ALIPHATIC SEMIDIONES—XI

RADICAL ANIONS DERIVED BY REDUCTION OF 1-PHENYL-3-METHYL-2-PYRAZOLINE-4,5-DIONE, 1,2-DIPHENYLPYRAZOLIDENE-3,4,5-TRIONE AND 1,1'-DIPHENYL-3,3'-DI-METHYL-$\Delta^{4,4'}$-BIS-2-PYRAZOLINE-5,5'-DIONE (PYRAZOLE-BLUE)*

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Abstract—The title compounds all furnish stable radical anions (pyrazole semiquinones) upon exposure to the reducing system of dimethyl sulfoxide plus base. The radical anions have been detected by ESR spectroscopy. Excess base in DMSO will cleave pyrazole-blue to yield the radical anion of 1-phenyl-3-methyl-2-pyrazoline-4,5-dione. The radical anion of pyrazole-blue is formed from pyrazole-blue in solvents such as DMSO without added base or reducing agents.
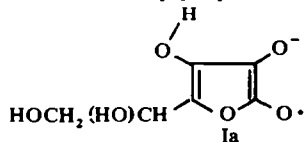
A VARIETY of heterocyclic analogues of the *ortho-* and *para*-semiquinones are known wherein the oxygen atoms are substituents to a $(4n + 2)$ π-system, e.g., *ortho*-semiquinones:
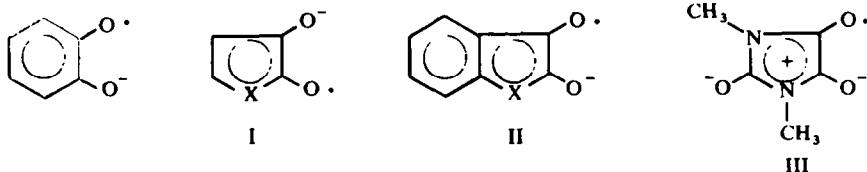
para-semiquinones:
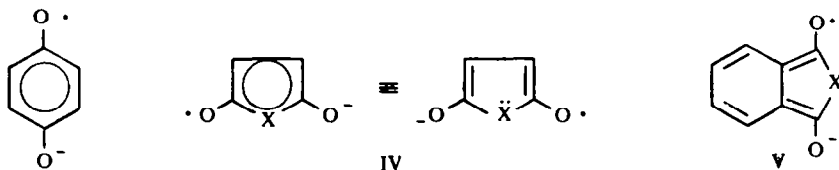
Ascorbic acid yields the furan semiquinone Ia upon mild oxidation,[1,2] while derivatives of II with X = O, S, N—R are easily prepared.[3]

Radical anion III is prepared by the electrolytic reduction of N,N'-dimethylparabanic acid.[4] Examples of IV and V with X = O and N—R have been provided by Nelsen.[5]

We would like to describe some work in the pyrazole area in which the semi-quinones VI–VIII have been examined in dilute solution.
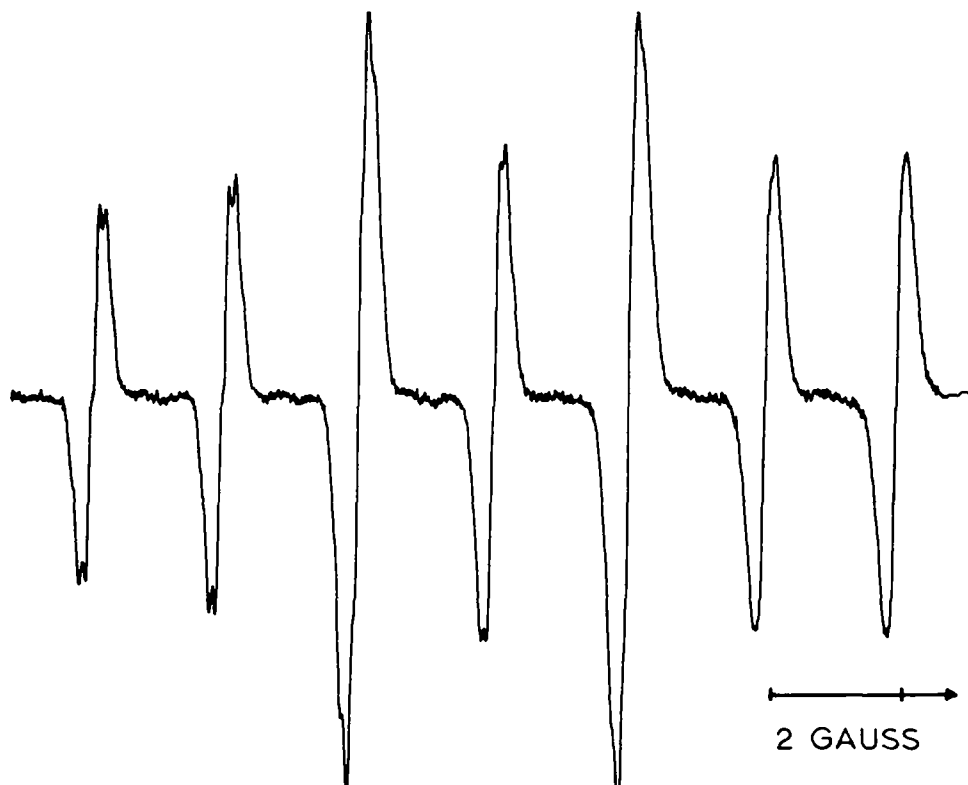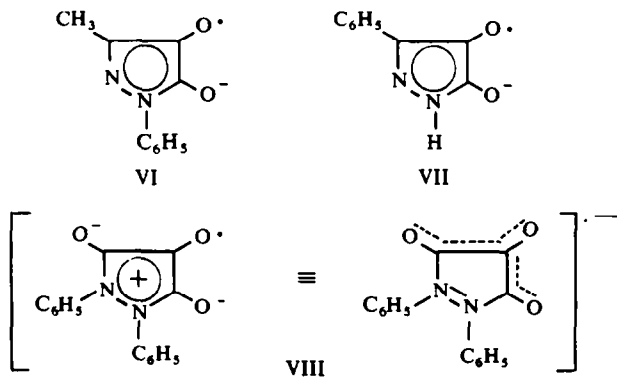

FIG. 1 Electron spin resonance first derivative spectrum of radical VI. The low field peaks show a tendency to split further, perhaps into a 1:3:3:1 quartet with $a^H \sim 0.1$ gauss.

Treatment of 1-phenyl-3-methyl-2-pyrazoline-4,5-dione with a solution of potassium t-butoxide in dimethyl sulfoxide (DMSO) led to the formation of a radical anion identified as VI by electron spin resonance spectroscopy (ESR), Fig 1. The reducing ability of DMSO and base is well known.[6, 7] Thus, solutions of potassium t-butoxide in DMSO will reduce cyclooctatetraene, anthracene, or nitrobenzene to the radical anions. The reduction apparently involves the methylsulfinylcarbanion $(CH_3SOCH_2^-)$,[6] but the details are not understood. The presence of the propiophenone enolate anion $(C_6H_5C(O^-)\!\!=\!\!CHCH_3)$ in DMSO or DMSO–alcohol mixtures gives a particularly effective one-electron reducing agent for a wide variety of unsaturated substances.[8] All attempts to oxidize 1-phenyl-3-methyl-2-pyrazoline-5-one with oxygen in the presence of base failed to produce any ESR signal.

$$a^N = 4\cdot22, 2\cdot00$$
$$a_{CH_3}^H \sim 0\cdot1 \text{ gauss}$$
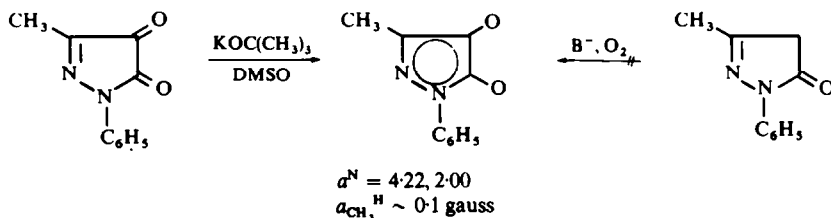
1,2-Diphenylpyrazolidine-3,4,5-trione was reduced to VIII by propiophenone in basic DMSO solution to yield the semitrione radical anion (Fig 2).

VIII

$$a^N = 1\cdot19, 1\cdot19$$
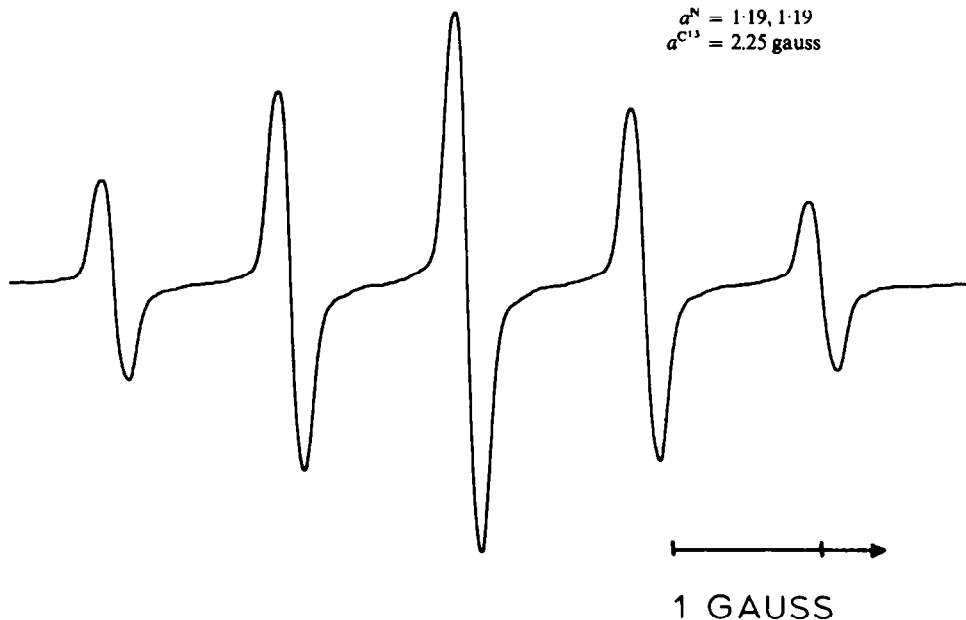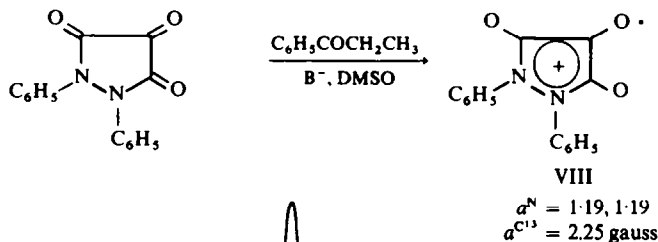$$a^{C^{13}} = 2.25 \text{ gauss}$$

1 GAUSS

FIG. 2 ESR first derivative spectrum of VIII.

3-Phenyl-2-pyrazoline-5-one slowly produced a radical anion in DMSO solution in the presence of potassium t-butoxide and oxygen. Using only one equivalent of base for each molecule of the pyrazolinone yielded a spectrum with $a^N = 5.10$ and 2.22 gauss. With an excess of potassium t-butoxide a spectrum with $a^N = 6.20$ and 1.50 gauss was obtained. Apparently an acid-base equilibrium between VII and the dianion radical is involved.
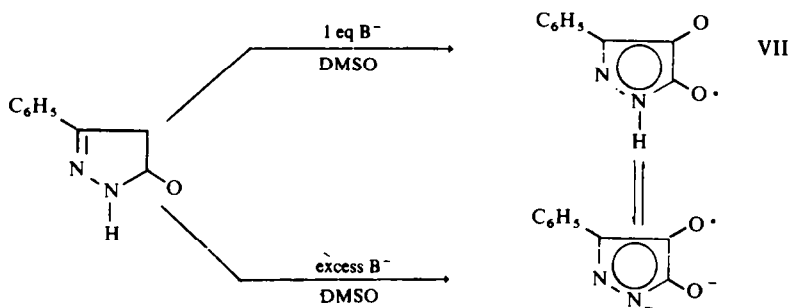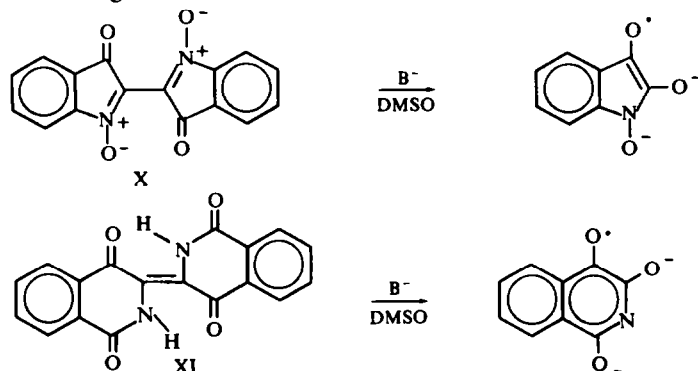

Another route to the radical anion VI was observed. The treatment of the dione IX with an excess of potassium t-butoxide in DMSO solution yielded VI. This conversion may involve the reaction sequence of Scheme 1.

Scheme 1 :
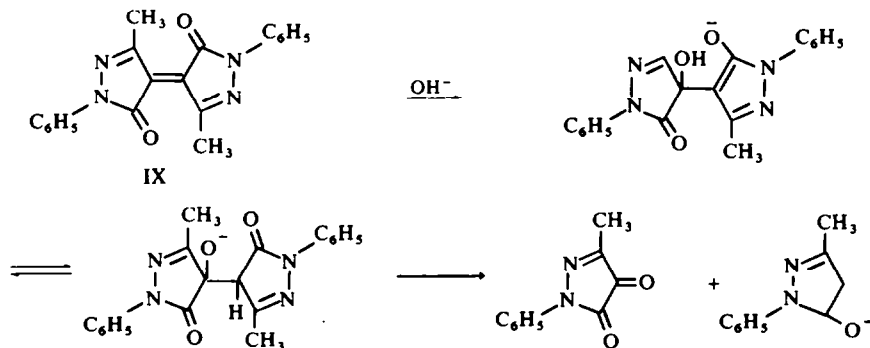
We have observed a process similar to that of Scheme 1 for several other dimeric substances, including X[5] and XI.[9]

When IX is dissolved in a solvent such as DMSO in the absence of base, a different paramagnetic substance is produced (Fig 3).
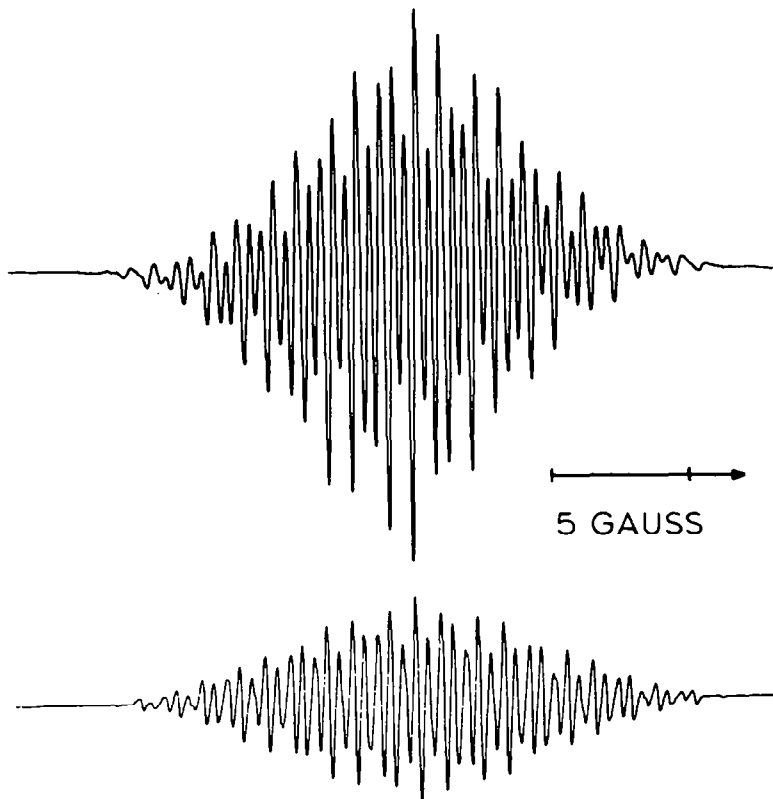
5 GAUSS

Fig. 3 Top, ESR first derivative spectrum of XII; bottom, calculated spectrum with Lorentzian linewidth of 0·2 gauss and hyperfine splitting constants given in text. Spectrum was calculated with a Japanese Electron Optics Corp. JNM-RA-1 spectrum analyzer.

The same spectrum is obtained from IX in the presence of an equivalent of potassium t-butoxide or by the reaction of a trace of oxygen with the dihydro derivative of IX. These observations in connection with the ESR spectrum define the radical anion as XII.

XII

$a^N = 3·06, 3·06, 1·28, 1·28$

$a_{CH_3}{}^H = 0·90, 0·90$ gauss
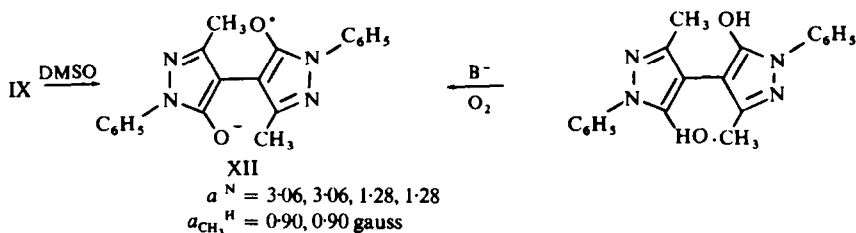
Oxidation of 4,4'-bis-2-pyrazoline-5,5'-dione by a trace of oxygen in DMSO containing potassium t-butoxide yielded an ESR signal (Fig 4) assigned to radical anion XIII.

$$a^N = 3·44, 3·44, 1·50, 1·50$$
$$a^H = 0·12, 0·12$$

5 GAUSS
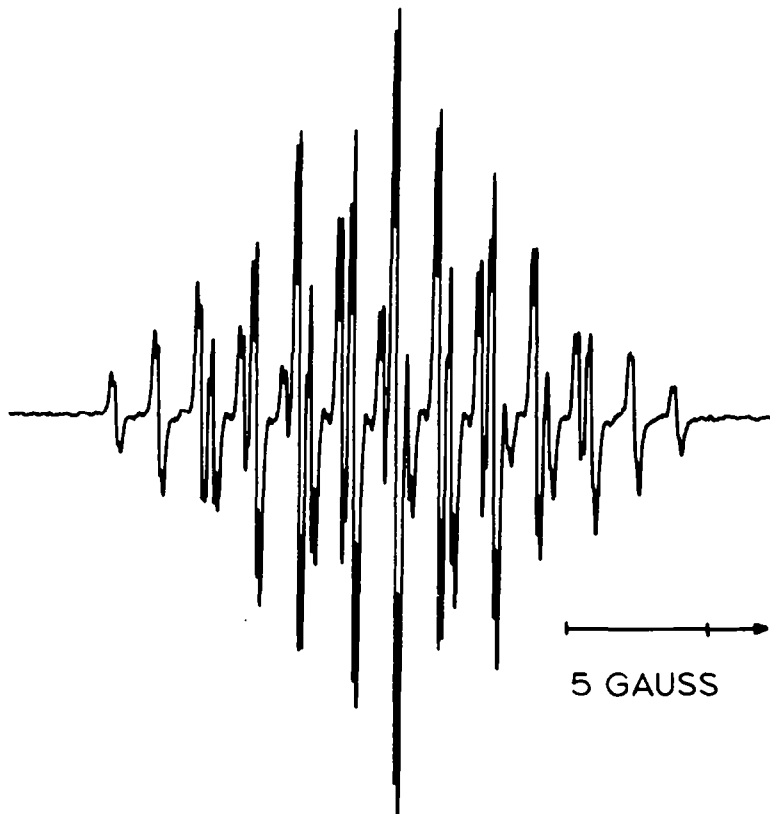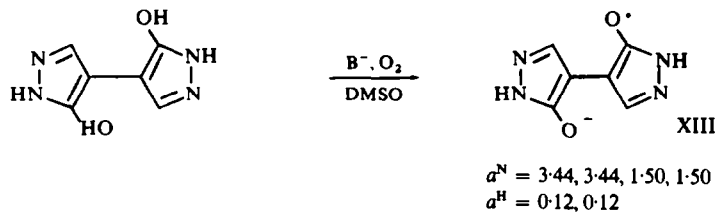
FIG. 4 First derivative, ESR spectrum of XIII. The intensity of peaks is in excellent agreement with the hfsc given in the text.

The assignment of the observed values of a^N in XIII, XII, VII and VI presumably could be made unambiguously by the use of ^{15}N introduced at specific locations. Other results lead us to believe that the lowest value of a^N is connected with the nitrogen atom adjacent to the carbonyl position. When we attempted to prepare radical anion XIV by the oxidation of N,N-diphenyl-N'-(phenylacetyl)hydrazine, the ESR spectrum observed had multiplicities consistent with the formation of a dimeric species, XV.

$$(C_6H_5)_2NNHCOCH_2C_6H_5 \longrightarrow$$

$$\xrightarrow[\;\;\;\;\;]{B^-,\,O_2} (C_6H_5)_2NNHC(O\cdot)\!\!=\!\!C(O^-)C_6H_5$$

XIV

$$\xrightarrow[\;\;\;\;\;]{B^-,\,O_2} (C_6H_5)_2NNHC(O\cdot)\!\!=\!\!C(C_6H_5)C(C_6H_5)\!\!=\!\!C(O^-)NHN(C_6H_5)_2$$

XV

$$a^N = 3.40,\,3.40,\,1.50,\,1.50$$
$$a^H = 0.125,\,0.125 \text{ gauss}$$
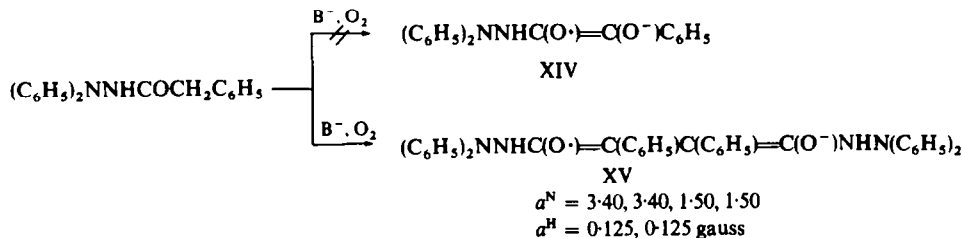
The ratio $a_{NH}{}^N/a_{NH}{}^H$ is usually about 1 in radicals although in isatin semidione it is 5[2] and in phthalimide radical anion the ratio is 6.[7] It thus appears that in XV the nitrogen atom adjacent to the dicarbonyl system has $a^N = 1.50$, $a^N/a_{NH}{}^H = 12$. Extending this result to XIII, XII, VII and VI suggests that the smallest value of a^N in each system ($a^N = 1.3$–2.2 gauss) is associated with the nitrogen atom adjacent to the carbonyl position. Further support for this conclusion is furnished by Hückel and McLachlan molecular orbital calculations.[10] Table 1 clearly shows that for the HOMO of XII the lowest spin density (ρ) is at the phenyl-substituted nitrogen atom.[11] The absence of detectable splitting by the phenyl hydrogen atom in XII is consistent with the low spin density of N-3 and of the phenyl ring. The value of $\rho_{>\dot{C}CH_3}$ obtained from the relationship $a_{CH_3}{}^H = 20\rho_C$[12] is $\rho_C = 0.045$; calculated ρ_C (McLachlan) $= 0.07$.

The proton splitting in XIII is somewhat surprising. Generally $a_{CH}{}^H \simeq a_{CCH_3}{}^H$ in a π-radical. This would lead to an expected value of $a_{C-5}{}^H$ of ~ 1 gauss in XIII using XII ($a_{CH_3}{}^H = 0.90$ gauss) as a model. The observed value was 0.12 gauss. This is more consistent with the value of $a_{NH}{}^H$ expected for XIII and suggests that for XIII the spin density at C-5 is quite low as it apparently is in VI where $a_{CH_3}{}^H$ is barely detectable (Fig 1).

TABLE 1. MOLECULAR ORBITAL CALCULATIONS OF SPIN DENSITIES FOR RADICAL XII
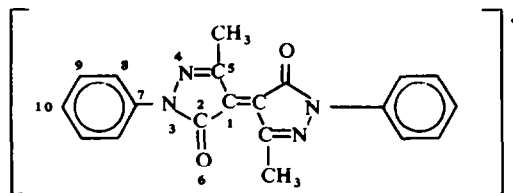
Atom No	Hückel[a]	McLachlan[a]
1	0.186	0.231
2	0.058	0.051
3	0.002	−0.020
4	0.109	0.121
5	0.064	0.073
6	0.080	0.070
7	0.000	−0.002
8	0.001	−0.007
9	0.000	−0.001
10	0.001	−0.008

[a] $\alpha_N = \alpha_C + 1.2\,\beta_{CC}$; $\alpha_O = \alpha_C + 1.5\,\beta_{CC}$; $\beta_{NN} = \beta_{CC}$; $\beta_{CN} = 1.2\,\beta_{CC}$; $\beta_{CO} = 1.6\,\beta_{CC}$.

EXPERIMENTAL

1-*Phenyl-3-methyl-2-pyrazolin-5-one*[13] was prepared from phenylhydrazine and ethyl acetoacetate, m.p. 127° (from ethanol).

3-*Phenyl-2-pyrazolin-5-one*[14] was prepared from hydrazine hydrate and ethyl benzoylacetate, m.p. 236°.

1-*Phenyl-3-methyl-2-pyrazoline-4,5-dione*[15] was prepared by the acidic hydrolysis of 1-phenyl-3-methyl-4-(p-dimethylaminophenylimino)-2-pyrazolin-5-one, m.p. 119° from petroleum ether.

1,2-*Diphenylpyrazolidione-3,4,5-trione*[16] was prepared by the nitrogen dioxide oxidation of 1,2,1′,2′-tetraphenyl-4,4′-bipyrazolidine-3,5,3′,5′-tetrone, m.p. 130°.

1,1′-*Diphenyl-3,3′-dimethyl-4,4′-bis-2-pyrazoline-5,5′-dione*[17,18] was prepared by refluxing phenylhydrazine (3 equiv) with ethyl acetoacetate (1 equiv). The mixture solidified upon cooling and was washed with warm ethanol, acetone, and ether to yield material with m.p. >300°. Oxidation of this material with HNO_2 yielded pyrazole-blue (1,1′-diphenyl-3,3′-dimethyl-$\Delta^{4,4'}$-bis-2-pyrazoline-5,5-dione), as violet needles, m.p. 230° from ethanol–ether.

4,4′-*Bis-2-pyrazoline-5,5′-dione*[19] was prepared by heating for 6 hr on a steam bath 16 g of 3,4-furan-dicarboxylic acid dihydrazide and 25 ml of hydrazine hydrate. The product had m.p. >360°.

N,N-*diphenyl-N′-(phenylacetyl)hydrazine*[20] was obtained by oxidation of N-phenyl-N′-(phenylacetyl)-hydrazine,[21] m.p. 188° from ethanol.

Electron spin resonance spectroscopy

Spectra were recorded on a Varian E-3 instrument using a simple mixing cell previously described.[8] All spectra were recorded in a flat "aqueous" sample cell at $25 \pm 2°$. For oxidation reactions the solutions were incompletely deoxygenated by a N_2 stream before mixing. Additional oxygen was added if required. The reduction processes involved complete deoxygenation of the solutions of the substrate and base before mixing.

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