

Table II. ^{13}C Chemical Shifts (ppm)^a of the C- α Carbon in Benzylidene Malononitriles

X	Posner and Hall ⁷	Laszlo et al. ³³	this work ^b	Robinson et al. ⁴⁹
NMe ₂	158.4	158.04	158.01	158.0
OMe	159.1	158.91	158.79	159.0
F		158.44	158.23	158.4
Cl	159.7	158.07		158.2
Br	159.4		158.38	158.4
Me	160.3		159.69	159.8
H	160.8	159.85	159.86	160.1
CN	159.0	156.50	157.31	157.3
NO ₂	158.7	157.55	156.77	156.8
solvent concn (w/v), %	acetone ~5	CDCl ₃ ~25 ^c	CDCl ₃ 3	CDCl ₃ ~30

^a Relative to Me₄Si. ^b Shifts are accurate to ± 0.05 ppm and were measured on a FX-200 spectrometer operating at 50.10 MHz. ^c The concentrations used were not specified directly in this study but are assumed to be similar to those of the preliminary study.⁸

similar to that observed in carbonyl systems.²⁵

Finally, we note that Laszlo and co-workers do not obtain a good DSP correlation for the C- α position of series 2 (benzylidene malononitriles). In other studies²⁵ we have measured extensive series of ^{13}C spectra for structurally related compounds and found that when the data are measured with precision, at low concentration, the DSP correlations for the C- α position of a conjugating side chain are of good quality and consistently show a negative polar substituent effect. We note that ^{13}C spectra for substituted benzylidene malononitriles have been measured by three groups (Laszlo et al.,³³ Posner and Hall,⁷ and Robinson et al.⁴⁹) and that the SCS values derived differ somewhat. We have therefore carefully remeasured ^{13}C SCS values for a series of these compounds.

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An examination of Table II reveals that for the three independent sets of data measured in the same solvent (CDCl₃) there is agreement (within experimental error) between our data and that of Robinson et al.⁴⁹ However, the data of Laszlo and co-workers³³ for the NO₂ and CN substituents differ from the other two sets by more than the maximum expected experimental error of ± 0.2 ppm. Since these are the only two electron-accepting substituents included in the DSP analyses, errors in their SCS values markedly affect the correlations.

DSP analysis of our data gives a good correlation (eq 2)

$$\delta^c = -4.1\sigma_1 - 0.7\sigma_R \quad \text{SD} = 0.19 \quad f = 0.11 \quad (2)$$

provided that the SCS for the NMe₂ substituent is excluded. The observed SCS value for the NMe₂ substituent differs from that predicted from eq 2 by about 8 times the standard deviation, and we have checked that it is not a concentration effect by measuring the shift at a concentration of less than 1% w/v. We suggest that the two highly electron-deficient nitrile groups induce a large through-conjugation effect, hence modifying the electronic properties of this substituent (and hence its SCS value). Similar suggestions have been made by other authors.²² This conclusion is also implicit in Laszlo's study.³³

In conclusion, we reemphasize the following points. (1) While in *some* situations there might be no significant improvement in fits obtained by the DSP method compared with single parameter treatments, this is not so in the general case. (2) The ρ_1 and ρ_R values obtained from a DSP analysis are extremely useful in assigning mechanistic significance to proposed pathways for the transmission of substituent effects. (3) The SCS data for the two carbonyl groups in 3-5 provide evidence that π -polarization effects may be transmitted (partially) via molecular lines of force.

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Registry No. 2 (X = NMe₂), 2826-28-0; 2 (X = OMe), 2826-26-8; 2 (X = F), 2826-22-4; 2 (X = Br), 2826-24-6; 2 (X = Me), 2826-25-7; 2 (X = H), 2700-22-3; 2 (X = CN), 36937-92-5; 2 (X = NO₂), 2700-23-4.

Carbon-13 Nuclear Magnetic Resonance Spectra of 7-Heterotetracyclo[4.1.0.0^{2,4}.0^{3,5}]heptanes. Annulation Effects of Aziridine, Oxirane, and Thiirane Rings. Unusual γ and δ Substituent Effects

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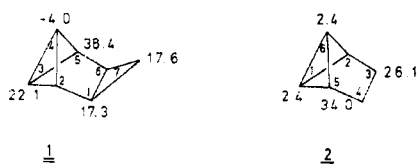
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The ^{13}C NMR spectra of 7-heterotetracyclo[4.1.0.0^{2,4}.0^{3,5}]heptanes and of the 7-methyl- and 7-phenyl-tetracyclo[4.1.0.0^{2,4}.0^{3,5}]heptanes have been measured, and the three-membered-ring annulation effects were determined. The unusual deshielding found for the C-3 resonance in a cyclopropane-annulated cyclopentane derivative (bicyclo[3.1.0]hexane derivative) in the chair conformation carries an even stronger effect in the analogous aziridine-, oxirane-, and thiirane-annulated systems. Substituents in the 7-position of tetracyclo[4.1.0.0^{2,4}.0^{3,5}]heptanes exert unprecedented long-range effects. Literature data of dehydroadamantanes, dehydronoradamantane, [3.3.1]- and [3.1.1]propellanes containing bicyclo[3.1.0]hexane systems are summarized and discussed from the viewpoint of cyclopropane annulation.

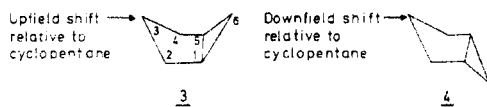
In a ^{13}C NMR spectroscopic investigation of the two tricyclo[3.2.1.0^{2,4}]octenes 42 and 44, Tori et al.¹ discovered

two cyclopropane annulation effects, which are observed intramolecularly in tetracyclo[4.1.0.0^{2,4}.0^{3,5}]heptane (1) in



that the resonances of C-3 and C-4 differ by 26.1 ppm.² Compared to the chemical shift of C-1 in tricyclo-[3.1.0.0^{2,6}]hexane (2), the hydrocarbon devoid of the cyclopropane ring, the C-4 resonance of 1 is shielded by 6.4 ppm, which can be classified as a usual γ effect (γ -syn effect). In contrast, the C-3 signal is deshielded by 19.7 ppm, and this unusual γ -anti effect seems to be caused by the interaction between the unoccupied Walsh orbital of the cyclopropane ring (36, X = CH₂) and the highest occupied orbital of proper symmetry (34) in the other part of the molecule.

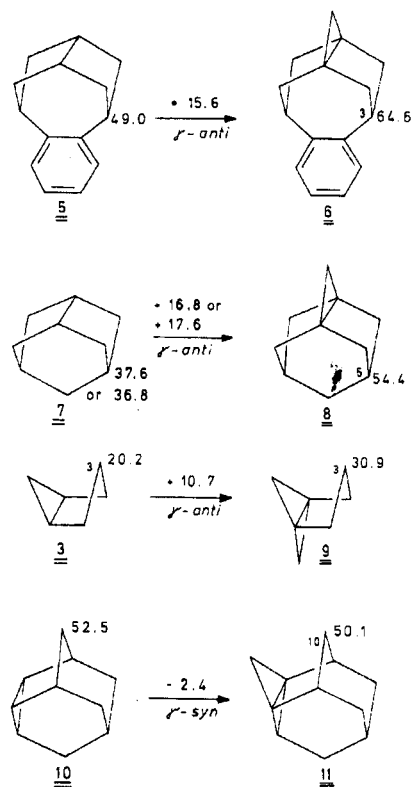
The effects of cyclopropane rings operate, in general, if these are annelated to cyclopentane rings, i.e., if bicyclo-[3.1.0]hexane derivatives are considered. In four model compounds (1, 3, 14, and 44) containing the boat conformation 3, the γ -syn effects range from -6.3 to -14.2 ppm



relative to the corresponding cyclopentanes. If, however, the chair conformation 4 is fixed, three model compounds (1, 14, and 42) show γ -anti effects of 19.7, 17.1, and 15.2 ppm, respectively.³

These effects can be applied to the assignment and the interpretation of the ¹³C NMR spectra of dehydroadamantanes, dehydronoradamantane, and [3.3.1]- and [3.1.1]propellanes. Scheme I collects four examples from the literature in which, through formal annelation of a cyclopropane ring, a bicyclo[3.1.0]hexane derivative is formed. The surprising low-field absorption of C-3 in 6 requires no special effect of the "inverted carbon atoms" of the propellane bridgeheads,⁴ since the γ -anti effect of 15.6 ppm caused at the C-3 resonance by cyclopropane annelation to 5 follows closely the above-mentioned size. Also, in 1,3-dehydroadamantane (8)⁵ the deshielding of 16.8 or 17.6 ppm observed at the C-5 signal relative to the corresponding absorption of noradamantane (7)⁶ is expected on the basis of the γ -anti effect. By comparison of [3.1.1]propellane (9) with 3, which prefers the boat conformation, it can be seen that a bicyclo[3.1.0]hexane system in the chair conformation is generated by annelation of the second cyclopropane ring. Only the ¹³C chemical shifts of 9, but no assignments, have been reported.⁷ Application of the γ -anti effect predicts that the resonance at δ 30.9 belongs to C-3. On formal transformation of 2,4-dehydroadamantane (10)⁵ to 11⁶ a [3.1.1]propellane system is also formed, but now the new bicyclo[3.1.0]hexane system is fixed in the boat form. Consequently, an upfield shift has to be expected for the C-10 resonance and is indeed found, although the absolute value of this γ -syn effect is not as great as that of the model compounds.³

Scheme I. γ -Syn and γ -Anti Effects on Formal Annelation of a Cyclopropane Ring to a Cyclopentane Derivative^a



^a The numbers on the structures are ¹³C chemical shifts; the numbers on the arrows are chemical shift differences.

If one starts from a cyclohexane derivative and formally installs a C-1,C-3 bond by removing two hydrogen atoms, these bicyclo[3.1.0]hexane effects can be derived in a second manner, thus allowing an expanded application. Scheme II illustrates the procedure. Compared to the chemical shift of the cyclohexane carbons (12), the C-3 resonance of 3 appears upfield by 7.6 ppm, because 3 prefers the boat form. The formal conversion of norpinane (13)⁸ to 14³ produces two bicyclo[3.1.0]hexane systems: one in the boat and the other in the chair conformation. Therefore, the C-7 resonance of 14 is shielded by 8.4 ppm as compared to the chemical shift of the cyclobutane methylene carbons in 13. On the other hand, C-6, as member of the chair form, shows a deshielding of its resonance by 22.9 ppm. Downfield shifts of similar size are calculated for 6 and 1,3-dehydroadamantane (8) relative to 15⁴ and adamantane (16), respectively. Although bicyclo[3.1.0]hexane chair derivatives arise in the same way in 10 from 16 and in 17³ from 7, the deshielding effects for the resonances of the carbon atoms in the cyclopentane rings situated opposite to the newly formed bond are considerably decreased. On going from the cyclobutane derivatives 13 and 18⁶ to [3.1.1]propellane (9) and its derivative 11, respectively, one obtains two bicyclo[3.1.0]hexane systems in each case which share the cyclopentane ring. Accordingly, C-3 in 9 and C-10 in 11 are located syn to one cyclopropane ring and anti to the other. The downfield shifts of their resonances (14.6 and 16.4 ppm) reveal that the chair effect prevails. This is not surprising, as the boat effect, being a usual γ effect, just replaces the

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Table I. ¹³C Chemical Shifts (in Parts per Million Downfield from Internal Me₄Si) and One-Bond ¹³C-H Coupling Constants (in Parentheses) of 7-Hetero-, 7-Methyl-, and 7-Phenyltetracyclo[4.1.0.0^{2,4}.0^{3,5}]heptanes in CDCl₃

structure	no.	R	shift, ppm (J, Hz)				other carbon atoms
			C-1,6 ^a	C-2,5 ^a	C-3 ^a	C-4 ^a	
	19 ^b	H	35.1 (182)	41.2 (169)	27.2 (214)	-5.3 (220)	
	20	CH ₃ C ₆ H ₅	44.6 (178.0)	36.5 (168.4)	21.9 (213.3)	-0.4 (219.9)	CH ₂ , 59.8 (t, 133.8); C-1', 139.2 (s); C-2', C-3', 127.5, 128.0 (2 d, 159), C-4', 126.5 (d, 159.6)
	21	C ₆ H ₅	44.9 (182.4)	37.0 (169.9)	24.0 (214.0)	0.4 (220.6)	C-1', 152.9 (s); C-2', 120.6 (d, 158.1); C-3', 128.6 (d, 158.1); C-4', 121.6 (d, 161.8)
	22	CO ₂ C ₂ H ₅	42.7 (186.1)	38.0 (172.1)	27.3 (214.0)	-0.3 (220.6)	C=O, 161.9 (s); CH ₂ , 61.6 (t, 147.1); CH ₃ , 14.4 (q, 126.5)
	23	CO ₂ C(CH ₃) ₂	42.7 (185.3)	37.9 (172.1)	27.1 (214.0)	-0.1 (220.6)	C=O, 160.8 (s); C, 79.8 (s); CH ₃ , 27.9 (q, 126.5)
	24	SO ₂ C ₆ H ₄ -4-CH ₃	46.4 (185.3)	35.9 (173.6)	24.1 (217.7)	0.5 (223.6)	C-1', 144.0 (s); C-2', C-3', 127.7, 129.6 (d, 166.2, 161.8); C-4', 135.7 (s); CH ₃ , 21.6 (q, 127.2)
	25		56.9 (189.0)	37.0 (170.6)	26.5 (214.7)	-1.1 (221.8)	
	26		39.1 (181.6)	40.1 (173.1)	31.4 (214.0)	2.0 (219)	
	27		51.7 (183.8)	32.9 (175.0)	8.4 (222.1)	-2.9 (226)	
	28 ^b	R _{endo} = H, R _{exo} = CH ₃	25.5 (171.0)	37.5 (165.0)	20.0 (208.8)	-3.0 (215)	C-7, 25.2 (d, 161.2); CH ₃ , 15.9 (q, 125.3)
	29 ^b	R _{endo} = CH ₃ , R _{exo} = H	23.9 (170)	32.2 (165)	22.3 (209.1)	2.6 (215)	C-7, 28.1 (d, 149.5); CH ₃ , 10.5 (q, 125.6)
	30	R _{endo} = CH ₃ , R _{exo} = CH ₃	32.0 (169)	33.0 (166)	21.6 (211)	3.1 (213)	C-7, 33.2 (s); endo-CH ₃ , 16.9 (q, 126); exo-CH ₃ , 27.9 (q, 125)
	31	R _{endo} = H, R _{exo} = C ₆ H ₅	28.2 (171)	38.2 (167)	21.0 (211)	-2.1 (215)	C-7, 34.9 (d, 162); C-1', 141.6 (s); C-2', 125.8 (d, 155.9); C-3', 127.9 (d, 158.8); C-4', 125.1 (d, 160.3)
	32	R _{endo} = C ₆ H ₅ , R _{exo} = H	24.6 (171)	33.9 (164)	25.2 (207)	2.6 (215)	C-7, 37.9 (d, 164); C-1', 140.4 (s); C-2', C-3', 130.3, 127.6 (2 d, ≈158); C-4', 125.8 (d, ≈158)
	33	R _{endo} = C ₆ H ₅ , R _{exo} = C ₆ H ₅	34.6 (170)	35.1 (166)	25.8 (212)	4.8 (218)	C-7, 51.0 (s); C-1', 142.4 (s), 146.4 (s); C-2', C-3', 131.2, 128.1, 127.9, 127.0 (d, 157-159); C-4', 125.5, 125.3 (d, 160)

^a These resonances appear as doublets in the proton-coupled spectra. ^b Solvent C₆D₆.

γ effect exerted by the cyclobutane methylene groups in 13 and 18.

The examples from Scheme II clearly show that formation of a bicyclo[3.1.0]hexane derivative in the chair conformation from a cyclohexane derivative uniformly results in a substantial deshielding of the C-3 resonance. However, the effect, with actual values of 11.7–25.9 ppm, is subject to wide variation, depending on the individual geometry of the system under consideration and possibly on the strain of the bonds, acting as transmitters.

On replacement of the cyclopropane ring in bicyclo[3.1.0]hexane chair systems with cyclobutane, cyclopentane, or cyclohexane rings, the γ-anti effects rapidly decrease to a small or negligible size.⁹ If the five-membered ring of the bicyclo[3.1.0]hexane system is enlarged, the γ-anti effect of the annelated cyclopropane ring also approaches zero.¹⁰

With the annelation effect of the cyclopropane ring in mind, it was intriguing to investigate that of three-membered

heterocycles systematically, although some data on oxiranes¹¹ had already been published. A further target was a study of the influence of substituents at the three-membered rings on the annelation effects.

Results and Discussion

Table I contains the ¹³C NMR data of the compounds investigated. Complete assignments are possible by means of the proton-coupled spectra on the basis of criteria advanced earlier.^{12,13} Thus, the C-3 resonance shows, aside from the characteristically large one-bond ¹³C-H coupling constant, at most one further doublet of about 4 Hz which is probably caused by H-4. The C-4 signal, however, has more fine structure, frequently consisting of a triplet (about 9 Hz) of doublets (about 4 Hz), indicating coupling to H-1,6 and H-3, respectively. The resonances of C-1,6 and C-2,5 also show multiple fine splittings, which in the

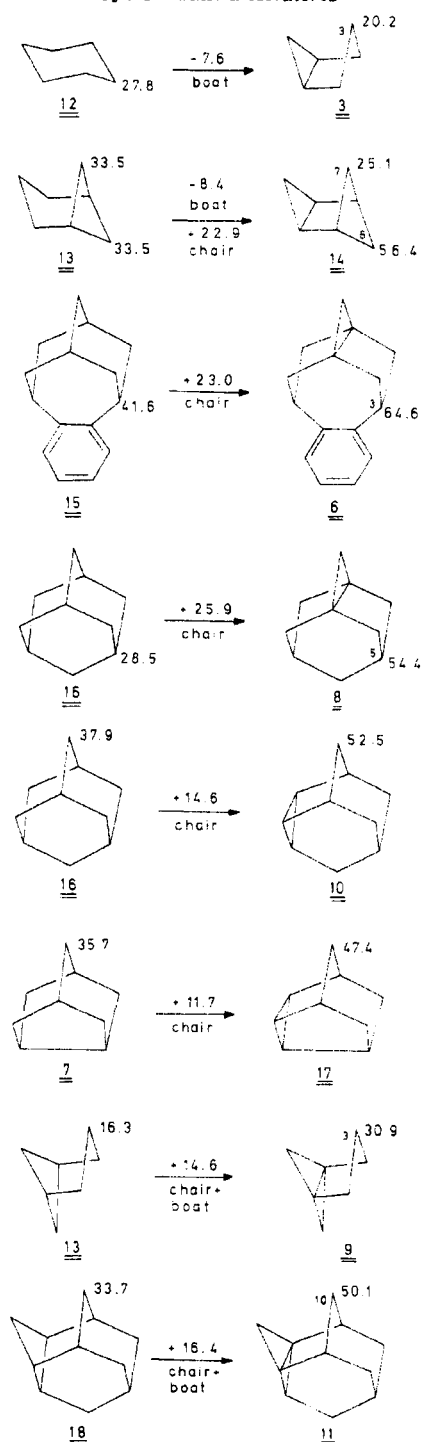
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Scheme II. Boat and Chair Effects on Formal Formation of Bicyclo[3.1.0]hexane Derivatives from Cyclohexane Derivatives^a

^a The numbers on the structures are ¹³C chemical shifts; the numbers on the arrows are chemical shift differences.

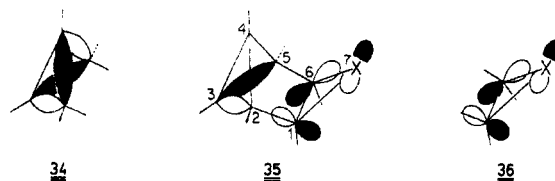
former remain below 10 Hz but in the latter always contain a doublet of about 13 Hz. The coupling between C-2 (C-5) and H-5 (H-2) most probably manifests itself in this doublet. Furthermore, in the heterocycles 19–27, due to the well-known heteroatom effect, the C-1,6 resonance is characterized by a considerably larger one-bond ¹³C–H coupling constant compared to that of C-2,5. The specific

assignments of the chemical shifts in the pairs of endo,exo isomers 28, 29 and 31, 32 are achieved by means of the ¹H NMR spectra.

(1) **Effect of Annulation of Three-Membered Heterocycles.** The annulation effects of three-membered rings are collected in Table II. The size of the α effects, which follows from the chemical shifts of C-1,6, should depend on two major factors: the deshielding owing to the atom added, which increases with increasing electronegativity, and the shielding effect of the three-membered ring formed. For the least electronegative carbon in the cyclopropane derivative 1 a net shielding of 8.8 ppm results, while for the most electronegative oxygen in the oxirane derivative 25 a deshielding of 30.8 ppm is calculated. As expected, the α effects of the aziridine 19 and the thiirane derivative 26 are also deshielding, but less than that of 25.

The γ -syn effects of the annulated rings move the C-4 resonances upfield. Frequently, these well-known effects reach maximum values if the steric interactions between the groups under consideration are especially severe. From molecular models, the distance between H-4 and H-7_{endo} in 1 is estimated to be about 300 pm. This results in a 6.4-ppm shielding for the C-4 resonance. In the oxirane derivative 25, the corresponding upfield shift is smaller (3.5 ppm), obviously because the lone pair at the oxygen interacts less seriously with H-4. Since the carbon-sulfur bond in the thiirane derivative 26 is longer than the carbon-oxygen bond in 25, this tendency continues, and the γ -syn effect nearly vanishes. The aziridine ring in 19, however, causes the largest shielding (7.7 ppm), possibly indicating the stereochemically unfavorable endo orientation of the nitrogen-hydrogen bond. A smaller γ -syn effect, closer to that of 25, would be expected if the lone pair at the nitrogen atom occupied the endo position.

The resonances of the carbon atoms in position 3 reveal that the aziridine, oxirane, and thiirane rings cause downfield shifts of 24.8, 24.1, and 29.0 ppm, respectively, thus exhibiting a greater effect than the cyclopropane ring (19.7 ppm). In the case of 1, this γ -anti effect has been explained on the basis of the interaction between the occupied orbital (see 34) of the bicyclo[1.1.0]butane system



(1a₂) and the unoccupied Walsh orbital (see 36) of the cyclopropane ring (1a₂').^{2,3} Formula 35 indicates that for steric reasons overlap occurs only with the lower half of 34. Therefore, only the C-3 resonance suffers the downfield shift relative to the C-1,6 signal in 2. At present, it cannot be decided whether this deshielding results from electron back-donation, which necessarily accompanies the orbital interaction described, or from the lower lying excited states within the Karplus-Pople approximation.¹⁴

The unoccupied Walsh orbitals (36) of cyclopropane, aziridine, and oxirane differ significantly.¹⁵ In cyclopropane it is completely symmetric, but in aziridine and oxirane the coefficients of the carbon atoms increase substantially compared to those of the heteroatoms, im-

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Table II. Three-Membered-Ring Annellation Effects (ppm) in Tetracyclo[4.1.0.0^{2,4}.0^{3,5}]heptane and 7-Heterotetracyclo[4.1.0.0^{2,4}.0^{3,5}]heptanes Calculated by Subtracting the Chemical Shifts of the Appropriate Carbons in Tricyclo[3.1.0.0^{2,6}]hexane (2)


X	no.	type of three-membered ring	α effect, C-1,6	β effect, C-2,5	γ -anti effect, C-3	γ -syn effect, C-4	
	CH ₂	1	cyclopropane	-8.8	4.4	19.7	-6.4
	NH	19	aziridine	9.0	7.2	24.8	-7.7
	O	25	oxirane	30.8	3.0	24.1	-3.5
	S	26	thiirane	13.0	6.1	29.0	-0.4

Table III. Effects of 7-Substituents (ppm) in Tetracyclo[4.1.0.0^{2,4}.0^{3,5}]heptanes and 7-Heterotetracyclo[4.1.0.0^{2,4}.0^{3,5}]heptanes Calculated by Subtracting the Chemical Shifts of the Appropriate Carbons in the Corresponding Unsubstituted Compounds

substituent	comps compared	α effect, C-7	β effect, C-1,6	γ effect, C-2,5	δ effect	
					C-3	C-4
Tetracyclo[4.1.0.0 ^{2,4} .0 ^{3,5}]heptanes						
<i>exo</i> -CH ₃	28-1	7.6	8.2	-0.9	-2.1	1.0
	30-29	5.1	8.1	0.8	-0.7	0.5
<i>exo</i> -C ₆ H ₅	31-1	17.3	10.9	-0.2	-1.1	1.9
	33-32	13.1	10.0	1.2	0.6	2.2
<i>endo</i> -CH ₃	29-1	10.5	6.6	-6.2	0.2	6.6
	30-28	8.0	6.5	-4.5	1.6	6.1
<i>endo</i> -C ₆ H ₅	32-1	20.3	7.3	-4.5	3.1	6.6
	33-31	16.1	6.4	-3.1	4.8	6.9
7-Azatetracyclo[4.1.0.0 ^{2,4} .0 ^{3,5}]heptanes						
CH ₃ C ₆ H ₅	20-19		9.5	-4.7	-5.3	4.9
C ₆ H ₅	21-19		9.8	-4.2	-3.2	5.7
CO ₂ C ₆ H ₅	22-19		7.6	-3.2	0.1	5.0
CO ₂ C(CH ₃) ₃	23-19		7.6	-3.3	-0.1	5.2
SO ₂ C ₆ H ₅ -4-CH ₃	24-19		11.3	-5.3	-3.1	5.8
7-Thiatetracyclo[4.1.0.0 ^{2,4} .0 ^{3,5}]heptane 7-Oxide						
O	27-26		12.6	-7.2	-23.0	-4.9

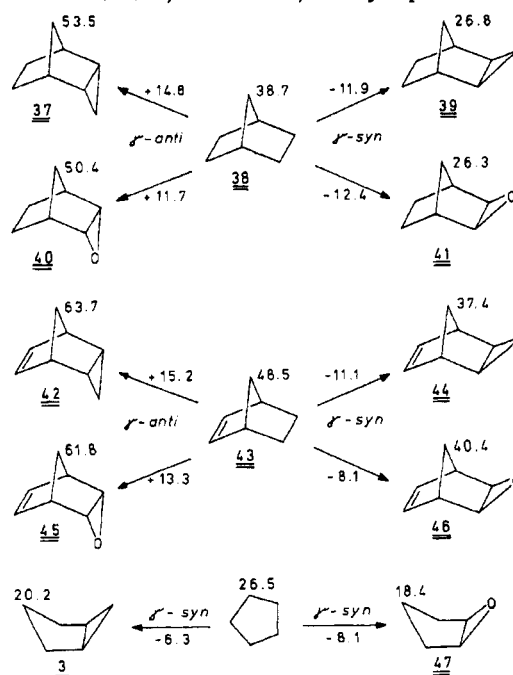
proving the overlap with 34. The energies of 36 of cyclopropane (X = CH₂, $E = 2.79$ eV^{15b}), aziridine (X = NH, $E = 2.87$ eV^{15b}), and oxirane (X = O, $E = 2.63$ eV^{15b}) are only little different, but that of thiirane (X = S, $E = 0.93$ eV^{15b}) is considerably lower. This also improves the interaction 35 and thus accounts for the extreme γ -anti effect of 29 ppm in 26.

Scheme III compares published data on relevant oxirane derivatives¹¹ to those of the corresponding carbocyclic systems. Relative to norbornane (38) and norbornene (43), the cyclopropane rings in 37¹⁶ and 42¹ cause γ -anti effects of 14.8 and 15.2 ppm, respectively, which are larger than those of the oxirane rings in 40 and 45¹¹ (11.7 and 13.3 ppm). Therefore, the correlation of the size of the γ -anti effects and orbital properties in 1 and 25 is either accidental or, in the examples of Scheme III, hidden by consequences of different geometry.

The γ -syn effects in Scheme III are larger than those in Table II, as now the three-membered rings face CH₂ groups in the cyclopentane part of the bicyclo[3.1.0]hexane systems, requiring more space than the CH group of position 4 in 1 and 25. Whereas the oxirane and cyclopropane shieldings in 46¹¹ and 44¹ show the same relative magnitude as in Table II, the values are virtually equal in the pair 41¹¹ and 39.¹ And, in 47,¹¹ the oxirane ring is even more effective (-8.1 ppm) than the cyclopropane ring of 3² (-6.3 ppm). Thus, the assumption that the oxirane rings exert smaller γ -syn effects than cyclopropane rings, as in the case of 25 and 1, is not generally valid.

It can be concluded, however, that oxirane rings within 6-oxabicyclo[3.1.0]hexanes behave in a similar manner as cyclopropane rings within the corresponding carbocyclic systems. The magnitude of the γ -anti and γ -syn effects,

Scheme III. γ -Anti and γ -Syn Effects on Formal Annellation of Cyclopropane and Oxirane Rings to Norbornane, Norbornene, and Cyclopentane



as well as the relative influence of the cyclopropane and oxirane rings, depends considerably on the nature of the ring systems in which the bicyclo[3.1.0]hexane moiety and its 6-oxa derivative are incorporated.

(2) Effects of Substituents in the 7-Position. For the discussion of the influences of the substituents on

nitrogen in the aziridine derivatives 20–24 relative to 19, it is useful to know the effects of substituents in the 7-position of 1. Hence, the upper part of Table III contains the effects of methyl and phenyl groups as calculated from the chemical shifts of 1 and 28–33 (Table I). The α and β effects offer little new information in comparison to the same substituents on cyclohexane. Also, the γ effects which are obtained from the C-2,5 resonances are quite normal. Being cis oriented relative to C-2,5, the endo substituents exert the expected shielding (3.0–6.2 ppm), while exo substituents appear to be of little influence.

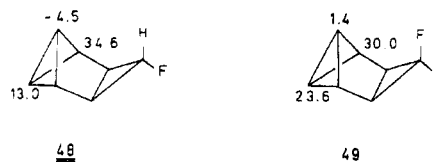
Two types of δ effects can be derived: those from the C-3 resonance, which are small, with the exception of those from an endo-phenyl group (deshielding by 3.1 and 4.8 ppm), and those from the C-4 resonance. The latter show a clear-cut distinction between exo substituents, which cause only an insignificant deshielding, and endo substituents, the deshielding of which is unusually large (6.1–6.9 ppm). Most severe steric interactions occur between the CH groups of the 4-position and 7-endo substituents, the δ effects of which almost exactly cancel the γ -syn effect of the cyclopropane ring. Similar influences of several parts per million induced by syn axial δ substituents have been observed occasionally in cyclic molecules.^{17,18}

Although extremely different substituents are attached to the nitrogen in the 7-azatetracyclo[4.1.0.0^{2,4}.0^{3,5}]heptanes 20–24, they cause nearly constant β effects of a size similar to those of the phenyl groups in the carbocycles 31–33. Without exception, the γ effects are directed to higher field (3.3–5.3 ppm), and the effects induced at the C-4 resonance are directed to lower field (4.9–5.8 ppm) to an even greater extent. In comparison to 28–33, this would suggest an endo orientation of the N-substituents. This stereochemistry is not supported by the δ effects for the C-3 resonance, however, as they vary from being ineffectual (carboxylate groups) to substantially shielding (benzyl group). This variability possibly mirrors the different interactions of the substituents with the lone pair of the nitrogen atom. An X-ray analysis of 24 has revealed the exo position of the tosyl group in the crystalline state,¹⁹ thus proposing the same invertomer to be favored in solution. Furthermore, the sterically less constrained exo isomers should prevail in 20–23.

By comparison of the chemical shifts of the episulfoxide 27 with those of the episulfide 26, the effects induced by the sulfoxide oxygen atom are obtained. Only the β effect is deshielding. The γ and both the δ effects cause upfield shifts, and the size of the δ effect at the C-3 resonance (–23 ppm) is without precedent. According to the literature,²⁰ on oxidation of thiiranes with peracid, the method we utilize to prepare 27 from 26,²¹ the addition of the oxygen atom always proceeds from the sterically less hindered side, thus suggesting the exo stereochemistry for 27. This is supported by the ¹H NMR resonances which, with the exception of the H-1,6 signal, appear upfield relative to those of 26.²¹ ¹H shielding effects of this kind have been used in configurational analysis of episulfoxides.²⁰ Kellogg et al.²² have reported the ¹³C NMR data of both the di-

tert-butylthiiranes and two of the corresponding sulfoxides. There, the oxygens give rise to similar β effects as in 27; the γ and δ effects, however, are smaller than 2 ppm.

The size of the shielding effects in the bicyclo[1.1.0]butane system of 27 seems to indicate an electron donation by the oxygen atom. Similar, although smaller, influences are observed upon substitution of the H-7_{exo} of 1 with a fluorine atom as in 48.¹³ Since the unoccupied Walsh orbitals (36) of fluorocyclopropane (X = CHF, $E = 2.17$ eV^{15b,c}) and thiirane S-oxide (X = SO, $E = -0.12$ eV^{15b}) have lower energies than those of cyclopropane and thiirane, respectively (vide supra), the interaction 35 should be improved in 27 and 48 relative to that of 26 and 1,



respectively. Consequently, the C-3 resonances of 27 and 48 should appear downfield from those of 26 and 1, respectively. The upfield shifts actually found suggest a counteracting effect, which most probably results from hyperconjugation of a lone pair of oxygen in 27 and of fluorine in 48. Hyperconjugative effects across three bonds have been invoked to explain upfield shifts caused by first-row heteroatoms located at the γ position and anti-periplanar to the ¹³C nucleus observed.²³ The fact that only 7-F_{exo} as in 48, where two four-bond zigzags act as transmitters, exerts the upfield shift, but not 7-F_{endo} as in 49, supports this interpretation.

Even if it is a general feature in ¹³C NMR spectroscopy that substituent effects are little understood, they undoubtedly hold great value in the analysis of configurations and conformations. The intention of this study is to show on an empirical basis that in polycyclic small-ring compounds substantial γ and δ effects may be operative and that these effects may cause upfield or downfield shifts depending on the stereochemical situation.

Experimental Section

The syntheses of the compounds studied have been described elsewhere: 19, 21–24,²⁴ 20, 26, 27,²¹ 25,²⁵ 28–33.²⁶ ¹³C NMR spectra were recorded on a Bruker WH-90 spectrometer operating at 22.64 MHz. Proton-coupled spectra were obtained by using the gated decoupling mode. The concentration of the samples was not standardized. The experimental error for the chemical shifts, which were measured relative to Me₄Si, is smaller than 0.1 ppm, and in the coupling constants the last digit of each value given in Table I is uncertain.

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Registry No. 1, 50861-26-2; 19, 72393-12-5; 20, 80063-05-4; 21, 72393-08-9; 22, 72393-09-0; 23, 72393-10-3; 24, 72393-11-4; 25, 73688-12-7; 26, 80063-06-5; 27, 80063-07-6; 28, 77429-85-7; 29, 77481-22-2; 30, 77429-86-8; 31, 77429-87-9; 32, 77481-23-3; 33, 77429-88-0.

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