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Synthesis and Stereochemistry of Some New 1,3-Dioxane Derivatives of 1,4-Diacetylbenzene

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Summary. The synthesis and stereochemistry of new 1,3-dioxane derivatives of 1,4-diacetylbenzene are reported. The anancomeric structure of these compounds, the axial orientation of the aryl group for both 1,3-dioxane rings, and the *cis* and *trans* isomerism of some of these compounds is discussed considering data of conformational analysis, NMR investigations, and single crystal X-ray diffractometry.

Keywords. 1,3-Dioxanes; Conformation analysis; NMR; *cis-trans*-Isomers; X-Ray.

Introduction

Investigations of the stereochemistry of 1,3-dioxane derivatives bearing aryl groups at position 2 of the heterocycle revealed interesting structural aspects. The *A* values (free conformational enthalpy [1]) of aryl groups located in the acetal part of the 1,3-dioxane ring are high (*e.g.* $A_{Ph} = 13.04\,kJ/mol$ [2, 3]). The 2-aryl-1,3-dioxanes are anancomeric compounds with the characteristic conformational equilibrium between **I** and **II** shifted toward **I** with the aryl group in the equatorial position (Scheme 1 [4–8]). The conformational equilibrium of 2,2-disubstituted-1,3-dioxanes (**III**, **IV**; *e.g.* 2-phenyl-2-methyl-1,3-dioxanes, Scheme 1) is shifted toward the conformer exhibiting the aryl group in the axial position [2, 9, 10]. The axial preference of the phenyl group is predicted from the higher *A* value of the methyl group at position 2 ($A_{Me} = 16.63\,kJ/mol$ [2]) with respect to the *A* value of the phenyl group ($A_{Ph} = 13.04\,kJ/mol$ [2]) at the same position. Thermodynamic measurements of 2-methyl-2-phenyl-1,3-dioxanes showed a considerably higher preference of the methyl group for the equatorial position ($\Delta G^0_{\mathbf{III}-\mathbf{IV}} = 10.11\,kJ/mol$ [2]) than that calculated from the *A*-values of methyl and phenyl groups ($\Delta A = A_{Me} - A_{Ph} = 3.63\,kJ/mol$).

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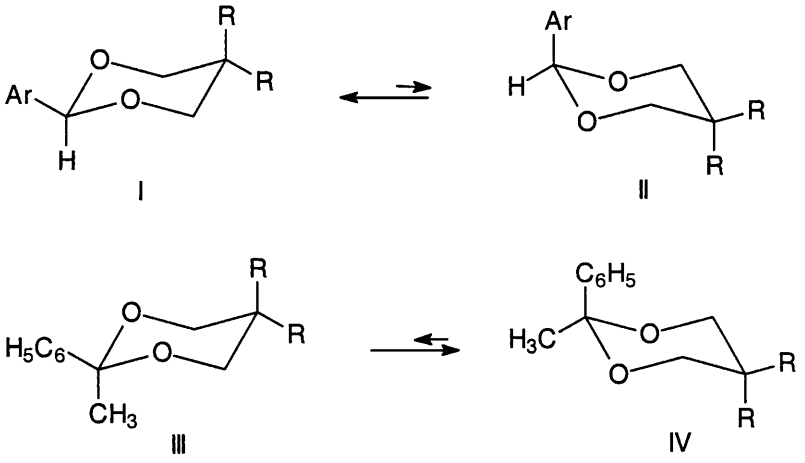
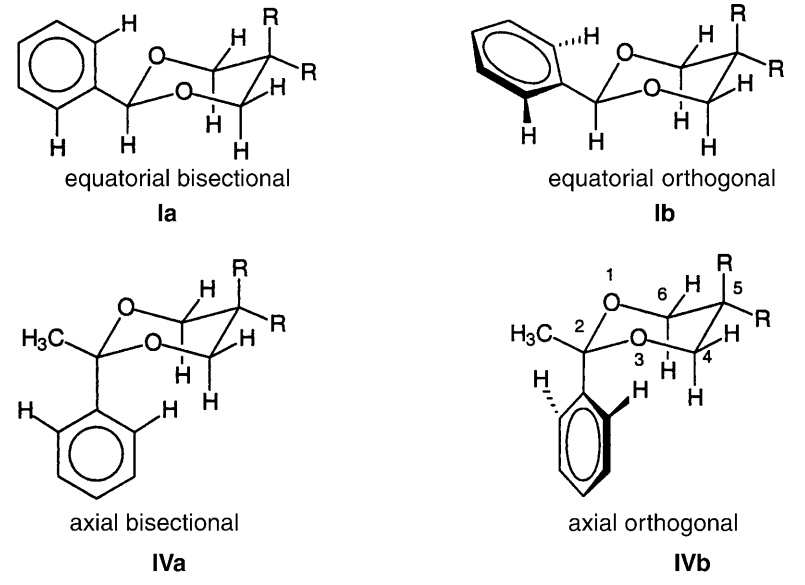


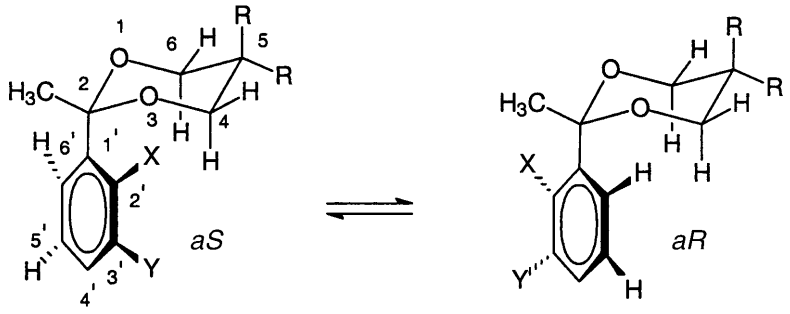
Scheme 1



Scheme 2

Studies on the rotameric behaviour of the aryl groups revealed a weak preference of the equatorial phenyl group for the bisectional orientation ($\mathbf{I}_a$) [11–13] and a high preference of the axial phenyl group for the orthogonal orienta tion ($\mathbf{IV}_b$, Scheme 2 [9, 10, 14–18]). This is consistent with the ^{1}H NMR shifts [9].

For some 2-aryl-2,5,5-trimethyl-1,3-dioxanes, the chemical shifts for the signals belonging to the equatorial methyl groups at C^5 are close to 0 ppm or even exhibit negative values [10]. The axial protons at positions 4 and 6 are located in the deshielding area of the orthogonal aryl groups, whereas the equatorial protons at these positions are in the shielding area. The differences between the chemical shifts of the equatorial and axial protons of these positions are considerably lower



Scheme 3

than in the compounds bearing the same aromatic substituent in equatorial orientation, and unusually in some of the cases the axial protons are more deshielded than the equatorial ones [6, 10]. The values of the shielding or deshielding influence of the orthogonal axial aromatic substituents are in agreement with the estimated values using the model of *Haigh* and *Mallion* [19]. Data on the barrier for the rotation of the aryl groups at C^2 were obtained from NMR investigations [5, 20].

Interesting results were obtained in the NMR investigations of compounds bearing nonsymmetric axial aryl groups (α-naphtyl, β-naphtyl, *o*-nitrophenyl, *m*-nitrophenyl). In these compounds, the bond between the aromatic substituent and the 1,3-dioxane ring is an axis of chirality (Scheme 3 [10]). The chirality of the molecule determines the diastereotopicity of the positions 4 and 6 of the 1,3-dioxane ring, which is consistent with the NMR data [10].

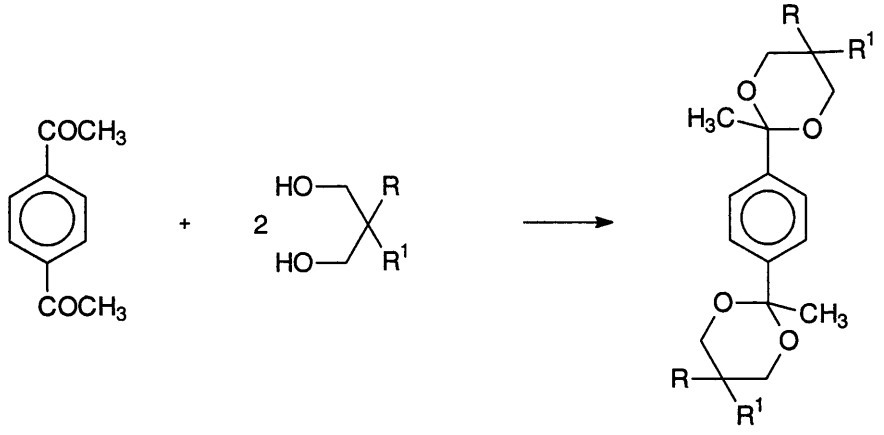
Investigations on the stereochemistry of compounds bearing two 1,3-dioxane rings on the same aromatic system obtained from benzenedicarboxaldehydes have revealed the equatorial orientation of the aromatic ring for both heterocycles [5–7]. The derivatives bearing different substituents in positions 5 and 5′ of the 1,3-dioxane rings show three diastereoisomers (*cis*,*cis*, *cis*,*trans*, and *trans*,*trans*) in agreement with the disposition of the groups with higher precedence in position 5 (5′) on the same side (*cis*) or on different sides (*trans*) with the aromatic group at position 2.

It was considered of interest to investigate the stereochemistry of 1,3-dioxane derivatives of 1,4-diacetylbenzene and to determine the conformational behaviour of the heterocycles, the orientation of the aromatic substituent in both heterocycles, and to identify and to characterize the possible *cis* and *trans* isomers.

Results and Discussion

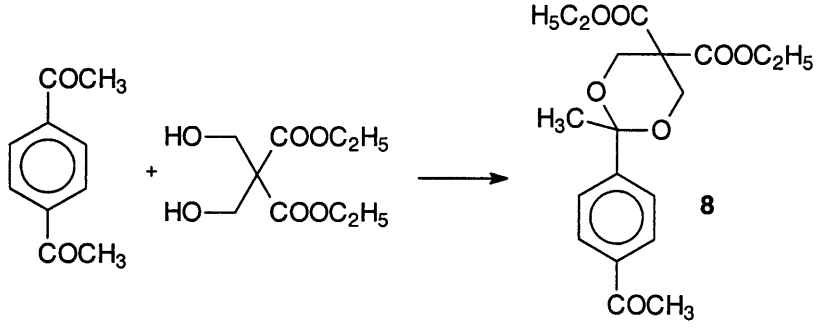
Compounds **1**–**7** exhibiting two 1,3-dioxane rings located on the same aromatic system were obtained by the condensation of 1,4-diacetylbenzene with several propanediols (Scheme 4).

In some cases (synthesis of **2** and **3**), the mono-1,3-dioxane derivatives were observed in the raw products; in the case of **3** it could be isolated by crystallization (**8**, Scheme 5).



1: $R = R^1 = H$
2: $R = R^1 = CH_3$
3: $R = R^1 = COOC_2H_5$
4: $R = H$, $R^1 = CH_3$
5: $R = H$, $R^1 = C_6H_5$
6: $R = CH_3$, $R^1 = C_2H_5$
7: $R = CH_3$, $R^1 = CH_2OH$

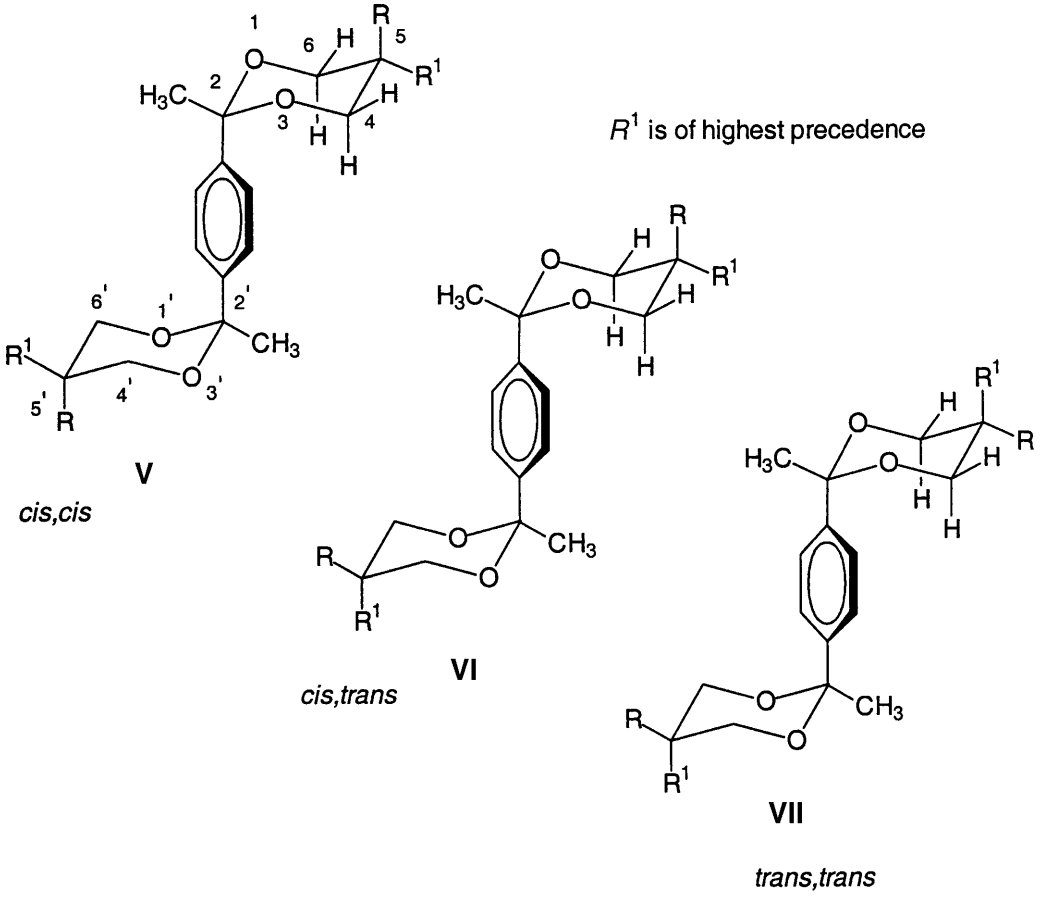
Scheme 4



Scheme 5

Compounds **1**–**3** are single configurational isomers, whereas **4**–**7** exhibit three isomers with the *cis* or *trans* disposition of the aryl group at position 2 and 2′ and of the substituents with highest precedence at positions 5 and 5′ (*cis*,*cis* (**V**), *cis*,*trans* (**VI**), and *trans*,*trans* (**VII**) Scheme 6). All investigated compounds exhibit anancomeric structures, and the axial orientation of the aromatic ring in both 1,3-dioxane rings is assumed.

The preference of the methyl groups at positions 2 and 2′ for the equatorial orientation and of the aromatic substituent for the axial one, as predicted by thermodynamic data for similar compounds [2], was confirmed by NMR investigations and by the molecular structure in the solid state as established for **2** by X-ray diffractometry.



Scheme 6

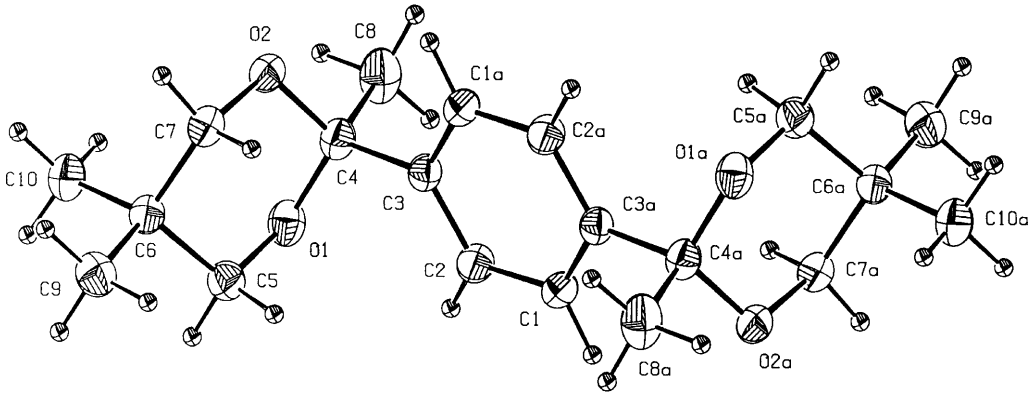


Fig. 1. ORTEP drawing of compound **2**

The ORTEP diagram (Fig. 1) of **2** shows a centrosymmetric structure with chair conformations for the heterocycles and the axial orientation of the aromatic substituent. The bond lengths, bond angles, and torsion angles in the heterocycles exhibit normal values. The aromatic substituent is orthogonal, the value of the

angle between the plane of the aromatic ring (C^1–C^2–C^3) and the best plane of the 1,3-dioxane ring (C^9–C^6–C^{10}) is close to 90° (93.3°).

NOE experiments performed on **2** in C_6D_6 solution confirmed the same arrangement of the substituents as in the solid state. Thus, irradiation of the singlet originating from the methyl groups at position 2 ($\delta = 1.69$ ppm) showed a small effect on the protons of the heterocycles (somewhat stronger on the equatorial ones; doublet, $\delta = 3.28$ ppm), whereas the irradiation of the signal of the aromatic protons (singlet, $\delta = 7.65$ ppm) caused a strong enhancement of the signals of the protons of the heterocycles, observed especially on the doublet pertaining to the axial ones ($\delta = 3.42$ ppm).

The NMR spectra of compounds **1**–**3** exhibited different signals for the axial and equatorial protons at positions 4 (4′) and 6 (6′) as well as for those of the axial and equatorial groups located at position 5 (5′) of the 1,3-dioxane rings. At the same time, the spectra display a unique set of signals for the protons and carbons of the heterocycles and only one singlet for the protons of the aromatic ring, showing that the two heterocycles are equivalent. For example, the ^{1}H NMR spectrum of **2** exhibits two doublets, one for the equatorial ($\delta_{eq} = 3.28$ ppm) and another one for the axial ($\delta_{ax} = 3.42$ ppm) protons at positions 4 (4′) and 6 (6′) and two singlets for the protons of the axial ($\delta_{ax} = 1.21$ ppm) and equatorial ($\delta_{eq} = 0.14$ ppm) methyl groups at position 5 (5′).

The strong shielding of the protons of the equatorial methyl groups ($\delta_{5\text{-(Me)}eq} = 0.14$ ppm; usually $\delta_{5\text{-(Me)}eq} > 0.4$–$0.5$ ppm) and of the equatorial protons at positions 4 (4′) and 6 (6′) ($\delta_{4eq,6eq} = 3.28$ ppm; in compounds obtained from aromatic aldehydes, $\delta_{4eq,6eq} > 4.4$–4.5 ppm) are due to the magnetic anisotropy of the aromatic ring that prefers the axial orthogonal orientation. Unusually, the signal of the equatorial protons at positions 4 (4′) and 6 (6′) is more shielded than the signal pertaining to the axial ones. A careful inspection of the NMR spectra reveals further splittings of the peaks of the signals of the protons at positions 4 (4′) and 6 (6′) due to long-range couplings between the axial and the equatorial protons of these positions. The values of the coupling constants were calculated from simulated spectra ($J_{4ax,6eq} = -10.5$; $J_{4(eq)ax,6(ax)eq} = -0.5$ and $J_{4eq,6eq} = -1.9$ Hz).

The main isomers (*cis*,*cis*, V; Scheme 6) of compounds **4** and **5** were isolated as single compounds. This isomer exhibits the aromatic ring in the axial orientation and the groups at positions 5 and 5′ in equatorial positions. The NMR spectra of these compounds exhibit a unique set of signals for the protons of the 1,3-dioxane rings and a singlet for the aromatic protons showing the equivalence of the two heterocycles. The equatorial orientation of the substituents at positions 5 and 5′ was deduced from the values of the coupling constants involving the protons at positions 5 and 5′. Thus, the ^{1}H NMR spectrum of the *cis*,*cis* isomer of **5** exhibits a triplet for the axial protons at positions 4 (4′) and 6 (6′) of the heterocycles (overlapped doublet of doublets with two close and large coupling constants; $J_{4(6)ax,5ax} = J_{4(6)eq,4(6)ax} = 11.6$ Hz; $\delta = 3.86$ ppm) and a doublet of doublets with a large coupling constant ($J_{4(6)eq,4(6)ax} = 11.6$ Hz) and a smaller one $J_{4(6)eq,4(6)ax} = 5.7$ Hz; $\delta = 3.99$ ppm) pertaining to the equatorial protons at the same positions. The protons at positions 5 (5′) showed an overlapped triplet of triplets ($\delta = 3.31$ ppm).

The *A*-values of methyl and ethyl groups at position 5 of the 1,3-dioxane ring are very close ($A_{Me} = 3.30–3.70\,kJ/mol$; $A_{Et} = 2.80–3.40\,kJ/mol$ [2]). Compound **6** was obtained as a mixture of the three possible isomers in a ratio close to **V**:**VI**:**VII** = 1:2:1 as it can be estimated from statistic rules. This result is supported by the ^1H NMR spectrum for the protons of the methyl groups at positions 2 and 2′ containing four signals with close intensities ($\delta = 1.72$, 1.725, 1.75, and 1.755 ppm). One signal belongs to isomer **V**, another one to isomer **VII**, and remaining two signals pertain to the ring with an axial methyl group (at position 5) and to the ring with an axial ethyl group (at position 5) of isomer **VI**. The differences of magnetic environments for the majority of similar protons in the three isomers are small and, the majority of the signals belonging to the three isomers are overlapped. However, two sets of signals with similar intensities were observed. One of these sets belongs to the protons of the rings (denoted with A, experimental part) exhibiting axial ethyl groups and the other one to the rings showing equatorial ethyl groups (denoted with B).

The A values of methyl ($A_{Me} = 3.30–3.70\,kJ/mol$ [2]) and hydroxymethyl groups ($A_{CH_2OH} = -0.70$ to $+0.50\,kJ/mol$ [2]) at the position 5 of the 1,3-dioxane ring are somewhat different, showing a preference of the hydroxymethyl group for the axial orientation. Thermodynamic measurements on 5-hydroxymethyl-5-methyl-1,3-dioxanes confirmed the preference of the hydroxymethyl group for the axial orientation ($\Delta G^0 = -2.30$ to $-4.30\,kJ/mol$ [2]). The crude product of **7** contained isomers **VII** (*trans*,*trans*) and **VI** (*cis*,*trans*) in a ratio of **VII**:**VI** = 1:1 and small amounts of isomer **V** (Scheme 6). A mixture of **VII** and **VI** in equimolar ratio was isolated from the crude product by crystallization. As in the case of **6**, the ^1H NMR spectrum of the mixture did not exhibit different signals for the two isomers but showed two sets of signals (ratio of intensities: 3:1) belonging to the rings (of the two isomers) with axial hydroxymethyl (major one, rings A) and to the rings bearing the hydroxymethyl group in equatorial orientation (rings B).

Experimental

^1H and ^{13}C NMR spectra were recorded at room temperature using C_6D_6, $CDCl_3$, or CD_3OD as solvents in 5 mm tubes on a Bruker AM 400 NMR spectrometer equipped with a dual ^{13}C–^1H probe operating at 400 MHz for protons and 100 MHz for carbon atoms. Melting points were measured with a Kleinfeld melting point apparatus and are uncorrected. The experimental conditions for the X-ray structure determination of compound **2** and details of the refinements are given in Table 1.

The structural data were deposited at the Cambridge Crystallographic Data Center, deposition number CCDC 177903.

Compounds **1**–**8** *(general procedure)*

Stoichiometric amounts of 1,3-diol (0.2 mol), diketone (0.1 mol), and catalytic amounts (0.1 g) of *p*-toluenesulfonic acid were dissolved in 200 cm^3 benzene. The mixture was refluxed, and H_2O was removed by a *Dean-Stark* trap. When 80% of the H_2O was separated the mixture was cooled to room temperature, and the catalyst was neutralized (stirring, 0.5 h) with 0.2 g sodium acetate. The reaction mixture was washed twice with 100 cm^3 H_2O. After drying with Na_2SO_4 the benzene was removed,

Table 1. Parameters of the crystallographic determinations[a] for compound **2**

Chemical formula	$C_{10}H_{15}O_2$
Formula weight	167.22
Crystal system/space group	monoclinic, P21/c
Crystal size/mm	$0.33 \times 0.30 \times 0.25$
Unit cell dimensions	
a/Å	10.181(2)
b/Å	6.502(2)
c/Å	14.854(4)
α/°	90
β/°	108.55(2)
γ/°	90
V/A^3	932.2(4)
Z	4
D_{calc}/Mg · m^{-3}	1.191
μ/mm^{-1}	0.081
$2\theta_{max}$/°	54
Scan mode	$\varpi/2\theta = 1$
t_{max}/s	60
Reflns collected/unique	2139/2027
Final R indices	$R_1 = 0.0396$, $wR_2 = 0.0996$
R indices	$R_1 = 0.0758$, $wR_2 = 0.1132$

[a] Collected on an automatic diffractometer CAD4 NONIUS with graphite monochromatized MoK_α radiation; the cell parameters were obtained by fitting a set of 25 high-θ reflections; after *Lorentz* and polarization corrections [21] the structure was solved with SIR-97 [22] which reveals the non hydrogen atoms of the structure; after anisotropic refinement, all hydrogene atoms were found with a *Fourier* difference synthesis; $w = 1/(\sigma^2(F^2) + (0.0951P)^2 + 0.1000P)$ where $P = (F_0^2 + 2F_c^2)/3$ with resulting $R = 0.039$, $R_w = 0.099$, and $S_w = 1.026$ (residual $\Delta\rho \leqslant 0.21$ eA^{-3})

and the compounds were purified by crystallization from EtOH or MeOH. Elemental analyses agreed favourably with the calculated values.

1,4-Bis-(2-methyl-1,3-dioxan-2-yl)-benzene (**1**; $C_{16}H_{22}O_4$)

Yield: 48%; white crystals; m.p.: 156–158°C; ^{1}H NMR (C_6D_6, δ, 400 MHz): 0.64 (m, 2H, 5-H$_{eq}$, 5′-H$_{eq}$), 1.73 (s, 6H, 2-CH$_3$-*eq*, 2′-CH$_3$-*eq*), 1.88 (m, overlapped peaks, 2H, 5-H$_{ax}$, 5′-H$_{ax}$), 3.60–3.66 (overlapped peaks, 8H, 4-H$_{eq}$, 4′-H$_{eq}$, 6-H$_{eq}$, 6′-H$_{eq}$, 4-H$_{ax}$, 4′-H$_{ax}$, 6-H$_{ax}$, 6′-H$_{ax}$), 7.63 (s, 4H, aromatic protons) ppm; ^{13}C NMR (C_6D_6, δ, 100 MHz): 20.31 (C^5, C$^{5'}$), 27.46 (2-CH$_3$-*eq*, 2′-CH$_3$-*eq*), 55.62 (C^4, C$^{4'}$, C^6, C$^{6'}$), 95.23 (C^2, C$^{2'}$), 122.20 (tertiary aromatic carbon atoms), 136.22 (quaternary aromatic carbon atoms) ppm.

1,4-Bis-(2,5,5-trimethyl-1,3-dioxan-2-yl)-benzene (**2**; $C_{20}H_{30}O_4$)

Yield: 53%; white crystals; m.p.: 204–205°C; ^{1}H NMR (C_6D_6, δ, 400 MHz): 0.14 (s, 6H, 5-CH$_3$-*eq*, 5′-CH$_3$-*eq*), 1.21 (s, 6H, 5-CH$_3$-*ax*, 5′-CH$_3$-*ax*), 1.69 (s, 6H, 2-CH$_3$-*eq*, 2′-CH$_3$-*eq*), 3.28 (d, 4H, $J = 10.5$ Hz, 4-H$_{eq}$, 4′-H$_{eq}$, 6-H$_{eq}$, 6′-H$_{eq}$), 3.42 (d, 4H, $J = 10.5$ Hz, 4-H$_{ax}$, 4′-H$_{ax}$, 6-H$_{ax}$, 6′-H$_{ax}$), 7.65 (s, 4H, aromatic protons) ppm; ^{13}C NMR (C_6D_6, δ, 100 MHz): 21.17 (5-CH$_3$-*eq*, 5′-CH$_3$-*eq*), 22.71 (5-CH$_3$-*ax*, 5′-CH$_3$-*ax*), 29.58 (C^5, C$^{5'}$) 32.21 (2-CH$_3$-*eq*, 2′-CH$_3$-*eq*), 71.38 (C^4, C$^{4'}$, C^6, C$^{6'}$), 100.17 (C^2, C$^{2'}$), 127.26 (tertiary aromatic carbon atoms), 141.33 (quaternary aromatic carbon atoms) ppm.

1,4-Bis-(2-methyl-5,5-diethyloxycarbonyl-1,3-dioxan-2-yl)-benzene (**3**; $C_{28}H_{38}O_{12}$)

Yield: 44%; white crystals; m.p.: 155–156°C; ^{1}H NMR (C_6D_6, δ, 400 MHz): 0.69 (t, 6H, $J = 7.1$ Hz, 5-COO–CH_2–CH_3-*eq*, 5′-COO–CH_2–CH_3-*eq*), 1.02 (t, 6H, $J = 7.1$ Hz, 5-COO–CH_2–CH_3-*ax*, 5′-COO–CH_2–CH_3-*ax*), 1.60 (s, 6H, 2-CH_3-*eq*, 2′-CH_3-*eq*), 3.62 (q, 4H, $J = 7.1$ Hz, 5-COO–CH_2–CH_3-*eq*, 5′-COO–CH_2–CH_3-*eq*), 4.12 (q, 4H, $J = 7.1$ Hz, 5-COO–CH_2–CH_3-*ax*, 5′-COO–CH_2–CH_3-*ax*), 4.20 (d, 4H, $J = 11.5$ Hz, 4-H_{ax}, 4′-H_{ax}, 6-H_{ax}, 6′-H_{ax}), 4.84 (d, 4H, $J = 11.5$ Hz, 4-H_{eq}, 4′-H_{eq}, 6-H_{eq}, 6′-H_{eq}), 7.51 (s, 4H, aromatic protons) ppm; ^{13}C NMR (C_6D_6, δ, 100 MHz): 8.14 (5-COO–CH_2–CH_3-*eq*, 5′-COO–CH_2–CH_3-*eq*), 8.55 (5-COO–CH_2–CH_3-*ax*, 5′-COO–CH_2–CH_3-*ax*), 26.14 (2-CH_3-*eq*, 2′-CH_3-*eq*), 48.26 (C^5, $C^{5'}$), 56.03 (5-COO–CH_2–CH_3-*eq*, 5′-COO–CH_2–CH_3-*eq*), 56.35 (5-COO–CH_2–CH_3-*ax*, 5′-COO–CH_2–CH_3-*ax*), 58.60 (C^4, $C^{4'}$, C^6, $C^{6'}$), 95.61 (C^2, $C^{2'}$), 121.45 (tertiary aromatic carbon atoms), 135.02 (quaternary aromatic carbon atoms), 161.49 (5-COO–CH_2–CH_3-*eq*, 5′-COO–CH_2–CH_3-*eq*), 162.52 (5-COO–CH_2–CH_3-*ax*, 5′-COO–CH_2–CH_3-*ax*) ppm.

1,4-Bis-(2,5-dimethyl-1,3-dioxan-2-yl)-benzene (**4**; $C_{18}H_{26}O_4$)

Yield: 48%; white crystals; m.p.: 200–201°C; ^{1}H NMR (C_6D_6, δ, 400 MHz): 0.01 (d, 6H, $J = 6.8$ Hz, 5-CH_3-*eq*, 5′-CH_3-*eq*), 1.71 (s, 6H, 2-CH_3-*eq*, 2′-CH_3-*eq*), 1.98 (m, overlapped ttq, 2H, $J = 6.8$, $J' = 4.6$ Hz, 5-H_{ax}, 5′-H_{ax}), 3.27 (t, overlapped dd, 4H, $J = J' = 11.4$ Hz, 4-H_{ax}, 4′-H_{ax}, 6-H_{ax}, 6′-H_{ax}), 3.63 (dd, 4H, $J = 11.4$, $J'' = 4.6$ Hz, 4-H_{eq}, 4′-H_{eq}, 6-H_{eq}, 6′-H_{eq}), 7.65 (s, 4H, aromatic protons) ppm; ^{13}C NMR (C_6D_6, δ, 100 MHz): 11.63 (5-CH_3-*eq*, 5′-CH_3-*eq*), 29.23 (C^5, $C^{5'}$), 32.73 (2-CH_3-*eq*, 2′-CH_3-*eq*), 67.40 (C^4, $C^{4'}$, C^6, $C^{6'}$), 100.11 (C^2, $C^{2'}$), 127.58 (tertiary aromatic carbon atoms), 141.41 (quaternary aromatic carbon atoms) ppm.

1,4-Bis-(2-methyl-5-phenyl-1,3-dioxan-2-yl)-benzene (**5**; $C_{28}H_{30}O_4$)

Yield: 51%; white crystals; m.p.: 223–224°C; ^{1}H NMR ($CDCl_3$, δ, 400 MHz): 1.61 (s, 6H, 2-CH_3-*eq*, 2′-CH_3-*eq*), 3.31 (heptet, overlapped tt, 2H, $J = 11.6$, $J' = 5.7$ Hz, 5-H_{ax}, 5′-H_{ax}), 3.86 (t, overlapped dd, 4H, $J = J' = 11.6$ Hz, 4-H_{ax}, 4′-H_{ax}, 6-H_{ax}, 6′-H_{ax}), 3.99 (dd, 4H, $J = 11.6$, $J'' = 5.7$ Hz, 4-H_{eq}, 4′-H_{eq}, 6-H_{eq}, 6′-H_{eq}), 6.99 (m, 4H, 5-C_6H_5, 5′-C_6H_5), 7.20 (m, 6H, 5-C_6H_5, 5′-C_6H_5), 7.52 (s, 4H,–C_6H_4–, aromatic protons) ppm; ^{13}C NMR ($CDCl_3$, δ, 100 MHz): 32.32, (2-CH_3-*eq*, 2′-CH_3-*eq*), 40.80 (C^5, $C^{5'}$) 66.33 (C^4, $C^{4'}$, C^6, $C^{6'}$), 100.37 (C^2, $C^{2'}$), 127.20, 127.34, 127.41 (5-C_6H_5, 5′-C_6H_5, tertiary aromatic carbon atoms), 128.57 (–C_6H_4–, tertiary aromatic carbon atoms), 138.06 (5-C_6H_5, quaternary aromatic carbon atoms), 140.20, (–C_6H_4–, quaternary aromatic carbon atoms) ppm.

1,4-Bis-(5-ethyl-2,5-dimethyl-1,3-dioxan-2-yl)-benzene (**6**; $C_{22}H_{34}O_4$)

Yield: 57%; white crystals; m.p.: 183–186°C; ^{1}H NMR (C_6D_6, δ, 400 MHz), (mixture of three diastereoisomers): 0.09, 0.10 (s, 6H, 5-CH_3-*eq*, 5′-CH_3-*eq*; rings A), 0.42 (t, 6H, $J = 6.6$ Hz, 5-CH_2–CH_3-*eq*, 5′-CH_2–CH_3-*eq*; rings B), 0.50 (q, 4H, $J = 6.6$ Hz, 5-CH_2–CH_3-*eq*, 5′-CH_2–CH_3-*eq*; rings B), 0.83 (t, 6H, $J = 7.5$ Hz, 5-CH_2–CH_3-*ax*, 5′-CH_2–CH_3-*ax*; rings A), 1.25 (s, 6H, 5-CH_3-*ax*, 5′-CH_3-*ax*; rings B), 1.72, 1.725, 1.75, 1.755 (s, 6H, 2-CH_3-*eq*, 2′-CH_3-*eq*; rings A and B), 1.81 (q, 4H, $J = 7.5$ Hz, 5-CH_2–CH_3-*ax*, 5′-CH_2–CH_3-*ax*; rings A), 3.39, 3.46 (d, 4H, $J = 11.0$ Hz, 4-H_{ax}, 4′-H_{ax}, 6-H_{ax}, 6′-H_{ax}; rings A and B), 3.42, 3.47 (d, 4H, $J = 11.0$ Hz, 4-H_{eq}, 4′-H_{eq}, 6-H_{eq}, 6′-H_{eq}; rings A and B), 7.71 (s, 4H, aromatic protons) ppm; ^{13}C NMR (C_6D_6, δ, 100 MHz): 1.28 (5-CH_2–CH_3-*eq*, 5′-CH_2–CH_3-*eq*; rings B), 2.63 (5-CH_2–CH_3-*ax*, 5′-CH_2–CH_3-*ax*; rings A), 12.36 (5-CH_3-*eq*, 5′-CH_3-*eq*; rings A), 13.90 (5-CH_3-*ax*, 5′-CH_3-*ax*; rings B), 21.03 (5-CH_2–CH_3-*eq*, 5′-CH_2–CH_3-*eq*; rings B), 22.89 (5-CH_2–CH_3-*ax*, 5′-CH_2–CH_3-*ax*; rings A), 27.03 (2-CH_3-*eq*, 2′-CH_3-*eq*; rings A), 64.28, 65.52 (C^4, $C^{4'}$, C^6, $C^{6'}$; rings A and B), 95.07 (C^2, $C^{2'}$; rings A and B), 122.13 (tertiary aromatic carbon atoms), 136.28 (quaternary aromatic carbon atoms) ppm.

1,4-Bis-(5-hydroxymethyl-2,5-dimethyl-1,3-dioxan-2-yl)-benzene (**7**; $C_{20}H_{30}O_6$)

Yield: 60%; white crystals; m.p.: 213–218°C; ^{1}H NMR (CD_3OD, δ, 400 MHz), (mixture of two diastereoisomers): 0.60 (s, 6H, 5-CH_3-*eq*, 5′-CH_3-*eq*; rings A), 1.24 (s, 6H, 5-CH_3-*ax*, 5′-CH_3-*ax*; rings B), 1.51, 1.60 (s, 6H, 2-CH_3-*eq*, 2′-CH_3-*eq*; rings B), 3.34 (d, 4H, $J = 5.7$ Hz, 5-C*H*$_2$–OH-*eq*, 5′-C*H*$_2$–OH-*eq*; rings B), 3.48 (d, 4H, $J = 11.2$ Hz, 4-H_{ax}, 4′-H_{ax}, 6-H_{ax}, 6′-H_{ax}; rings A), 3.59 (d, 4H, $J = 11.0$ Hz, 4-H_{ax}, 4′-H_{ax}, 6-H_{ax}, 6′-H_{ax}; rings B), 3.69 (d, 4H, $J = 11.2$ Hz, 4-H_{eq}, 4′-H_{eq}, 6-H_{eq}, 6′-H_{eq}; rings A), 3.70 (d, 4H, $J = 11.0$ Hz, 4-H_{eq}, 4′-H_{eq}, 6-H_{eq}, 6′-H_{eq}; rings B), 3.91 (d, 4H, $J = 5.7$ Hz, 5-C*H*$_2$–OH-*ax*, 5′-C*H*$_2$–OH-*ax*; rings A), 7.35 (s, 4H, aromatic protons) ppm; ^{13}C NMR (CD_3OD, δ, 100 MHz): 17.05 (5-CH_3-*eq*, 5′-CH_3-*eq*; rings A), 32.19 (2-CH_3-*eq*, 2′-CH_3-*eq*; rings A and B), 65.76 (5-*C*H$_2$–OH-*eq*, 5′-*C*H$_2$–OH-*eq*; rings B), 67.04 (5-*C*H$_2$–OH-*ax*, 5′-*C*H$_2$–OH-*ax*; rings A), 67.43 (C^4, $C^{4'}$, C^6, $C^{6'}$; rings A and B), 95.07 (C^2, $C^{2'}$; rings A and B), 126.76, 126.98 (tertiary aromatic carbon atoms) ppm.

2-Methyl-2-(p-acetylphenyl)-5,5-diethyloxycarbonyl-1,3-dioxane (**8**; $C_{19}H_{24}O_7$)

Yield: 11%; white crystals; m.p.: 73–74°C; ^{1}H NMR (C_6D_6, δ, 400 MHz): 0.69 (t, 3H, $J = 7.1$ Hz, 5-COO–CH_2–C*H*$_3$-*eq*), 0.99 (t, 3H, $J = 7.1$ Hz, 5-COO–CH_2–C*H*$_3$-*ax*), 1.55 (s, 3H, 2-CH_3-*eq*), 2.10 (s, 3H, 2-C_6H_4–CO–C*H*$_3$), 3.67 (q, 2H, $J = 7.1$ Hz, 5-COO–C*H*$_2$–CH_3-*eq*), 4.08 (d, 2H, $J = 10.9$ Hz, 4-H_{ax}, 6-H_{ax}), 4.11 (q, 2H, $J = 7.1$ Hz, 5-COO–C*H*$_2$–CH_3-*ax*), 4.80 (d, 2H, $J = 10.9$ Hz, 4-H_{eq}, 6-H_{eq}), 7.72 (d, 2H, $J = 6.6$ Hz, 3′-H, 5′-H, aromatic protons), 7.34 (d, 2H, $J = 6.6$ Hz, 2′-H, 6′-H, aromatic protons) ppm; ^{13}C NMR (C_6D_6, δ, 100 MHz): 13.36 (5-COO–CH_2–*C*H_3-*eq*), 13.70 (5-COO–CH_2–*C*H_3-*ax*), 25.86 (2-CH_3-*eq*), 31.06 (2-C_6H_4–CO–*C*H_3), 53.35 (C^5), 61.38 (5-COO–*C*H_2–CH_3-*eq*), 61.57 (5-COO–*C*H_2–CH_3-*ax*), 63.91 (C^4, C^6), 100.63 (C^2), 126.58 ($C^{2'}$, $C^{6'}$, aromatic carbon atoms), 128.89 ($C^{3'}$, $C^{5'}$, aromatic carbon atoms), 137.00 ($C^{1'}$, aromatic carbon atom), 144.78 ($C^{4'}$, aromatic carbon atom), 166.77 (5-*C*OO–CH_2–CH_3-*eq*), 167.57 (5-*C*OO–CH_2–CH_3-*ax*), 195.67 (2-C_6H_4–*C*O–CH_3) ppm.

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