (*endo*), 17827-66-6; **3c** (*exo*), 17827-67-7; **3c** (*endo*), 17827-68-8; **3d** (*exo*), 17827-69-9; **3d** (*endo*), 17827-70-2; **3e** (*exo*), 17827-71-3; **3e** (*endo*), 17827-72-4; **4a**, 17831-28-6; **4b**, 17831-30-0; **4c**, 17831-29-7; **4d**, 17831-31-1; **4e**, 17831-32-2; **4f**, 17831-33-3; **5a**, 17831-34-4; **5b**, 17831-35-5; **5c**, 17831-36-6; **5d**, 17831-37-7; **5e**, 17831-38-8; **5f**, 17831-39-9; **6**, 17831-40-2; **7**, 17831-41-3; **8e**, 17831-42-4; **8f**, 17831-43-5; 4-acetoxy-2-benzoyl-5-methyl-6-phenyl-2,3-dihydro-4H-1,2-diazepine, 17827-27-9.

(26) C. G. Hatchard and C. A. Parker, *Proc. Roy. Soc.* (London), **A235**, 518 (1956).

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1,3-Dipolar and Diels–Alder Cycloaddition Reactivity of Lumisantonin[1]

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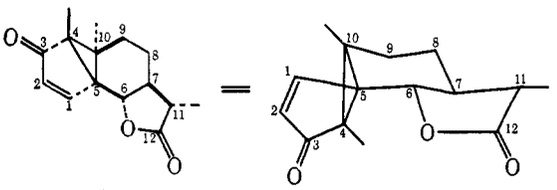
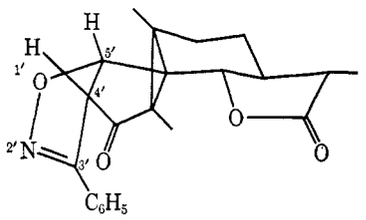
Some double-bond derivatives of lumisantonin (**1**) were prepared by its 1,3-dipolar and Diels–Alder cycloaddition reactions. Benzonitrile oxide, α,N-diphenylnitrone, and diazomethane afforded the corresponding 1:1 adducts **2**, **3a**, **3b**, and **4**, respectively, but diphenylnitrilimine, phenyl azide, and tosyl azide did not give any adduct. The pyrolysis and photolysis of **4** afforded 1-methyl lumisantonin (**5**) and 1,2-methylene lumisantonin (**6**), respectively; **6** was surprisingly stable on heating at 250°. The Diels–Alder reactions with cyclopentadiene, furan, isoprene, and myrcene were investigated, but only cyclopentadiene gave the corresponding 1:1 adduct **8a**. In the reactions with isoprene and myrcene, pyrolumisantonin was produced in very low yields as a by-product.

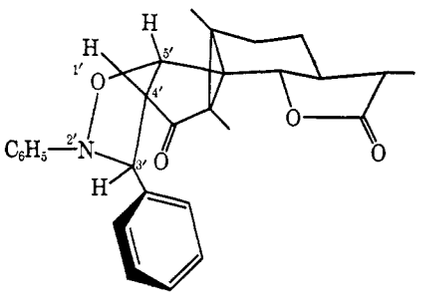
Although a number of double-bond derivatives of santonins and their derivatives have been reported,[2] only little about those of lumisantonin (**1**) has been known.[3] In aiming to prepare some double-bond derivatives of **1**, its 1,3-dipolar and Diels–Alder cycloaddition reactions were investigated. As the 1,3 dipoles were utilized, benzonitrile oxide, α,N-diphenylnitrone, diazomethane, diphenylnitrilimine, and phenyl and tosyl azide, the former three gave the corresponding adducts, **2**, **3a**, **3b**, and **4**, respectively, but the latter



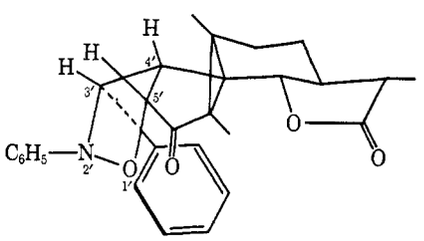
1



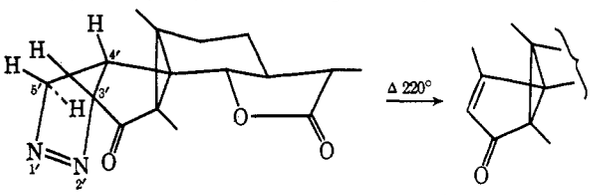
2



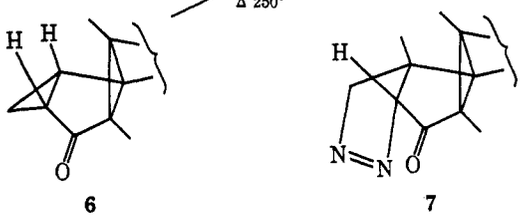
3a



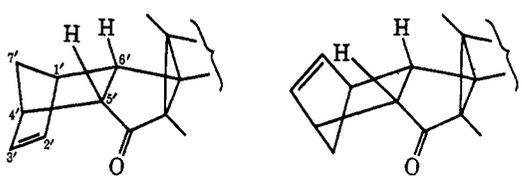
3b



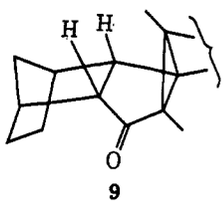
4 **5**



6 **7**



8a **8b**



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(1) Part III in the series of "Studies on the Reactions of Isoprenoids." Part II: T. Sasaki and S. Eguchi, *Bull. Chem. Soc. Jap.*, **41**, 2453 (1968).

(2) See, for example, J. B. Hendrickson and T. L. Bogard, *J. Chem. Soc.*, *B*, 1678 (1962).

(3) For pioneering works on lumisantonin and its stereochemistry, see (a) D. Arigoni, H. Bosshard, H. Bruderer, G. Büchi, O. Jeger, and L. J. Krebaum, *Helv. Chim. Acta*, **40**, 1732 (1957); (b) W. Cocker, K. Crowley, J. Edwards, T. B. H. McMurry, and E. R. Stuart, *J. Chem. Soc.*, 3416 (1957); (c) D. H. R. Barton, P. de Mayo, and M. Shafiq, *ibid.*, 140 (1958); (d) D. H. R. Barton, and P. T. Gilham, *ibid.*, 4596 (1960); (e) D. H. R. Barton, J. T. Pinhey, and R. J. Wells, *ibid.*, 2518 (1964).