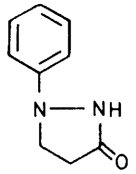
Electrochemical Oxidation of 3-Amino-4,5-dihydro-1-phenylpyrazole

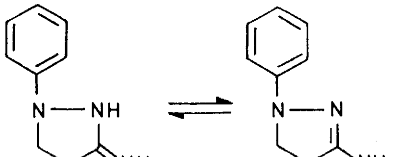
By **Brian D. Baigrie** * and **Trevor A. Joslin**, Kodak Limited, Headstone Drive, Harrow, Middlesex HA1 4TY
David W. Sopher, Brunel University, Kingston Lane, Uxbridge, Middlesex UB8 3PH

The electrochemical oxidation of 3-amino-4,5-dihydro-1-phenylpyrazole in acetonitrile has been examined. One reversible oxidation wave was observed between the potentials −0.6 and 0.9 V *versus* s.c.e. Controlled potential electrolysis indicated the formation of a persistent red radical-cation which decayed to give mainly the dimeric species 3-amino-4,5-dihydro-1-[4′-(3-amino-4,5-dihydropyrazol-1-yl)biphenyl-4-yl]pyrazole plus a small amount of 3-amino-1-phenylpyrazole. Kinetic studies using visible light spectroscopy and e.s.r. were made in conjunction with the usual electrochemical techniques.

1-PHENYLPYRAZOLIDIN-3-ONE (I) is a well known photographic developer [1] and its electrochemical properties in aqueous [2,3] and non-aqueous [4,5] media have been studied extensively. 3-Amino-4,5-dihydro-1-phenylpyrazole (II), which is iso-π-electronic with (I), is however not an active developer in aqueous solution,[6] possibly because of lack of solubility. Because we are interested in the behaviour of developers in non-aqueous media, a study of the oxidation of (II) in acetonitrile was undertaken. The results obtained between the electrode potentials of −0.6 and 0.9 V *versus* saturated calomel reference electrode (s.c.e.) are reported in this paper.



(I)



(II)

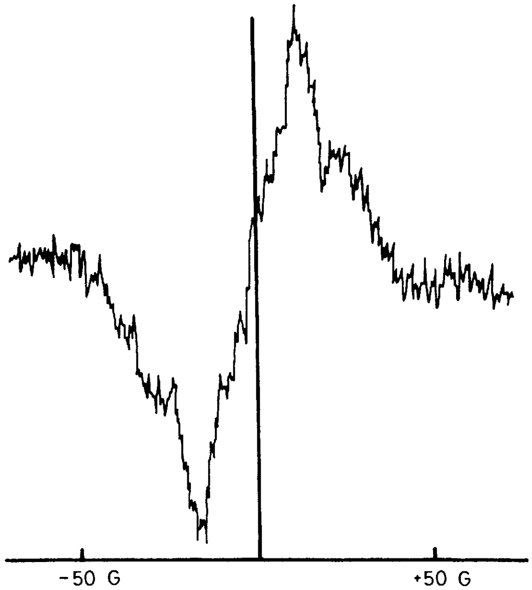
RESULTS

Cyclic Voltammetry.—Cyclic voltammograms were obtained with a platinum wire working electrode (geometric surface area 3.5×10^{-5} m^2) in acetonitrile containing 10^{-2} mol dm^{-3} (II) and 10^{-1} mol dm^{-3} tetra-n-butylammonium tetrafluoroborate or tetraethylammonium perchlorate. One reversible oxidation wave was observed between −0.6 and 0.9 V *versus* s.c.e. The oxidation peak potential occurred at 0.26 V with a corresponding reduction peak potential at 0.20 V, with a voltage sweep rate (ν) of 0.1 V s^{-1}. This reversible one-electron wave had a half-wave potential at 0.21 V. A comparison of the oxidation peak current with the corresponding peak current observed for ferrocene (10^{-2} mol dm^{-3}), which is known to undergo a reversible one-electron transfer [7,8] was made. The ratio of the peak currents of (II) to ferrocene was 0.95. Complete reversibility of the current–voltage curves was observed with sweep rates above 0.01 V s^{-1}, whilst at slower sweep rates the ratio of the cathodic to anodic peaks began to decrease indicating a slow following chemical reaction. A plot of the peak current function $i_p/\nu^{\frac{1}{2}}$ against $\nu^{\frac{1}{2}}$ was horizontal between 0.4 and 0.01 V s^{-1} indicating diffusion control at 0.26 V.

During the oxidative sweep a red intermediate was generated which was removed by the corresponding reductive scan suggesting that the red species is probably the radical-cation of (II).

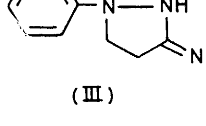
Coulometry.—Cyclic voltammograms were recorded during a controlled potential electrolysis at 0.26 V and the decrease in the oxidative peak current was plotted as a function of the charge passed. A linear relation was observed for a 5×10^{-3} mol dm^{-3} solution of (II) giving an n value of 0.91. This result was confirmed by polarography in acetonitrile (n 0.92, $E_{\frac{1}{2}}$ 0.21 V). The diffusion coefficient of (II) was calculated from the Ilković equation to be 1.05×10^{-9} m^2 s^{-1}.

E.s.r. Studies.—E.s.r. measurements were obtained from samples of (II) which were externally and internally electrochemically oxidised.[9] Both techniques gave the same broad signal using several concentrations of the generated radical in solutions degassed with nitrogen. The signal, which could not be resolved, is shown in the Figure.



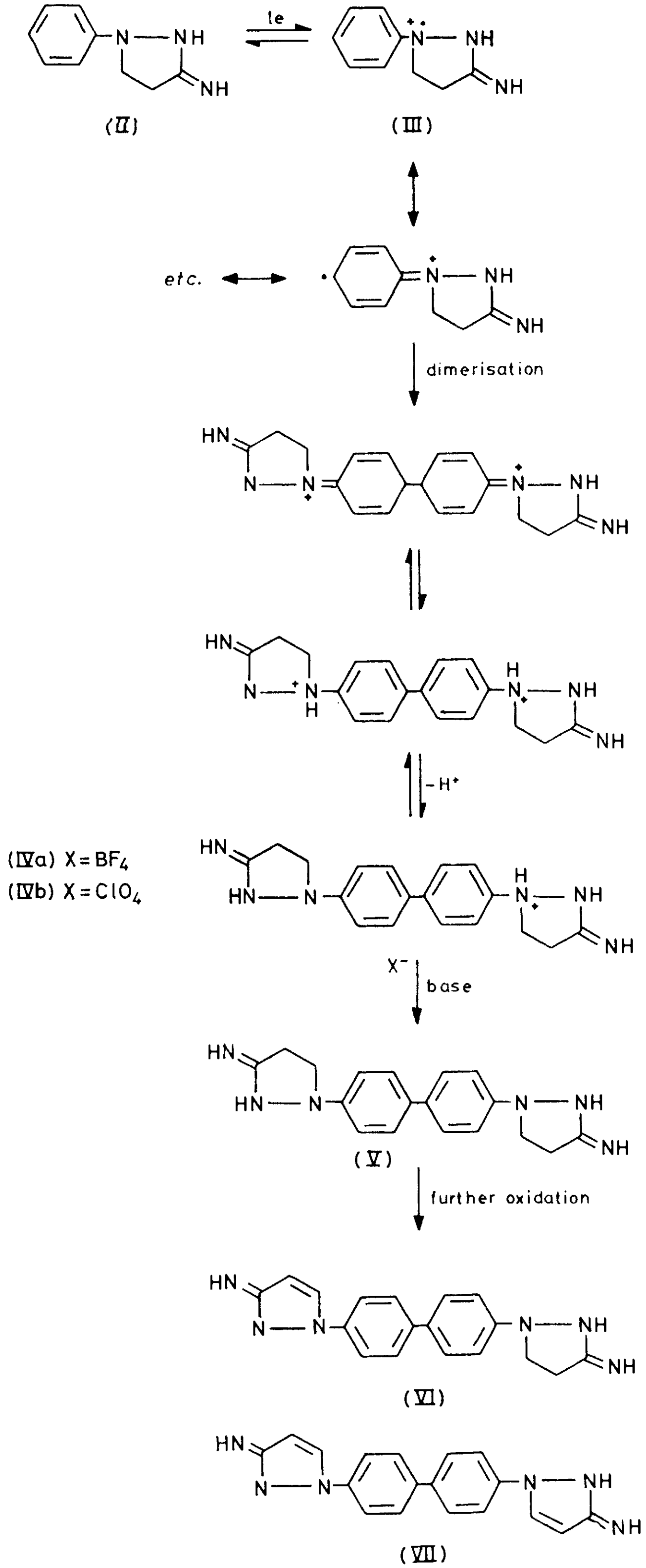
Resonance signal of the radical species (III). Field set 3 349 G; time constant 1.0 s; scan time 16 min; modulation frequency 100 KHz; modulation amplitude 4 G

Kinetic Studies.—The red intermediate which was generated electrochemically was initially studied by visible light spectroscopy. A sample of the oxidised solution was



(III)

transferred rapidly from the anode compartment of the electrochemical cell to a spectrophotometer and scanned between 350 and 700 nm. The spectrum showed one strong absorption ($\lambda_{max.}$ 530 nm) with shoulders at 506 and 475 nm. The absorption at 530 nm slowly decreased and a sharp absorption at $\lambda_{max.}$ 584 nm appeared and increased in intensity. Eventually a deep blue solution was obtained.

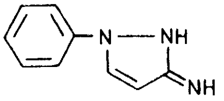


SCHEME 1

The disappearance of the red intermediate as a function of time was monitored by following the decay of the absorbance at 530 nm. The results indicated that the intermediate was decaying by a second-order reaction; the decay of the second-order absorbance function *versus* time was linear over four half-lives. Similar experiments were also performed by monitoring the decay of the e.s.r. signal as a function of time. This signal was also found to decay by a second-order relation suggesting that the generated red intermediate was the radical-cation species (III).

The second order homogeneous rate constant for the disappearance of (III) was calculated to be 11.3 dm^3 mol^{-1} s^{-1} from e.s.r. experiments. The initial concentration of the radical, which was necessary for the determination of the second-order rate constant, was obtained by comparison with a known concentration of 2,2-diphenyl-1-picrylhydrazyl in carbon tetrachloride solution.

Controlled Potential Electrolyses.—Controlled potential electrolyses were performed at 0.26 V in a divided glass cell containing platinum gauze electrodes (0.04 dm^2). The major product isolated from the anolyte consisted predominantly (>90% by n.m.r.) of 3-amino-4,5-dihydro-1-[4′-(3-amino-4,5-dihydropyrazol-1-yl)biphenyl-4-yl]pyrazole (V) (Scheme 1). A number of other products was also formed as indicated by t.l.c. Only one of these, 3-amino-1-phenylpyrazole (VIII) was obtained in sufficient quantity (9% current yield) to allow full characterisation.



(VIII)

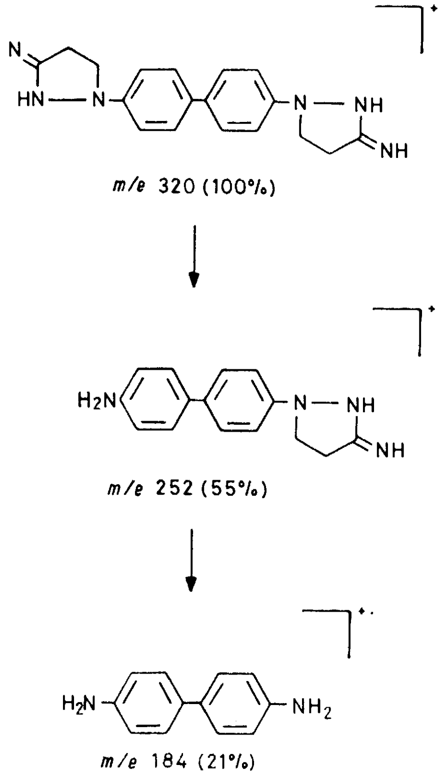
DISCUSSION

Our experiments indicate that (I) is electrochemically oxidised to a red, persistent [10] radical-cation (III). The persistence of this species may be attributed to extensive resonance stabilisation as indicated by the numerous possible mesomeric forms. By blocking the *para*-position of the phenyl ring, thus precluding the possibility of head-to-head dimerisation, an even more persistent radical-cation would be expected. Cyclic voltammetry of 3-amino-4,5-dihydro-1-(*p*-tolyl)pyrazole showed a reversible oxidation process (E_p 0.31, $E_{p/2}$ 0.25 V) resulting in the generation of a red radical-cation with a lifetime of several weeks.

Radical (III) slowly reacts *via* a second-order reaction to give a head-to-head dimeric product (V) as shown in Scheme 1. Similar reactions of this type have been reported for aromatic amines [11] and dihydropyrazoles.[12-14]

The major product was initially obtained either as a blue-black monofluoroborate (IVa) or monoperchlorate (IVb) salt, dependent on the nature of the background electrolyte. The dihydrochloride salt of (V) could however be obtained by crystallisation of (V) from concentrated hydrochloric acid–water (1 : 1). The relative solubilities of the mono- and di-salts of (V) in acetonitrile may explain why, contrary to our expectations, the monosalt was obtained.

That the dimerisation had occurred in a head-to-head manner was confirmed by ^1H n.m.r. and mass spectral data. In the ^1H n.m.r. spectrum of (V) in deuteriotrifluoroacetic acid, a characteristic AA′BB′ pattern was observed at δ 7.38 and 7.72, each doublet integrating for four protons which was consistent with *para*-substitution in the phenyl rings. In addition, two triplets at δ 3.4 and 4.23 confirmed the presence of ring methylene groups. Detailed analysis of the mass spectrum supplied strong supporting evidence for structure (V) (Scheme 2). Accurate mass measurements of each of these fragments confirmed the postulated fragmentation pattern (Table 1).



SCHEME 2

TABLE 1

m/e	Formula	Calculated mass	Measured mass
320	$C_{18}H_{20}N_6$	320.174 936	320.173 184
252	$C_{15}H_{16}N_4$	252.137 490	252.135 842
184	$C_{12}H_{12}N_2$	184.100 043	184.098 586

Attempts to obtain an analytically pure sample of (V) were frustrated by the insolubility of the dimeric products in common organic solvents. Careful attempts to recrystallise (V) from 1-methylpyrrolidin-2-one or hexamethylphosphoramide under nitrogen invariably resulted in a more complex mixture of products. That products (VI) and (VII) were present was shown by mass spectral evidence (Table 2), and confirmed by n.m.r. data which recorded the appearance of four doublets at δ 6.37, 7.74, 8.04, and 8.22 assigned to the vinylic protons of (VI) or (VII). Attempts to isolate (VI) and (VII) were unsuccessful.

TABLE 2

m/e	Formula	Calculated mass	Measured mass
318	$C_{18}H_{18}N_6$	318.159 289	318.158 663
316	$C_{18}H_{16}N_6$	316.143 637	316.142 572

It is interesting to note that a blue solid was also obtained when (II) was chemically oxidised with nitrous acid or other oxidising agents in acid solutions,[15] although the original authors did not assign a structure to this product.

A priori one would not expect acidic solutions of (V) to be strongly chromogenic; salts of radical-cations are known to give coloured solutions of various hues, Wurster's salts and viologens being classic examples.[16] However, e.s.r. measurements at room temperature of acidic solutions of (V) and (IVb) indicated that no radical species were present. A likely explanation of the chromogenic properties exhibited by (V) in acid solution is the formation of a charge-transfer complex between (V) acting as a donor species and the appropriate acid acting as the acceptor [equation (1)]. In accord with

$$(V) + HX \longrightarrow [(V)HX]^* \longrightarrow [(V)^{+\cdot}][HX^{-\cdot}] \quad (1)$$

this postulate is the observation that $\lambda_{max.}$ of the complex varied with changes in the acceptor component when a sample of the monofluoroborate (IVa) was dissolved in the appropriate acid and diluted with water (Table 3).

TABLE 3

Aqueous acid	HCl	HBr	$HClO_4$
$\lambda_{max.}$/nm	591	589	588
Aqueous acid	H_2SO_4	CF_3COOH	CH_3COOH
$\lambda_{max.}$/nm	587	586	584

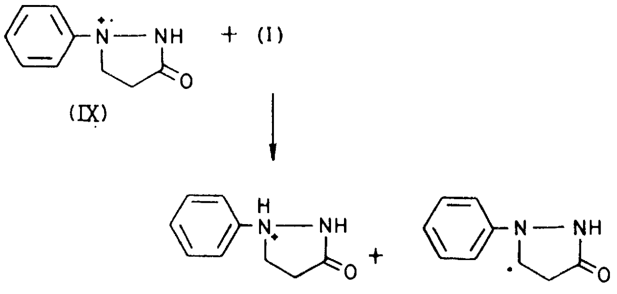
Moreover, a green solution ($\lambda_{max.}$ 600 nm) is obtained when dilute solutions of (V) and iodine in dimethyl sulphoxide are mixed. It is well known that hydrogen halides and strongly accepting halogens such as I_2 and ICl can act as σ-type sacrificial acceptors.[17]

In addition when (V) in dimethyl sulphoxide was added to a solution of 7,7,8,8-tetracyanoquinodimethane in dimethyl sulphoxide another green solution was obtained. Visible spectroscopy between 450 and 850 nm showed an intense absorption, $\lambda_{max.}$ 604 nm, with a narrow half-band width (20 nm). 7,7,8,8-Tetracyanoquinodimethane is a well known acceptor component in numerous charge transfer complexes.[17]

The formation of (V) as a major product and (VIII) as a minor product differs from our results,[4] obtained previously with 1-phenylpyrazolidin-3-one (I), although similar trends have been reported in the oxidation of dihydropyrazoles.[12] A simple rationale for our findings lies in the ease of proton loss from the radical-cation (IX) compared with (III). Cyclic voltammograms of (I) showed an oxidation wave for protonated substrate, formed by transfer of a proton from (IX) (Scheme 3).

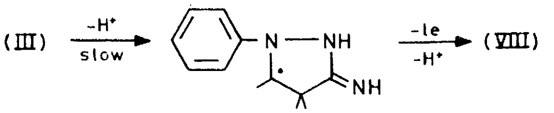
No such wave was observed in voltammograms of (II), although a wave due to the oxidation of protonated (II) is obtained at 0.98 V (E_p) upon addition of 40% perchloric acid.

A further anodic oxidation wave observed at 1.27 V (E_p) with a half-wave potential at 1.19 V (sweep rate 0.1 V s^{-1}) was ascribed to further oxidation of (III). The separation between the initial oxidation peak at 0.26 V and this second peak was 1.01 V which militates against the possibility of disproportionation of (III).[18] Although the magnitude of the separation between the two anodic waves is larger than that normally observed for the stepwise oxidation–reduction of a compound,[18] similar large separations have previously been reported.[19-21]



SCHEME 3

Because disproportionation of (III) is highly disfavoured, the most probable route to the minor product (VIII) is by slow proton loss followed by further oxidation (Scheme 4).



SCHEME 4

A similar mechanism is postulated for the electrochemical formation of pyrazoles in the presence of bases.[12,22]

EXPERIMENTAL

Equipment.—To obtain u.v. spectra and study the decay of the radical species a Unicam SP 800 spectrophotometer was used. E.s.r. spectra were recorded on a Varian E3 spectrometer and n.m.r. spectra were recorded on a JEOL FX100 instrument. Polarography was accomplished using a Radiometer PO4 Polariter. All other electrochemical equipment was as previously reported.[4]

Chemicals.—Acetonitrile (B.D.H.) was purified as previously described.[4] Ferrocene (B.D.H.) was used directly. Tetra-n-butylammonium tetrafluoroborate and tetraethylammonium perchlorate (Eastman Kodak) were dried at 80 °C in a vacuum oven for 6 h before use.

3-Amino-4,5-dihydro-1-phenylpyrazole was prepared by the method of Duffin and Kendall [15,23] in 62% yield, m.p. 168 °C (lit.,[15,23] 168—169 °C).

3-Amino-4,5-dihydro-1-(*p*-tolyl)pyrazole, prepared analogously, was obtained as plates from chloroform–petroleum, m.p. 142 °C (lit.,[15,23] 143 °C).

Controlled Potential Electrolyses.—A controlled potential electrolysis was performed at 0.20 V *versus* s.c.e. with a divided glass cell containing tetraethylammonium fluoroborate (16.5 g, 0.05 mol) in acetonitrile (5×10^{-1} dm^3) with a working electrode compartment containing 3-amino-4,5-dihydro-1-phenylpyrazole (3.0 g, 0.019 mol). After passage of 1 205 coulombs, the precipitate in the working compartment was filtered off, washed well with acetonitrile and ether, and dried (Found: C, 53.4; H, 5.0; N, 20.4. $C_{18}H_{20}N_6HBF_4$ required C, 53.0; H, 5.1; N, 20.6%). The mother liquors were concentrated to half the original volume and on standing a further precipitate was obtained. The combined precipitates [1.8 g, 71% current yield based on the monotetrafluoroborate salt of (V)] were dissolved in trifluoroacetic acid (1×10^{-1} dm^3) and the resultant deep blue solution was added dropwise to a saturated solution of sodium carbonate (5×10^{-1} dm^3). The fine beige precipitate was filtered off and washed thoroughly until the washings were neutral. The precipitate (1.0 g) was dried and recrystallised from 1-methylpyrrolidin-2-one to give a pale yellow product identified as 3-*amino*-4,5-*dihydro*-1-[4′-(3-*amino*-4,5-*dihydropyrazol*-1-*yl*)*biphenyl*-4-*yl*]*pyrazole* (0.8 g, 40% current yield), *m*/*e* 320 (Found: M^+, 320.173 184. $C_{18}H_{20}N_6$ requires M^+, 320.174 936); $\delta(CF_3CO_2{}^2H)$ 3.48 (4 H, t, CH_2), 4.23 (4 H, t, CH_2), 7.38 (4 H, d, aromatic), and 7.72 (4 H, d, aromatic). The dihydrochloride was obtained from concentrated hydrochloric acid–water (1 : 1) as a pale blue solid (Found: C, 50.6; H, 6.3; N, 19.9; Cl, 16.4. $C_{18}H_{20}N_6,2HCl,2H_2O$ requires C, 50.4; H, 6.1; N, 19.6; Cl, 16.6%).

The anolyte was further concentrated to 5×10^{-2} dm^3, ether (5×10^{-2} dm^3) was added, and the precipitated base electrolyte was filtered off and washed with ether. The filtrate was evaporated to dryness and the residue (2.4 g) was chromatographed on silica gel (150 g), eluting with chloroform. The major fraction was further purified by p.l.c. (toluene–ethyl acetate 1 : 1) to give, after recrystallisation from toluene–petroleum, 3-amino-1-phenylpyrazole (0.09 g, 9% current yield) as pale yellow needles, m.p. 90—92 °C (lit.,[15] 101 °C) (Found: C, 67.7; H, 5.8; N, 26.4%; M^+, 159. Calc. for $C_9H_9N_3$: C, 67.9; H, 5.7; N, 26.4%; $\delta(C^2HCl_3)$ 3.84br (2 H, exchangeable with ^2H_2O), 5.82 (1 H, d, C=CH), 7.0—7.6 (5 H, m, aromatic), and 7.67 (1 H, d, HC=C).

A controlled potential electrolysis was also performed using tetra-n-butylammonium perchlorate as electrolyte. Both dimer and pyrazole were obtained as before from a work-up identical with that described above.

We thank Dr. K. A. Lott, Brunel University, for his work pertaining to e.s.r. studies, Dr. J. H. P. Utley, Queen Mary College, for drawing our attention to relevant aspects of charge-transfer complexes, and Dr. P. Hillson, these laboratories, for useful discussions. One of us (D. W. S.) thanks Kodak Limited for supporting this work during an industrial training period.

[8/212 *Received*, 8*th February*, 1978]

REFERENCES

[1] L. F. A. Mason, ' Photographic Processing Chemistry,' Focal Press, London, 1975.

[2] E. R. Brown in ' The Theory of the Photographic Process,' ed. T. H. James, Macmillan, New York, 4th edn., 1977.

[3] H. H. Adam and T. A. Joslin, *J. Electroanalyt. Chem. Interfacial Electrochem.*, 1975, **58**, 393.

[4] H. H. Adam, B. D. Baigrie, and T. A. Joslin, *J.C.S. Perkin II*, 1977, 1287.

[5] B. D. Baigrie and T. A. Joslin, *J. Electroanalyt. Chem. Interfacial Electrochem.*, 1978, **87**, 405.

[6] H. Ulrich and H. Schueler, *J. Photographic Sci. Eng.*, 1960, **4**, 225.

[7] T. Kuwana, D. E. Bublitz, and G. Hoh, *J. Amer. Chem. Soc.*, 1960, **82**, 5811.

[8] I. V. Nelson and R. T. Iwamoto, *Analyt. Chem.*, 1961, **33**, 1795.

[9] B. Kastening in 'Advances in Analytical Chemistry and Instrumentation,' ed. H. W. Nurnberg, Wiley, London, vol. 10, 1974.

[10] D. Griller, J. W. Cooper, and K. U. Ingold, *J. Amer. Chem. Soc.*, 1975, **97**, 4269.

[11] S. D. Ross, M. Finkelstein, and E. J. Rudd, 'Anodic Oxidation,' Academic Press, New York, 1975.

[12] F. Pragst and C. Böck, *J. Electroanalyt. Chem. Interfacial Electrochem.*, 1975, **61**, 47.

[13] I. Tabaković, M. Laćan, and Sh. Damoni, *Electrochim. Acta*, 1976, **21**, 621.

[14] P. Corbon, G. Barbey, A. Dupré, and C. Caullet, *Bull. Soc. chim. France*, 1974, 768.

[15] G. F. Duffin and J. D. Kendall, *J. Chem. Soc.*, 1954, 408.

[16] A. R. Forrester, J. M. Hay, and R. H. Thomson, ' Organic Chemistry of Stable Free Radicals,' Academic Press, London, 1968.

[17] R. Foster, ' Organic Charge-Transfer Complexes,' Academic Press, London, 1969.

[18] A. J. Bard, A. Ledwith, and H. J. Shine, *Adv. Phys. Org. Chem.*, 1976, **13**, 155.

[19] J. A. Richards, P. E. Whitson, and D. H. Evans, *J. Electroanalyt. Chem. Interfacial Electrochem.*, 1975, **63**, 311.

[20] F. Pragst, H. Köppel, W. Jugelt, and F. G. Weber, *J. Electroanalyt. Chem. Interfacial Electrochem.*, 1975, **60**, 323.

[21] G. Cauquis and J. P. Billon, *Compt. rend.*, 1962, **255**, 2128.

[22] G. Cauquis, J. Badoz-Lambling, and J. P. Billon, *Bull. Soc. chim. France*, 1965, 1433.

[23] J. D. Kendall and G. F. Duffin, B.P. 679,678/1952.