A Carbon-13 NMR Study of Benzonorbornene Isomers

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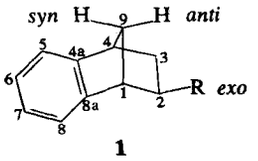
The carbon-13 NMR spectra of a series of *exo*-and *endo*-epimers of 2-substituted benzonorbornene (2-substituent = OH, OCHO, Br, NH_2, NHMe or NMe_2) have been examined. The spectra are readily assigned by comparison with the coupled and off-resonance proton decoupled spectra as well as by the use of shift reagents. Interesting and diagnostic features of the spectra allow the distinction between epimers.

INTRODUCTION

The ^1H NMR spectra of benzonorbornadiene and benzonorbornene derivatives have been extensively studied[1–4] and have been the cause of considerable controversy,[2–5] in particular regarding the shielding of the 9-*syn* and 9-*anti* protons. However, due both to complexity and inaccessibility, the ^1H NMR spectra of the 2-*exo* and 2-*endo* isomers of benzonorbornenes (**1** and **2**) have been little studied. The 2-protons of the parent hydrocarbon were assigned by the magnitude of the coupling to the bridgehead protons,[3] while the stereochemistry of the two 2-bromo isomers has been assigned on the basis of the chemical shift of the 2-proton.[6] A similar approach[7] supported by IR studies[8] was used to assign the 2-hydroxy isomers.

Recently Roberts *et al.*[9] have made a ^{13}C NMR study of norbornanes including *exo* and *endo*-isomerism, and the ^{13}C NMR spectra of benzonorbornadiene[10] and benzonorbornene[11] have been reported. We now report the use of ^{13}C NMR for the assignment of 2-*exo* and *endo*-benzonorbornene isomers.



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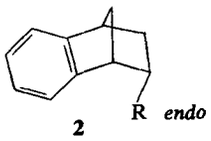
a: R = H **e:** R = NH_2
b: R = OH **f:** R = NHMe
c: R = OCHO **g:** R = NMe_2
d: R = Br



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RESULTS AND DISCUSSION

The ^{13}C NMR spectra of two new and ten previously reported[6,13–16] *exo*- and *endo* isomers of 2-substituted benzonorbornene are shown in Table 1. The chemical shifts relative to tetramethylsilane, together with the shifts relative to the parent benzonorbornene (**1a**) were determined in chloroform solution, off-resonance proton decoupled spectra being used to assist assignment. Previously reported stereochemical assignments for the known compounds are in accord with the observed carbon shifts. In addition, some useful diagnostic features are immediately apparent. (a) The difference between the chemical shifts of carbons 4a and 8a (easily seen as low field singlets in the off-resonance spectrum) are generally larger in the *endo* than in the *exo* isomers. (The one exception is where R = OCHO; these epimers bear a π-bond in the substituent R—this needs further study). (b) A considerably larger downfield shift of C-8 is observed in the *endo* series compared to the *exo* series. We attribute this to orbital overlap of the substituent with C-8 in the *endo* series while only δ-shifts are present in the *exo* series. (c) Significant upfield steric compression effects are evident at C-9 of the *exo* series while only very small γ-effects are noticed in the corresponding *endo* isomers. This is in line with similar observations in the norbornenes.[9]

We have further underpinned these assignments by use of shift reagents. As a test case, the two hydroxy isomers were thoroughly studied. It is seen that linear downfield shifts are observed by addition of aliquots of $Eu(fod)_3$ to both isomers (Table 2). Furthermore, these shifts and the stereochemical assignments for these epimers are clearly in agreement since in the *exo* isomer, the larger shifts are associated with carbons 2, 3, 9, 1 and 4 in order, while in the *endo* isomer the order is 2, 3, 8a, 8, 4a, 1, 4. Similarly, the assignments for the amino and methylamino epimers are also consistent with the europium shifts observed in these compounds, but it is evident that angular as well as distance relationships of the shift reagent must be considered since negative (upfield) shifts are also listed

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Table 1. Carbon-13 NMR spectra of *exo* and *endo* isomers of 2-substituted benzonorbornenes (1 and 2)

Carbon[a]	1		2		3		4		4a		5	
2-Substituent	δ	Δ[b]	δ	Δ[b]	δ	Δ[b]	δ	Δ[b]	δ	Δ[b]	δ	Δ[b]
H	43.75		27.13		27.13		43.75		148.06		120.40	
exo-OH	52.15	8.40	73.25	46.12	39.54	12.41	42.88	−0.87	149.42	1.36	120.61	0.21
endo-OH	50.31	6.56	71.32	44.19	38.79	11.66	43.85	0.10	149.23	1.17	120.44	0.04
exo-NH_2	52.92	9.17	53.41	26.28	39.45	12.32	43.36	−0.39	148.53	0.47	121.18	0.45
endo-NH_2	51.23	7.48	51.65	24.52	39.33	12.20	44.22	0.47	149.19	1.13	120.38	−0.35
exo-NHMe	48.04	4.29	62.50	35.37	37.33	10.20	43.07	−0.68	149.03	0.97	121.18	0.45
endo-NHMe	47.05	3.30	60.14	33.01	36.50	9.37	43.62	−0.13	149.03	0.97	120.49	0.09
exo-NMe_2	46.59	2.84	69.72	42.59	34.45	8.32	43.66	−0.11	149.13	1.07	120.52	0.12
endo-NMe_2	47.52	3.77	68.83	41.70	35.04	7.91	43.93	0.18	148.92	0.86	119.98	−0.42
exo-OCHO	49.32	5.57	75.69	48.56	37.35	10.22	42.73	−1.02	149.28	1.22	120.73	0.33
endo-OCHO	47.76	−4.01	74.12	46.99	35.86	8.73	43.37	−0.38	148.08	0.02	120.43	−0.30
exo-Br	49.79	6.04	53.68	26.55	41.18	14.05	44.22	0.47	148.04	−0.02	120.79	0.06
endo-Br[d]	48.72	4.97	51.45	24.32	39.16	12.03	43.85	0.10	147.27	−0.79	120.21	−0.19

Carbon[a]	6[c]		7[c]		8		8a		9		Others
2-Substituent	δ	Δ[b]	δ	Δ[b]	δ	Δ[b]	δ	Δ[b]	δ	Δ[b]	δ
H	125.48		125.48		120.40		148.06		49.31		
exo-OH	126.08	0.60	125.50	0.02	121.96	1.56	144.53	−3.53	45.98	−3.33	
endo-OH	126.48	1.00	125.59	0.11	124.21	3.81	141.79	−6.27	48.25	−1.06	
exo-NH_2	125.48	0	125.68	0.02	120.59	0.19	146.39	−1.67	45.39	−3.92	
endo-NH_2	125.38	−0.10	126.33	0.85	123.81	3.41	142.56	−5.50	49.29	−0.02	
exo-NHMe	125.50	0.02	125.68	0.02	120.52	0.12	146.48	−1.58	45.91	−3.40	NHMe−35.04
endo-NHMe	125.49	0.01	126.25	0.77	123.32	2.92	142.66	−5.40	48.54	−0.79	NHMe−34.17
exo-NMe_2	125.78	0.30	125.50	0.02	121.11	0.71	146.89	−1.17	45.90	−3.41	NMe_2−44.35
endo-NMe_2	125.96	0.48	125.47	−0.01	122.63	2.23	143.44	−4.62	49.11	−0.20	NMe_2−44.81
exo-OCHO	126.70	1.22	125.97	0.49	122.56	2.16	142.94	−5.12	46.63	−2.68	CHO−160.66
endo-OCHO	125.78	0.30	126.50	1.02	123.54	3.14	142.17	−5.89	48.25	−1.06	CHO−160.84
exo-Br	126.14	0.66	126.84	1.36	122.03	1.63	144.05	−4.01	46.87	−2.44	
endo-Br[d]	124.10	−1.38	125.39	−0.09	overlaid		143.16	−4.90	48.23	−1.08	

[a] δ ^{13}C NMR chemical shift from TMS (ppm).
[b] Δ refers to the shift with respect to the 2-unsubstituted system. A minus sign indicates an upfield shift.
[c] These shifts for the 2-OH, 2-NMe_2 and 2-OCHO compounds may be reversed.
[d] These results were taken on a 400 mg sample containing only 20% *endo* isomer and are thus less reliable.

in three of these four isomers. From the McConnell-Robertson[12] relationship [$\Delta Eu_i = k(3\cos^2\theta_i - 1)r_i^{-3}$ where ΔEu_i is the shift induced in proton i, r_i is the distance from the europium ion, θ_i the angle between the *N*–Eu axis and the $C_i \ldots$ Eu axis, and k is a constant] it is evident that an angle of between 55–125° must be present in the case of the carbon nuclei showing negative shifts.

In conclusion, ^{13}C NMR spectroscopy is a useful technique for the structural assignment of *exo*- and *endo*-epimers of 2-substituted benzonorbornenes.

EXPERIMENTAL

NMR spectra

Proton decoupled ^{13}C NMR spectra were obtained on a Varian CFT 20 spectrometer (10 mm probe). All spectra were determined in chloroform-*d* (400 mg in 1 ml solvent) at 35 ± 2 °C using TMS as internal standard and deuterium oxide as an external lock.

Table 2. Carbon-13 NMR shifts (ppm) of benzonorbornenes (1 and 2) addition of $Eu(fod)_3$

Compound (400 mg) (1 or 2; R=)	Amount $Eu(fod)_3$ (mg)	Europium shifts (ppm) 1	2	3	4	4a	5	6	7	8	8a	9	Me
	100	0.60	2.25	0.71	0.37	0.37	0.27	0.26	0.27	0.28	0.28	0.69	
exo-OH	200	1.16	4.87	1.38	0.96	0.67	0.47	0.39	0.46	0.49	0.49	1.31	
	300	1.76	7.60	2.17	1.47	0.98	0.67	0.60	0.66	0.70	0.78	2.06	
	100	0.47	2.51	0.77	0.40	0.57	0.45	0.37	0.38	0.51	0.59	0.38	
endo-OH	200	0.86	4.47	1.42	0.78	1.05	0.74	0.66	0.67	0.98	0.99	0.68	
	300	1.25	6.50	2.03	1.17	1.46	1.04	0.95	0.97	1.46	1.47	1.05	
exo-NH_2	100	−1.00	3.88	0.76	0.67	0.45	0.28	0.27	0.27	0.29	0.26	0.80	
endo-NH_2	100	−1.63	3.40	0.69	0.50	0.50	0.38	0.28	0.30	0.46	0.57	0.31	
exo-NHMe	100	0.43	2.67	0.68	0.50	0.30	0.13	0.11	0.13	0.19	0.31	0.60	3.65
endo-NHMe	100	2.24	5.19	1.74	0.80	0.76	0.89	0.30	0.45	0.86	0.99	−1.85	6.15

Compounds

Compounds **1a**,[13] **1b** and **2b**,[14] **1d** and **2d**[6] and **1e**, **2e**, **1f**, **2f**, **1g** and **2g**[15,16] were prepared as previously described.

***Exo*-2-hydroxybenzonorbornene formyl ester (1c).** This was prepared by refluxing **1b** (2.0 g, 12.5 mmol) with formic acid (98%, 1.5 g, 22.3 mmol) for 12 h. The reaction mixture was cooled, diluted with water (10 ml) and neutralized with saturated sodium bicarbonate solution. The mixture was extracted with ether and the extracts washed with water, dried and evaporated. Distillation of the oily residue gave the formyl ester (**1c**) (1.86 g, 81%), b.p. 140–142 °C at 18 mm, IR (liquid film) 3030, 2990, 2980, 2880, 2320, 1725, 1470 cm^{-1} (Found: C, 76.7; H, 6.5. $C_{12}H_{12}O_2$ requires C 76.59; H 6.38%).

***Endo*-2-hydroxybenzonorbornene formyl ester (2c).** This compound was prepared using the method described for **1c**, from **2b** (2.0 g). The distilled oily residue (1.8 g, 78%) had b.p. 102 °C at 1.5 mm, IR (liquid film) 3040, 2995, 2690, 2890, 2370, 2340, 1730, 1475, 1465 cm^{-1}. (Found: C, 76.5; H, 6.1%.)

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