Serendipitous, one-pot formation of 2,3,7-triphenylcyclopenta[*c*]pyran from 1,2-diphenylethanedione ("benzil") and cyclopentadiene

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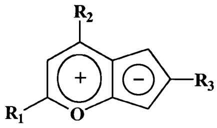
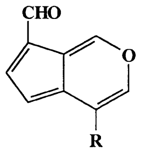
The reaction of 1,2-diphenylethanedione ("benzil") with cyclopentadiene in the presence of sodium methoxide unexpectedly afforded a novel 2,3,7-triphenyl derivative of the bicyclic cyclopenta[*c*]pyran. The structure was elucidated by physical methods (IR, UV/VIS, ^{1}H-NMR, ^{13}C-NMR, MS) and a single-crystal X-ray analysis.

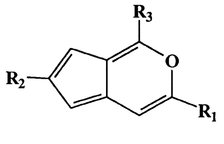
In 1958 Boyd[1] described the synthesis of 2,4,6-trisubstituted derivatives (**1**) of a new hetero-bicyclic system, cyclopenta[*b*]pyran. In spite of the fact that the skeleton of **1** (named oxalene) is isoelectronic with azulene (hence the generic term pseudoazulenes), the investigation of pseudoazulenes does not appear to be very active at the present time.[2,3] On the other hand, naturally occurring iridoids with a cyclopenta[*c*]pyran skeleton, usually bearing formyl substituents, such as norviburtinal, **2a**,[4] viburtinal, **2b**,[5] cerbinal, **2c**,[6] baldrinal, **2d**,[7] *etc.* are actively being investigated due to their various biological activities.[8,9]



1a $R_1 = R_2 = R_3 = Ph$
b $R_1 = t\text{-Bu}; R_2 = R_3 = Ph$

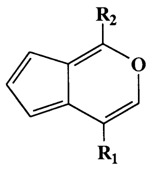


2a R = H
b R = Me
c R = COOMe
d $R = CH_2OAc$

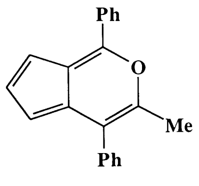


3a $R_1 = R_2 = R_3 = H$
b $R_1 = R_3 = H; R_2 = t\text{-Bu}$
c $R_1 = R_3 = Ph; R_2 = t\text{-Bu}$

Until recently, only three pseudoazulenes with a cyclopenta[*c*]pyran skeleton and devoid of electron-acceptor groups had been synthesised: the parent compound **3a** [in four steps from $BrCH_2CH(OMe)_2$ and 5-(trimethylsilyl)-1,3-cyclopentadiene[10]] and the substituted derivatives **3b**[10] and **3c**.[11] A major breakthrough in this area is due to Christl and co-workers[12] who in 1998 designed a general method for the synthesis of di- and tri-substituted cyclopenta[*c*]pyrans **4** and **5** in a three-step sequence including cycloaddition of cyclopentadiene to 6-oxo-6*H*-1,3,4-oxadiazines, dehydrogenation with dichlorodicyano-*p*-benzoquinone and reduction of the resulting α-pyrones. Compounds **4** were shown to undergo electrophilic substitution (*e.g.*, formylation, nitration, *etc.*).[12] In spite of these notable achievements, the 2,3,7-triphenyl-substituted derivative **6** of **3a** has not been synthesised until now.



4a $R_1 = R_2 = Ph$
b $R_1 = Ph; R_2 = p\text{-}MeOC_6H_4$
c $R_1 = Ph; R_2 = COOMe$
d $R_1 = i\text{-Pr}; R_2 = Ph$
e $R_1 = i\text{-Pr}; R_2 = p\text{-}MeOC_6H_4$



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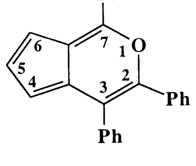

6

Results and discussion

In this contribution we report a simple and convenient, one-pot synthesis of compound **6** (isomeric with **1a**),

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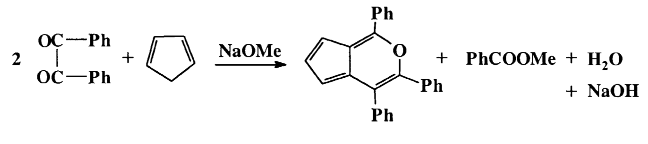
serendipitously formed during an attempt to obtain fulvenes from α-dicarbonyl compounds. Thus, the treatment of 1,2-diphenylethanedione ("benzil") with excess cyclopentadiene in a strongly basic medium (NaOMe, KOH, *etc.*) leads to the formation of a red compound that could be isolated and purified by column chromatography on a neutral alumina. The structure of the new compound **6**, m.p. 140–142 °C, established on the basis of physico-chemical data including X-ray analysis, corresponds to 2,3,7-triphenylcyclopenta[*c*]pyran.



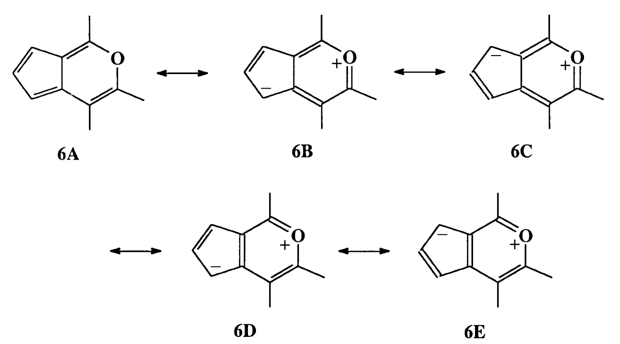
6

Along with large amounts of polymeric materials, methyl benzoate was identified among the reaction products when sodium methoxide was used as condensation agent. The unexpected formation of **6** in the reaction of benzil with cyclopentadiene can be rationalised by the mechanism suggested in Scheme 1.

The IR spectrum confirms the presence of cyclopentadienic C=C bonds by their stretching frequency at 1619 cm^{-1} and of the monosubstituted benzenic rings by their characteristic absorptions at 694, 746 and 912 cm^{-1} as well as by the "quartet" between 1600–2000 cm^{-1}. The IR absorption bands at 848, 942, 1054 and 1174 cm^{-1} can be assigned to the pyrylium ring evidenced by the mesomeric forms **6B–E**[13] shown in Scheme 2.

The electronic spectrum of the deep red **6** presents absorptions at 257, 301.2 and 349.6 nm as well as a broad one centered at 471.5 nm. This spectrum differs from that of **1a**[1] [247 ($\log\varepsilon = 4.49$); 290 ($\log\varepsilon = 4.61$); 418 ($\log\varepsilon = 4.56$) and *ca.* 508 nm ($\log\varepsilon = 3.07$) inflexion] due to the different annelation of the 5- and 7-membered rings, and the different substitution pattern.

The mass spectrum of **6** shows the molecular peak (which is also the base peak) at $m/z = 346$ and the fragmentation pattern allowed the assignment of all peaks in agreement with the structure.

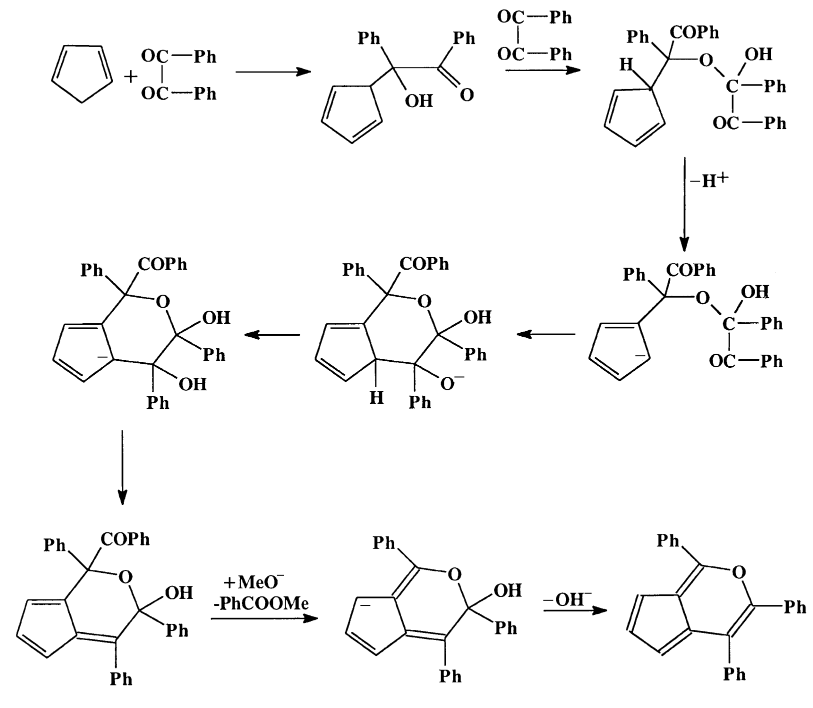


Scheme 2 Mesomeric forms of **6**.

The ^{1}H-NMR spectrum clearly demonstrates the presence of the cyclopentadienic ring by the signals at 6.40, 7.13 and 7.33 ppm (all of them as doublets of doublets with the corresponding couplings). The ^{13}C-NMR spectrum permitted the assignment of the cyclopentadienic carbon atoms (C4, C5, C6) using ^{1}H–^{13}C COSY determinations and the tertiary (CH) and quaternary (Cq) character of the remaining C atoms using APT experiments.

The molecular structure of **6** determined by single crystal X-ray analysis is shown in Fig. 1, where selected bond lengths and angles are also given. The cyclopenta[*c*]pyran skeleton is nearly planar. The carbon–carbon bonds in the five-membered [C2–C3 1.428(2), C4–C5 1.421(2), C3–C4 1.360(3) and C5–C6 1.375(3) Å] and six-membered rings [C1–C2 1.361(2), C7–C8 1.359(2), C2–C6 1.464(2) and C6–C7 1.431(2) Å] show the variations expected for structure **6** (distinct double and single bonds). The differences in the carbon–oxygen bond lengths in the six-membered ring [C1–O1 1.395(2) and C8–O1 1.381(2) Å] may be ascribed to the prevailing contributions of limiting structures **6B** and **6C** over **6D** and **6E**, due to the general preference for endocyclic double bonds in the 6-membered rings,[14] such that these bonds are exocyclic for the five-membered ring.

In conclusion, this reaction used readily available and cheap reagents, and the synthesis reported here opens up a facile route to cyclopenta[*c*]pyrans. The generality of the synthesis



Scheme 1 Suggested mechanism for the formation of **6**.

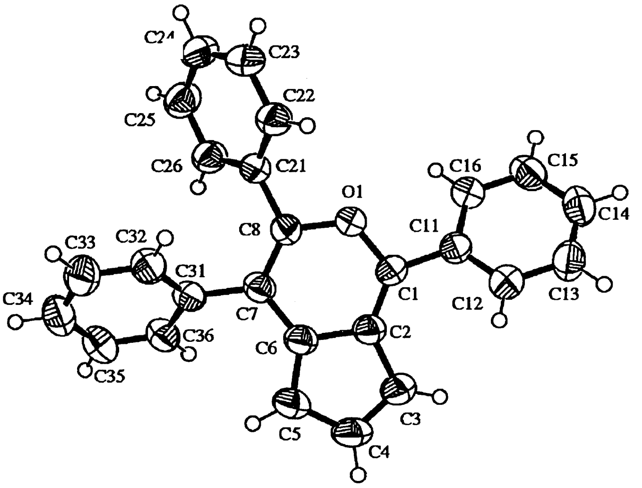


Fig. 1 Molecular structure of 2,3,7-triphenylcyclopenta[*c*]pyran **6**. Bond lengths: C1–O1 1.395(2), O1–C8 1.381(2), C1–C2 1.361(2), C1–C11 1.471(2), C2–C3 1.428(2), C2–C6 1.464(2), C3–C4 1.360(3), C4–C5 1.421(3), C5–C6 1.375(2), C6–C7 1.431(2), C7–C8 1.359(2), C7–C31 1.488(2), C8–C21 1.475(2) Å; bond angles: C1–O1–C8 122.62(12), O1–C1–C2 119.69(15), O1–C1–C11 111.01(13), C2–C1–C11 129.24(15), C1–C2–C3 133.57(16), C1–C2–C6 119.13(15), C3–C2–C6 107.29(15), C4–C3–C2 106.85(17), C3–C4–C5 111.00(17), C6–C5–C4 107.78(17), C5–C6–C7 133.75(16), C5–C6–C2 107.06(15), C6–C7–C31 120.60(14), C8–C7–C31 121.69(15), C7–C6–C2 119.20(14), C8–C7–C6 117.71(15), C7–C8–O1 121.54(15), O1–C8–C21 109.23(13)°.

reported here, MO calculations as well as protonation experiments (occurring mainly at the C6 position) are now under investigation in our laboratory and will be published at a later date.

Experimental

Synthesis of 2,3,7-triphenylcyclopenta[*c*]pyran (6)

Into a cooled solution of sodium methoxide prepared from 4.5 g (196 mmol) sodium in 50 mL anhydrous methanol a solution of freshly distilled cyclopentadiene (17 mL, 206 mmol) in 10 mL anhydrous methanol was added dropwise with stirring under an inert (argon) atmosphere. The solution became red due to the formation of cyclopentadienylsodium. Then a solution of benzil (20 g, 95 mmol) in 500 mL anhydrous methanol was added dropwise with stirring over 2 h. The red–brown reaction mixture was stirred at 50 °C for an additional 3 h while maintaining the inert atmosphere. After cooling to room temperature, the reaction mixture was decomposed by adding of 150 mL cold water (formation of a black tarry material was observed). The red–brown solution was extracted with petroleum ether (b.p. 30–40 °C; 4 × 125 mL). The combined red solutions were washed with water until the pH reached 7, dried on anhydrous magnesium sulfate, filtered and evaporated *in vacuo*. The resulting red oily product was subjected to column chromatography on neutral alumina using petroleum ether (b.p. 30–40 °C) as eluent. The red zone was collected as an eluate that, after evaporation of the solvent, afforded a deep-red oily solution that was left overnight at 0 °C. The crystals that were formed were filtered off from an oily red liquid (methyl benzoate contaminated with **6**) and subsequently recrystallized from petroleum ether or from methanol, affording red crystals of **6** (1.6 g, 9.7%) with m.p. 140–2 °C. Anal. found: C, 89.91; H, 5.35; calc. for $C_{26}H_{18}O$: C, 90.20; H, 5.20%.

IR (KBr, cm^{-1}): 659 m, 694 vs, 746 m, 768 s, 800 w, 848 w, 912 m, 942 w, 1027 m, 1054 m, 1080 w, 1120 w, 1174 m, 1211 w, 1252 w, 1330 m, 1379 s, 1445 m, 1496 m, 1539 w, 1574 w, 1619 m, 3020 w, 3060w. UV/VIS (dioxane; λ_{max}/nm; log ε_{max}): 257 (4.27); 301.2 (4.39); 349.5 (3.96); 471.5 (3.06). MS *m*/*z* (%): 51 (11); 63 (3); 76 (2); 77 (26); 78 (3); 105 (15); 151 (3); 165 (3); 213 (3); 237 (3); 238 (2); 239 (15); 240 (6); 241 (8); 302 (3); 315 (3); 317 (7); 345 (16); 346 (M+; 100); 347 (M^++1; 27); 348 (M^++2; 4). ^{1}H-NMR ($CDCl_3$; δ, J/Hz): 6.40 (dd, 2.9, 1.3, 1H, H4); 7.13 (dd, 4.7, 1.3, 1H, H6), 7.33 (dd, 4.7, 2.9, 1H, H5); 7.22–7.48 (m, 10H, H_{arom}); 7.61 (m, 3H, H_{arom}); 8.19 (dd, 8.1, 2.1, 2H, H_{arom}). ^{13}C-NMR ($CDCl_3$; δ): 110.43 (C6); 110.54 (C4); 121.26 (Cq); 121.36 (Cq); 127.63 (CH); 127.87 (CH); 127.99 (2 CH); 128.60 (2 CH); 128.83 (2 CH); 128.98 (2 CH); 129.17 (2 CH); 130.19 (2 CH); 130.56 (CH); 131.06 (Cq); 133.67 (Cq); 134.12 (Cq); 135.52 (C5); 136.32 (Cq); 144.55 (Cq); 155.05 (Cq).

X-Ray crystallography

Crystal data for **6**: $C_{26}H_{18}O$, $M = 346.40$, triclinic, space group $P\bar{1}$, $a = 8.2130(4)$, $b = 9.9120(4)$, $c = 11.5310(5)$ Å, $\alpha = 98.303(2)$, $\beta = 94.060(3)$, $\gamma = 96.414(2)°$, $V = 919.44(7)$ $Å^3$, $Z = 2$, $\lambda = 0.71070$ Å, $T = 293(2)$ K, $\mu = 0.075$ mm^{-1}, crystal size $0.250 \times 0.115 \times 0.087$ mm^3. Data were collected on an Enraf–Nonius diffractometer using Mo-Kα radiation. A total of 6152 reflections were collected, of which 3243 were independent [$R(\text{int}) = 0.0175$]. The structure was solved by direct methods and refined by full-matrix least-squares on F^2 using COLLECT, HKL Denzo and scalepack, SHELXS-97 and SHELX-97 programs: $R_1 = 0.0471$, $wR_2 = 0.1250$.

CCDC reference number 160799. See http://www.rsc.org/suppdata/nj/b1/b105878a/for crystallographic data in CIF or other electronic format.

References

1 G. V. Boyd, *J. Chem. Soc.*, 1958, 1978.
2 H.-J. Timpe and A. V. El'tsov, *Adv. Heterocycl. Chem.*, 1983, **33**, 185.
3 A. T. Balaban, A. Dinculescu, G. N. Dorofeenko, G. W. Fischer, A. V. Koblik, V. V. Mezheritskii and W. Schroth, *Pyrylium Salts. Syntheses, Reactions and Physical Properties*, *Adv. Heterocycl. Chem. Supp. 2*, Academic Press, New York, 1982, p. 59.
4 K. C. Joshi, P. Singh, S. Taneja, P. J. Cox, R. A. Howie and R. H. Thomson, *Tetrahedron*, 1982, **38**, 2703.
5 R.-P. Godeau, J.-C. Rossi and I. Fouraste, *Phytochemistry*, 1977, **16**, 604.
6 H. Ohashi, T. Tsurushima, T. Ueno and H. Fukami, *Agric. Biol. Chem.*, 1986, **50**, 2655; Y. Ge and S. Isoe, *Chem. Lett.*, 1992, 139.
7 G. Schneider and M. Willems, *Arch. Pharm. (Weinheim, Ger.)*, 1982, **315**, 691; R. Braun, H. Dieckmann, M. Machut, C. Echarti and H. R. Maurer, *Planta Med.*, 1986, 446.
8 F. E. Koehn, S. P. Gunasekera, D. N. Niel and S. S. Cross, *Tetrahedron Lett.*, 1991, **32**, 169.
9 R. Bos, H. Hendricks, J. J. C. Scheffer and H. J. Woerdenbag, *Phytomedicine*, 1998, **5**, 219.
10 T. Kämpchen, G. Moddelmog, D. Schultz and G. Seitz, *Liebigs Ann. Chem.*, 1988, 855.
11 H. Kato, T. Kobayashi, M. Ciobanu, H. Iga, A. Akutsu and A. Kakehi, *Chem. Commun.*, 1996, 1011.
12 M. Christl, N. Bien, G. Bodenschatz, E. Feineis, J. Hegmann, C. Hofmann, S. Mertelmeyer, J. Ostheimer, F. Sammtleben, S. Wehner, E.-M. Peters, K. Peters, M. Pfeiffer and D. Stalke, *Chem. Commun.*, 1998, 2387.
13 A. T. Balaban, G. D. Mateescu and M. Elian, *Tetrahedron*, 1962, **18**, 1083.
14 R. B. Turner and R. H. Garner, *J. Am. Chem. Soc.*, 1957, **79**, 253.