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Diels-Alder Reactions of 2,4-Cyclohexadienones.* III.** Formation of Stereoisomers in the Dimerization of an *o*-Quinol Acetate

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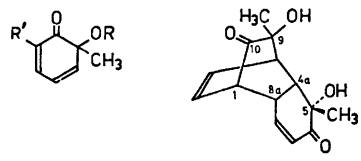
o-Quinol acetate *4*, which at 120 °C gives the *endo* Diels-Alder dimer *8*, at temperatures of 160 – 180 °C gives the C-5 stereoisomeric dimer *9* in addition to *8*. On heating at 160 – 180 °C *8* is also converted to *9*. When treated with ethanolic KOH, the diacetates *8* and *9* are hydrolyzed to give the stereoisomers *10* and *12*, respectively, the phenol *11* being formed as an additional product in both cases. The non-acetylated dimer *12* isomerizes at 160 – 180 °C to give dimer *10*. These results indicate that of the two acetylated dimers isomer *9* is thermodynamically more stable than isomer *8*, whereas the reverse seems to be the case for the corresponding non-acetylated dimers *12* and *10*, respectively. This behaviour can be understood by considering the bulkiness of the substituents at C-5 of the two types of dimers.

Acid hydrolysis of dimer diacetate *8* initially gives dimer *10*, which subsequently undergoes proton-catalyzed opening of the bicyclooctenone ring system to give phenol *13*. Similar treatment of the dimer diacetate *9* with acid effects, in addition to ester hydrolysis, aromatization of the unbridged ring followed by rearrangement of the bicyclooctenone system with the formation of phenol *16*.

In a number of papers the spontaneous Diels-Alder dimerization of 2,4-cyclohexadienones has been reported.[1–7] The reactions were found to proceed with a high degree of selectivity, only one of several conceivable dimerization products being obtained in each case. By using chemical, photochemical, and spectrometric methods,[4–8] as well as X-ray diffraction analysis,[9,10] all dimers so far investigated were shown to be *endo* forms with the same stereochemical and structural orientation.

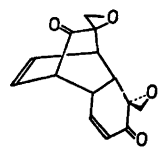
The stereochemical orientation at C-5 and C-9 was interpreted as being due to steric approach control [11] in the dimerization, the most bulky substituent being directed away from the reaction center. This is illustrated by formula *5* for the dimer of the parent *o*-quinol (*1*) (6-hydroxy-6-methyl-2,4-cyclohexadienone) and by formula *7* for the dimer of the corresponding spirooxirane (*6*). Analogous configurations have been proposed for dimers of 2,4-cyclohexadienones carrying halogen atoms instead of hydroxyl groups in the 6-position.[12,13]



1 R=R'=H
2 R=Ac ; R'=H
3 R=H ; R'=CH_3
4 R=Ac ; R'=CH_3

5

6



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Contrary to *o*-quinols (type *1*) and spiro-epoxydienones (type *6*), *o*-quinol acetates such as *2* and *4* are comparatively stable at room temperature, but dimerize when heated at

* Part XIII in the series "Periodate Oxidation of Phenols".

** Part II, see Ref. 7.

120 °C.[14,3] Hydrolysis of the dimeric *o*-quinol acetates gave the free dimers which were identical with those obtained by spontaneous dimerization of the corresponding *o*-quinols (*1* and *3*), and, *vice versa*, acetylation of the latter dimers gave the dimerization products of the corresponding *o*-quinol acetates *2* and *4*. Since the structures of the non-acetylated dimers (*5* and *10*) were known,[6,10] these interconversions also established the structures of the dimeric diacetates, the dimer of *o*-quinol acetate *4*, for instance, possessing structure *8*.

FORMATION OF STEREOISOMERS IN THE DIMERIZATION OF *o*-QUINOL ACETATE *4*

In earlier work [3] it has been observed that in the dimerization of *o*-quinol acetate *4* at 120 °C which mainly yields the *endo* dimer *8*, m.p. 159 – 160 °C, small amounts of an isomeric by-product of m.p. 182 – 184 °C are also formed. It has now been found that the yield of the higher-melting compound increases if the heating temperature is raised above 120 °C (see below). According to a recent X-ray investigation [15] the product of m.p. 182 – 184 °C is the C-5 stereoisomer *9* of dimer *8*. Dimer *8* is a Diels-Alder adduct of two sterically identical molecules of monomer *4* ($S+S$ and $R+R$ enantiomers, respectively). The structure of *9* indicates that it is formed by Diels-Adler addition of $S+R$ enantiomers and of $R+S$ enantiomers of the monomer.

Fig. 1 shows the influence of temperature and heating time on the weight proportions of monomer *4*, dimer *8* and dimer *9* in the reaction mixtures. The proportions of the latter isomer increases with increasing temperature, optimum yields being obtained within the range of 160 – 180 °C. In a preparative experiment *9* was obtained in a yield of 60 % after heating of monomer *4* for 2.5 h at 165 °C.

At higher temperatures dimer *9* undergoes retro Diels-Alder reaction, cleavage being nearly complete; heating of *9* for 30 min at 205 °C thus gave 84 % of monomer *4*. Under the same conditions, the earlier reported [3] thermal cleavage of dimer *8* similarly produced the monomer in a yield of 79 %.

As indicated in Fig. 1, the reaction mixtures obtained on heating of monomer *4* further contained an "unidentified product", which predominated after 6 hours' heating at 185 °C (Fig. 1 c). The dark viscous oil obtained under the last-mentioned conditions probably was a mixture and was not further investigated. It may be noted that brief heating of *o*-quinol acetates at 450 °C has been reported [16] to produce monoacetates of substituted hydroquinones and catechols.

Dimer *9* was also formed when dimer *8* was heated just above its melting point (2.5 h at 165 °C); this isomerization can be interpreted to be due to retro Diels-Alder reaction of *8*, followed by recombination of the enantiomers of the monomer.

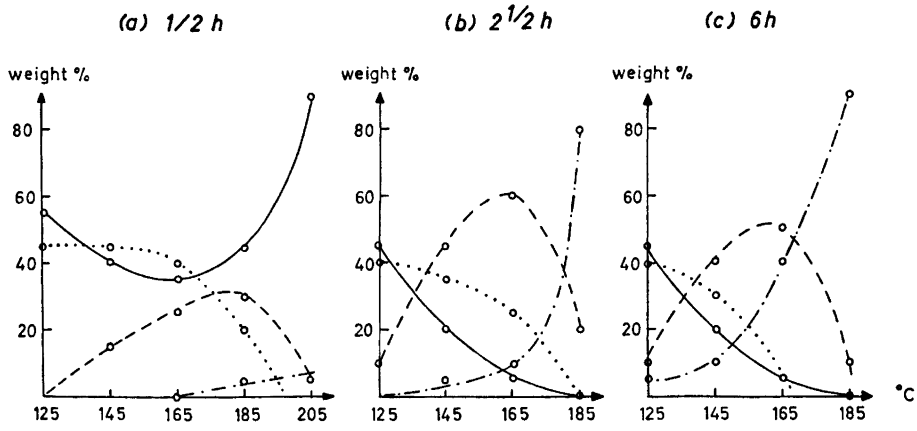


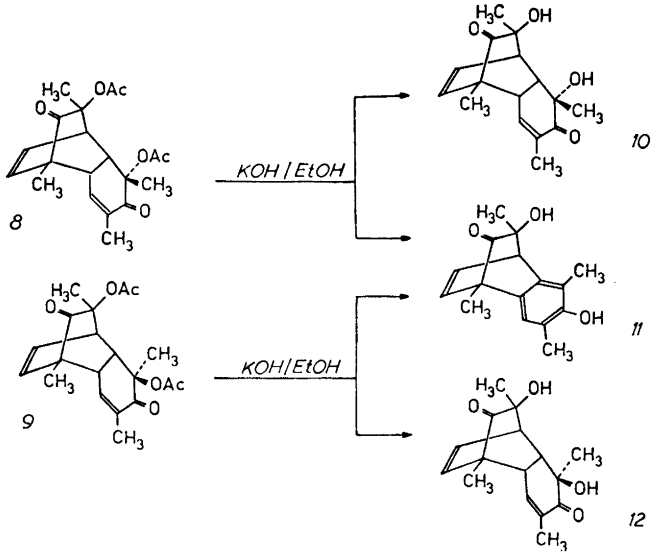
Fig. 1. Yields of products formed on heating of *o*-quinol acetate *4 vs.* temperature (*cf.* also Experimental). Compounds *4* (——), *8* (...), *9* (– – –) and unidentified product (–.–.–.).

These findings indicate that the sterically favoured configuration at C-5 is that present in compound *9*, this isomer being thermodynamically more stable than *8*. Evidently, the methyl group at C-5 is less bulky than the acetoxy group, although in the latter substituent free rotation around the C-5 – O linkage is possible.

The formation of isomer *8* from the monomeric *o*-quinol acetate (*4*) obviously is kinetically controlled; this may be connected with the *endo* oriented acetoxy group of the dienophile providing additional π-electrons to the reacting double bond system.

Contrary to the configuration of C-5 that of C-9 is retained in the heat isomerization of *8*. In the formation of both isomers the C-9 acetoxy group is oriented towards the reaction center and the C-9 methyl group away from it. This may possibly be understood on the basis of a proposal made by Williamson *et al.*,[17] according to which *syn-anti* isomerism of Diels-Alder reactions is governed not only by steric factors but also by electronic factors: if the dienophile is a dipole, electrostatic forces will direct the most polarizable bridge substituent into a position *anti* to the ethylene bridge. The configurations at C-9 of dimers *8* and *9* are in accord with this view, the methyl groups, which are the less polarizable substituents, heading towards the C-1, C-4 ethylene bridge.

The behaviour of dimer *9* on alkaline hydrolysis is noteworthy (Scheme 1). As reported earlier, treatment of isomer *8* with ethanolic potassium hydroxide gives the phenolic compound *11*, in addition to the expected hydrolysis product, *i.e.* the non-acetylated dimer *10*.[3] The two compounds were formed in about equal yields. The ease of the base-catalyzed elimination of acetic acid in compound *8* has been interpreted to be due to a favourable *trans* relationship of H-4a and AcO-5 with *anti* elimination taking place.[7] In the C-5 stereoisomer (dimer *9*) H-4a and AcO-5 are in *cis* position and elimination must consequently proceed by a *syn* mechanism. According to a recent monograph on elimination reactions,[18] *syn* elimination in 6-membered rings takes place much less readily than *anti* elimination. Alkaline hydrolysis of dimer *9* was therefore expected to give the non-acetylated dimer *12* in high yield. Surprisingly, however, phenol *11* was formed as the major reaction product (68 %) on treatment with ethanolic potassium hydroxide and only minor amounts (9 %) of dimer *12* were obtained. The ease of elimination in both *8* and *9* may be due to initial abstraction of a proton from C-8a to give enolates which readily aromatize by loosing HOAc.



Scheme 1.

THERMAL BEHAVIOUR OF DIMERS *10* AND *12*

For comparison with the thermal behaviour of the acetylated dimers *8* and *9*, that of the corresponding free dimers *10* and *12* was also investigated. Dimer *12* (m.p. 147 – 149 °C), when heated at temperatures between 160 and 180 °C, readily isomerized to compound *10*. For instance, after 1 h at 160 °C 83 % of isomer *10* were obtained and no starting material was detected in the reaction product. This result indicates that in the case of the non-acetylated dimers isomer *10* is thermodynamically more stable than isomer *12*, while the reverse is true for the corresponding diacetates (*8* and *9*, respectively), as shown by the experiments discussed above.

Apparently, the greater stability of dimer *10* as compared to dimer *12* is due to the fact that in the former isomer the smallest C-5 substituent, *i.e.* the OH group, is *endo* oriented. This, of course, indicates that steric approach control is essential in the dimerization of the monomeric *o*-quinol (*3*) which arises when dimer *12* is heated as described above.

It may also be mentioned that no formation of an *exo* form of a 2,4-cyclohexadienone dimer has hitherto been reported.

Dimer *10* proved to be unstable when heated at 210 °C, *i.e.* 15 °C above its melting point, an isomeric compound of m.p. 163 – 165 °C being formed as a major product. Dimer *12* on similar heat treatment gave the same compound, the reaction obviously passing via isomer *10*. Wessely *et al.*[19,20] reported that at 280 °C dimer *10* gives small amounts of 6-hydroxy-5,6-dimethyl-2,4-cyclohexadienone as the product of an acyloin rearrangement of the primarily formed isomer *3*. It was recently found in this laboratory that a major product of the thermolysis at 280 °C is the above-mentioned compound of m.p. 163 – 165 °C.[21] Its structure is still unknown.

ACID-CATALYZED FORMATION OF PHENOLS *13* AND *16* FROM DIMER ACETATES *8* AND *9*, RESPECTIVELY

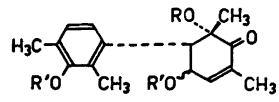
As mentioned earlier, dimer *12* is obtained in a very poor yield (9 %) by alkaline hydrolysis of its diacetate *9*, the phenolic compound *11* being formed predominantly. In an attempt to find a better method for the preparation of *12*, diacetate *9* was subjected to acid hydrolysis (7 h reflux with aqueous-ethanolic sulfuric acid) as previously used[14] for the preparation of dimer *5* from its diacetate. Under these conditions, *9* gave the desired *o*-quinol dimer *12* in a yield of 45 %. In addition, a phenolic compound (26 %, m.p. 205 – 206 °C) was obtained; it was not identical with phenol *11*.

Similar acid treatment of diacetate *8* produced, in addition to *o*-quinol dimer *10* (28 %), a phenolic product (46 %, m.p. 139 – 140 °C) which, unexpectedly, differed from both the aforementioned phenols.

The structures of the two new phenols are discussed in the following sections.

Phenol, m.p. 139 – 140 °C, from dimer diacetate 8. The compound, $C_{16}H_{20}O_4$, is isomeric with the dimeric *o*-quinols (*10*, *12*). Its UV and IR spectra indicated the presence of an aromatic ring, an α,β-conjugated keto group and hydroxyl groups. Treatment with Ac_2O/pyridine gave a diacetate showing the IR characteristics of both an aryl ester and an alkyl ester group, as well as remaining hydroxyl absorption. Acid-catalyzed acetylation[22] produced a triacetate, indicating that the last-mentioned hydroxyl group was a tertiary one. From the shift of the IR absorption peak due to the conjugated CO group from 1680 cm^{-1} (untreated phenol) and 1675 cm^{-1} (diacetate) to 1704 cm^{-1} (triacetate) it could be concluded that the tertiary hydroxyl group is located adjacent to the CO group (*cf.* Ref. 4, p. 2056).

These findings, as well as NMR data (see Exptl.), suggested structures *13*, *13a*, and *13b*



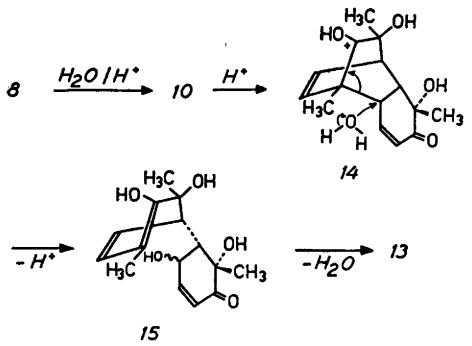
13 R=R'=H
13a R=H; R'=Ac
13b R=R'=Ac

for the phenol, its diacetate, and its triacetate, respectively.

It was found that the yield of dimer *10*, obtained in addition to the phenol *13*, decreased with increasing heating time, the yield of *13* simultaneously increasing. Furthermore, 7 h treatment of *10* under the hydrolysis conditions produced phenol *13* in a yield of 66 %, 15 % of unreacted *10* being recovered. These findings

indicated that dimer *10* is an intermediate in the formation of phenol *13*, the initial ester hydrolysis (*8*→*10*) being faster than the subsequent consumption of *10*.

The mechanism shown in Scheme 2 is proposed for the conversion of dimer *8 via 10* to phenol *13*. It is believed that protonation

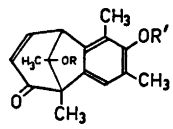


Scheme 2.

of the keto group at C-10 initiates ring opening at C-8a, a hydroxyl group being introduced at the latter carbon atom, as indicated in formula *14*. Acid-catalyzed elimination of water from the cyclohexadienol ring of the resulting intermediate *15* leads to the phenolic end-product *13*.

For the suggested conversion *14*→*15*, a few analogies have been found in the literature, *viz.* the acid-catalyzed formation of isocamphorquinone from camphorquinone [23] and the conversion of *endo* bornylamine into α-terpineol.[24]

Phenol, m.p. 205–206 °C, from dimer diacetate 9. This compound had the composition $C_{16}H_{18}O_3$ and was thus isomeric with phenol *11*. The strong red-shift of the UV maxima of its ethanolic solution which took place on addition of alkali indicated the presence of a phenolic group. The IR spectrum of the compound revealed a conjugated carbonyl group in addition to hydroxyl groups and an aromatic ring. Treatment with Ac_2O/pyridine gave a monoacetate, exhibiting IR absorptions at 1752 cm^{-1} (aryl ester) and at 3480 cm^{-1} (OH). Acetylation with $Ac_2O/HClO_4$ [22] esterified also the last-mentioned hydroxyl group, which must be tertiary. On the basis of these results, as well as of NMR data, structures *16*, *16a*, and *16b* are proposed for the phenol of m.p. 205–206 °C, its monoacetate, and its diacetate, respectively.



16 R=R'=H
16a R=H; R'=Ac
16b R=R'=Ac

Phenol *16* was also obtained by acid hydrolysis of the diacetate *17* of phenol *11*. However, the non-acetylated *o*-quinol dimer *12*, as well as phenol *11*, proved to be stable under the conditions of the acid hydrolysis. These findings suggest the following pathway for the formation of phenol *16* (Scheme 3).

Elimination of acetic acid from *9* accompanied by aromatization gives monoacetate *18*, the latter also being formed by partial hydrolysis of diacetate *17*. Protonation of the keto group of *18* induces two consecutive 1,2-shifts resulting in the formation of monoacetate *21* which is finally hydrolyzed to give phenol *16*.

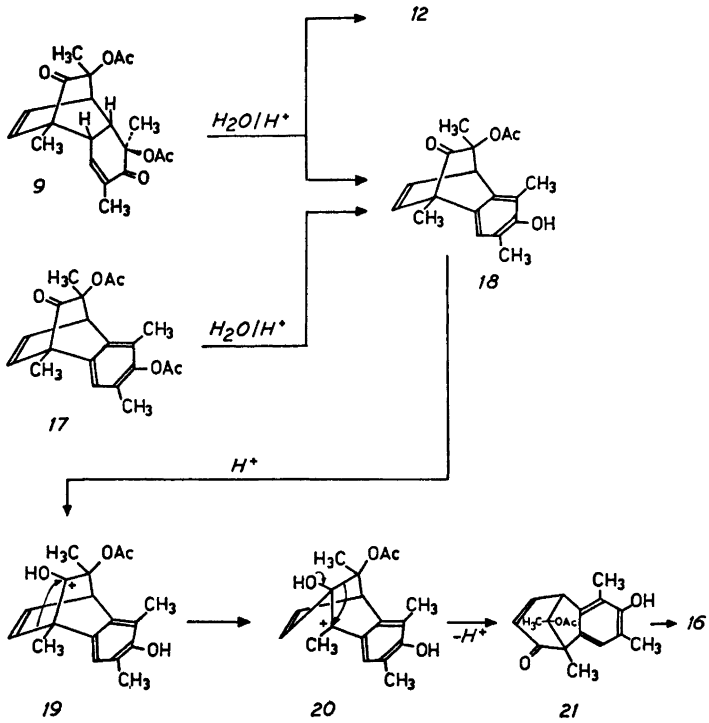
The assumption that the rearrangement takes place before the tertiary acetoxyl group is hydrolyzed, is based on the fact that neither the non-acetylated dimer *12*, which is the major product of the acid hydrolysis of *9*, nor the non-acetylated phenol *11* is affected under the conditions used. The role of the tertiary acetoxyl group is not clear; it might be considered that its $-I$ effect causes the electron density at C-10 in *19* to become sufficiently low for the Wagner-Meerwein type rearrangement *19*→*20* to occur. The intermediate *20* is a well-stabilized tertiary *p*-hydroxybenzylium ion.

It seems remarkable that diacetate *8*, contrary to its isomer *9*, under the acidic conditions used does not undergo elimination of acetic acid with aromatization of the unbridged ring, in competition with ester hydrolysis (*cf.* p. 859). Similar to the base-catalyzed eliminations, acid-catalyzed *syn* elimination of acetic acid seems to proceed more readily than the corresponding *anti* elimination.

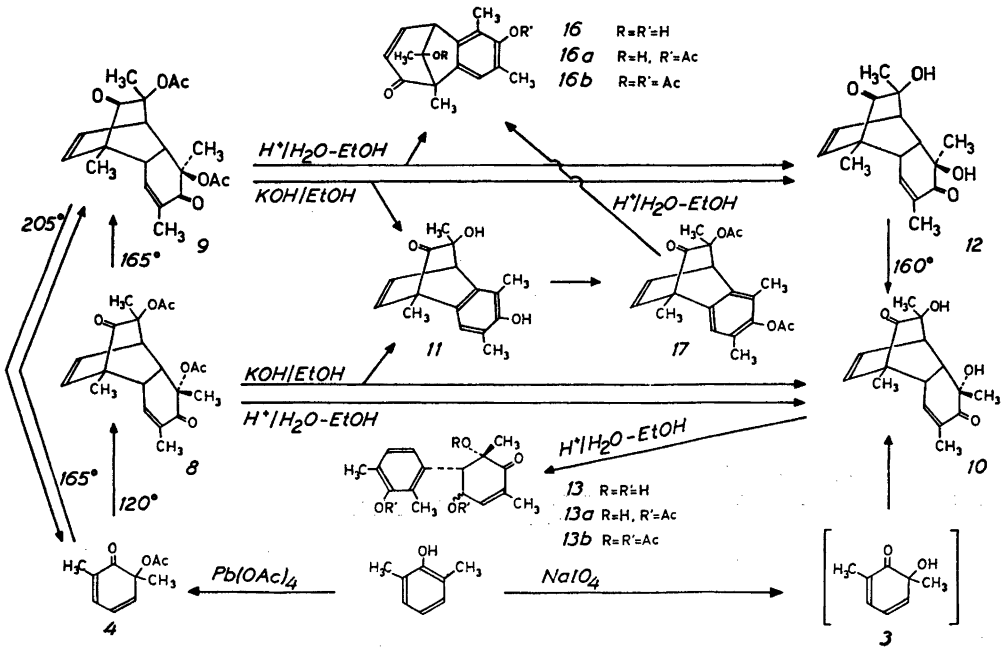
The reactions discussed in this paper are summarized in Scheme 4.

EXPERIMENTAL

Ultraviolet spectra were recorded on a Cary Model 14 spectrophotometer; IR and NMR spectra were obtained using Beckman 9A and Varian A-60 instruments, respectively. Chemical shifts are given in δ (ppm) units with TMS being used as internal standard.



Scheme 3.



Scheme 4.

6-Acetyloxy-2,6-dimethyl-2,4-cyclohexadienone (4) was prepared using the method reported by Wessely *et al.*[19] with slight modifications. Lead tetraacetate (57.5 g, 0.13 mol), which had been freed from acetic acid by washing with ether, was added to a solution of 2,6-dimethylphenol (13.6 g, 0.11 mol) in chloroform which was cooled with ice-water. After 16 h at room temperature the mixture was filtered and the filtrate brought to dryness. The residue was treated with ether (40 ml) and, after cooling the solution in the refrigerator for 4 h, undissolved material was filtered off. The solvent was evaporated, leaving an oil which crystallized when kept in the refrigerator for 24 h. Recrystallization from ether-light petroleum (b.p. 60–80 °C) gave yellow crystals of *4*, m.p. 35–36 °C (lit.[19,25] 36 °C) in a yield of 76 %. NMR ($CDCl_3$): δ 1.38 (s, 3 H, CH_3), 1.93 (d, 3 H, olefinic CH_3), 2.08 (s, 3 H, CH_3CO), 6.11 and 6.19 (broad singlets, 1 H each, H-4 and H-5), 6.69 (m, 1 H, H-3).

Dimer diacetate 8. *o*-Quinol acetate *4* (10 g) was heated under N_2 for 1 h at 120 °C. The resulting oil was dissolved in ether (50 ml) and, after 24 h at room temperature, the crystalline product deposited was recrystallized from ethanol to give 48 % of *8*, m.p. 159–160 °C (lit.[3] 159–160 °C). NMR ($CDCl_3$): δ 1.42, 1.50 and 1.73 (singlets, 3 H each, 3 CH_3), 1.83 (t, 3 H, olefinic CH_3), 2.10 and 2.17 (singlets, 3 H each, 2 CH_3CO), 3.00 (broad d, 1 H, H-8a. Coupling with H-4a gives rise to the doublet, which is further split by coupling with H-8 and by homoallylic coupling with CH_3-7), 3.48 (dd, 1 H, H-4a), 3.77 (td, 1 H, H-4), 5.64 (dd, 1 H, H-2), 6.23 (broad signal, 1 H, H-8), 6.29 (dd, 1 H, H-3). $J_{2,3}=7.8$ Hz, $J_{2,4}=1.5$ Hz, $J_{3,4}=7.0$ Hz, $J_{4,4a}=1.5$ Hz, $J_{4a,8a}=8.1$ Hz.

Dimer diacetate 9. *o*-Quinol acetate *4* was heated under N_2 for 2.5 h at 165 °C and the resulting oily product purified as described for isomer *8*. M.p. 182–184 °C; yield, 60 %. Elemental analysis, see Ref. 3, p. 1595. UV (ethanol): λ_{max}, nm (log ε) 209 (3.82) (β,γ-enone), 238 (3.80) (α,β-enone), 310 (2.18) (α,β- and β,γ-enones). IR (KBr), see Ref. 3. NMR ($CDCl_3$): δ 1.36 (s, 3 H, CH_3), 1.50 (s, 6 H, 2 CH_3), 1.80 (broad s, 3 H, olefinic CH_3), 1.95 and 2.12 (singlets, 3 H each, 2 CH_3CO), 2.90 (broad s, 2 H, H-4a and H-8a), 3.84 (td, 1 H, H-4), 5.60 (dd, 1 H, H-2), 6.14 (dd, 1 H, H-3), 6.17 (broad s, 1 H, H-8). $J_{2,3}=8.2$ Hz, $J_{2,4}=1.6$ Hz, $J_{3,4}=6.9$ Hz.

Estimation of yields of products formed by heat treatment of o-quinol acetate 4 (see Fig. 1). Monomer *4* was heated under N_2 for 0.5, 2.5, and 6 h, in each instance at temperatures of 125, 165, and 185 °C; an experiment with a heating time of 0.5 h at 205 °C was also carried out. After rapid cooling the reaction mixtures were dissolved in $CDCl_3$ and NMR spectra were recorded. The proportions of *4*, *8*, and *9* were estimated from the integrals of the signals of the various CH_3 and CH_3CO groups of the compounds present. The "unidentified product", increasing in amount with increasing temperature and heating time, is characterized by broad signals between δ 2.10 and 2.35, as shown for a product obtained on 6 h heating of *4* at 185 °C. It was assumed to have the same empirical formula as the three known products.

Isomerization of diacetate 8 *to diacetate* 9. Compound *8* (5.0 g) was heated under N_2 at 165 °C for 2.5 h. Ether (50 ml) was added, and *9* (3.0 g, 60 %) was collected after 24 h. The product was identical with that obtained from *4* (see above) by m.p., mixed m.p. and spectral properties.

Thermal degradation of dimer diacetates 8 *and* 9. Heating of the compounds under N_2 at 205 °C for 30 min, followed by rapid cooling, gave *o*-quinol acetate *4* in yields of 79 and 84 %, respectively.

Alkaline hydrolysis of dimer diacetate 8 with ethanolic KOH was carried out as described in Ref. 3. The reaction products *10* and *11* gave the following NMR spectra. *o-Quinol dimer* 10. NMR ($CDCl_3$): δ 1.25, 1.31 and 1.33 (singlets, 3 H each, 3 CH_3), 1.85 (t, 3 H, olefinic CH_3), 2.86 (s, 1 H, OH, exchangeable with D_2O), 2.90 (m, 1 H, H-8a. The signal is split by vicinal coupling to H-4a and H-8 and homoallylic coupling to CH_3-7), 3.30 (dd, 1 H, H-4a), 3.41 (td, 1 H, H-4), 4.06 (s, 1 H, OH, exchangeable with D_2O), 5.51 (dd, 1 H, H-2), 6.27 (dd, 1 H, H-3), 6.31 (broad signal, H-8). $J_{2,3}=7.0$ Hz, $J_{2,4}=1.5$ Hz, $J_{3,4}=6.0$ Hz, $J_{4,4a}=2.0$ Hz, $J_{4a,8a}=7.0$ Hz.

Phenol 11. NMR ($CDCl_3$): δ 1.47 and 1.70 (singlets, 3 H each, 2 CH_3), 2.02 (s, 1 H, OH), 2.21 and 2.32 (singlets, 3 H each, 2 aromatic CH_3), 4.30 (dd, 1 H, H-4), 4.98 (s, 1 H, OH), 6.22 (dd, 1 H, H-2), 6.66 (t, 1 H, H-3), 6.89 (s, 1 H, H-8).

Alkaline hydrolysis of dimer diacetate 9. A solution of *9* (5.0 g) in 10 % ethanolic KOH (200 ml) was kept under N_2 for 16 h at room temperature. Ethanol was removed under vacuum, water being added during the evaporation, and the aqueous solution (about 100 ml) was extracted with three 50 ml portions of chloroform. The dried extract on evaporation gave an oil which was purified on a silica gel column using acetone-hexane (2:1) as eluent. *o-Quinol dimer* 12, $R_F=0.50$, m.p. 147–149 °C (from ethanol), was obtained in a yield of 9 %. (Found: C 69.50; H 7.32. Calc. for $C_{16}H_{20}O_4$: C 69.54; H 7.30.) UV (ethanol): λ_{max}, nm (log ε) 211 (3.91), 238 (3.87), 310 (2.13). IR (KBr): ν_{max}, cm^{-1} 1672 (conj. CO), 1722 (CO), 3480 and 3500 (OH). NMR ($CDCl_3$): δ 1.31 (s, 6 H, 2 CH_3), 1.38 (s, 3 H, CH_3), 1.86 (t, 3 H, olefinic CH_3), 2.75 (broad signal, 2 H, H-4a and H-8a), 3.27 (s, 2 H, 2 OH, exchangeable with D_2O), 3.35 (broad d, 1 H, H-4), 5.50 (dd, 1 H, H-2), 6.30 (broad signal, 2 H, H-3 and H-8).

The alkaline aqueous phase was neutralized with acetic acid and extracted with chloroform.

Evaporation of the chloroform phase and treatment of the residue with ether gave 68 % of a product of m.p. 172 – 173 °C, identical by m.p., mixed m.p. and spectral properties with phenol *11*.[3]

Thermal isomerization of o-*quinol dimer* 12 *to* o-*quinol dimer* 10. A sample of compound *12* (3.0 g) was heated under N_2 for 1 h at 160°C. After cooling, ether (40 ml) was added. The crystalline product obtained after recrystallization from ethanol had m.p. 194 – 196 °C. Yield, 83 %. The product was identical by m.p., mixed m.p. and spectral properties with dimer *10*.[3]

Acid hydrolysis of dimer diacetate 8. A solution of *8* (2.0 g) in a mixture of ethanol (75 ml) and 10 % aqueous sulfuric acid (75 ml) was heated under reflux for 7 h in an atmosphere of nitrogen. The reaction mixture was extracted with three 75 ml portions of chloroform, the combined organic phases were concentrated to half their volume and then extracted with 3 × 50 ml of 2.5 M aqueous NaOH. The chloroform phase was dried and evaporated. Addition of ethanol (5 ml) to the semi-solid residue gave 28 % of crude *o*-quinol dimer *10*, m.p. 191 – 193 °C. Recrystallization from ethanol raised the m.p. to 195 – 196 °C (lit.[3] 194 – 196 °C).

The combined aqueous alkaline phases were neutralized with aqueous HCl and extracted twice with 100 ml portions of chloroform. The residue obtained after removal of the chloroform, when treated with ether gave a crystalline product which was recrystallized from benzene yielding 46 % of *4,6-dihydroxy-2,6-dimethyl-5-(3-hydroxy-2,4-dimethylphenyl)-2-cyclohexenone* (13), m.p. 139 – 140 °C. (Found: C 69.57; H 7.31. Molecular ion, M = 276. Calc. for $C_{16}H_{20}O_4$: C 69.54; H 7.30. Molecular ion, M = 276.). UV (ethanol): λ_{max}, nm (log ε) sh 239 (3.81), 276 (3.22). IR (KBr): ν_{max}, cm^{-1} 1492 and 1580 (arom. ring), 1680 (conj. CO), 3420 and 3520 (OH). NMR ($CDCl_3$): δ 1.48 (s, 3 H, CH_3-6), 1.95 (t, 3 H, CH_3-2), 2.15 and 2.22 (singlets, 3 H each, 2 aromatic CH_3), 2.10, 3.52 and 4.98 (broad singlets, 1 H each, 3 OH, exchangeable with D_2O), 4.11 (d, 1 H, H-5), 4.76 (broad signal, 1 H, H-4), 6.66 (broad signal, 1 H, H-3), 6.57 and 6.71 (doublets, 1 H each, 2 aromatic H, J = 8.0 Hz). $J_{CH_3\text{-}2,H\text{-}3}$ and $J_{CH_3\text{-}2,H\text{-}4}$ = 1.5 Hz; $J_{4,5}$ = 6.0 Hz.

Acid treatment of o-*quinol dimer* 10. The same procedure as described above for the acid hydrolysis of dimer acetate *8* gave unreacted *10* (15 %) and phenol *13* (66 %).

Diacetate 13a. From phenol *13* with Ac_2O/pyridine. Yield, 81 %; m.p. 136 – 137 °C (ethanol). (Found: C 66.62; H 6.73. Calc. for $C_{20}H_{24}O_6$: C 66.65; H 6.71), IR (KBr): ν_{max}, cm^{-1} 1675 (conj. CO), 1739 and 1752 (alkyl and aryl ester), 3480 (OH). The NMR signals of the CH_3CO groups are located at δ 1.78 and 2.29 ($CDCl_3$).

Triacetate 13b. From phenol *13* with Ac_2O/$HClO_4$.[22] Yield, 84 %; m.p. 157 – 158 °C (ethanol). (Found: C 65.66; H 6.49. Calc. for $C_{22}H_{26}O_7$: C 65.66; H 6.51). IR (KBr): ν_{max}, cm^{-1} 1704 (conj. CO), 1738 (2 alkyl ester CO) and 1755 (aryl ester CO). The NMR signals of the CH_3CO groups are located at δ 1.92, 1.94 and 2.31 ($CDCl_3$).

Acid hydrolysis of dimer diacetate 9. A 2 g sample of diacetate *9* was treated as described above for isomer *8*. The neutral fraction gave *o*-quinol dimer *12*, m.p. 147 – 149 °C, identical with the product of the same melting point obtained on alkaline hydrolysis of *9* by mixed m.p. and spectral properties.

The aqueous alkaline phase after neutralization was extracted with chloroform, and the dried extract concentrated to a volume of 30 ml. From the solution colourless crystals of *2,3-dihydro-2,5-dihydroxy-1,2,4,6-tetramethyl-1,3-propeno-1H-inden-10-one* (16) deposited. After recrystallization from acetone-chloroform, m.p. 205 – 206 °C; yield, 26 %. (Found: C 74.42; H 7.03. Molecular ion, M = 258. Calc. for $C_{16}H_{18}O_3$: C 74.40; H 7.02. Molecular ion, M = 258). UV (ethanol): λ_{max}, nm (log ε) 241 (4.03), 301 (3.71). UV (0.1 M NaOH in 80 % aqueous ethanol): λ_{max}, nm (log ε) 268 (4.03), 332 (3.83), 373 (4.24). IR (KBr): ν_{max}, cm^{-1} 1470, 1582, 1593 (aromatic ring), 1655 (conj. CO), 3320 (broad, OH). NMR (DMSO-d_6): δ 1.12 and 1.43 (singlets, 3 H each, 2 CH_3), 2.17 (s, 6 H, 2 aromatic CH_3), 3.61 (d, 1 H, H-3), 4.84 (broad signal, 1 H, OH, exchangeable with D_2O), 5.56 (d, 1 H, H-9), 6.56 (dd, 1 H, H-8), 7.37 (s, 1 H, H-7), 8.67 (broad signal, 1 H, OH). $J_{3,8}$ = 3.5 Hz, $J_{8,9}$ = 6.0 Hz.

Monoacetate 16a. From phenol *16* with Ac_2O/pyridine. Yield, 73 %; m.p. 175 – 176 °C (benzene). (Found: C 71.83; H 6.67. Calc. for $C_{18}H_{20}O_4$: C 71.88; H 6.71). UV (ethanol): λ_{max}, nm (log ε) 232 (4.09), 237 (3.72), 303 (3.16). IR (KBr): ν_{max}, cm^{-1} 1670 (conj. CO), 1752 (arylester), 3480 (OH). The NMR signal of the CH_3CO group is located at δ 2.32 ($CDCl_3$).

Diacetate 16b. From *16* with Ac_2O/$HClO_4$.[22] Yield, 80 %; m.p. 143 – 144 °C (ethanol). (Found: C 70.01; H 6.50. Calc. for $C_{20}H_{22}O_5$: C 69.98; H 6.39). IR (KBr): ν_{max}, cm^{-1} 1685 (conj. CO), 1735 and 1750 (alkyl and aryl ester). NMR signals of the CH_3CO groups: δ 1.66 and 2.36 (DMSO-d_6).

Acid hydrolysis of diacetate 17. A solution of diacetate *17*[3] (0.5 g) in a mixture of ethanol (20 ml) and 10 % aqueous sulfuric acid (20 ml) was refluxed under N_2 for 7 h and then worked up as described above for the similar hydrolysis of *8*. The neutral fraction consisted of unreacted diacetate *17* (65 %). The phenolic fraction gave compound *16*, m.p. 205 – 206 °C. in a yield of 22 %.

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