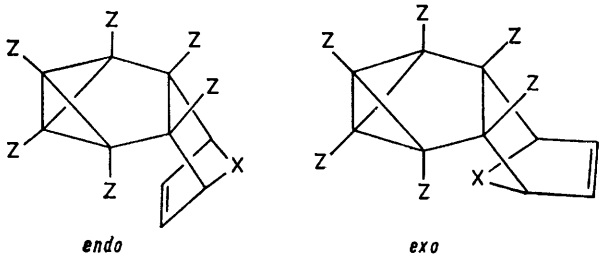
Studies on Organic Fluorine Compounds. Part 25.[1] Diels–Alder Reaction of Hexakis(trifluoromethyl)benzvalene[2]

By Yoshiro Kobayashi,* Masamitsu Honda, Yuji Hanzawa, Itsumaro Kumadaki, and Akio Ohsawa, Tokyo College of Pharmacy, Horinouchi, Hachioji, Tokyo 192–03, Japan

Diels–Alder reactions of hexakis(trifluoromethyl)benzvalene (1) with cyclic and acyclic dienes have been examined. The Diels–Alder reaction of cyclic dienes gave only the *exo*-isomer of two possible stereoisomers. Cyclohexa-1,3-diene gave the dihydro-compound of (1), rather than a Diels–Alder adduct, by an ene-reaction or [$_{\pi}2_s + {}_{\sigma}2_s + {}_{\sigma}2_s$] process.

HEXAKIS(TRIFLUOROMETHYL)BENZVALENE (1)[3] has a very interesting structure with a bicyclobutane framework and a strained double bond; it is thermally stable owing to the perfluoroalkyl effect,[4] and therefore it might be a precursor to other highly strained stable compounds. For this purpose, the Diels–Alder reaction would be suitable since a highly strained double bond with trifluoromethyl groups reacts as a dienophile.[5] Two examples of Diels–Alder reaction of (1), with cyclopentadiene and pyrrole, were reported by Haszeldine and his co-workers,[5a,b] but the stereochemical structures of the adducts (*i.e. endo* or *exo*) were not determined. We were interested in the scope and limitation of the Diels–Alder reaction of (1), in order to use the products for the further synthesis of strained cage compounds. In this paper we examine the reaction of (1) with a number of dienes, in order to clarify the stereochemistry of the adducts and the reactivity of (1) as a dienophile.

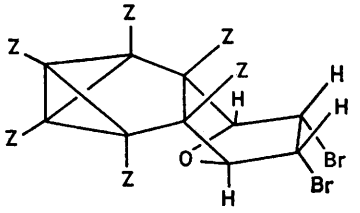


RESULTS AND DISCUSSION

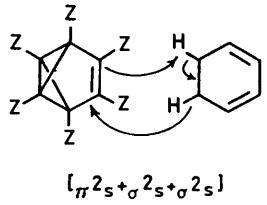
The results are summarized in Table 1. No reaction occurred with cyclic dienes having a bulky X-portion. The introduction of methyl substituents at the 2- and 5-positions of furan, made the reaction very slow, but the introduction of two more methyl groups, at the 3- and 4-positions, did not cause a large difference.

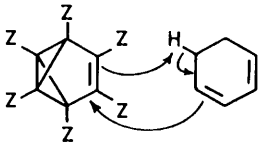
These results suggest that the transition state of this reaction is *exo* rather than *endo*. An examination of stereochemical models also shows that repulsion between the trifluoromethyl groups and the 3,4 bond of the cyclic diene is greater in the *endo*-form.

To confirm the stereochemistry of the Diels–Alder adducts, we carried out an *X*-ray analysis on a derivative of one of the adducts. Treatment of the furan adduct (3a) with bromine in carbon tetrachloride gave a dibromide (5) in 88% yield, which showed four signals in the ^{19}F n.m.r. spectrum † (δ −9.6, −7.6, −4.4, and −2.6: intensity ratio 1 : 1 : 2 : 2), and two singlets due to methine protons in the ^{1}H n.m.r. spectrum, showing



that *cis*-addition of bromine occurred. The *X*-ray study[2] of (5) confirmed that the structure was *exo* and therefore the stereochemistry of the adduct (3a) is also *exo*.





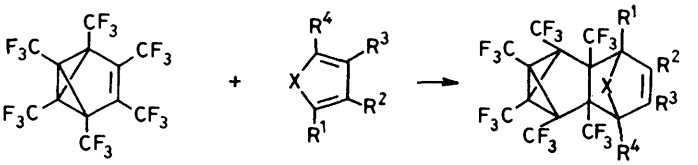
The rather unexpected product from the reaction of 1,3-cyclohexadiene with (1) is considered to arise from one of the two mechanisms shown: one is a concerted [$_{\pi}2_s + {}_{\sigma}2_s + {}_{\sigma}2_s$] process, and the other is the ene-reaction. Similar mechanisms were proposed in the reaction of ethyl azodicarboxylate with 1,3-cyclohexadiene.[6]

We next examined the Diels–Alder reactions of (1) with acyclic dienes (Table 1) which required a higher temperature than the reaction with cyclic dienes, probably due to the *cisoid–transoid* equilibrium of the conjugated diene: if it were not for this equilibrium the

† The benzotrifluoride signal is used as internal standard: upfield shifts are quoted as positive.

TABLE 1

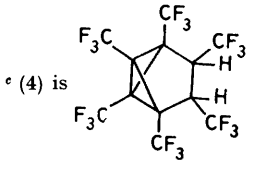
Diels–Alder reactions of (1)



(1) (2a–o)

	X	R¹	R²	R³	R⁴	Molar ratio diene : (1)	Solvent	Temperature (°C) [a]	Time	Product (yield) [b]
(2a)	O	H	H	H	H	1.2 : 1	n-C_5H_{12}	r.t.	5 min	(3a) (86%)
(2b)	O	Me	H	H	Me	9.2 : 1	n-C_5H_{12}–$CHCl_3$	r.t.	8 d	(3b) (92%)
(2c)	O	Me	Me	Me	Me	5.5 : 1	n-C_5H_{12}–$CHCl_3$	r.t.	8 d	(3c) (68%)
(2d)	NH	H	H	H	H	1.6 : 1	n-C_5H_{12}–$CHCl_3$	r.t.	6 month	(3d) (12%)
(2e)	NMe	H	H	H	H	3.0 : 1	n-C_5H_{12}	90	24 h	n.r.
								180	6 h	
(2f)	S	H	H	H	H	1.4 : 1	n-C_5H_{12}	90	12 h	n.r.
								180	6 h	
(2g)	CH_2	H	H	H	H	3.0 : 1	n-C_5H_{12}	r.t.	5 min	(3g) (quantitative)
(2h)	CO	Ph	Ph	Ph	Ph	1.0 : 1	n-C_5H_{12}	90	24 h	n.r.
								180	6 h	
(2i)	$C(OEt)_2$	H	H	H	H	2.4 : 1	n-C_5H_{12}	90	13 h	n.r.
								180	6 h	
(2j)	CH_2–CH_2	H	H	H	H	1.0 : 1	CCl_4	90	7 d	(4) (75%),[c] C_6H_6 (80%)
(2k)	–C(=O)–O	H	H	H	H	2.4 : 1	n-C_5H_{12}	90	13 h	n.r.
								180	6 h	
(2l)	–H,H–	H	H	H	H	excess	n-C_5H_{12}	90	4 h	(3l) (78%)
(2m) [d]	–H,H–	Me	H	H	H	excess	Me_2CO	100	18 h	(3m) (85%)
(2n)	–H,H–	Me	H	H	Me	excess	Me_2CO	90	12 h	n.r.
								180	6 h	
(2o)	–H,H–	H	Me	H	H	1.6 : 1	Me_2CO	r.t.	20 d	(3o) (43%)
(2p)	–H,H–	H	Me	Me	H	2.2 : 1	n-C_5H_{12}	r.t.	10 h	(3p) (52%)

[a] r.t. = Room temperature. [b] n.r. = No reaction.

[c] (4) is 

[d] (2m) is (E)-penta-1,3-diene.

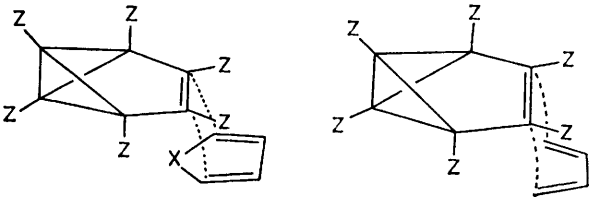
TABLE 2

Purification and physical data of the adducts (3) [a]

	Crystallization solvent	M.p. (°C)	N.m.r. ^{19}F [b]	N.m.r. ^{1}H [c]	Mass spectrum M^+	Mass spectrum Found (calculated)	I.r. (cm^{-1})
(3a)	n-pentane	80	−9.2 (3F), −7.2 (3F), −2.4 (12F)	6.60 (2 H), 5.27 (2 H)	554	553.9997 (553.9974)	1 570 [d] 1 220 [e]
(3b)	n-pentane at −78 °C	103	−11.2 (3F), −6.8 (3F), −2.4 (12F)	6.37 (2 H), 1.68 (6 H)	582	$[M - F]^+$ 563.0309 (563.0303)	1 555 [d] 1 240—1 200 [e]
(3c)	MeOH	95	−10.4 (3F), −9.2 (3F), −7.2 (6F), −3.6 (6F)	1.60 (12 H)	610	610.0574 (610.0600)	1 560 [d] 1 236 [e]
(3l)	n-pentane	100	−10.4 (3F), −8.8 (3F), −3.2 (6F), 3.0 (6F)	6.09 (2 H), 3.01 (2 H, J_{gem} 14.8 Hz), 2.50 (2 H, J_{gem} 14.8 Hz)	540	540.0153 (540.0182)	1 565 [d] 1 240 [e]
(3m) [f]	n-pentane				554	$[M - CF_3]^+$ 485.0397 (485.0386)	
(3o)	n-pentane	172	−10.4 (3F), −8.8 (3F), −3.6 (6F), 2.8 (6F)	5.68 (1 H), 2.32—3.00 (4 H), 1.86 (3 H)	554	$[M - CF_3]^+$ 485.0397 (485.0386)	1 560 [d] 1 200 [e]
(3p)	MeOH	132—133	−10.7 (3F), −8.7 (3F), −3.6 (6F), 2.9 (6F)	2.60 (4 H), 1.77 (6 H)	568	568.0503 (568.0495)	1 550 [d] 1 230 [e]

[a] All the adducts were colourless needles. [b] P.p.m. from benzotrifluoride. [c] P.p.m. from tetramethylsilane. [d] Cyclopropyl ring vibrations. [e] C–F vibrations. [f] A mixture of the α- and β-methyl isomers.

approach of acyclic dienes in the transition state would be sterically more favoured than that of cyclic dienes.



Z = CF_3

These results are in good agreement with those reported previously.[7] The unreactivity of hexa-2,4-diene towards (1) under all the reaction conditions employed is explained by a combination of the steric repulsion between trifluoromethyl groups and methyl groups in the transition state, and the *cisoid–transoid* equilibrium.

In conclusion, although the reactivity of (1) as a dienophile is high, the steric effect of the trifluoromethyl groups must be taken into consideration. However, the steric effect of the trifluoromethyl groups of (1) is considered to be smaller than those of hexakis(trifluoromethyl)-Dewar benzene (6), since (6) did not give any adduct with dienes at room temperature.[5a,b]

EXPERIMENTAL

The Diels–Alder Reaction of Hexakis(trifluoromethyl)benzvalene (1). *General Procedure.*—The solution of (1) and the diene (2) in a suitable solvent(s) was sealed *in vacuo* in a Pyrex n.m.r. tube and heated at the temperature shown in Table 1. The reaction was followed by ^{19}F n.m.r. spectroscopy. The reaction mixture was concentrated *in vacuo* and the residue recrystallized from the solvent shown in Table 2; all the spectral data are also summarized in Table 2. In the case of butadiene, a stainless-steel tube was used instead of a Pyrex one. If no reaction was observed, the reaction temperature was finally raised to 180 °C, when isomerization of (1) to hexakis(trifluoromethyl)benzene was observed.

1,2,3,4,5,6-*Hexakis(trifluoromethyl)tricyclo*[3.1.0.$0^{2,6}$]-*hexane* (4). A solution of (1) (185.7 mg) and cyclo-1,3-hexadiene in CCl_4 was sealed in a Pyrex tube and heated at 90 °C for 7 d. The formation of two products was confirmed by g.l.c. and ^1H n.m.r. spectroscopy. One of the products is benzene, and the other 1,2,3,4,5,6-hexakis-(trifluoromethyl)tricyclo[3.1.0.$0^{2,6}$]hexane (4). The yields of the above compounds using ^1H n.m.r. spectroscopy were 80.4 and 75.3%, respectively. Solvent was evaporated off *in vacuo*, and the residual oil was purified by preparative gas chromatography at 118 °C. The oil obtained was assigned the structure shown from the following spectral data: $\nu_{max.}$ (CCl_4) (cm^{-1}) 1 550 (cyclopropane ring) and 1 205 [ν(C–F)]; δ_H(CCl_4) 3.47 (2 H, br s, 4-H and 5-H); δ_F(CCl_4) −11.6 (3 F, m), −8.0 (3 F, m), and 0 (12 F, m); *m/e*, 488 (M^+) (Calc. for $C_{12}H_{12}F_{18}$: *M*, 487.986 9. Found: *M*, 487.988 7).

2,3,4,5,6,7-*Hexakis(trifluoromethyl)*-9,10-*dibromo*-11-*oxapentacyclo*[6.2.1.$0^{2,7}$.$0^{3,5}$.$0^{4,6}$]*undecane* (5). To a solution of (3a) (105.6 mg) in CCl_4 was added an excess of Br_2. The reaction mixture was set aside at room temperature for 1 d, and the solvent and excess of Br_2 were evaporated off *in vacuo*. The residue was taken up in n-pentane and the solution was washed with water, dried, and solvent removed *in vacuo*. The residue was recrystallized from MeOH to give colourless needles of (5) (119.1 mg, 88.4%), m.p. 109 °C; $\nu_{max.}$(KBr) (cm^{-1}) 1 569 (cyclopropane ring) and 1 260 [ν(C–F)]; δ_H(CCl_4) 5.07 (2 H, s, 1-H and 7-H) and 4.83 (2 H, s, 8-H and 9-H); δ_F(CCl_4) −9.6 (3 F, m), −7.6 (3 F, m), −4.4 (6 F, m), and −2.6 (6 F, m); *m/e* 712 (M^+) (Calc. for $C_{16}H_3OF_{18}$: [*M* − HBr_2], 552.989 6. Found: [*M* − HBr_2]$^+$, 552.986 8).

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