Model Substances for Electro-optical and Dielectric Studies, Part I
Synthesis and Structure of 1,4-Bis(4′-dimethylamino-3′,5′-dicyanophenyl)bicyclo[2.2.2]octane

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A synthesis for a new 1,2,6-donor-acceptor-substituted chromophoric benzene system is given. This chromophore is incorporated in a bicyclo[2.2.2]octane system to build up model compounds for electro-optical and dielectrical studies. Furthermore a preparative convenient route to derivatives of 1,4-bis(diphenyl)bicyclo[2.2.2]octane is worked out. The structures of the new compounds are proven by spectroscopical means.

Introduction
For electro-optical studies was a need for the synthesis of model substances of the structure \( R_{DA}G_{DA} \). Where \( R_{DA} \) is an aromatic chromophore and \( G \) a rigid aliphatic frame [1, 2, 3]. With suitable structure elements \( G \) the interactions between the chromophores are negligible and therefore the electronic states corresponding to their long-wave absorption band are nearly twofold degenerated. These requirements are strong limitation factors for the choice of appropriate molecules. Choice and synthesis of molecules I are described below.

Results and Discussion
Choice and synthesis of the chromophore \( R_{DA} \)
Suitable as chromophores are molecules with strong donating-(D)- and accepting-(A)-groups in conjugation with an aromatic \( \pi \)-electron system. These molecules show an intensive long-wave absorption band and generally a strong change of the electric dipole moment in the excited state [4, 5]. These features and an at least approximate \( C_2 \) symmetry are the conditions desired for the evaluation of the data obtained by electro-optical measurements.

Principally, molecules of the following structures are suitable: For reasons of the donor strength, the symmetry, and to avoid hydrogen-bonding (both intra- and intermolecular) of the solute, only the dimethyl amino group fits as an appropriate donor. On the other hand, both the nitro and the cyano group are suitable as acceptors. For sterical reasons, especially in the case of structure 4, the more voluminous nitro group may prevent coplanarity of the donor group. Therefore the linear cyanogroup was preferred as an acceptor at synthesis. To obtain a molecule which owns at least approximately three mutually orthogonal twofold symmetry axes, substituents \( R_{DA} \) of the type 2 are outruled. In the case of structure 3, strong sterical hindrance of the acceptor with the frame \( G \) of 1 may prevent the synthesis. So structure 4 was chosen as optimal chromophore and the influence of \( G \) on the absorption spectrum of \( R_{DA} \) was studied for \( R = \text{methyl} \).

Scheme 1 shows the possible ways for the synthesis of the new molecules 4:

* Reprint requests to Dr. N. Detzer.

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We found the last step in the elegant synthesis of 11 by Friedel-Crafts reaction of 12 with benzene to have an 45% yield. Starting material 12 can be obtained either by a 5-step [21—23] (path 2a) or by a 9-step [24—27] synthesis (path 2b).

Experiments performing way 2a gave 11 only in an 1.3% overall yield. The essential step in the synthesis of 12 by path 2b is a high pressure [4+2]-cycloaddition reaction (p > 2000 bar). The lack of an adequate apparatus provided us finally to perform this very promising experiments. So we tried to synthesize 11 according to path 3 or path 4 starting with 15 after a decisive improvement of the synthesis of this compound (see Experimental Part).

Thereby path 4 affords a Diels-Alder reaction of 15 with ethylene, that leads directly to 20, the last intermediate in the synthesis of 11. Since ethylene is a poor dienophile, we expected drastic reaction conditions. All experiments failed*. The diene reaction (path 3) of 15 with maleic anhydride in mesitylene under an argon atmosphere leads to the dicarboxylic acid anhydride 16 in a 67% yield. Starting with 16 the two shown reaction pathways (16 → 17 → 19) or (16 → 18 → 19) lead to compound 19. For solubility reasons we choose the first pathway and obtained 19 in 80% yield.

As expected, the oxidative decarboxylation of the diacid 19 to olefine 20 was the critical step in this synthesis. From all methods [28—35] tested we found the oxidation by lead tetraacetate in a mixture of absolute DMSO/pyridine to be the method of choice. The yield of olefine 20 was 48%. Catalytic hydrogenation of 20 finally produces the key substance 11 in a 91% yield.

This new synthetic way* gave 11 in an overall yield of 14.4% related to starting material 13. With this eightfold improvement of the known synthesis we get

* The [4+2]-cycloaddition experiments with ethylene were carried out by Dr. F. B. Müller, high pressure laboratories of BASF (pressures up to 3000 bar). We wish to thank Dr. Müller for the performing of the experiments.

* In the meantime an analogous synthesis of 11 was published by Geivandor and Kosher [36] with an overall yield of 7.3%. The 50% lower yield compared with our synthesis is mainly caused by another method of the preparation of the diene 15.
the essential condition for a successful synthesis of the model substance 25.

Synthesis of 25 was accomplished according to Scheme 3.

Nitration of 11 with mixed acid in glacial acetic acid/acetic anhydride gives 21 in 49% yield. On the other hand, use of fuming nitric acid in glacial acetic acid gives only a 32% yield*. The isomers 26 (10%) and 27 (1%) could be isolated and identified.

Reduction of 21 was best done by catalytic hydrogenation over palladium coal in a mixture of dichloromethane/methanol/acetic acid; 22 was obtained in a 78% yield. Reduction of 21 with sodiumborohydride [37] fails because of a suitable solvent; classical reduction by tin chloride/hydrochloric acid [38] yielded at best 55% of 22. 22 was smoothly transformed to the tetrabromide 23 by reaction with bromine in acetic acid with iron as a catalyst. Methyl-

* Compound 21 was first synthesized by Zimmermann [18] in a 30% yield by nitration of 11 by aqueous mixed acid. Use of the given conditions, e.g. waterfree mixtures increases the yield considerably.

The expected high symmetry of the model compound 25 is especially documented by its $^1$H NMR spectrum. The bicyclo[2.2.2]octane derivatives 11 and 21 to 28 show a very characteristic fragmentation upon electron impact. A proposed fragmentation pattern is given in Scheme 4 and discussed below.
Scheme 4. Fragmentation pattern of the compounds 11 and 21 to 28.

Table I. Analytical data of the compounds 4 to 25.

<table>
<thead>
<tr>
<th>Compound</th>
<th>Yield [%] a</th>
<th>M.p. [°C] b</th>
<th>Molecular formula</th>
<th>Molar mass [g mole⁻¹]</th>
<th>Elementary analysis [%] C H N Br</th>
</tr>
</thead>
<tbody>
<tr>
<td>4a</td>
<td>91.0</td>
<td>141</td>
<td>C₁₀H₁₀N₃</td>
<td>171</td>
<td>Calcd 70.16 5.30 24.54</td>
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<td></td>
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<td></td>
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<td></td>
<td>Found 70.00 5.33 24.40</td>
</tr>
<tr>
<td>4b</td>
<td>82.0</td>
<td>172–173</td>
<td>C₁₁H₁₁N₃</td>
<td>185</td>
<td>Calcd 71.33 5.98 22.69</td>
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<td></td>
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<td>Found 71.12 6.08 22.53</td>
</tr>
<tr>
<td>6a</td>
<td>26.5</td>
<td>152</td>
<td>C₆H₆N₂O₂</td>
<td>173</td>
<td>Calcd 55.50 1.75 24.27</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Found 55.39 1.84 24.38</td>
</tr>
<tr>
<td>7b</td>
<td>15.0</td>
<td>179</td>
<td>C₆H₆N₂</td>
<td>157</td>
<td>Calcd 68.78 4.49 26.73</td>
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<td></td>
<td></td>
<td></td>
<td>Found 68.54 4.35 26.53</td>
</tr>
<tr>
<td>11</td>
<td>91.0</td>
<td>207</td>
<td>C₂₀H₂₂</td>
<td>262</td>
<td>Calcd 91.55 8.45</td>
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<td></td>
<td>Found 91.54 8.52</td>
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<td>16</td>
<td>63.0</td>
<td>238–239</td>
<td>C₂₂H₂₄O₃</td>
<td>330</td>
<td>Calcd 79.98 5.49</td>
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<td>Found 79.89 5.44</td>
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<td>17</td>
<td>90.0</td>
<td>236</td>
<td>C₂₂H₂₄O₄</td>
<td>348</td>
<td>Calcd 75.84 5.79</td>
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<td>Found 75.99 5.65</td>
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<tr>
<td>18</td>
<td>90.0</td>
<td>222–223</td>
<td>C₂₂H₂₄O₃</td>
<td>332</td>
<td>Calcd 79.50 6.06</td>
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<td>Found 79.43 6.10</td>
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<td>19</td>
<td>88.7</td>
<td>222</td>
<td>C₂₂H₂₄O₄</td>
<td>350</td>
<td>Calcd 75.55 6.19</td>
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<td>Found 75.55 6.19</td>
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<td>20</td>
<td>48.0</td>
<td>160</td>
<td>C₂₀H₂₀</td>
<td>260</td>
<td>Calcd 92.26 7.74</td>
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<td>Found 92.26 7.63</td>
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<td>21</td>
<td>49.0</td>
<td>323–324</td>
<td>C₂₀H₂₆N₂O₄</td>
<td>352</td>
<td>Calcd 68.17 5.72 7.95</td>
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<td></td>
<td></td>
<td>Found 68.30 5.70 7.83</td>
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<tr>
<td>22</td>
<td>78.0</td>
<td>276–278</td>
<td>C₂₀H₂₆N₂</td>
<td>292</td>
<td>Calcd 82.15 8.27 9.58</td>
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<td>Found 82.26 8.41 9.63</td>
</tr>
<tr>
<td>23</td>
<td>41.0</td>
<td>313–315</td>
<td>C₂₀H₂₆Br₂N₂</td>
<td>608</td>
<td>Calcd 39.51 3.32 4.61 52.57</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Found 39.34 3.37 4.41 52.85</td>
</tr>
<tr>
<td>24</td>
<td>78.0</td>
<td>271–273</td>
<td>C₂₀H₂₆Br₂N₂</td>
<td>664</td>
<td>Calcd 43.40 4.25 4.22 48.13</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Found 43.28 4.21 4.21 48.38</td>
</tr>
<tr>
<td>25</td>
<td>60.0</td>
<td>322</td>
<td>C₂₀H₂₆N₆</td>
<td>448</td>
<td>Calcd 74.97 6.29 18.74</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Found 74.87 6.21 18.76</td>
</tr>
</tbody>
</table>

a After purification; b all melting points are corrected.
Electron impact causes the fission of the 1- or 4-C–C-bond in the bicyclooctane skeleton forming radical cation 29. Hydrogen shifting in 29 immediately leads to 30 having mainly two fragmentation possibilities.

Path A: In a Retro-Diels-Alder reaction [41] the fragments 31 \( [m/e = 1/2 (M^+ - 2)] \) and 32 \( [m/e = 1/2(M^+ + 2)] \) are formed. Both fragments can take the charge and are indicated therefore as intensive peaks in the mass spectrum.

### Table II. Spectroscopical data of the compounds 4 to 7 (see Scheme 1).

<table>
<thead>
<tr>
<th>Compound</th>
<th>IR (KBr) [cm(^{-1})]</th>
<th>(^1)H NMR (solvent) ( \delta ) [ppm]</th>
<th>(^13)C NMR (solvent) ( \delta ) [ppm]</th>
<th>MS (70 eV) ( m/e ) (int.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4a</td>
<td>3067, 3012 (=CH-arom.), 2924, 2889, 2809 (CH(_3)), 2222 (CN), 1587, 1560, 1510, 1426 (arom.), 1247, 1171, 1081, 973, 952, 794, 744 (trisubst. arom.)</td>
<td>((CD(_3))(_2)CO), 7.06–7.80 (m, 3H, arom.), 3.26 (s, 6H, CH(_3))</td>
<td>(CD(_3)(_2)CO), 156.94 (C(_7)), 139.2 (C(_7)), 120.15 (C(_7)), 117.42 (C(_7), C(_8)=CN), 105.6 (C(_2), C(_3)), 43.6 (C(_7), C(_9)=N(CH(_3))(_2))</td>
<td>171 (M(^+), 82), 170 (M(^-), 100), 156 (M(^-)–CH(_3), 95), 143 (M(^-)–HCN, 15), 129 (13), 128 (25), 127 (M(^-)–CH(_2), 14), 116 (M(^-)–CH=NH(_2), 14), 44 (CH(_3)=CH=NH(_2), 14), 42 (28)</td>
</tr>
<tr>
<td>4b</td>
<td>3003 (=CH-arom.), 2857, 2778 (CH(_3)), 2183 (CN), 1587, 1548, 1534, 1515 (arom.), 1495, 1488, 1453, 1429, 1410, 1342 (tert. arom. amin), 1236, 1178, 1136, 1070, 989, 887, 743 (trisubst. arom.)</td>
<td>(CD(_3)(_2)CO), 7.52 (s, 2H, CH(_3))</td>
<td>(CD(_3)(_2)CO), 155.44 (C(_7)), 139.39 (C(_7)), 130.94 (C(_7), C(_9)=CN), 117.49 (C(_7), C(_9)=CN), 106.51 (C(_7), C(_9)), 46.66 (C(_7), C(_9)=N(CH(_3))(_2)), 19.55 (C(_9), –CH(_3))</td>
<td>186 (M(^+)–CH(_2), 100), 168 (M(^-)–CH(_3), 100), 168 (M(^-)–CH(_2), 100), 168 (M(^-)–CH=NH(_2), 14), 44 (CH(_3)=CH=NH(_2), 14), 42 (28)</td>
</tr>
<tr>
<td>6a</td>
<td>3106, 3077 (=CH-arom.), 2232 (CN), 1605, 1529, 1449 (arom.), 1299, 1241, 1163 (1,2-subst. arom.), 952, 852, 826, 813, 774 (trisubst. arom.), 719 (NO(_2)), 684</td>
<td>(CD(_3)(_2)CO), 7.75–8.25 (m, 3H, AB(<em>2), ( J</em>{AB} = 6.7 \text{ Hz} ))</td>
<td>(CD(_3)(_2)CO), 156.3 (C(_7)), 139.0 (C(_7)), 134.2 (C(_7), C(_8)=CN), 113.8 (C(_7), C(_8)=CN), 110.4 (C(_2), C(_6))</td>
<td>174 (M(^+)–CH(_2), 10), 173 (M(^-)–CH(_3), 100), 143 (M(^-)–NO, 26), 127 (M(^-)–NO(_2), 34), 116 (16), 115 (M(^-)–NO–CO, 30), 101 (32), 100 (M(^-)–NO(_2)–HCN, 75), 99 (13), 88 (M(^-)–NO–CO–HCN, 12), 76 (C(_3)H(_4)), 2, 31), 75 (38), 64 (23), 63 (9), 61 (10), 58 (41), 55 (43), 54 (28)</td>
</tr>
<tr>
<td>7b</td>
<td>3412, 3332, 3226 (NH(_2)), 2967, 2924, 2857 (CH(_3)), 2208 (CN), 1653, 1634, 1587, 1570, 1541, 1497, 1437, 1397, 1387, 1290, 1250, 1212, 877, 807 (tetrasubst. arom.)</td>
<td>(CD(_3)(_2)CO), 7.43 (s, 3H, CH(_3))</td>
<td>(CD(_3)(_2)CO), 149.27 (C(_7)), 137.51 (C(_7)), 127.56 (C(_7)), 115.80 (C(_7), C(_8)=CN), 97.97 (C(_2), C(_6)), 19.68 (C(_9), –CH(_3))</td>
<td>157 (M(^+), 87), 156 (M(^-)–CH(_2), 100), 130 (M(^-)–HCN, 10), 129 (21), 102 (M(^-)–CH=NH(_2), 20), 76 (C(_3)H(_4)), 11, 52 (11), 51 (C(_4)H(_2)), 12)</td>
</tr>
</tbody>
</table>
### Table III. Spectroscopical data of the compounds 11 to 20 (see Scheme 2).

<table>
<thead>
<tr>
<th>Compound</th>
<th>IR (KBr) [cm⁻¹]</th>
<th>¹H NMR (solvent) δ [ppm]</th>
<th>¹³C NMR (solvent) δ [ppm]</th>
<th>MS (70 eV) m/e (int.) [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>11</td>
<td>3096, 3077, 3030 (=CH-arom.), 2863 (=CH₂-), 1600, 1493 (arom.), 1004, 758, 701 (monosubst. arom.)</td>
<td>(CDCl₃), 7.43–7.01 (m, 10H, arom.), 1.93 (s, 12H, CH₃)</td>
<td>(CDCl₃), 32.81 (C₂), 34.95 (C₁) , 125.55 (Cₓ, Cᵧ), 128.08 (Cₓ), 149.85 (Cₓ)</td>
<td>263 (M⁺+1⁺, 23), 262 (M⁺, 83), 233 (B, 14), 232 (7), 225 (12), 158 (20), 143 (11), 133 (14), 132 (A, 100), 130 (A, 99), 129 (43), 128 (17), 117 (48), 115 (40), 91 (C-H⁺, 46)</td>
</tr>
<tr>
<td>15</td>
<td>3058, 3040 (=CH-arom.), 2933, 2882, 2857 (=CH₂-), 1629 (C=C), 1592, 1570, 1495 (arom.), 745, 689 (monosubst. arom.)</td>
<td>(CDCl₃), 7.68–7.33 (m, 10H, arom.), 6.61 (s, 2H, CH=CH), 2.80 (s, 4H, CH₂)</td>
<td></td>
<td>233 (M⁺+1⁺, 18), 232 (M⁺, 100), 231 (M⁺-1⁺, 12), 230 (22), 225 (43), 217 (11), 215 (15), 202 (10), 177 (18), 154 (12), 153 (11), 152 (12), 141 (25), 131 (10), 128 (16), 115 (18), 91 (46)</td>
</tr>
<tr>
<td>16</td>
<td>3096, 3067, 3030 (=CH-arom.), 2874 (=CH₂-), 1862, 1845, 1835, 1776 (C=O), 1595, 1575, 1495 (arom.), 1214, 1193 (CO), 1005, 758, 703 (monosubst. arom.)</td>
<td>(CDCl₃), 7.60–7.10 (m, 10H, arom.), 6.93 (s, 2H, CH=CH cis), 4.10 (s, 2H, CH), 2.06 (s, 4H, CH₂)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>17</td>
<td>3000 (OH, very broad), 3096, 3058, 3030 (=CH-arom.), 2941, 2865 (=CH₂-), 1718 (C=O), 1595, 1494 (arom.), 1229, 1217 (CO), 1003, 756, 689 (monosubst. arom.)</td>
<td>(Me₂CO-d₆), 7.62–7.27 (m, 10H, arom.), 6.95 (s, 2H, CH=CH cis), 3.97 (s, 2H, CH), 2.18 (d, 2Hₐ), 1.40 (d, 2Hₐ)</td>
<td></td>
<td>230 (M⁺<em>-CO-CO₂, 45), 232 (M⁺</em>-MA, RETRO-DA, 100), 231 (20), 230 (M⁺*-CO-CO₂-C₄H₆, 67), 229 (10), 228 (14), 215 (11), 154 (12), 152 (11), 141 (18), 128 (13), 115 (25), 91 (33)</td>
</tr>
<tr>
<td>18</td>
<td>3058, 3030 (=CH-arom.), 2959, 2941, 2874 (=CH₂-), 1852, 1819, 1770 (C=O), 1595, 1572, 1493 (arom.), 1247, 1236, 1225, 1209 (CO), 1192, 1007, 758, 704 (monosubst. arom.)</td>
<td>(CDCl₃), 7.32 (m, 10H, arom.), 3.65 (s, 2H, CH), 2.20 (s, 8H, CH₂)</td>
<td>(CDCl₃), 25.92, 34.56 (Cₓ), 37.75 (Cₓ), 49.51 (Cₓ), 125.87 (Cₓ), 126.98 (Cₓ), 128.47 (Cₓ), 143.42 (Cₓ), 170.78 (Cₓ)</td>
<td>333 (M⁺+1⁺, 15), 332 (M⁺, 64), 286 (5), 260 (6), 234 (33), 233 (78), 232 (M⁺*-2H-MA, RETRO-DA, 100), 231 (15), 156 (11), 155 (11), 143 (21), 141 (17), 131 (13), 130 (91), 129 (34), 128 (21), 117 (17), 115 (33), 104 (15), 102 (12), 91 (64)</td>
</tr>
<tr>
<td>19</td>
<td>3000 (OH, very broad), 3096, 3058, 3030 (arom.), 2950, 2865, (=CH₂-), 1773, 1724 (C=O), 1597, 1577, 1493 (arom.), 1220 (CO), 1002, 751, 695 (monosubst. arom.)</td>
<td>(DMSO-d₆), 7.46–7.00 (m, 10H, arom.), 3.59 (s, 2H, CH), 2.26 (m, 8H, CH₂)</td>
<td></td>
<td>332 (M⁺*-H₂O, 4), 231 (21), 230 (A, 100), 229 (13), 228 (18), 227 (10), 226 (12), 202 (8), 115 (14)</td>
</tr>
<tr>
<td>20</td>
<td>3096, 3067, 3030 (=CH-arom.), 2959, 2915, 2865 (=CH₂-), 1600, 1577, 1493 (arom.), 1005, 759, 698 (monosubst. arom.)</td>
<td>(CDCl₃), 7.47–7.23 (m, 10H, arom.), 6.49 (s, 2H, CH), 2.16–1.60 (sym. m, 8H, CH₂)</td>
<td></td>
<td>261 (M⁺+1⁺, 9), 260 (M⁺, 42), 245 (2), 233 (20), 232 (A, 100), 231 (18), 215 (12), 156 (16), 143 (10), 141 (22), 128 (19), 115 (16), 91 (36)</td>
</tr>
</tbody>
</table>

*Assignments of fragments according to Scheme 4 are indicated as (A) and (B); RETRO-DIELS-ALDER-Reaction = RETRO-DA, maleic anhydride = MA; for numbering of protones and C-atoms see Scheme 2.*

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Table IV. Spectroscopical data of the compounds 21 to 28 (see Scheme 3).

<table>
<thead>
<tr>
<th>Compound</th>
<th>IR (KBr) [cm(^{-1})]</th>
<th>(^1)H NMR (solvent) [ppm]</th>
<th>(^1)C NMR (solvent) [ppm]</th>
<th>MS (70 eV) m/e (int.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>21</td>
<td>3096 (arom.), 2950, 2933, 2875 (–CH(_2)–), 1592, 1493 (arom.), 1508, 1351, 1345, 1100, 857 (1,4-disubst. arom.), 844, 755 (NO(_2))</td>
<td>(CDCl(<em>3)), 8.20 (4H, AB-type, J(</em>{AB} = 9) Hz), 7.54 (4H, AB-type, J(<em>{AB} = 9) Hz), 2.04 (s, broad, (\delta</em>{\text{H}} = 4) Hz, 12H, CH(_2))</td>
<td>353 (M(^+)), 17, 352 (M(^+)), 323 (B, 8), 203 (15), 178 (12), 177 (A, 100), 175 (A, 36), 159 (10), 158 (58), 141 (11), 130 (8), 129 (65), 128 (47), 127 (10), 116 (30), 115 (36), 91 (17)</td>
<td></td>
</tr>
<tr>
<td>22</td>
<td>3096, 3030 (=CH-arom.), 2941, 2924, 2857 (–CH(_2)–), 1629 (NH(_2)), 1511 (arom.), 1271, 1093, 813 (1,4-disubst. arom.), 757, 713</td>
<td>(DMSO-d(<em>6)), 7.00 (4H, AB-type, J(</em>{AB} = 8) Hz), 6.55 (4H, AB-type, J(_{AB} = 8) Hz), 4.75 (s, very broad, 4H, NH(<em>2)), 1.78 (s, broad, (\delta</em>{\text{H}} = 4) Hz, 12H, CH(_2))</td>
<td>293 (M(^+)), 10, 292 (M(^+)), 45, 263 (B, 2), 148 (10), 147 (A, 100), 146 (12), 145 (A, 49), 144 (18), 132 (19), 119 (13), 118 (10), 106 (16)</td>
<td></td>
</tr>
<tr>
<td>23</td>
<td>3472, 3378 (NH(_2)), 3086 (=CH-arom.), 2941, 2924, 2857 (–CH(_2)–), 1610 (NH(_2)), 1570, 1486, 1475 (arom.), 1222 (NH(_2)), 868, 621 (C–Br)</td>
<td>(CDCl(_3)), 7.33 (s, 4H, arom.), 4.42 (s, broad, 4H, NH(_2)), 1.85 (s, 12H, CH(_2))</td>
<td>612 (8), 611 (8), 610 (35), 608 (M(^+)), 52, 606 (38), 604 (10), 307 (37), 306 (10), 305 (A, 100), 304 (13), 303 (A, 77), 301 (20), 277 (12), 264 (20), 225 (11), 224 (10), 223 (13), 209 (10), 143 (54), 130 (45), 117 (10), 116 (12), 115 (18)</td>
<td></td>
</tr>
<tr>
<td>24</td>
<td>3100, 3067 (=CH-arom.), 2941, 2924, 2857 (–CH(_2)–), 2778 (CH(_3)), 1577, 1520, 1477 (arom.), 1222 (C–N), 861, 621 (C–Br)</td>
<td>(CDCl(_3)), 7.48 (s, 4H, arom.), 2.90 (s, 12H, CH(_3)), 1.90 (s, 12H, CH(_2))</td>
<td>668 (17), 667 (19), 666 (68), 665 (32), 664 (M(^+)), 100, 663 (27), 662 (69), 661 (11), 660 (18), 585 (10), 583 (10), 335 (18), 334 (11), 333 (A, 61), 332 (48), 331 (A, 81), 330 (27), 329 (15), 171 (11), 115 (13)</td>
<td></td>
</tr>
<tr>
<td>25</td>
<td>3058, 3030 (=CH-arom.), 2950, 2907, 2865 (–CH(_2)–), 2817 (CH(_3)), 2227 (CN), 1603, 1563, 1511 (arom.), 1250 (C–N), 877</td>
<td>(CDCl(_3)), 7.63 (s, 4H, arom.), 3.25 (s, 12H, CH(_3)), 1.92 (s, 12H, CH(_2))</td>
<td>449 (29), 448 (M(^+)), 148, 419 (B, 1), 226 (15), 225 (A, 100), 224 (23), 223 (A, 75), 222 (13), 210 (19), 209 (11), 208 (13), 196 (13), 184 (14)</td>
<td></td>
</tr>
<tr>
<td>26</td>
<td>3096, 3058 (=CH-arom.), 2950, 2933, 2875 (–CH(_2)–), 1592, 1493 (arom.), 1508, 1351, 1100, 857, 844 (1,4-disubst. arom.), 810, 756, 750 (NO(_2)), 685 (1,3-disubst. arom.)</td>
<td>(CDCl(<em>3)), 8.17 (2H, AB-type, J(</em>{AB} = 9) Hz), 7.61–7.10 (m, 6H, arom.), 2.04 (s, 12H, CH(_2))</td>
<td>503 (M(^+)), 44, 422 (6), 280 (13), 278 (40), 276 (27), 225 (13), 184 (11), 149 (11), 78 (100)</td>
<td></td>
</tr>
<tr>
<td>27</td>
<td>3096, 3058 (=CH-arom.), 2950, 2933, 2875 (–CH(_2)–), 1592, 1493 (arom.), 1508, 1351, 1110, 857 (1,4-disubst. arom.), 785 (1,2-disubst. arom.), 756, 750 (NO(_2))</td>
<td>(CDCl(_3)), 7.63 (s, broad, 3H, arom.), 7.46 (s, broad, 1H, arom.), 3.25 (s, 6H, CH(_3)), 3.01 (s, 6H, CH(_3)), 1.91 (s, 12H, CH(_2))</td>
<td>analogous mass spectrum compound 22</td>
<td></td>
</tr>
<tr>
<td>28</td>
<td>3086 (=CH-arom.), 2941, 2865, (–CH(_2)–), 2809 (CH(_3)), 2227 (CN), 1595, 1553, 1499 (arom.), 1250 (C–N), 878, 570 (C–Br)</td>
<td>(CDCl(_3)), 7.63 (s, broad, 3H, arom.), 7.46 (s, broad, 1H, arom.), 3.25 (s, 6H, CH(_3)), 3.01 (s, 6H, CH(_3)), 1.91 (s, 12H, CH(_2))</td>
<td>analogous mass spectrum compound 22</td>
<td></td>
</tr>
</tbody>
</table>

\(^a\) For numbering of protons and C-atoms see Scheme 3; \(^b\) assignments of fragments according to Scheme 4 are indicated as (A) and (B).
All above mentioned compounds, except the unsubstituted molecule 11 which does not preferably build one of the fragments, form preferably neutral fragment 31 so that these compounds show the most intensive mass peak at $m/e = 1/2 (M^+ + 2)$.

The intensity of the peak at $m/e = 1/2 (M^+-2)$ depends strongly on the substituents at the phenyl moiety and runs to 20–60% of the intensity of mass peak $m/e = 1/2 (M^+ + 2)$.

Path B: This fragmentation pathway obviously shares only to a less extent in the decomposition of fragment 30. However, it indicates the appearance of 30 and therefore is a strong support for the suggested fragmentation pattern.

**Experimental**

All reactions described below were carried out in an argon atmosphere (99.996%; OXISORB-apparatus Fa. Messer-Griesheim) in order to prevent autoxidation reactions of the amines, respectively in the case of organometallic intermediates other side reactions. The $^1$H and $^{13}$C NMR spectra were taken on a JEOL MH 254 and therefore is a strong support for the suggested fragmentation pattern.

**Benzenamine-2,6-dicyano-N,N-dimethyl (4a)**

A stirred mixture of 8.4 g (30 mmole) of 10a, 11.1 g (0.124 mole) Cu(I) cyanide, 100 ml dimethylformamide (abs.) and 8 ml pyridine (abs.) was heated to 140 °C over a 24 h period. The greenish yellow hot reaction mixture is poured into a vigorously stirred, icecooled solution of 50 ml sodiumcyanide in 500 ml water, 150 ml chloroform added and the stirring continued for 30 min. The chloroform layer is separated and the water phase extracted with chloroform. The combined chloroform-extract is washed with 5% sodiumcyanide solution and the solvent is removed in vacuo (traces of DMF required high vacuum application).

**Purification:**

1. LC: stat. phase: silica 60, act. III; mob. phase: chloroform (absolute). 2. Sublimation: 0.01 mm Hg; bath temperature: 90 °C.

**Benzenamine-2,6-dibromo-N,N-trimethyl (10b)**

This compound was prepared exactly by the same method described above at the preparation of 10a starting from 9b [14].

**Purification:** Fractionating of crude 10b by the method above [16]. The fraction of b.p. 0.05 mm Hg = 58.59 °C, $n^20 = 1.5842$ proved to be analytically pure. Yield: 85%. – Mass spectrum: 293 (M+, 86), 292 (M–1, 100), 198 (M–CH$_2$Br, 11), 132 (M–1–Br, 20), 91 (C$_2$H$_4^+$, 14), 65 (C$_2$H$_6^+$, 8), 44 (CH$_3$–CH=NH$_2^+$, 7). – $^1$H-NMR (CCl$_4$): 2.17 (s, 3H, –CH$_3$), 2.78 (s, 6H, –(CH$_3$)$_2$), 7.18 (s, 2H, arom.)/ppm.

**Benzenamine-2,6-dicyano-N,N-trimethyl (4b)**

14.65 g (40 mmole) 10b react with 17.9 g (0.2 mole) Cu(I) cyanide in a mixture of 150 ml
DMF (absolute) and 10 ml pyridine (absolute) in the manner described at the preparation of 4a to yield crude 4b.

Purification: 1. LC: stat. phase: silica 60, act. III; mob. Phase: chloroform (absolute). 2. Sublimation: 0.05 mm Hg; bath temperature: 100 °C.

_Benzene-1-nitro-2,6-dicyano (6a)_

1 g (4.8 mmole) 5a [6—11] was mixed with 20 g phosphorus pentoxide (moisture exclusion!) and heated in vacuo up to 160 °C for 1.5 h. The cold reaction mixture is powdered and extracted with dichloromethane in a Soxhlet apparatus. The extract is reduced to 20 ml and the crude product is precipitated by addition of ligroin 40/80.

Purification: LC: stat. Phase: silica 60, act. III; mob. phase: a) ligroin 40/80, b) ethyl acetate.

_Benzene-2,6-dicyano-4-methyl (7b)_

7b was prepared analogously to compound 4a by reaction of 6.28 g (40 mmole) 9b with 14.3 g (0.16 mole) Cu(I) cyanide in a mixture of 100 ml DMF (abs.) and 8 ml pyridine (abs.).

Purification: 1. LC: stat. phase: silica 60, act. III; mob. phase: chloroform (abs.)/ethyl acetate (abs.) (2:1). 2. Recrystallization: cyclohexane. 3. Sublimation: 0.05 mm Hg; bath temperature: 100 °C.

1,4-Diphenyl-cyclohexane-1,4-diol (14)

Because of the low solubility of 1,4-cyclohexanediol in ether the method described by E. Müller [42] is not suitable for a larger preparative scale.

In addition to the applied inert gas atmosphere (see above) all reagents must be carefully dried and the employed apparatus must be freed of any trace of adsorbed moisture by repeated heating (200 °C) in the argon stream. The ether is refluxed over LiAlH₄ for 3 h and directly distilled into the reaction vessel.

A stirred mixture of 565 ml of an ethereal solution of phenyllithium* (0.89 mole, standard measured acidoimetrically) and 500 ml ether was heated to gently boiling (bath temperature 50 °C). 24.8 g (0.22 mole) of 1,4-cyclohexanediol (Fa. Aldrich; recryst. from CC₄) were placed in a special solid extractor (250 ml content) and added by distillation of the ether into the extractor solving the 1,4-cyclohexanediol by additional heating (hot air gun) over a period of 5 h**. Thereby a colourless precipitation is formed. The reaction mixture is refluxed for another 30 min, cooled down and poured on ice. After acidifying with sulfuric acid (50%) the precipitate (26.4 g) is separated and the water phase extracted with ether. The ether extracts are washed with a sodium hydrogen carbonate solution (5%) and with water. After drying over anhydrous sodium sulfate the solvent was removed in vacuo. Hereby another fraction of 14 (13.8 g) was obtained.

Purification: Recrystallization: benzene m.p.: 169—174 °C, m.p. (Lit. [43]): 170—175 °C. Yield: 35.4 g (60%) (average from 25 experiments).

Product 14 is a mixture of stereoisomers [43]; it is directly used for the synthesis of 15.

1,4-Diphenyl-cyclohexa-1,3-diene (15)

A stirred mixture of 134.1 g 14 (0.5 mole) and 1000 ml hydrobromic acid (47%) is refluxed for a 4 h period. After cooling down the reaction mixture, the yellow solid is sucked off and washed several times with a 5% sodium hydrogen carbonate solution and water. It is dried with KOH as dessicant in vacuo.

Purification: Recrystallization: benzene/ethanol = 5:2 (v/v). Yield: 101.7 g (88%) (average from 5 experiments) (Lit. [44]: 50%); m.p.: 182 °C; m.p. (Lit. [44]): 179—180 °C.

Compound 15 cannot be proved for purity by TLC methods for it is dehydrogenized easily to p-terphenyl by all adsorbents. The 1H NMR spectra of 15 show however the absence of the isomeric 1,4-diene and of p-terphenyl corresponding to the literature [45]. The mother liquors contain about 10% of the 1,4-diphenyl-cyclohexa-1,4-diene [46] but no p-terphenyl.

1,4-Diphenyl-bicyclo[2.2.2]oct-2-ene-5,6-dicarbonic-acid-anhydride (16)

A stirred mixture of 23.2 g (0.1 mole) 15, 29.3 g (0.3 mole) maleic anhydride in 75 ml mesitylene are heated first to 140 °C (2 h) and then refluxed for another 4 h. After removing of the solvent, the crude product is digested with hot glacial acetic acid (70 °C), sucked off and dried over KOH***.

Purification: Recrystallization: acetic acid/water = 10:1 (v/v).

*** Geivandov and Koshev carried out an analogous reaction in the melt at 180—190 °C without further details. Our experiments show however that this variant is only valid up to 20 mmole quantities: in a larger scale the yield of 16 diminishes drastically.

* For handling of the filtrated solution of phenyllithium an apparatus consisting of a 100 ml burette, a 1000 ml reservoir, inert gas flushing and a connection to the reaction vessel was used.

** This method is necessary because of the mentioned low solubility of 1,4-cyclohexanediol in ether. The discontinuous operation would afford about 30 litres of ether for this quantity.
1,4-Diphenyl-bicyclo[2.2.2]oct-2-ene-5,6-dicarboxylic acid (17)

The stirred mixture of 33 g (0.1 mole) 16 and 400 ml of a 10% potassium hydroxide solution was heated to 90 °C for 2 h. After cooling down the reaction mixture was acidified with concentrated hydrochloric acid. The dicarboxylic acid 17 was filtered off, washed with water and dried over phosphorus pentoxide.

Purification: Recrystallization: benzene (2 x ).

1,4-Diphenyl-bicyclo[2.2.2]octane-2,3-dicarboxylic acid anhydride (18)

3.3 g 16 (10 mmole) are dissolved in 100 ml glacial acetic acid at 70 °C. 0.33 g palladium coal (10% Pd; Fa. Merck) added and hydrogenated in a micro-hydrogenation apparatus. After 2.5 h the catalyst was filtered off and the still hot reaction mixture was mixed with water to opaqueness. After cooling down the appeared precipitation was sucked off and dried over KOH.

Purification: Recrystallization: acetic acid/water = 5:1 (v/v).

Hydrolysis analogous to that at the synthesis of 16 yielded the dicarboxylic acid 19.

1,4-Diphenyl-bicyclo[2.2.2]octane-2,3-dicarboxylic acid (19)

The solution of 25 g 17 (72 mmole) in 250 ml absolute THF (freed from peroxides) was placed in a laboratory autoclave (Fa. Roth). 2.5 g palladium coal (10% Pd, Merck) added and hydrogenated at ambient temperature at a hydrogen pressure of 7.5 bar. After 2 h the reaction was completed, the catalyst was filtered off and the solvent removed in vacuo.

Purification: Recrystallization: methanol.

1,4-Diphenyl-bicyclo[2.2.2]octane (11)

a) Catalytic hydrogenation of 20.

A stirred mixture of a solution of 16 g (62 mmole) 20 in 320 ml absolute THF (freed from peroxides) and 0.8 g palladium coal (10% Pd, Fa. Merck) is hydrogenated (autoclave see above) at r.t. and a hydrogen pressure of 5 bar. After 2 h the hydrogen absorption is finished, the catalyst is filtered off and the solvent removed in vacuo.

Purification: Recrystallization: ethanol/benzene.

b) Friedel-Crafts reaction of 1,4-dichloro-bicyclo[2.2.2]octane (12).

A solution of 0.49 g (2.7 mmole) 12 [21—23] in 20 ml absolute benzene is dropped to a vigorously stirred suspension of 0.2 g powdered aluminium chloride in 5 ml of absolute benzene (moisture exclusion). The reaction mixture is refluxed for 5 h, cooled down and poured on a mixture of 50 ml concentrated hydrochloric acid and 50 g of ice. The water phase is extracted with benzene. The combined benzene extracts are washed with 5% sodium hydroxide solution and water and dried over anhydrous sodium sulfate. Removal of the solvent yields crude 11.

Purification: 1. LC: stat. phase: alumina, basic, act. I; mob. phase: chloroform (absolute). 2. Sublimation: 0.01 mm Hg; bath temperature: 110 °C. Yield: 0.32 g (45%).

The identity of the two products is proven by spectroscopic means and a mixed melting point.

1,4-Bis(4'-nitrophenv)bicyclo[2.2.2]octane (21)

a) To a stirred and external icecooled solution of 10.5 g (40 mmole) 11 in a mixture of 400 ml glacial acetic acid and 900 ml acetic anhydride mixed acid (prepared from 200 ml conc. nitric acid (d = 1.4 g cm⁻³) and 500 ml sulfuric acid (98%)) is dropped so, that the temperature of the reaction mixture does not exceed 25 °C. After stirring for another 12 h at r.t., the mixture is poured on ice and the water phase extracted with chloroform. The combined chloroform phases are washed with 2 N sodium hydroxide solution, dried over calcium chloride and the solvent removed in vacuo.

Purification: Recrystallization: benzene (2×).
b) To a vigorously stirred suspension of 2.62 g (10 mmole) 11 in 60 ml glacial acetic acid, 10 ml (0.23 mole) of nitric acid (100%, $d = 1.5 \text{ g cm}^{-3}$) is added. The mixture is heated to 115 °C for 4 h. After cooling down it is poured on ice and worked up like method a).

Purification: Analogous method a). Yield: 1.12 g (32%).

Isolation of the by-products 26 and 27

The by-products can be isolated from crude material 21 by the following methods:

Per run 25 mg of the main fraction of the LC could be charged.

1,4-Bis(4'-aminophenyl)bicyclo[2.2.2]octane (22)

2.0 g (5.7 mmole) 21 are dissolved in a mixture of 280 ml dichloromethane, 120 ml methanol and 2.5 ml glacial acetic acid. After adding 0.3 g palladium coal (10% Pd, Fa. Merck), the stirred mixture is hydrogenated in an autoclave at r.t. for 2 h (hydrogen pressure: 8 bar). The catalyst is then filtered off, the organic phase reduced to 100 ml and treated with 3 N hydrochloric acid. Thereby 22 precipitates partially as hydrochloride. The collected precipitates are combined with the water phase and alcalized by addition of solid sodium hydroxide (external ice cooling). The mixture is then stirred and heated to 50 °C for another hour. After cooling down, the crude 22 is filtered off, washed with water and dried over potassium hydroxide.

Purification: Recrystallization: benzene.

1,4-Bis(4'-aminophenyl)bicyclo[2.2.2]octane (23)

To a stirred solution of 4.4 g (15 mmole) 22 in 80 ml glacial acetic acid, 20 mg of iron powder (“ferrum reductum”, Merck) are added. Then a solution of 12 g (75 mmole) bromine in 10 ml glacial acetic acid is dropped in and the reaction mixture stirred for another 4 h. The excess of bromine is blown off by a strong argon stream, 300 ml of water are added and the precipitate is sucked off. It is thoroughly washed with first glacial acetic acid, then 5% sodium disulfite solution. 2N potassium hydroxide solution and water and dried over KOH in vacuo.


1,4-Bis(4'-dimethylamino-3',5'-dibromophenyl)bicyclo[2.2.2]octane (24)

A stirred mixture of 4 g (6.6 mmole) 23, 40 ml formic acid (99%) and 3.95 g (0.13 mole) paraformaldehyde are heated to 95 °C. After repeated addition of 7 ml formic acid and 2 g (65 mmole) paraformaldehyde, the mixture is heated to 105 °C for another 2 h. The cold, homogeneous reaction mixture is then poured (ice cooling!) into an alkaline sodium disulfite solution (20% molar excess of sodium hydroxide and sodium disulfite related to formic acid and paraformaldehyde). The precipitate is isolated, washed with 10% sodium disulfite solution and water and dried over KOH in vacuo.


1,4-Bis(4'-dimethylamino-3',5'-dicyanophenyl)bicyclo[2.2.2]octane (25)

The vigorously stirred mixture of 1.24 g (1.9 mmole) 24, 1.34 g (15 mmole) Cu(I) cyanide in 35 ml DMF (absolute) and 2 ml pyridine (absolute) is first heated to 120 °C for 9 h, then refluxed for another 9 h. A solution of 0.92 g (19 mmole) sodium cyanide in 10 ml water is then added and the stirring at 90 °C continued for 3 h in addition. After cooling down, 100 ml of water and chloroform are added until the solid is dissolved. The organic phase is separated, the water phase is extracted with chloroform. The combined chloroform extracts are washed thoroughly with a 5% sodium cyanide solution, water and dried over calcium chloride. The solvent is removed and the crude 25 dried over KOH in vacuo.

Purification: 1. LC: stat. phase: silica 60, act. III; mob. phase: benzene. At the elution first the by product 28 and then 25 are isolated. 2. Recrystallization: cyclohexane/benzene. – Purity test: DC: stat. phase: alumina, silica; mob. phase: chloroform (absolute), toluene (absolute).

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