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CYCLOADDITION RATES OF DIAZOMETHANE AND DIPHENYLDIAZOMETHANE

Lubor Fišera, Jochen Geittner, Rolf Huisgen,* and Hans-Ulrich Reissig

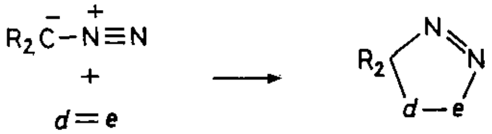
Institut für Organische Chemie der Universität München, Karlstraße 23, D-8000 München 2,
West Germany

Dedicated to Adolf Butenandt on the Occasion of His Seventy-fifth Birthday

Reactivity sequences of dipolarophiles are 1,3-dipole specific. Electron-attracting substituents increase the rate constants of alkenes and alkynes towards diazomethane and diphenyldiazomethane in DMF, whereas electron-releasing substituents decelerate; this is in accordance with a predominant HO(diazoalkane) - LU(dipolarophile) control. The cycloadditions of diazomethane are generally faster and more selective than those of diphenyldiazomethane. Similarly substituted ethylenes and acetylenes do not differ much in their dipolarophilic activity.

*MO perturbation theory (PMO) provides the first general concept to explain reac*tivity sequences in concerted cycloadditions.[1-3] Diazomethane additions constitute a simple test case amongst 1,3-dipolar cycloadditions insofar as they can be approximately treated as HOMO(diazomethane) - LUMO(dipolarophile) controlled. Fifteen ethylenic dipolarophiles for which rate constants, ionization potentials and $\pi \rightarrow \pi^*$ transition energies were available, produced a straight line when log k_2 was plotted versus the reciprocal energy distance of HO(diazomethane) and LU(dipolarophile).[4] A good fit with atomic orbital coefficients and MO energies calculated by CNDO/2 was only achieved after including the interaction with higher unoccupied olefinic MOs; the interaction of LU(diazomethane) with the occupied ethylenic MOs could still be neglected.[5] We report here on structure-rate correlations of old[4,6] and new cyclo*additions of diazomethane* (DMF, 25°C) and diphenyldiazomethane (DMF, 40°C) to many olefinic and acetylenic dipolarophiles.

The spectrophotometric and the volumetric method for monitoring the disappearance of the diazoalkane were briefly described recently.[7] Only very slow additions required correction for the thermolysis of the diazoalkanes which follows the first order up to 60 % conversion. Diazoalkane (DM) decomposes with $k_1 = 3.6\ 10^{-7}\ \mathrm{sec}^{-1}$ in DMF at 25°C ($t_{1/2} = 22$ d); diphenyldiazomethane (DDM), $k_1 = 8.1\ 10^{-7}\ \mathrm{sec}^{-1}$ in DMF at 40°C. The solubility of the volatile diazomethane in DMF is so high that no color can be detected in the gas phase above the deep yellow solution. All the cycloadditions obeyed the second order rate law. The rate constants are expressed in the dimension $10^5 k_2$ ($\mathrm{l\ mol^{-1}\ sec^{-1}}$) and the addition direction corresponds to



The 1-pyrazolines from DM often tautomerize to 2-pyrazolines, whereas many adducts of DDM eliminate N_2 at 40°C to give cyclopropanes. The products will be described elsewhere.

$H_2C{=}CH{-}R$

R =	$CO_2C_2H_5$	C_6H_5	H	$CH{=}CH_2$	C_4H_9	OC_4H_9
DM	112 000	45	40	21.4	0.44	0.01
DDM	812	1.23		0.79	0.06	

The rate constants of DM additions to monosubstituted ethylenes cover a 10^7 range. The ester group appears at the top, whereas phenyl and vinyl activate ethylene only little. The butyl in 1-hexene deactivates 90-fold, the butoxy group in the vinyl ether even 4000-fold. Enamines do not react with DM. DDM cycloadditions at 40°C are slower by factors of 7 – 140 than those of DM at 25°C.

$H_2C{=}CH{-}CH{=}CH{-}R$ (trans)

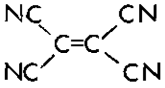
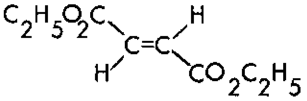
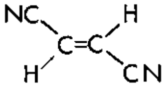
R =	CO_2CH_3	C_6H_5	$OCOCH_3$	H	CH_3	OCH_3	$N(C_2H_5)_2$
DM	2 570	21.0		21.4	2.43	1.34	0.06
DDM	11.4	0.58	0.45	0.78	0.10	0.08	$\leqslant 0.01$

1-Substituted butadienes accept DM and DDM exclusively at the 3,4 double bond.[8] The electronic effect of the 1-substituent is dampened by the interconnecting ethylene system, whereas steric effects are constant. As anticipated, the substituent scale is compressed : only a factor of 1900 between ester and alkoxy group towards DM here versus 10^7 for the monosubstituted ethylenes. The deactivation by the diethylamino function exceeds that by OCH_3 still 20-fold. DDM reacts here with R = CO_2CH_3 10^2 faster than with R = Alkyl compared with a difference of 10^5 for the ethylene derivatives.

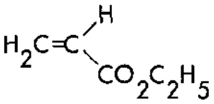
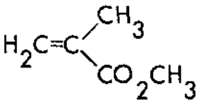
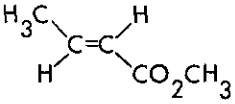
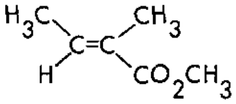
$H_2C{=}CH{-}R$

R =	$CO_2C_6H_5$	CO_2CH_3	CN	$CONH_2$
DDM	2 780	831	474	82

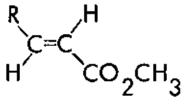
Carbonyl groups are the more electron-attracting, the less they are tied up by resonance. Therefore, increasing resonance stabilization of the acrylic acid derivatives leads to diminishing cycloaddition rate.

		Maleic Anhydride		
DDM	190 000	7 880	2 470	402

Fumaric ester exceeds acrylic ester 3 times in activity towards DDM, whereas fumaronitrile is somewhat slower than acrylonitrile. The record value of tetracyanoethylene and the other k_2 of the preceding line reveal a correlation with electron affinity.

				
DM	112 000	6 270	770	59
DDM	812	51	2.46	

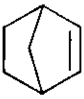
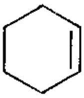
A methyl group in α-position of acrylic ester deactivates 18-fold, whereas β-methyl causes a 145-fold deceleration in the DM addition. This could well be the result of increasing LUMO energies.[4] Tiglic ester (α,β-dimethylacrylic ester) adds DM 1900 times slower than acrylic ester; this is less than the product of α- and β-methyl effects (2600).



R =	H	CH_3	C_2H_5	$CH(CH_3)_2$	$C(CH_3)_3$
DM	112 000*	770	730	350	136

* Ethyl ester

The trans-β-methyl reduces the rate constant of acrylic ester 150-fold, whereas the increase of the β-alkyls bulk up to tert.-butyl causes only a further 6-fold rate decrease.

				$H_2C=CH-C_4H_9$
DM	21.7	0.27	0.004	0.44
DDM	3.83	0.044		0.06

1,2-Dialkylethylenes do not react with DM except cycloalkenes which add the faster the more they suffer from angle strain.

A plot of DM reactivities versus those of DDM on the log scale defines a fairly linear function (Fig. 1); the straight line was drawn to satisfy the monosubstituted ethylenes (circles in Fig. 1). Considering the different steric requirements of the two diazoalkanes, one can probably not expect a better linearity of the correlation. The line is steeper than 45°, i.e., DM is somewhat more selective than DDM. That the more reactive species (DM) is also the more selective one, is not an inconsistency, but rather a consequence of the PMO approach;[1] analogously, tetracyanoethylene is more reactive and more selective in its Diels-Alder additions than maleic anhydride.

It was shown for many 1,3-dipoles that the dipolarophilic activities of ethylenes and acetylenes with the same substitution pattern are rather similar.[9] Diazoalkanes

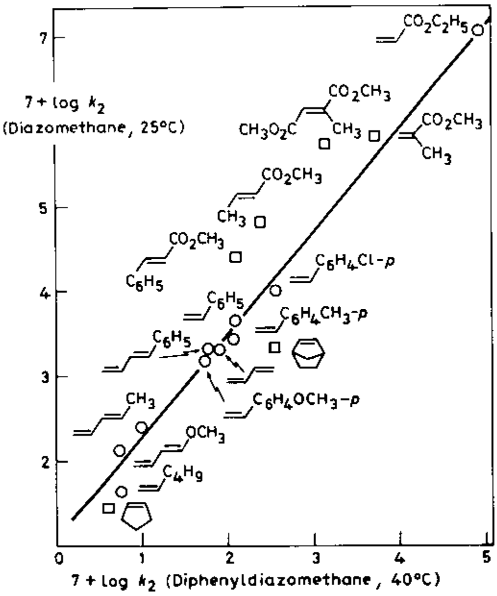


Figure 1

possess a higher nucleophilicity than most other 1,3-dipoles, and the CC triple bond is more electrophilic than the double bond. Does this create a greater preference of diazoalkanes for acetylenes than ethylenes ?

Table 1. Rate Comparison of Alkenes and Alkynes in Cycloadditions; 10^5k_2 (l mol^{-1}sec^{-1})

R	R′	RCH=CHR′	R-C≡C-R′	Ratio
	a. Diazomethane in DMF at 25°C			
H	C_4H_9	0.44	0.14	3.1
H	C_6H_5	44.5	2.73	16
H	CO_2R	112 000	49 700	2.3
CH_3	CO_2CH_3	770	175	4.4
C_6H_5	CO_2R	264	397	0.66

Table 1. (Continued); 10^5k_2 (l $mol^{-1}sec^{-1}$)

R	R′	RCH=CHR′	R-C≡C-R′	Ratio
		b. Diphenyldiazomethane in DMF at 40°C		
H	C_4H_9	0.06	0.09	0.7
H	C_6H_5	1.23	1.18	1.0
H	$CO_2C_2H_5$	812	1 020	0.8
C_6H_5	$CO_2C_2H_5$	1.25	3.33	0.4
$CO_2C_2H_5$	$CO_2C_2H_5$	2 470	7 640	0.3

Table 1 discloses a small effect of DDM in the expected direction. However, DM reacts faster with most of the olefinic than with the acetylenic bonds. Thus, the reactivities of double and triple bond do not differ a great deal.

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