fluoroacetoxy-1,1-diphenylethane (4c): mass spectrum calcd for $C_{16}H_{11}O_2F_5$ *m/e* 330.0701, found *m/e* 330.0670, *m/e* 330 (M^+, 46), 279 (100), 165 (33), 105 (42), 77 (21); NMR δ H 7.1 ppm (t), J_{FH} = 55.5 Hz.

Phenyl-Substituted Derivates of 1,2-Difluoroethanes (2d–h). The reaction time for **1d** was 10 min, while the reaction time for **1h** was 1 h. The fluorination, workup procedure, and TLC purification were the same as described for **2a**. The products were unstable, oily compounds. NMR data are listed in Table II. Mass spectra: **2d,** calcd for $C_{15}H_{14}F_2O$ *m/e* 248.1013, found *m/e* 248.1000, *m/e* 248 (M^+, 1), 228 (100), 215 (12), 198 (14), 183 (16), 165 (20), 77 (10); **2e,** calcd for $C_{15}H_{14}F_2$ *m/e* 232.1064, found *m/e* 232.1063, *m/e* 232 (M^+, 16), 199 (100), 184 (13), 183 (13), 119 (10), 84 (22); **2f,** calcd for $C_{15}H_{14}F_2$ *m/e* 232.1064, found *m/e* 232.1063, *m/e* 232 (M^+, 14), 199 (100), 184 (14), 183 (12), 119 (12); **2g,** calcd for $C_{14}H_{11}F_2Cl$ *m/e* 252.0517, found *m/e* 252.0518, *m/e* 254 ($M^+ + 2$, 6), 252 (M^+, 17), 221 (33), 219 (100), 183 (26), 92 (17); **2h,** calcd for $C_{14}H_{11}F_2Cl$ *m/e* 252.0517, found *m/e* 252.0518, *m/e* 254 ($M^+ + 2$, 7), 252 (M^+, 20), 221 (33), 219 (100), 183 (30), 92 (18).

1,2-Difluoro-1-phenylethane (8a). The fluorination, workup procedure, and VPC purification were essentially the same as for **5a** (SE-30, Chromosorb A, AW, 10%, 150 °C). Liquid unstable product (50%) was isolated. NMR data are stated in Table II. Mass spectrum: calcd for $C_8H_8F_2$ *m/e* 142.0603, found *m/e* 142.0592, *m/e* 142 (M^+, 33), 109 (100), 83 (7), 77 (8).

1,2-Difluoro-2-phenylpropane (8b), 2-Phenyl-3-fluoropropene-1 (9). The fluorination, workup procedure, and VPC purification were essentially the same as for **5a** (SE-30, Chromosorb A, AW, 10%, 150 °C). **8b** was isolated in 22% yield as a liquid, unstable product. NMR data are listed in Table II. Mass spectrum: calcd for $C_9H_{10}F_2$ *m/e* 156.0759, found *m/e* 156.0748, *m/e* 156 (M^+, 10), 136 (100), 103 (65), 87 (35), 77 (31). **9** was isolated in 38% yield as a liquid product: mass spectrum calcd for C_9H_9F *m/e* 136.0688, found *m/e* 136.0687, *m/e* 136 (M^+, 100), 103 (80), 78 (27), 77 (27); NMR δ F −237 ppm (td), J_{FH} = 51, 2 Hz.

Acknowledgment. We thank Professor J. Slivnik for the xenon difluoride, Professor J. Marsel for providing facilities, and the Boris Kidric Foundation for financial assistance.

Registry No.—**1a,** 530-48-3; **1b,** 778-66-5; **1c,** 390-75-0; **1d,** 4333-75-9; **1e,** 948-55-0; **1f,** 4333-70-4; **1g,** 18218-20-7; **1h,** 29265-81-4; **2a,** 379-83-9; **2b,** 309-45-5; **2c,** 14090-30-3; **2d,** 59888-08-3; **2e,** 59888-09-4; **2f,** 59888-10-7; **2g,** 59888-11-8; **2h,** 59888-12-9; **3b,** 2042-85-5; **4c,** 52108-02-8; **5a,** 390-75-0; **5b,** 59888-13-0; **6,** 337-72-4; **7a,** 100-42-5; **7b,** 98-83-9; **8a,** 33315-79-6; **8b,** 59888-14-1; **9,** 14584-33-9; xenon difluoride, 13709-36-9.

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Mechanism of Bromination of 6-Azauracil in Aqueous Acid Solutions

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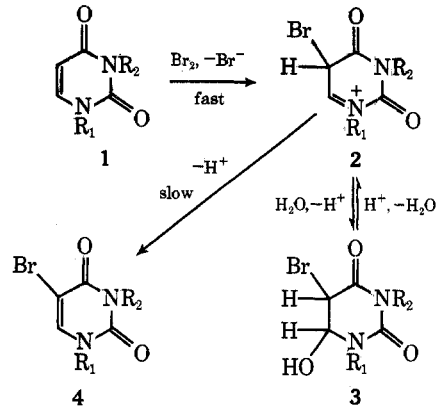
Received April 27, 1976

In dilute aqueous sulfuric acid solution the rates of bromination of 6-azauracil and 3-methyl-6-azauracil vary inversely with the hydronium ion concentration, whereas under the same conditions 1,3-dimethyl-6-azauracil is barely reactive. It is suggested that 6-azauracil and its 3-methyl derivative react with bromine via their anions resulting from deprotonation at N_1. It appears that a 6-aza nitrogen depresses the rate of bromine attack at the 5 position of a uracil by at least 10^{10}.

We have recently obtained evidence that the primary route for the monobromination of uracils (**1**, R_1, R_2 = H or Me) in aqueous acidic solutions involves two discrete steps[1] (Scheme I). Firstly, there is a rapid reaction of **1** and bromine

Scheme I



to give the cation **2** which is then captured by water to yield an observable intermediate[1] **3**. Secondly, there is a slow acid-catalyzed[1] dehydration **3** ⇄ **2** → **4**. Such a mechanism would appear to be less likely for the analogous brominations of 6-azauracils (**6** in Scheme II), since the cationic intermediate **5** should be much less stable than **2**.

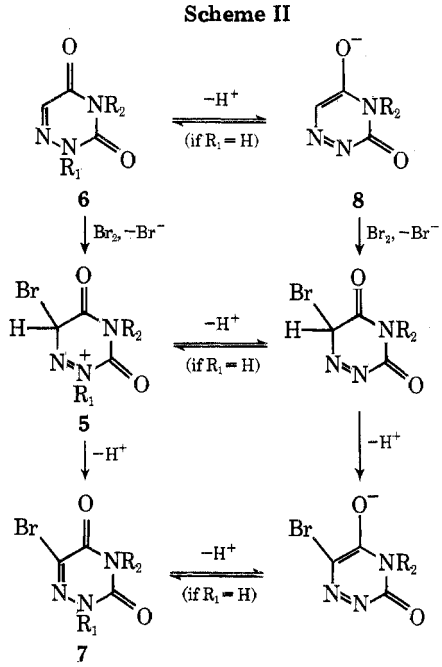
In aqueous solution, the 6-azauracils (**6**, R_1, R_2 = H or Me) react smoothly with bromine to give the appropriate 5-bromo derivatives[2,3] (**7**). In contrast to the behavior of uracils, this reaction is quite slow, and may be conveniently followed by monitoring the decrease in uv absorbance at 400 nm due to bromine. In dilute aqueous acid, and in the presence of an excess of a substrate (**6**), the rate of disappearance of bromine obeys first-order kinetics. Table I lists the derived second-order rate constants[4] for the reaction of bromine with substrates **6** (R_1 = R_2 = H) and **6** (R_1 = H; R_2 = Me) at various acid concentrations. These clearly show an inverse dependence upon the hydronium ion concentration, and thus suggest a mechanism in which bromine attacks the anion **8** (Scheme II). Support for this interpretation is the observation

Table I. Variation of the Rate of Disappearance of Bromine with [H_3O^+] Due to Reaction with 6-Azauracils (6)[a,b]

		$k_2^{obsd} \times 10^3$, M^{-1} s^{-1}	
$[H_2SO_4]$, N	$1/[H_3O^+]$, M^{-1}	6 ($R_1 = R_2 =$ H)[c]	6 (R_1 = H; R_2 = Me)[d]
0.05	31.3	8.15	11.5
0.07	23.3	6.06	8.70
0.10	16.9	5.17	6.55
0.15	11.9	3.86	4.69
0.30	6.25	2.44	2.76
0.50	3.85	2.12	

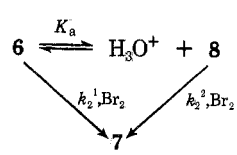
[a] [6] = 1×10^{-2} to 4×10^{-2} M; $[Br_2]_0 = 2 \times 10^{-3}$ to 4×10^{-3} M. [b] Each k_2^{obsd} is an average of two or three determinations. At 30 °C. [c] These data fit $k_2^{obsd} \times 10^3 = 1.2 + 0.22/[H_3O^+]$ (corr coeff = 0.997). [d] These data fit $k_2^{obsd} \times 10^3 = 0.56 + 0.35/[H_3O^+]$ (corr coeff = 0.999).

Scheme II



that, under the same conditions, the dimethyl derivative **6** ($R_1 = R_2$ = Me) reacts with bromine much more slowly ($k_2^{obsd} \simeq 10^{-4}$ M^{-1} s^{-1}) than the other two substrates.

The known[5] pK_a for deprotonation of 3-methyl-6-azauracil (**6**, R_1 = H; R_2 = Me) is 9.52 (at 25 °C), whereas that for 6-azauracil[5] is 7.00 (at 25 °C). However, this last value is for the loss of the 3-H, and presumably the pK_a for loss of the 1-H is also about 9.5. In any event, it is clear that under the conditions of our kinetic runs (pH 0.58–1.50) the actual concentration of **6** and the stoichiometric concentration of **6** are virtually identical. Given these circumstances, the proposed mechanism



requires that

$$k_2^{obsd} = k_2^1 + k_2^2 K_a/[H_3O^+] \quad (1)$$

as the data in Table I support.

Table II lists the individual second-order rate constants associated with **6** and **8** derived by fitting eq 1 to the data in Table I. For the reaction of bromine with the anions **8** we have $k_2^2 \simeq 10^6$ M^{-1} s^{-1}. This value seems quite reasonable in that phenoxide ions react with bromine at similar rates (10^6–10^9 M^{-1} s^{-1}).[6] The slight difference in reactivity between the two anions **8** (R_2 = H) and **8** (R_2 = Me) is in the direction expected for methyl substitution.

Table II. Kinetic Parameters for the Reaction of 6 with Bromine[a]

	6		
Parameter in eq 1	$R_1 = R_2$ = H	R_1 = H; R_2 = Me	$R_1 = R_2$ = Me
$k_2^1 \times 10^3$, M^{-1} s^{-1}	1.2	0.56	~0.1
$k_2^2 K_a \times 10^3$, s^{-1}	0.22	0.35	
pK_a (25 °C)[b]	9.5?	9.52	
$k_2^2 \times 10^{-6}$, M^{-1} s^{-1}	~0.7	~1.0	

[a] Obtained by fitting eq 1 to the data in Table I. See footnotes *c* and *d* in Table I. At 30 °C. [b] Reference 5.

More curious is the apparent range of reactivities for attack of bromine upon the un-ionized forms **6**. It seems that the dimethyl derivative **6** ($R_1 = R_2$ = Me) is about one-tenth as reactive as the parent **6** ($R_1 = R_2$ = H). On the basis of the simple pathway

$$6 + Br_2 \xrightarrow{slow} 5 + Br^- \xrightarrow{fast} 7 + HBr$$

one might expect a reverse order to obtain. Without further data it is difficult to rationalize the observed order, but it might be understandable if the deprotonation **5** → **7** were partially or completely rate determining.

As a final point, we return to the comparison with uracils (**1**). In view of the rapidity of attack upon **1**,[7] we estimate that the presence of the 6-aza nitrogen (in **6**) depresses the rate of this reaction by at least 10^{10}. It should also be pointed out that uracils having an ionizable 1-H (i.e., **1**, R_1 = H) may react via their anions since the pK_a's for this proton loss[5] are also about 9.5.

Experimental Section

The following compounds used in this study were prepared by literature procedures: 6-azauracil (**6**, $R_1 = R_2$ = H),[2] 3-methyl-6-azauracil (**6**, R_1 = H; R_2 = Me),[5] 1,3-dimethyl-6-azauracil (**6**, $R_1 = R_2$ = Me),[5] 5-bromo-6-azauracil (**7**, $R_1 = R_2$ = H),[2] 5-bromo-3-methyl-6-azauracil (**7**, R_1 = H; R_2 = Me),[3] and 5-bromo-1,3-dimethyl-6-azauracil (**7**, $R_1 = R_2$ = Me).[3]

The kinetics of bromine disappearance were measured spectrophotometrically using a Cary 14 instrument with cells thermostatted at 30.00 ± 0.02 °C. In the presence of an approximate tenfold excess of substrates (**6**) good first-order rate constants (k_1^{obsd}) were obtained. These were converted to second-order rate constants using[8] $k_2^{obsd} = k_1^{obsd}/([6] - [Br_2]_0)$, since the excess of substrate over bromine was not particularly large. The values given in Table I are the average of two or three such determinations. As previously,[9] hydronium concentrations were calculated from the acid concentrations assuming the second dissociation constant of sulfuric acid[10] to be 1.20×10^{-2}.

Acknowledgments. We thank the National Research Council of Canada for continued financial support.

Registry No.—**6** ($R_1 = R_2$ = H), 461-89-2; **6** (R_1 = H; R_2 = Me), 1627-30-1; **6** ($R_1 = R_2$ = Me), 15677-10-8.

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Fluorine-19 Nuclear Magnetic Resonance Studies of Nitrogen-Substituted Fluorobenzenes

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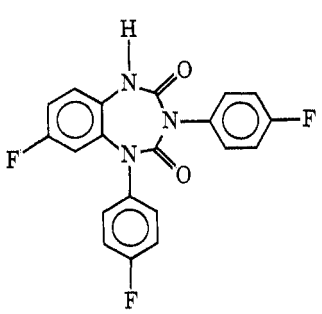
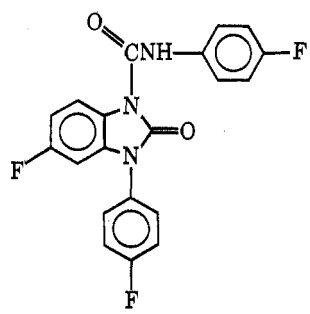
Received June 14, 1976

^{19}F chemical shifts of a series of nitrogen-substituted fluorobenzenes have been investigated to demonstrate their use as a probe in determining structure. σ constants are evaluated for selected nitrogen substituents from chemical shifts of the meta- and para-substituted fluorobenzenes. The results are discussed in terms of inductive, resonance, and conformational effects of the substituents on nitrogen.

Although many ^{19}F chemical shifts of fluorobenzenes with nitrogen substituents have been reported,[1-5] the appropriate model compounds required for the structure elucidation of a by-product from the reaction of nitrobenzene with carbon monoxide[6] were not available. A series of carbonyl-substituted nitrogen derivatives were compiled (Tables I and II) and analzed to show that the structure was **58a** or **58b**, but the final assignment of **58b** had to be accomplished



58a



58b

by preparing authentic samples of the nonfluorinated analogues and comparing spectral properties. In addition, we prepared and measured the ^{19}F chemical shifts for a series of meta- and para-substituted fluorobenzenes to determine σ constants for a number of nitrogen functions not previously reported.

Results and Discussion

In Table I the meta- and para-^{19}F chemical shifts for a series of nitrogen-substituted fluorobenzenes are reported relative to fluorobenzene. For this series, Taft's inductive and resonance parameters, σ_I and σ_R,[1] are calculated and compared to literature values. Although this is not a complete compilation of substituent effects for nitrogen functions from ^{19}F shift measurements, it is comprehensive and includes much new data. Table II gives the ^{19}F NMR chemical shifts of a further series of para-nitrogen-substituted fluorobenzenes. The data in Table I are arranged in order of increasing inductive power of the substituent (downfield shift of *m*-fluorine) in contrast to Table II which emphasizes the resonance effects.

Oxygen Bonded to Nitrogen (ArNO). The *p*-fluoro resonance for nitrobenzene (**34**) appears at very low field because the large resonance withdrawal effect of nitro reinforces its strong inductive withdrawal effect. However, the *p*-fluoro shift for nitrosobenzene (**17**) is slightly further downfield although the nitroso group is inductively less effective (expected from the electronegative substitution by one vs. two oxygens). Steric factors may inhibit the resonance interaction of nitro relative to nitroso. The azoxyphenyl group [–N(O)=NAr, see **25**] has an inductive effect intermediate between nitroso (NO) and nitro (NO_2) as expected from replacement of one oxygen by the less electronegative NAr group. The resonance interaction of this group is less than nitro or nitroso ($\sigma_R \sim +0.06$ vs. +0.21 for nitro and +0.32 for nitroso; note that the *p*-fluoro shifts in azoxybenzenes have not been definitely assigned but are not significantly different) as would be expected if the bulky ArN group inhibits coplanarity required for effective resonance interaction.

Nitrogen Substituents of Nitrogen (ArNN). The *p*-fluoro shifts for both the phenylhydrazine **3b** and hydrazobenzene **40** are only slightly downfield from aniline. Both fluorines in azoxybenzene **25** are very similar, and close to *cis*-azobenzene rather than the trans isomer. The ammonium cation (see **35**) has almost no effect on the *p*-fluoro resonance, whereas the resonance effect of the diazonium ion (see **39**) shifts its resonance to the lowest field of all fluoroaromatic compounds.

The meta shifts move downfield in order NH_2, NHOH, N=NAr (trans), N=N(→O)Ar, N=NAr (cis), –N=O. The cis form of azobenzene **22** has an inductive effect larger than the =N(→O)Ar group (assuming the assignment indicated for the *m*-fluoro shifts for the azoxybenzene). Direct interaction of the π system of the phenyl groups may occur in the cis isomer causing this unusual downfield shift. The resonance effects suggest that the phenyl groups must be twisted and the N=N system cannot effectively conjugate to withdraw charge density from the ring [σ_R(cis) −0.04 vs. σ_R(trans) +0.08, see Figure 1]. In the cis form, resonance donation of charge density (Figure 1) may become the major factor. Such electron donation by resonance has been proposed for arylazoplatinum compounds.[7a] Our conclusions on the cis and trans structures are supported by other experimental evidence.[7b]