

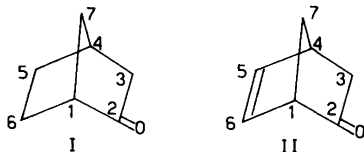
Base-catalyzed Protodetrutiation of Some Methyl-substituted 2-Norbornanones and 2-Norbornenones

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The effect of a methyl group at the 1, 4, 5 or 6 position of the substrate on the hydroxide-ion-catalyzed detrutiation rates of *exo*-3- and *endo*-3-tritiated 2-norbornanone (norcamphor) and 2-norbornenone (dehydronorcamphor) has been observed to be small (a factor of 0.3 to 2.3). The effects agree with the delocalization of the negative charge from C-3 *via* C-2 to the carbonyl oxygen but argues against its delocalization to the 5,6-double bond in the transition state. The retarding influence of the homoconjugation between the 5,6-carbon and 2-carbon-oxygen double bonds in 2-norbornenone upon the reaction rate is estimated to correspond to a factor of 0.04 ± 0.01 .

A tritium counting technique was recently employed for measuring the hydroxide-ion-catalyzed exchange rates of *exo*- and *endo*-3-hydrogens of some 2-bicyclo[2.2.1]heptanones and a 2-bicyclo[2.2.1]heptenone.¹ This technique is easier and better suited for small substrate concentrations than the usually used NMR and mass spectrometry. In this work tritium counting is utilized for measuring the exchange rates of 3-hydrogens in monomethyl-substituted 2-norbornanones (norcamphors or 2-bicyclo[2.2.1]heptanones), I, and 2-norbornenones (dehydronorcamphors or 2-bicyclo[2.2.1]hept-5-enones), II.



EXPERIMENTAL

2-Norbornenones (1-, 4-, 5- and 6-methylated) were prepared by the methods of Krieger and Masar,² and Goering and Chang.³ 5-Methyl- and 6-methyl-2-norbornenones were easily hydrogenated to 5- and 6-methyl-2-norbornanones by catalysis with palladium on carbon under normal pressure. As 1- and 4-methyl-2-norbornenones reacted very poorly they were first reduced with lithium aluminium hydride to the corresponding alcohols, which were hydrogenated to the saturated alcohols. These were oxidized to 1- and 4-methyl-2-norbornanones with chromic acid.⁴ The purities of the substrates were determined by GLC to be 99% or more with the exception of 4-methyl-2-norbornanone, which contained 4% of the corresponding alcohols. The ketones were identified from their IR and ¹H and ¹³C NMR spectra.^{5,6} The *exo*- and *endo*-3-hydrogens were partly tritiated by a method reported earlier.¹

The protodetrutiation rates of the *exo*-3- and *endo*-3-hydrogens were measured consecutively in the case of 2-norbornanones ($k_{exo}/k_{endo} = 25$ to 230 at 75 °C) and concurrently in the case of 2-norbornenones ($k_{exo}/k_{endo} = 9$ to 13 at 75 °C).¹ For all substrates k_{exo} was assumed to be greater than k_{endo} . The second-order rate constants were calculated by dividing the first-order constants with the sodium hydroxide concentrations used.

RESULTS AND DISCUSSION

The observed hydroxide-ion-catalyzed detrutiation rates of *exo*-3 and *endo*-3 tritiated 2-norbornanone and 2-norbornenone and their monomethyl homologues at different temperatures are listed in Table 1. The rate constants were measured at different hydroxide-ion concentrations (0.01 to 1 mol dm⁻³), but no marked salt effect could be

Table 1. Observed protodetrutiation rates of *exo*-3- and *endo*-3-hydrogens of 2-norbornanones (I) and 2-norbornenones (II) in aqueous 0.01–1 mol dm⁻³ sodium hydroxide solutions at different temperatures.

Substrate	Temp. °C	$k_{b,exo}$ 10 ⁻⁴ dm ³ mol ⁻¹ s ⁻¹	$k_{b,endo}$ 10 ⁻⁴ dm ³ mol ⁻¹ s ⁻¹
I	75	469	15.7
1-Me-I	55	88.3	
	65	179	3.80
	75	386	9.85
	85		22.1
	65	203	7.03
4-Me-I	75	406	17.1
	85	934	38.7
	95		93.7
	55	231	
5-Me-I	65	542	2.03
	75	1048	4.40
	85		11.26
	95		20.6
	65	183	3.63
6-Me-I	75	349	9.22
	85	733	19.8
	75	30.5	3.23
II	75	30.5	3.23
1-Me-II	55	2.91	0.26
	65	6.72	0.60
	75	15.2	1.58
	85	35.9	4.03
	55	3.73	0.25
5-Me-II	65	8.94	0.63
	75	21.6	1.74
	85	44.2	3.83
	55	3.23	0.25
6-Me-II	65	6.05	0.61
	75	14.5	1.64
	85	34.9	3.99

seen, e.g. 2-norbornenone at 75 °C, $k_b/10^{-4}$ dm³ mol⁻¹ s⁻¹ (base concentrations in mol dm⁻³ are in parentheses), *exo* detrutiation: 30.9 (0.1), 31.8 (0.2), 30.3 (0.3), 27.5 (0.6) and 31.9 (1.0), *endo* detrutiation: 3.10 (0.1), 3.36 (0.2), 3.20 (0.3), 3.20 (0.6) and 3.29 (1.0). In the detrutiation of *exo*-3-T-2-norbornanone a small negative salt effect (ca. 10% between 0.01 and 0.1 mol dm⁻³ NaOH) was observed earlier.¹ The rate constants of 2-norbornanone, 1-methyl-2-norbornanone and 2-norbornenone agree with those measured earlier under the same conditions.¹

The activation parameters, ΔS^\ddagger and ΔH^\ddagger , and the rate constants calculated from them at 75 °C are presented in Table 2. The values for 2-norbornanone and 2-norbornenone are from Ref. 1 except the rate constants of the latter, which are

mean values obtained from measurements in different base concentrations (see above). The activation entropies are negative (-52 to -85 J mol⁻¹ K⁻¹), which is typical of this kind of carbon acids.^{7,8} Relative rates at 75 °C are also presented in Table 2 for the *exo* and *endo* exchange with 2-norbornanone and 2-norbornenone as reference compounds.

The observed detrutiation rates of the *exo* hydrogens consist for the most part of the departure rate of tritium from the *exo* position, but those observed for the *endo* hydrogens consist of both its departure rate from the *endo* position and its rate of shift from the *endo* to the *exo* position (owing to the departure of protium from the *exo* position and the return of the same or another protium to the *endo* position).^{1,8,9} However, a comparison of the rates of the different members of the bicyclic family

Table 2. Activation parameters for the hydroxide-ion-catalyzed protodetritiation of *exo*-3- and *endo*-3-hydrogens of 2-norbornanones (I) and 2-norbornenones (II) and the rate coefficients as well as the relative rates calculated from them at 75 °C.

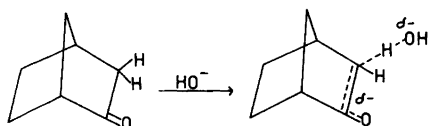
Substrate	Position of tritium	ΔS^\ddagger J mol ⁻¹ K ⁻¹	ΔH^\ddagger kJ mol ⁻¹	k_b 10 ⁻⁴ dm ³ mol ⁻¹ s ⁻¹	k_{rel} <i>exo</i>	<i>endo</i>
I	<i>exo</i>	-81(4) ^a	66(1) ^a	461(13) ^a	1.00	
	<i>endo</i>	-59(2) ^a	84(1) ^a	15.6(1) ^a		1.00
1-Me-I	<i>exo</i>	-81(9)	67(3)	379(15)	0.82	
	<i>endo</i>	-58(8)	86(3)	9.55(21)		0.61
4-Me-I	<i>exo</i>	-60(15)	74(5)	432(19)	0.94	
	<i>endo</i>	-52(5)	86(2)	17.2(4)		1.10
5-Me-I	<i>exo</i>	-67(12)	69(4)	1075(59)	2.33	
	<i>endo</i>	-83(11)	79(4)	4.65(21)		0.30
6-Me-I	<i>exo</i>	-82(11)	67(4)	365(12)	0.79	
	<i>endo</i>	-67(10)	83(3)	8.86(25)		0.57
II	<i>exo</i>	-85(8) ^a	73(3) ^a	30.5(8) ^b	1.00	
	<i>endo</i>	-64(2) ^a	87(1) ^a	3.23(4) ^b		1.00
1-Me-II	<i>exo</i>	-74(6)	79(2)	15.8(4)	0.52	
	<i>endo</i>	-69(10)	87(3)	1.62(7)		0.50
5-Me-II	<i>exo</i>	-73(5)	78(2)	20.7(4)	0.68	
	<i>endo</i>	-69(7)	87(2)	1.65(5)		0.51
6-Me-II	<i>exo</i>	-84(16)	75(6)	15.2(11)	0.50	
	<i>endo</i>	-66(6)	88(2)	1.63(4)		0.50

^a From Ref. 1. ^b Measured in this work at different base concentrations.

gave similar *endo* rate ratios both from the estimated departure rates and from the observed rates.¹ Thus the comparison is here made between the observed rate constants.

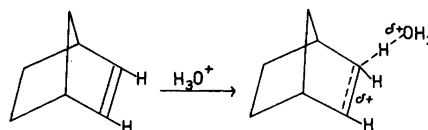
The effect of a methyl group on the protodetritiation rates of the *exo*- and *endo*-3 hydrogens is relatively small (0.3 to 2.3). A methyl group can affect the rate in different ways: by electrostatic interaction, *i.e.* inductively and by field effect, and by steric interaction, *i.e.* by torsional and non-bonded effects, but the hyperconjugative effect is very probably insignificant in the carbanion-enolate reaction.

The purest inductive effect is probably caused by the 1-methyl group since C-2 preserves its *sp*² hybridization when the initial state changes via the transition state to the carbanion-enolate intermediate (*e.g.* *exo* departure, see Scheme 1). The rate reducing effect is small but significant (0.50 to 0.82;



Scheme 1.

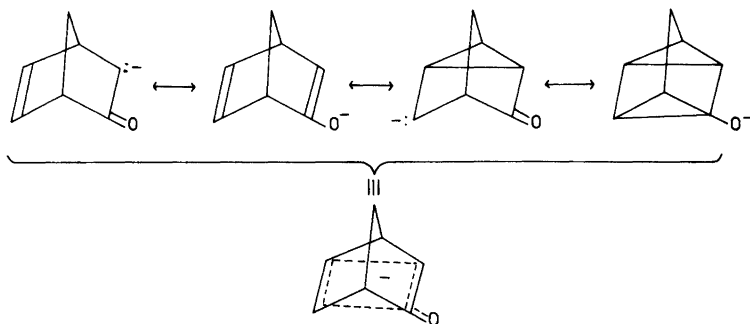
cf. $k_{Me}(2\text{-butanone})/k_{Me}(2\text{-propanone})$ is 0.45 to 0.50 in deuterodeprotonation^{10,11}). It indicates that a negative charge has been formed in the transition state. The effect is of the same magnitude but opposite to that of the 1-methyl group on the acid-catalyzed hydration rates of the 5,6-double bond of 2-norbornenone and 2-norbornenols (1.6 to 2.3 at 75 °C; see Scheme 2).^{12,13} The transition states of



Scheme 2.

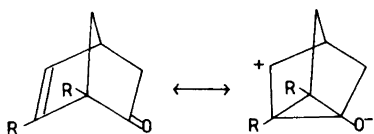
the two opposite proton transfer reactions evidently have a similar character: the charge is delocalized over the double bond, although the charges are opposite. In the *S*_N1 and *A*-1 reactions of 2-norbornyl esters and alcohols the influence of the 1-methyl group is greater (4 to 10). In these cases the charge is more localized at C-2 (or even delocalized to C-1).^{13,14}

The rather similar effects of the 5- and 6-methyls (0.50 to 0.68) are also electrostatic by nature in the



Scheme 3.

case of 2-norbornenones. Their values also support the delocalization of charge from C-3 via C-2 to the carbonyl group, but argue against its delocalization to the 5,6-double bond (cf. Ref. 15), since in the latter case the retarding effect of the 6-methyl group would be larger than that of the 5-methyl group (see Scheme 3). The very similar influences of the 1- and 6-methyls (0.50 to 0.52) may also be, at least partly, due to the homoconjugation between the 5,6-double bond and the carbonyl group in the initial state (see Scheme 4) which makes the methyls more alike



Scheme 4.

than in "pure" 2-norbornenone and besides retards the rate of exchange of 2-norbornenone as compared with that of 2-norbornanone.^{1,12} However, the effects of the 1- and 6-methyl groups are also alike in 2-norbornanones (0.82 to 0.79 for *exo* and 0.61 to 0.57 for *endo*; cf. $k_{\text{Me}}(2\text{-pentanone})/k_{\text{Me}}(2\text{-butanone})=0.92$ in deuterio-deprotonation¹⁰).

In the case of 2-norbornanones the effects of the 5- and 6-methyl groups can be partly steric since their positions are *endo*.^{6,16} Thus, they can even increase the rate of the *exo* departure if a steric interaction occurs between them and the *endo*-3-hydrogen in the initial state and the interaction diminishes at least partly in the transition state. In the case of the 6-methyl compound this is less probable than in the case of the 5-methyl one. Perhaps this explains the relatively great rate of 5-methyl-*exo*-3-T-2-norbornanone ($k_{\text{rel}}=2.3$). A marked retarding steric effect of the *endo*-5-methyl

group on the departure of the *endo*-3-T is also observable ($k_{\text{rel}}=0.30$). The portions of the inductive and field effects are difficult to estimate, but the latter can be significant in the cases of 5- and 6-methyl-2-norbornanone and -2-norbornenone.

The torsional effect should be most easily found in the detritiation of 4-methyl-2-norbornanone and -2-norbornenone since the hybridization of C-3 changes from sp^3 in the initial state to sp^2 (or nearly) in the transition state. The total effect of the 4-methyl group is, however, very small (0.94 for *exo* and 1.10 for *endo*) in the case of 2-norbornanone, which observation is similar to that made in the deuterodeprotonation of camphor and 4-methylcamphor (0.92 for *exo* and 1.05 for *endo*)¹⁷ but differs from the effect of the β methyl in the exchange of acyclic ketones [$k_{\text{methylene}}(2\text{-pentanone})/k_{\text{methylene}}(2\text{-butanone})=0.43$].¹⁰ (4-Methyl-2-norbornenone was unfortunately lost hence its values are lacking.) The changes of rates are mutually even in the wrong direction since in terms of the torsional effect the methyl group should increase the rate of the *exo* departure and decrease the rate of the *endo* departure.¹⁸ Evidently this effect is insignificant and the inductive effect is also small due to the delocalization of charge to the carbonyl group in the transition state. The small effect of the 4-methyl group was also observed in the acid-catalyzed hydration of the 5,6-double bond of 2-norbornenones [$k(4\text{-methyl-2-norbornenone})/k(2\text{-norbornenone})=1.15$ at 75 °C].¹² An interaction between the 4-substituent and the catalyst (HO^- or H_3O^+) may also retard the *exo* exchange sterically.¹⁹

In order to estimate the retarding influence of the homoconjugation in 2-norbornenone (see above) on the detritiation rates, the inductive effect of the 5,6-double bond should be known. It can be roughly estimated by assuming its size equal but

opposite to the effect of one double bond of 2,5-norbornadiene on the acid-catalyzed hydration of the other [$k(2,5\text{-norbornadiene})/2k(2\text{-norbornene}) = 0.75$ at 75°C ;²⁰ the divisor 2 is a statistical correction term for the two double bonds of 2,5-norbornadiene]. Thus the inductive effect of the 5,6-double bond is *ca.* 1.3 and the homoconjugation effect 0.04 ± 0.01 for the *exo* and 0.14 ± 0.02 for the *endo* exchange [$k(2\text{-norbornenone})/1.3k(2\text{-norbornanone})$]. The unmethylated and 1- and 6-methylated substrates have been used in the calculations, but the 5-methylated ones have been omitted owing to the steric interactions observed (see above). The differences in the steric interactions are mostly cancelled out in the calculations in the case of the *exo* detritiation, but they partly remain in the *endo* detritiation. Thus the retarding effect 0.04 for the homoconjugation seems more probable.

Acknowledgement. We are grateful to Professor Tidwell for helpful comments.

REFERENCES

- Lajunen, M. and Pilbacka, H. *Acta Chem. Scand. A* 30 (1976) 391.
- Krieger, H. and Masar, S.-E. *Suom. Kemistil. B* 43 (1970) 318.
- Goering, H. L. and Chang, C.-S. *J. Org. Chem.* 40 (1975) 2526.
- Brown, H. C. and Garg, C. P. *J. Am. Chem. Soc.* 83 (1961) 2952.
- Masar, S.-E. and Krieger, H. *Suom. Kemistil. B* 42 (1969) 1.
- Stothers, J. B., Tan, C. T. and Teo, K. C. *Can. J. Chem.* 51 (1973) 2893.
- Margolin, Z. and Long, F. A. *J. Am. Chem. Soc.* 95 (1973) 2757.
- Abad, G. A., Jindal, S. P. and Tidwell, T. T. *J. Am. Chem. Soc.* 95 (1973) 6326.
- Banerjee, S. and Werstiuk, N. H. *Can. J. Chem.* 53 (1975) 1099.
- Rappe, C. and Sachs, W. H. *J. Org. Chem.* 32 (1967) 4127.
- Warkentin, J. and Barnett, C. *J. Am. Chem. Soc.* 90 (1968) 4629.
- Lajunen, M. and Sura, T. *Tetrahedron* 34 (1978) 189.
- Lajunen, M. and Ollikka, R. *Finn. Chem. Lett.* (1978) 272.
- Brown, H. C. and Rei, M.-H. *J. Am. Chem. Soc.* 86 (1964) 5004.
- Tidwell, T. T. *J. Am. Chem. Soc.* 92 (1970) 1448.
- Korvola, J., Häkli, H. and Paasivirta, J. *Finn. Chem. Lett.* (1974) 16.
- Jindal, S. P. and Tidwell, T. T. *Tetrahedron Lett.* (1971) 783.
- Schleyer, P. v. R. *J. Am. Chem. Soc.* 89 (1967) 701.
- Brown, F. C., Casadevall, E., Metzger, P. and Morris, D. G. *J. Chem. Res. (S)* (1977) 335 and *(M)* (1977) 3588.
- Lajunen, M. and Hirvonen, P. *Finn. Chem. Lett.* (1978) 38.

Received December 8, 1978.