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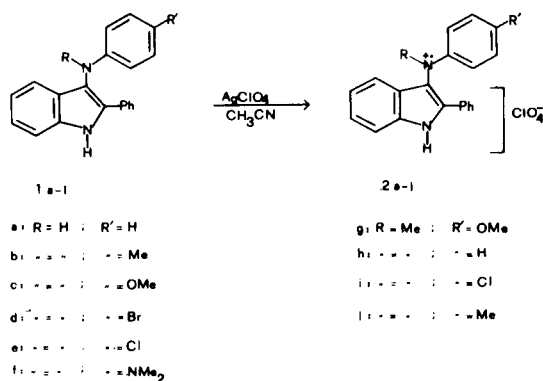
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The varying stabilities of certain aminoindole radical cations toward oxidation with molecular oxygen have been studied. Oxidation leads to different products depending upon the environment around the *N*-amino nitrogen. A plausible reaction mechanism is proposed based on electronic and magnetic resonance spectroscopy.

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Aminoindole radical cations **2a-l** have been obtained by direct oxidation of the corresponding amines **1a-l** in an epr spectrometer cavity with silver perchlorate (2); as reported in the literature (2,3), epr spectra favour radicals with the unpaired electron localized primarily on the *exo*-nitrogen. Some of these radicals ( $R' =$  methoxy and *p*-dimethylamino) were stable enough so as to be isolated and characterized (2).

Oxygen and water were reported (3) to lead to decomposition of these radicals; their stability has tentatively been related to *p*-substituents on the aminophenyl group as well as to the nature of *R* (hydrogen or methyl). In this work we study possible decomposition pathways in this reaction of aminoindole radical cations with molecular oxygen.



Unsubstituted 2-phenyl-3-aminoindoles **3a-d** were prepared as potential precursors of unsubstituted aminoindole radical cations. Oxidation in the epr spectrometer cavity with silver perchlorate gave rise to stable signals which do not allow definite radical structure interpretation. However, structure **4** can be excluded, since the spectra cannot be related to radicals centered on an amino nitrogen atom bonded to two hydrogen atoms. Further, a seven-line spectrum was observed for the radical derived from **3b**, while a six-line spectrum was observed for the radical derived from **3d**. These observations cannot be reasonably interpreted (Figure 1). Compounds **3a,c** exhibited different behaviour, having identical coupling constants, and gave four-line spectra corresponding to the

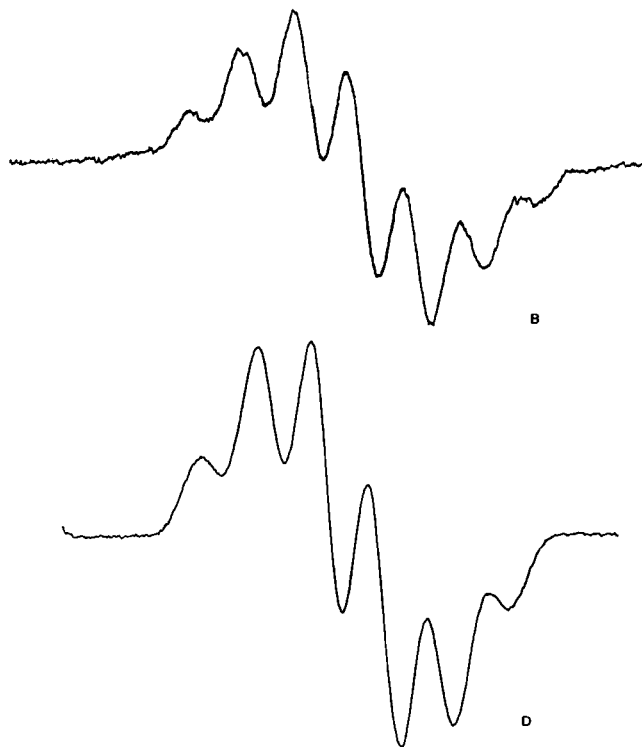
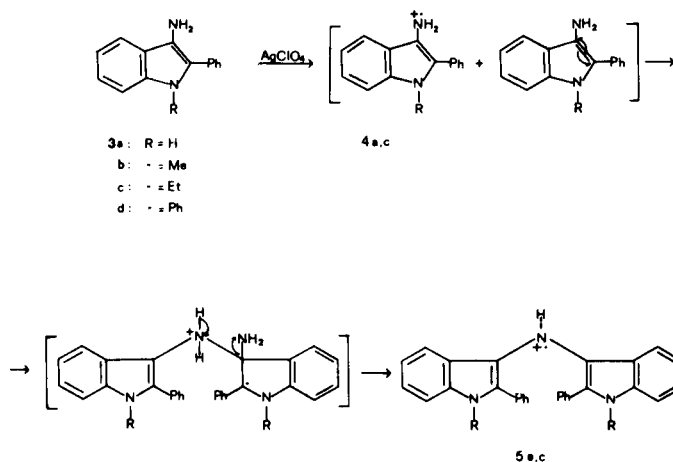


Fig. 1. EPR spectra of radicals derived from **3b** (B) and **3d** (D).



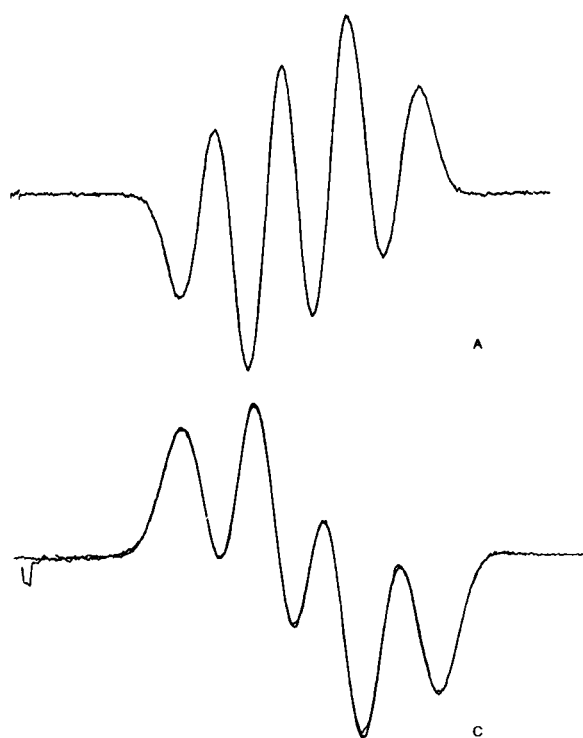
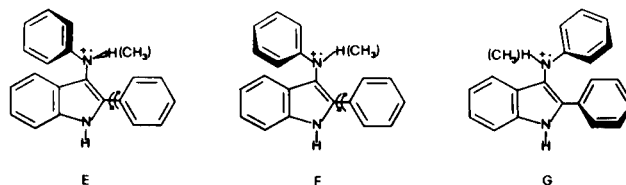


Fig. 2. EPR spectra of radicals **5a** (A:  $a_{\text{NH}}^{\text{N}} = a_{\text{NH}}^{\text{H}} = 7$  gauss); and **5c** (C:  $a_{\text{NH}}^{\text{N}} = a_{\text{NH}}^{\text{H}} = 7.5$  gauss).

structures **5a,c**, respectively, obtained by direct oxidation of bisindolylamines (Figure 2). This finding can be rationalized as follows: the unstable radical cations **4a,c** combine with unreacted aminoindoles (bearing an extremely mobile double bond), followed by elimination of ammonia, which leads to the radicals **5a,c**. In agreement, with this interpretation, a time interval of from 30 minutes to one hour occurs before any epr signal appears. It is therefore possible to argue that the indolic framework has a negligible stabilizing effect on radical cations, which conclusion is more evident if one compares the above reported results with the stability of the radical cations **2a-l**, which has already been mentioned.

A question arises as to the geometry of the radical cations **2a-f** (4). As the observed influence of *p*-substituents suggests, the stability of these radicals must be related to

resonance effects, particularly associated with the *N*-phenyl ring. Such requirements for stability necessitate coplanarity between the  $\pi$ -electrons of the *exo*-nitrogen and those of the *N*-phenyl ring. Molecular models clearly show that maximum coplanarity can be achieved in structure **E** with the axis of the phenylamino group perpendicular to that of the indolic framework; partial



coplanarity can be realized in structure **F**, while no coplanarity is possible in structure **G**, with the two phenyl groups opposed with respect to the pyrrolic double bond. The same conformations can be attributed to *N*-methyl derivatives **2g-l**.

In accordance with the hypothesis that such coplanarity has a definite effect on radical stability, five compounds were selected for study from compounds **2a-l** (namely **2c,g,h,i,l**), based on the following considerations: (i) compound **2f** can be neglected owing to its already recognized stability when compared with **2c**;

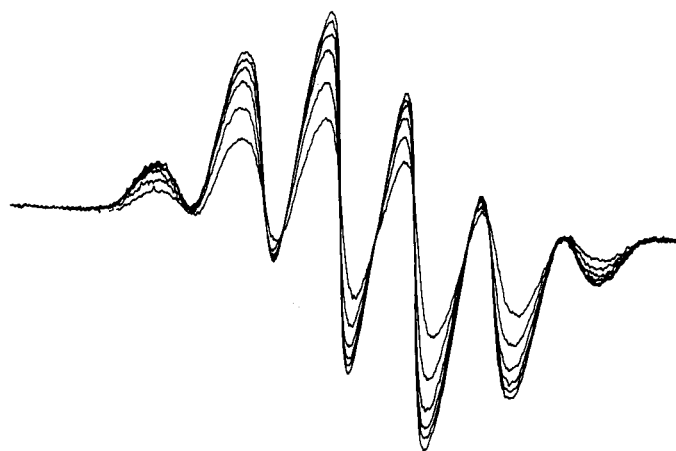
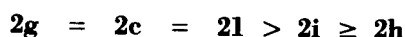


Fig. 3. Evolution of EPR spectrum of **2i**, oxygen added, as measured at time intervals of 4, 8, 12, 20, 50, 120 minutes.

Table I

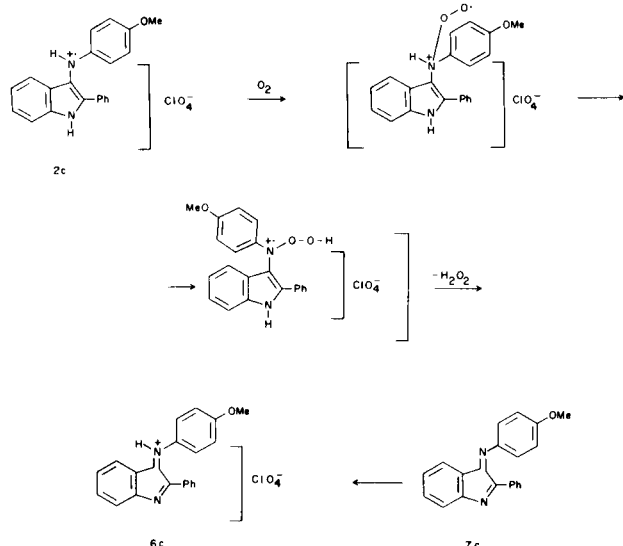
Compound No.	Relative Concentration After 4 Minutes	Relative Concentration After 20 Minutes	Relative Concentration After 16 Hours	Stability Ratios
<b>2c</b>	1	1	0.72	$2c/2g = 1$
<b>2g</b>	1	1	1	
<b>2h</b>	0.81	0.67		$2h/2g = 0.81$
<b>2i</b>	0.94	0.81		$2h/2i \approx 0.83$
<b>2l</b>	1	1		$2l/2g = 1$

(ii) compounds **2a,b,d,e** are too unstable; and (iii) compounds **2g-l** cover a large range of stabilities and allow for the consideration of the effect of both the *N*-methyl group and that of substituents on the phenyl ring. The change in radical cation concentration *versus* time was measured using epr spectra (see Figure 3, referring to **2i** as an example) and is reported in Table 1. For **2g**, 100% concentration (determined with respect to DPPH sample) was assured and all initial concentrations were measured 4 minutes after mixing at room temperature. Stability coefficients calculated at 30 minute time interval show the sequence:



The above reported results clearly indicate that both *N*-methylation and the presence of *p*-electron-donor substituents in the phenyl ring must be responsible for radical stability. Compound **2c** exhibits roughly the same stability as **2g** (the most stable among all radicals), because of the strong effect of the *p*-methoxy group. Stability is also favoured by *N*-methylation, which can be seen by comparing the relative stabilities of both stable **2l** with unstable **2b** and of relatively stable **2i**, where the *p*-chloro substituent should lead to destabilisation, with the unstable radicals **2e** and **2h**. Radical stabilisation by steric (4) and mesomeric (5) effects is already a well known fact.

The oxidation of radicals **2a-l** leads to the perchlorates of the corresponding imino compounds. An extended study was carried out on radical **2c**, which appeared to be the most suitable substrate with respect to the decomposition reaction.



Because of the differences in absorption maxima between **2c** and **6c**, it has been possible to study the oxidation reaction with electronic spectroscopy, by following the

Table 2

Compound No.	Absorption Maxima (Nm) in Acetonitrile
<b>1c</b> (2)	305
<b>2c</b> (2)	402, 460 (sh), 602
<b>6c</b>	575
<b>7c</b>	263, 345, 452

variation of peaks at 402 nm (characteristic of the radical perchlorate) and 575 nm (characteristic of the imino perchlorate) (see Table 2). The radical perchlorate shows an additional peak at 602 nm, which progressively shifts to the peak at 575 nm during the reaction; decreasing absorptions at 402 nm correspond to increasing values at 575 nm.

The above reported considerations suggest a direct free radical attack on an oxygen molecule on the *exo*-nitrogen bearing the unpaired electron, leading to a hydroperoxide type intermediate. This attack would be followed by hydrogen peroxide (or hydroperoxy radical) elimination as illustrated in the reaction sequence.

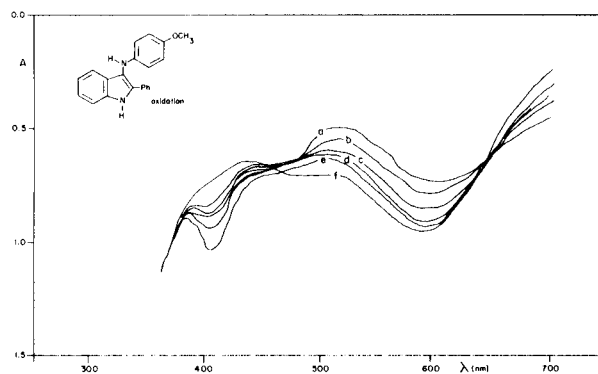


Fig. 4. Absorption spectra of radical **2c**, oxygen added; a, at time reference 0; b, after 15 minutes; c, after 45 minutes; d, after 90 minutes; e, after 180 minutes; f, after 20 hours.

## EXPERIMENTAL

### Spectroscopy.

Electronic spectra were measured on a Perkin-Elmer 402 uv spectrometer at room temperature. 2-Phenyl-3-(*N*-*p*-methoxyphenyl)aminoindole was dissolved in anhydrous acetonitrile and diluted to a concentration of  $3 \times 10^{-3}$  M. Dry oxygen was bubbled directly into the cell during the time in which the measurements were taken. Epr spectra were measured on a VARIAN E-3 ESR spectrometer using a deaerated inverted cell (6) for radical generation. For decomposition measurements, a small amount of air was allowed to enter the cell and the spectrum was repeated at proper intervals. Concentration measurements were referred to a standard sample of DPPH and determined according to the methods reported by Wyard (7).

### Oxidation of the 2-Phenyl-3-(*N*-*p*-methoxyphenyl)aminoindole Radical Cation.

The radical cation (0.1 g.) dissolved in 50 ml. of dry acetonitrile was reacted with anhydrous oxygen until all of the radical cation disappeared (about 20 minutes). The solution was then evaporated under vacuum at

room temperature, neutralized with dilute ammonia and extracted with ethyl ether. Evaporation of the solvent left quantitative amounts of 2-phenyl-3-(*p*-methoxyphenylimino)-3*H*-indole (8).

2-Phenyl-3-(*p*-methoxyphenylimino)-3*H*-indole Perchlorate.

Equimolar amounts of 2-phenyl-3-(*p*-methoxyphenylimino)-3*H*-indole and perchloric acid were dissolved in anhydrous acetonitrile and stirred for half an hour. The resulting solution was used for reference in the uv determinations.

#### REFERENCES AND NOTES

(1) Preliminary results of this study were presented at the Fifth Inter-

national Congress of Heterocyclic Chemistry, Ljubljana, Yugoslavia, 1975.

(2) P. Bruni, M. Colonna and L. Greci, *Tetrahedron*, **27**, 5893 (1971).

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(4) The question can be resolved by an X-ray structure determination which is at present under investigation.

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(7) G. A. Russell, E. G. Janzen and E. T. Strom, *J. Am. Chem. Soc.*, **86**, 1807 (1964).

(8) S. J. Wyard, *J. Sci. Instrum.*, **42**, 769 (1965).

(9) M. Colonna and P. Bruni, *Gazz. Chim. Ital.*, **97**, 1569 (1967).