Trapping and Identification of the Intermediate Aryl Radicals from the Reaction of Aroylarylhydrazines (Arylarenecarbohydrazides) with Sodium Hydride

By **R. A. W. Johnstone** and **A. F. Neville**, The Robert Robinson Laboratories, The University, Liverpool L69 3BX
P. J. Russell, The Donnan Laboratories, The University, Liverpool L69 3BX

Treatment of *N*-aryl-*N'*-aroylhydrazines (*N*-arylarenecarbohydrazides) with sodium hydride in the presence of oxygen afforded biphenyls and arylcarboxylic acids in good yields. E.s.r. trapping techniques have demonstrated conclusively the formation of phenyl and other radicals in high concentrations. The reaction is compared with the previously known simple oxidation of hydrazines.

PHENYLHYDRAZINE is oxidised by oxygen, silver oxide, or mercuric oxide to benzene with evolution of nitrogen.[1] The reaction with oxygen is accelerated by the presence of a base, probably because of the instability of phenylhydrazine salts. In the absence of oxygen however, no decomposition of the hydrazine occurs and crystals of the potassium or sodium salts of phenylhydrazine are readily isolated. Exposure of these salts to oxygen results in rapid and vigorous decomposition with the reaction

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[1] F. D. Chataway, *J. Chem. Soc.*, 1907, 1323; 1908, 270.

mixture turning dark crimson.[1,2] When arylhydrazines are oxidised in aromatic solvents, the bi-aryl compounds which are formed [3] are believed to arise from the attack of aryl radicals on the solvent; the aryl radicals themselves are considered to be formed by the decomposition of the initial oxidation product, a di-imide. In separate

$$\mathrm{Ar^1NH{\cdot}NH_2} \xrightarrow{\text{Oxid.}} \mathrm{Ar^1N{=}NH} \longrightarrow \mathrm{Ar^{1\cdot}} + \mathrm{N_2} + \mathrm{H^{\cdot}}$$

$$\mathrm{Ar^{1\cdot}} + \mathrm{Ar^2H(solvent)} \longrightarrow$$

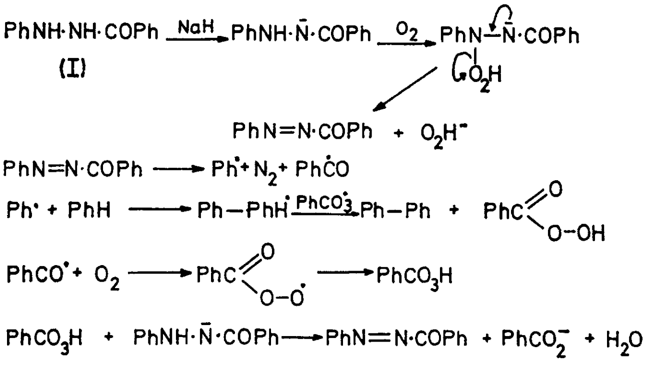
$$\mathrm{Ar^1{-}Ar^2H^{\cdot}} \xrightarrow{\mathrm{R^{\cdot}}} \mathrm{Ar^1{-}Ar^2} + \mathrm{RH}$$

experiments, the preparation and decomposition of phenyldi-imide have been extensively investigated,[4] and oxidation of various other phenylhydrazines has been interpreted as decomposition of intermediately formed unstable di-imides.[5]

Similar treatment of *N*-aryl-*N'*-aroylhydrazines (*N*-arylarenecarbohydrazides) with oxidising agents such as mercuric oxide [6] or lead tetra-acetate [7] has afforded relatively stable *N*-aryl-*N'*-aroyldi-imides which, however, decomposed rapidly in the presence of traces of acid or base; the reaction is also efficiently catalysed by ferric ions.[7] The oxidation products from the *N*-aryl-*N'*-aroylhydrazines, as from the simple arylhydrazines, are best explained by the formation of highly reactive phenyl radicals. Because of their great reactivity, free phenyl radicals in solution have not yet been detected by e.s.r. spectroscopy although their less reactive primary addition products have been.[8]

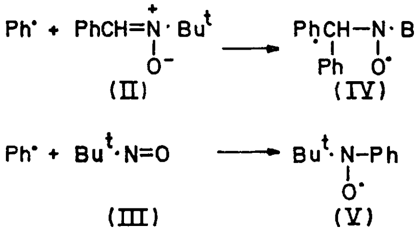
Experiments using Sodium Hydride.—Treatment of *N'*-benzoyl-*N*-phenylhydrazine (I) with sodium hydride in benzene gave an orange solution from which the major products were biphenyl (*ca*. 120% yield, based on one phenyl ring from each molecule of the hydrazine), and benzoic acid (70%). In the absence of air, no reaction was observed and, when the reaction was quenched with methanol, the hydrazine (I) was recovered in 96% yield and no biphenyl could be detected.

The reaction of *N'*-*p*-anisoyl-*N*-phenylhydrazine with sodium hydride in benzene in the presence of air gave *p*-anisic acid and biphenyl in almost identical yields to the benzoic acid and biphenyl obtained from the hydrazine (I). Similar treatment of the hydrazine (I) in anisole as solvent gave a mixture of *o*-, *m*-, and *p*-methoxybiphenyls and benzoic acid. Thus, the reaction of *N*-aryl-*N'*-aroylhydrazines with sodium hydride in the presence of oxygen appears to be very similar to the oxidation of these substances with mercuric oxide and lead tetra-acetate.[6,7] A proposed mechanism is shown in the Scheme. The arylcarboxylic acid appears to be produced directly through the action of oxygen and not on working up the reaction mixture because when the reaction was quenched with methanol, no methyl benzoate was detected.



SCHEME

The recently introduced e.s.r. trapping technique has enabled short-lived radical intermediates such as the phenyl radical to be detected and identified in solution.[9,10] This prompted us to investigate the oxidation of *N*-aryl-*N'*-aroylhydrazines in the presence of the free-radical traps (spin-traps), t-butylphenylnitrone (II) [10,11] and 2-methyl-2-nitrosopropane (III),[12] in an attempt to trap the phenyl radicals postulated in the Scheme.



Aerial oxidation of a benzene solution of the hydrazine (I) and sodium hydride in the presence of the nitrone (II) produced a very strong and sharply defined e.s.r. signal due to the nitroxide (IV), consisting of a 1 : 1 : 1 triplet of doublets with nitrogen and hydrogen hyperfine coupling constants as shown in Table 1. The e.s.r. spectrum was compared with that obtained by the scavenging of phenyl radicals derived from the thermal decomposition of phenylazotriphenylmethane, also in benzene solution.*

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* Janzen and Blackburn have shown (ref. 10) that it is the phenyl radical and not the triphenylmethyl radical which is trapped during the thermal decomposition of phenylazotriphenylmethane.

[2] A. Michaelis, *Annalen*, 1889, **252**, 267.

[3] R. L. Hardie and R. H. Thomson, *J. Chem. Soc.*, 1957, 2512.

[4] P. C. Huang and E. M. Kosower, *J. Amer. Chem. Soc.*, 1968, **90**, 2367.

[5] R. B. Kelly, G. R. Umbreit, and W. F. Liggett, *J. Org. Chem.*, 1964, **29**, 1273; A. F. Rekasheva and B. E. Gruz, *Doklady Akad. Nauk S.S.S.R.*, 1952, **92**, 337; E. S. Huyser and R. H. S. Wang, *J. Org. Chem.*, 1968, **33**, 3901; J. B. Aylward, *J. Chem. Soc.* (*C*), 1969, 1663.

[6] G. Fraenkel and E. Pecchold, *Tetrahedron Letters*, 1969, 4821.

[7] S. G. Cohen and J. Nicholson, *J. Org. Chem.*, 1965, **30**, 1162; *J. Amer. Chem. Soc.*, 1964, **86**, 3892; J. Nicholson and S. G. Cohen, *ibid.*, 1968, **88**, 2247.

[8] A. L. J. Beckwith and R. O. C. Norman, *J. Chem. Soc.*, (*B*) 1969, 403.

[9] M. J. Perkins, P. Ward, and A. Horsfield, *J. Chem. Soc.* (*B*), 1970, 395.

[10] E. G. Janzen and B. J. Blackburn, *J. Amer. Chem. Soc.*, 1969, **91**, 4481.

[11] E. G. Janzen and B. J. Blackburn, *J. Amer. Chem. Soc.*, 1968, **90**, 5909.

[12] I. H. Leaver and G. C. Ramsay, *Tetrahedron*, 1969, **25**, 5669; K. J. Klabunde, *J. Amer. Chem. Soc.*, 1970, **92**, 2427; C. Lagercrantz and K. Torsell, *Acta Chem. Scand.*, 1968, **22**, 1935; S. Forshult, C. Lagercrantz, and K. Torsell, *ibid.*, 1969, **23**, 522.

As shown in Table 1, the two spectra were identical. Although the trapped radical does not contribute to the hyperfine structure in the e.s.r. signal of the nitroxide (IV) the identity of the two spectra is good evidence for a trapped phenyl radical, as other types of radical under the same conditions produce small but significant changes in the hyperfine splittings [10,13] which are generally 10—20% different from those obtained in these experiments [also, see later use of spin-trap (III)].

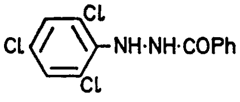
TABLE 1

Hyperfine coupling constants (mT) of the nitroxides derived from t-butylphenylnitrone in benzene

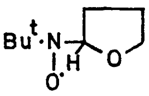
Reaction [a]		a_N	a_H
Hydrazine (I) with sodium hydride		1·452 [b]	0·221
Thermal decomposition of phenylazo-triphenylmethane		1·453	0·219
Hydrazine (VI) with sodium hydride	(i)	1·436 [c]	0·698
	(ii)	1·446	0·227
Thermal decomposition of 2,4,6-trichlorophenylazotriphenylmethane	(i)	1·429 [d]	0·692
	(ii)	1·436	0·223

Hyperfine coupling constants in millitesla (mT).

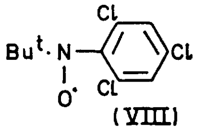
[a] Each reaction performed at *ca.* 50° in benzene in the presence of spin-trap (II); the solutions were allowed to cool to room temperature (22 ± 2°) for e.s.r. measurements. [b] Each coupling constant is an average of at least 24 measurements and the standard deviation is typically ±0·004 mT and ±0·002 mT for the nitrogen and hydrogen coupling constants respectively. [c] Intensity ratio, (*i*) : (*ii*) = 10 : 1. [d] Intensity ratio, (*i*) : (*ii*) = 8 : 1.



(VI)



(VII)



(VIII)

To confirm that the nitrone (II) was trapping free aryl radicals and not solvent adduct radicals, the hydrazine (VI) was synthesised. When this hydrazine was treated with sodium hydride in a benzene solution of the nitrone (II), another intense e.s.r. spectrum was obtained with the splitting constants shown in Table 1. There are two distinct sets of signals. The triplet of doublets with the large β-hydrogen coupling constant (0·698 mT) is about ten times as intense as the triplet of doublets with the small β-hydrogen coupling (0·227 mT); the nitrogen hyperfine couplings of the two signals are not significantly different. The same spectrum due to the addition of 2,4,6-trichlorophenyl radicals to the nitrone (II) has been obtained in three different experiments including the thermal decomposition of trichlorophenylazotriphenylmethane. The angular dependence of β-hydrogen coupling constants in alkyl-substituted free-radicals follows a $\cos^2\theta$ relationship,[14] where θ is the dihedral angle between the N, C, H plane and the nitrogen *p*-orbital. Pending further investigation, we suggest that the addition of the 2,4,6-trichlorophenyl radical to the nitrone (II) produces a nitroxide in which serious steric interactions restrict free rotation about the carbon–nitrogen bond. Molecular models (Dreiding) support this suggestion. The rotation is slowed down sufficiently to permit observation of two conformers, the more preferred having the β-hydrogen atom such that the dihedral angle θ is small thus accounting for the large β-hydrogen coupling constant.

The second free-radical trap employed was the *C*-nitroso-compound (III), which has the advantage over the nitrone (II) that any scavenged phenyl radical would be strongly coupled to the nitroxide function and so contribute directly to the hyperfine structure observed in the e.s.r. spectrum.

TABLE 2

Hyperfine coupling constants (mT) of the nitroxides derived from 2-methyl-2-nitrosopropane in benzene

Reaction	a_N	$a_{o\text{-}H}$	$a_{m\text{-}H}$	$a_{p\text{-}H}$	a_{oth}
Irradiation of nitrosobenzene with red light (*cf.* ref. 15)	1·256	0·190	0·094	0·190	
Decomposition of benzoyl peroxide (results from ref. 9)	1·23	0·20	0·09	0·20	
Hydrazine (I) with sodium hydride	1·253	0·190	0·096	0·190	
Hydrazine (VI) with sodium hydride	1·269		0·06		*o*-Cl = *p*-Cl = 0·03
Hydrazine (IX) with sodium hydride	1·267	0·188	0·093	0·188	

The e.s.r. spectrum of t-butyl phenyl nitroxide (V) can be easily generated by irradiating a solution of 2-methyl-2-nitrosopropane and an excess of nitrosobenzene with red light; [15] a well resolved 27-line spectrum is produced (Table 2). The nitroxide obtained by treatment of *N'*-benzoyl-*N*-phenylhydrazine (I) with sodium hydride in a benzene solution of the nitroso-compound (III) had an identical spectrum to that of the nitroxide (V). The splitting constants demonstrate conclusively that it is the phenyl radical which is trapped and not any secondary addition products of that radical. No spin-trapped radicals were observed when the hydrazine (I) reacted with sodium hydride in the absence of oxygen, in keeping with the observation that no biphenyl was formed under similar reaction conditions.

The effects of change of solvent on the oxidation reaction are shown in Table 3. When the hydrazine (I) was treated with sodium hydride in anisole in the presence of oxygen, a much less vigorous reaction occurred and, in the presence of the nitroso-trap (III) no radicals were scavenged; the e.s.r. signal consisted only of weak lines derived from the nitroso-compound itself. Again, this is in agreement with the observation that production of

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[13] P. J. Russell and L. H. Sutcliffe, private communication.

[14] D. H. Geske, *Prog. Phys. Org. Chem.*, 1967, **4**, 179; O. W. Maender and E. G. Janzen, *J. Org. Chem.*, 1969, **34**, 4072.

[15] A. Makor, ' Photochemical Nitrosation of Hydrocarbons by Alkyl Nitrites,' Thesis, University of Amsterdam, Bronder-Offset, Rotterdam, 1968, ch. 9.

biphenyls is much slower in anisole than in benzene, possibly owing to the greater stabilisation of the sodium salt of the hydrazine (I) in the strongly polar anisole.

TABLE 3

Hyperfine coupling constants (mT) of nitroxides derived from 2-methyl-2-nitrosopropane during reaction of hydrazine (I) with sodium hydride in various solvents

Solvent	Signal intensity [a]	a_N	$a_{o\text{-H}}$	$a_{m\text{-H}}$	$a_{p\text{-H}}$	a_{other}
Benzene	vs	1·253 [b]	0·190	0·096	0·190	
Carbon tetrachloride	s	1·251	0·191	0·096	0·191	
Anisole	ns					
Tetrahydrofuran [c]	w	1·46				$a_{\alpha\text{-H}}$ = 0·32

[a] vs, Very strong; s, strong; ns, no signal; w, weak. [b] Values of a_N are an average of at least 20 measurements, those of a_H are an average of *ca.* 15. [c] An identical spectrum was obtained during photolysis of di-t-butyl peroxide in a tetrahydrofuran solution containing 2-methyl-2-nitrosopropane.

In carbon tetrachloride, a moderately strong signal of the nitroxide (V) was obtained indicating the formation of phenyl radicals but little biphenyl was isolated from the reaction mixture. Instead, in the absence of the spin-trap, a modest amount of chlorobenzene was isolated resulting from attack of the phenyl radicals on the solvent. Somewhat surprisingly, in the presence of the spin-trap, no signal from the addition of CCl_3 radicals was evident although they must presumably have been present and chlorobenzene was again formed. The yields of chlorobenzene are generally low and CCl_3 radicals may not have been observed because of their low concentration; the generated phenyl radicals seem to react with other species faster than with carbon tetrachloride.

$$\text{PhNH·NH·CO·Ph} \xrightarrow[\text{O}_2]{\text{NaH}} \text{Ph}^{\cdot} \xrightarrow{\text{CCl}_4} \text{PhCl} + \text{CCl}_3^{\cdot}$$

Tetrahydrofuran as solvent afforded very little biphenyl and the e.s.r. spectrum consisted of a triplet of doublets. The spectrum and the splitting constants suggest that this species is the spin-trapped tetrahydrofuryl radical (VII). Rapid abstraction of hydrogen from the α-position in tetrahydrofuran by initially produced phenyl radicals, followed by addition to the nitroso-compound (III), would yield the nitroxide (VII). The structure of the radical (VII) was confirmed by acquiring an identical spectrum during the photolysis of di-t-butyl peroxide in a tetrahydrofuran solution of the nitroso-compound.

The *N*′-benzoyl-*N*-2,4,6-trichlorophenylhydrazine (VI) was also treated with sodium hydride in the presence of 2-methyl-2-nitrosopropane (III). The e.s.r. spectrum afforded the hyperfine coupling constants shown in Table 2 which suggest structure (VIII) for the spin-trapped species. Thus, in the oxidation of the *N*-aryl-*N*′-aroylhydrazines, the aryl radicals do not appear to be produced from the aroyl moiety, in keeping with the chemical results. The signal from the radical (VIII) exhibits small splittings in the hyperfine structure from the *ortho*- and *para*-chlorine atoms as well as the splittings expected from the *meta*-hydrogen atoms; tentative values are given in Table 2.

Experiments using Mercuric Oxide.—Since the oxidation of the hydrazine (I) with sodium hydride and oxygen appeared very similar to earlier reported oxidations with mercuric oxide or lead tetra-acetate, we carried out spin-trapping experiments during treatment of the hydrazine (I) with mercuric oxide in the various solvents listed in Table 3. The e.s.r. results are shown in Table 4 and a comparison with Table 3 shows the close similarity of the two series of experiments. Again, direct confirmation is provided for the intermediacy of free phenyl radicals and for the greater efficiency of benzene as a solvent in this reaction.

TABLE 4 *

Hyperfine coupling constants (mT) of nitroxides derived from 2-methyl-2-nitrosopropane during reaction of hydrazine (I) with mercuric oxide in various solvents

Solvent	Signal intensity [a]	a_N	$a_{o\text{-H}}$	$a_{m\text{-H}}$	$a_{p\text{-H}}$	a_{other}
Benzene	vs.	1·255 [b]	0·189	0·093	0·189	
Carbon tetrachloride	s	1·248	0·189	0·092	0·189	
Anisole	vw					
Tetrahydrofuran	s	1·458				$a_{\alpha\text{-H}}$ = 0·326

* For footnotes, see Table 3 (vw = very weak).

Most of the experiments described above were carried out at around 50° and in an attempt to produce an effective phenyl radical generator at lower temperatures we synthesised *N*-phenyl-*N*′-trifluoroacetylhydrazine. At 0° in the presence of sodium hydride and oxygen, or with mercuric oxide, a benzene solution of the trifluoroacetyl compound readily afforded biphenyl and trifluoroacetic acid. That *N*-phenyl-*N*′-trifluoroacetylhydrazine was an excellent low-temperature source of phenyl radicals in solution was confirmed by the strong signal corresponding to the spin-adduct (V) obtained in the e.s.r. experiments.

EXPERIMENTAL

N-*Aryl*-N′-*aroylhydrazines*.—These were prepared from the appropriate arylhydrazine and aroyl chloride: *N*′-benzoyl-*N*-phenylhydrazine, m.p. 171—173° (lit.,[16] 169°); *N*′-*p*-anisoyl-*N*-phenylhydrazine, m.p. 185—186° (Found: C, 69·4, H, 5·9, N, 11·4. Calc. for $C_{14}H_{14}N_2O_2$: C, 69·4, H, 5·8, N, 11·6%); *N*′-benzoyl-*N*-2,4,6-trichlorophenylhydrazine, m.p. 166—167° (Found: C, 49·6, H, 3·0, N, 9·0. Calc. for $C_{13}H_9Cl_3N_2O$: C, 49·4, H, 2·9, N, 8·9%); and *N*-phenyl-*N*′-trifluoroacetylhydrazine, m.p. 125—126° (Found: C, 47·0, H, 3·5, N, 13·5. Calc. for $C_8H_7F_3N_2O$: C, 47·0, H, 3·5, N, 13·7%).

Oxidation of N-*Aryl*-N′-*aroylhydrazines*.—(*i*) Typically, *N*′-benzoyl-*N*-phenylhydrazine (5 g) in dry benzene (100 ml) was stirred with sodium hydride (0·5 g) for 30 min at 50°. Hydrogen was evolved and, in the absence of air, a colourless suspension of the sodium salt of the hydrazine was obtained. When air was admitted to the reaction mixture,

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[16] E. Fischer, *Annalen*, 1877, **190**, 125.

or the reaction was carried out in the presence of air, the solution became orange and nitrogen was evolved. Ethanol (5 ml) was added to the reaction product to destroy any excess of sodium hydride, followed by water (100 ml). The benzene layer was washed with water, dried ($MgSO_4$), and evaporated, and the residue was chromatographed on neutral alumina (Woelm, Grade I) to yield biphenyl (4·4 g). The aqueous layer was acidified and extracted with chloroform to give benzoic acid (2·0 g). Similarly, in carbon tetrachloride as solvent, chlorobenzene was isolated in 20% yield, and in anisole, a mixture of *o*-, *m*-, and *p*-methoxybiphenyls was obtained (20% yield) and identified by i.r. and mass spectrometry.

(*ii*) Treatment of *N'*-benzoyl-*N*-phenylhydrazine (1 g) with mercuric oxide (1 g) in benzene (25 ml) with stirring at 50° for 30 min. afforded biphenyl (65% yield) and benzoic acid (80%).

E.s.r. Experiments.—Spectra were recorded on a Varian V 4500 spectrometer with 100 kHz modulation and an *X*-band klystron. The field sweep was calibrated with alkaline aqueous solutions of potassium nitrosodisulphonate (Fremy's salt) having $a_N = 1{\cdot}309$ mT. Errors in the hyperfine splittings were estimated to be $\pm 0{\cdot}005$ mT.

For experiments using t-butylphenylnitrone, at least six spectra (triplet of doublets) were measured and averaged to give the nitrogen and β-hydrogen coupling constants reported. Only spectra which were sharply resolved were analysed. With 2-methyl-2-nitrosopropane as the spin-trap, the spectrum itself was proof of the identity of the trapped radical and so only four scans were measured and averaged to give the values shown.

Typically, a mixture of *N'*-benzoyl-*N*-phenylhydrazine (150 mg) with sodium hydride (100 mg) in benzene (2 ml) containing the spin-trap [t-butylphenylnitrone, (14 mg) or 2-methyl-2-nitrosopropane (3 mg)] was warmed to 50° for a few minutes, filtered, and the filtrate was de-gassed for 30 min with pure nitrogen. The solution was then transferred to an aqueous sample cell which had also been flushed with nitrogen. All measurements were carried out at 22 ± 2°.

Spin-traps.—t-Butylphenylnitrone and 2-methyl-2-nitrosopropane were prepared from 2-t-butyl-3-phenyloxaziran as described in the literature.[17]

We thank Dr. L. H. Sutcliffe for his interest and advice, Dr. P. N. Preston for gifts of the two spin-traps, and the S.R.C. for a studentship (P. J. R.).

[0/1860 *Received, October* 30*th*, 1970]

[17] W. D. Emmons, *J. Amer. Chem. Soc.*, 1957, **79**, 5739, 6522.