Monatshefte für Chemie 123, 99 – 104 (1992)

Monatshefte für Chemie
Chemical Monthly

The Benzene Ring as a Dipolarophile: Reactions of Monosubstituted Benzenes with Tetracyanoethylene Oxide

A. de la Hoz[1, *], **C. Pardo**[2], **J. Elguero**[3, *], and **M. L. Jimeno**[3]

[1] Facultad de Ciencias Químicas, Universidad de Castilla-La Mancha, E-13071 Ciudad Real, Spain
[2] Departamento de Química Orgánica I, Facultad de Química, Universidad Complutense, E-28040 Madrid, Spain
[3] Instituto de Química Médica, CSIC, E-28006 Madrid, Spain

Summary. The reaction of tetracyanoethylene oxide on one hand and toluene, chlorobenzene, fluorobenzene, anisole, and nitrobenzene, on the other, has been studied. Toluene and the halogenobenzenes yield mixtures of monoadducts, anisole yield *p*-methoxyphenylmalononitrile and its dimer and nitrobenzene does not react. These results are discussed with the help of a qualitative orbital model. ^{1}H-NMR analysis of some monoadducts has been carried out.

Keywords. Benzene derivatives; Tetracyanoethylene oxide; 1,3-Dipolar cycloaddition.

Der Benzolring als Dipolarophil: Reaktionen monosubstituierter Benzole mit Tetracyanoethylenoxid

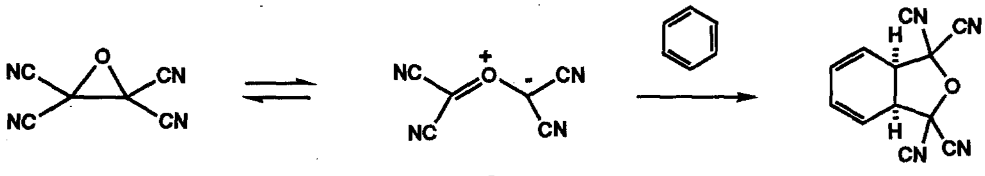
Zusammenfassung. Es wurden die Reaktionen von Tetracyanoethylenoxid mit Toluol, Chlorbenzol, Fluorbenzol, Anisol und Nitrobenzol untersucht. Toluol und die Halogenbenzole ergaben Mischungen von Monoaddukten, Anisol ergab *p*-Methoxyphenylmalononitril und sein Dimer, Nitrobenzol zeigte keine Reaktion. Diese Resultate werden mit Hilfe eines qualitativen Orbitalmodells diskutiert. Die Analyse einiger Monoaddukte erfolgte mittels ^{1}H-NMR-Analyse.

Introduction

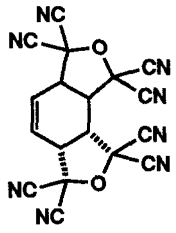
Reactions of the benzene ground state in which it behaves like an olefin are very unusual. One of these reactions involves tetracyanoethylene oxide **1** (*TCNEO*). This remarkable compound opens to a carbonyl ylide intermediate **2** which is so reactive that even a benzene ring does not withstand cycloadduct formation with *TCNEO* (**2**–**3 a**) [1, 2].

Discovered in 1965 [4], the reaction proceeds further on since the monoadduct **3 a** reacts with *TCNEO* (**1**) to yield a bis-adduct **4**. Its structure was independently determined by NMR [5] and by crystallography [6]. This second step is conventional since **3 a** is a diene.

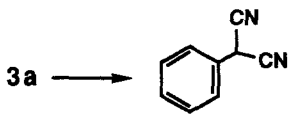
The reaction was reexamined [7] and extended to condensed aromatic hydrocarbons, such as naphtalene, anthracene, and phenanthrene. Both groups of authors [4, 7] observed the ring opening of tetracyanotetrahydrofuran with loss of $CO(CN)_2$ to yield arylmalononitriles like **5 a**.



1 **2** **3a**



4



5a

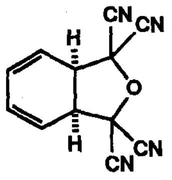
It is the aim of this paper to present the results obtained with five monosubstituted benzenes (toluene, chlorobenzene, fluorobenzene, anisole, and nitrobenzene) in their reaction with *TCNEO*.

Results and Discussion

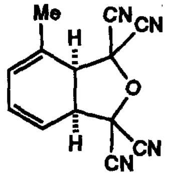
Structures **3a**–**3h** represent the eight monoadducts either isolated or postulated as intermediates.

Due to the facile ring opening in arylmalononitriles **5**, the compositions of the mixtures are difficult to determine. The qualitative results we obtained can be summarized as follows:

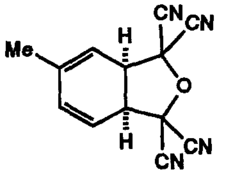
i) no adduct with a substituent at position 1 (or 6) was observed. These adducts are observed in the case of durene [7], where there is no other possibility (remark that the structure with two substituents at positions 1 and 6 is not formed),



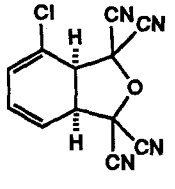
3a



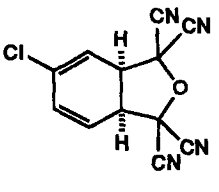
3b



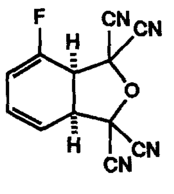
3c



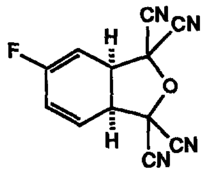
3d



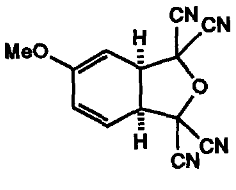
3e



3f



3g



3h

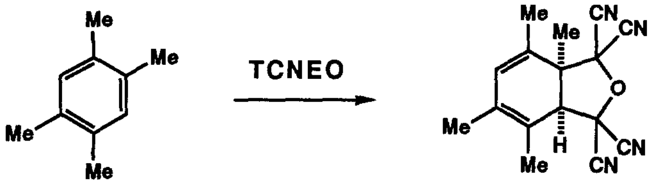
ii) with toluene, chlorobenzene, and fluorobenzene mixtures of two monoadducts are obtained, **3b**+**3c**, **3d**+**3e**, **3f**+**3g**, respectively,

iii) the monoadduct of chlorobenzene **3b** yields *m*-chlorophenylmalononitrile **5d** by spontaneous ring opening,

iv) with anisole, the reaction proceeds faster than with the preceding compounds, but it does not stop at the monoadduct **3h**. The only observed products are the arylmalononitrile **5h** and its dimer **6**,

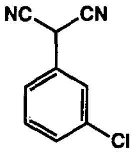
v) nitrobenzene does not react with *TCNEO*. If the reaction is carried out in benzene, **3a** was formed. In other solvents, like 1,2-dichloroethane, no reaction is observed.

These results can be rationalized qualitatively by means of the Sustmann-Fukui approach. *TCNEO* is a 1,3-dipole of class III according to the Sustmann classification [8, 9], since it has low energies HOMO (−9.0 eV) and LUMO (−1.1 eV) [10a]. Then, its reactivity towards dipolarophiles is controlled by the dipole LUMO, due to the fact that the difference in energy E_L (dipole)-E_H (dipolarophile) is generally lower than the difference E_H (dipole)-E_L (dipolarophile) [12, 13].

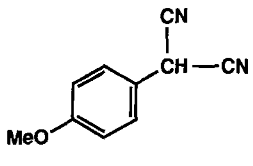


Electron-donating substituents, like methyl, and even more methoxy, will increase the reaction rate through an increase of the benzene HOMO and concomitant decrease of the difference E_{LUMO} (*TCNEO*)-E_{HOMO} (aromatic). The opposite effect is expected for nitrobenzene. For halogens, not only the HOMO but the next-HOMO (Ψ_3) of the aromatic compound must be considered, since both are very similar in energy. Taking into account both interactions, a somewhat reduced reactivity is expected for halobenzenes [10b].

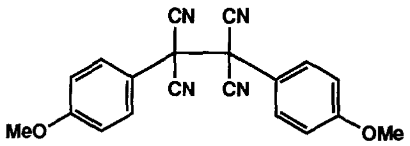
The fact that the reaction is selective only in the case of anisol and the fact that monoadduct **3h** is formed is related to the largest HOMO coefficient for carbon *para* [10c]. These coefficients for toluene [10d] and halobenzenes [10c], also explain why in these cases mixtures of isomers are obtained.



5d



5h



6

Finally, even if the carbon bearing the substituents has a large HOMO coefficient, it is not involved in the cycloaddition probably due to steric effects.

Structure of the Monoadducts

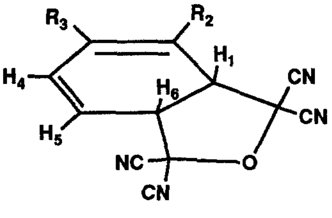
We have used ^{1}H and ^{13}C-NMR spectroscopy to determine the position of the substituent in compounds **3b**–**3g** (obviously, also to determine that **5h** is a *para*-substituted benzene).

^{1}H-NMR iterative analysis (PANIC program) of compounds **3a**, **3d**, and **3f**+**3g** (mixture) was carried out for 200 MHz spectra in *DMSO-d*$_6$. The results are gathered in Table 1.

The AA'BB'MM' system of **3a**, the ABCDE system of **3d** and the ABCDEX system of **3f** and **3g** were difficult to analyze. The diene nature appears both in ^{1}H-^{1}H and ^{1}H-^{19}F coupling constants, when $^3J_{23}$ or $^3J_{45}$ are compared with $^3J_{34}$ a ratio about 1.5 is found.

In the case of chlorobenzene adducts, only **3d** was isolated, the other isomer **3e** was characterized from the ^{1}H-NMR spectrum of the mixture but not analyzed.

Table 1. ^{1}H-NMR data of compounds **3a**, **3d**, and **3f**+**3g** (mixture)



3a : R_2 = H R_3 = H
3d : R_2 = Cl R_3 = H
3f : R_2 = F R_3 = H
3g : R_2 = H R_3 = F

	3a	3d	3f*	3g
δ H-1	4.548	4.940	5.024	4.722
δ H-2	6.018	—	—	5.714
δ H-3	6.454	6.782	6.319	—
δ H-4	6.454	6.315	6.292	6.497
δ H-5	6.018	5.995	5.846	6.260
δ H-6	4.548	4.781	4.849	4.667
J (H-1, H-2)	4.36	—	7.29 (F)	5.05
J (H-1, H-3)	-1.90	0.0	0.0	-5.12 (F)
J (H-1, H-4)	0.40	0.1	0.1	0.19
J (H-1, H-5)	-0.39	-0.1	-0.05	-0.29
J (H-1, H-6)	10.67	11.74	11.86	10.81
J (H-2, H-3)	9.64	—	12.35 (F)	11.60 (F)
J (H-2, H-4)	0.86	—	6.09 (F)	-2.17
J (H-2, H-5)	1.17	—	0.3 (F)	0.95
J (H-2, H-6)	-0.39	—	3.00 (F)	-0.36
J (H-3, H-4)	5.48	6.37	7.03	7.64 (F)
J (H-3, H-5)	0.86	0.0	-0.2	-5.31 (F)
J (H-3, H-6)	0.40	0.49	0.38	0.46 (F)
J (H-4, H-5)	9.64	9.82	9.98	10.20
J (H-4, H-6)	-1.90	-2.92	-0.98	-2.34
J (H-5, H-6)	4.36	3.00	3.11	3.98

* Poor agreement except for H-1

Owing to couplings with the methyl group, the mixture **3b**+**3c** is difficult to study by ^{1}H-NMR, but the 300 MHz spectrum is sufficient to identify both isomers (see experimental part).

Experimental Part

Melting points were determined on a Büchi 510 apparatus and are uncorrected. IR spectra were recorded for KBr discs on a Perkin-Elmer 781 spectrophotometer. ^{1}H-NMR spectra were recorded at 300 MHz on a Varian XL-300 or at 200 MHz on a Bruker AC-200 spectrometer while ^{13}C-NMR spectra were recorded at 20 MHz on a Varian FT-80 spectrometer using *TMS* as internal standard. Microanalyses were performed at Centro Nacional de Química Orgánica (CSIC, Madrid).

Tetracyanoethylene oxide (*TCNEO*) was prepared by the reaction of tetracyanoethylene with hydrogen peroxide [14].

Reaction of Benzene Derivatives with TCNEO, General Method

A suspension of 10 mmol of *TCNEO* in 15 ml of the corresponding anhydrous benzene derivative was refluxed during the time indicated below. The residue was filtered off, the filtrate evaporated to dryness in vacuo and the crude residue treated as indicated below.

Reaction with Toluene

Reaction time 18 hours. The crude product was sublimed (202°C/10^{-3} mbar) affording a 1 : 3 mixture of adducts **3b** and **3c**, m.p. 127–132°C, yield 69%. IR: 2250 and 2260 cm^{-1} (CN). $C_{13}H_8N_4O$ (236.2). Calc. C 66.10, H 3.42, N 23.73; found C 65.79, H 3.35, N 23.48.

3b, ^{1}H-NMR (*DMSO-d$_6$*) δ (ppm): 1.99 (s, 3 H, CH_3), 4.50 (m, 2 H, H-1 and H-6), 5.74 (ma, 1 H, H-5), 6.29 (m, 2 H, H-3 and H-4).

3c, ^{1}H-NMR (*DMSO-d$_6$*) δ (ppm): 1.89 (s, 3 H, CH_3), 4.48 (m, 2 H, H-1 and H-6), 5.69 (m, 1 H, H-2), 6.01 (dm, 1 H, H-4, ^3J=9.4 Hz), 6.33 (dd, 1 H, H-5, ^3J=9.4 Hz)

Reaction with Chlorobenzene

Reaction time 24 hours. The crude was sublimed (140°C/10^{-3} mbar) affording a 3 : 1 mixture of **3d** and **3e**, yield 36%. ^{1}H-NMR (*DMSO-d$_6$*) δ (ppm) **3d**: 4.85 (m, 2 H, H-1 and H-6); **3e**: 4.67 (m, 2 H, H-1 and H-6).IR **3d**: 2220 cm^{-1}; **3e**: 2190 cm^{-1} (CN).

Recrystallization of the mixture from isopropanol afforded 9% of pure **3d**, m.p. 169–170°C (subl. 160°C/10^{-3} mbar). ^{1}H-NMR (*DMSO-d$_6$*) (see Table 1). $C_{12}H_5N_4OCl$ (256.7). Calc. C 56.14, H 1.98, N 21.83; found 55.94, H 1.98, N 21.77.

Reaction with Fluorobenzene

Reaction time 18 hours. The crude was sublimed (100°C/10^{-2} mbar) affording a 1 : 1 mixture of adducts **3f** and **3g**, m.p. 99–109°C. IR: 2260 cm^{-1} (CN). ^{1}H-NMR (*DMSO-d$_6$*) (see Table 1).

Reaction with Anisole

Reaction time 4 hours. Addition of ethyl acetate to the crude product precipitated the *p*-methoxyphenylmalononitrile dimer **6**, yield 26%, m.p. 206–210°C (desc.) (ethanol). ^{1}H-NMR ($DCCl_3$) δ (ppm): 3.88 (s, 3 H, CH_3O), 6.99 and 7.43 (AA'BB', 4 H, aromatics); ^{13}C-NMR ($DCCl_3$) δ (ppm): 52.8 [$C(CN)_2$], 110.5 (CN), 114.8 (C-3), 116.0 (C-1), 129.8 (C-2), 162.4 (C-4). $C_{20}H_{14}N_4O_2$ (342.4). Calc. C 70.15, H 4.13, N 16.37; found C 69.71, H 4.37, N 16.27.

The mother liquors were evaporated to dryness and chromatographed on silica gel. Elution with hexane: toluene (2 : 1) afforded *p*-methoxyphenylmalononitrile **5h**, yield 2%, m.p. 60–62°C (hexane-toluene). ^{1}H-NMR ($DCCl_3$) δ (ppm): 3.83 (s, 3H, CH_3O), 5.00 (CHexo), 6.97 and 7.37 (AA'BB', 4H, aromatics); ^{13}C-NMR ($DCCl_3$) δ (ppm): 21.0 (CHexo), 55.9 (CH_3O), 111.1 (CN), 115.2 (C-1), 115.4 (C-3), 129.9 (C-2), 162.4 (C-4).

Acknowledgement

We express our gratitude to the DGICYT (Ministerio de Educación y Ciencia, Spain) for financial support (grant no. PB87-0064-C03-02).

References

[1] Tenant G. (1979) Imines, nitrones, nitriles and isocyanides. In: Barton D., Ollis W. D. (eds.) Comprehensive Organic Chemistry, Vol. 2, p. 561

[2] Recently [3] the reaction of a benzene ring as a dienophile in an intramolecular Diels-Alder reaction was described

[3] Saito K., Omura Y., Maekawa E., Gassman P. G. (1990) Bull. Chem. Soc. Jpn. **63**: 395

[4] Linn W. J., Benson R. E. (1965) J. Am. Chem. Soc. **87**: 3657

[5] Diez-Barra E., Pardo C., Arriau J., Fruchier A., Elguero J. (1985) Rev. Real Acad. Cienc. **79**: 303

[6] Rodriguez A., Monge A., Gutierrez-Puebla E. (1985) Acta Crystallogr. **C41**: 1128

[7] Brown P., Cookson R. C. (1968) Tetrahedron **24**: 2551

[8] Sutsmann R. (1971) Tetrahedron Lett. **46**: 2717; Sutsmann R., Trill H. (1972) Angew. Chem. Int, Ed. **11**: 838

[9] Sutsmann R. (1974) Pure Appl. Chem. **40**: 569

[10] a) Fleming I. (1976) Frontier Orbitals in Organic Reactions. Wiley, London, p. 149; data from [11]; b) ibid, pp. 60–62; c) ibid, p. 61; d) ibid, p. 55

[11] Houk K. N., Sims J., Duke R. E., Strozier R. W., George J. K. (1973) J. Am. Chem. Soc. **95**: 7287; Houk K. N., Sims J., Watts C. R., Luskus L. J. (1973) J. Am. Chem. Soc. **95**: 7301; see also: Bastide J., Ghandour N. E., Henri-Rousseau O. (1973) Bull. Soc. Chim. Fr.: 2290 and 2294; Bastide J., Henri-Rousseau O. (1974) Bull. Soc. Chim. Fr.: 1037

[12] Fukui K., Yonezawa T., Shingu H. (1952) J. Chem. Phys. **20**: 722; Fukui K., Yonezawa T., Nagata C., Shingu H. (1954) J. Chem. Phys. **22**: 1433

[13] Padwa A. (ed.) (1984) 1,3-Dipolar Cycloaddition Chemistry, Vol. 1. Wiley, New York, p. 108

[14] Linn W. J. (1969) Org. Synth. **49**: 103

Received April 16, 1991. Accepted May 15, 1991