A Novel Photoaddition of 2-Phenylbenzimidazole

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Irradiation of 2-phenylbenzimidazole (**3**) in the presence of methyl acrylate (20 equivalents) using a medium pressure mercury lamp gives methyl 2-(2-phenylbenzimidazol-1-yl)propionate (**4**) (75%) whose structure has been confirmed by an X-ray analysis. A similar reaction using acrylonitrile gave only a low yield (1%) of the corresponding propionitrile derivative **5**. A mechanism involving photoexcitation of 2-phenylbenzimidazole (**3**) followed by sequential single electron transfer, proton transfer and radical coupling is proposed to account for the formation of the novel photoadducts **4** and **5**.

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Our interest in the *syn*-addition of hypervalent reagents [1] led us to investigate the reactions of the sulphimide **1** [2] and the phosphinimide **2** [3] with methyl acrylate. When either compound **1** or compound **2** in toluene solution was heated under reflux with methyl acrylate (5-10 equivalents) no reaction was observed. However, when an acetonitrile solution of the sulphimide **1** containing methyl acrylate (6 equivalents) was irradiated (22 hours) using a medium pressure mercury lamp two major products were formed. These were isolated by chromatography and identified as 2-phenylbenzimidazole (**3**) (13%) and methyl 2-(2-phenylbenzimidazol-1-yl)propionate (**4**) (45%). The structure of the major product **4** was fully supported by its spectroscopic properties and was confirmed by an X-ray analysis of its picrate salt. Figure 1 shows a perspective view and atom labeling of the crystal structure. Tables 1 and 2 list atom coordinates and bonding geometries.

The bond lengths within the picrate ring are in excellent agreement with previous studies on this anion [4,5] with the bond lengths *ipso* to the phenolic oxygen being somewhat shorter than the other C-C distances within the ring. The C-N bond lengths within the benzimidazolium cation are slightly longer than those found in the parent ion [6,7] and are comparable to those found in 1,3-dimethyl-2-dimethylaminobenzimidazolium perchlorate [8] and may reflect the delocalization of charge using the phenyl group. The NH function of the benzimidazolium nucleus is involved in a strong hydrogen bond with the phenolic oxygen (N-----O 2.631(3) Å, H-----O 1.736(3) Å).

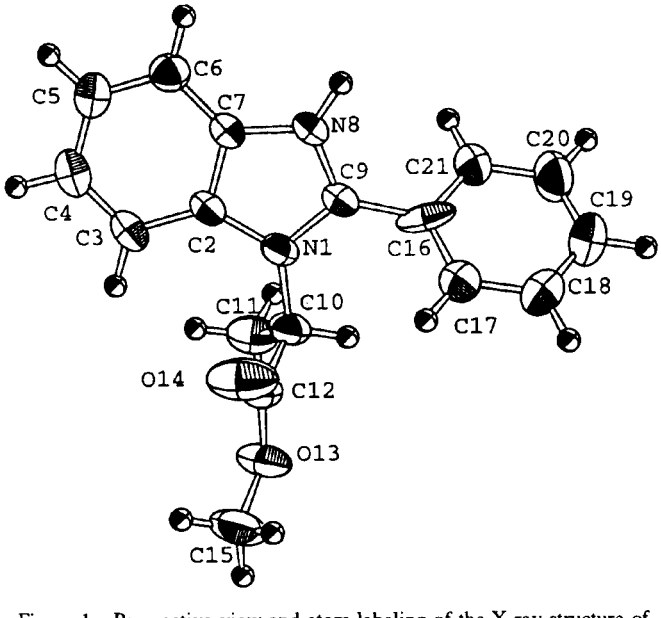
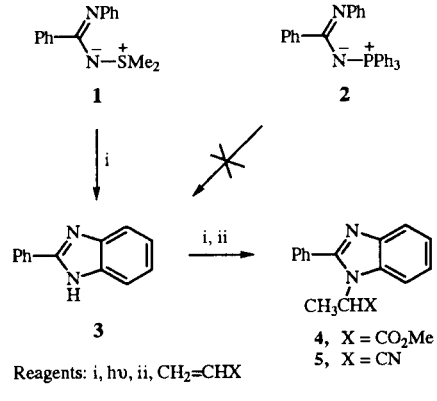


Figure 1a. Perspective view and atom labeling of the X-ray structure of the benzimidazolium cation of **4**.

Scheme 1



The yield of the photoproduct **4** increased (63%) when a greater concentration of methyl acrylate (20 equivalents) was used but no products were formed when a low pressure mercury lamp (<254 nm) was used for the irradiation. No products were observed when the phosphinimide **2** was irradiated under similar conditions using a medium pressure lamp.

Rees and co-workers [2] have previously described the efficient photochemical cyclisation of *N*-(*N*-arylimidoyl)-sulphimides to benzimidazoles (*e.g.* **1** → **3**). To investigate the possibility that the product **4** is derived from initially formed 2-phenylbenzimidazole **3** we irradiated a solution containing the benzimidazole **3** and methyl acrylate (20 equivalents) under identical conditions and obtained a 75% yield of the *N*-substituted derivative **4**. This clearly

Table 1

Atomic Coordinates (x 10^4) and Equivalent Isotropic Displacement Parameters (Å x 10^3)

Atom	x	y	z	U(eq) [a]
N(1)	-4096(2)	2627(2)	12174(2)	41(1)
C(2)	-4147(3)	2989(3)	10950(3)	39(1)
C(3)	-4862(3)	2452(3)	10350(3)	48(1)
C(4)	-4655(3)	3075(3)	9113(3)	54(1)
C(5)	-3788(3)	4188(3)	8486(3)	53(1)
C(6)	-3103(3)	4730(3)	9071(3)	46(1)
C(7)	-3303(3)	4108(3)	10318(3)	37(1)
N(8)	-2794(2)	4402(2)	11178(2)	40(1)
C(9)	-3271(3)	3518(3)	12271(3)	40(1)
C(10)	-4630(3)	1388(3)	13172(3)	47(1)
C(11)	-4052(3)	167(3)	12958(3)	61(1)
C(12)	-6258(3)	1457(3)	13428(3)	48(1)
O(13)	-6757(2)	316(2)	14253(2)	67(1)
O(14)	-6971(2)	2407(3)	12998(2)	88(1)
C(15)	-8307(3)	242(4)	14583(3)	81(1)
C(16)	-2899(3)	3525(3)	13379(3)	45(1)
C(17)	-3935(3)	3441(3)	14359(3)	55(1)
C(18)	-3528(4)	3520(4)	15359(3)	72(1)
C(19)	-2102(4)	3686(4)	15367(3)	79(1)
C(20)	-1075(4)	3776(4)	14397(3)	69(1)
C(21)	-1465(3)	3699(3)	13392(3)	55(1)
O(50)	2056(2)	3426(2)	8679(2)	63(1)
C(51)	1064(3)	2706(3)	8758(3)	45(1)
C(52)	-48(3)	2190(3)	9776(3)	42(1)
C(53)	-1134(3)	1402(3)	9841(3)	47(1)
C(54)	-1220(3)	1111(3)	8866(3)	50(1)
C(55)	-189(3)	1533(3)	7853(3)	55(1)
C(56)	940(3)	2269(3)	7816(3)	50(1)
N(51)	-36(3)	2472(3)	10829(3)	58(1)
N(52)	-2384(3)	309(3)	8925(4)	69(1)
N(53)	2040(3)	2635(3)	6739(3)	64(1)
O(51)	-661(3)	1712(3)	11807(2)	77(1)
O(52)	557(2)	3468(2)	10718(2)	82(1)
O(53)	-3188(3)	-182(3)	9888(3)	88(1)
O(54)	-2508(3)	150(3)	8021(3)	108(1)
O(55)	1741(3)	2647(3)	5824(3)	104(1)
O(56)	3232(3)	2840(3)	6836(3)	99(1)

[a] U(eq) is defined as one third of the trace of the orthogonalized U_{ij} tensor.

suggests that the product **4** is formed by photochemical addition of methyl acrylate to the initial photocyclisation

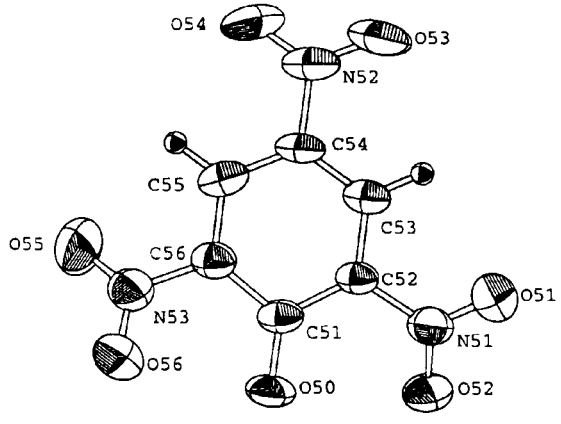


Figure 1b. Perspective view and atom labeling of the X-ray structure of the picrate anion.

Table 2

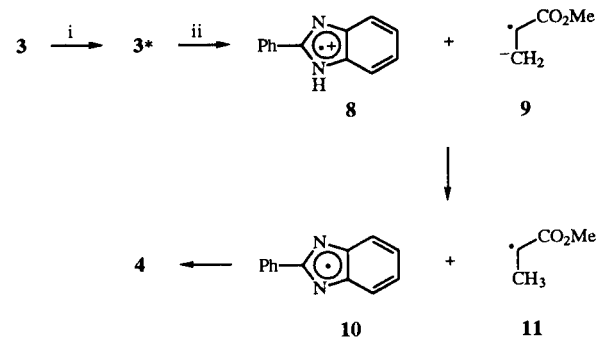
Bond Lengths (Å) and Angles (°)

N(1)-C(9)	1.360(3)	C(18)-C(19)	1.383(5)
N(1)-C(2)	1.399(4)	C(19)-C(20)	1.376(5)
N(1)-C(10)	1.473(4)	C(20)-C(21)	1.385(4)
C(2)-C(3)	1.397(3)	O(50)-C(51)	1.248(3)
C(2)-C(7)	1.393(4)	C(51)-C(52)	1.437(4)
C(3)-C(4)	1.376(4)	C(51)-C(56)	1.447(4)
C(4)-C(5)	1.400(4)	C(52)-C(53)	1.375(3)
C(5)-C(6)	1.368(4)	C(52)-N(51)	1.450(4)
C(6)-C(7)	1.387(4)	C(53)-C(54)	1.375(4)
C(7)-N(8)	1.392(3)	C(54)-C(55)	1.380(4)
N(8)-C(9)	1.327(3)	C(54)-N(52)	1.447(4)
C(9)-C(16)	1.468(4)	C(55)-C(56)	1.381(4)
C(10)-C(11)	1.516(4)	C(56)-N(53)	1.470(4)
C(10)-C(12)	1.524(4)	N(51)-O(52)	1.224(3)
C(12)-O(14)	1.182(4)	N(51)-O(51)	1.233(3)
C(12)-O(13)	1.317(4)	N(52)-O(54)	1.218(4)
O(13)-C(15)	1.456(4)	N(52)-O(53)	1.229(4)
C(16)-C(17)	1.391(4)	N(53)-O(55)	1.201(3)
C(16)-C(21)	1.395(4)	N(53)-O(56)	1.208(3)
C(17)-C(18)	1.386(4)		
C(9)-N(1)-C(2)	107.9(2)	C(19)-C(18)-C(17)	119.7(3)
C(9)-N(1)-C(10)	124.9(2)	C(20)-C(19)-C(18)	121.1(3)
C(2)-N(1)-C(10)	126.4(2)	C(19)-C(20)-C(21)	119.8(3)
C(3)-C(2)-C(7)	121.1(3)	C(20)-C(21)-C(16)	119.4(3)
C(3)-C(2)-N(1)	132.1(3)	O(50)-C(51)-C(52)	125.3(3)
C(7)-C(2)-N(1)	106.8(2)	O(50)-C(51)-C(56)	122.4(3)
C(4)-C(3)-C(2)	116.1(3)	C(52)-C(51)-C(56)	112.3(2)
C(3)-C(4)-C(5)	122.3(3)	C(53)-C(52)-C(51)	124.2(3)
C(6)-C(5)-C(4)	121.9(3)	C(53)-C(52)-N(51)	116.3(3)
C(5)-C(6)-C(7)	116.3(3)	C(51)-C(52)-N(51)	119.4(2)
C(6)-C(7)-C(2)	122.4(2)	C(54)-C(53)-C(52)	119.3(3)
C(6)-C(7)-N(8)	131.3(2)	C(53)-C(54)-C(55)	121.1(2)
C(2)-C(7)-N(8)	106.4(2)	C(53)-C(54)-N(52)	119.3(3)
C(9)-N(8)-C(7)	109.6(2)	C(55)-C(54)-N(52)	119.6(3)
N(8)-C(9)-N(1)	109.2(2)	C(56)-C(55)-C(54)	119.3(3)
N(8)-C(9)-C(16)	123.4(2)	C(55)-C(56)-C(51)	123.5(3)
N(1)-C(9)-C(16)	127.3(3)	C(55)-C(56)-N(53)	116.9(3)
N(1)-C(10)-C(11)	112.5(3)	C(51)-C(56)-N(53)	119.6(2)
N(1)-C(10)-C(12)	109.3(2)	O(52)-N(51)-O(51)	122.0(3)
C(11)-C(10)-C(12)	113.8(2)	O(52)-N(51)-C(52)	119.5(3)
O(14)-C(12)-O(13)	124.5(3)	O(51)-N(51)-C(52)	118.5(2)
O(14)-C(12)-C(10)	125.4(3)	O(54)-N(52)-O(53)	123.6(3)
O(13)-C(12)-C(10)	110.0(3)	O(54)-N(52)-C(54)	118.3(4)
C(12)-O(13)-C(15)	115.8(3)	O(53)-N(52)-C(54)	118.0(3)
C(17)-C(16)-C(21)	120.5(3)	O(55)-N(53)-O(56)	122.9(3)
C(17)-C(16)-C(9)	122.0(2)	O(55)-N(53)-C(56)	119.0(3)
C(21)-C(16)-C(9)	117.4(3)	O(56)-N(53)-C(56)	117.9(3)
C(16)-C(17)-C(18)	119.4(3)		

product **3** (Scheme 1). This novel photoaddition of a benzimidazole is of some interest in that it reverses the normal thermal Michael addition to α,β-unsaturated carbonyl compounds and leads to a product formally derived from an α-aminoacid. We have therefore examined the behaviour of some related alkenes and imidazole derivatives under similar conditions.

When 2-phenylbenzimidazole (**3**) was irradiated in the presence of acrylonitrile (20 equivalents) only a low yield (*ca* 1%) of the corresponding photoadduct **5** was obtained. This product **5** was fully characterised and clearly showed a methyl group at δ 1.92 coupled (J 7.3 Hz) to an adjacent

Scheme 2



Reagents: i, hυ; ii, CH_2=$CHCO_2Me$

methine proton at δ 5.58 but we have not attempted to optimise the yield. Other reagents such as dimethylacrylamide, dimethyl maleate, dimethyl acetylenedicarboxylate, cyclohexene and, surprisingly, ethyl acrylate gave no corresponding photoaddition products. Furthermore, when benzimidazole (**6**) or 2-phenylimidazole (**7**) were irradiated with methyl acrylate under similar conditions no products were formed and the starting materials were recovered.

The formation of the product (**4**) can be rationalised by the mechanism shown in Scheme 2. We propose that photoexcitation of the benzimidazole (**3**) is followed by a single electron transfer to methyl acrylate to give the radical cation-radical anion pair, **8** + **9**. This is followed by a proton transfer giving a radical pair, **10** + **11**, which couples to form the observed product **4**. This mechanism is consistent with a number of the observations described above. The wavelengths emitted by the medium-pressure lamp are at 254, 265, 297, 313 and 366 nm. None of the olefins absorb above 220 nm [9-11] suggesting that it is not the olefinic component that forms the electronically excited state. For the imidazole derivatives **3**, **6** and **7** it can be seen from Table 3 that only 2-phenylbenzimidazole (**3**) absorbs at wavelengths above 300 nm [9] [12] [13] and we suggest that it is one of the low energy wavelengths ≥ 300 nm which is responsible for the initial photoexcitation. This is consistent with the observation that formation of compound **4** was not observed using a low pressure mercury lamp (254 nm). Unexpectedly, ethyl acrylate did not give the corresponding ethyl ester photoadduct. This may possibly be because the corresponding radical intermediate (*c.f.* **11**) can undergo an intramolecular hydrogen transfer to give ethylene, carbon dioxide and an ethyl radical *via* a six-membered transition state.

Table 3

UV Absorption Data for Selected Imidazole Derivatives [a]

Compound	λ_{max} (nm)	Reference
2-Phenylbenzimidazole (**3**)	240, 250, 300, 310, 320	[12]
Benzimidazole (**6**)	244, 249, 266, 272, 279	[9]
2-Phenylimidazole (**7**)	271	[13]

[a] Spectra determined in ethanol solution.

EXPERIMENTAL

The ^1H nmr spectra were recorded on a Jeol FX 270 FT spectrometer; ir spectra on a Perkin-Elmer 881 spectrophotometer, mass spectra on a Hitachi-Perkin-Elmer MSI 12 spectrometer, and microanalyses on a Perkin-Elmer 240 elemental analyser. High resolution mass spectra were determined by the EPSRC Mass Spectrometry Centre, Swansea. Unless otherwise stated, ir spectra were measured as thin-films (liquids) or potassium bromide discs (solids) and 270 MHz nmr spectra in deuteriochloroform (tetramethylsilane as internal standard). Only significant bands for the ir spectra are quoted. Melting points were determined on a Kofler block and are uncorrected.

Chromatotron chromatography was performed on plates prepared using silica gel 60 PF_{254} containing calcium sulphate.

The uv irradiation experiments were carried out in a Hanovia photochemical reactor made of quartz (1 mm thickness giving 80% transmission down to 185 nm) using a medium-pressure Mercury Vapour Straight Arc Tube emitting predominantly 254, 265, 297, 313 and 366 nm.

Methyl 2-(2-Phenylbenzimidazol-1-yl)propionate (**4**). (Method 1).

A solution of *S,S*-dimethyl-*N*-(*N*-phenylbenzimidoyl)sulphimide (**1**) [2] (1.02 g, 4 mmoles) and methyl acrylate (2.2 ml, 24 mmoles) in acetonitrile (60 ml) was irradiated using a medium pressure mercury lamp (22 hours). The solution smelled strongly of dimethyl sulphide and an insoluble solid, which was assumed to be polymerised methyl acrylate, was removed. Evaporation of the filtrate gave an oil which was purified by chromatotron chromatography (9:1 chloroform:methanol as eluent). The first major fraction (R_f 0.9) was collected, the eluent concentrated and the residue identified as compound **4**, (0.5 g, 45%), yellow oil, bp 150-160° at 0.05 mm Hg; ir: 3050, 2954, 1734, 1656, 1590, 1476, 1442, 1374, 1322, 1222 cm^{-1}; ^1H nmr: 1.77 (d, J 7.3 Hz, CCH_3), 3.71 (s, OCH_3), 5.33 (q, J 7.3 Hz, C*H*), 7.23-8.09 (m, 9 aromatic *H*); ms: m/z 280 (M^+). A sample of compound **4** (0.1 g, 0.35 mmole) and picric acid (0.08 g, 0.35 mmole) were each dissolved in a minimal volume of hot ethanol and the two solutions were then mixed. After cooling the resulting solid was collected and recrystallised from acetonitrile giving the picrate salt (0.12 g, 67%), bright yellow crystals, mp 175-178°.

Anal. Calcd. for $C_{23}H_{19}H_5O_9$: C, 54.2; H, 3.76; N, 13.8. Found: C, 54.5; H, 3.89; N, 13.6.

The second fraction (R_f 0.5) was collected, the eluent concentrated and the residue recrystallised from acetonitrile giving 2-phenylbenzimidazole (**3**) (0.1 g, 13%), mp 288-291° (lit [14] mp 289-291°).

Under identical conditions but using 20 equivalents of methyl acrylate the isolated yields were compound **4** (63%) and compound **3** (5%).

Methyl 2-(2-Phenylbenzimidazol-1-yl)propionate (**4**). (Method 2).

A solution of 2-phenylbenzimidazole (**3**) (0.19 g, 1.0 mmole) and methyl acrylate (1.8 ml, 20 mmoles) in acetonitrile (60 ml) was irradiated using a medium pressure mercury lamp (24 hours). After removal of insoluble material, the filtrate was evaporated and the residue purified by chromatography to give compound **4** (0.21 g, 75%), identical with an authentic sample.

2-(2-Phenylbenzimidazol-1-yl)propionitrile (**5**).

A solution of 2-phenylbenzimidazole (**3**) (0.38 g, 2.0 mmoles) and acrylonitrile (2.6 ml, 40 mmoles) in acetonitrile (60 ml) was irradiated using a medium pressure mercury lamp (24 hours). After filtration, the solution was evaporated and purified by chromatotron chromatography (9:1 $CHCl_3$/MeOH as eluent) giving compound **5**, (0.05 g, 1%), pale yellow oil; ^1H nmr: 1.92 (d, J 7.3 Hz, CCH_3), 5.58 (q, J 7.3 Hz, C*H*), 7.35-7.88 (m, 9 aromatic *H*); gc-ms: t = 19.8 minutes, m/z 247 (M^+), 232, 219, 193, 90, 77.

Anal. Calcd. for $C_{16}H_{13}N_3$: M, 247.11100. Found: 247.11109.

X-Ray Crystallography.

Intensity data were collected with an Enraf-Nonius FAST diffractometer using monochromatized Mo-K_α λ = 0.70169 Å, radiation. The crystal used was a yellow block of dimensions 0.22 x 0.24 x 0.22 mm. The intensities of 5042 reflections were collected and corrected for Lorentz and polarisation effects but not for absorption.

The structure was solved by direct methods using SHELX86 [15] and refined on F^2 by full-matrix least-squares procedures using SHELX93 [16]. All non-hydrogen atoms were refined with anisotropic displacement parameters. CH hydrogen atoms were included in calculated positions and allowed to ride on the atoms to which they were attached. The NH hydrogen was found in a difference map and allowed to ride on the nitrogen atom. The function minimised was $\Sigma w[(F_o^2 - F_c^2)$ with $w = [\sigma^2(F_o^2) + 0.0805P^2]^{-1}$ where $P = [Max(F_o^2) + 2F_c^2]/3$. A final difference map showed no features greater than 0.24(5) e/Å^3. Final non-hydrogen atom coordinates, bond lengths and angles are listed in Tables 1 and 2. Tabulations of hydrogen atom coordinates, anisotropic thermal parameters and structure factors are available from the authors.

Crystal data 22°: $C_{23}H_{19}N_5O_9$ MW = 509.43, triclinic, space group P-1, a = 9.493(7), b = 11.032(7), c = 12.283(7) Å, α = 66.15(6), β = 79.92 (5), γ = 85.21(7)°. U = 1158.23 Å3, F(000) = 528, Z = 2, D_c = 1.461 g cm^{-3}, μ(Mo-K_α) = 1.2 cm^{-1}, $2\theta_{max}$ = 49.8°, 5042 measured data, 3292 unique R_m = 0.067, 335 parameters S = 0.861, wR^2 = 0.138 for all data, R = 0.053 for 2072 data with $F_o > 4\sigma(F_o)$.

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REFERENCES AND NOTES

[1] C. A. Ramsden, *Chem. Soc. Rev.*, **23**, 111 (1994).

[2] T. L. Gilchrist, C. J. Moody and C. W. Rees, *J. Chem. Soc., Perkin Trans. 1*, 1964 (1975).

[3] H. Yoshida, T. Ogata and S. Inokawa, *Bull. Chem. Soc. Japan*, **52**, 1541 (1979).

[4] M. Botoshansky, F. H. Nerbstein and M. Kapon, *Acta Cryst.*, **B50**, 191 (1994).

[5] M. D. Walkinshaw, *Acta Cryst.*, **C42**, 246 (1986).

[6] A. Quick and D. J. Williams, *Can. J. Chem.*, **54**, 2482 (1976).

[7] C. B. Aakeröy and P. B. Hitchcock, *Acta Cryst.*, **C50**, 759 (1994).

[8] R. Benassi, R. Grandi, U. M. Pagnoni, F. Taddei, G. Bocelli and P. Sgarabotto, *J. Chem. Soc., Perkin Trans. 2*, 1513 (1985).

[9] Organic Electronic Spectral Data, Vol I (1946-1952); M. J. Kamlet, ed, Wiley Interscience, New York, 1960.

[10] Organic Electronic Spectral Data, Vol **IV** (1958-1959); J. P. Phillips and F. C. Nachod, eds, Wiley Interscience, New York, 1963.

[11] Organic Electronic Spectral Data, Vol **XIII** (1971); J. P. Phillips, D. Bates, H. Feuer and B. S. Thyagarajan, eds, Wiley Interscience, New York, 1977.

[12] Organic Electronic Spectral Data, Vol **III** (1956-1957); O. H. Wheeler and L. A. Kaplan, eds, Wiley Interscience, New York, 1966.

[13] Organic Electronic Spectral Data, Vol **II** (1953-1955); H. E. Ungnade, ed, Wiley Interscience, New York, 1960.

[15] G. M. Sheldrick, SHELX-86, University of Gottingen, 1986.

[16] G. M. Sheldrick, SHELX-93, University of Gottingen, 1986.