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2,2-BIS(TRIFLUOROMETHYL)ETHYLENE-1,1-DICARBONITRILE AND STYRENES A DICHOTOMY OF CYCLOADDITION PATHWAYS [1]

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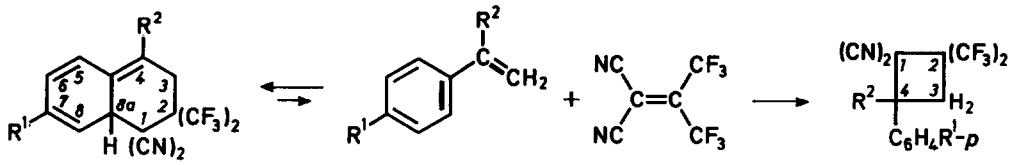
Summary: The title compounds undergo reversible Diels-Alder reactions and irreversible [2+2] cycloadditions. The nonaromatic Diels-Alder adducts were isolated and subjected to [4+2] cycloadditions with *N*-methyl-triazolinedione.

Middleton prepared 2,2-bis(trifluoromethyl)ethylene-1,1-dicarbonitrile (BTF; **2**) and described its [2+2] and [2+4] cycloadditions [2]. Cycloadducts of styrene and 4-methoxystyrene - the first reversibly formed - were considered as the cyclobutanes **3a** and **3j**. In a thorough study, we never encountered noticeable equilibration of a cyclobutane with the two constituent olefins [3,4]. A reinvestigation of Middleton's experiments showed structure **3j** being correct and **3a** incorrect. With styrene and derivatives as donor olefins, BTF furnished [4+2] cycloadducts **1** under conditions of *kinetic* control whereas [2+2] cycloadducts **3** arose under *thermodynamic* control.

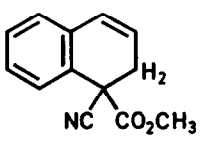


1 **2** **3**

	Yield	mp [°C]	R^1	R^2		Yield	mp [°C]
1a	85%	76-76.5	H	H	**3a**	46%	83-83.5
1b	79%	84-85	F	H	**3b**	35%	93-96
1c	65%	67-68	Cl	H	**3c**	34%	-
1d	64%	49-51	Br	H	**3d**	24%	115-116
1e	63%	96-102	Me	H	**3e**	52%	110-111
1f	78%	66.5-68	*t*Bu	H	**3f**	86%	oil
1g	NMR experiment		H	Ph	**3g**	87%	127-127.5
1h	82%	93.5-94	H	Me	**11a**	59%	68-69
1i	75%	75-78	Cl	Me	**11b**	77%	glassy
1j	not observed		OMe	H	**3j** [2]	85%	103-104
1k	not observed		SMe	H	**3k**	76%	106-106.5
1l	not observed		H	OMe	**3l**	63%	111.5-112

The nonaromatic tetrahydronaphthalenes **1** were readily isolable [5] since they crystallized - analytically pure - 30s to **1d** after combining the reactants in pentane at room temperature (**1g** was examined in solution only). In solution, the Diels-Alder adducts **1a-i** dissociate by [4+2] cycloreversions to a variable extent. The dissociation is the smallest for the adduct **1f** of 4-*tert*-butylstyrene (20% in 1 M benzene solution at 25°C) and largest for compound **1d** obtained from *p*-bromostyrene (62%). Rate and equilibrium constants will be discussed in the accompanying paper.

The styrene adduct **1a** crystallized after 20 min. The two doublets of triplets in the ^{1}H NMR spectrum ($CDCl_3$) were assigned to 3-H_2 (δ 2.65, 2.94); J_{gem} = 19.4 Hz would be too large for a cyclobutane [6], but fits the allylic position of a 6-membered ring. The homoallylic coupling $J_{3,8a}$ and - by coincidence - $J_{3,4}$ amount to 4.4 Hz for 3-H_A and to 4.7 Hz for 3-H_B. The unresolved m of five vinyl-H at δ 5.6-6.3 is the absorption at lowest field, except for that of styrene in equilibrium with **1a**. The ^{19}F NMR signals occur at δ -68.1 and -68.8 with $J_{F,F}$ = 10.8 Hz. The spectra of the other [4+2] cycloadducts **1** are closely related. The binding sites of the CF_3 (at C-2) and C≡N groups (at C-1) in adducts **1** are unproven but plausible. In the regioisomer the CF_3 groups would be located at the sterically more hindered position C-1. Furthermore, the suggested regioselectivity of the Diels-Alder reaction leading to **1** is favored by the AO coefficients and corresponds to the known cycloadduct **4** of methyl α-cyanoacrylate and styrene (subsequent HBr elimination) [7].



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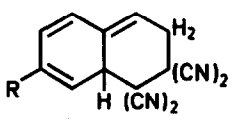

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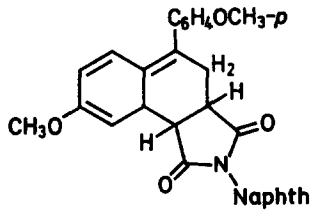

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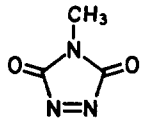

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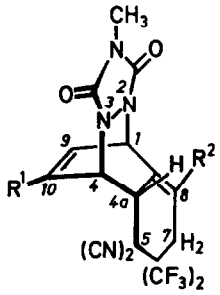
Tetracyanoethylene (TCNE) was supposed not to combine with styrene at room temperature, in contrast to 4-methoxystyrene [8]. However, Nakahara et al. observed that the red CT color rapidly diminished at 8 kbar, and the ^{13}C NMR spectrum at -50°C suggested the [4+2] cycloadduct **5**, R = H [9]. Due to the high dissociation, adducts **5**, R = H, Cl, Br, CH_3, OCH_3, have not been isolated [10]; only for **5**, R = OCH_3, a subsequent conversion to the cyclobutane was noticed [11]. The role of styrene as a diene in Diels-Alder reactions is well-documented [12], but cycloadducts analogous to **1** either add a second equivalent of dienophile to the built-in cyclohexadiene unit or rearomatize by 1,3-prototropy. To the best of our knowledge, **6** is the only representative of primary Diels-Alder adducts which has been isolated [13] prior to our work.

It is remarkable that **1** and **5** fail to add a second molecule of the acceptor olefin; possibly, a decrease of the HO energy by the electron-attracting substituents is responsible. Dimethyl acetylenedicarboxylate or azodicarboxylate were likewise inert toward **1a**. Gratifyingly, *N*-methyltriazolinedione (**7**) as a more potent dienophile furnished the Diels-Alder adducts **8**, thus

confirming the 1,3-diene character of **1**. Styrene itself combines with **7** providing various 1:2 adducts [14]. We suppressed this undesired reaction by diminishing the equilibrium concentration of styrene alongside **1a**. Styrene was reacted with 6 equiv of BTF in CH_2Cl_2; now 1 equiv of **7** at -18°C converted **1a** into **8a**. The adducts **8** obtained in 62-73% yield were structurally homogenous; it is a safe assumption that **7** approaches **1** from the less hindered side.

R^1	R^2	**8**	Yield	decomp. [°C]
H	H	**a**	62%	250
Me	H	**b**	70%	197.5-199
H	Me	**c**	69%	210-211
H	Ph	**d**	73%	228-229
Cl	Me	**e**	62%	204-205



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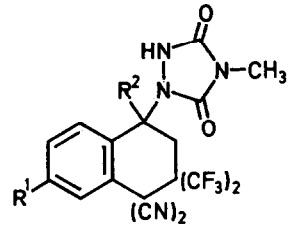

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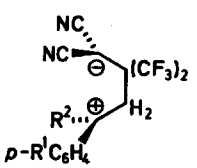
The ^1H NMR spectrum (D_6-DMSO) of **8a** shows the AB pattern of 7-H_2 (δ 2.83 and 3.20, J_{gem} = 18.8 Hz) further split by coupling with the olefinic 8-H (m_c δ 6.20) and the homoallylic 4a-H (m_c δ 3.48); the vinylic 9-H and 10-H occur as m_c at δ 6.59. The lack of signals for aromatic H and for NH excluded the conceivable ene product **9**. The assignments were endorsed by the simpler spectra of the mono- and disubstituted representatives, **8b** - **8e**.

Competing with the *reversible* formation of **1** is the *irreversible* [2+2] cycloaddition; in the energy balance the loss of aromatic resonance in **1** exceeds the ring strain in cyclobutane **3**. Styrene and BTF combined at room temperature in pentane, and 86% of the [4+2] adduct **1a** crystallized after 20 min. When the reaction was run for *32 days*, **1a** dissolved again and 46% of cyclobutane **3a** was isolated. 4-Methylstyrene + BTF afforded 52% of **3e** after *3 days*, whereas the reaction of 4-(methylthio)styrene required only *2 min* (76% **3k**). Finally, the [2+2] cycloaddition of α-methoxystyrene + BTF was finished after *5 sec* as the fading of the CT complex color indicated. The steep rise in the rate of [2+2] cycloaddition reflects the stabilization of the benzyl type carbenium ion by substituents and is in harmony with the intermediacy of zwitterion **10**.

Thus, for styrene + BTF the [4+2] cycloaddition surpasses the cyclobutane formation in rate, but the [2+2] cycloaddition wins out with increasing stability of the 1,4-dipole **10**; no [4+2] cycloadducts were observed with 4-methoxy-, 4-(methylthio)-, or α-methoxystyrene. This evidence suggests that the [4+2] cycloaddition *does not pass the same intermediate* **10**.

The 100 MHz ^{19}F-decoupled ^1H NMR spectrum ($CDCl_3$) of **3a** reveals a well-resolved ABX type at δ 2.80, 3.23, and 4.49 for 3-H_2 and 4-H ($J_{3A,3B}$ = 13.9, $J_{3A,4}$ = 10.0, $J_{3B,4}$ = 11.4 Hz); C_6H_5 protons occur at δ 7.2-7.6. Similar spectra of the other cyclobutanes **3** leave no doubt about the structure. The yields of isolated **3** listed in the table are not optimized.



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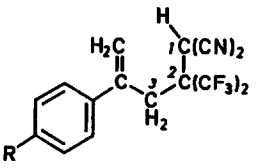
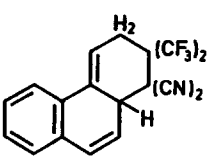


11a R = H; 11b R = Cl



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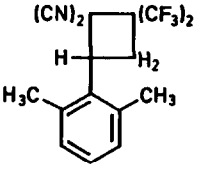

13

α-Methylstyrene or its 4-chloro derivative and BTF entered into the [4+2] cycloaddition, but the subsequent irreversible reaction (4 weeks) generated the ene products **11a** and **11b**. The two vinyl-H of **11a** are found as singlet at δ_H 5.46, and the singlet of 3-H_2 at 3.27 is broadened by long range coupling with ^{19}F. The acidic 1-H (δ_H 3.94) exchanges with CH_3OD. The intervention of 1,4-dipole **10** on the way to **11** is plausible, but a concerted pathway is not ruled out. 1,1-Diphenylethylene and BTF furnished cyclobutane **3g** under conditions of thermodynamic control.

The stable Diels-Alder adduct **12** (68%, mp 125-126°C) is formed from 1-vinylnaphthalene + BTF; only 20-22 kcal mol^{-1} of aromatic resonance are sacrificed here in contrast to ≈ 36 kcal mol^{-1} for styrene + BTF → **1a**; the TCNE adduct of 1-vinylnaphthalene is likewise known [15]. 2,6-Dimethyl-styrene constitutes another limiting case. Its nonplanarity [16] is probably accountable for its failure to undergo the Diels-Alder reaction with BTF; the cyclobutane **13** (4d, 67%, mp 114-115°C) results directly.

REFERENCES AND NOTES

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