Tetrahedron Letters No. 26, pp 2199 - 2202, 1975. Pergamon Press. Printed in Great Britain.

^1H NMR SOLVENT SHIFTS INDUCED BY HEXAFLUOROBENZENE IN MONOTERPENES

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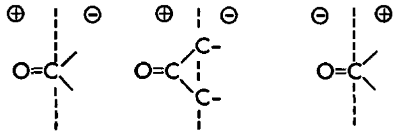
(Received in Japan 1 May 1975; received in UK for publication 12 May 1975)

Aromatic solvent-induced shifts (ASIS)[1] with benzene[2,3] and pyridine[4] in ^1H NMR spectroscopy have been shown to be of value in signal assignments and structural elucidation of organic compounds. The ASIS method is still useful in view of the simple procedure and easy recovery of the sample, although applications of NMR shift reagents have been more popular in recent years.[5] In an earlier stage, reference plane rules [see FIGs. (a) and (b) for benzene[6] and pyridine,[7] respectively] were proposed concerning the solvent shifts of ^1H signals in various types of compounds having a carbonyl group. These rules are well accepted as a conventional generalization, although some theoretical approaches to the nature of the benzene-solute interaction have been made thereafter.[3,8]

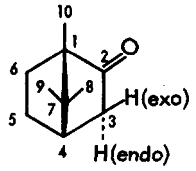
Meanwhile, Verkade and his coworkers[9] discovered that the direction of C_6F_6-induced shifts observed for some polar solutes is opposed to that of C_6H_6-induced shifts. They stated that, while the downfield shifts at the positive end of the dipole in C_6F_6 are decidedly smaller than the upfield shifts in C_6H_6, the upfield shifts in C_6F_6 in the negative region of the solute are up to three times larger than the downfield shifts in C_6H_6.[9] This behaviour seems to make the ASIS method more powerful when C_6F_6 is used as a solvent after C_6H_6 and/or pyridine. However, the C_6F_6-induced shift has not been applied yet to a wide variety of organic compounds, particularly natural products, although a few studies have been reported with interests in the solvent-solute interaction mechanism.[9-11]



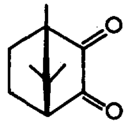
(a) C_6D_6 (b) C_5D_5N (c) C_6F_6

FIGURE. Carbonyl reference plane rules. Dotted line shows a reference plane.

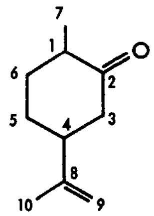
Thus, we wish to report here the applicability of this method examined for ^1H NMR spectra of some



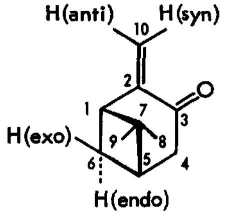
Camphor
(1)



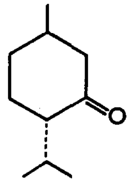
Camphor-quinone
(2)



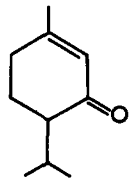
Carvone
(3)



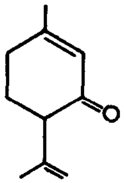
Pinocarvone
(4)



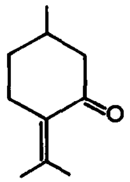
Menthone
(5)



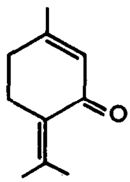
Piperitone
(6)



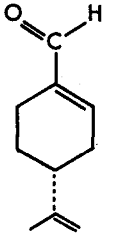
Isopiperitenone
(7)



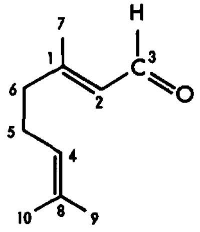
Pulegone
(8)



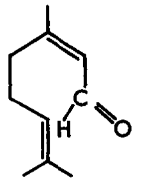
Piperitenone
(9)



Perillaldehyde
(10)



Citral-a
(11)



Citral-b
(12)

monoterpenic carbonyl compounds (1-12). The TABLE lists the NMR shift data obtained in CCl_4, C_6F_6, C_6D_6, C_5D_5N, and $CDCl_3$.† The C_6D_6- and C_5D_5N-induced shifts obtained for these compounds agree with results already reported in the literature.[1-4,6-8] Inspection of the TABLE indicates that a carbonyl reference plane rule shown in FIG. (c) can be conventionally applied to ASIS with C_6F_6 also.

Protons in front of the reference plane (see syn-10-H in 4, and 9-H in 8 and 9, as indicated by Dreiding models) are shielded in C_6F_6 and deshielded in C_6D_6, both to considerably large extents. However, signals due to protons close to the reference plane show different types of shifts depending on the presence of conjugated double bond(s) and/or steric hindrance against the solvent-solute interaction. The presence of a conjugated double bond appears to move the plane towards the double bond to some extent. Thus, 10-H in 1, 7-H in 3, and 2-H in 6 and 7 indicate larger downfield-shift values for C_6F_6 than upfield-shift values for C_6D_6 as described above,[9] whereas 2-H in 9 has large similar magnitudes for the three ASIS (-0.23, +0.23, and +0.24 ppm for C_6F_6, C_6D_6, and C_5D_5N, respectively) like a proton in front of the plane (see syn-10-H

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† We chose CCl_4 and TMS as a reference solvent and an internal standard, respectively; we should like to claim a wide applicability for CCl_4 and $CDCl_3$ in organic chemistry, although cyclohexane might be recommended for both references.[1a,12] Therefore, we have also given δ values in $CDCl_3$ in the TABLE.

TABLE. ^{1}H Chemical Shifts (δ) and ASIS[a] Data on Monoterpenic Carbonyl Compounds Examined[b]

Proton	δ_{CCl_4}	ASIS (ppm)			δ_{CDCl_3}
		C_6F_6	C_6D_6	C_5D_5N	
(1)[c]					
3-H(exo)	2.27	+0.04	-0.17	+0.01	2.37
3-H(endo)	1.74	+0.05	-0.18	0.00	1.83
8-H	0.83	+0.05	-0.23	-0.11	0.84
9-H	0.95	+0.14	-0.30	-0.15	0.96
10-H	0.85	-0.05	+0.04	+0.05	0.91
(2)[c]					
4-H	2.54	+0.02	-0.35	+0.04	2.63
8-H	0.92	+0.08	-0.39	-0.15	0.92
9-H	1.05	+0.25	-0.58	-0.20	1.06
10-H	1.05	+0.10	-0.23	-0.05	1.10
(3)					
6-H	6.62	+0.13	-0.48	-0.07	6.75
7-H	1.72	-0.09	+0.07	+0.07	1.76
9-H	4.76	+0.02	-0.08	-0.01	4.77
			-0.16	-0.08	4.82
10-H	1.75	+0.09	-0.31	-0.12	1.78
(4)[d]					
6-H(endo)	1.30	0.00	-0.28	-0.14	1.29
8-H	0.82	+0.03	-0.20	-0.12	0.82
9-H	1.37	+0.12	-0.31	-0.16	1.38
10-H(syn)	5.86	-0.20	+0.24	+0.22	5.97
10-H(anti)	4.91	0.00	-0.18	+0.06	5.01
(5)					
7-H	0.90	+0.17	-0.19	-0.05	0.95
9- and 10-H	0.83	-0.03	+0.04	+0.03	0.86
	0.89	-0.02	+0.03	+0.03	0.92
(6)					
2-H	5.72	-0.20	+0.12	+0.17	5.82
7-H	1.92	+0.14	-0.48	-0.17	1.93
9- and 10-H	0.82	-0.02	+0.03	+0.04	0.86
	0.93	-0.02	-0.03	-0.01	0.94
(7)					
2-H	5.73	-0.16	+0.10	+0.17	5.88
7-H	1.93	+0.17	-0.53	-0.18	1.95
9-H	4.66	-0.10	+0.12	+0.17	4.75
	4.83	-0.07	+0.09	+0.11	4.93
10-H	1.71	-0.07	+0.03	+0.04	1.75
(8)					
7-H	1.01	+0.08	-0.28	-0.16	1.00
9-H	1.93	-0.15	+0.13	+0.11	1.99
10-H	1.76	+0.08	-0.28	-0.12	1.78
(9)					
2-H	5.75	-0.23	+0.23	+0.24	5.89
7-H	1.91	+0.14	-0.47	-0.17	2.10
9-H	2.03	-0.15	+0.21	+0.18	1.93
10-H	1.83	+0.09	-0.28	-0.11	1.86
(10)					
2-H	6.68	+0.10	-0.61	-0.05	6.81
7-H	9.34	-0.09	-0.06	+0.15	9.42
9-H	4.71	+0.02	-0.08	+0.02	4.73
	4.73	0.00	0.00	+0.05	4.78
10-H	1.75	+0.09	-0.23	-0.09	1.76
(11)[e]					
2-H	5.78	-0.15	+0.04	+0.16	5.88
3-H	9.89	-0.06	-0.01	+0.21	9.98
4-H	5.06	+0.10	-0.09	+0.02	5.01
7-H	2.15	+0.15	-0.57	-0.14	2.16
9-H	1.68	+0.03	-0.10	-0.05	1.68
10-H	1.61	+0.10	-0.15	-0.08	1.61
(12)[e]					
2-H	5.78	-0.15	-0.01	+0.16	5.88
3-H	9.80	-0.05	+0.07	+0.27	9.90
4-H	5.06	+0.10	-0.11	+0.02	5.11
7-H	1.95	+0.17	-0.52	-0.14	1.98
9-H	1.67	+0.04	-0.10	-0.04	1.68
10-H	1.60	+0.11	-0.20	-0.05	1.60

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[a] ASIS values are indicated by δ(aromatic solvent) - δ(CCl_4) by using TMS as an internal standard.[†] Plus sign represents a downfield shift.

[b] ^{1}H NMR spectra were taken with a Varian A-56/60D spectrometer at ordinary probe temperature (*ca*. 40°). Sample concentrations were about 5% (w/v) or less. Accuracies of chemical shifts (δ) are within ±0.01.

[c] See ref 6a for the assignments of the three methyl signals.

[d] Signal assignments were confirmed by NOE and spin-decoupling experiments on a Varian HA-100 spectrometer; the other signals were second-order and unassigned.

[e] For the signal assignments, see M. Ohtsuru, M. Teraoka, K. Tori, and K. Takeda, *J. Chem. Soc.* (B) 1033 (1967).

in 4). On the other hand, exo-3-H, endo-3-H, and 8-H in 1, and endo-6-H, 8-H, and anti-10-H in 4 are strongly shielded in C_6D_6 and weakly deshielded in C_6F_6; exo-3-H and endo-3-H in 1 have almost equal ASIS values in each solvent, a fact which implies that the two geminal protons have almost equal geometries in relation to the carbonyl group. The aldehydic proton signals in 10-12 all have negative ASIS values in C_6F_6 as a proton in front of the plane does, whereas the shift directions of the signals in C_6D_6 are different in each compound. The ASIS values for 2-H in 10, and 2-H and 7-H in 11 and 12 clearly demonstrate that their carbonyl groups preferentially adopt s-trans conformations.

As described above, ASIS features can be more clearly characterized by using not only C_6D_6 but C_6F_6 also; pyridine-induced shifts can assist the characterization strongly, its usefulness having already been pointed out in literature[1,4,7] (e.g., see 2-H and 3-H in 11 and 12). Further applications of C_6F_6-induced shifts to ^{1}H NMR spectra of other organic natural products will be presented elsewhere.

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