639. *Autoxidation of Tetraisopropylbenzene.*

By E. G. E. Hawkins and W. F. Maddams.

Oxygenation of 1,2,4,5-tetraisopropylbenzene, in the presence of metal-salt catalysts, has been carried out at *ca.* 140—170°. It gave low-boiling alcohols, carbonyl compounds, and acids, as well as a series of phthalans and phthalides.

Although the catalysed oxidation of dialkylbenzenes to the isomeric phthalic acids has been the subject of a number of patents,[1] and certain trialkylbenzenes have been converted into hydroperoxides,[2] very little study appears to have been devoted to the oxidation of polyalkylbenzenes. Larsen, Thorpe, and Armfield[3] examined the rates of oxidation of a large number of hydrocarbons, including hexaethylbenzene, but provided little information about the products formed from this compound apart from a rough classification into acids, esters, peroxides, alcohols, and carbonyl compounds, based on analytical

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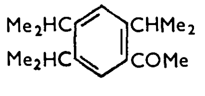
[1] *Inter alia,* I.C.I., B.P. 804,612, 833,440, 840,009, 840,130; Mid-Century Corp., U.S.P. 2,833,816—2,833,820.

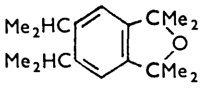
[2] V.E.B. Farbenfabrik Wolfen, G.(East)P. 12,239: Volkov and Zavgorodnii, *Zhur. obshchei Khim.*, 1959, **29**, 3672.

[3] Larsen, Thorpe, and Armfield, *Ind. Eng. Chem.*, 1942, **34**, 183.

figures. Recently, however, Volkov and Zavgorodnii [4] have shown that the autoxidation of a number of isopropylxylenes leads, *inter alia*, to the formation of phthalides.

The oxidation of neat 1,2,4,5-tetraisopropylbenzene at *ca.* 160°, when catalysed by cobalt and manganese salts, gave a variety of products which, although not easily separable by distillation, could generally be isolated as individual compounds by column chromatography. The solid products identified were (I)—(V) with the further possibility of (VI); other solid materials obtained in traces were not identified although, from their infrared spectra, they appeared to contain similar groups to the above compounds. The major product was the phthalide (III).


(I)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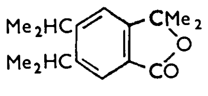
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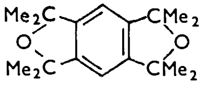
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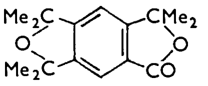
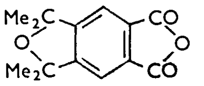
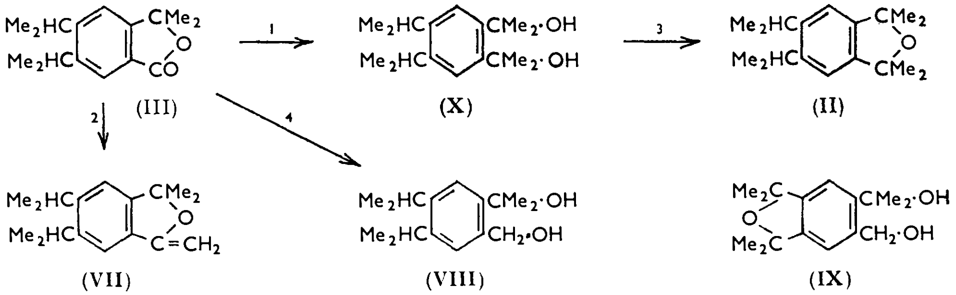

(V)


(VI)

The formation of phthalides as intermediates during the oxidation of *o*-dialkylbenzenes [5,6] and of isopropylxylenes [4] has already been noted, but the isolation of the above series of compounds sheds considerable light on the mechanism of oxygenation of polyalkylbenzenes.

Proof of the structures of these compounds depended on elementary analysis, the characteristic bands in the infrared spectra of the phthalans (985 ± 6 cm.$^{-1}$) and phthalides (1750—1760 cm.$^{-1}$), and the conversion of the phthalides (III) and (V) into the corresponding phthalans (II) and (IV) by treatment with methylmagnesium iodide in boiling dibutyl ether followed by dehydration of the di-tertiary glycols produced. Reaction of the phthalide (III) with the Grignard reagent in diethyl ether provided a compound having a phthalan ring (band at 988 cm.$^{-1}$) and an elementary analysis in agreement with that expected for the methylene-phthalan (VII); its absorption at 1683 cm.$^{-1}$ can probably be assigned to C=C stretching. Moreover, ozonolysis of the product (VII) regenerated the phthalide (III), as required by the suggested structure. Reduction of the phthalides (III) and (V) by lithium aluminium hydride in boiling dibutyl ether led to the primary-tertiary glycols (VIII) and (IX), which afforded monophenylurethanes.



Reagents: 1, MeMgI in Bu_2O. 2, MeMgI in Et_2O. 3, Heat. 4, $LiAlH_4$.

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[4] Volkov and Zavgorodnii, *Doklady Akad. Nauk S.S.S.R.*, 1960, **132**, 591; *Zhur. obshchei Khim.*, 1961, **31**, 2629, 3090.

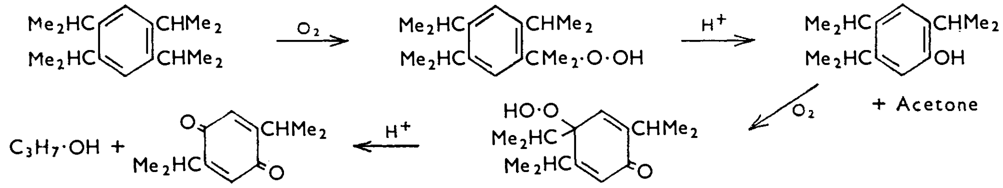
[5] Shizu Tomura, *Reports Sci. Res. Inst. (Japan)*, 1949, **25**, 256 (*Chem. Abs.*, 1951, **45**, 6592).

[6] Lumpkin and Nicholson, *Analyt. Chem.*, 1960, **32**, 74.

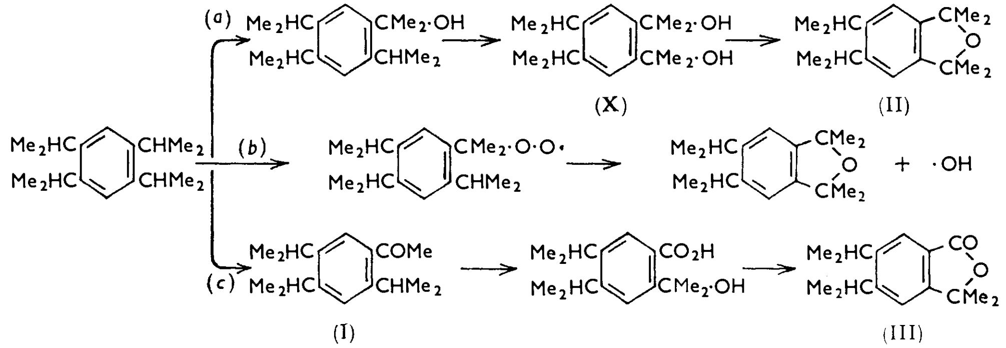
The tri-isopropylacetophenone (I) isolated from the oxidation products was identical with that obtained by treatment of tetraisopropylbenzene with acetyl chloride and aluminium chloride.[7]

The structure assigned to compound (VI) is based on spectroscopic evidence [absorption at 989 cm.$^{-1}$ (phthalan) and at 908, 1775, and 1842 cm.$^{-1}$ (anhydride)] but elementary analysis did not support this, possibly because of the inclusion of other compounds in the crystals. It was also difficult to assign structures to a number of trace products; in certain cases this may have been due to incomplete separation. However, some products were shown spectroscopically to contain phthalan or phthalide rings whilst others had hydroxyl groups or phenolic ether linkages.

This oxidation, which became inhibited after absorption of *ca.* $\frac{3}{4}$ mole of oxygen per mole of hydrocarbon (cf. ref. 3), also gave products of low molecular weight (*ca.* 7% w/w on initial hydrocarbon), *i.e.*, water, formaldehyde, acetone, and isopropyl alcohol, in addition to a recovery of 75—80% of the tetraisopropylbenzene. Although phenols were not isolated from the reaction mixture they may have been formed as intermediates, *via*



normal hydroperoxidation and acid decomposition, under these forcing conditions. Their presence would explain the inhibition, the darkening of the colour of the oxidate, and the formation of acetone. The production of isopropyl alcohol is less readily explained, although it might lie in further oxidation of the polyalkylphenols and decomposition of the substituted cyclohexadienone hydroperoxides formed by an acid-catalysed, ionic



mechanism, as shown in the accompanying scheme. Similar low-boiling products were also produced during the autoxidation of hexaethylbenzene.

The formation of both phthalans and phthalides may well represent different modes of oxidation [(*a*) or (*b*), and (*c*), respectively], since the phthalans, once formed, have no reactive hydrogen atoms for further attack in the positions α to the ring-oxygen. Moreover, the phthalans could be formed either by intramolecular radical attack[8] (*b*) or by thermal dehydration (*a*) of di-tertiary glycols. Volkov and Zavgorodnii[4] have suggested a radical mechanism for the formation of the phthalides.

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[7] Koch and Steinbrink, *Brennstoff-Chem.*, 1938, **19**, 277.

[8] Bailey and Norrish, *Proc. Roy. Soc.*, 1952, *A*, **212**, 311; Rust and Collamer, *J. Amer. Chem. Soc.*, 1954, **76**, 1055; Jones and Fenske, *Ind. Eng. Chem.*, 1959, **51**, 262.

EXPERIMENTAL

The oxidations were carried out in a three-neck flask fitted with an oxygen inlet, recycle stirrer, and water condenser (with a trap at the base), and with an outlet to an acetone–carbon dioxide bath. Oxygen was metered in and out.

Oxidation of Tetraisopropylbenzene.—The hydrocarbon (400 g.), containing manganese naphthenate (0·5 g.), was melted, and oxidised at 160—170° (bath); from time to time further additions of catalyst were made, but after 65 hr. the uptake of oxygen (25·2 l.) had slowed down and the reaction was stopped. The cold-trap liquid (10·0 g.), analysed by gas chromatography and infrared and mass spectrometry, was shown to contain 60—70% of water, 20—25% of isopropyl alcohol, and 10—15% of acetone, as well as traces of other compounds (esters). Acetone was also identified as its 2,4-dinitrophenylhydrazone, m. p. and mixed m. p. 125—126°. The water-condenser trap liquid (17·1 g.) also contained isopropyl alcohol, with some acetone and water, together with tetraisopropylbenzene which had sublimed; it also provided formaldehyde 2,4-dinitrophenylhydrazone, m. p. and mixed m. p. 164—166°. The main product (596 g.) was distilled, and ten fractions, with broad boiling ranges over 128—220°/12 mm., were taken. The black, hard residue weighed 12·6 g. The second fraction (311 g., b. p. 128—130°/12 mm.) contained most of the unchanged tetraisopropylbenzene, and as much as possible of this was removed by crystallisation from ethanol before chromatography. The individual fractions were chromatographed, generally on alumina (Mayfair) columns although silica gel was used for fraction 9. For development of the columns were used, in order, light petroleum, light petroleum–benzene, benzene, benzene–ethyl acetate, and ethyl acetate, or benzene–ether, ether, and ether–ethanol.

From chromatography, solid fractions A—O (described below) were finally obtained.

Fraction B. This was very weakly adsorbed on alumina. It had m. p. 144·5—146·5° (from ethanol) (Found: C, 82·7; H, 10·65. $C_{18}H_{28}O$ requires C, 83·1; H, 10·8%). Its infrared spectrum showed the absence of carbonyl and hydroxyl groups, and the absorption at 991 cm.$^{-1}$ (Nujol) suggested a cyclic ether; the greatly increased intensity of the aromatic bands in the ultraviolet spectrum indicated a rigid cyclic system as an *ortho*-substituent ($\lambda_{max.}$ 2650, 2693, 2728, 2775 Å; ε 1500, 2250, 2200, 2940). That fraction B was 5,6-*di-isopropyl*-1,1,3,3-*tetramethylphthalan* (II) was confirmed by reduction of the corresponding phthalide, fraction E (III) (see below).

Fraction C. M. p. 246—247° (from light petroleum) (Found: C, 78·6; H, 9·4. $C_{18}H_{26}O_2$ requires C, 78·8; H, 9·5%). The infrared spectrum had a band at 987 cm.$^{-1}$, stronger than the corresponding band in fraction A, and a sharper ultraviolet absorption ($\lambda_{max.}$ 2610, 2647, 2689, 2732, 2783; ε 3780, 5560, 7620, 8440, 8470) than that fraction. This evidence that the compound was the diphthalan, 1,1,3,3,5,5,7,7-*octamethyl*-1*H*,3*H*,5*H*,7*H*-*benzo*[1,2-*c*:4,5-*c*′]*difuran* (IV), was confirmed by its preparation from the phthalide-phthalan (V) (below).

Fraction D. M. p. 103—105° (from ethanol); no depression on admixture with 2,4,5-tri-isopropylacetophenone (m. p. 105—106°) [(Found: C, 82·5; H, 10·6. Calc. for $C_{17}H_{26}O$: C, 82·9; H, 10·8%); 2,4-*dinitrophenylhydrazone*, m. p. 215—217° (Found: C, 64·5; H, 7·2; N, 12·0. $C_{24}H_{30}N_4O_4$ requires C, 64·8; H, 7·0; N, 13·1%)], prepared by heating tetraisopropylbenzene with acetyl chloride and aluminium chloride in carbon disulphide under reflux.[7]

Fraction E. M. p. 124—125·5° (from benzene–light petroleum) (Found: C, 77·75; H, 8·8. $C_{16}H_{22}O_2$ requires C, 78·05; H, 8·9%). The infrared spectrum ($\nu_{max.}$ 1753 cm.$^{-1}$) supported the structure (III), 5,6-*di-isopropyl*-3,3-*dimethylphthalide*, and confirmation was provided by (*i*) reduction with lithium aluminium hydride, and (*ii*) reaction with methylmagnesium iodide.

(*i*) The phthalide (3 g.) in dibutyl ether was stirred and heated under reflux for 2 hr. with an excess of lithium aluminium hydride in the same solvent. The solution was cooled, treated with water, and worked up normally. The crude product (3 g.), crystallised from benzene–light petroleum, gave 1-*hydroxymethyl*-2-(1-*hydroxy*-1-*methylethyl*)-4,5-*di-isopropylbenzene* (VIII), m. p. 116·5—118° (Found: C, 77·3; H, 10·6. $C_{16}H_{26}O_2$ requires C, 76·8; H, 10·4%) [*monophenylurethane*, m. p. 155—156·5° (Found: C, 74·7; H, 8·7; N, 3·55. $C_{23}H_{31}NO_3$ requires C, 74·8; H, 8·4; N, 3·8%)].

(*ii*) The Grignard reagent from magnesium (0·9 g.) and methyl iodide (5 g.) in diethyl ether (55 c.c.) was heated under reflux for 1 hr. with the phthalide; normal working-up gave a solid, m. p. 186—188° (from ethanol) (Found: C, 83·2; H, 9·8. $C_{17}H_{24}O$ requires C, 83·6; H, 9·8%), considered to be 5,6-di-isopropyl-1,1-dimethyl-3-methylenephthalan (VII); it had $\nu_{max.}$ at 988 (phthalan) and at 1683 cm.$^{-1}$. Ozonolysis yielded the original phthalide (III).

The Grignard reagent was prepared as above, but with dibutyl ether (20 c.c.) as solvent, and heated under reflux for 2 hr. with the phthalide (0·5 g.). Normal working-up yielded a crude solid (0·7 g.) which provided 1,2-*di*-(1-*hydroxy*-1-*methylethyl*)-4,5-*di-isopropylbenzene* (X), m. p. 232—233° (from benzene) (Found: C, 77·1; H, 10·6. $C_{18}H_{30}O_2$ requires C, 77·7; H, 10·8%). On distillation at atmospheric pressure this gave the phthalan (II), m. p. 140—142°, undepressed on admixture with that from fraction B.

Fraction G. M. p. 215—216·5° (from benzene–light petroleum) (Found: C, 78·6; H, 9·4. $C_{18}H_{26}O_2$ requires C, 78·8; H, 9·5%); $\nu_{max.}$ 979 (phthalan), 1072, and 1753 cm.$^{-1}$ (phthalide), in agreement with the 3,3,5,5,7,7-*hexamethyl*-1*H*,3*H*,5*H*,7*H*-*benzo*[1,2-*c*:4,5-*c*′]*difuran*-1-*one* (V) structure, which was again confirmed by (*i*) reduction with lithium aluminium hydride, and (*ii*) reaction with methylmagnesium iodide.

(*i*) The compound (0·4 g.) was treated with lithium aluminium hydride in dibutyl ether, as above, to give 5-*hydroxymethyl*-6-(1-*hydroxy*-1-*methylethyl*)-1,1,3,3-*tetramethylphthalan* (IX), m. p. 191—193° (from benzene–ethyl acetate) (Found: C, 73·2; H, 9·25. $C_{16}H_{24}O_3$ requires C, 72·7; H, 9·1%) [*phenylurethane*, m. p. 183—185° (from aqueous ethanol) (Found: N, 3·8. $C_{23}H_{29}NO_4$ requires N, 3·7%)].

(*ii*) The phthalan-phthalide (0·3 g.) was treated, in boiling dibutyl ether, with the Grignard reagent from magnesium (0·6 g.) and methyl iodide (3 g.) in the same solvent. The crude product was sublimed from a flask without prior purification. The product was dissolved in light petroleum and purified by chromatography to give the diphthalan (IV), m. p. and mixed m. p. 245—246°, identified spectroscopically.

The nature of the other (trace) products from the chromatograms was not definitely established. Fraction A, only weakly adsorbed on alumina, before the phthalan (II), had m. p. 110—112°, and its infrared spectrum showed the presence of a phthalan system; in addition, absorption at 1235 cm.$^{-1}$ indicated an aromatic ether group. Fraction F, m. p. 134—142° (Found: C, 76·85; H, 8·3%), had phthalan and phthalide absorption bands. Fraction H, m. p. 123—125° (from ethanol), had absorption bands indicating the presence of phthalan and anhydride groups, but elementary analysis was not in agreement with this (Found: C, 65·4, 65·9, 66·6; H, 7·45, 7·6, 7·7. $C_{14}H_{14}O_4$ requires C, 68·3; H, 5·7%). Fraction I, m. p. 166—169° (Found: C, 77·0; H, 9·5%), was shown to contain a phthalan and hydroxyl groups. Fraction J, m. p. >340° (Found: C, 72·5; H, 7·15%), had a spectrum resembling that of the phthalan-phthalide but also contained hydroxyl. Fraction K contained a phthalide group; fraction L (Found: C, 76·8; H, 8·7%) had a spectrum rather similar to that of fraction F; fractions M (m. p. 160—170°), N (m. p. 223—234°), and O (m. p. 202—212°) all contained phthalan and hydroxyl groups and their spectra were rather similar to that of fraction I.

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