

Synthesis and characterization of the *syn*-bromonium ion of 4-equ chloroadamantylidenadamantane, towards a chiral bromination reagent

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Abstract—Synthesis and characterization of the stable bromonium ion of 4-equ-chloroadamantylideneadamantane is described. ¹³C and ¹H NMR spectroscopy reveal preferred formation of the *syn*-isomer, which might be used as chiral bromination reagent using resolved starting material.

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Efficient chiral brominations of prochiral alkenes do not exist; for the only example *e,e*-values are in the range of only 0.05.¹ Stable bromonium ions as salts exist from adamantylideneadamantane, adad,² electrophilic bromine can be transferred from this substrate to alkenes via a spirobromonium ion as intermediate.³ While unsubstituted adad is achiral the readily available 4-equ derivatives⁴ are chiral compounds, which might be used as chiral bromination reagents. After studying CT complexes of derivatives of 4-equ substituted adad using UV spectroscopy,⁵ we report here on structurally related studies of stable bromonium ions of 4-equ Cl-adad using state-of-the-art NMR techniques.

The bromonium ion of 4-equ Cl-adad can be generated in CD₂Cl₂ with ca. 30-fold molar excess of bromine (20 mg adad-Cl in 1.3 g of solvent, addition of 230 mg Br₂); no starting material is observed under this condition, the anion is likely Br₅⁻ and/or Br₇⁻. Excess of bromine is necessary to convert the alkene completely to the product, which is in equilibrium with starting material. Further addition of bromine does not change the spectrum. All 20 signals for the 20 chemically different ¹³Cs can be observed and can be assigned by depths, COSY,

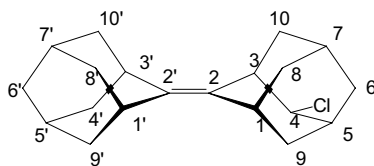
and NOESY along with the determination of ¹³C/¹H couplings. The results are summarized in Table 2 along with Table 1 with results of the starting material. NMR spectra were recorded on a Bruker AC 400 (400 MHz ¹H frequency). Phase sensitive (TPPI) NOESY *t*_{mix} = 50, 450 ms and HSQC and absolute value DQF-COSY NMR spectra were recorded using Bruker standard software. Chemical shift values for assignment purposes were calculated with the ACD (Advanced Chemistry Development) Science Serve, Pegnitz, Germany. In Tables 1 and 2 the results are summarized.

Stereochemistry of the bromonium ion: Br⁺ can be situated to chlorine in *syn* and *anti* stereochemistry. The two diastereomeric bromonium ions should give distinctly different signals in the NMR spectra for most of the carbons and protons. However, since the formation of these ionic intermediates is a reversible process,⁵ the equilibrium between the two eventually formed bromonium ions, which occurs through the return to CT-complexes and reagents, may affect the NMR spectra determining a reduction in the signals number: the signal numbers due to same nucleus in the two diastereoisomers coalesce to an average chemical shift value if the exchange is fast on the NMR time scale (see Scheme 1).

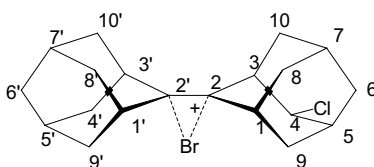
In the case of adad a dynamic phenomena of this type has been demonstrated, although a reduction of the Br⁺ exchange rate between the two double bond faces (*k*_{NMR}) could be obtained increasing Br₂ concentration

Keywords: Bromonium ion; Chirality; NMR spectroscopy.

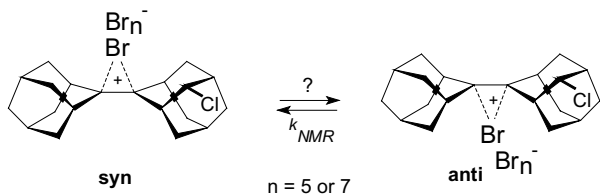
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Table 1. ^1H and ^{13}C NMR chemical shifts (400 MHz) for 4-equi Cl-adad in CD_2Cl_2 at 30 °C (δ , ppm using CD_2Cl_2 as internal standard)

Position	^{13}C δ	^1H δ	Position	^{13}C δ	^1H δ
2	137.64		2'	131.41	
1	33.06	2.92	1'	32.77	2.92
9	32.93	2.17; 2.12	9'	39.89	1.91; 1.72
5	36.36	2.14	5'	28.97	1.96
4	69.12	4.30	4'	39.99	1.91; 1.72
3	40.02	3.09	3'	31.00	2.92
10	30.92	2.36; 1.68	10'	39.92	1.91; 1.72; 2.15
7	29.28	1.98	7'	28.28	1.96
6	37.53	2.17; 2.02	6'	37.53	2.17; 2.3; 2.54; 1.93
8	39.25	1.92; 1.73	8'	39.65	1.92; 1.73

Table 2. ^1H and ^{13}C NMR chemical shifts (400 MHz) for the bromonium ion of 4-equi Cl-adad in CD_2Cl_2 at 30 °C (δ , ppm using CD_2Cl_2 as internal standard)

Position	^{13}C δ	^1H δ	Position	^{13}C δ	^1H δ
2	165.94		2'	146.78	
1	39.06	3.17	1' (or 3')	39.37	3.24
9	39.25	2.73; 2.38	3' (or 1')	36.95	3.18
5	34.50	2.48	9' (or 4')	44.18	2.73; 2.36
4	65.11	4.75	4' (or 9')	44.06	2.68; 2.34
3	43.86	3.19	10' (or 8')	42.88	2.4; 2.7
10	37.52	3.07; 2.15	8' (or 10')	42.88	2.4; 2.7
7	26.66	2.34	5'	27.6	2.48
6	30.59	2.54; 1.93	7'	27.6	2.48
8	43.15	2.63; 2.32	6'	37.3	2.13

**Scheme 1.**

or lowering temperature; that is, through two approaches able to shift all the equilibria towards the bromonium Br_5^- (or Br_7^-) salt.⁶

Under the presently described experimental conditions the bromonium ion of 4-equi Cl-adad has Br_5^- (or Br_7^-) as counteranion. All ^{13}C signals are however sharp lines, indicating a strong preference for one isomer. Cooling

to ca. 0 °C do not show line broadening, as well as an increase in bromine concentration. Therefore, one isomer should be favored over the other one by at least 96%. Preference of *syn*-stereochemistry is expected on the theory of cage molecules (Cieplak's stereoelectronic effect).⁷ This predicted stereochemistry can be derived experimentally using the shift difference ($\Delta\delta$) for ^{13}C and ^1H signals of hydrocarbon and corresponding bromonium ion. According to Olah⁸ aliphatic carbocations, generated by ionization from their chlorides, show characteristic downfield shifts for ^1H and ^{13}C signals. For example, the average ^1H shift of 4-equi Cl-adad is ca. 1.82 ppm, while the average shift for the corresponding bromonium ion is at ca. 2.53 ppm. The ^{13}C shifts are also changed by ca. 3 ppm into the downfield region, but the changes δ are more pronounced at the *syn*-side compared to the *anti* side of the cage molecule of adad (see Table 3). Therefore, the stronger ^{13}C shifts of the *syn* side can be used for conclusive evidence for the

Table 3. ^{13}C and ^1H shift differences for bromonium ion minus, $\Delta\delta$ calculated for bromonium ion hydrocarbon for C4,4',9,9',5,5' (*syn*-positions) versus C8,8',10,10',7,7' (*anti*-position)

	<i>syn</i> -Positions			<i>anti</i> -Positions	
	^{13}C	^1H		^{13}C	^1H
4	-4.01	-0.35	8	3.90	0.71; 0.59
4'	4.07	0.77; 0.62	8'	3.13	—; 0.58
9	6.12	0.56; 0.26	10	4.10	0.47; 0.27
9'	4.30	0.82; 0.64	10'	2.96	0.88; 0.59
5	1.86	0.34	7	1.62	0.35
5'	1.73	0.52	7'	1.68	0.52

syn-stereochemistry. Only carbon C-4 shows an upfield shift of 4.01 ppm going from the neutral to the ionic species likely an effect of the electronegative chlorine. The results are summarized in Table 3.

Evidence of bridged character of stable bromonium ions of adad and its derivatives: Until now stable bromonium ions are only observed from adad⁹ and from two of its derivatives: E-(1-methyl-2-adamantyliden)-1-methyladamantane¹⁰ and 4-equ Cl-adad, studied in this paper. For stable carbocations the degree of bridging has been derived empirically by the value of the difference of ^{13}C shifts: sum of all ^{13}C of cation minus sum of all ^{13}C of corresponding hydrocarbon.¹¹ If we apply this criterion to the bromonium ions of adad and the two adad derivatives we obtain for the parent compound a value of 78.8 ppm, for the dimethyl compound a value of 82.6 ppm and for 4-equ Cl-adad a value of 79.9 ppm. These three values are very similar. In addition, the value is in the range for nonclassical cations and show the bridged character for all three species. Classical cations show much larger delta shift values in the range of 300 ppm.¹¹ This result is also in agreement with the X-ray structure of bromonium ion salts of adad, which revealed a symmetrically bridged structure,^{2,12} although two rapidly equilibrating partially bridging intermediates could give the same results. The chloronium ion of adad is characterized by C–Cl bonds of different length but the ^{13}C NMR spectrum is in agreement with an apparent plane of symmetry, which bisects the halonium ring, indicating that the chloronium ion is present in solution as two rapidly equilibrating ion pairs.¹³

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