and the residue was examined by tlc as described in the previous experiment. In this manner starting material, two new and unknown substances and no epoxide i or dihydroxy ketone **7** were detected.

Acid-Catalyzed Hydrolysis and Rearrangement of the Proposed Transannular Epoxide to the Proposed 5α,11α-Dihydroxy-4-pregnane-3,6,20-trione 3,20-Bis(cyclic ethylene acetal) 11-Acetate (ii).—The photolysis product (i) above (120 mg) was suspended in 15 ml of methanol, the solution heated on a steam bath, and treated with 1 ml of 3 *N* hydrochloric acid (dropwise). The solution was allowed to come to room temperature overnight. The solution was then diluted to 30 ml with water and the alcohol was removed under reduced pressure. The residual semisolid was separated and crystallized fractionally (decant from oil) from acetone–Skellysolve B, mp 171.5–174°. A single recrystallization provided an analytical sample: ν_{max} 3070 (bonded OH), 1737, 1675, 1608, and 1245 cm^{-1}; λ_{max} 231 mμ (11,550).

Anal. Calcd for $C_{23}H_{30}O_6$: C, 67.71; H, 8.09. Found: C, 68.63; H, 7.51.

6β-Azido-5α-hydroxycholestan-3-one Cyclic Ethylene Ketal (12).—A sample of epoxide 11[26] containing some β isomer (5.15 g, mp 101–112°) dissolved in dioxane (100 ml) was treated with sodium azide (1.4 g) and *p*-toluene sulfonic acid (100 mg), dissolved in water (25 ml), and the solution heated to reflux for 7 days. The dioxane was distilled under reduced pressure and the residue suspended in water (200 ml). The product was extracted into methylene chloride. The combined extracts were washed with water, saturated sodium chloride solution, and dried (Na_2SO_4). The methylene chloride solution was adsorbed onto a column of Florisil (350 g) and eluted over a linear gradient of from 2 to 10% acetone–petroleum ether during 25, 400-ml fractions. Fractions 3–5 proved by tlc (silica gel G, 25% ethyl acetate–cyclohexane) to be a mixture of the azide and epoxide. These fractions (3.83 g) were adsorbed onto a 4.0 × 42 cm column of silica gel made up with cyclohexane and the column eluted with 25, 50-ml portions of ethyl acetate–cyclohexane (1:3). Fractions 7–10 (1.17 g) were combined and recrystallized from acetone–methanol, 1.05 g of azide, mp 89.5–91°. A sample was recrystallized for analysis with no change in melting point: ν_{max} 3460, 2080, 1190, 1170, 1100, and 1025 cm^{-1}.

Anal. Calcd for $C_{29}H_{49}N_3O_3$: C, 71.41; H, 10.31; N, 8.62. Found: C, 71.29; H, 10.05; N, 8.80.

6β-Azido-5α-hydroxycholestan-3-one (13).—The above ketal (**21**) (700 mg) dissolved in 15 ml of acetic acid with warming and further treated with 2 ml of water. The solution, after standing overnight at room temperature, was diluted with 50 ml of water, whereupon a solid precipitated. The product was isolated, washed with water, and recrystallized from acetone to give 530 mg, mp 180–182° dec. The sample was recrystallized three times from acetone for analysis: mp 182.5–184.0°; λ_{max}^{EtOH} 228 mμ (ε 1050); ORD (dioxane) $[M]_{372.5,min}$ −1001°, $[M]_{317.5,max}$ −97°, $[M]_{470}$ −702°; infrared spectrum consistent with structure.

Anal. Calcd for $C_{27}H_{45}N_3O_2$: C, 73.09; H, 10.22; N, 9.47. Found: C, 72.86; H, 10.41; N, 9.55.

Acknowledgment.—The author wishes to thank the Physical and Analytical Chemistry Department of the Upjohn Company for analytical and spectroscopic data, A. J. Taylor for technical assistance, and Dr. Fred Kagan for helpful discussions during the preparation of this manuscript.

(26) G. Cooley, B. Ellis, D. N. Kirk, and V. Petrow, *J. Chem. Soc.*, 4112 (1957).

Stereoisomerism of 5-(α-Hydroxy-α-2-pyridylbenzyl)-7-(α-2-pyridylbenzylidene)-5-norbornene-2,3-dicarboximide, a Selective Rat Toxicant[1,2]

R. J. MOHRBACHER, H. R. ALMOND, JR., E. L. CARSON, J. D. ROSENAU, AND G. I. POOS

Department of Chemical Research, McNeil Laboratories, Inc., Fort Washington, Pennsylvania

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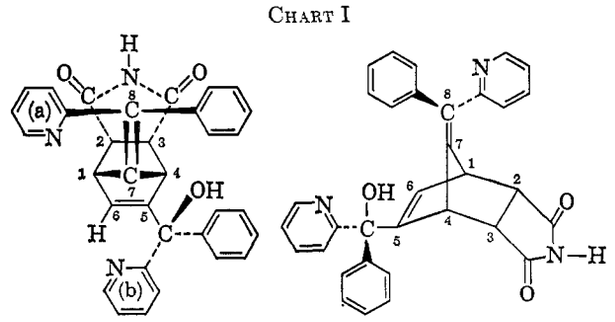
The eight possible racemates of norbormide **2**[2] were isolated and characterized. Assignments of stereochemistry are presented in Table I. The *endo–exo* assignments were based on (1) the preponderance of *endo* isomers from the Diels–Alder synthesis, (2) the thermal isomerization of *endo* to *exo* isomers, and (3) the downfield location in the nmr spectra of the resonance peaks of the 2,3-protons of *endo* isomers relative to the corresponding peaks of the *exo* isomers. The *cis–trans* assignments are based on the relative positions of the 1- and 4-proton peaks, the *trans* isomer having the 1-proton peak downfield. Photochemical isomerization indicated that *trans* to *cis* was the preferred conversion and demonstrated which *endo* (or *exo*) isomers had the same configurations of substituents on the carbinol carbon. These assignments based on chemical and spectral data have been confirmed by an independent X-ray study which also permitted *erythro–threo* designations to be made for the four *endo* isomers.

The selective toxicity of norbormide **2**[2] to members of the genus *rattus* has been reported.[3a] It is not lethal to any of the other 38 species of mammals (including ten rodent species), fish, or fowl tested, generally at 100 times the dose lethal to rats.[3b] The observation[3a] that a very considerable difference in rat toxicity existed among several of the isomers which comprise norbormide led us to obtain all of the isomers and investigate them in detail.

Two representations of a norbormide isomer are illustrated in Chart I. The molecule has four elements

CHART I



trans–endo–erythro-orbormide (**2**)

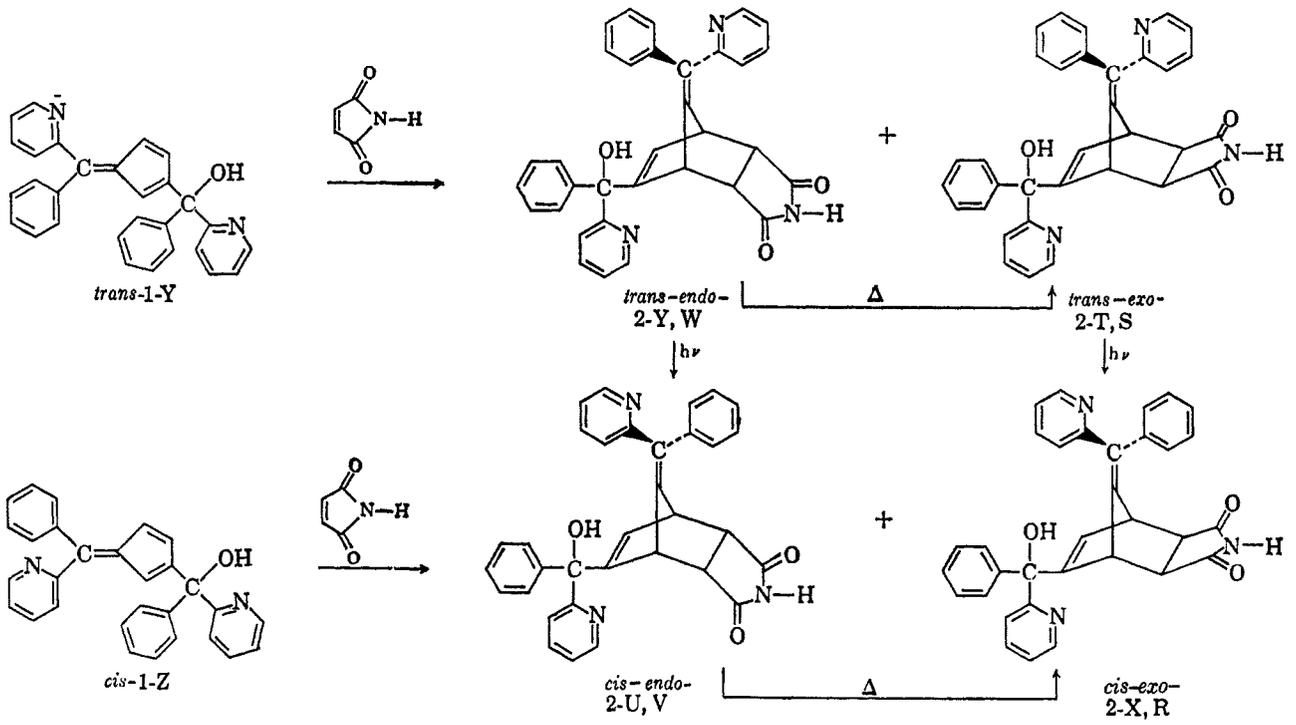
of dissymmetry which give rise to eight racemates. There are five asymmetric carbon atoms: the carbinol carbon and atoms 1–4. Owing to the restriction of *cis* bridging across atoms 1 and 4 and the *cis* fusion of the imide at C-2 and C-3, each of these pairs is equivalent to one asymmetric carbon. Thus, three asymmetric

(1) Presented in part before the Division of Medicinal Chemistry, 149th National Meeting of the American Chemical Society, Detroit, Mich., April 1965.

(2) Norbormide is the common name of the mixture of stereoisomers of 5-(α-hydroxy-α-2-pyridylbenzyl)-7-(α-2-pyridylbenzylidene)-5-norbornene-2,3-dicarboximide (**2**).

(3) (a) A. P. Roszkowski, G. I. Poos, and R. J. Mohrbacher, *Science*, **144**, 412 (1964); (b) A. P. Roszkowski, *J. Pharmacol. Exptl. Therap.*, **149**, 288 (1965).

CHART II



elements lead to eight isomers. Geometric isomerism caused by different substituents on C-8 doubles the number to 16 isomers or eight racemates. In addition to using the *endo–exo* convention, we have arbitrarily defined two configurations of norbormide as follows. (1) *cis–trans*—The isomer in which the pyridyl group (a) is on the side opposite the carbinol group is assigned the *trans* configuration. (2) *erythro–threo*—The isomer with the hydroxyl group in the same plane as the methylene double bond (and above the norbornene ring as seen in Chart I) and in which pyridyl group (b) is on the same side as the hydrogen atom on C-6 is assigned the *erythro* configuration.

The structural assignments that we have been able to make for the eight racemates of norbormide are given in Table I. The letter designations "R–Y" are arbitrary and have no structural or chemical significance.

TABLE I

STRUCTURAL ASSIGNMENTS OF ISOMERS OF NORBORMIDE 2

trans isomers	*cis* isomers
endo–threo-2-Y	*endo–threo*-2-V
endo–erythro-2-W	*endo–erythro*-2-U
exo-2-T[a]	*exo*-2-R[a]
exo-2-S[a]	*exo*-2-X[a]

[a] Isomers 2-R and -T have the same *erythro* (or *threo*) configurations which are opposite that of the *threo* (or *erythro*) pair 2-S and -X.

Results and Discussion

Reaction of the mixture of *cis*- and *trans*-fulvenylmethanols 1[4,5] with maleimide in refluxing benzene solution gave a 90% yield of a mixture of stereoisomers 2 in which five racemates comprised 96% of the product (see Table II).

One paper strip (psc) and three thin layer (tlc) chromatographic systems were developed for the qualitative and quantitative[6] detection and separation of the isomers.

The five predominant isomers of norbormide (2-U–Y) were separated by either fractional crystallization, chromatography, or both. The other three isomers of 2 (R–T) were obtained by thermal isomerization of the *endo* isomers and were separated by chromatography. These procedures were very tedious and only milligram quantities of the pure compounds were obtained. Chemical and spectral data characterizing the eight racemates are given in Tables II and III.

The *cis* and *trans* isomers of norbormide were also obtained from the corresponding *cis*- and *trans*-fulvenylmethanols (Chart II). *cis–trans* assignments were made to the fulvenylmethanols 1 based on the configurations of their maleimide adducts (see below). Thus, the reaction of *cis*-fulvenylmethanol-1-Z with maleimide afforded the four *cis* isomers, 2-R,U,V,X, in 90% yield with the *endo* isomers 2-U,V comprising 80% of the mixture. *exo* isomer 2-X and a trace of isomer 2-R accounted for 20% of the mixture. In a similar manner *trans*-fulvenylmethanol-1-Y afforded the *trans* isomers of norbormide in 90% yield. The *trans–endo* isomers 2-Y,W accounted for 99% of the product. *trans–exo*-2-T was present to the extent of about 1% while *trans–exo* isomer 2-S was not detected in the reaction product.

The stereoisomeric composition of the reaction products from 1 and maleimide obtained at 25 and 80° was very similar[7] with the *endo* adducts 2-U,V,W,Y accounting for approximately 85% of the total mixture. The predominance of *endo* isomers is in agreement with earlier work describing the Diels–Alder reactions of di-

(4) Derived from 2-benzoylpyridine and cyclopentadienyl sodium in 72% yield (ref 3a).

(5) R. J. Mohrbacher, V. Paragamian, E. L. Carson, B. M. Puma, C. R. Rasmussen, J. A. Meschino, and G. I. Poos, *J. Org. Chem.*, **31**, 2149 (1966).

(6) A quantitative assay for the isomers of norbormide has been developed in these laboratories by Dr. C. Janicki.

(7) A 96% conversion of 1 to 2 required 10 days at 25°.

TABLE II

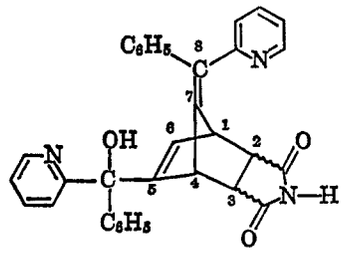
ISOMERS OF NORBORMIDE 2[a]

Isomer	Mp, °C	Recrystn solvent	Compn of mixture, %[b]	λ_{max},[c] mμ (ε)	Found,[d] % C	H	N
Y	192–195	Ethyl acetate	29	251 (16,200)	77.09	5.00	7.90
W	180–183	Ethyl acetate	16	248 (15,600)	77.63	5.02	8.06
V	225–226.5	Ethyl acetate	26	250 (17,900)	76.98	4.99	8.10
U	207–210	Ethyl acetate	14	248 (15,600)	*e*		*e*
T	230–231	Ethanol	<2	247 (14,900)	*e*		8.20
S	218–220	Ethanol	*f*	248 (11,700)	*e*		*e*
R	188–190	Chloroform–hexane	<1	247 (12,400)	76.10[g]	5.18[g]	7.77[g]
X	239	Ethanol–ether	11	244 (16,900)	77.68	5.17	8.25
Mixture[b]	190–198	Methylene chloride–ether	...	248 (16,500)	77.61	5.05	7.92

[a] The infrared spectra were very similar: λ_{max}^{KBr} 2.95, 5.76 (w), and 5.84 (s) μ. [b] Determined by quantitative tlc (see ref 6) for a typical mixture obtained from 1-Y and -Z and maleimide at 80°. [c] Broad maxima in methanol. In acidic methanol, λ_{max} 240 (17,200), 260 (sh) (14,500), 305 (6,500). [d] Calcd for $C_{33}H_{25}N_3O_3$: C, 77.48; H, 4.93; N, 8.22. [e] Insufficient material available for microanalysis. [f] Not detectable. [g] Calcd for $(C_{33}H_{25}N_3O_3)_2 \cdot H_2O$: C, 76.14; H, 5.03; N, 8.07.

TABLE III

NMR SPECTRA OF NORBORMIDE ISOMERS



2

Isomer	Solvent	Chemical shifts of the proton resonance peaks, δ[a] 2,3-Protons	1-Proton	4-Proton	6-Proton
endo 2-Y	DMF-d_7	3.45–3.83[b]	4.38	3.45–3.83[b]	5.74
	$CDCl_3$	3.40–3.66	4.44	3.98	5.67
2-W	DMF-d_7	3.32–3.85[b]	4.33	3.32–3.85[b]	5.90
	$CDCl_3$	3.30–3.75[b]	4.37	3.30–3.75[b]	6.07
2-V	DMF-d_7	3.58–3.78[b]	3.58–3.78[b]	4.24	5.75
	$CDCl_3$	3.50–3.63	3.87	4.30	5.67
2-U	DMF-d_7	3.38–3.72[b]	3.38–3.72[b]	4.00	5.94
	$CDCl_3$	3.46–3.59	3.85	4.12	6.09
exo 2-T	DMF-d_7	2.80, 3.03	4.20	3.62	6.00
	$CDCl_3$	2.89, 3.25	4.32	3.80	5.78
2-S	DMF-d_7	2.94	4.25	3.48–3.60[c]	6.28
	$CDCl_3$	2.91, 3.03	4.27	3.53	6.20
2-R	DMF-d_7	~3.13, ~3.40[c]	3.64	3.95	5.98
	$CDCl_3$	2.98, 3.42	3.75	4.11	5.77
2-X	DMF-d_7	2.93	3.68	3.88	6.27
	$CDCl_3$	----------Insoluble----------			

[a] Chemical shifts given in parts per million (ppm) downfield from tetramethylsilane (TMS). In almost all cases, the integrated intensities for the resonance peaks were within 10–15% of theoretical. [b] Because of considerable overlapping of resonance peaks, precise assignment of portions of the curve to specific protons was difficult. [c] The precise location of the resonance peak was difficult to measure because impurities in the solvent exhibited resonance peaks in this area.

phenylfulvene with maleic anhydride[8,9] or maleimide.[9]

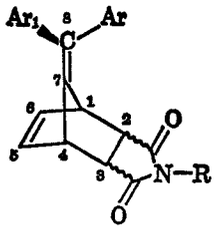
Isomerization studies were carried out in an effort to establish stereochemical interrelationships as well as to prepare isomers 2-R–T in sufficient quantity for isolation. As shown in Chart II, the *endo* isomers could be thermally converted to *exo* forms. Thus a mixture of *endo*-2-U,V (or pure 2-V) gave predominantly *exo*-2-R and -X and minor amounts of the two *endo* compounds. Similarly, a mixture of *endo*-2-Y,W (or pure 2-Y) gave mainly the *exo* isomers 2-S and -T and traces of *endo*-2-W and -Y. Among isomeric diphenylfulvene Diels–Alder adducts, *exo* isomers are thermodynamically favored over *endo* isomers.[8,9] Attempts to isomerize *exo* compounds 2-T and -X thermally gave evidence of formation of only small amounts of the corresponding *endo* forms. The generation of the other three *cis* (or *trans*) isomers from one *endo* isomer demonstrated that the conversion involved a reversible generation of fulvene 1, whose presence was demonstrated by tlc and ultraviolet spectra. In no case was there evidence of any *cis–trans* interconversion.

Ultraviolet photolysis of the isomers effected *trans–cis* isomerization. In methanol solution, ultraviolet exposure gave a 35% conversion of isomer 2-Y to 2-V. The reverse experiment under the same conditions failed to give any significant conversion. However, under considerably longer exposure, approximately 5% conversion of 2-V to 2-Y was observed. Similarly, 2-W

(8) K. Alder, F. W. Chambers, and W. Trimborn, Ann., **566**, 27 (1950).
(9) G. I. Poos, M. M. Lehman, E. B. Landis, and J. D. Rosenau, *J. Med. Pharm. Chem.*, **5**, 883 (1962).

TABLE IV

NMR SPECTRA OF NORBORNENEDICARBOXIMIDES



Compd	Ar	Ar1	R	Solvent	Chemical shifts of the proton resonance peaks, δ[a] 2,3-Protons	1-Proton	4-Proton	5,6-Protons
endo-**3**	C_6H_5	2-C_5H_4N	H	DMF-d_7	3.47–3.67[b]	3.47–3.67[b]	4.25	6.48
				$CDCl_3$				
exo-**3**	C_6H_5	2-C_5H_4N	H	DMF-d_7	2.92	3.77	4.10	6.71
				$CDCl_3$				
endo-**4**	2-C_5H_4N	2-C_5H_4N	H	DMF-d_7	3.59	4.05	4.05	6.44
				$CDCl_3$				
exo-**4**	2-C_5H_4N	2-C_5H_4N	H	DMF-d_7	2.94	3.96	3.96	6.60
				$CDCl_3$				
endo-**5**	C_6H_5	C_6H_5	CH_3	DMF-d_7	3.62–3.72[b]	3.62–3.72[b]	3.62–3.72[b]	6.34
				$CDCl_3$	3.46	3.93	3.93	6.35
exo-**5**	C_6H_5	C_6H_5	CH_3	DMF-d_7	2.92	3.62	3.62	6.62
				$CDCl_3$	2.82	3.76	3.76	6.53
endo-**6**	C_6H_5	2-C_5H_4N	CH_3	DMF-d_7	3.60–3.68[b]	3.60–3.68[b]	4.22	6.33
				$CDCl_3$	3.37, 3.58	3.82	4.40	6.35
endo-**7**	C_6H_5	C_6H_5	H	DMF-d_7	3.48–3.78[b]	3.48–3.78[b]	3.48–3.78[b]	6.45
				$CDCl_3$	3.49	3.89	3.89	6.43

[a] See footnote *a*, Table III. [b] See footnote *b*, Table III.

was converted to 2-U in 30% yield. The reverse isomerization again proceeded to only a small extent. Isomers 2-T and 2-X were converted to 2-R and 2-S, respectively. No other elements of dissymmetry (*e.g.*, *erythro–threo*) were effected in these experiments even under more vigorous conditions.

Nuclear Magnetic Resonance Spectra

The assignments of the norbornene proton signals in the nuclear magnetic resonance spectra (nmr) of the isomers of norbormide and a series of model norbornenedicarboximides are listed in Tables III and IV, respectively. The proton signals of the 1-, 2-, 3-, and 4-protons overlapped in many cases (Figure 1, 2-Y). However, the assignments were facilitated by the dissimilar substitution on C-8 and at the 5,6 olefinic positions. Correlation of the nmr spectra of norbormide isomers with those of the *endo* and *exo* isomers of the norbornenedicarboximide **5**, whose stereochemistry has been demonstrated,[9] was particularly useful.

Assignment of 2,3-Protons.—The difference between the coupling of the bridgehead protons with the *exo* and *endo* 2,3-protons of norbornenes[10] ($J_{12\ exo}$ = 3.2–5.0 cps and $J_{12\ endo} \cong 0$ cps) is well known.[11] Thus, the *endo* 2,3-protons of the *exo* isomers (**3**,**4**,**5**,2-R,S,T,X), which couple only with each other, are observed as sharp AB patterns.[12] On the other hand, the bridgehead (1,4) protons of these *exo* compounds which interact with the vinyl protons, can form A_2X_2 splitting patterns in the model compounds and AMX patterns in the isomers of norbormide. On this basis, the sharp two-proton resonance signals in the spectra of *exo* isomers were assigned to the 2,3-protons and the broad multiplets to the 1,4-protons. The resonance signals for the bridgehead protons were observed as two-proton multiplets for the symmetrically substituted (at C-8) model compounds (*exo*-**4** and -**5**) or as two, single-proton multiplets for those compounds (*exo*-**3**,2-R,S,T,X) with dissimilar methylene substitution (see Figure 1, 2-X).

Comparison of the chemical shifts of these *exo* isomers with those of the corresponding *endo* compounds allows assignments of the 2,3-proton signals of *endo* isomers. It is well known that *exo* 2,3-protons are deshielded relative to *endo* 2,3-protons.[11a,13] The peaks assigned to the *exo* 2,3-protons of *endo* isomers are observed substantially downfield (~0.5 ppm) from the 2,3-proton peaks of the *exo* isomers (Tables III and IV). By contrast, the 1,4-proton peaks of *endo* isomers are only slightly downfield (<0.2 ppm) compared with those of *exo* isomers. In the isomers of norbormide (Table III), the observed deshielding of *exo* 2,3-protons (δ 3.60–3.85) relative to *endo* 2,3-protons (δ 2.80–3.40) reinforces the *endo*/*exo* structural assignments based on chemical evidence.

Assignments of 1- and 4-Protons.—The difference between the coupling of the 1- and 4-protons of norbormide isomers is their interaction with the vinyl proton (at C-6). The vicinal coupling (J_{16} = 2.4–3.8 cps)[11,13] of the 1-proton is substantially greater than the allylic coupling (J_{46} = 0.5–1.0 cps)[11] of the 4-proton. Thus the 1- and 4-proton signals of norbormide isomers can be distinguished from each other by the broader width of the 1-proton peak. This is more easily seen in the less complicated spectra of the *exo* isomers

(10) Comparison of Dreiding Stereomodels of norbornenedicarboximides with norbornene showed only slight differences in the H–C_1–C_2–H dihedral angles. Thus, it has been assumed that similar couplings should apply.

(11) (a) P. Laszlo and P. von R. Schleyer, *J. Am. Chem. Soc.*, **86**, 1171 (1964), and references cited therein; (v) J. C. Davis, Jr., and T. V. Van Auken, *ibid.*, **87**, 3900 (1965).

(12) Except where isochronous (having the same chemical shift) (see below).

(13) P. M. Subramanian, M. T. Emerson, and N. A. LeBel, *J. Org. Chem.*, **30**, 2624 (1965).

(see Figure 1), but can also be seen[14] in the *endo* isomers. A double resonance experiment with *endo* isomer 2-V confirmed the 1- and 4-proton assignments. Irradiation of the 1,2,3-proton multiplet caused the resonance peak for the downfield proton to collapse essentially to a singlet, indicating that it was the 4-proton peak.

The aryl groups on C-8 exert a significant field effect on the bridgehead proton and a lesser effect on the 2,3-protons. These aryl groups are conjugated with the 7,8-ethylenic bond and, therefore, are in nearly the same plane as, and in proximity to, the bridgehead protons. The difference in the field effects of dissimilar aryl groups (phenyl *vs.* 2-pyridyl) can be readily demonstrated by comparing the chemical shifts of the bridgehead protons of the model compounds. In compound **5** (both 8-substituents phenyl), the 1,4-proton bands occur at the same chemical shift (*endo* or *exo*, δ ~3.62). When one of the phenyl substituents on C-8 is replaced by 2-pyridyl, one bridgehead proton remains at the same chemical shift (δ 3.60–3.77 for compounds **3** and **6**) and the other bridgehead proton of these compounds shifts downfield (δ 4.10–4.25). When both of the "overhead" aryl groups are pyridyl, both bridgehead protons are shifted downfield (δ 3.96–4.05 for compound **4**). Thus it can be seen that the 2-pyridyl ring has a stronger deshielding effect than does the phenyl ring. Application of these observations to the spectra of the isomers of norbormide is complicated by a field effect of the substituents on the carbinol carbon. However, this effect, which is greater on the 4-proton than it is on the 1-proton, is significantly less than that exerted by the "overhead" aryl groups. Thus the bridgehead proton under the pyridyl group exhibits its resonance signal downfield of the signal given by the other bridgehead proton.

Configurational Assignments.—With the proton assignments in hand, certain configurational aspects of the isomers of norbormide can be deduced. The stronger deshielding effect on the bridgehead proton by an "overhead" pyridyl group (on C-8) compared with that of a phenyl group allows assignment of *cis–trans* configurations. Those isomers of norbormide with a chemical shift of the 1-proton downfield from that of the 4-proton (2-Y,W,T,S, see Table III) have the pyridyl group over the 1-proton and, therefore, possess *trans* configurations. Isomers with the 4-proton bands downfield of the 1-proton bands have *cis* configurations (2-U,V,X,R). Figure 1 illustrates the spectra of a *cis* and a *trans* isomer. These conclusions from the nmr spectra are in agreement with both the genesis of these compounds from the geometrically isomeric fulvenylmethanols[15] (see Chart II) and with the photochemical isomerization studies.

Certain observations of general interest can be made from the nmr spectra of the compounds studied. In $CDCl_3$ solution,[16] the 2,3-*endo* protons of *exo* isomers **2**-R–T exhibit AB patterns, J_{23} = 7.0, 7.5, and 7.25 cps, respectively.[17] The displacement (*ca.* δ 0.25)

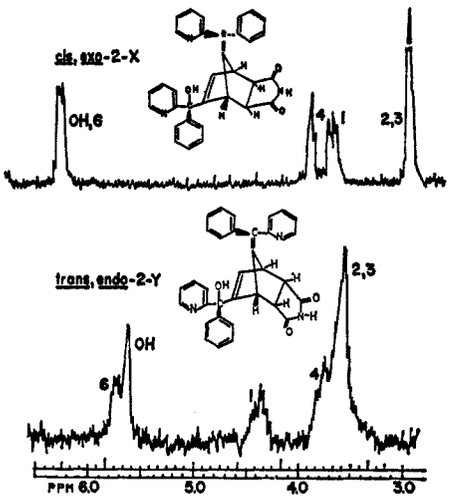


Figure 1.—Spectra of *trans–endo*-norbormide 2-Y and *cis–exo*-norbormide 2-X in DMF-d_7 solution.

of the resonance peaks for the *endo* 2- and 3-protons in these *exo* isomers is probably due to a field effect of the nearby substituents attached to the carbinol carbon. Fortuitously, the 2,3-protons of isomers **2**-S and X are isochronous in DMF-d_7 solution.[14,18] Unfortunately, the limited solubility of isomers **2**-S and -X prevented studying these solvent effects more extensively.

Comparison of the resonance signals of individual protons (Table III) of isomers opposite each other in Table I [which have the same *erythro* (or *threo*) configuration] demonstrates a near identity in chemical shifts which undoubtedly is related to structural similarity.

These structural assignments were recently confirmed by an X-ray diffraction analysis of a *p*-bromobenzyl derivative of isomer **2**-V.[19] These studies verified the *cis–endo* assignment and revealed a *threo* configuration at the carbinol carbon atom for **2**-V.

Since **2**-V possesses the *threo* configuration, its *cis–trans* mate, **2**-Y, must be a *threo* isomer. Therefore, the other pair of *endo* isomers, **2**-U and **2**-W, possess the *erythro* configuration.

erythro–threo assignments of the *exo* isomers cannot be made from the available data because thermal isomerization of an *erythro* (or *threo*) *endo* isomer generated both the *erythro* and *threo exo* isomers.

The raticidal activity of the isomers of norbormide which is reported more fully elsewhere[20] differed markedly, isomer **2**-V being at least 70 times more lethal to rats than isomer **2**-X.

Experimental Section

All melting points are corrected and were taken with a Kofler melting point apparatus unless otherwise specified. Infrared spectra were determined with a Perkin-Elmer Model 21 spectrom-

(14) Better separations of the resonance peaks were observed in $CDCl_3$ than in DMF-d_7 solutions.

(15) The *cis–trans* configurations of the Diels–Alder adducts **2** are the basis for assigning fulvenylmethanol **1**-Y the *trans* structure and **1**-Z the *cis* structure.

(16) *exo* isomer **2**-X is too insoluble in $CDCl_3$ to obtain the nmr spectrum, but in trifluoroacetic acid solution exhibited an AB pattern, J_{23} = ~7.5 cps.

(17) This appears to be one of the few cases in which a $J_{23\ endo,\ endo}$ can be observed for a norbornene symmetrically substituted at the 2,3 positions.

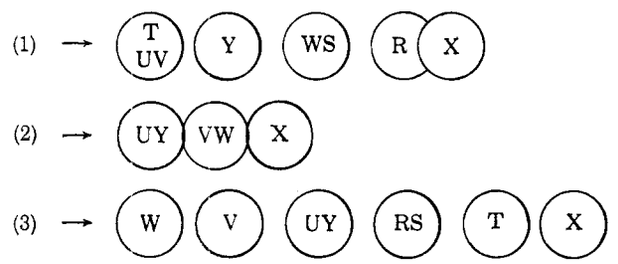
(18) *cis–exo*-**2**-X and *trans–exo*-**2**-S have identical configurations of the substituents on the carbinol carbon atom (see photochemical isomerization results above). Isomers **2**-X,S may have preferred conformations in DMF-d_7, unattainable by isomers **2**-T,R, which negate the field effect of the carbinol group substituents on the 2,3-protons.

(19) S. Abrahamsson, *et al.*, paper in preparation.

(20) G. I. Poos, R. J. Mohrbacher, E. L. Carson, V. Paragamian, B. M. Puma, C. R. Rasmussen, and A. P. Roszkowski, *J. Med. Chem.*, **9**, 537 (1966).

eter and ultraviolet spectra with a Cary Model 14 spectrometer. The nmr spectra were determined with a Varian A-60 spectrometer at ambient temperature. The solutions, in $CDCl_3$ or DMF-d_7, were approximately 20% (w/v) or saturated. Tetramethylsilane was used as an internal standard. The chemical shifts and coupling constants are probably accurate to within δ ± 0.03 and ± 0.2 cps, respectively. The double resonance experiment was done on a Varian HA-100 spectrometer using frequency sweep conditions.

Thin Layer Chromatography. A. Qualitative.—To glass plates (2 × 8 in.) coated with absorbent were applied samples of 2–100 μg dissolved in a suitable solvent. The plates were developed in a sealed tank until the solvent front had run close to the top of the plate. After drying, the plates were redeveloped one to five times depending on the separation, which was followed by examining the plates under short wavelength ultraviolet light in the dark. The isomers of norbormide appeared as light blue fluorescent spots. Iodine vapor can also be used for detection. Three systems of absorbents and solvent were most generally used: (1) silica gel G, chloroform–ethyl acetate (3:7) (the reverse ratio of solvents runs slower but gives better separation), (2) silica gel G, acetic acid–ethyl acetate (5:95), and (3) cellulose,[21] organic phase of a mixture of 1-butanol–concentrated hydrochloric acid–water (100:6:100). The observed order of spots of the isomers of norbormide are as follows.

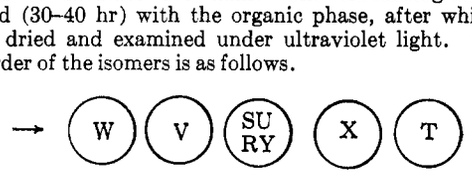


B. Quantitative.—The qualitative tlc was developed into a quantitative assay[6] using the method of mechanical removal of spots, elution of solute, and quantitative ultraviolet assay of the extract.

C. Preparative.—A chloroform–methanol solution of the sample (10–50 mg/plate) was applied to silica gel G plates (8 × 8 in., absorbent thickness, 1 mm) as a narrow strip. Commercially coated plates[22] were also used. After development and detection as described above, the outlined bands were scraped off and the combined silica gel was eluted three to five times with chloroform–methanol. Recovery was excellent. The extract was evaporated to dryness and extracted with chloroform. The materials from the chloroform solutions were further purified by repeated preparative tlc or recrystallization.

Paper Strip Chromatography.—Two-phase descending chromatography in a sealed tank was employed both qualitatively and preparatively.

A. Qualitative.—The solute was applied (2–150 μg/spot) on Whatman No. 1 paper which was then wet with the aqueous phase of the mixture 1-butanol–*n*-butyl acetate–concentrated hydrochloric acid–water (75:25:6:100). The aqueous phase was used to saturate the tank. The chromatograms were developed (30–40 hr) with the organic phase, after which they were air dried and examined under ultraviolet light. The observed order of the isomers is as follows.



B. Preparative.—The solution containing 40–90 mg of norbormide was applied as a narrow streak across the width (18 in.) of Whatman No. 1 or 3MM paper (18 × 24 in.). The same solvent system was used as for the qualitative psc. After ultraviolet visualization, bands of paper containing the individual isomers were cut out and the compounds were eluted by arranging the segments of paper as descending wicks in 3 *N* hydrochloric acid–methanol (5:95). Recovery of isomers ranged from 25 to 65%.

(21) Avicel®, superfine, FMC Corp., American Viscose Division, Marcus Hook, Pa.

(22) Analtech, Inc., Wilmington, Del.

α-Phenyl-α-[6-phenyl-6-(2-pyridyl)-2-fulvenyl]-2-pyridinemethanol (1-Y,Z).—The previously reported synthesis[3a] gives a mixture of geometric isomers of the fulvenylmethanol **1** in which the more soluble *trans* isomer **1-Y** (mp 175–176°) and the less soluble *cis* isomer **1-Z** (mp 181–182°) are present in a ratio of about 4:6,[23] respectively. The isomers were separated by fractional recrystallization as follows. A 1.26-kg sample of the mixture of isomers of α-phenyl-α-[6-phenyl-6-(2-pyridyl)-2-fulvenyl]-2-pyridinemethanol[3a] was extracted with 21 l. of boiling methanol to give 90 g of insoluble orange crystals. This solid was recrystallized from benzene to give 49 g of the orange fulvene, mp 177–181°, which was stirred in 100 ml of boiling ethyl acetate for 18 hr. Filtration gave 38 g of crystals: mp 179.5–181°. Two recrystallizations of this material from ethyl acetate gave 18 g of ***cis*-α-phenyl-α-[6-phenyl-6-(2-pyridyl)-2-fulvenyl]-2-pyridinemethanol (1-Z)**: mp 181–182° (oil bath); λ_{max}^{MeOH} 240 mμ (ε 14,600), 262 mμ (sh) (ε 12,600), 268 mμ (sh) (ε 12,200), 324 mμ (ε 24,300).

Anal. Calcd for $C_{21}H_{16}N_2O_2$: N, 6.72. Found: N, 6.68.

The 21 l. of filtrate was concentrated to 16 l. *in vacuo*, diluted with 3.8 l. of hot water, and cooled slowly to −20°. Filtration gave 697.9 g of orange crystals. The filtrate was concentrated to smaller volume *in vacuo* and cooled to 0° to give 279 g of crystals. A 150-g sample of this material was stirred at reflux in 2500 ml of methanol for 1 hr and filtered to give 36.4 g of orange solid: mp 173–175°. This material was stirred at reflux in 600 ml of ethyl acetate for 2 hr and filtered hot to give 3.5 g of orange crystals: mp 176–178°. The filtrate was cooled to 25° then to 0° to give two crops of crystals which were combined: mp 174–176°, 18.5 g. This material was stirred at reflux in 250 ml of ethyl acetate and filtered to give 2.1 g of insoluble solid. The mother liquor was concentrated *in vacuo* to about 150 ml until crystals began to separate. Slow cooling to 0°, followed by filtration, gave 13.1 g of orange crystals: mp 175–176°. A similar extraction of the 13.1 g gave 2.8 g of material insoluble in 170 ml of boiling ethyl acetate. This material was recrystallized twice from aqueous ethanol (1:1) to give 1.9 g of ***trans*-α-phenyl-α-6-phenyl-6-(2-pyridyl)-2-fulvenyl]-2-pyridinemethanol (1-Y)**: mp 175–176° (oil bath). The ultraviolet spectrum was essentially identical with that of the *cis* isomer.

Anal. Calcd for $C_{21}H_{16}N_2O_2$: N, 6.76. Found: N, 6.79.

5-(α-Hydroxy-α-2-pyridylbenzyl)-7-(α-2-pyridylbenzylidene)-5-norbornene-2,3-dicarboximide, Norbormide (2). Typical Mixture of Isomers.—A 5.4-g (0.013 mole) sample of a mixture of geometric isomers of α-phenyl-α-[6-phenyl-6-(2-pyridyl)-2-fulvenyl]-2-pyridinemethanol (~60% of **1-Z**, ~40% of **1-Y**)[3a,23] and 1.26 g (0.013 mole) of maleimide were combined in 25 ml of benzene and the solution was refluxed[24] for 3 hr. After 13 hr of standing at room temperature, the solution was refluxed for 90 min, then cooled in an ice bath and filtered to give 5.4 g of white solid. The filtrate was concentrated *in vacuo* to give a second crop; the combined yield was 5.9 g (90% of theory):[25,26] mp 190–198°. The first crop was recrystallized four times from ethyl acetate (small amounts of insoluble crystalline **2-X** removed by filtration) to yield 0.75 g of a constant-melting *isomeric mixture* **2-Q**:[27] mp 193.5–194.5° (oil bath); λ_{max}^{MeOH} 250 mμ (br) (ε 17,100).

Anal. Calcd for $(C_{33}H_{23}N_3O_3)_2 \cdot H_2O$: C, 76.14; H, 5.04; H_2O, 1.73. Found: C, 76.08; H, 5.04; H_2O (Karl Fischer), 1.54.

The second crop of crystals from the reaction mixture was recrystallized three times from ethyl acetate to give 0.15 g of a constant-melting white, crystalline isomeric mixture **2-Z**:[27] mp 217–218° (oil bath); λ_{max}^{MeOH} 250 mμ (ε 17,480).

Anal. Calcd for $C_{33}H_{23}N_3O_3$: C, 77.48; H, 4.93; N, 8.22. Found: C, 77.39; H, 5.09; N, 8.10.

In another experiment, a solution of the fulvene (mixture of **1-Y** and **-Z**) and maleimide in benzene was allowed to stand at

(23) Estimated from qualitative psc as described above in which isomer **1-Y** runs at R_f 0.4 and isomer **1-Z** runs at R_f 0.6.

(24) The solution can also be refluxed continuously for 16–18 hr and worked up to give a good yield of norbormide.

(25) The average percentage composition of the typical mixture of isomers is given in column 4 of Table II.

(26) In some experiments a small amount of 3a,4,7,7a-tetrahydro-1,8-bis(α-2-pyridylbenzylidene)-4,7-methanoindene is present in the fulvenyl methanol (**1-Y,Z**) starting material, which gives rise to 1–3% of the *endo*-norbornenedicarboximide **3** (see below).

(27) Isomeric mixture **2-Q**, which was also isolated from the reaction of essentially pure fulvenylmethanol **1-Y**, was shown to consist of 76% **2-Y** and 24% of **2-W** by quantitative tlc.[6] Similarly, isomeric mixture **2-Z** was shown to consist of 62% **2-V** and 38% **2-U**.[6] These two mixtures appear to be constant composition mixtures.

room temperature until the fulvene color had virtually disappeared (10 days). The yield of norbormide was 96% and the composition was essentially identical to that of the typical mixture given in Table II.

Reaction of *cis*-Fulvenylmethanol 1-Z with Maleimide.—A 1.0-g sample (0.0024 mole) of *cis*-α-phenyl-α-[6-phenyl-6-(2-pyridyl)-2-fulvenyl]-2-pyridinemethanol (1-Z), (mp 181–182°, estimated to be >95% 1-Z and <5% 1-Y)[28] and 0.23 g (0.0024 mole) of maleimide in 6 ml of benzene was refluxed for 5 hr; 2 ml of hexane was added to the hot slurry which was then cooled in an ice bath and filtered to give fraction a as 0.6 g of crystals: mp 216.5–218°. The filtrate was concentrated *in vacuo* and diluted with ether. Cooling in an ice bath gave fraction b as 0.15 g of crystals: mp 208.5–210°. The filtrate was evaporated to dryness and stirred with 7 ml of chloroform at 25°. Filtration of the slurry gave fraction c as 0.12 g: mp 238–239°. Combined yield of the three fractions was 71% of theory. Thin layer chromatography of the three fractions [silica gel, ethyl acetate–chloroform (7:3)] showed fraction a to be mostly mixture 2-Z and c to be mostly isomer 2-X. Fraction a was pulverized and stirred in 100 ml of boiling ethyl acetate, filtered from a small amount of insoluble material, and the filtrate was concentrated slightly. Cooling gave crystals: mp 216–217°. Recrystallization from chloroform–hexane and finally from ethyl acetate gave white crystals of isomeric mixture 2-Z,[27] mp 217–218° (oil bath), identical with the material isolated from the typical reaction mixture described above. Fraction c was stirred in 11 ml of boiling chloroform for 35 min. Filtration gave a solid, mp 236–238°, which was recrystallized from a large volume of absolute ethanol to give white, crystalline *cis–exo*-2-X: mp 239°. Psc showed a trace (~2%) of 2-R.

Reaction of *trans*-Fulvenylmethanol 1-Y with Maleimide.—A 3.0-g sample (0.0072 mole) of *trans*-α-phenyl-α-[6-phenyl-6-(2-pyridyl)-2-fulvenyl]-2-pyridinemethanol (1-Y), (mp 171–174°, estimated to be 90% 1-Y and 10% 1-Z)[23] and 0.72 g (0.0074 mole) of maleimide in 18 ml of benzene was refluxed with stirring for 4 hr, allowed to stir at room temperature overnight, and then refluxed for 2 hr. Addition of a small amount of hexane to the slurry followed by cooling and filtration gave 2.7 g of white crystalline solid: mp 195.5–197°. The filtrate was concentrated and cooled to give an additional 0.55 g of solid [total yield 3.25 g (87.5%)]. The 2.7 g of solid was recrystallized twice from chloroform–ether and methylene chloride–ether to give white crystalline isomeric mixture 2-Q,[27] mp 193.5–194.5° (oil bath), identical in melting point and composition with the sample isolated from the typical mixture of five isomers. Psc demonstrated the presence of a small amount (~1%) of isomer 2-T.

***cis–endo* Isomer 2-U.**—A solution of isomeric mixture 2-Z was applied to preparative tlc plates (silica gel G). The plates were developed in acetic acid–ethyl acetate (5:95). The bands of silica gel containing 2-U were scraped off, combined, and eluted with chloroform. The chloroform layer was extracted with dilute sodium hydroxide and then with water. After drying over magnesium sulfate and evaporation to dryness, the crude 2-U was rechromatographed twice in the same fashion. Work-up as described above gave a white solid which was recrystallized from ethyl acetate to give crystalline isomer 2-U: mp 207–210° (dec). Psc showed only a trace of 2-V estimated as <2%.

***cis–endo* Isomer 2-V.**—The silica gel band containing 2-V from the preparative tlc isolation of 2-U was eluted with chloroform–methanol and the solution was evaporated to dryness. Chloroform extraction gave crude 2-V. This material was rechromatographed using acetic acid–chloroform–ethyl acetate (5:20:75). Removal of the top half of the band containing 2-V gave material which, after recrystallization from methylene chloride–ethyl acetate, afforded white, crystalline 2-V: mp 225–226.5° dec. Psc showed the sample to be pure isomer 2-V.

***trans–endo* Isomer 2-Y.**—The typical mixture of norbormide isomers in chloroform–methanol solution was applied to preparative tlc plates (silica gel) at 25 mg/plate. The plates were developed twice in chloroform–ethyl acetate (3:7). After removal of the bands of silica gel containing 2-Y and elution of these bands with chloroform–methanol, the crude 2-Y was rechromatographed in the same fashion. The solid obtained from elution of the silica gel was recrystallized from ethyl acetate to give white, crystalline 2-Y: mp 192–195°.

***cis–endo* Isomer 2-W.**—The silica gel bands containing 2-W from the preparative tlc isolation of 2-Y were combined and eluted with chloroform–methanol. This solution was treated in a similar manner to that described for 2-Y to give white, crystalline isomer 2-W: mp 180–183°.

***trans–exo* Isomers 2-T and -S by Thermal Isomerization of *endo* Isomers.**—A 1.9-g sample of isomeric mixture 2-Q and 1.9 g of maleimide were dissolved in chloroform and the solvent removed *in vacuo* to give an intimate mixture which was placed in a glass tube and heated to 184° in an oil bath. After 4 min at 184–188°, the mixture was completely melted. During the following 5 min the bath temperature was taken to 211°. The brown melt was cooled and then triturated with boiling chloroform–methanol (4:1) several times to give 0.17 g of insoluble polymeric material, and a solution which on evaporation to dryness gave 3 g of amorphous solid: λ_{max}^{MeOH} 255 mμ (ε 6750); ~1.2 g of norbormide isomers, 63% recovery. Tlc system 1 and psc showed the sample to be composed almost exclusively of isomers 2-S,T,Y,W with 2-T and -S predominating. The solid was stirred overnight in 65 ml of ether and filtered to give 0.65 g of insoluble-solid which was recrystallized to give 0.13 g of crude 2-T [λ_{max}^{MeOH} 253 mμ (ε 15,300)]. A solution of this sample was applied to preparative tlc plates (silica gel) at 25 mg/plate. The plates were developed twice in chloroform–ethyl acetate (7:3) and the bands of silica gel containing 2-T were collected. After elution of the silica gel, the combined solution was evaporated to dryness and the residue was recrystallized from ethyl acetate–hexane to give 35 mg of white, crystalline *trans–exo*-2-T: mp 230–231°. Psc showed a trace (~1%) of 2-S present.

The ethereal filtrate from which the 0.65 g of solid separated was evaporated to dryness and crystallized from ethyl acetate to give 30 mg of white solid. The mother liquor was evaporated to a mixture of gummy crystals which was recrystallized from chloroform–hexane solution to give 0.61 g of maleimide. The filtrate was applied to preparative tlc plates (silica gel) and developed three times in chloroform–ethyl acetate (7:3). The bands of silica gel containing 2-S and -W were collected and eluted with chloroform–methanol. This solution was applied to Whatman 3MM paper (90 mg/18-in.-wide strip) and allowed to run for 41 hr. After drying the papers, the bands containing 2-S were removed and eluted (26% recovery). The eluted product was rechromatographed by preparative tlc and the resulting solid was recrystallized from ethanol to give crystalline *trans–exo*-2-S: mp 218–220°. Psc showed a trace (<2%) of isomer 2-W.

***cis–exo* Isomer 2-R by Thermal Isomerization of *endo* Isomers.**—An intimate mixture of 2 g of isomeric mixture 2-Z and 2 g of maleimide in a glass tube was placed in a heated oil bath at 185°. After 4 mins at 185–193°, the mixture was completely melted. During the following 5 mins the bath temperature was taken to 209°.[28] The melt, after cooling, was triturated with boiling chloroform. Filtration gave 0.87 g of insoluble polymeric material. The filtrate was evaporated to give 2.9 g of solid (60% norbormide isomers by ultraviolet assay). Tlc and psc showed the sample to be composed of only isomers 2-U,V,X and R with 2-X and -R predominating. The 2.9 g of solid was triturated three times in boiling ether to give 0.65 g of insoluble solid composed mainly of 2-X and -R. A solution of this material was applied to preparative tlc plates (silica gel) at 15 mg/plate. The plates were developed two times in chloroform–ethyl acetate (3:7) and the bands containing 2-X,R were collected. After elution the solution was applied to Whatman 3MM paper and chromatographed as described above for isomer 2-S. The eluate, containing mainly 2-R, was chromatographed again by preparative tlc and the isolated solid was recrystallized from chloroform–hexane solution to give white, crystalline *cis–exo*-2-R: mp 188–190°.

Norbornenedicarboximide Model Compounds.—Compounds *endo*-**3**, *endo*-**5**, *exo–endo*-**6**, and *endo*-**7** have been reported previously.[9] The following is an improved synthesis of *endo*-**3** starting from the dimer of 6-phenyl-6-(2-pyridyl)fulvene [3a,4,7,7a-tetrahydro-1,8-bis(α-2-pyridylbenzylidene)-4,7-methanoindene].[5]

***endo*-7-(α-2-Pyridylbenzylidene)-5-norbornene-2,3-dicarboximide** (*endo*-**3**).—The previously reported synthesis,[9] utilizing an impure mixture of fulvenes, gave a 25% yield of the imide product. The following method gave high yields of the imide. A 41.5 g (0.09 mole) sample of 3a,4,7,7a-tetrahydro-1,8-bis(α-2-pyridylbenzylidene)-4,7-methanoindene[5] was combined with 17.5 g (0.18 mole) of maleimide and heated under reflux in 500

(28) In several experiments the oil bath temperature was allowed to rise to 210–225°, which caused vigorous decomposition. Isomeric mixture **2-Q** was more stable than mixture **2-Z** at these elevated temperatures.

ml of benzene for 18 hr. After cooling to room temperature, filtration gave 42.5 g (72%) of crystalline imide. A second crop of crystals [2.3 g, total yield 44.8 g (76% of theory)] was combined with the first crop and recrystallized several times from dioxane to give white, crystalline *endo*-**3**: mp 223–225° dec (oil bath); λ_{max}^{KBr} 3.15, 3.25, 5.64, 5.86, 6.30 μ; λ_{max}^{MeOH} 242 mμ (ϵ 15,600), 276 mμ (sh) (ϵ 6550).

Anal. Calcd for $C_{21}H_{16}N_2O_2$: C, 76.81; H, 4.91; N, 8.53. Found: C, 76.54; H, 5.06; N, 8.44.

The sample was shown to be homogeneous by tlc in systems 1 and 3 and runs ahead of isomer **2**-X in both systems.

A 1-g sample of pure *endo*-**3** was intimately mixed by pulverizing with 3 g of maleimide and placed in a glass tube in an oil bath heated to 210°. The mixture, which was completely melted in 2 min, was stirred intermittently for 11 min while the bath temperature was taken slowly to 228°. After cooling, the dark brown melt was extracted by stirring overnight with 40 ml of chloroform. Filtration gave 0.9 g of insoluble polymeric material. The filtrate was concentrated, diluted with hexane, and cooled to precipitate 1.4 g of impure maleimide. The filtrate was evaporated to leave a gummy solid containing *exo*-**3** which was not purified further. The nmr spectrum indicated an approximate ratio of 1:2 of *endo*-**3** to *exo*-**3** based on comparison of the integrated areas under the vinyl proton peaks.

***endo*-7-(Di-2-pyridylmethylene)-5-norbornene-2,3-dicarboximide** (*endo*-**4**).—A solution of 5.5 g (0.03 mole) of di-2-pyridyl ketone[29] in 120 ml of absolute ethanol was added to a solution of sodium ethoxide (from 3.5 g, 0.15 g-atom of sodium) in 125 ml of absolute ethanol containing 12 g (0.18 mole) of cyclopentadiene over a period of 3 hr at room temperature. The solution was concentrated, diluted with water, and extracted with ether. After drying, the ethereal solution of 6,6-di-2-pyridylfulvene was treated with a solution of 5 g of maleimide in 80 ml of benzene. After 4 days at room temperature the solvents were removed *in vacuo* and the residual solid was recrystallized from dioxane–ether solution to give 2.7 g (30%) of white, crystalline *endo*-**4**: mp 216–217° (oil bath); λ_{max}^{KBr} 5.65, 5.88, 6.3 μ; λ_{max}^{MeOH} 241 mμ (ϵ 14,700), 271 mμ (ϵ 11,200).

Anal. Calcd for $C_{20}H_{15}N_3O_2$: N, 12.76. Found: N, 12.70.

In a manner similar to the synthesis of *exo*-**3** (see above), 120 mg of pure *endo*-**4** and 280 mg of maleimide were placed in oil bath at 188° and heated to 200° over 5 min. The brown melt was stirred overnight with chloroform, filtered to remove polymeric material, and the filtrate was evaporated to an amorphous solid containing *exo*-**4** which was not purified further. The nmr spectrum indicated an approximate ratio of 1:1 of *endo*-**4** to *exo*-**4** based on a comparison of the integrated area of the resonance peaks of the 2,3-protons.

Thermal Isomerization of Individual Isomers.—A 1-mg sample of *endo*-**2**-V was mixed with maleimide and was heated at 180–196° for 4 min and then at 196–204° for 7 min. After cooling the melt was shown to consist mainly of *exo*-**2**-X and -R by psc and tlc.

In a similar manner [193–200° (8 min)] *endo*-**2**-W gave predominantly *exo*-**2**-T and -S; *endo*-**2**-Y gave an identical result.

exo-**2**-X (5.2 mg) and maleimide (4.5 mg) were heated at 193–200° for 3.5 min. The melt was shown to consist mainly of *exo*-**2**-X and -R with some **2**-U and -V. A mixture of *exo*-**2**-T (12 mg) and maleimide (12 mg) treated similarly gave a mixture of **2**-T,S,Y,W. The proportion of *endo* isomers appears higher in this experiment than from isomer **2**-X. Ultraviolet spectral assay of the reaction product indicated ~70% norbormide present.

Heating a toluene solution of **2**-Q or -Z for 19 hr (or heating the crystalline solids to their melting point for several minutes) caused formation of a substantial amount of fulvenylmethanol **1** as determined by ultraviolet spectra and tlc.

Photoisomerization.—Methanolic solutions of the isomers (3.3×10^{-5} *M*) were deoxygenated and irradiated at room temperature with a high-pressure mercury arc lamp (Hanovia, type SOL, 100 w) placed in a water-jacketed, quartz immersion well. The following experiments were conducted for 90 min using a Pyrex glass filter. The reaction mixture was evaporated to dryness and the residue was analyzed by tlc and psc.

trans		*cis*	*cis*[30]		*trans*
2-Y	35% →	2-V	2-V	5%[31] →	2Y
2-W	30% →	2-U	2-X	5% →	1-S
2-T	>20% →	2-R			

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(29) H. R. Henze and M. B. Knowles, *J. Org. Chem.*, **19**, 1127 (1954).

(30) Under these conditions, *cis* isomers **2**-U and **2**-R were unchanged.

(31) No change in 90 min; approximately 5% of **2**-Y was observed after 6.75 hr. No other isomers were generated in these experiments. In one experiment, a methanolic solution of **2**-V was irradiated for 4 hr. using a Vycor filter, resulting in complete decomposition.