Decomposition of a 1-Hydroperoxynaphthalen-2(1*H*)-one by Bases

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The decomposition of 1-hydroperoxy-1-isopropylnaphthalen-2(1*H*)-one (1) by various bases has been studied. Complex redox and rearrangement processes lead to 1-hydroxy-1-isopropylnaphthalen-2(1*H*)-one (11), the *trans*-epoxide (12) of this enone, and the rearrangement product (14) of that epoxide, along with *r*-3,4-epoxy-3,4-dihydro-*c*-2-hydroxy-2-isopropylnaphthalen-1(2*H*)-one (15) and an acid resulting from oxidation and ring cleavage. Both intra- and inter-molecular oxygen transfers between the hydroperoxy and enone groups probably occur.

THE readily available [1] hydroperoxynaphthalenone (1) has a hydroperoxy-group, a carbonyl group, and an electron-deficient alkene system in close proximity. Several paths for breakdown in basic media could be predicted from past experience with simple hydroperoxides, with α-hydroperoxy-ketones, and with enones treated with a separate hydroperoxide. It is known that hydroperoxides exposed to certain bases can lose one oxygen atom either by substitution of HO⁻ for HOO⁻,[2] or by loss of oxygen gas [3] yielding alcohols; and certain hydroperoxycyclohexadienones have been observed to lose both oxygen atoms of the hydroperoxy-group to give the phenol from which they had been made by autoxidation.[4] It is well known [5] that α-hydroperoxy-ketones can be isomerised by bases to oxo-acids, either *via* a dioxetan or by fragmentation of the adduct of hydroxide ion or other base with the ketone

[1] J. Carnduff and D. G. Leppard, *Chem. Comm.*, 1967, 829; *J.C.S. Perkin I*, 1976, 2570.

[2] (*a*) M. S. Kharasch and B. S. Joshi, *J. Org. Chem.*, 1957, **22**, 1439; (*b*) U. Cuntze, H. Musso, and R. Zunker, *Chem. Ber.*, 1969, **102**, 2862; (*c*) H. Musso and D. Maasen, *Annalen*, 1965, **689**, 93.

[3] R. Hiatt in 'Organic Peroxides,' vol. II, ed. D. Swern, Wiley, New York, 1971, p. 77.

[4] H. R. Gersmann and A. F. Bickel, *J. Chem. Soc.*, 1959, 2711; 1962, 2356; A. Nishinaga, T. Itahara, T. Shimizu, and T. Matsuura, *Tetrahedron Letters*, 1976, 2467.

[5] Y. Sawaki and Y. Ogata, *J. Amer. Chem. Soc.*, 1975, **97**, 6983.

(Scheme 1). If a dioxetan is formed and decomposes thermally by a concerted pericyclic process, an excited state of one of the carbonyl products should be formed; the decompositions in base of certain α-hydroperoxy-esters and certain α-hydroperoxy-imines have been found to produce light under certain conditions.[6] The
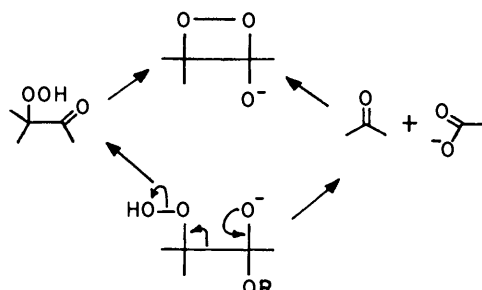
SCHEME 1

epoxidation of enones by hydroperoxides and base is also well known.[7] A molecule containing both groups could undergo intramolecular self-epoxidation leading to an isomeric epoxy-oxo-alcohol or intermolecular epoxidation leading to an alcohol and a hydroperoxy-epoxide which could, of course, undergo further reactions.

Since the preliminary communication [8] of our findings with the hydroperoxide (1), Maumy [9] has reported that


(1)

(2)   (5)

(3)   (4)
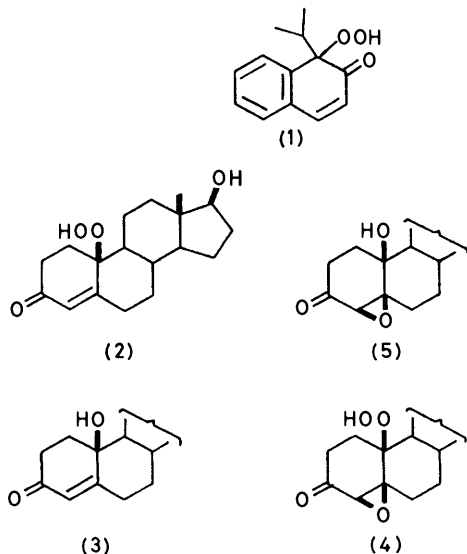
the γ-hydroperoxy-enone (2) is decomposed by methanolic sodium hydroxide to give 95% of the epoxy-oxo-alcohol (5) in which the epoxide and hydroxylic groups are cis-disposed. The reaction is not however a simple intramolecular process, since milder base produces the redox products (3) and (4) of intermolecular oxygen transfer, which were isolated and shown to react together to give

the cis-epoxy-oxo-alcohol. He states that epoxidation of the enone (3) from the β-face is to be expected and finds β-epoxidation to be the sole path when alkaline hydrogen peroxide is the oxidant. The high yield and stereospecificity in the decomposition of the hydro-peroxide are remarkable for such a complex reaction offering so many alternatives.

Nishinaga has recently described the behaviour of the anions of a number of hydroperoxycyclohexadienones obtained as intermediates in the autoxidation of alkyl-phenols in various basic media. When phenols such as 2,4,6-tri-t-butylphenol were oxygenated in diethylamine containing sodamide, he obtained good yields of 4-hydroxycyclohexadienones (7), presumably arising by oxygen loss from the initially formed oxocyclohexa-dienylperoxide anion (6).[10] Oxygenation of the same phenol in dimethylformamide containing potassium t-butoxide gave quantitatively an epoxy-alcohol (8) which

(6)   (7)

(8)
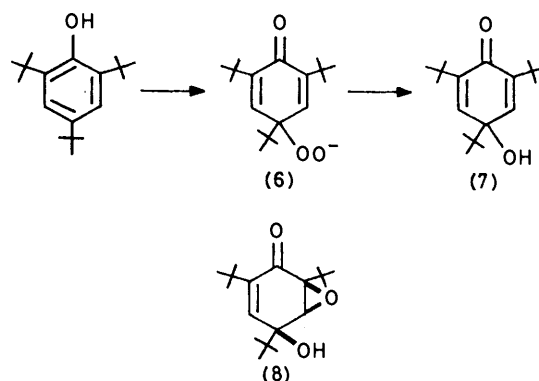
was assumed to arise by an intramolecular self-epoxid-ation and therefore to have the oxygens cis-disposed.[11] Similar assumptions are made in reports on related oxygenations.[12,13]

Yet another decomposition mode is reported by Musso,[2c] who finds that the hydroperoxycyclohexa-dienone (9) is dehydrated by hot concentrated potassium hydroxide solution with shift of one alkyl group to give the enedione (10).

(9)   (10)
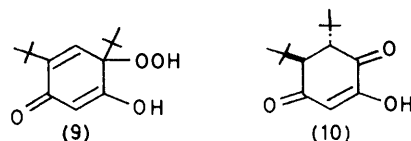
When the hydroperoxynaphthalenone (1) was treated with sodium hydroxide in aqueous ethanol we isolated four neutral and one acidic product. The four neutral components were separated by chromatography and are here designated A—D in order of elution. Component B (23% yield) was easily identified as the enone alcohol

[6] F. McCapra, Progr. Org. Chem., 1973, 8, 256.
[7] Y. Sprinzak, J. Amer. Chem. Soc., 1958, 80, 5449; N. C. Yang and R. A. Finnegan, ibid., p. 5845.
[8] J. Carnduff and D. G. Leppard, Chem. Comm., 1971, 975.
[9] M. Maumy, Bull. Soc. chim. France, 1974, 2895.
[10] A. Nishinaga, T. Itahara, and T. Matsuura, Bull. Chem. Soc. Japan, 1975, 48, 1683.

[11] A. Nishinaga, T. Itahara, and T. Matsuura, Chem. Letters, 1974, 667.
[12] A. Nishinaga, T. Itahara, and T. Matsuura, Tetrahedron Letters, 1974, 4481.
[13] A. Nishinaga, T. Itahara, T. Matsuura, A. Rieker, and D. Koch, Angew. Chem. Internat. Edn., 1976, 15, 160; A. Nishinaga and A. Rieker, J. Amer. Chem. Soc., 1976, 4667.

(11) previously obtained by reduction of the hydro-peroxide.[1] This material is expected as a product of oxygen loss, of substitution by hydroxide ion, or of intermolecular oxygen atom transfer.

Component A (3% yield) is an oxo-alcohol isomeric with the hydroperoxide. The carbonyl group, absorbing at 1 710 cm⁻¹, appears to be in a six-membered ring and not conjugated to any other functional group. The u.v. spectrum indicates that the benzene ring is not conjugated to any other functional group and the n.m.r. spectrum shows signals for two aliphatic protons as an AB quartet (J 4 Hz) at τ 5.8 and 6.2 compatible with oxiran protons. The structure (12) agrees with this evidence, and compound A was found to be identical with the product (12) of epoxidation of enone (11) with alkaline hydrogen peroxide. This epoxidation gives a

(11)   (12)   (14)

(13)   (15)

(16)   (17)
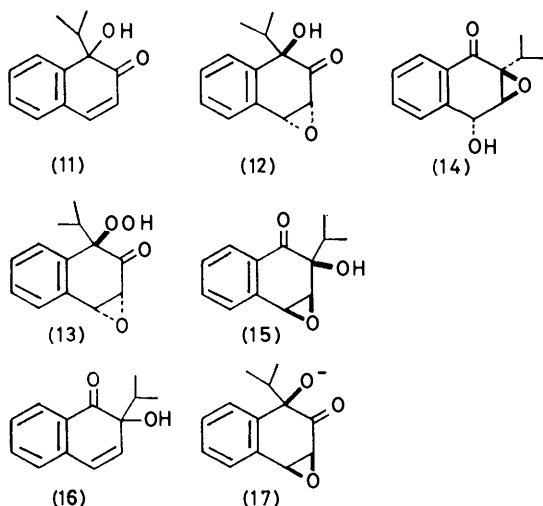
single epoxide in good yield and we have allocated to it the *trans*-stereochemistry shown on the basis of a re-arrangement reaction.[14] Such a product (12) is to be expected from an intermolecular self-epoxidation of the hydroperoxide followed by epoxidation of one product (11) by the other (13). The hydroperoxy-epoxide (13) has not been isolated but its anion would be expected to epoxidise the enone (11) from the same face as does alkaline hydrogen peroxide and it would itself be reduced to the epoxide (12). The formation of (13), rather than its diastereoisomer, in the intermolecular self-epoxidation of the hydroperoxide may also be akin to the exclusive formation of (12) from (11) with alkaline hydrogen peroxide.

Component D (9% yield) was another epoxy-oxo-alcohol isomeric with (1) and (12). It was identical with the substance (14) obtained [14] from the rearrange-ment of (12) with sodium carbonate or potassium t-butoxide. Presumably it arises here by similar base-induced rearrangement of the product A (12).

*A referee has emphasised that the *endo*-peroxy-enolate ion, intermediate in such an intramolecular epoxidation, has limited conformational mobility and a geometry less than perfect for the ring closure step to (17). We consider that the intramolecular process is possible and, until further evidence is available, offers the simplest explanation.
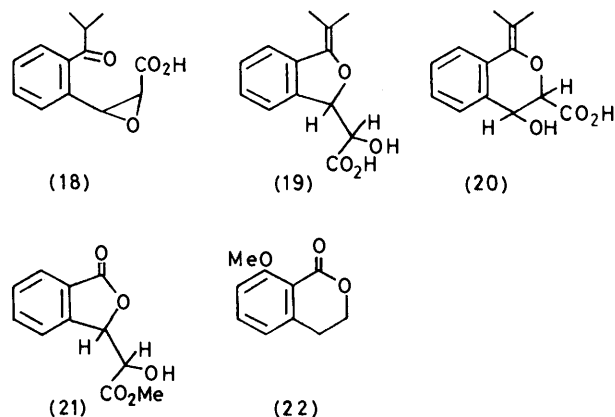
The remaining neutral product (C) (20% yield) was yet another epoxy-oxo-alcohol isomeric with (1). The i.r. absorption at 1 700 cm⁻¹ and the u.v. spectrum indicate that the carbonyl group is conjugated to the benzene ring. Neither of the oxiran protons (τ 5.93 and 6.13, both d, J 4 Hz) is coupled to any other proton. It appears that the isopropyl group has migrated in a ketol rearrangement and the *cis*-structure (15) seems a likely candidate. [The stereoisomer of (15) is the presumed intermediate in the base-induced rearrange-ment of (12) to (14).[14]] An independent synthesis of (15) was sought in the deliberate ketol rearrangement of (11) to (16) and epoxidation of this allylic alcohol with a peroxy-acid. Such epoxidations of 3-hydroxycyclo-alkenes give hydroxy-epoxides in which the hydroxy and oxiran oxygens are *cis* on the ring.[15] In the event treatment of ketol (11) with sodium ethoxide in methanol gave a 1 : 3 mixture of the two isomers from which most of the starting ketone (11) crystallised leaving the major component (16) as an oil. Epoxidation of this with *m*-chloroperbenzoic acid at room temperature gave in good yield a material identical with component C from the decomposition of the hydroperoxide. The formation of the rearranged *cis*-epoxide (15) from the hydroperoxide (1) is most simply explained by an intramolecular self-epoxidation of the anion of (1) * leading to the anion (17) and ketol rearrangement giving the more stable conjugated ketone (15). Formation of (17) by an intermolecular epoxidation, of (11) by (1) or (13), would not be in accord with the observed *trans*-epoxidation of (11) by alkaline hydrogen peroxide.

The acidic materials from decomposition of the hydroperoxide (1) consisted of a trace of hydrogen carbonate-insoluble material which was not examined and a hydrogen carbonate-soluble material F (25% yield). The acid F is only slightly soluble in organic solvents but its methyl ester was made with diazo-methane and found to be a tractable crystalline solid. The analysis and the mass spectrum of the ester show that the acid has the formula ($C_{13}H_{14}O_4$) of a product of oxidation of the hydroperoxide. The acid might there-fore arise by cleavage of the α-hydroperoxy-ketone group of the redox product (13). This would lead to the isobutyrylcinnamic acid epoxide (18), but the spectra were not compatible with this structure. The i.r. spectrum of the methyl ester shows an alcohol hydroxy-band at 3 510 cm⁻¹ and only one carbonyl band (ester at 1 735 cm⁻¹); its n.m.r. spectrum shows two methyl singlets at τ 8.03 and 8.17 suggesting an isopropylidene group. The hydroxy-proton is coupled (J 8 Hz) to one methine proton at 5.52, which is coupled (J 2 Hz) to a neighbouring methine proton at 4.35. The two struc-tures (19) and (20) for the acid are compatible with this spectral evidence and could reasonably arise by attack on the epoxide by the enolate ion of the isobutyryl group of (18).

[14] J. Carnduff and D. G. Leppard, *Chem. Comm.*, 1968, 822; preceding paper.
[15] G. Berti, *Topics Stereochem.*, 1973, **7**, 93.

A decision between these structures could not be made on the basis of the spectral data. An attempt to use the success or failure of oxidation by periodate to decide between the α-hydroxy- and the β-hydroxy-acid structures failed. Periodate caused degradation to a material which gives spectra suggesting that it is 2-isobutyryl-benzaldehyde. Oxidation of the enol ether double bond of the methyl ester of F with either ozone or ruthenium tetraoxide removed the isopropylidene group and produced a lactone still containing the ester and secondary alcohol groups. This lactone was assigned the γ-lactone structure (21) on the basis of two observations. The
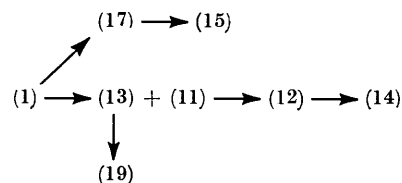
(12) and thence (14). More than half (13) reacts with the base giving (19) and some of the (11) formed may arise directly from (1) by S_N replacement of OOH by OH or by oxygen loss (Scheme 2).

SCHEME 2

A brief survey was made of the effects of other bases on the hydroperoxide (1). Sodium methoxide gave the same four neutral products as sodium hydroxide. The methyl ester of F was not detected. Potassium t-butoxide in benzene gave (11) (30%) and (15) (30%) but not the others, and sodium hydride in dimethoxy-ethane gave (11) (18%), (15) (10%), and acidic material which was not studied. No conditions could be found under which the base-induced decomposition of (1) was chemiluminescent.

lactone carbonyl group absorbs at 1 784 cm⁻¹ in carbon tetrachloride. Phthalide and 7-methoxyphthalide are reported [16] to absorb at 1 782 cm⁻¹ in this solvent, whereas the isocoumarin (22) absorbs at 1 741 cm⁻¹. Secondly, when the lactone ester was hydrolysed in alkali, reacidification yielded a lactone acid which was re-esterified with diazomethane to give back the starting lactone ester. Such recyclisation on acidification is typical of a γ-lactone.

These observations on the lactone establish that the acid F has the structure (19). A more careful study of the n.m.r. spectrum of the ester of (19) revealed a small coupling between the ester methyl protons and the carbinol proton. Couplings of 0.2 Hz have been observed [17] in methyl esters with protons on the α-carbon atom. A small coupling was also observed between the benzylic proton of the ester of (19) and one of the isopropylidene methyl groups. None of this evidence confirms the stereochemistry of F. The pathway from (1) to (19) probably involves epoxidation of (1) giving (13) and cleavage via a dioxetan to (18) followed by S_N2 attack by the enolate on the epoxide. The alternative that ring cleavage precedes epoxidation is less likely. 2-Isobutyrylcinnamic acid was made by periodate cleavage of (11) but it did not react with alkaline hydrogen peroxide.

The overall pattern for the breakdown of the hydroperoxide (1) in aqueous ethanolic sodium hydroxide thus appears to involve intramolecular oxygen transfer giving (15) via (17) and intermolecular oxygen transfer giving (11) and (13) which to a minor extent react giving

[16] J. Blair and G. T. Newbold, J. Chem. Soc., 1955, 2871.

EXPERIMENTAL

M.p.s were taken with a Kofler hot-stage apparatus. Unless otherwise stated u.v. spectra were measured for solutions in ethanol and i.r. spectra for Nujol mulls. N.m.r. spectra were run for solutions in deuteriochloroform with tetramethylsilane as internal standard. Light petroleum refers to the fraction b.p. 60—80 °C. T.l.c. was carried out on Kieselgel G with 20% ethyl acetate in light petroleum unless otherwise stated.

Decomposition of the Hydroperoxide (1) *with Aqueous Sodium Hydroxide.*—A mixture of 1-hydroperoxy-1-iso-propylnaphthalen-2(1H)-one (2 g), ethanol (50 ml), water (50 ml), and sodium hydroxide (2 g) was stirred at room temperature for 3 h, diluted with water, and extracted with ether. The ether layer yielded a mixture which was separated by chromatography on silica with petroleum–diethyl ether mixtures of increasing polarity to yield components A (12) (0.06 g), B (11) (0.485 g), C (15) (0.41 g), and D (14) (0.185 g) in that order. The aqueous layer was acidified and extracted with ether and the extract washed with sodium hydrogen carbonate solution. Acidification of the hydrogen carbonate layer and extraction into ether yielded the crude acid F (0.35 g). The properties of the alcohol (11) and epoxides (12) and (14) were as previously described.[1,14] Component C, r-3,4-*epoxy*-3,4-*dihydro*-c-2-*hydroxy*-2-*isopropylnaphthalen*-1(2H)-*one* (15) crystallised from ethanol; m.p. 123—124°, $\lambda_{max.}$ 253 and 293 nm (ε 7 600 and 1 230), $\nu_{max.}$ (CCl₄) 3 500 and 1 700 cm⁻¹, τ 9.28 (3 H, d, J 7 Hz), 9.02 (3 H, d, J 7 Hz), 8.20 (1 H, sept, J 7 Hz), 6.30 (1 H, s), 6.13 (1 H, d, J 4 Hz), 5.93 (1 H, d, J 4 Hz), and 2.8—2.0 (Found: C, 71.25; H, 6.5. C₁₃H₁₄O₃ requires C, 71.55; H, 6.4%).

Synthesis of the Epoxide C (15).—1-Hydroperoxy-1-iso-propylnaphthalen-2(1H)-one (1) (2.4 g) was dissolved in methanol (100 ml) containing sodium methoxide [from sodium (1.0 g)]. After 90 min at room temperature the mixture was diluted with water and extracted with ether. The ether layer was dried and evaporated; the residue

[17] K. Hayamizu and O. Yamamoto, J. Mol. Spectroscopy, 1967, 22, 119.

partly crystallised. The supernatant oil was diluted with petroleum and separated from the crystals. Evaporation of the petroleum layer left almost pure 2-hydroxy-2-isopropylnaphthalen-1(2H)-one (16), $\lambda_{max.}$ 235, 268, 278, 288, and 318 nm, $\nu_{max.}$ 3 520 and 1 675 cm^{-1}, τ 9.16 (3 H, d, J 7 Hz), 9.14 (3 H, d, J 7 Hz), 8.1 (1 H, sept, J 7 Hz), 6.7br (1 H, s), 3.78 (1 H, d, J 10 Hz), 3.52 (1 H, d, J 10 Hz), and 3.0—2.0 (4 H, m). At 20 °C this oil was slowly and partially reconverted into its isomer. This ketol (16) (0.5 g) was dissolved in methylene chloride (20 ml) and treated with m-chloroperbenzoic acid (1.5 g) for 24 h at room temperature. The solution was washed with aqueous sodium sulphite and then with aqueous sodium hydrogen carbonate, dried, and evaporated. Crystallisation from ethanol gave the epoxide C (0.41 g, 75%), m.p. 122—123°.

Methyl Ester of the Acid F.—The crude acid F obtained from the hydroperoxide (1) was dissolved in ether and treated with a slight excess of diazomethane at 0 °C. Evaporation left a residue which crystallised from ether–petroleum yielding *methyl* 2-(1,3-*dihydro*-3-*isopropylidene-isobenzofuran*-1-*yl*)*glycolate* as crystals, m.p. 106.5—107.5°, $\lambda_{max.}$ 279 (ε 11 000), $\nu_{max.}$ (Nujol) 3 510 and 1 730 cm^{-1}, τ 8.17 (3 H, s), 8.03 (3 H, s), 7.22 (1 H, d, J 8 Hz), 6.15 (3 H, s), 5.52 (1 H, dd, J 8 and 2 Hz), 4.35br (1 H, s), and 2.8—2.4 (4 H, m) (Found: C, 67.6; H, 6.5. $C_{14}H_{16}O_4$ requires C, 67.7; H, 6.5%). On addition of D_2O the n.m.r. doublet at 7.22 disappeared and the double doublet at 5.52 became a doublet. Several double irradiation experiments were carried out at 100 MHz. Irradiation at τ 8.03 causes the singlet at 4.35 to split into a doublet. Irradiation at τ 4.35 causes collapse of the 5.52 band to a simple doublet (J 8 Hz).

Oxidation with Ruthenium Tetraoxide.—The foregoing methyl ester (0.36 g) was dissolved in carbon tetrachloride (50 ml) and treated with a solution of ruthenium tetraoxide in carbon tetrachloride. After 2 h the ruthenium dioxide was removed, reoxidised, and introduced again into the ester solution. This recycling procedure [18] was continued until oxidation was complete (no further production of brown RuO_2). After addition of propan-2-ol and removal of the RuO_2, the solution was evaporated leaving an oil (0.29 g). Crystallisation from ether–petroleum gave *methyl* 2-(*phthalid*-3-*yl*)*glycolate* (21), m.p. 134—136°, $\nu_{max.}$ (Nujol) 3 520, 1 784, and 1 745 cm^{-1}, τ 6.9vbr (1 H), 6.16 (3 H, s), 5.34br (1 H, s), 4.20 (1 H, d, J 2 Hz), and 2.6—1.9 (4 H, m) (Found: C, 59.3; H, 4.5. $C_{11}H_{10}O_5$ requires C, 59.45; H, 4.55%). On addition of D_2O the broad band at 6.9 disappears and the band at 5.34 sharpens to a doublet (J 2 Hz). The same lactone ester was obtained by ozonolysis at -50 °C. The lactone ester was dissolved in aqueous sodium hydroxide and then reacidified to give a lactone acid, m.p. 208—210°, which with diazomethane gave back the original lactone ester.

[18] P. J. Beynon, P. M. Collins, P. T. Doganges, and W. G. Overend, *J. Chem. Soc.* (C), 1966, 1131.