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1,3-Dipolar Cycloadditions. LXXVI.*,1) Cycloadditions of Diazomethane to Substituted Butadienes

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1-Substituted butadienes (R=CH_3, CH_3O, C_6H_5, CO_2CH_3, CN) and 2-phenylbutadiene accept diazomethane at the 3,4-bond yielding 3-vinylpyrazoline derivatives. Tautomerization of the 1- to 2-pyrazolines takes place either at room temperature (R=CO_2CH_3, CN), on heating (R=C_6H_5) or on acid catalysis (R=H, CH_3, OCH_3); the 2-pyrazolines are characterized as 1-carbamoyl and 1-nitroso derivatives. 1-Substituted butadienes follow in their rate constants of diazomethane cycloaddition a linear free energy relationship with Hammett's σp values, $\rho=+4.2$. The rates and orientations are discussed in the light of the recent MO perturbation treatment.

The cycloadditions of diazoalkanes to unsaturated compounds, discovered by Buchner in 1888,5) were the subject of numerous investigations. A kinetic study of diazoalkane additions to angle-strained double bonds led in 1960 to the development of the general concept of 1,3-dipolar cycloaddition.6,7) The rate and orientation phenomena in these processes posed tough problems for many years;8) it was only recently that MO perturbation theory initiated a deeper understanding of reactivity sequences9,10) and regiochemistry11,12) in these concerted cycloadditions. The use of monosubstituted butadienes as dipolarophiles with their two double bonds, capable of accepting the 1,3-dipole, should allow a better discrimination between steric and electronic substituent effects on rate and addition direction than monosubstituted ethylenes. The preparative investigation on which this paper is based was carried out ten years ago,2) while the kinetic study was recently supplemented.3)

The Cycloadducts and Their Structure

Müller and Roser13) ascribed to the adduct from diazomethane and butadiene the structure of a 5-vinyl-2-pyrazoline (I). The bisadduct (II), obtained with excess of diazomethane, was

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* This paper is dedicated to the memory of Eiji Ochiai, likewise admirable as personality and scientific pioneer.

1) Part LXXV: W. Fliege and R. Huisgen, *Liebbigs Ann. Chem.*, 1973, 2038.

2) Alexander von Humboldt Fellow 1964—1966; Present address: *Tokyo College of Pharmacy.*

3) Ph. D. Thesis J. Geittner, University of Munich 1974.

4) Location: *Karlstr. 23, 8 München 2, Germany.*

5) Diazoacetic ester+α,β-unsaturated carboxylic esters: E. Buchner, *Ber. Deut. Chem. Ges.*, **21**, 2637 (1888); 23, 701 (1890); *Liebigs Ann. Chem.*, **273**, 214 (1893).

6) R. Huisgen, "10 Jahre Fonds der Chemischen Industrie", Düsseldorf, 1960, p. 73; *Proc. Chem. Soc.* [London], 357 (1961).

7) R. Huisgen, *Angew. Chem., Int. Ed. Engl.*, **2**, 633 (1963).

8) Reviews: R. Huisgen, *Angew. Chem., Int. Ed. Engl.*, **2**, 565 (1963); *J. Org. Chem.*, **33**, 2291 (1968).

9) R. Sustmann, *Tetrahedron Letters*, **1971**, 271; R. Sustmann and H. Trill, *Angew. Chem., Int. Ed. Engl.*, **11**, 838 (1973).

10) K. Bast, M. Christl, R. Huisgen, and W. Mack, *Chem. Ber.*, **106**, 3312 (1973).

11) *a*) J. Bastide, N. El Ghandour, and O. Henri-Rousseau, *Bull. Soc. Chim. France*, **1973**, 2290; *b*) J. Bastide and O. Henri-Rousseau, *ibid.*, **1973**, 2294.

12) *a*) K.N. Houk, J. Sims, R.E. Duke, R.W. Strozier, and J.K. George, *J. Am. Chem. Soc.*, **95**, 7287 (1973); *b*) K.N. Houk, J. Sims, C.R. Watts, and L.J. Luskus, *ibid.*, **95**, 7301 (1973).

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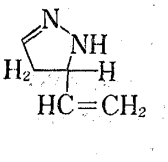
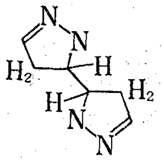
oxidized by permanganate to 3,4-dihydroxyadipic acid, thus establishing the addition direction.


I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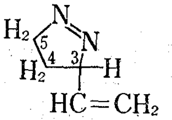
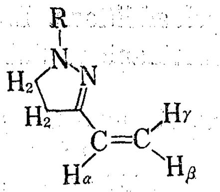
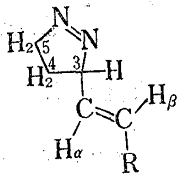
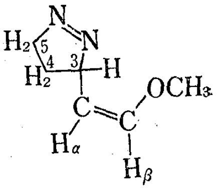

III


IV : R=H
V : R=CO−NH$_2$


VI : R=CH$_3$
VII : R=OCH$_3$


VIII

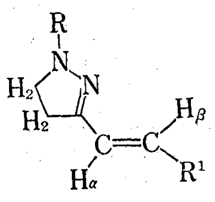
On reinvestigating the distilled monoadduct, we found spectroscopic evidence in favor of the 3-vinyl-1-pyrazoline (III); Crawford and Cameron[14] came to the same conclusion. The infrared (IR) spectrum showed the C=C and the N=N stretching vibration at 1630 and 1535 cm^{-1}, respectively. The high-field 4-CH$_2$ appears in the well-resolved unclear magnetic resonance (NMR) spectrum as the XY part of an ABCXY spectrum.

Acidic reagents converted III to polymeric material instead of the expected 2-pyrazoline; IV, but not I, should suffer cationic polymerization. The intermediacy of IV was shown by the conversion of III to the urea V by acetic acid and potassium cyanate. The NMR spectrum of V indicates a symmetrical AA'BB' pattern for the ring protons at τ 5.9—7.2, which are not coupled to the vinyl group. The double doublet of Hα at τ 3.31 reveals $J_{cis}=10.7$ and $J_{trans}=17.5$ Hz; Hβ and Hγ appear at τ 4.41 and 4.51 with a small $J_{\beta,\gamma}\leq 0.5$ Hz.

The slow reactions of diazomethane with *trans*-piperylene and 1-methoxybutadiene (60% *trans* +40% cis) in ether at 5° compete with the self-decomposition of diazomethane and produced 28% VI and 25% VII+VIII, respectively. In the NMR spectrum of VI the methyl doublet emerges at τ 8.26 with $J=5.0$ Hz, thus clearly in the region of =C–CH$_3$, from the multiplet of 4-H$_2$. The vinylic Hα and Hβ form an AB pattern at τ 4.54 and 4.26 with $J\alpha,\beta=15$ Hz. Hα is further split by 3-H with $J\alpha,3=5.5$ Hz, while Hβ appears as a doublet of quadruplets. The spectrum offers no indication that the liquid adduct VI contains positional isomers. The wagging vibration of the *trans*-vinylic protons occurs at 965 cm^{-1}.

The *trans*-methoxybutadiene reacted in the *cis*, *trans* mixture preferentially with diazomethane and was enriched in the product to 82%, as testified by the methoxy singlets at τ 6.43 for VII and at 6.32 for VIII in the NMR spectrum of the liquid mixture. The complexity of the spectrum makes the structural assignment of VIII provisional and does not exclude the presence of further isomers. The low-field doublet for Hβ of VII at τ 3.32 is split by $J_{trans}=11.5$ Hz, while Hβ of VIII at τ 3.88 shows besides $J_{cis}=6.0$ Hz[15] an allylic coupling by 0.8 Hz. Treatment of the adduct mixture with cold acetic acid and HNCO provided 53% of the crystalline IX; the AB spectrum of the *trans*-olefinic protons is found at τ 3.20 and 4.24 with $J=13.0$ Hz. The IR spectrum of IX accords with the urea group.

trans-1-Phenylbutadiene combined with one equivalent of diazomethane in ether to give after high vacuum distillation at 150° the crystalline 2-pyrazoline (X); it may well be that the tautomerization of the 1-pyrazoline occurred thermally. The NMR spectrum with the symmetrical AA'BB' spectrum of the ring protons, the AB pattern of the vinylic protons at τ 2.90



	R	R′
IX:	CO–NH$_2$	OCH$_3$
X:	H	C$_6$H$_5$
XI:	NO	C$_6$H$_5$
XII:	CO–NH$_2$	C$_6$H$_5$
XIII:	H	CO$_2$CH$_3$
XIV:	NO	CO$_2$CH$_3$
XV:	CO–NH$_2$	CO$_2$CH$_3$

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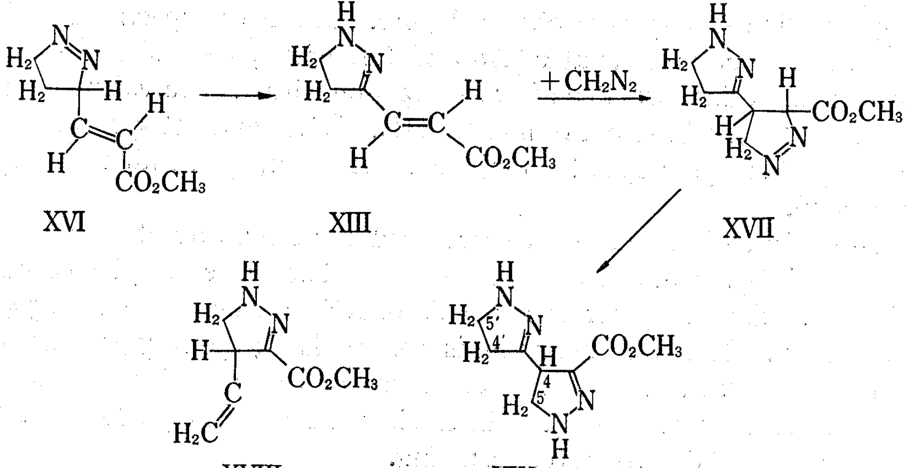
[14] R.J. Crawford and D.M. Cameron, *Canad. J. Chem.*, **45**, 691 (1967).

[15] $J_{trans}=12.8$ and $J_{cis}=6.6$ Hz have been observed for the structurally analogous *cis*- and *trans*-propenyl methyl ether; G. Steiner, Ph. D. Theses, "Univ. of Munich," 1973, p. 13.

and 3.39 with $J_{trans}=16.3$ Hz as well as the NH singlet at τ 4.65 leave no doubt about the structure. The strong infrared absorption at 3285 cm^{-1} is in the region expected for 2-pyrazolines. The 1-nitroso derivative (XI) and the 1-carbamoyl compound (XII) served for further characterization.

Interestingly enough, methyl butadiene-*trans*-1-carboxylate furnished with 1.2 equivalents of diazomethane in ether 85% of the bisadduct (XIX). It was only in the reaction of diazomethane with 3 equivalents of the dipolarophile that 20% of the monoadduct (XIII) were isolated besides 42% XIX. The NMR spectrum of XIII disclosed that again the distant double bond had accepted the 1,3-dipole. The doublets of the olefinic protons at τ 2.48 and 4.14 couple with $J_{trans}=16.4$ Hz. The broad NH signal at 3.61 reflects the increased electronegativity of N-1 compared with that of X. The infrared C=O frequency of XIII was found at 1708 cm^{-1}. The NH band at 3380 cm^{-1} disappeared on nitrosation; the structures of the derivatives XIV and XV were confirmed by their spectra.



XVI XIII XVII

XVIII XIX

The base-catalyzed tautomerization of 1-pyrazoline-3-carboxylic esters to the conjugated 2-pyrazoline-3-carboxylates is very fast; *e.g.*, the 1-pyrazoline from diazomethane and methyl acrylate can be isolated only under special precautions.[16] The vinylog XVI probably suffers also fast conversion to the 2-pyrazoline (XIII). Adduct (XIII) contains not only an intact acrylic ester group, but even a second electron-attracting substituent on the olefinic double bond. With rising electron deficiency of the ethylenic bond its dipolarophilic activity increases (see below). Therefore, the first diazomethane addition leading to XVI and subsequent tautomerization to XIII is followed by an even faster cycloaddition of the second diazomethane molecule producing the bisadduct (XVII) which tautomerizes again to XIX.

While the NMR spectrum of XIX is not very informative except for an OCH_3 singlet as low as τ 6.13, the IR spectrum establishes the addition direction of the second molecule of diazomethane. The ester carbonyl at 1691 cm^{-1} is in the region of 2-pyrazoline-3-carboxylic esters, while the NH is found at 3310 cm^{-1}.

If the first molecule of diazomethane had added partially to the ester substituted double bond to give XVIII *via* the 1-pyrazoline, this material should not be converted to a bisadduct in contrast to XIII. XVIII possesses a double bond of the 1-alkene type which is rather inert towards diazomethane; *e.g.*, 1-hexene adds diazomethane at 25° 250000 times slower than ethyl acrylate.[3] Thus, the absence of XVIII suggests that the primary diazomethane addition takes place at the unsubstituted double bond only.

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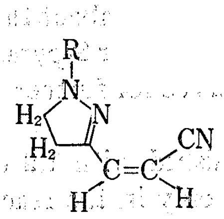
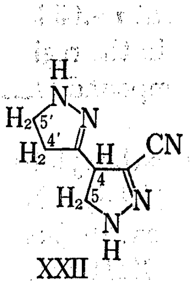
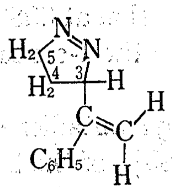
16) D.S. Matteson, *J. Org. Chem.*, **27**, 4293 (1962).



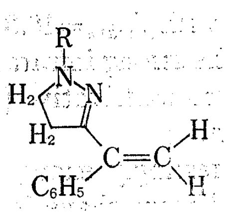
XX: R=H
XXI: R=NO



XXII



XXIII



XXIV: R=H
XXV: R=CO−NH_2

A 5:1 ratio of *cis*-1-cyanobutadiene and diazomethane was chosen to suppress bisadduct formation; the diazomethane was consumed after 10 minutes. The monoadduct lost N_2 partially on distillation as elementary analysis and high field NMR signals of cyclopropane protons indicate. The strong infrared NH absorption at 3350, the C=N vibration at 1582 and the *cis*–CH=CH wagging frequency at 740 cm^{-1} suggest the 2-pyrazoline (XX). Its hydrochloride and the N-nitroso-pyrazoline (XXI) were obtained pure. The NMR spectrum of XXI displays the doublets of the olefinic protons at τ 2.75 and 4.67 with $J_{cis}=11.8$ Hz.

The crystalline bisadduct, isolated after the reaction with 1.2 equivalents of diazomethane in ether, appears to be the bis-2-pyrazoline (XXII). NMR and IR spectrum show the NH signals. The sharp absorption at 2210 cm^{-1} would fit a conjugated nitrile group, while C=N absorbs at 1515 cm^{-1}.

Amongst 2-substituted butadienes, isoprene produced a mixture of monoadducts in poor yield. Treatment of 2-phenylbutadiene with diazomethane in ether yielded 48% of the 1-pyrazoline (XXIII). The IR spectrum is devoid of NH, but shows the strong =CH_2 wagging frequency at 905 cm^{-1}. The NMR spectrum is well resolved; the ring protons occur in three multiplets in the ratio 1: 2: 2. The fine structure of the 3-H signal suggests long-range coupling over the azo linkage with 5-H_2. The singlets of the vinylic protons at τ 4.58 and 4.89 are only slightly broadened due to mutual coupling.

A crystalline hydrochloride is probably derived from the 2-pyrazoline (XXIV); the infrared C=N frequency was found at 1570 cm^{-1}. Acetic acid and HNCO converted XXIII into 63% of the carbamoyl derivative (XXV). The four ring protons form a symmetrical AA'BB' spectrum; the vinyl proton singlets at τ 4.39 and 4.48 emerge from broad hump of NH_2 around 4.50.

Kinetic Study of Cycloaddition

The rate constants of diazomethane cycloadditions were followed in dimethyl formamide (DMF) at 25° by a volumetric or a titrimetric method. The first one consisted of withdrawing samples from the reaction mixture and determining the N_2 volume which was set free from the unconsumed diazomethane by trichloroacetic acid. In the second method the diazomethane content in samples was reacted with benzoic acid of which the excess was titrated. The very active butadiene-*trans*-1-carboxylic ester was measured at low concentration and evaluated by the second-order law, while the less reactive butadiene and its derivatives were applied in large excess; k_2 was determined *via* the pseudo-first-order constant. The very sluggish reaction with 1-dimethylamino-butadiene competes with the self-decomposition of diazomethane; the decrease of IR extinction at 2074 cm^{-1} with time allowed the measurement. A cycloadduct of diazomethane and the dienamine could not be obtained.

The k_2 values of Table I cover a range of nearly five powers of ten. The exclusive cycloaddition to the 3,4 double bond of the 1-substituted butadienes makes it highly probable that the steric effect of the substituents does not play a role at all. Thus, the 3,4 double bond is reached by the "long-range" electronic effect of the 1-substituent. This effect will be attenuated by the "conducting" 1,2-double bond. While ethyl acrylate adds diazomethane in dimethyl formamide (DMF) at 25° 10^7 times faster than 1-hexene,3) the rate ratio of 1-methoxycarbonyl- and 1-methoxy-butadiene amounts only to 1920.

The data fit fairly well a linear free energy relation when plotted versus Hammett's σp values17) (Fig. 1). The σp constants offer the correct comparison, because it is the same blend of inductive and resonance effects which reaches the 3,4 double bond of butadiene as well as the *p*-position of a benzene derivative. $\rho=+4.2$ underlines the strong substituent influence. The log k_2 for the diazomethane addition to p-substituted styrenes obey also a Hammett relation, but due to the larger distance between substituent and ethylenic side chain the ρ value is much smaller, namely $+1.5$3) or $+1.3$.18) To our knowledge Fig. 1 constitutes the first example of a linear free energy relation in the butadiene series.

TABLE I. Rate Constants for the Cycloadditions of Diazomethane to Butadiene Derivatives in DMF

Temp. °C	R	R–CH=CH–CH=CH_2 (mmole·l^{-1})	Diazomethane (mmole·l^{-1})	$10^5\,k_2$ (l·mole^{-1}·Sec^{-1})
25	*trans*-CO_2CH_3	50.6	32.5	2570
25	H	501	54	21.9
25	H	501	33.5	21.0
15	*trans*-C_6H_5	697	61	9.22
25	*trans*-C_6H_5	703	67	21.0
40	*trans*-C_6H_5	253	26.9	68.1
25	*trans*-CH_3	540	51	2.45
25	*trans*-CH_3	550	47	2.42
35	*trans*-CH_3	580	54	6.29
35	*trans*-CH_3	575	47	6.13
25	OCH_3 (60% *trans* +40% *cis*)	341	100	1.34
25	OCH_3 (60% *trans* +40% *cis*)	348	102	1.34
25	*trans*-$N(CH_3)_2$	939	66	0.06
25	*trans*-$N(CH_3)_2$	939	66	0.06

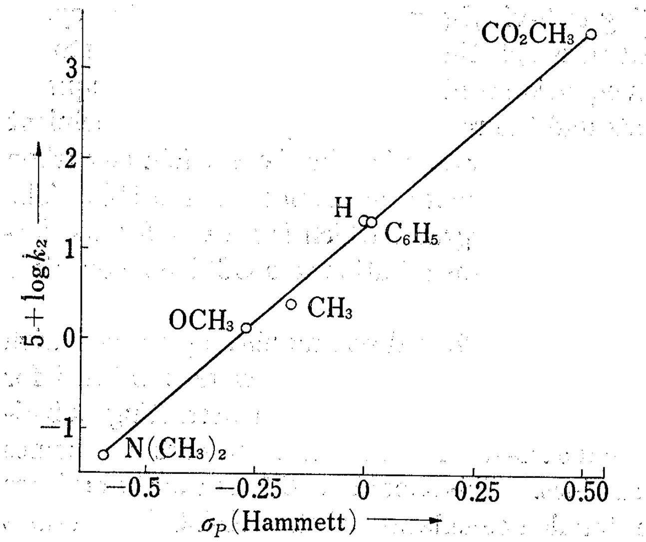


Fig. 1. Relation of log k_2 for the cycloaddition of diazomethane to 1-substituted butadienes with substituent constants σ_p

Rate measurements of the system diazomethane + 1-phenylbutadiene in DMF provided the Eyring parameters:

$\Delta H^{\neq} = 13.8 \pm 0.8$ kcal/mole, $\Delta S^{\neq} = -29 \pm 2$ e.u.

The large negative activation entropy is in the usual region for 1,3-dipolar cycloadditions.7) Thus, nearly 40% of the activation free energy at room temperature has to be attributed to the entropy portion.

PMO Interpretation of Rate and Regiochemistry

1,3-Dipoles are hetero-allyl anions. While allyl cations undergo cycloadditions with 1,3-dienes to form seven-membered rings,19) no 1,4-addition was observed in the reaction of diazomethane with butadiene derivatives. With the allyl anion being a 4_π system, the ring

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17) Werte nach H.H. Jaffe, *Chem. Rev.*, **53**, 191, 222 (1953).

18) P.K. Kadaba and T.F. Colturi, *J. Heterocycl. Chem.*, **6**, 829 (1969).

19) H.M.R. Hoffmann, D.R. Joy, and A.K. Suter, *J. Chem. Soc. B*, 57 (1968).

size description 3+2→5 satisfies the electronic demand $[_{\pi}4_S+_{\pi}2_S]$ of the symmetry-allowed concerted cycloaddition.[20]

Reactions of this type have early transition states as underlined by the modest activation enthalpies; thus, the application of perturbation theory is permitted. Due to energetic distances, one of the two HO–LU interactions plays a dominant role in diazomethane cycloadditions, namely HO(1,3-dipole)-LU(dipolarophile). This is borne out by CNDO/2 calculations[21,22] and finds ample experimental confirmation in the structure-rate relationship. Electron-attracting, conjugated substituents in the dipolarophile increase the mentioned interaction by a lowering of the LU (and HO) energy. On the other hand, electron-releasing substituents push up the HO and LU energies; the rising energy distance between HO(diazomethane) and LU(dipolarophile) effects lower rate constants.

Beyond the common experience that α,β-unsaturated carbonyl compounds react fast with diazomethane, the data of Fig. 1 offer an elegant proof for the mentioned relation, because steric effects are eliminated here. The size of the substituent effects documents the preponderance of the HO(diazomethane)-LU(butadiene) interaction. Diazomethane combines with methyl butadiene-1-carboxylate 1050 times faster than with 1-methyl-butadiene. This dipolarophile activity ratio shrinks to 10 in the case of diphenylnitrilimine as 1,3-dipole;[23] the second interaction, LU (1,3-dipole)-HO(dipolarophile), counterbalances nearly the first one here. *E.g.*, the lowering of HO and LU energies due to electron-attracting substitution of the dipolarophile strengthens the interaction HO(1,3-dipole)-LU(dipolarophile), but weakens the one between LU(1,3-dipole) and HO(dipolarophile).

Why do all 1-substituted butadienes accept diazomethane at the unsubstituted double bond and what determines the direction leading to 3-vinyl-pyrazolines? In concerted cycloadditions that combination should be favored in which the centers with the largest atomic orbital coefficients interact. The perturbation equation contains in the numerator the squares of the products of the atomic orbital coefficients and the resonance integral β for the incipient σ-bond.[24] Diazomethane possesses in HO and LU a larger atomic orbital coefficient on carbon than on the terminal nitrogen,[12,21] the difference being more pronounced in the HO. The orientational effect is strengthened by the resonance integral β which is greater for the formation of a CC than for an NC bond[11a] in the diazomethane addition to a CC double or triple bond.

While the CNDO/2 calculated LU coefficients of olefinic dipolarophiles agree well with the observed diazomethane additions,[11a,22] only qualitative descriptions were published for substituted butadienes.[12a,25] Butadienes with conjugated and electron attracting substituents in 1-position have the largest LU coefficient at C-4. The diazomethane carbon becomes attached at C-4, thus providing 3-vinyl-1-pyrazolines. This should be different for butadienes with electron-releasing substituents. Only a detailed calculation of the HO-LU-interactions could show, why 1-methoxybutadiene still obeys the same orientational pattern as the other substituted butadienes in its very slow diazomethane addition – at least in the main part of the reaction. A reinvestigation with improved analytical technique is needed. Butyl vinyl ether shows a reversal of the direction of diazomethane addition[24] compared with acrylic ester.

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[20] R.B. Woodward and R. Hoffmann, *Angew. Chem., Int. Ed. Engl.*, **8**, 781, 817 (1969).

[21] J. Bastide, N. El Ghandour, and O. Henri-Rousseau, *Tetrahedron Letters*, **1972**, 4225; J. Bastide, O. Henri-Rousseau, and L. Aspart-Pascot, *Tetrahedron*, **30**, 3355 (1974).

[22] K.N. Houk, *J. Am. Chem. Soc.*, **94**, 8953 (1972).

[23] Ph. D. Thesis W. Fliege, Univ. of Munich, 1969, p. 61.

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[25] K.N. Houk, *J. Am. Chem. Soc.*, **95**, 4092 (1973).

[26] I.A. D'yakonov, *J. Gen. Chem.* (USSR), **17**, 67 (1947) [*C.A.* **42**, 902 *h* (1948)].

Experimental[27]

3-Vinyl-1-pyrazoline (III)[14]——bp 53—54°/12 mmHg, $n_D^{20}=1.4663$ (1.4665[12]). IR (CCl_4) cm^{-1}: 1630 (C=C), 1535 (N=N), 915 and 972 (vinyl CH wagging). Destillation over acidic Al_2O_3 *in vacuo* left III unchanged, while 2 hr with Al_2O_3 at 100—110° led to complete polymerization. The equimolar mixture of III + HOAc contained after 1 hr no volatile material.

1-Carbamoyl-3-vinyl-2-pyrazoline (V)——Potassium cyanate (0.81 g, 10 mmole) was added to III (0.48 g, 5 mmole) in HOAc (5 ml). After 1 hr at 25° one treated with H_2O (30 ml) and potassium hydrogen carbonate, extracted with CH_2Cl_2 and evaporated the organic phase: 0.58 g residue. From EtOH 0.33 g (47%), colorless prisms, mp 134.5—136°. *Anal.* Calcd. for $C_6H_9ON_3$: C, 51.78; H, 6.52; N, 30.20. Found: C, 51.91; H, 6.51; N, 29.73. IR (KBr) cm^{-1}: 3400, 3230 (NH_2), 1672 (amide I), 1650 (amide II), 1602 (C=C), 1562 (C=N), 906 and 987 (vinyl CH wagging). NMR τ ($CDCl_3$): 3.31 (1H, dd, $J_{\alpha,\beta}=10.7$ Hz, $J_{\alpha,\gamma}=17.5$ Hz, H_α), 4.1—4.5 (2H, broad s, NH), 4.41 (1H, d, H_β), 4.51 (1H, d, H_γ), 5.8—6.3 (2H, m, 5-H_2), 6.8—7.3 (2H, m, 4-H_2).

3-*trans*-Propenyl-1-pyrazoline (VI)——*trans*-Piperylene (3.41 g, 50 mmole) and N-phenyl-β-naphthylamine (0.2 g, polymerization inhibitor) were dissolved in 78 ml ethereal diazomethane (50 mmole). After 22 d at 5° ether and excess dipolarophile were distilled off. The colorless residue distilled at 69—70°/10 mmHg (bath temp.), 1.53 g (28%), $n_D^{20}=1.4736$. *Anal.* Calcd. for $C_6H_{10}N_2$: C, 65.42; H, 9.15; N, 25.43. Found: C, 65.23; H, 9.17; N, 25.38. IR (liq.) cm^{-1}: 1660 (C=C), 1539 (N=N), 965 (s, *trans*-CH=CH wagging). NMR τ ($CDCl_3$, vinyl protons evaluated as spectrum of higher order): 4.26 (1H, dq, $J_{\alpha,\beta}=15$ Hz, $J_{\beta,CH_3}=5.0$ Hz, H_β), 4.54 (1H, dd, $J_{\alpha,3}=5.5$ Hz, H_α), 5.1—6.3 (3H, 25 lines visible, 3-H and 5-H_2), 7.9—9.2 (2H, m, 17 lines visible, 4-H_2), 8.26 (3H, d, $J=5.0$, CH_3).

3(2-Methoxyvinyl)-1-pyrazoline (*trans* VII, *cis* VIII)——Diazomethane (127 mmole) reacted with 10.65 g (127 mmole) 1-methoxybutadiene (60% *trans*, 40% *cis*)[28] in 220 ml ether 4 weeks at 5° in the presence of N-phenyl-β-naphthylamine (0.1 g). The adduct mixture (VII: VIII = 82: 18) distilled at 105—112°/12 mmHg, 4.06 g (25%), $n_D^{20}=1.4880$, sensitive to air. IR (liq.) cm^{-1}: 1650 (s, C=C), 1542 (N=N), 935 (s, *trans*-CH=CH wagging). NMR τ ($CDCl_3$): 3.32 (0.82H, $J_{trans}=11.5$ Hz, H_β of VII), 3.88 (0.18H, $J_{cis}=6.0$, $J_{3,\beta}\approx 0.8$ Hz, H_β of VIII), 5.1—6.1 (3H, m, 3-H and 5-H_2 of VII and VIII), 6.32 (18% of 3H, s, OCH_3 of VIII), 6.43 (82% of 3H, s, OCH_3 of VII), 7.6—9.1 (2H, m, 4-H_2 of VII and VIII).

1-Carbamoyl-3(2-*trans*-methoxyvinyl)-2-pyrazoline (IX)——The above adduct mixture was treated with HOAc and KOCN as described for III; pale yellow prisms, 53%, mp 154—156°. *Anal.* Calcd. for $C_7H_{11}O_2N_3$: C, 49.69; H, 6.55. Found: C, 50.28; H, 6.74. IR (KBr) cm^{-1}: 3430, 3290 (NH), 1671 (amide I), 1648 (amide II), 1598 (C=C), 1134 (C–O), 928 (*trans*-CH=CH wagging). NMR τ ($CDCl_3$, HC=CH evaluated as AB spectrum): 3.20 (1H, d, $J_{trans}=13.0$ Hz, H_β), 4.24 (1H, d, $H\alpha$), ~4.65 (2H, broad s, NH_2), 5.9—6.3 (2H, m, 5-H_2), 6.31 (3H, s, OCH_3), 6.9—7.3 (2H, m, 4-H_2).

3-*trans*-Styryl-2-pyrazoline (X)——8.85 g (68 mmole) *trans*-1-Phenylbutadiene,[29] 0.2 g N-phenyl-β-naphthylamine and 68 mmole diazomethane in 100 ml ether were kept in the refrigerator for 21 d. After distillation of ether and phenylbutadiene (95° bath/0.001 mmHg, 2.01 g), the adduct followed at 150°/0.001 mmHg: 5.01 g (43%), from MeOH pale yellow needles, mp 102—104°. *Anal.* Calcd. for $C_{11}H_{12}N_2$: C, 76.71; H, 7.02; N, 16.27. Found: C, 76.31; H, 7.07; N, 15.85; IR (KBr) cm^{-1}: 3285 (NH), 1620 (w, C=C), 952 (s, *trans*-CH=CH wagging), 744, 725, 685 (C_6H_5 wagging). NMR τ ($CDCl_3$): 2.4—2.9 (m, C_6H_5), AB spectrum at 2.90 and 3.39 (2H, 2d, $J_{trans}=16.3$ Hz, H_α and H_β), 4.65 (1H, s, half-width 4 Hz, NH), 6.35—6.8 (2H, m, 5-H_2), 7.0—7.4 (2H, m, 4-H_2). Hydrochloride: yellow needles, mp 169.5—170° (EtOH). IR (KBr) cm^{-1}: 2500, 2630, 2840 (NH^+), 1635 (C=N), 1604, 1597 (C=C, C_6H_5), 963 (HC=CH wagging), 760, 689 (C_6H_5 wagging).

1-Nitroso-3-*trans*-styryl-2-pyrazoline (XI)——From X (2.0 mmole) and $NaNO_2$ (2.5 mmole) in HOAc (3 ml) at room temperature; after 15 min + 20 ml H_2O, precipitation of 90% XI, pale yellow needles (acetone), mp 157—158° (decomp.). *Anal.* Calcd. for $C_{11}H_{11}ON_3$: C, 65.67; H, 5.51; N, 20.88. Found: C, 65.35; H, 5.88; N, 20.07. IR (KBr) cm^{-1}: 1630 (C=C), 1560 (C=N), 1380 (st, N=O). NMR τ ($CDCl_3$): 2.3—2.8 (5H m, C_6H_5), 2.84 (2H, s, H_α and H_β), 5.7—6.2 (2H, m, 5-H_2), 6.6—7.1 (2H, m, 4-H_2).

1-Carbamoyl-3-*trans*-styryl-2-pyrazoline (XII)——From X as described for III, colorless needles, mp 169.5—170° (EtOAc). *Anal.* Calcd. for $C_{12}H_{13}ON_3$: C, 66.95; H, 6.09; N, 19.52. Found: C, 67.00; H, 6.37; N, 19.03. NMR τ ($CDCl_3$): AB spectrum at 2.97 and 3.27 (2H, $J_{trans}=16.6$ Hz, H_α and H_β).

3(2-*trans*-Methoxycarbonyl-vinyl)-2-pyrazoline (XIII)——43.3 g (387 mmole) methyl butadiene-*trans*-1-carboxylate[30] was dissolved in 250 ml ethereal diazomethane (129 mmole). After several hr at 5° 5.36 g (42%) bisadduct (XIX) was filtered. The ether was removed and the excess butadiene-1-carboxylate (34.0 g)

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27) Melting points are uncorrected. NMR spectra were recorded on a Varian A-60 spectrometer using TMS as internal standard. IR spectra were taken on a Leitz spectrometer, model III, or on a Perkin-Elmer grating spectrograph 125.

28) W. Flaig, *Liebigs Ann. Chem.*, **568**, 1 (1950).

29) O. Grummit and E.I. Becker, "Org. Syntheses," Coll. Vol. IV, 1963, p. 771.

30) H.O. House and G.H. Rasmussen, *J. Org. Chem.*, **26**, 4278 (1961).

was distilled at 25°/0.001 mmHg. Distillation at 130—140° (bath temp., 0.001 mmHg) afforded 4.04 g (20%) yellow liquid which solidified, mp 41—47°; sensitive to air and light. IR (CCl_4) cm^{-1}: 3380 (NH), 1708 (C=O), 1610 (C=C), 1515 (C=N), 1294, 1260, 1156 (C–O), 968 (*trans*-CH=CH wagging). NMR τ ($CDCl_3$): 2.48 (1H, d, $J_{trans}=16.4$ Hz, H_α), 4.14 (1H, d, H_β), 3.61 (1H, broad s, NH), 6.23 (s, OCH_3), 6.2—6.7 (2H, m, 5-H_2), 7.0—7.5 (2H, m, 4-H_2).

1-Nitroso Derivative (XIV)——Nitrosation of XIII in HOAc gave yellow leaflets (EtOH), mp 147—148° (decomp.). *Anal.* Calcd. for $C_7H_9O_3N_3$: C, 45.90; H, 4.95; N, 22.94. Found: C, 46.40; H, 4.99; N, 22.56. IR(KBr) cm^{-1}: 1705 (C=O), 1638 (C=C), 1558 (C=N). 1385, 1320 (st, N=O), 1270, 1195, 1170 (C–O), 986 (CH=CH wagging). NMR τ ($CDCl_3$): AB spectrum of H_α and H_β at 2.40 and 3.66, $J_{trans}=16.2$ Hz.

1-Carbamoyl Derivative (XV)——From 0.46 g XIII and 0.41 g KOCN in 6 ml HOAc for 1 hr at room temperature; working up with H_2O/CH_2Cl_2 produced 0.53 g (90%) yellow needles, mp 207—209° (EtOH). *Anal.* Calcd. for $C_8H_{11}O_3N_3$: C, 48.72; H, 5.62; N, 21.31. Found: C, 49.19; H, 5.85; N, 21.15. IR(KBr) cm^{-1}: 3440, 3200, 3160 (NH), 1710 (C=O), 1690 (amide I), 1614 (amide II), 1595 (C=C), 1541 (C=N). NMR τ ($CDCl_3$): 2.53 (1H, d, $J_{trans}=15.8$ Hz, H_α), 4.02 (1H, d, H_β), 6.21 (s, OCH_3).

Methyl 4-[2-pyrazolinyl-(3′)]-2-pyrazoline-3-carboxylate (XIX)——Diazomethane (60 mmole) reacted with 5.6 g (50 mmole) methyl butadiene-1-carboxylate in 100 ml ether at 5°. After several days 4.98 g (85%) of the bisadduct had crystallized; from MeOH colorless prisms, mp 161—163° (decomp.). *Anal.* Calcd. for $C_8H_{12}O_2N_4$: C, 48.97; H, 6.17; N, 28.56. Found: C, 49.12; H, 6.56; N, 28.04. IR (KBr) cm^{-1}: 3310 (NH) 1691 (C=O), 1532 (C=N), 1220, 1106 (C–O). NMR τ ($CDCl_3$): 3.3—3.7 (1H, broad s, NH), 4.9—5.2 (1H, broad s, NH), 5.3—6.6 (4H, m, 5-H_2 and 5′-H_2), 6.13 (s, OCH_3), 7.00 (1H, dd, $J=6.3$, 11.0 Hz, 4-H), 8.0—9.2 (2H, m, 4′-H_2). Monohydrochloride of XIX: mp 177—178° (EtOH). *Anal.* Calcd. for $C_8H_{13}O_4N_2Cl$: C, 41.34; H, 5.63. Found: C, 41.62; H, 5.87. IR (KBr) cm^{-1}: 3300 (NH), 2850, 2600, 2470 (NH^+).

3(*cis*-2-Cyanvinyl)-2-pyrazoline (XX)——The solution of 38.0 g (480 mmole) 1-cyanobutadiene (98% *cis*, 2% *trans*) and 96 mmole diazomethane in 150 ml ether become colorless in 10 min. The monoadduct XX was distilled at 98—103°/0.001 mmHg, whereby partial N_2 loss occurred: 8.4 g pale yellow oil, sensitive to air. IR (liq.) cm^{-1}: 3350 (NH), 2205 (C≡N), 1582 (C=N), 740 (*cis*-CH=CH wagging). NMR τ ($CDCl_3$): 2.98 (d, $J=11.8$ Hz, $H\alpha$), 3.63 (broad s, NH), 4.66 (d, $J=11.8$ Hz, H_β), 6.1—8.5 (4H, m, ring protons). Hydrochloride: in EtOH with conc. HCl, needles, mp 111—113° (EtOH). *Anal.* Calcd. for $C_6H_8N_3Cl$: C, 45.73; H, 5.12. Found: C, 46.05; H, 5.48.

Nitroso Derivative (XXI)——In HOAc with $NaNO_2$, light brown needles (EtOH), 72%, mp 104—105.5° (decomp.). *Anal.* Calcd. for $C_6H_6ON_4$: C, 48.00; H, 4.03. Found: C, 48.16; H, 4.49. IR (KBr) cm^{-1}: 2210 (C≡N), 1605 (w, C=C), 1543 (C=N), 1385 (st, N=O), 768 (st, HC=CH wagging ?). NMR τ ($CDCl_3$): 2.75 (1H, d, $J=11.8$ Hz, $H\alpha$), 4.67 (1H, d, $H\beta$), 5.6—6.1 (2H, m, 5-H_2), 6.3—6.8 (2H, m, 4-H_2).

3-Cyano-4-[2-pyrazolinyl-(3′)]-2-pyrazoline (XXII)——3.95 g (50 mmole) 1-cyanobutadiene and 60 mmole diazomethane reacted in 107 ml ether at 5°. The slow crystallization was complete after 14d: 2.97 g (61%), mp 101—102° (benzene). *Anal.* Calcd. for $C_7H_9N_5$: C, 51.52; H, 5.56; N, 42.92. Found: C, 51.75; H, 6.04; N, 42.27. IR (KBr) cm^{-1}: 3350 (NH), 2210 (C≡N), 1515 (s, C=N). NMR τ ($CDCl_3$): 3.02 (1H, s broad, NH), 4.8—6.1 (4H, m, 5-H_2, 5′-H_2), 6.13 (1H, s, NH), 6,43 (1H, dd, $J=6.0$, 12.5 Hz, 4-H), 7.5—9.1 (2H, m, 4′-H_2). Hydrochloride: pale yellow prisms (MeOH), mp 173—175.5° (decomp.). *Anal.* Calcd. for $C_7H_{10}N_5Cl$: C, 42.11; H, 5.05; N, 35.09. Found: C, 42.41; H, 5.21; N, 34.89.

3(1-Phenyl-vinyl)-1-pyrazoline (XXIII)——30.5 g (234 mmole) 2-phenylbutadiene,[31] 117 mmole diazomethane and 0.2 g N-phenyl-β-naphthylamine in 200 ml ether were kept 10 d at 5°. Distillation at 115—120°/0.001 mmHg gave 9.58 g (48%) of colorless oil, $n_D^{20}=1.5712$. *Anal.* Calcd. for $C_{11}H_{12}N_2$: C, 76.71; H, 7.02; N, 16.27. Found: C, 77.01; H, 7.19; N, 15.80. IR (liq.) cm^{-1}: 1624 (C=C), 1540 (w, N=N), 905 (=CH_2 wagging), 699 (C_6H_5 wagging). NMR τ ($CDCl_3$): 2.55—2.85 (m, C_6H_5), 4.58 (s, vinyl-H), 4.6—4.8. (m, 3-H), 4.89 (s, slight splitting, vinyl-H), 5.3—6.0 (m, 5-H_2), 7.8—9.1 (m, 30 signals visible, 4-H_2).

3(1-Phenyl-vinyl)-2-pyrazoline hydrochloride (XXIV•HCl)——After dropping 2 ml conc. HCl to 1 g XXIII in 2 ml EtOH, one isolated 0.77 g (63%) colorless needles, mp 123—124° (EtOH). *Anal.* Calcd. for $C_{11}H_{13}N_2Cl$: C, 63.30; H, 6.28; N, 13.43. Found: C, 63.14; H, 6.36; N, 13.41. IR (KBr) cm^{-1}: 2840, 2610, 2480 (NH^+), 1620 (C=C), 1600, 1495 (C_6H_5), 1570 (C=N), 785, 705 (C_6H_5 wagging).

1-Carbamoyl-3(1-phenyl-vinyl)-2-pyrazoline (XXV)——Reaction of 7.0 mmole XXIII with 10 mmole KOCN in 10 ml HOAc for 1 hr, work-up with H_2O/CH_2Cl_2 and layer chromatography (silicagel, benzene/acetone 6:1) yielded 63%, mp 148—149° (acetone). *Anal.* Calcd. for $C_{12}H_{13}ON_3$: C, 66.95; H, 6.09; N, 19.52. Found: C, 67.25; H, 6.17; N, 18.76. IR (KBr) cm^{-1}: 3460, 3200 (NH), 1670 (amide I), 1575 (st, C=N), 907 (=CH_2 wagging), 777, 763, 699 (C_6H_5 wagging). NMR τ ($CDCl_3$): 2.65 (s, broadened, C_6H_5), 4.39 and 4.48 (2s, vinyl-H), 4.3—4.7 (s, broad, NH), 5.8—6.3 (m, 5-H_2), 5.7—6.2 (m, 4-H_2).

Rate Measurements——Freshly distilled N,N-dimethylformamide turned out to be a superior solvent; the solubility of diazomethane is so high, that hardly a yellow color is perceptible in the gas phase above an 0.1M diazomethane solution at 25°. The thermal stability of diazomethane is often underrated; kept under

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31) E.G.E. Hawkins, British Pat. 869 456 (1961) [*C.A.* **56**, 1391 (1962)].

pure nitrogen in DMF at 25° (light excluded), the half-life amounts to 22 days. Diazomethane was generated from nitrosomethyltosylamide[32] and was swept with nitrogen *via* a drying tube (KOH pellets) into the DMF.[33]

1) Titrimetric Method: 100 ml DMF solution of known diazomethane content (*ca.* 0.05M) and 40 ml of 0.18M methyl butadiene-1-*trans*-carboxylate in DMF, both thermostated at 25.0° ± 0.05°, were combined. Ten 10 ml samples were withdrawn at defined reaction times (the first after 2 min) and mixed with 5 ml 0.1M benzoic acid in DMF. After the disappearance of the yellow color, 25 ml water and bromothymolblue were added and the excess benzoic acid titrated with 0.1N NaOH. The rate constant, evaluated by the second-order law, may be somewhat high, because the formation of the bisadduct cannot be suppressed.

2) Volumetric Method: DMF solutions of diazomethane (100 ml sol.) and dipolarophile (50 ml sol.) were combined at 25°. The initial concentrations of the dipolarophile were *ca.* 10 times higher than that of CH_2N_2 (Table I). 5 ml samples were introduced by hypodermic syringes through a rubber septum into a long-necked 25 ml flask which contains 15 ml 2M trichloroacetic acid in ethylene glycol monomethyl ether. The flask is connected with a 25 ml gas buret and is placed in a 20°-thermostat; the water of the thermostat circulates also through the jacket of the gas buret. Nitrogen is evolved quickly, but it needs 2 min of vigorous shaking of the decomposition flask to remove the N_2 retention of the solvent completely. The N_2 volume is a measure of the diazomethane concentration (A_t) at the time of sample withdrawal; 8—12 measurements were taken in each run up to 80% reaction.

Plotting of log (A_0/A_t) *vs.* time allowed the graphic determination of the pseudo-first order constant. After eventual subtraction of k_{dec} (diazomethane self-decomposition), $k_{1\psi}$ was divided by the mean dipolarophile concentration, *i.e.*, the initial concentration minus half of the initial diazomethane concentration ($D_0 - A_0/2$), thus providing the k_2 of Table I. Reproducibility in several runs ±3%.

The rate of the self-decomposition of diazomethane, measured by the volumetric method, followed the first order law up to 60% reaction; $k_{dec} = 3.6 \cdot 10^{-7}$ (sec^{-1}) at 25° in DMF.

3) IR Method: The dimethylamine set free from 1-dimethylaminobutadiene[34] by acid treatment of samples of the cycloaddition solution would disturb the volumetric diazomethane analysis. Here the extinction of the IR absorption of diazomethane at 2074 cm^{-1}, measured in a fixed liquid cell (Perkin-Elmer Corp.) of 0.2 mm path length between rock salt windows, offered a convenient concentration measurement; *e.g.*, 0.04M diazomethane gave 40% transmission. 10 ml each of thermostated DMF solutions of diazomethane (0.13M) and dimethylaminobutadiene (2M) were combined under pure N_2. 1 ml samples were pipetted, diluted with 3 ml DMF and introduced into the cuvette; solvent compensation in the second light beam. Careful exclusion of air, humidity and light furnished the small rate constant within ±30%. With exposure of the reaction mixture to air and daylight the k_2 values were 2—4 times greater. With 30—40% self-decomposition of diazomethane, the correction is here substantial.

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32) T.J. de Boer and H.J. Backer, *Rec. Trav. Chim. Pays-Bas*, 73, 229 (1954).

33) Purification: W. Bunge "Methoden der Organischen Chemie," Houben-Weyl, Vol. I/2, 1959, p. 831, G. Thieme Stuttgart.

34) S. Hünig and H. Kahanek, *Chem. Ber.*, **90**, 238 (1957).