Benzofurazan *N*-Oxides as Synthetic Precursors. Part 2.[1a] Conversion of Benzofurazan *N*-Oxides into 2*H*-Benzimidazoles and Some Unusual Reactions of 2*H*-Benzimidazoles [1b,c]

By **D. W. S. Latham, O. Meth-Cohn,* H. Suschitzky,** and (in part) **J. A. L. Herbert,** The Ramage Laboratories, Department of Chemistry and Applied Chemistry, University of Salford, Salford M5 4WT, Lancashire

Benzofurazan *N*-oxides react with primary nitroalkanes to give 1-hydroxybenzimidazole 3-oxides; with secondary nitroalkanes, red 2,2-dialkyl-2*H*-benzimidazole 1,3-dioxides are formed. The 2*H*-benzimidazole oxides react as bis-1,3-dipolar nitrones with acetylenic dipolarophiles (methyl acetylenedicarboxylate and benzyne) but undergo a complex series of redox reactions with tetracyanoethylene giving purple quinonoid dicyanomethylene derivatives, also formed by the action of the malononitrile anion. *O*-Alkylation of the 2*H*-benzimidazole oxides occurs with methyl fluorosulphate, and irradiation results in rearrangement to *O*-2-nitrophenylhydroxylamine derivatives.

THE interaction of benzofurazan *N*-oxides (1) with a wide variety of carbanions has been thoroughly investigated and leads to quinoxaline di-*N*-oxides, benzimidazole *N*-oxides, and related systems.[2] However, reactions with nitroalkanes had not been reported until recently.[3] We describe here the formation of 1-hydroxybenzimidazole 3-oxides (3) and 2*H*-benzimidazole 1,3-dioxides (5) by the action of primary (2) and secondary nitroalkanes (4), respectively, on benzofurazan *N*-oxides.

Preparation and Structure of 2H-*Benzimidazole* 1,3-*Dioxides*.—Benzofurazan *N*-oxide (1) reacts readily with primary nitroalkanes in the presence of a base. Reproducible yields (60—70%) of the white products (3) could be obtained by boiling a solution of the reagents with 1 equiv. of triethylamine in chloroform. Commercial samples of primary nitroalkanes have a red colour during this reaction, due to the presence of small amounts of the secondary nitro-analogues (usually 2-nitropropane as shown by g.l.c.). Indeed, this reaction is a useful colour test for secondary nitroalkanes. The hydroxybenzimidazole *N*-oxides (3) are known, but our reaction is the method of choice for their synthesis. With only catalytic amounts of base a mixture of the parent benzimidazole, its mono-*N*-oxide, and its di-*N*-oxide (3) is obtained. It appears that the base acts as a trap for the eliminated nitrous acid, which can be shown to reduce the *N*-oxides successively. A probable

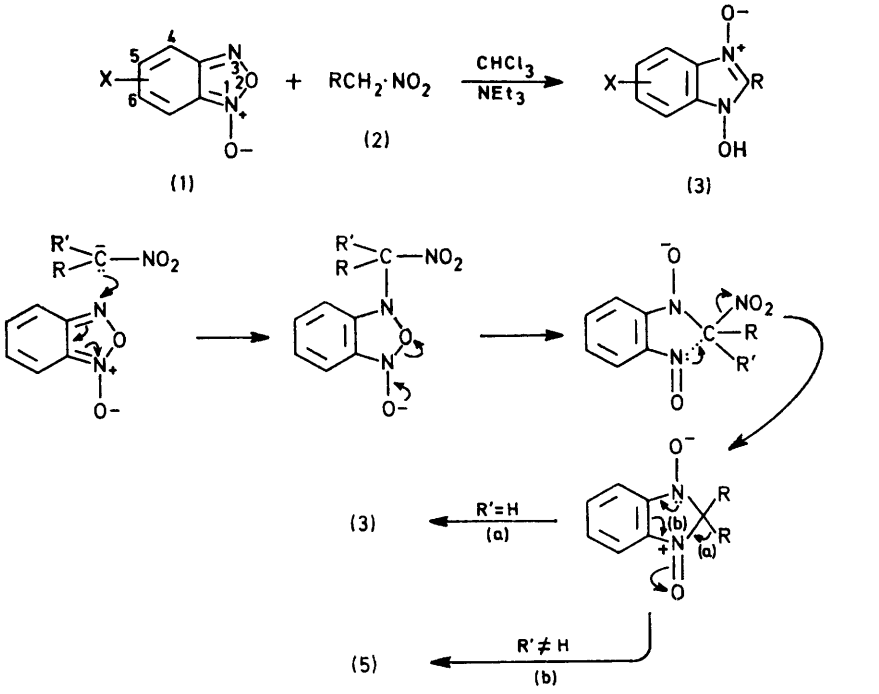
[1] (*a*) D. W. S. Latham, O. Meth-Cohn, and H. Suschitzky, *J.C.S. Perkin I*, 1976, 2216 is considered as Part 1; preliminary communications, (*b*) D. W. S. Latham, O. Meth-Cohn, and H. Suschitzky, *J.C.S. Chem. Comm.*, 1972, 1040; (*c*) J. A. L. Herbert, D. W. S. Latham, O. Meth-Cohn, and H. Suschitzky, *ibid.*, p. 1302.

[2] See, for example, K. Ley and F. Seng, *Synthesis*, 1975, 415.

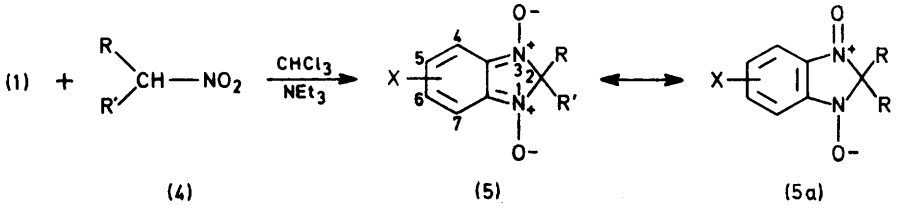
[3] M. J. Abu-el-Haj, *J. Org. Chem.*, 1972, **37**, 2519.

mechanism, in line with other related carbanion reactions of benzofurazan *N*-oxide, is outlined in Scheme 1.

The reaction of benzofurazan *N*-oxide with secondary nitroalkanes in the presence of base is exothermic and leads in most cases to the deep red 2,2-dialkyl-2*H*-benzimidazole 1,3-dioxides (5) in >80% yield when conducted below 30 °C in chloroform solution and with 1.2 equiv. of triethylamine. Thus 5-chloro-, 5-bromo-, 5-methoxy-, and 5-trifluoromethyl derivatives (5) were readily prepared and 2-substituents (R and R′) utilised



SCHEME 1



include alkyl (R = R′ = Me), polymethylene (RR′ = $[CH_2]_4$ or $[CH_2]_5$), and alkyl and aryl (R = Me, R′ = Ph). However, the reaction was ineffective with 5(6)- or 4(7)-nitrobenzofurazan *N*-oxide, giving only tarry products.

The products (5), which owe their colour to the extended conjugation indicated in such mesomeric forms as (5a) (*cf.* mesomerism in *o*-nitroaniline), were identified both spectroscopically and chemically. Thus the simplest example (5; X = H, R = R′ = Me) is readily soluble both in water and in petroleum, gives a simple AA′BB′ ^{1}H n.m.r. spectrum for its aromatic protons and a singlet for the methyl groups (τ 8.38), yields acetone (but not *o*-nitroaniline) on hydrolysis with 4M-hydrochloric acid (characterised as its 2,4-dinitrophenyl-

hydrazone), is converted into *o*-phenylenediamine on catalytic reduction (Pd–C), and is resistant to further oxidation (H_2O_2 or MnO_2). It is reduced stepwise with sodium borohydride to give a mono-*N*-oxide (6) and then the unstable parent 2*H*-benzimidazole (7). In the case of the pentamethylene derivative (5; X = H, R = R′ = $[CH_2]_5$) the borohydride reduction gives the known 2*H*-benzimidazole [4] which is converted into the corresponding mono- or di-*N*-oxide on oxidation with *m*-chloroperbenzoic acid. The ^{13}C n.m.r. spectra of the di- and mono-*N*-oxides are also in accord with their structures (Table 1). In particular that of the di-*N*-oxide (5; X = H, R = R′ = Me) supports a symmetrical structure, showing signals for three aromatic carbons (two bearing a hydrogen atom and one not, from the off-resonance spectrum), one methyl signal, and a diagnostic quaternary sp^3 carbon resonance at 96.78 p.p.m. for C-2. These results rule out the alternative structures (8) and (9).

The formation of the 2*H*-benzimidazoles (5) is readily rationalised by a mechanism analogous to that shown (Scheme 1) for the 1-hydroxybenzimidazole 3-oxides. Small amounts of the yellow mono-*N*-oxide (6) sometimes

[4] R. Garner, G. V. Garner, and H. Suschitzky, *J. Chem. Soc.* (*C*), 1970, 825.

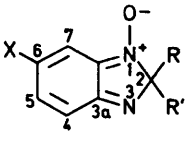
accompanied the di-*N*-oxide (5) during the preparation. This agrees with the tendency for the di-*N*-oxide to undergo deoxygenation slowly in warm solvents. These mono-*N*-oxides may be isolated in high yield by reduction of the di-*N*-oxide with 1 equiv. of sodium borohydride in ethanol. The possibility of either of these compounds [(5) or (6)] being stable radicals was ruled out by e.s.r. experiments on both the solids and the solutions.

Thus the *N*-oxide function has been shown to behave as a 1,3-dipole in reactions with acetylenedicarboxylates.[5] When the di-*N*-oxide (5; X = H, R = R′ = Me) was treated with 3 equiv. of dimethyl acetylenedicarboxylate (DMAD) at room temperature in benzene, the red colour faded after 48 h in the dark and evaporation caused precipitation of a crystalline solid, which gave analytical and mass spectral evidence to indicate a 2 : 1 adduct of DMAD and (5). It showed strong carbonyl i.r. absorptions (1 765 and 1 740 cm^{-1}) as well as a peak at

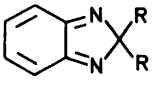
TABLE 1

^{13}C N.m.r. data for compounds (5), (6), and (14)

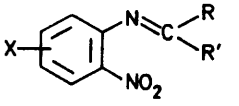
Compound			δ_C (p.p.m.) from Me_4Si and off-resonance multiplicity							
No.	R,R′	X	H-2	H-3a	H-4	H-5	H-6	H-7	H-7a	Other
(5)	Me, Me	H	96.8s	136.4s	115.6d	130.7d	130.7d	115.6d	136.4s	24.1q (Me)
(5)	Me, Me	5-Cl	97.8s	135.7s	114.5d	137.1s	132.2d	116.9d	134.9s	24.1q (Me)
(5)	Me, Me	5-OMe	97.5s	136.3s	90.4d	162.0s	128.6d	116.6d	134.2s	56.2q (OMe), 24.1q (Me)
(5)	Me, Ph	H	99.4s	137.4s	115.8d	131.1d	131.1d	115.8d	137.4s	133.s (Ph, C-1), 130.1d (Ph, C-4), 129.1d (Ph, C-2 and -6), 126.2 (Ph, C3- and -5), 24.3 (Me)
(5)	$[CH_2]_4$	H	104.8s	136.8s	115.5d	130.4d	130.4d	115.5d	136.8s	39.7t and 26.6t (CH_2)
(6)	Me, Me	H	102.4s	162.3s	125.8d	135.5d	128.4d	116.9d	134.5s	23.7q (Me)
(6)	$[CH_2]_5$	H	104.9s	162.2s	125.6d	135.0d	128.0d	116.7d	135.0s	34.9t and 23.6t ($[CH_2]_2$), 24.8t (CH_2)
(14)			93.0	114.2	125.0	129.0	147.6	87.7	114.2	25.0 (Me), 155.3 and 156.4 (CN), 64.3 [*C*$(CN)_2$]



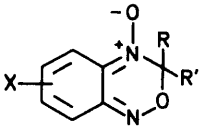
(6)



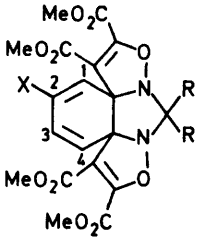
(7)



(8)

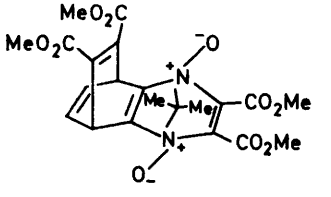


(9)

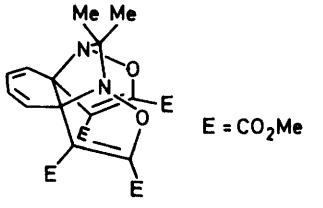


(10)

a; X = H, R = Me
b; X = Br, R = Me
c; X = H, RR = $[CH_2]_5$



(11)



E = CO_2Me

(12)

5 S. Takahashi and H. Kano, *J. Org. Chem.*, 1965, **30**, 1118.

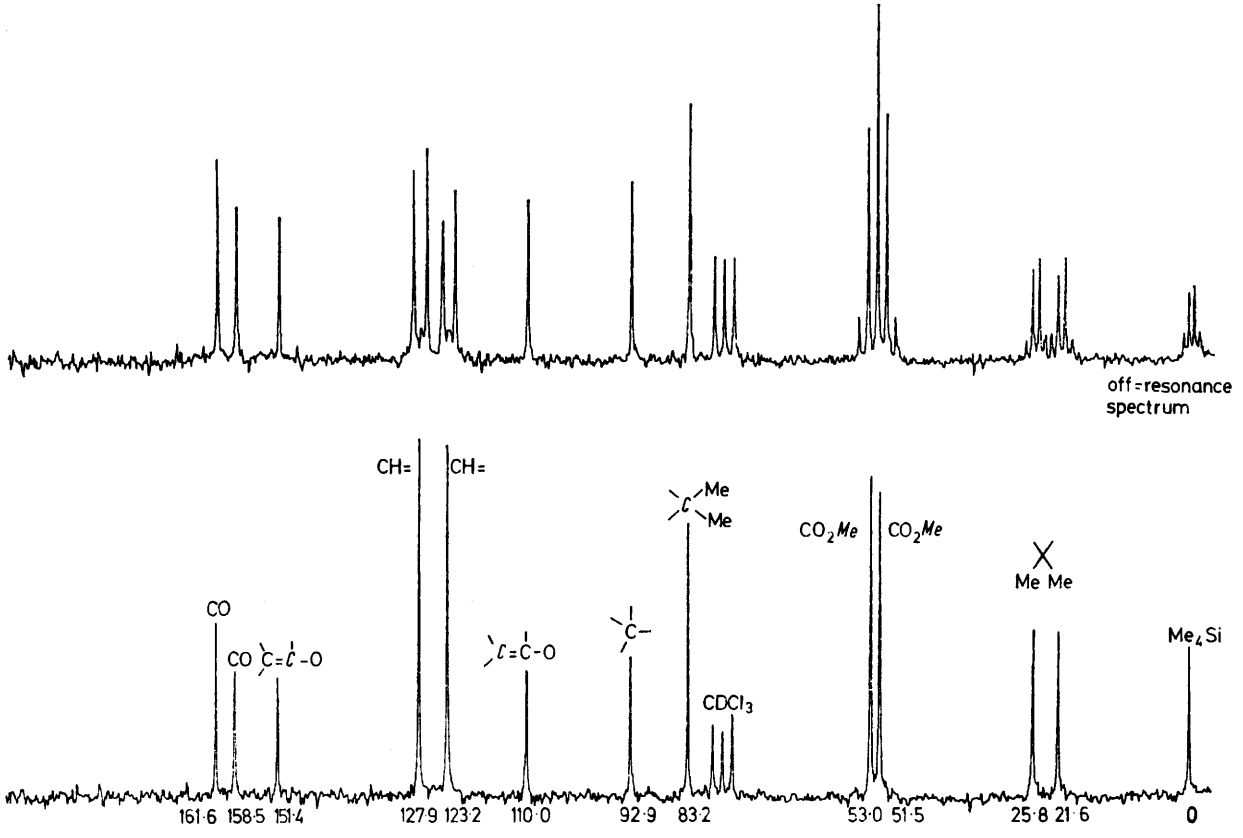
Benzimidazole *N*-oxides has been thoroughly explored.

Reactions of the 2H-*Benzimidazole* 1,3-*Dioxides*.—(A) *With acetylenic dienophiles*. The chemistry of

1 670 cm^{-1}, assigned to conjugated C=C. The ^1H n.m.r. spectrum is composed of five singlets, two of three protons each (τ 8.63 and 8.22) suggestive of the *gem*-dimethyl group, two of six protons each (τ 6.35 and 6.11) indicative of methyl ester groups, and a broader 4-proton signal (τ 3.91) appropriate for olefinic protons. Two structures in particular fit this information, (10a) and (11) (the latter being suggested in our preliminary communication).[1c]

Structure (10a) would be formed by a double 1,3-dipolar reaction, whereas (11) would be derived from a double Diels–Alder reaction (in which the first cycloaddition must involve the homocyclic ring otherwise aromatisation would have ensued). Several subsequent pieces of evidence ruled out (11) and confirmed the unusual bis-isoxazole structure; for example (*a*) the product did not respond to a Coates–Katritzky *N*-oxide test and was not reduced with sodium borohydride or triethyl phosphite; (*b*) the 2*H*-benzimidazole (7; RR = $[CH_2]_5$) did not react with DMAD even in the presence of boron trifluoride; (*c*) the mass spectrum did not show $M - 16$ and $M - 32$ signals. The most conclusive evidence came from the ^{13}C n.m.r. spectrum, in particular the proton-noise-decoupled off-resonance spectrum. In the two structures (10a) and (11) a major difference lies in the hybridisation of the four methine (CH) carbon atoms. In (10a) four sp^2-hybridised carbon atoms (two pairs) are present, whereas (11) contains two sp^2- and two sp^3-hybridised carbons. Since signals of sp^3 carbon not attached to a hetero-atom generally occur to high field of *ca.* 70 p.p.m., whereas isolated sp^2 carbon atoms absorb at *ca.* 120 p.p.m., the presence of two doublets in the off-resonance spectrum at 123.2 and 127.9 p.p.m. rules out structure (11). The full assignment is in complete agreement with the bis-isoxazole structure (10a) (see Figure). Models indicate that this compound can only arise by *cis*-addition of the DMAD to give the stereoisomer (12).

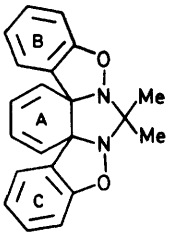
Several related compounds (10b and c) were prepared from the derivatives (5) as well as the adduct of the di-*N*-oxide (5) with benzyne (generated from 1-aminobenzotriazole with lead tetra-acetate), to which we assign the analogous structure (13) by comparison of n.m.r. and mass spectra (Experimental section). However, the di-*N*-oxides (5) did not react with diphenylacetylene, diethyl azodiformate, maleic anhydride, ethyl acrylate, or methyl vinyl ether even when hot.



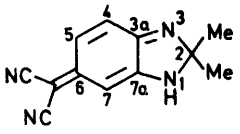
^{13}C N.m.r. spectrum of the acetylenedicarboxylate adduct (10a) [≡ (12)]

(B) *With tetracyanoethylene and carbanions.* The reaction of the di-*N*-oxide (5; X = H, R = R′ = Me) with tetracyanoethylene (TCNE) only proceeded in ethanol and required refluxing for 6 h to give a purple product (14) incorporating the di-*N*-oxide moiety less its oxygen atoms, together with half the tetracyanoethylene. The corresponding deoxygenated analogue (7; R = Me) as well as its dihydro-derivative (15), underwent the same type of reaction rapidly at ambient

temperature to give the same purple product; the mono-*N*-oxide (6) was of intermediate reactivity. Since we have already commented on the *N*-oxides losing



(13)

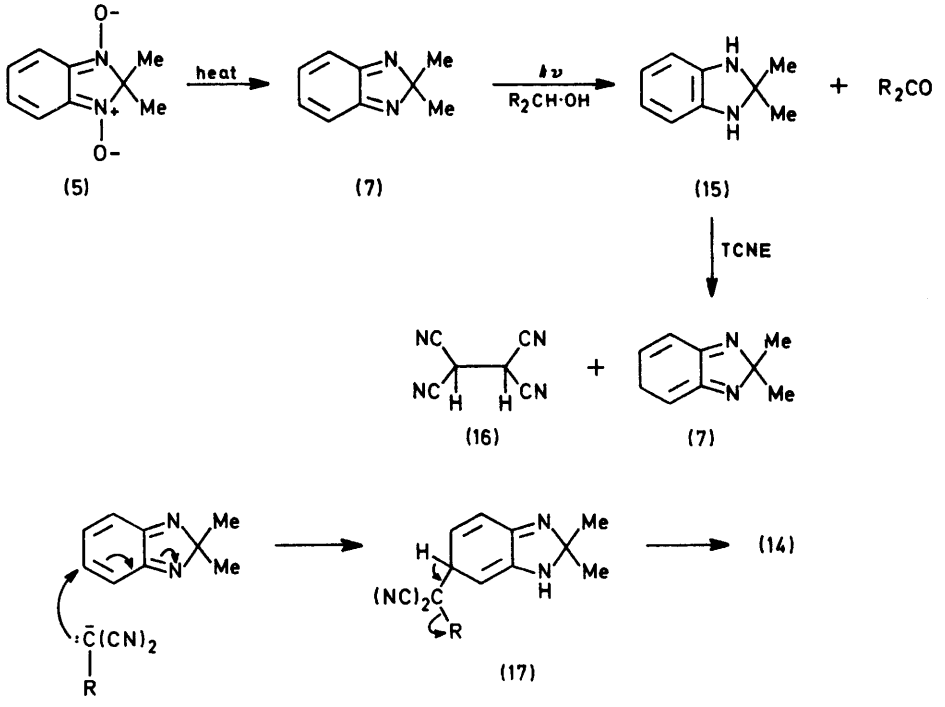


(14)

oxygen on heating in solution it seems reasonable that this product is derived in both cases from the 2*H*-benzimidazole (7).

malononitrile to give the same product (14), mixed in the latter case with its blue *N*-oxide (18).

The structures of these unusual dicyanomethylene derivatives such as (14) follow from their spectra. Thus the i.r. spectrum reveals the presence of an NH group (3 320 cm^{-1}), a nitrile (sharp doublet, 2 190 and 2 230 cm^{-1}), and olefinic grouping (stretching at 1 580 and 1 655; bending at 840 cm^{-1}). The ^1H n.m.r. spectrum shows an ABX pattern for the three olefinic protons (H-5, -4, and -7), as a double doublet and two doublets, respectively [τ 2.55 (J 1.5 and 10 Hz), 2.83 (J 10 Hz), and 3.79 (J 1.5 Hz)]; the methyl groups give a singlet at τ 8.42 and the NH group a broad signal at τ −0.05. In trifluoroacetic [^2H]acid both the NH and the 7-proton are exchanged, thus supporting the enaminic nature of this 7-position. The ^{13}C n.m.r. spectrum (Table 1) shows



SCHEME 2

This curious reaction has two important prerequisites: (*a*) an alcohol solvent, and (*b*) light. No reaction occurs in the dark or in benzene or other non-protic solvents. When propan-2-ol is used, acetone is produced along with the purple product. We have already observed elsewhere [6] the ready redox reactions of 2*H*-benzimidazoles and envisage the mechanism as a series of redox processes as outlined in Scheme 2. TCNE is known to show dehydrogenating properties [7] and the derived tetracyanoethane (16) (pK_a 3.6) may then undergo a Michael condensation followed by fragmentation of the intermediate (17). In further support of this mechanism, the 2*H*-benzimidazole (7; R = Me), as well as its dioxide (5; R = R′ = Me), reacts analogously with several peaks at unexpected high-field positions, owing again to enaminic and related mesomeric effects. For example the signals for C-7 and $C(CN)_2$ appear at 87.7 and 64.3 p.p.m., respectively, in line with similar high field shifts of cyano-enamine derivatives [*e.g.* (19)], and the cyano-groups absorb at very low field.[8]

A by-product from the interaction of malononitrile with the di-*N*-oxide (5) was characterised as the green, tricyclic quinonoid system (20), derived by interaction of (14) with another molecule of malononitrile. [The purple product (14) did indeed yield this green compound when treated with malononitrile.] Three NH absorp-

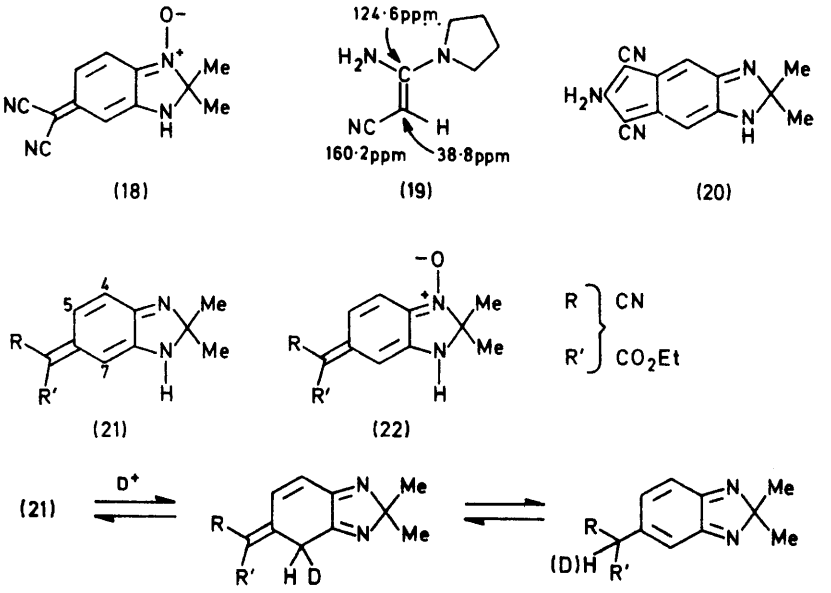
[6] J. A. L. Herbert and H. Suschitzky, *Chem. and Ind.*, 1973, 482.

[7] See, for example, D. T. Longone and G. L. Smith, *Tetrahedron Letters*, 1962, 205.

[8] J. Clark, B. Parvizi, and I. W. Southon, *J.C.S. Perkin I*, 1976, 125.

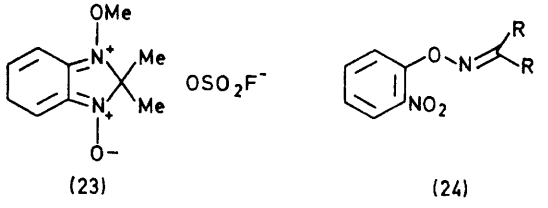
tions (3 480, 3 335, and 3 200 cm^{-1}) and a nitrile absorption (2 205 cm^{-1}) are observed in the i.r. spectrum and mass spectral data confirm the overall structure.

When the di-*N*-oxide was similarly treated with ethyl cyanoacetate a related mixture of highly coloured products, (21) and (22), was isolated. The ^1H n.m.r. spectrum of (21) in $CDCl_3$ (obtained by Fourier-transformed pulsed ^1H n.m.r. owing to its insolubility in $CDCl_3$) indicated the presence of only one component, showing the expected ABX pattern of olefinic protons and appropriate methyl, ethyl, and NH absorptions. However, as with the dicyano-analogues, both the N*H* and the 7-proton underwent exchange in trifluoroacetic [^2H]acid. We believe this exchange of the 7-proton involves an equilibrium as shown in Scheme 3, in which the stereochemical integrity of the exocyclic methylene substituent is lost. The n.m.r. spectrum of (21) in trifluoroacetic [^2H]acid revealed two pairs of olefinic doublets (4 : 3) in the region τ 0.5—2.7 characteristic of the 4- and 5-protons of the two isomers.

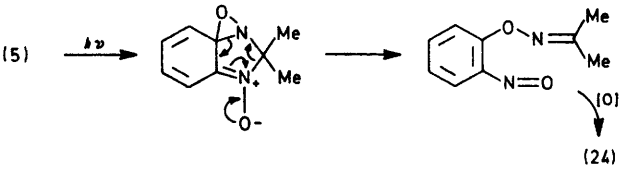


SCHEME 3

(C) *With methyl fluorosulphate.* When the di-*N*-oxide (5; X = H, R = R′ = Me) was boiled with an excess of methyl fluorosulphate in dichloromethane for 3 h, a deep blue crystalline solid was precipitated, and was identified by the usual means as the mono-*O*-methyl salt (23).



(D) *Under irradiation.* Irradiation of the di-*N*-oxide (5; X = H, R = R′ = Me) in methanol with a medium-pressure mercury lamp through Pyrex showed no change after 100 h. However, in ethyl acetate the red colour was discharged in 30 h, yielding, after chromatography, an off-white low-melting solid. Characteristic i.r. absorptions for a nitro-group (1 350 and 1 530 cm^{-1}) and a C=N group (1 610 cm^{-1}) were evident, and the ^1H n.m.r. spectrum revealed an ABCD multiplet of aromatic protons (centred at τ 2.45) and two singlet methyl resonances (τ 7.93 and 7.82) at lower field than in the starting material. A molecular ion (M^+ 194) in the mass spectrum indicated that an oxygen atom was added to the system, and peaks at *m/e* 139, 122, 65, 64, and 63, characteristic of *o*-nitrophenol, were evident. These data suggested the *o*-nitrophenylhydroxylamine structure (24; R = Me), which was verified by its synthesis from *O*-(2-nitrophenyl)hydroxylamine and acetone. The reaction is best viewed as a typical *N*-oxide ⟶ oxaziridine phototransformation with subsequent rearrangement and oxidation (Scheme 4).



SCHEME 4

EXPERIMENTAL

General conditions are as given in Part 1, as are the conditions for preparing the benzofurazan *N*-oxides.[1a] The common nitroalkanes were purchased from Koch–Light. Literature methods were employed for the synthesis of phenylnitromethane,[9] nitro-cyclopentane and

[9] N. Kornblum, H. O. Larson, R. K. Blackwood, D. D. Mooberry, E. P. Oliveto, and G. E. Graham, *J. Amer. Chem. Soc.*, 1956, **78**, 1497.

-cyclohexane,[10] 1-nitro-1-phenylethane,[11] ethyl 2-nitropropionate,[12] and diethyl 2-nitromalonate.[13]

Reactions of Benzofurazan N-*Oxide with Nitroalkanes.*—(a) *In ethanolic ammonia.* Benzofurazan *N*-oxide (2.0 g; 0.015 mol) in ethanol (50 ml) was cooled to 0 °C and saturated with gaseous ammonia. The primary nitroalkane (0.02 mol) was added and the mixture kept at room temperature for 72 h. The solvent was evaporated off below 40 °C and the 1-*hydroxybenzimidazole* 3-*oxide* recrystallised (Table 2).

(b) *In chloroform–triethylamine.* To benzofurazan *N*-oxide (2.0 g, 0.015 mol) in chloroform (30 ml) were added the primary nitroalkane (0.02 mol) and triethylamine (2.0 g), and the mixture was boiled for 24 h. Evaporation and recrystallisation gave the 1-hydroxybenzimidazole 3-oxide (Table 2).

(c) *In ethanol with a catalytic amount of base.* Benzofurazan *N*-oxide (2.0 g, 0.015 mol), ethanol (5 ml), and 1,4-diazabicyclo[2.2.2]octane (0.2 g) were warmed together to 40 °C and the nitromethane or nitroethane (2.0 g) was added. After 6 h at 40 °C the solvent was evaporated off and the residue eluted through an alumina column. Elution with ethyl acetate gave benzimidazole or 2-methylbenzimidazole (6—8%); the corresponding *N*-oxides (14 and 27%, respectively) were eluted with ethyl acetate–ethanol. The products were recrystallised and their m.p.s and i.r. spectra compared with literature data: benzimidazole, m.p. 168° (lit.,[14] 170°); 2-methylbenzimidazole, m.p. 176° (lit.,[15] 175°); benzimidazole *N*-oxide, m.p. 209° (lit.,[16] 212°); and 2-methylbenzimidazole *N*-oxide, m.p. 248° (lit.,[16] 251°).

(d) *Reaction with secondary nitroalkanes.* To the benzofurazan *N*-oxide (0.03 mol) in chloroform (100 ml) was added the nitro-compound (0.032 mol) followed by triethylamine (4.0 g). The colour changed from yellow to deep red or purple in a few hours and the mixture was set aside until the benzofurazan oxide was consumed (t.l.c.). Alumina (20 g) was added to the solution and the chloroform was removed at room temperature. Chromatography of the solid on alumina gave starting material [ethyl acetate–petroleum (1 : 5)] traces of the yellow 2*H*-benzimidazole mono-*N*-oxide (6) [ethyl acetate–petroleum (1 : 4)] and the red di-*N*-oxide (5) (ethyl acetate). The red solids were recrystallised from petroleum or petroleum–ethyl acetate (Table 2). Their mass spectra showed significant molecular ions and $M - 16$ and $M - 32$ peaks.

Reactions of the 2H-*Benzimidazole Oxides.*—(a) *Hydrolysis.* 2,2-Dimethyl-2*H*-benzimidazole 1,3-dioxide (5; X = H, R = R′ = Me) (0.3 g) was boiled in 4N-sulphuric acid (20 ml) for 2 h and then the mixture was steam distilled into aqueous acidic 2,4-dinitrophenylhydrazine to give a yellow precipitate of acetone 2,4-dinitrophenylhydrazone, m.p. 128°, identical with an authentic specimen (mixed m.p. and i.r. spectrum). The remaining solution from steam distillation gave no identifiable products on basification.

TABLE 2

Preparation of benzimidazoles (3) and 2*H*-benzimidazoles (5)

Method (time in days)	Product No.	X	R, R′	Yield (%)	M.p. (°C)	Found (%) C	H	N	Formula	Required (%)[a] C	H	N
(a), (b)	(3)	H	H	62	203 †[a]							
(a), (b)	(3)	H	Me	64	195—196 †[c]							
(a), (b)	(3)	H	Ph	52	215[b]							
(d) (5)	(5)	H	Me, Me	86	136—137	61.0	5.9	15.9	$C_9H_{10}N_2O_2$	60.7	5.7	15.7
(d) (7)	(5)	H	$[CH_2]_4$	78	130	65.1	5.9	13.9	$C_{11}H_{12}N_2O_2$	64.7	5.9	13.7
(d) (7)	(5)	H	$[CH_2]_5$	67	112—114	65.7	6.4	12.7	$C_{12}H_{14}N_2O_2$	66.0	6.5	12.8
(d) (10)	(5)	H	Me, Ph	38	139—140	69.9	5.0	12.1	$C_{14}H_{12}N_2O_2$	70.0	5.0	11.7
(d) (11)	(5)	5-Cl	Me, Me	85	138	50.9	4.3	13.0	$C_9H_9ClN_2O_2$	50.8	4.3	13.2
(d) (7)	(5)	5-Br	Me, Me	82	140—141	41.9	3.5	11.1	$C_9H_9BrN_2O_2$	42.0	3.5	10.9
(d) (11)	(5)	5-OMe	Me, Me	84	208	57.2	5.7	13.5	$C_{10}H_{12}N_2O_3$	57.7	5.8	13.5
(d) (4)	(5)	5-CF_3	Me, Me	83	246	48.9	3.9	11.5	$C_{10}H_9F_3N_2O_2$	48.8	3.7	11.4

A. J. Boulton, A. C. Gripper-Gray, and A. R. Katritzky [*J. Chem. Soc.* (*B*), 1967, 911] record [a] m.p. 204—205 °C (decomp.); [b] M.p. 212 °C; [c] Lit.,[3] 194—195° (decomp.)

(b) *Hydrogenation.* To the di-*N*-oxide (5; X = H, R = R′ = Me) (0.5 g) in ethanol (100 ml) was added palladium–charcoal (0.05 g; 10%), and the mixture was hydrogenated at atmospheric pressure until colourless, yielding *o*-phenylenediamine, m.p. 102°, identical (mixed m.p. and i.r. spectrum) with an authentic sample.

(c) *Reduction with sodium borohydride.* The di-*N*-oxide (5; X = H, R = R′ = Me) (3.56 g, 0.02 mol) (in ethanol 100 ml) was treated with sodium borohydride (0.2 g) under reflux and the reaction was followed by t.l.c. until all the red dioxide had been consumed (*ca.* 30 min). The mixture was evaporated, water (30 ml) was added, and the resulting solution was extracted with chloroform (3×). The dried extract was chromatographed on alumina to give the following yellow mono-*N*-oxides (6) by elution with ethyl acetate–petroleum: (i) 2,2-*dimethyl*-2H-*benzimidazole* 1-*oxide* (6; X = H, R = R′ = Me) (83%), m.p. 65° (Found: C, 66.4; H, 6.3; N, 17.2. $C_9H_{10}N_2O$ requires C, 66.6; H, 6.2; N, 17.3%), τ (CCl_4) 8.75 (s, Me) and 2.8—3.5 (m, aromatic); (ii) 2H-*benzimidazole*-2-*spirocyclopentane* 1-*oxide* (6; X = H, RR′ = $[CH_2]_4$) (77%), m.p. 72° (Found: C, 69.7; H, 6.5; N, 15.2. $C_{11}H_{12}N_2O$ requires C, 70.2; H, 6.4; N, 14.9%), τ ($CDCl_3$) 8.07br (CH_2) and 2.5—3.3 (m, aromatic); (iii) 2H-*benzimidazole*-2-*spirocyclohexane* 1-*oxide* (6; X = H, RR′ = $[CH_2]_5$) (72%), m.p. 86° (Found: C, 70.6; H, 7.0; N, 13.7. $C_{12}H_{14}N_2O$ requires C, 71.2; H, 7.0; N, 13.9%), τ ($CDCl_3$) 8.00br (CH_2) and 2.5—3.3 (m, aromatic); (iv) 6-*chloro*-2,2-*dimethyl*-2H-*benzimidazole* 1-

[10] W. D. Emmons and A. S. Pagano, *J. Amer. Chem. Soc.*, 1955, **77**, 4557.
[11] N. Kornblum and W. D. Garowitz, *Org. Reactions*, 1962, **12**, 132.
[12] N. Kornblum and R. K. Blackwood, *Org. Synth.*, 1963, Coll. Vol. IV, p. 454.
[13] D. I. Weisblot and D. A. Lyttle, *J. Amer. Chem. Soc.*, 1949, **71**, 3080.
[14] E. Wundt, *Ber.*, 1878, **11**, 826.
[15] K. Brand and E. Stohr, *Ber.*, 1906, **39**, 4062.
[16] S. von Niementowski, *Ber.*, 1910, **43**, 3012.

oxide (6; X = Cl, R = R′ = Me) (79%), m.p. 126° (Found: C, 55.0; H, 4.5; N, 13.9. $C_9H_9ClN_2O$ requires C, 55.0; H, 4.6; N, 14.2%), τ ($CDCl_3$) 8.42 (s, Me) and 2.84 (m) and 2.70 (m) (aromatic). When the reduction was repeated as above but with an excess of sodium borohydride the following 2*H*-benzimidazoles (7) were isolated; (i) 2,2-*dimethyl*-2H-*benzimidazole* (7; R = Me), obtained as an oil which solidified at 0 °C but was rapidly degraded at room temperature, $\lambda_{max.}$ 235, 274, and 351 nm, M^+ 146, τ (CCl_4) 8.55 (s, Me) and 2.95 (m, AA′BB′); (ii) 2*H*-benzimidazole-2-spirocyclohexane (41%), m.p. 65° (lit.,[4] 65—65.5°).

(d) *Reactions with dimethyl acetylenedicarboxylate.* To the 2*H*-benzimidazole dioxide (5) (0.01 mol) in benzene (15 ml) was added DMAD (3.0 g, 0.021 mol) and the solution was kept in the dark until the red colour had disappeared (*ca.* 72 h). Petroleum (100 ml) was added and the precipitate filtered off and recrystallised from ethyl acetate–petroleum. In this way the following *tetramethyl di-isoxazolo*[2,3-c:3′,2′-i]*benzimidazole*-5,6,12,13-*tetracarboxylates* were prepared: (i) 9,9-*dimethyl* (72%), m.p. 134° (decomp.) (Found: C, 54.6; H, 4.9; N, 6.1. $C_{21}H_{22}N_2O_{10}$ requires C, 54.5; H, 4.8; N, 6.1%), $\nu_{max.}$ (Nujol) 1 765 and 1 740 (CO) and 1 670 cm^{-1} (C=C), τ ($CDCl_3$) 8.63 (s, CMe), 8.22 (s, CMe), 6.35 (s, 2 OMe), 6.11 (s, 2 OMe), and 3.91br (=CH), *m/e* (120 °C) 462.1289 (M^+; $C_{21}H_{22}N_2O_{10}$ requires 462.1267), 447.1067 (M − Me; $C_{20}H_{19}N_2O_2$ requires 447.1033), 444.1144 (M − H_2O; $C_{21}H_{20}N_2O_9$ requires 444.1162), 431.1076 (M − OMe; $C_{20}H_{19}N_2O_9$ requires 431.1084), 430.1018 (M − MeOH; $C_{20}H_{18}N_2O_9$ requires 430.1006), 403.1105 (M − CO_2Me; $C_{19}H_{19}N_2O_8$ requires 403.1135), and 375.1221 (M − $C_3H_3O_3$; $C_{18}H_{19}N_2O_7$ requires 375.1192); (ii) 2-*bromo*-9,9-*dimethyl* (10b) (71%), m.p. 146° (decomp.) (Found: C, 46.3; H, 4.0; N, 5.1. $C_{21}H_{21}BrN_2O_{10}$ requires C, 46.6; H, 3.9; N, 5.2%), τ ($CDCl_3$) 8.67 (s, CMe), 8.24 (s, CMe), 6.25 (s, OMe), 6.23 (OMe), 6.12 (s, 2 OMe), 4.05 (dd, *J* 10.0 and 1.5 Hz, 3-H), 3.78 (dd, *J* 10.0 and *ca.* 1.5 Hz, 4-H), and 3.68br (1-H); (iii) 2-*spirocyclohexane* (10c) (78%), m.p. 138° (decomp.) (Found: C, 57.3; H, 5.3; N, 5.5. $C_{24}H_{26}N_2O_{10}$ requires C, 57.4; H, 5.2; N, 5.6%), τ ($CDCl_3$) 8.6—7.6 (m, CH_2), 6.33 (s, 2 OMe), 6.10 (s, 2 OMe), 3.92br (s, =CH), $\nu_{max.}$ (Nujol) 1 750, 1 730 (CO), 1 715, and 1 655 cm^{-1} (C=C).

(e) *Reaction with benzyne.* To a stirred solution of 2,2-dimethyl-2*H*-benzimidazole 1,3-dioxide (0.6 g) in dry dichloromethane (40 ml) was added lead tetra-acetate (5.0 g), followed dropwise by 1-aminobenzotriazole [17] (1.2 g) in dry dichloromethane (20 ml). The red colour was gradually discharged during addition; the resulting mixture was filtered and the filtrate was evaporated. The residue was extracted with ether and this extract was washed with sodium hydrogen carbonate solution (2 × 20 ml; 5%) then water, dried, and evaporated. The residual oil crystallised and was recrystallised from aqueous ethanol to give 11,11-*dimethylbisbenzisoxazolo*[2,3-c:3′,2′-i]*benzimidazole* (13) as white prisms, m.p. 137° (decomp.) (0.3 g, 37%) (Found: C, 76.7; H, 5.2; N, 8.5. $C_{21}H_{18}N_2O_2$ requires C, 76.3; H, 5.5; N, 8.5%), τ ($CDCl_3$) 8.52 (s, Me), 8.04 (s, Me), 3.8—4.3 (m, AA′BB′, ring A protons), and 3.15—3.8 [ABCD pattern (two d and two dt partly overlapped) ring B and C protons].

(f) *Reactions with tetracyanoethylene.* 2,2-Dimethyl-2*H*-benzimidazole 1,3-dioxide (1.0 g) and tetracyanoethylene (1.0 g) were boiled together in ethanol until the mixture was free of the dioxide (t.l.c.). The solution was evaporated and the residue was chromatographed on alumina. Elution with ethyl acetate–toluene gave a purple solid which was recrystallised from chloroform to give needles of 2,2-*dimethyl*-1H-*benzimidazol*-6(2H)-*ylidenemalononitrile* (14) (0.4 g, 35%), m.p. 246° (Found: C, 68.8; H, 4.9; N, 26.3. $C_{12}H_{10}N_4$ requires C, 68.6; H, 4.9; N, 26.7%), $\nu_{max.}$ 3 315 (NH), 2 205 (CN), 1 650, and 1 580 cm^{-1} (C=C), M^+ 210, τ [$CDCl_3$–$(CD_3)_2SO$] 8.35 (s, 2 Me), 3.79 (d, *J* 1.5 Hz, H-7), 2.83 (d, *J* 10.0 Hz, H-4), and 2.55 (dd, *J* 10.0 and 1.5 Hz, H-5). The same product was obtained from the mono-*N*-oxide (6; X = H, R = R′ = Me) (31%), and from the unstable oil (7; R = Me) (34%) on similar treatment with TCNE.

(g) *Reactions with carbanions.* (i) *Malononitrile.* 2,2-Dimethyl-2*H*-benzimidazole 1,3-dioxide (2.0 g) and malononitrile (0.5 g) in ethanol (60 ml) were kept together for 40 h [until the dioxide disappeared (t.l.c.)] and then the mixture was worked up as above to give first the purple product (14) (0.3 g, 13%), followed by its N-*oxide* (18) as deep blue needles from chloroform (0.9 g, 45%), m.p. 203—205° (Found: C, 64.7; H, 4.2; N, 24.4. $C_{12}H_{10}N_4O$ requires C, 63.7; H, 4.5; N, 24.8%), M^+ 226, M − 15 211, M − 16 210, $\nu_{max.}$ (Nujol) 3 240 (NH), 2 230 and 2 220 (CN), and 1 650 cm^{-1} (C=C), τ [$CDCl_3$–$(CD_3)_2SO$] 8.34 (s, Me), 3.78 (s, H-7), 2.79 (s, H-4 and -5), and 0.85br (NH). Further elution with ethyl acetate gave 6-amino-1,2-dihydro-2,2-dimethylindeno[5,6-*d*]imidazole-5,7-dicarbonitrile (20) as a brown-green solid (0.5 g, 20%) which decomposed on attempted recrystallisation; M^+ 249, $\nu_{max.}$ 3 480, 3 340 (sharp), and 3 200br (NH), and 2 200 cm^{-1} (CN), τ [$CDCl_3$–$(CD_3)_2SO$] 8.50 (s, Me), 3.90 (s) and 2.80 (s) (=CH), and 2.17br (NH). The same compound was obtained by treatment of the dicyanomethylene derivative (14) with malononitrile as above (24%).

(ii) *Ethyl cyanoacetate.* 2,2-Dimethyl-2*H*-benzimidazole 1,3-dioxide (1.0 g) and ethyl cyanoacetate (0.7 g) in ethanol (50 ml) were heated under reflux until the dioxide had disappeared (t.l.c.) (8 h). Evaporation left a residue which on elution through alumina with ethyl acetate gave a purple solid which crystallised as purple needles from chloroform (0.7 g, 49%), to yield the *cyano-ester* (21), m.p. 207° (Found: C, 65.0; H, 6.0; N, 15.9. $C_{14}H_{15}N_3O_2$ requires C, 65.4; H, 5.9; N, 16.3%), $\nu_{max.}$ (Nujol) 3 240 (NH), 2 220 (CN), and 1 710 cm^{-1} (CO), τ ($CDCl_3$; CFT 20 pulsed instrument) 8.66 (t, *J* 7.0 Hz, CH_2·CH_3), 8.43 (s, CMe_2), 5.75 (q, *J* 7.0 Hz, CH_2·CH_3), 3.57br (NH), 3.01 (d, *J* 10.0 Hz, H-4), 2.67 (d, *J* 1.5 Hz, H-7), and 2.50 (dd, *J* 10.0 and 1.5 Hz, H-5), τ (CF_3·CO_2D), 8.50 (t, *J* 7.0 Hz, CH_2·CH_3), 8.07 (s, CMe_2), 5.43 (q, *J* 7.0 Hz, CH_2·CH_3), 2.54 (d, *J* 10 Hz, H-4), 2.49 (d, *J* 10 Hz, H-4′), 1.70 (d, *J* 10 Hz, H-5), and 0.64 (d, *J* 10 Hz, H-5′). Further elution with ethyl acetate produced the blue N-*oxide* (22) as needles from chloroform (0.1 g, 7%), m.p. 216—218° (Found: C, 61.5; H, 5.4; N, 15.5. $C_{14}H_{15}N_3O_3$ requires C, 61.5; H, 5.5; N, 15.4%), M^+ 273, $\nu_{max.}$ (Nujol) 3 260 (NH), 2 220 (CN), and 1 705 cm^{-1} (CO), τ (CF_3·CO_2D) 8.55 (t, *J* 7.0 Hz, CH_2·CH_3), 8.18 (s, CMe_2), 5.54 (q, *J* 7.0 Hz, CH_2·CH_3), and 2.3—3.0 (m, =CH).

(h) *Reaction with methyl fluorosulphate.* 2,2-Dimethyl-2*H*-benzimidazole 1,3-dioxide (1.0 g) in dry dichloromethane (50 ml) was treated with methyl fluorosulphate (2.0 g) and the mixture was heated under reflux for 2 h, the colour changing from red to deep blue with deposition of crystals. The mixture was cooled, filtered, and washed

[17] A. O. Fitton and R. K. Smalley, ' Practical Heterocyclic Chemistry,' Academic Press, London and New York, 1968, p. 45.

with ether to give 3-*methoxy*-2,2-*dimethyl*-2H-*benzimidazolium* 1-*oxide fluorosulphate* (23) (1.4 g, 80%), as blue needles which decomposed rapidly on warming and slowly in air at ambient temperature (Found: C, 41.0; H, 4.9; N, 9.9. $C_{10}H_{13}FN_2O_5S$ requires C, 41.1; H, 4.5; N, 9.6%), τ ($CF_3{\cdot}CO_2D$) 7.97 (s, CMe_2), 5.52 (s, OMe), and 1.6—2.7 (m, =CH).

(i) *Reaction under irradiation.* 2,2-Dimethyl-2*H*-benzimidazole 1,3-dioxide (1.0 g) in ethyl acetate (250 ml) was degassed under nitrogen and irradiated (Hanovia 200 W medium-pressure mercury lamp through a Pyrex cooling jacket). After 30 h the starting material had been consumed (t.l.c.); the solution was evaporated and the residue chromatographed on alumina. Elution with ethyl acetate–petroleum gave an oil (0.23 g, 21%) which solidified and was recrystallised from aqueous ethanol to afford cream needles of *acetone* O-(2-*nitrophenyl*)*oxime* (24), m.p. 56° (Found: C, 55.2; H, 4.7; N, 14.7. $C_9H_{10}N_2O_3$ requires C, 55.7; H, 5.2; N, 14.4%), *m/e* 194 (M^+), 163 (M — NOH), 139 (base peak; *o*-nitrophenol), 122, 65, 64, 63, and 56, $\nu_{max.}$ (Nujol) 1 530 and 1 350 cm^{-1} (NO_2), τ ($CDCl_3$) 7.93 (s, Me), 7.82 (s, Me), and 1.85—3.05 (m, ABCD, aromatic). Further elution with ethyl acetate gave 2,2-dimethyl-2*H*-benzimidazole 1-oxide (0.1 g).

Preparation of Acetone O-(2-*Nitrophenyl*)*oxime*.—To a mixture of ethyl acetohydroxamate [18] (2.5 g) and sodium hydride (1.0 g) in dimethylformamide (30 ml), 1-fluoro-2-nitrobenzene (3.4 g) in dimethylformamide (10 ml) was added dropwise with stirring. The stirred mixture was heated at 70 °C for 3 h and then poured into water to afford ethyl *O*-2-nitrophenylacetohydroxamate (2.5 g, 43%). This was added to perchloric acid (0.9 g) in dioxan (50 ml) and after 3 h the solvent was removed and the crude *O*-(2-nitrophenyl)hydroxylamine was used directly in the next stage. To the hydroxylamine (1.0 g) in acetone (50 ml) was added toluene-*p*-sulphonic acid (0.01 g) and the mixture was refluxed for 4 h. Removal of the solvent and chromatography of the residue on alumina [elution with ethyl acetate–petroleum (1 : 9)] gave acetone *O*-(2-nitrophenyl)oxime (0.2 g), identical with the photolysis product (m.p., mixed m.p., and i.r. spectrum).

We thank Miss S. Bogle for ^1H n.m.r., Mrs. L. Phillips for ^{13}C n.m.r., Dr. H. Wardale for e.s.r., and Mrs. R. Maynard and Mrs. J. Jackson for mass spectra. We also thank the S.R.C. for a grant towards purchase of a Varian CFT 20 spectrometer and a maintenance grant (to D. W. S. L.), and Wander Limited for a grant in support of J. A. L. H.

[18] J. Houben and E. Schmidt, *Ber.*, 1913, **46**, 3616.

[6/982 *Received*, 24*th May*, 1976]