CYCLOADDITIONS OF HEXACHLOROCYCLOPENTADIENE TO 7-SUBSTITUTED NORBORNADIENES: REMOTE SUBSTITUENT EFFECTS ON REACTIVITY AND STEREOSELECTIVITY

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Abstract: The rates and stereoselectivities of the cycloadditions of hexachlorocyclopentadiene to norbornadienes substituted at the 7-position by tert-butyl, trimethylsilyl, methoxy, acetoxy, hydroxy, methoxymethyl, and methoxycarbonyl groups have been measured. The rates correlate with substituent electronegativities.

We have previously reported rates and stereoselectivities of hexachlorocyclopentadiene (HCCP) Diels-Alder cycloadditions to eleven 7-substituted norbornadienes.[2] We have now obtained additional data upon which to base a comprehensive theory of stereoselectivity in norbornadiene cycloadditions. The following paper reports our theoretical proposals.[3] Here we report measurements of the rates and products of HCCP cycloadditions to seven additional 7-substituted norbornadienes, whose electronic structures were also probed by photoelectron spectroscopy. We also prepared 7-fluoro- and 7-benzamido-norbornadienes, but these molecules were found to decompose faster than they undergo cycloadditions to HCCP. Reports by Wilt[4] and DeMicheli et al.[5] provide additional examples of stereochemistries of cycloadditions to 7-substituted norbornadienes.

Methoxy (1),[6] tert-butyl (2),[7] methoxycarbonyl (3),[8] hydroxy (4),[9] and acetoxynorbornadiene (5)[9] were prepared according to standard literature routes, while the trimethylsilyl (6), methoxymethyl (7), and fluoro (8) derivatives were synthesized via 7-lithionorbornadiene[8] by straightforward methods. Reactions were carried out by heating the norbornadienes with a 10% excess of HCCP under nitrogen at 120°C.

endo-syn   endo-anti   exo-anti
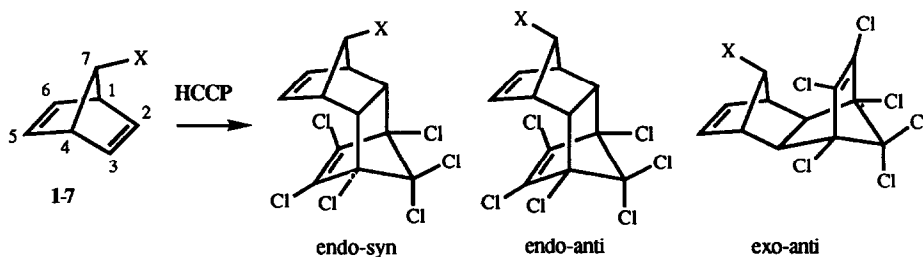
The product ratios, given in Table 1, were determined by analysis of NMR spectra of crude reaction mixtures.[2] *Exo-syn* adducts were not observed. Isomeric products were separated chromatographically and were fully characterized.

Table 1. Product ratios for HCCP Cycloadditions to 7-Substituted Norbornadienes.

7-Substituent	Endo-anti	Endo-syn	Exo-anti
MeO (1)	28.4	50.0	21.6
t-Bu (2)	12.1	11.3	75.7
MeO_2C (3)	9	9	82
HO (4)	41.2	35.3	23.5
AcO (5)	28	47	25
Me_3Si (6)	<1.5	<1.5	>97
$MeOCH_2$ (7)	4.5	5.5	90.0

Cycloaddition rates were determined as previously described.[2] From the overall rates of cycloaddition and the product ratios, partial rate factors for formation of *exo-anti*, *endo-anti*, and *endo-syn* adducts were obtained. These are given in Table 2, along with those obtained in the earlier work.[2]

Table 2. Overall Rates and Partial Rate Factors for HCCP Cycloadditions to 7-Substituted Norbornadienes and Inductive Substituent Constants.

Norbornadiene 7-Substituent	Overall Rate (10^{-5} s^{-1})	Partial Rate Factor			$\sigma_I{}^q$
		Endo-anti	Endo-syn	Exo-anti	
H (Norbornadiene)	39.8	1	1	16.9	0
MeO (1)	2.8	0.72	1.26	0.54	1.89
t-Bu (2)	1.27 ± 0.1	0.85	1.48	9.08	-0.2
MeO_2C (3)	6.87 ± 0.08	0.56	0.50	5.08	1.69
HO (4)	1.17 ± 0.01	0.41	0.35	0.25	1.76
Me_3Si (6)	107 ± 1	---	---	93.6	-0.22
$MeOCH_2$ (7)	8.3 ± 0.3	0.34	0.41	6.76	0.72

a. Error limits are standard deviations for these determined.

b. Values for $\sigma_I{}^q$ which were not available were estimated using the correlation given between $\sigma_I{}^q$ Charton's and σ_I values (Charton, M. *J. Org. Chem.*, **1964**, *29*, 1222).

In our previous paper on this subject, we plotted the rates of cycloadditions versus Huheey's group electronegativities[10] for the 7-substituents. Since other related data published by Klumpp[8] and Grob[11,12] have been discussed in terms of inductive substituent constants, we give here a plot of rates versus the Grob inductive substituent constants, $\sigma_I{}^q$, for both this data and those in reference 2. This plot is shown in Figure 1.
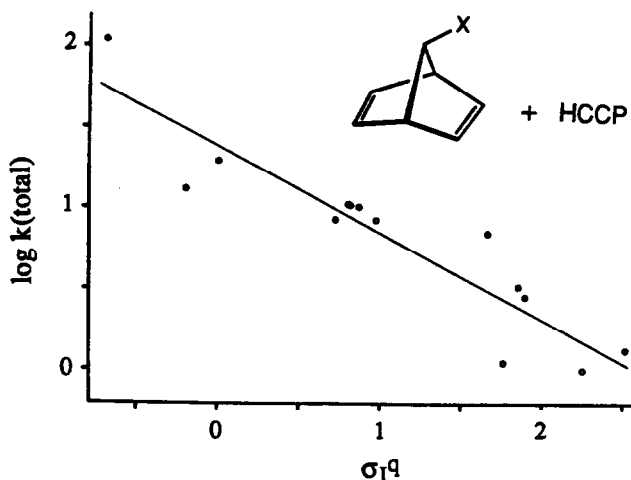
Figure 1. Plot of overall reaction rates versus σ_I^q of substituents for the cycloadditions of HCCP to 7-substituted norbornadienes.

It has been suggested that the anomalously high rate of formation of the *endo-syn* product in the 7-tert-butoxy case could be the result of a "buttressing" effect of the bulky tert-butoxy group.[13] The results we have obtained with 7-methoxynorbornadiene indicate that this effect is negligible, since normal partial rate factors are obtained for *exo* attack on both 7-methoxy and 7-tert-butoxy substituents, and yet *endo-syn* attack is still anomalously rapid for both. Furthermore, the 7-tert-butyl substituent, which is effectively larger than the 7-tert-butoxy substituent near the site of substitution, gives results very similar to those obtained for norbornadiene itself. The bulky trimethylsilyl substituent produces an increase in rate and almost exclusive *exo-anti* attack, consistent with the electropositive nature of Me_3Si.

The methoxycarbonyl and methoxymethyl substituted compounds were investigated because of the possibility that these groups might show anomalously high *endo-syn* rates.[14,15] However, the methoxycarbonyl substituent gives a somewhat anomalously rapid *exo-anti* rate, while the *endo* rates are normal. The methoxymethyl gives ordinary behavior compared to the trends observed for other compounds, so only tert-butoxy and methoxy show anomalously high *endo-syn* rates.

The general patterns detected before are reinforced by the additional examples studied here. The rates of *exo-anti* cycloadditions decrease regularly as the electronegativity of the 7-substituent increases. A similar pattern has been observed by Klumpp for the rates of dichlorocarbene cycloadditions to 7-substituted norbornadienes.[16] Electronegative

the solvolysis of 2-norbornyl tosylates by electronegative 6-substituents.[ ] Electronegative substituents slow down the rate of *exo*-solvolysis more than the rate of *endo*-solvolysis.

The general deceleration of the rates of these reactions by electronegative substituents is quite sensible, since in each case they involve attack of an electrophilic species (cycloadditions) or development of positive charge in the transition state (solvolysis). The more subtle question is why the rates of endo reactions are influenced much less than the rates of exo reactions. This question is addressed in the following communication.[3]

References and Notes

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