Electrophilic Substitution in a Basic Hydrazone System: The First Synthesis of *N*-Pyridylhydrazonyl Bromides

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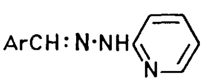
A kinetic study of the bromination of substituted benzaldehyde 3-pyridylhydrazones in 70% acetic acid has shown that the protonated hydrazone species is brominated. In water, both protonated and free hydrazones (the latter 162-fold more rapidly) react with bromine. The products formed are the corresponding *N*-(3-pyridyl) substituted benzohydrazonyl bromides, rather than *N*-bromo-complexes, and substituent effects ($\rho = -0{\cdot}42$ for *C*-aryl ring and $-1{\cdot}42$ for *N*-pyridyl ring) are in accord with direct electrophilic attack at methine carbon atom. The novel hydrazonyl bromides (isolated as hydrobromides) may be readily hydrolysed to *N*-(3-pyridyl) substituted benzohydrazides and react with azide ion to give benzohydrazonyl azides.

THE 2-pyridylhydrazones (1) are readily cyclised to the triazoles (2) when treated with oxidising agents, *e.g.* lead tetra-acetate,[1] or bromine in the presence of sodium acetate.[2] This is an example of the more general oxidative cyclisation of hydrazones to give fused triazole or oxadiazole systems.[3] Attempts to isolate and characterise the intermediates during bromination were hampered by the basic nature of the pyridine ring and its tendency to form complexes with electrophilic agents, and the known lability of hydrazonyl bromides [of type (3)], which (even at low pH) lose HBr to give a 1,3-dipolar ion.[4] This ion can be regarded also as a 1,5-dipolar ion (4) so that cyclisation *via* the hydrazonyl bromide (3) could ultimately involve a 1,5-dipolar cycloaddition.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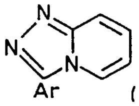
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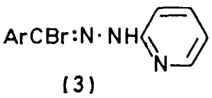
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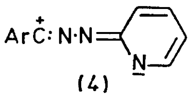
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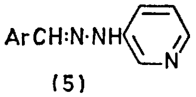
Direct bromination of the hydrazones (1) in glacial acetic acid did not lead to either the bromides (3) or the triazoles (2). Instead a 1 : 1 complex of bromine with the starting hydrazone is formed [(1),Br_2]. This has been formulated as an *N*-bromopyridinium bromide.[2] The formation of such complexes is not unexpected since relatively stable complexes of this type also result from bromination of pyridine itself.[5] Treatment of the complexes [(1),Br_2] with base gave finally the triazoles (2) and it has been proposed[2] that the first step is internal bromination to give the hydrazonyl bromides (3), which however were not isolated.[2]

We have investigated the bromination of the 3-pyridylhydrazones (5). In this case, steric restrictions minimise the possibility of cyclisation of the hydrazonyl bromides (6); moreover, 1,5-dipolar ion formation (and subsequent cyclisation) is inhibited.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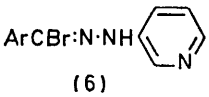
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RESULTS AND DISCUSSION

The rates of bromination of a series of substituted benzaldehyde 3-pyridylhydrazones (5) were investigated in 70% acetic acid containing 0·1M-potassium bromide at 20° (Table 1). Studies at various initial bromine and

TABLE 1

Observed second-order rate constants (k/l mol^{-1} s^{-1}) for the bromination of substituted benzaldehyde 3-pyridylhydrazones (5; Ar = XC_6H_4) at 20° in 70% acetic acid containing 0·1M-KBr

Substituent X	H	4-Me	4-Pr^i	4-Cl
k_{obs}	172	211	207	149
Substituent X	4-Br	3-Cl	3-Br	4-NO_2
k_{obs}	143	125	114	52

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[1] J. D. Bower and F. P. Doyle, *J. Chem. Soc.*, 1957, 727.

[2] M. S. Gibson, *Tetrahedron*, 1963, **19**, 1587.

[3] T. M. Lambe, R. N. Butler, and F. L. Scott, *Chem. and Ind.*, 1971, 996; F. L. Scott, D. A. Cronin, and J. K. O'Halloran, *J. Chem. Soc. (C)*, 1971, 2769; F. L. Scott and J. K. O'Halloran, *Tetrahedron Letters*, 1970, 4083; F. L. Scott and T. A. F. O'Mahony, *ibid.*, p. 1841; H. Najer, R. Giudicelli, C. Morel, and J. Menin, *Bull. Soc. chim. France*, 1966, 153.

[4] A. F. Hegarty, M. P. Cashman, and F. L. Scott, *J.C.S. Perkin II*, 1972, 44.

[5] H. A. Bent, *Chem. Rev.*, 1968, **68**, 587; S. G. W. Ginn, I. Hague, and J. L. Wood, *Spectrochim. Acta*, 1968, **24A**, 1531.

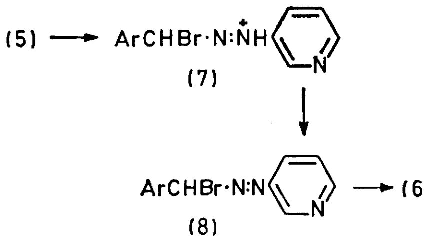
[6] R. M. Keefer, A. Ohenberg, and L. J. Andrews, *J. Amer. Chem. Soc.*, 1956, **78**, 225.

hydrazone concentrations showed that the reaction was second-order overall: first-order each with respect to bromine and hydrazone. The aqueous solvent mixture and, more particularly, the large excess of bromide ion obviated the intervention of a more complicated kinetic pattern with kinetic terms of higher order in bromine.[6]

The brominated products were the corresponding hydrazonyl bromides (6), which were also produced (as the hydrobromides) in good yield by bromination in glacial acetic acid. The hydrobromides were also formed in 70% acetic acid (under the conditions used to study the kinetics), but were accompanied by *N*′-(3-pyridyl)-benzohydrazides, which are the expected hydrolysis products of the bromides (6) (see later).

Substituents in the aryl ring (Ar) of the hydrazones (5) do not influence greatly the rate of bromination: as expected for electrophilic substitution, electron-donating substituents enhance, while electron-withdrawing substituents slow down reaction. A Hammett plot of the data in Table 1 give $\rho = -0{\cdot}42$ ($r = 0{\cdot}990$), using the σ values of McDaniel and Brown.[7] This is comparable to the value ($-0{\cdot}62$) reported[8] for analogous substituent variation in the bromination of arylmethylene-*p*-nitrophenylhydrazines under similar conditions.

We have interpreted the small substituent effect in terms of delocalisation of charge away from the aryl ring, leading to the formation of an ionic intermediate (7).[8] Loss of the *N*-proton gives the azo-compound (8), which tautomerises to the thermodynamically more stable hydrazone (6). The azo-tautomer (8) was not isolated, conversion into the hydrazonyl bromide (6) presumably being rapid. However the isolation of such an intermediate has recently been reported for the first time (in the bromination of an aldehyde *p*-nitrophenylhydrazone[9]); similar intermediates have also been reported in reactions of other electrophiles with hydrazones.[10]



The 3-pyridylhydrazones (5) are moderately basic; spectrophotometrically-determined pK_a values are listed in Table 2. The values are close to that of pyridine itself (pK_a 5·17),[11] the base-strengthening effect of the amino-group (2-aminopyridine is a stronger base than pyridine) being counteracted by the ArCH:N· group. The pK_a values are even less sensitive to the nature of the substituent in Ar; a Hammett plot in this case gives $\rho = -0{\cdot}21$ ($r = 0{\cdot}990$). This is readily explicable because the positive charge (on the pyridine nitrogen) is more remote from the centre of substitution than that generated during bromination [*i.e.*, (7)].

TABLE 2

pK_a Values for substituted benzaldehyde 3-pyridylhydrazones (5; Ar = XC_6H_4), measured in methanol–water (1 : 4) at 25° (μ 0·1 KBr)

Substituent X	4-Cl	4-Me	4-Br	H	3-Br
pK_a	5·37	5·46	5·38	5·42	5·34

In 70% acetic acid, the hydrazones (5) may be present partially as free bases and partially as their conjugate acids. Both species would be expected to have quite different rates of bromination. It is well-known that there is an enormous difference in reactivities towards electrophilic substitution of the pyridine nucleus between the protonated and neutral species.[12] This difference is also apparent when the protonation occurs on a side-chain proximate to an aromatic nucleus undergoing substitution.[13,14] During bromination of the hydrazones (5), protonation occurs on the heterocycle whereas electrophilic substitution is on the side-chain.

The hydrazone (5) itself can be used as an indicator to guage the degree of protonation of its pyridine nucleus in 70% acetic acid. Thus the u.v. spectrum of the benzaldehyde hydrazone (5; Ar = Ph) in 70% acetic acid ($\lambda_{max.}$ 332 nm) is essentially the same as that in acidic solution ($\lambda_{max.}$ 334 nm in 95% ethanol–0·01M-HCl), but distinctly different from that in neutral or basic solution ($\lambda_{max.}$ 327 and 348 nm in 95% ethanol–0·001M-NaOH). Also the addition of a strong acid to the 70% acetic acid solution (to make it 0·01M in HCl) did not bring about a noticeable spectral change: it can be concluded therefore that the hydrazones (5) exist almost entirely as the conjugate acids in 70% acetic acid. However, even though the conjugate acid is the major species in solution, it is still possible (and in fact quite likely in view of evidence for related systems[13,14]) that the free hydrazone (5) is the only species undergoing bromination. Surprisingly, the addition of a strong acid [$HClO_4$ (0·04 ml) to 70% acetic acid (20 ml)] did not bring about a change in the rate of bromination of the hydrazone (5; Ar = Ph) indicating the possibility that the conjugate acid might be the species being brominated in 70% acetic acid.

To test this further, the hydrazone (5; Ar = Ph) was

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[7] D. H. McDaniel and H. C. Brown, *J. Org. Chem.*, 1958, **23**, 420.

[8] A. F. Hegarty and F. L. Scott, *J. Chem. Soc.* (*B*), 1966, 672.

[9] J. M. J. Tronchet, B. Bachler, N. Le-Hong, and P. F. Lino, *Helv. Chim. Acta*, 1971, **54**, 921.

[10] E. Fahr and H. D. Rupp, *Angew. Chem. Internat. Edn.*, 1964, **3**, 693; A. F. Hegarty and F. L. Scott, *Chem. Comm.*, 1966, 622; H. J. Tenber and K. H. Dietz, *Angew. Chem. Internat. Edn.*, 1966, **5**, 1049.

[11] D. D. Perrin, 'Dissociation Constants of Organic Bases in Aqueous Solution,' Butterworths, London, 1965.

[12] See, *e.g.*, A. R. Katritzky and J. M. Lagowski, 'The Principles of Heterocyclic Chemistry,' Chapman and Hall, London, 1971, ch. 2.

[13] R. P. Bell and E. M. Ramsden, *J. Chem. Soc.*, 1958, 161; J. E. Dubois and R. Uzan, *Tetrahedron Letters*, 1964, 2397.

[14] P. J. Brignell, P. E. Jones, and A. R. Katritzky, *J. Chem. Soc.* (*A*), 1970, 117.

brominated in aqueous solution at various hydrogen ion concentrations (which could be accurately measured in this case). The solvent contained 0·1M-KBr and in all cases the ionic strength was maintained at 1·0M with potassium perchlorate. In this solvent, the second-order rates of bromination (at 25°) were considerably more rapid (than in 70% acetic acid) and varied with the pH of the solution (see Table 3). From pH 0 to *ca.* 2·5 the rate is independent of pH but thereafter increases rapidly with pH [a plot of log k_{obs} *vs.* pH has unit slope at higher pH (see Figure)]. This kinetic behaviour is consistent with the Scheme, in which k_0 and k_1 are the specific rate constants for the reaction of the protonated hydrazone and the hydrazone, respectively. The observed rate constants may be expressed by equation (1). Under conditions where

TABLE 3

Observed second-order rate constants (k/l mol^{-1} s^{-1}) for the bromination of benzaldehyde 3-pyridylhydrazone at 25° in water containing 0·1M-KBr [μ = 1·0 (KClO$_4$)]

pH	0	1·0	2·0	2·7	3·5	3·75	4·1	4·75
$10^{-4}k_{obs}$	1·23	1·20	1·02	1·14	2·04	4·20	9·24	36

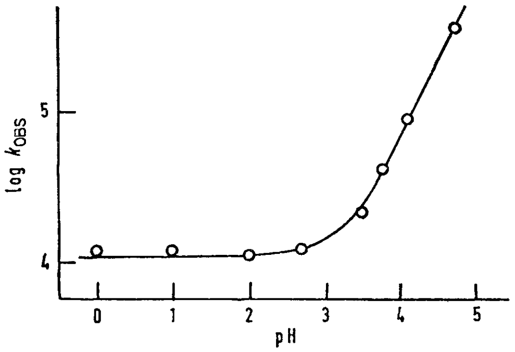
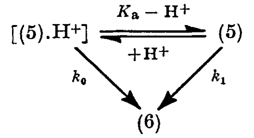


FIGURE Plot of log k_{obs} *vs.* pH for the bromination of benzaldehyde 3-pyridylhydrazones (5; Ar = Ph) at 25° in water [μ = 1·0 (KClO$_4$)]



SCHEME

$$k_{obs} = \frac{k_0 a_H}{a_H + K_a} + \frac{k_1 K_a}{a_H + K_a} \qquad (1)$$

$a_H \gg K_a$ this reduces to equation (2). Since the

$$k_{obs} = k_0 + k_1 K_a / a_H \qquad (2)$$

pK_a of the conjugate acid of the hydrazone (5; Ar = Ph) is 5·42, this condition holds (since the highest pH studied was 4·78: above this value the hydrazone precipitates). The curve in the Figure has been drawn using equation (2) with $k_0 = 1·15 \times 10^4$ l mol^{-1} s^{-1}, $k_1 K_a = 7·1$ l mol^{-1} s^{-1}, and the fit to the observed experimental points is good. Since K_a is also known [in methanol–water (1 : 4)], k_1, the rate constant for the bromination of the free hydrazone, can be estimated as $1·87 \times 10^6$ l mol^{-1} s^{-1}. The ratio of the rates for the neutral and protonated hydrazines is 162. Using the reported[15] σ constants for 3-pyridyl and 3-pyridylium groups (+0·55 and +2·10, respectively), a ρ value of −1·42 can be calculated for the variation of the *N*-aryl substituent in the hydrazone (5). This is considerably larger than the value (−0·42) for substituent variation in the *C*-aryl ring (see before) which is in accord with the postulated rate-determining step [formation of the ion (7)]. The ratio of the ρ values (−1·42 : −0·42 = 3·4) is similar to that reported for reaction of hydrazones with diazonium ion[16] or with bromine.[8]

The difference in the second-order rate constants for the bromination of the conjugate acid of the hydrazone (5; Ar = Ph) in H_2O and in 70% acetic acid is 67-fold. In both cases the active brominating species, molecular bromine,[17] is present in relatively small concentration being converted in the presence of Br^- into Br_3^-. However the equilibrium constant for the formation of Br_3^- is larger in 70% acetic acid than in water (84 *vs.* 16·7);[18] therefore the effective concentration of bromine is greater in water. Also a large increase in rate is to be expected on transfer of an electrophilic substitution from a solvent of relatively low dielectric constant (70% acetic acid) to water. It has recently been shown[19] that the rate of bromination of olefins is about as sensitive (m = 1·16) to solvent variation as is a typical S_N1 reaction.

The rate of bromination of *p*-nitrobenzaldehyde 3-pyridylhydrazone (5; Ar = *p*-$NO_2 \cdot C_6H_4$) was also investigated in aqueous solution. This also showed a pH-independent plateau at low pH (0—2·5), due to bromination of the protonated hydrazone ($k_0 = 3·33 \times 10^3$ l mol^{-1} s^{-1}). The *p*-nitro-substituent therefore deactivates the protonated hydrazone system 3·5-fold towards bromination. This is almost the same factor (which implies the same ρ) observed in 70% acetic acid (Table 1), supporting the foregoing conclusion that in this latter solvent, all the hydrazones are substantially protonated, and that bromination occurs on the protonated species. If this were not so then the Hammett plot in 70% acetic acid would either (*a*) be curved or (*b*) give a composite ρ value (involving k_1 and K_a, which would both vary with substituents).

When the amino-proton of the hydrazone is replaced by methyl group [*e.g.* (9)], the normal pathway for bromination [(6) ⟶ (7) ⟶ (8)] is blocked [since the azo-compound (8) cannot be formed except by dealkylation]. The rate of bromination of the hydrazone

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[15] J. M. Blanch, *J. Chem. Soc.* (*B*), 1966, 937.

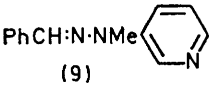
[16] A. F. Hegarty and F. L. Scott, *J. Org. Chem.*, 1967, **32**, 1957.

[17] A. F. Hegarty and F. L. Scott, *J. Chem. Soc.* (*B*), 1966, 1031.

[18] D. B. Scaife and H. J. V. Tyrrell, *J. Chem. Soc.*, 1958, 386; P. B. D. de la Mare, O. M. H. Dusouqui, J. G. Tillett, and M. Zeltner, *ibid.*, 1964, 5306.

[19] F. Garnier, R. H. Donnay, and J. E. Dubois, *Chem. Comm.*, 1971, 830.

(9) reflects this, being quite different from the corresponding N-protio-compound (6; Ar = Ph). In 70% acetic acid the rate of bromination of the hydrazone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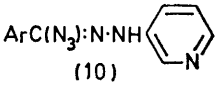
(9) is zeroth-order in bromine and first-order in hydrazone ($k_{\text{obs}} = 1{\cdot}07 \times 10^{-6}\ \text{s}^{-1}$). Similar kinetic behaviour has been noted [20] previously for the bromination of other NN-disubstituted hydrazones and it has been interpreted in terms of rate-determining interconversion of the *syn*- to the more reactive *anti*-isomer (about the azomethine bond) prior to bromination. This change in kinetic behaviour supports the proposed mechanism of direct methine bromination in the case of the hydrazones (6) (rather than, say, pyridine-ring bromination, which would be left unaffected on N-methylation).

N-(3-*Pyridyl*)*benzohydrazonyl Bromides*.—The hydrazonyl bromides (6) (which are the first reported such N-aryl compounds) were formed readily by direct bromination of the hydrazones (5) in glacial acetic acid, from which they precipitated as hydrobromides. These were very reactive, the bromine being replaced by a variety of nucleophiles: in acetone–water and sodium azide, the hydrazonyl azides (10) were formed (see Table 4). In acetone–water at reflux (or at room temperature in the presence of base), the hydrazides (11) were formed in good yield. This latter reaction is typical and serves to characterise the hydrazonyl bromides.[21] The role of the pyridyl ring (which can possibly act as an intramolecular catalyst) is being studied.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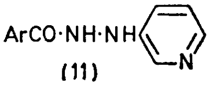
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EXPERIMENTAL

Materials.—The 70% acetic acid for the kinetic experiments was prepared by mixing acetic acid and water (7 : 3 v/v) at 20°. Acetic acid (AnalaR) was distilled twice from chromium trioxide and had b.p. 117—118°. Deionised water was twice distilled from alkaline potassium permanganate to remove traces of impurities capable of reacting with bromine.

All inorganic materials were AnalaR grade, potassium bromide being dried at 120° for 3 h before use.

The perchloric acid solutions were made up by mixing appropriate quantities of perchloric acid (1·0M), potassium perchlorate (1·0M), and potassium bromide (1·0M), so that the final solutions contained 0·1M-Br$^-$ and had ionic strength, $\mu = 1{\cdot}0$. The pH of final solution was measured using a Metrohm EA125U electrode and a Radiometer Model PHM 26 pH meter. For the solutions with pH > 3, 0·01M-sodium acetate was added as buffer and the pH adjusted to the required value using perchloric acid. In all cases the pH of the solutions was maintained during a kinetic run.

All compounds (see Table 4) gave satisfactory analyses, which are listed in Supplementary Publication No. SUP 20454 (4 pp., 1 microfiche).*

Substituted Benzaldehyde 3-*Pyridylhydrazones*.—The hydrazones were prepared by the addition of an equimolar amount of the appropriate substituted benzaldehyde to 3-hydrazinopyridine (prepared *in situ* from 3-aminopyridine [22]). The hydrazones (70%) were recrystallised from 95% ethanol (twice) and benzene (twice) (see Table 4).

TABLE 4

M.p.s (°C) for the hydrazonyl azides (10; Ar = XC_6H_4), the 3-pyridylhydrazones (5; Ar = XC_6H_4), and the hydrazonyl bromide hydrobromides [(6; Ar = XC_6H_4),HBr]

	Compound		
Substituent X	(10)	(5)	[(6),HBr]
H	97	174	237
4-Me	96	158	246
4-Pr^i	89	160	237
4-Cl	100	181	257
4-Br	104	194	270
4-NO_2	110	242	286
3-Cl	101	135	265
3-Br	98	145	266

Benzaldehyde N-*Methyl*-N-(3-*pyridyl*)*hydrazone* (9).—Benzaldehyde 3-pyridylhydrazone (2·0 g) was suspended in sodium hydroxide (10%; 41 ml), to which absolute alcohol (13·3 ml) and water (4·3 ml) were added. Methyl iodide (0·76 ml) in acetone (3 ml) was then added and the mixture was heated gently under reflux with stirring for 45 min. The solution was stirred and cooled in an ice-bath for a further 30 min to precipitate solid (A) and leave filtrate (*a*).

The solid (A) was taken up in boiling benzene: some remained undissolved (B). The solid benzene-soluble fraction was starting hydrazone (48%). The solid (B), recrystallised twice from absolute alcohol, was *benzaldehyde* N-*methyl*-N-(3-*pyridyl*)*hydrazone methiodide* (0·77 g, 21·5%) m.p. 246—249° (Found: C, 47·9; H, 4·9; N, 11·5. $C_{14}H_{16}IN_3$ requires C, 47·6; H, 4·6; N, 11·9%).

The filtrate (*a*) was evaporated under reduced pressure to leave a solid and some dark intractable gum. The solid was chromatographed [neutral alumina, benzene–chloroform (9 : 1)]. The light yellow material which was eluted first, was the desired N-*methylhydrazone* (0·15 g, 7·5%), m.p. 95° (from benzene) (Found: C, 73·6; H, 6·1; N, 19·8. $C_{13}H_{13}N_3$ requires C, 73·9; H, 6·2; N, 19·8%).

Bromination of the Substituted Benzaldehyde 3-*Pyridylhydrazones*.—The hydrazone (0·5 g) was dissolved in glacial acetic acid (5 ml) and stirred vigorously at room temperature while bromine (1 mol. equiv.; *ca.* 0·125 ml) in glacial acetic acid (3 ml) was added dropwise. In each case when approximately half the bromine had been added, a solid began to separate from solution. The hydrazonyl bromide hydrobromide was collected (>80% yield), and recrystallised to constant m.p. (from glacial acetic acid) (see Table 4).

Solvolysis of the Hydrazonyl Bromide Hydrobromides.—(*a*) *In dioxan–water–sodium azide*. The hydrazonyl bromide hydrobromide (0·10 g) was dissolved in dioxan–water (4 : 1; 10 ml) and stirred vigorously at 25 °C while

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* For details of Supplementary Publications, see Notice to Authors No. 7 in the index issue of *J. Chem. Soc.* (*A*), 1970.

[20] F. L. Scott, F. A. Groeger, and A. F. Hegarty, *J. Chem. Soc.* (*B*), 1971, 1411.

[21] F. L. Scott, M. P. Cashman, and A. F. Hegarty, *J. Chem. Soc.* (*B*), 1971, 1607.

[22] A. Binz and C. Rath, *Annalen*, 1931, **486**, 95.

sodium azide (2 mol. equiv.) in the same solvent (2 ml) was added dropwise. The mixture was stirred for 15 min and then poured into ice–water (50 ml). The azides precipitated and were recrystallised to constant m.p. [from acetone–water (1 : 1)]. The azides (see Table 4) had a characteristic i.r. absorption [23] at *ca.* 2150 cm^{-1} and sharp m.p.s at which they decomposed explosively.

(*b*) *In acetone–water.* 3-Chloro-*N*-(3-pyridyl)benzohydrazonyl bromide hydrobromide (0·30 g) in acetone–water (1 : 1; 10 ml) was heated under reflux for 30 min. Evaporation *in vacuo* yielded a yellow gum which on repeated crystallisation from acetone gave yellow 3-*chloro*-N-(3-*pyridyl*)*benzohydrazide hydrobromide* (85%), m.p. 195° (Found: C, 43·5; H, 3·14; N, 12·7; O, 5·1. $C_{12}H_{11}BrClN_3O$ requires C, 43·9; H, 3·3; N, 12·8; O, 4·9%). Treatment of the hydrazide hydrobromide in water with 5% sodium carbonate solution gave a quantitative yield of the free *hydrazide*, m.p. 145° (from benzene), $\nu_{max.}$ 1660 cm^{-1} (C=O) (Found: C, 58·0; H, 4·0; N, 16·8; O, 6·6. $C_{12}H_{10}ClN_3O$ requires C, 58·2; H, 4·0; N, 17·0; O, 6·7%).

N-(3-*Pyridyl*)*benzohydrazide hydrobromide* was prepared in the same manner (87%), m.p. 184° (Found: C, 48·9; H, 4·2; N, 14·1; O, 5·7. $C_{12}H_{12}BrN_3O$ requires C, 49·0; H, 4·1; N, 14·3; O, 5·4%). Treatment with base yielded the free *hydrazide*, m.p. 171° (Found: C, 67·3; H, 5·4; N, 19·6; O, 7·7. $C_{12}H_{11}N_3O$ requires C, 67·6; H, 5·2; N, 19·7; O, 7·5%).

Kinetic Method.—The brominations were followed by measuring the diffusion current due to bromine at a spinning platinum electrode; the method is sensitive to very small concentrations of bromine. The apparatus has already been described; [8] it was modified for the present study by the inclusion of a set of Metrohm electrolytic electrodes connected to a Metrohm E211 coulometer. Precisely known quantities of bromine could thus be generated. The reactions were, where possible, studied under pseudo-first-order conditions with hydrazone : bromine concentration at least 20 : 1. However, in the fastest rate measurements ($k_{obs} > 5 \times 10^4$ l mol^{-1} s^{-1}), the initial bromine concentration required to bring the rates within measurable range under these conditions was $<10^{-9}$M. It was found that at such low bromine concentrations, the diffusion current of bromine at the spinning platinum electrode was no longer directly proportional to the bromine concentration. When an attempt was made to measure rate constants under these conditions an apparently constant value of *ca.* 5×10^4 l mol^{-1} s^{-1}, which was independent of the reactivity of the substrate, was obtained. To overcome this, these fast rates were measured under second-order conditions, with [bromine] = [hydrazone]. The rate constants were measured at several initial concentrations of bromine and hydrazone, and the values obtained represent the mean values of several such experiments. The constants were calculated graphically or by a least-squares programme for the Olivetti Programma 101.

*p*K$_a$ *Determinations.*—The acid dissociation constants of the protonated hydrazones were determined spectrophotometrically at 25° in water–methanol (4 : 1). The hydrazone (*ca.* 2×10^{-6} mol) was added to a 25-ml thermostatted cell (3 cm path length), which was placed in the sample chamber of a Cary Model 14 u.v. spectrometer with a linear recorder attached. The contents of the cell were stirred magnetically with the drive motor located in the sample chamber. Into the cell dipped a Metrohm EA 125 U pH electrode [which both recorded the pH of the solution and controlled (*via* a Radiometer pH-stat) the addition of base] and a capillary Teflon tube (through which base was added).

The pH of the hydrazone solution was initially adjusted to *ca.* 3 by the addition of acid (<0·1 ml). Aliquot portions of 4·0N-potassium hydroxide were added and the change in optical density at a convenient wavelength was recorded at intervals of pH of 0·5 (0·1 pH interval near the pK_a). The resultant optical density (O.D.) *vs.* pH curves were compared with theoretical titration curves plotted from equation (3) to give the pK_a values.

$$(\mathrm{O.D.})_{obs} = (\mathrm{O.D.})_{max.}K_a/(a_H + K_a) \qquad (3)$$

Product Analysis.—Because of the high dilution involved in the kinetic experiments and the large hydrazone : bromine ratio, the bromination products could not be isolated directly. By t.l.c. [silica gel HF$_{256}$ (Merck); benzene–light petroleum (b.p. 40—60°)–methanol (3 : 1 : 1)] two distinct products were detected. With benzaldehyde 3-pyridylhydrazone in 70% acetic acid these were *N*-(3-pyridyl)benzohydrazonyl bromide (R_F 0·48) and *N*-(3-pyridyl)benzohydrazide (R_F 0·30). Note that the hydrazonyl bromides are the products formed in good yield from bromination of the hydrazones in anhydrous acetic acid. The formation of the hydrazide from the hydrazonyl bromide is not unexpected in the aqueous solvent mixture in view of the high solvolytic reactivity of these compounds. Similar results were obtained for the bromination of 3-chlorobenzaldehyde 3-pyridylhydrazone in 70% acetic acid: the corresponding hydrazonyl bromide (R_F 0·44) and hydrazide (R_F 0·29) were separated from the unchanged hydrazone (R_F 0·33).

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