

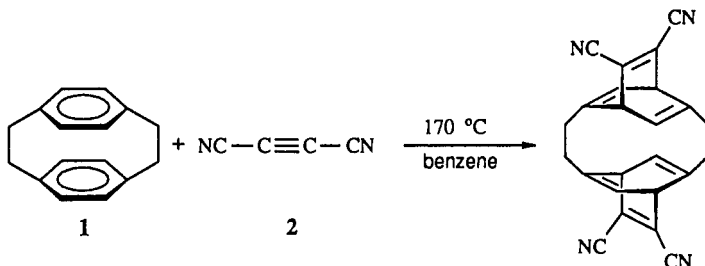
Cyanoalkynes: Magic wands for the preparation of novel aromatic compounds

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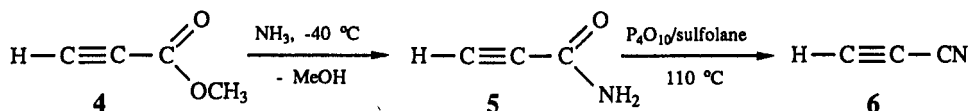
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Abstract: On heating, cyanoacetylene (**6**) dimerizes to 1,2-dicyanocyclobutadiene (**15**) which may be trapped by a variety of aromatic and heteroaromatic diene partners. In the former case novel derivatives of Nenitzescu's hydrocarbon result which by subsequent thermal and photochemical reactions are converted to numerous new polycyclic aromatics (*inter alia* basketenes, triquinacenes, bullvalenes). With various furanophanes (*e.g.* **23** and **24**) **6** provides ring-enlarged products like the cycloheptatrienophanes **39** and **41**. Dicyanoacetylene (**2**) and **23** react to give the first oxepinophane **69**.

In an investigation aimed at elucidating the application of simple aromatic hydrocarbons as diene components in the Diels-Alder addition Ciganek reported in 1967 that dicyanoacetylene (**2**) reacts with [2.2]paracyclophane (**1**) in benzene at 170 °C to provide a 2:1-addition product to which he assigned structure **3** (ref. 1):

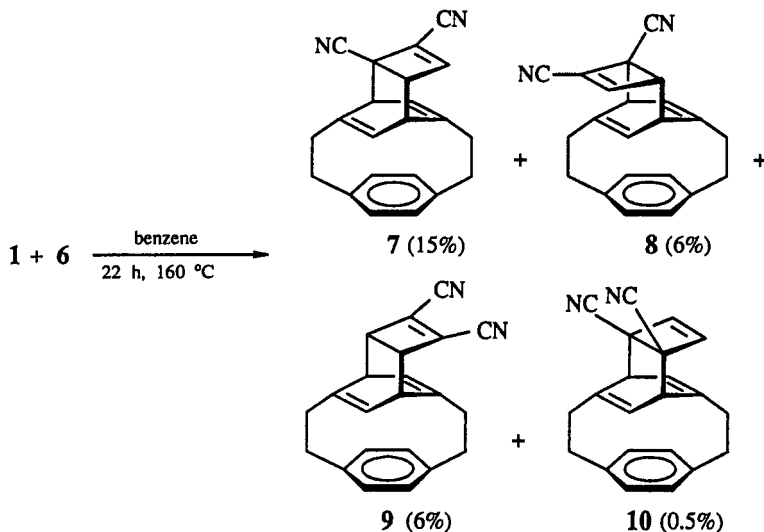


Adduct **3** may be regarded as the tetracyano derivative of a novel $C_{20}H_{20}$ -hydrocarbon which we have named "double barrelene" (ref. 2). As a novel and very short entry to the $C_{20}H_{20}$ -surface double barrelene could be of considerable importance and we have therefore started to prepare it. To reduce the number of defunctionalization steps it appeared desirable not to react **1** with **2** but to employ the less substituted monocyanoacetylene (**6**) as the dienophile. This highly reactive addend may be conveniently obtained from methyl propiolate (**4**) via the amide **5** by a route originally developed by Franck-Neumann (ref. 3) and optimized by us.

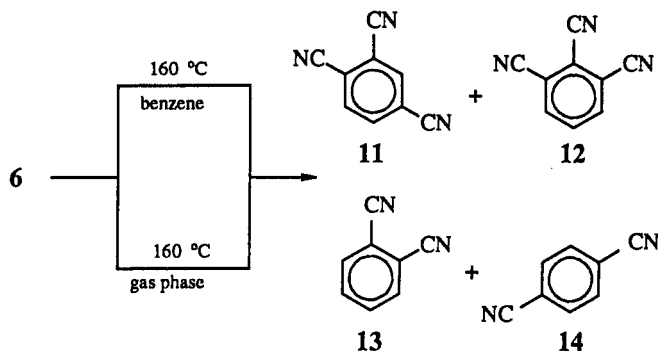


Cyanoacetylene can be safely handled in multi gram quantities, it is stable for extended periods of time in the refrigerator. However, since its toxicity is unknown we prefer to work with it only under a well-ventilated hood or employing high-vacuum techniques.

When 1 and 6 are heated under the reactions conditions shown in the scheme to our surprise none of the expected dicyano double barrelene isomer is produced. Rather, four 2:1-products, 7-10, of vastly different structural type are isolated as shown by x-ray structural analysis and nmr spectroscopy (ref. 4,5):

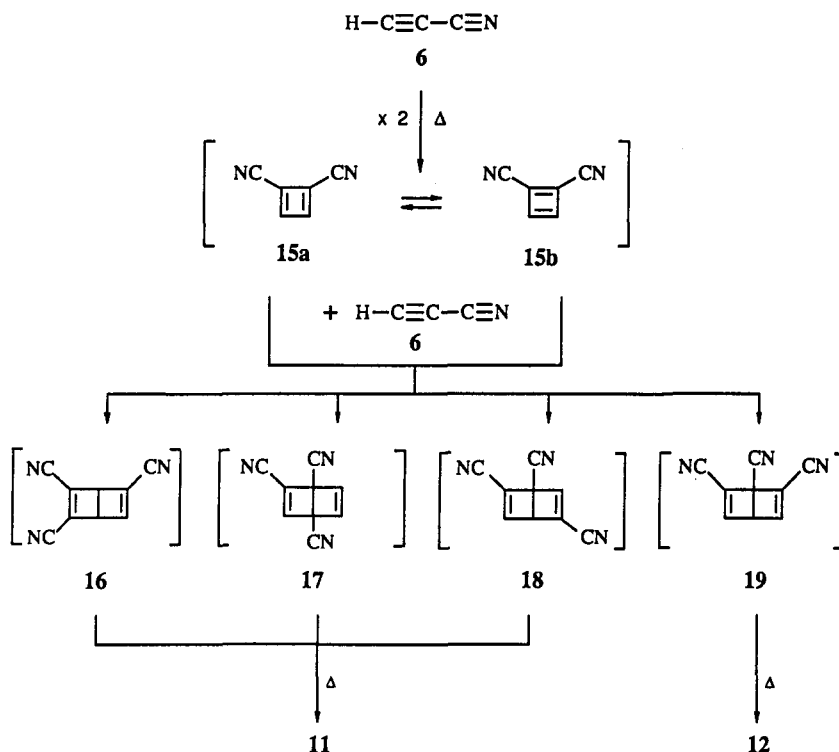


Besides 7-10 varying amounts of 1,2,4- (11) and 1,2,3-tricyanobenzene (12) are formed, and these as well as the ortho- and para-dicyanobenzenes 13 and 14, respectively, are the only products obtained if the addition is run in the absence of the trapping reagent 1 in solution or in the gas phase. In no case either 1,3,5-tricyanobenzene or 1,3-dicyanobenzene is produced:



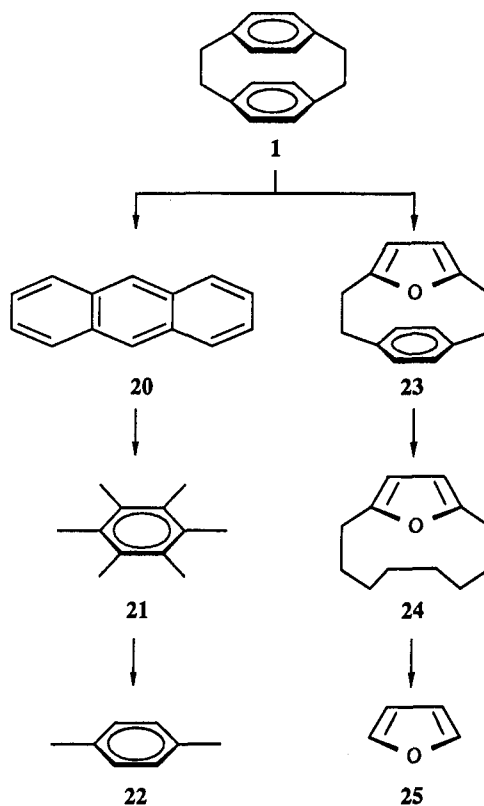
All these results may be rationalized if one assumes that 6 initially dimerizes to 1,2-dicyanocyclobutadiene (15). Since this compound may exist in either of two valence tautomers 15a and 15b, there are altogether three types of double bonds available for further cycloaddition steps. With [2.2]paracyclophane (1) the four 2:1-adducts 7-10 result, whereas the addition of another equivalent of 6 to 15a/15b results in the formation of four isomeric tricyano-dewarbenzenes, 16-19, which under the reaction conditions thermally isomerize to 11 and 12. As indicated by this scheme, no 1,3,5-tricyanobenzene can be produced by these routes (ref. 6). The formation of the isomeric dicyanobenzenes 13 and 14 may be explained analogously by postulating first the dimerization

of 15a/b followed by a sequence of ring-opening and retro-Diels-Alder cleavages:

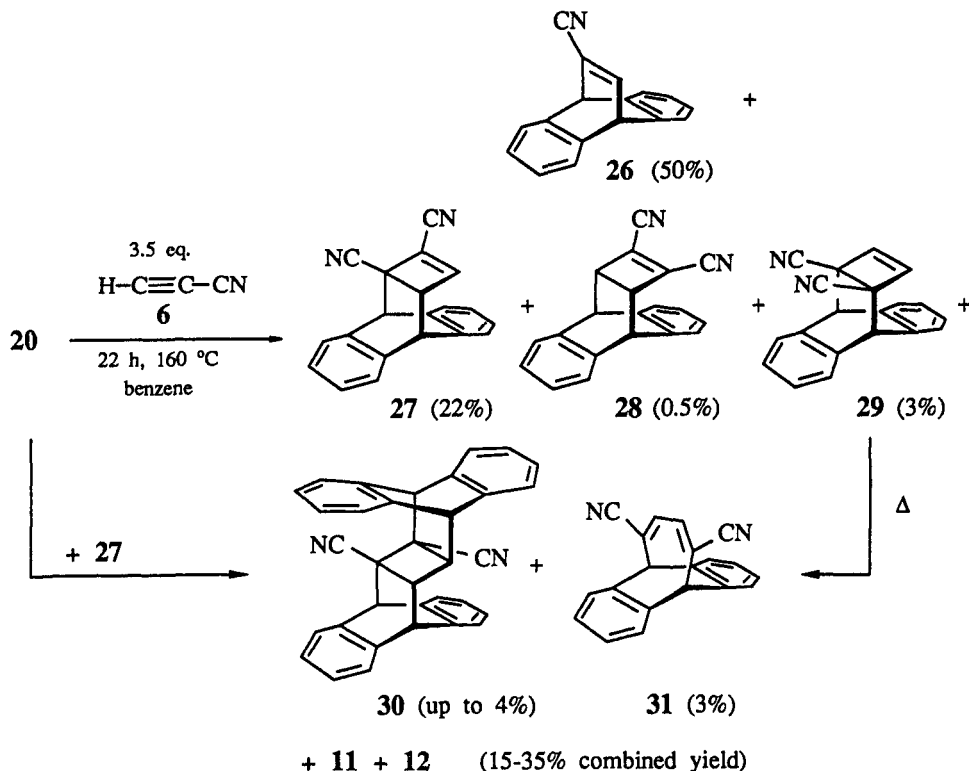


To test the concept of employing 6 as a cyclobutadiene equivalent we reacted the former with the following selection of aromatic and heteroaromatic compounds:

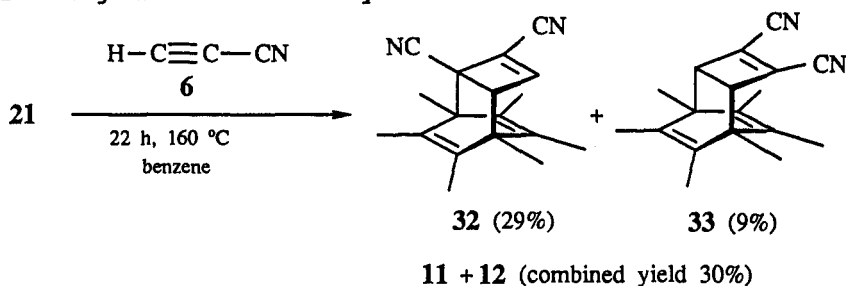
Starting from [2.2]paracyclophane (1, see above) we first replaced this reactive aromatic diene, which owes its reactivity to its high strain energy (ca. 30 kcal/mol; ref. 7) by anthracene (20), known, for a long time, to undergo [2+4] cycloaddition reactions at its 9 and 10 positions. The diene reactivity was then further reduced by substituting hexamethylbenzene (21) for 20, and the latter finally by para-xylene (22). Since benzene is employed as the solvent in most of these addition reactions its diene activity is evidently too low for adduct formation. In the heteroaromatic series the sequence [2.2]benzofuranophane (23), [8]furanophane (24) and finally furan (25) was traversed, again assuming that this is the order of decreasing reactivity.



When 20 is treated with a nearly fourfold excess of 6, a [2+4]cycloadduct, 26, is observed for the first time. But again sizeable amounts of the cyclobutadiene trapping products 27-29 are isolated. In fact, the butadiene-bridged anthracene adduct 31 must also be counted as one of the products of 15, since it was shown by independent control experiments that 29, when heated for extended periods of time under the reaction conditions, electrocyclically opens to 31. The interesting 2:2-product 30 is a cycloadduct of 20 to 27 as was shown again by control experiments. Note that 11 and 12 are again the only tricyanobenzenes produced.

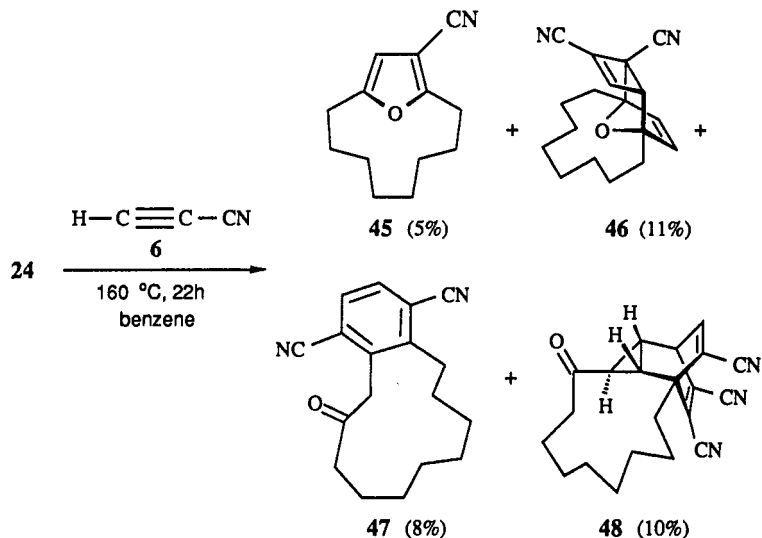


With hexamethylbenzene (21) 6 forms the two 2:1-adducts 32 and 33, respectively, derivatives of the so-called Neitzescu hydrocarbon. Although the yields are only fair this method of preparing derivatives of this interesting bird-cage molecule is particularly simple. Not surprisingly, the yield of the tricyanobenzenes 11 and 12 has increased: Since both the diene 21 and the dienophile 6 are competing for 15 it is obvious that the route leading to the dewarbenzene intermediates must increasingly be favored with decreasing diene reactivity.



This rationalization is also borne out by the last experiment in this series, the reaction of 6 and para-xylene (22). The Neitzescu adducts 34-36 are now only isolated as minor products or even traces - which nevertheless could be fully characterized

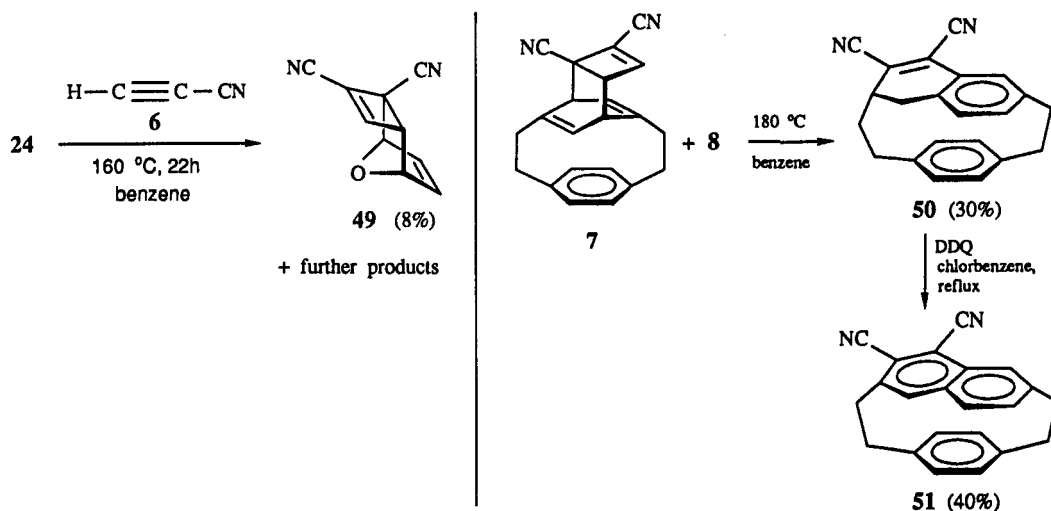
After the results of the reaction of 6 with 23 none of the adducts formed from [8](2,5)furanophane (24) and 6 comes as a real surprise.



Mononitrile 45 is most likely produced by a tandem Diels-Alder addition, Alder-Rickert cleavage process. Dinitrile 46 is the primary Diels-Alder adduct of 15a and 24, the "ring-enlarged" ketone 47 is again produced by a furan-ring destruction process, and trinitrile 48 is finally the Diels-Alder adduct of 6 and a norcaradiene intermediate.

The addition of 6 to furan (24) has been investigated in an exploratory manner only so far. Although several, as yet unknown adducts are also produced, the expected cyclobutadiene trapping product 49 is clearly the main product of the addition mixture.

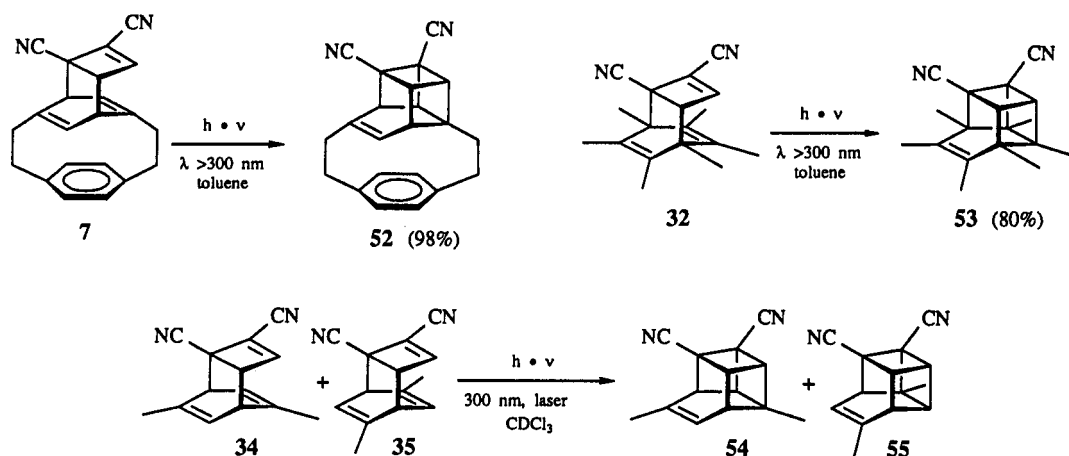
Since most of the adducts derived from 15 still possess double bonded systems of varying degrees of complexity these compounds offer themselves as starting materials for further transformations. In fact, as will be shown below, it is this possibility of carrying out subsequent transformations that make 6 - or 15 for that matter - such a valuable addition partner in synthesis. Among the reactions studied so far isomerizations, additions and attempts to remove the cyano function predominate.



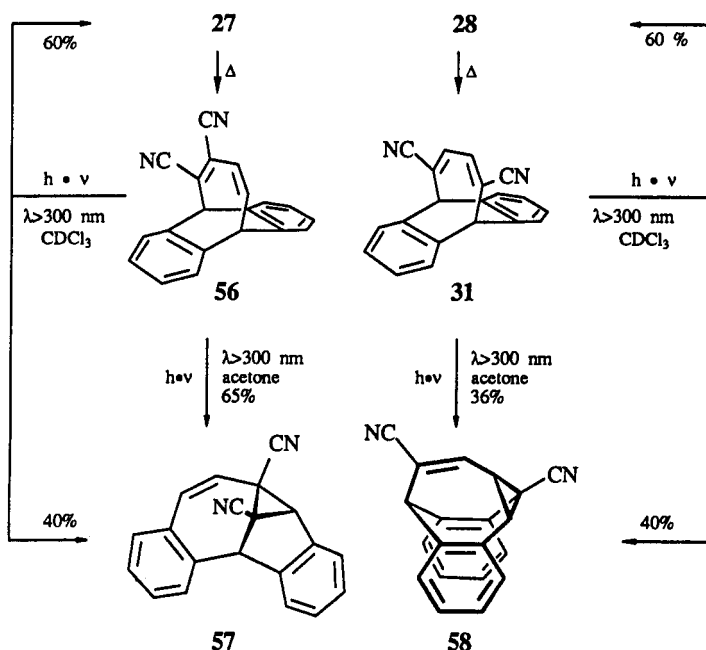
When a mixture of the adducts 7 and 8 is heated in benzene at 180 °C the dihydronaphthalenophane 50 is formed in fair yield. As most of the starting material in this deep-seated skeletal

rearrangement may be recovered, this process is preparatively acceptable. As expected, **50** may be dehydrogenated to the aromatic system **51**. Benzonaphthalenophanes have been prepared previously, notably by Haenel and Staab (ref. 10), but only in multi-step syntheses.

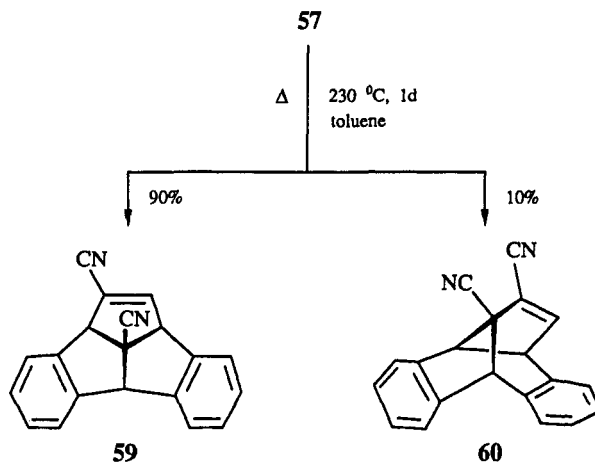
Since all adducts derived from Nenitzescu's hydrocarbon contain two double bonds in close proximity the obvious possibility of a [2+2]photoaddition, which should lead to novel types of basketene derivatives, was investigated. As summarized in the scheme all experiments carried out so far were successful: **7** being converted into **52**, **32** into **53**, and a mixture of **34** and **35** into a photoisomerisate consisting out of **54** and **55**. In the latter case the double bond carrying the cyano group was selectively excited by laser irradiation (ref. 11).



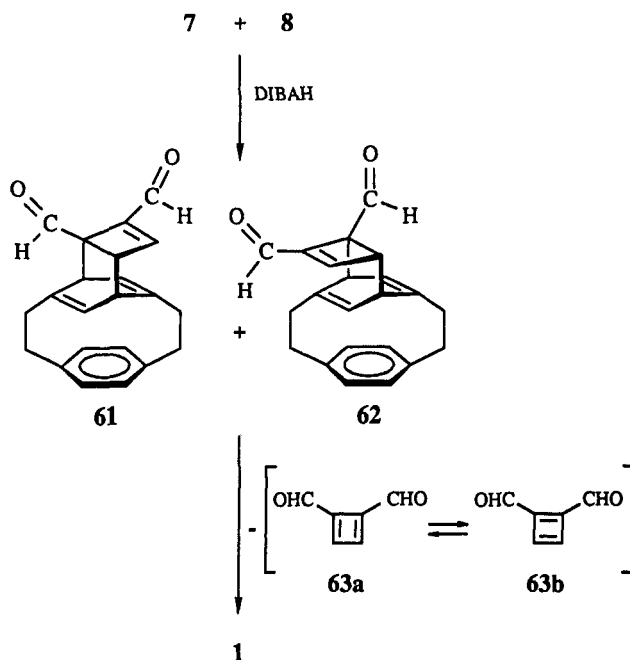
Mechanistically and preparatively very interesting transformations have been observed with the cycloadducts of 6/15 and anthracene (**20**). Thus thermal isomerization converts **27** and **28** to the dibenzoprebullvalenes **56** and **31**, respectively, and from the latter a photochemical entry to dibenzoisobullvalene, **57**, and dibenzobullvalene, **58**, is possible:



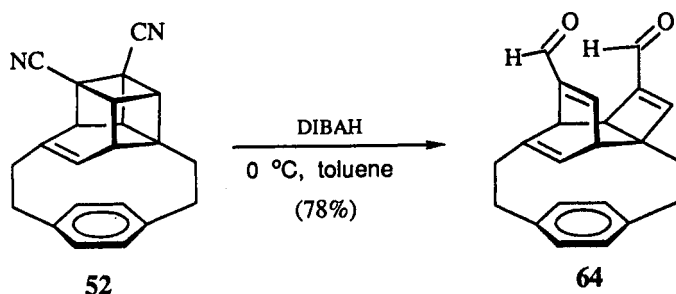
Since the former contains a vinylcyclopropane subunit it offers itself for yet another (thermal) transformation. Indeed, on heating to 230 °C 51 rearranges to the dibenzotriquinacene dinitrile 59 in excellent yield. Small amounts of the lumibullvalene derivative 60 are also produced.



Concerning the removal of the cyano substituents in the novel aromatic compounds obtained by the above processes, all attempts to change the functionality, while retaining the structural integrity of these substrates, have so far met with failure. The following examples are typical. Although the dinitriles 7 and 8 may be reduced to the bisaldehydes 61 and 62 in a good "raw" yield, on purification by column chromatography they are cleaved to paracyclophane (1), only 10% of 61 and 62 being recovered. It is quite likely that 1,2-bisformylcyclobutadiene 63a/b is formed in this apparent retro-Diels-Alder process, i.e. 61 and 62 hence offer themselves as cyclobutadiene transfer compounds.

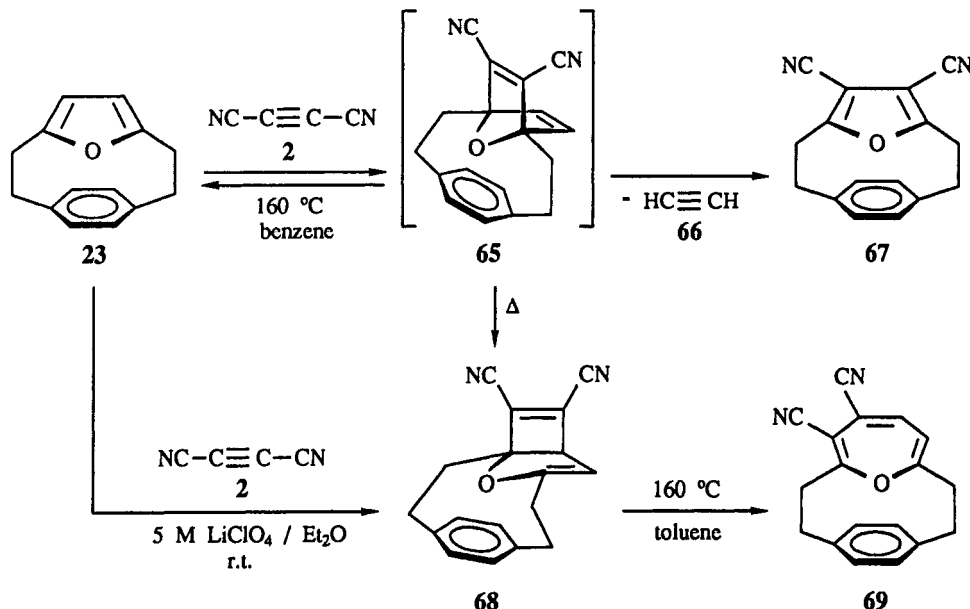


The strained nature of many of the cyanoacetylene bis-adducts is further illustrated by the basketene 52 which - as expected - is converted by DIBAH reduction at 0 °C to a bis-aldehyde, the latter, however, possesses the ring-opened structure 64.



Compared to cyanoacetylene (6) dicyanoacetylene (2) has been used much more often in cycloaddition reactions. As the following selection from our recent experiments with this highly reactive dienophile show, applications providing novel aromatic compounds of intriguing structural complexity still abound. Depending on the reaction conditions the furanophane 23, for example, may be induced to undergo an astonishing variety of cycloaddition reactions.

Under the usual thermal conditions 23 and 2 yield [2.2](2,5)furanoparacyclophandicarbonitrile 67. That this Diels-Alder/retro-Diels-Alder process involves the initial formation of 65 is made likely by the detection of this primary adduct in a high pressure experiment at 20 °C and 8 kbar (ref. 12).



The thermal reaction at normal pressure also provides traces of a deep-red compound shown to be 69 by nmr spectroscopy and x-ray structural analysis. Far superior yields of this first oxepinoparacyclophane, which very likely owes its color to a strong charge transfer interaction between its "aromatic" and its "antiaromatic" subunit, are realized when 23 and 2 are first reacted in a 5 M lithium perchlorate/diethylether solution. Now a [2+2]adduct, 68, may be isolated in 50% yield, and converted to 69 thermally (toluene, 160 °C) in 68% yield.

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11. We would like to thank Stefan Grimme and Olaf Palm for carrying out this photoisomerisation experiment.
12. F.-G. Klärner, H. Hopf, and B. Witulski, unpublished work.