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SUBSTITUENT EFFECTS ON THE CYCLIZATION OF HEX-5-ENYL RADICAL

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Using previously described methods[1-5] we have determined the direction and relative rates of cyclization of a number of radicals (**1a-o**) containing the hex-5-enyl system. Treatment of suitable halo compounds with Bu_3SnH in pentane or benzene affords mixtures of olefinic (**4**) and cyclized (**3**,**6**) products by further reactions of the initially generated radicals (**1**), as illustrated. Gas chromatographic analysis of the mixtures, and substitution of the results obtained into the appropriate integrated rate equation[1-3] enabled values of $k_{1,5}/k_H$ and $k_{1,6}/k_H$ to be computed.

The results are given in the Table together with values of $k_{1,5}/k_{1,6}$ and of k (rel), the rate constant for intramolecular addition relative to that for 1,5-cyclization of the radical (**1a**). The latter were calculated on the assumption that previously determined values of k_H for hexyl, cyclohexyl, and t-butyl radicals[4] provide reasonable indices of relative reactivity for the primary, secondary, and tertiary radicals used in this study.

Variations in k (rel) for radicals (**1a-e**), which differ only in the substitution pattern at C-1, are small and show that substituents at the radical centre have surprisingly little effect on its reactivity. This contrasts with the relatively large differences in formation tendencies between primary, secondary, and tertiary radicals reported for weakly exothermic atom-transfer reactions,[6] and suggests that in these addition reactions there is little change towards sp^3 hybridization at the transition state. Substituents at the 6-position have similarly small effects on the rate constants for 1,5-cyclization in the radicals (**1f-i**).

The presence of substituents on the olefinic bond at C-5 has a profound effect on the rate of 1,5-cyclization. Radicals (**1j-o**) all show low values of $k_{1,5}$ (rel) and relatively low values of $k_{1,5}/k_{1,6}$. The unusual[1,5] predominance of six-membered cyclic products from reactions of the radicals (**1j**, **1k**, **1o**) is seen to be mainly a consequence of particularly low

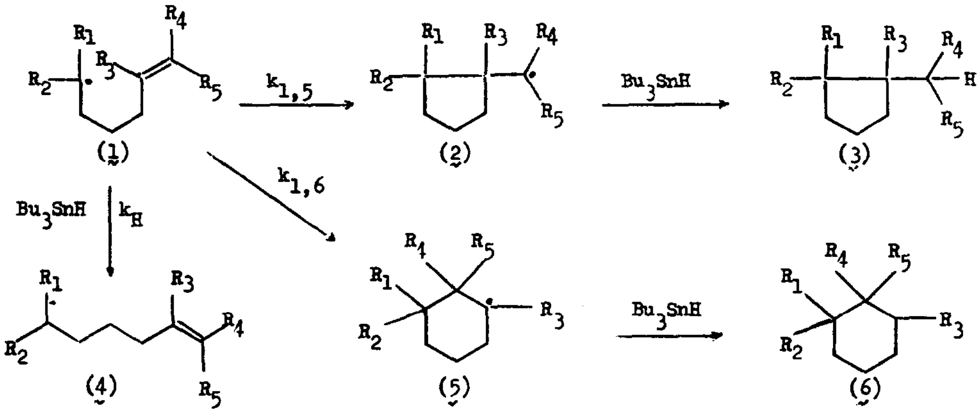
TABLE

Relative rate constants for cyclization of substituted hex-5-enyl radicals at 65°

Radical	R_1	R_2	R_3	R_4	R_5	$k_{1,5}/k_H$	$k_{1,6}/k_H$	$k_{1,5}/k_{1,6}$	$k_{1,5}$ (rel)[a]	$k_{1,6}$ (rel)[a]
(1a)	H	H	H	H	H	0.22	0.0046	48	1.0	0.02
(1b)	Me	H	H	H	H	0.26	0.0033	78	1.4	0.02
(1c)	Pr	H	H	H	H	0.29	0.0014	206	1.6	0.008
(1d)	Me	Me	H	H	H	0.41	0.006	68	1.4	0.02
(1e)	$-(CH_2)_4-$		H	H	H	0.28	_ca._ 0.02[b]	_ca._ 14[b]	0.94	_ca._ 0.07[b]
(1f)	H	H	H	3-butenyl	H	0.38	<0.002	> 200	1.7	< 0.009
(1g)	H	H	H	H	3-butenyl	0.30	<0.0015	> 200	1.4	< 0.007
(1h)	H	H	H	Me	Me	0.52	<0.0025	> 200	2.4	< 0.011
(1i)	H	H	H	$-(CH_2)_5-$		0.21	<0.002	> 100	0.94	< 0.009
(1j)	H	H	Me	H	H	0.005	0.008	0.62	0.022	0.04
(1k)	H	H	Pr^i	H	H	0.005	0.016	0.31	0.022	0.07
(1l)	H	H	$-(CH_2)_3-$		H	0.025	0.006	4.2	0.114	0.03
(1m)	H	H	$-(CH_2)_4-$		H	0.015	0.012	1.2	0.068	0.05
(1n)	H	H	Me	Me H	H Me	0.024	0.004	5.4	0.11	0.02
(1o)	Me	Me	Me	H	H	$<5 \times 10^{-5}$	0.005	< 0.01	< 0.0002	0.02

[a] Rate constant relative to $k_{1,5}$ for radical (1a).

[b] The yield of 1,6-cyclized product did not vary with $[Bu_3SnH]_o$ in the expected manner; its formation may proceed in part by polar mechanisms.



values of $k_{1,5}$ rather than of enhanced values of $k_{1,6}$, as might have been expected on simple thermochemical grounds.

Our data do not allow the effects of substituents at C-6 on the rate of 1,6-cyclization to be accurately assessed. However, comparison of $k_{1,6}$ (rel) for the radical (1a) with values for radicals (1f-i) suggests that they retard the reaction quite strongly.

In general it appears that steric factors are much more important than electronic factors in influencing the rate of intramolecular addition. The particularly low value for $k_{1,5}$ in the radical (1o), in which both reactive centres are tertiary, supports this view. However, the low values of $k_{1,5}$ (rel) for those radicals (1j-n) which bear no 1-substituent indicates that 1,5-steric hindrance is not the sole factor, and we conclude, therefore, that the major retardations seen in these radicals are due to B strain engendered at the 5-carbon atom by its change towards sp^3 hybridization.

Our results may have relevance to the mechanism of polymerization and other reactions involving intermolecular radical addition to olefins. They suggest that the observed preference for radical attack at the less substituted terminus of an unsymmetrical olefin is due primarily to steric factors, and not, as is often supposed, to the stabilizing effect of alkyl substituents on the newly formed radical. The effects of substituents on the rates of reaction of olefins with methyl[7] and with cyclopropyl radicals[8] accords with this view.

Finally, the fact that the rate of 1,5-cyclization in hex-5-enyl radicals generally appears to be more sensitive to the effect of substituents at C-5 than to those at C-1 suggests that the transition state[1] is unsymmetrical and involves considerable breakage of the π bond, but little formation of the new σ bond.

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