

Reactivity of 2-Fluoro-5-Nitrothiophene Towards Sodium Thiophenoxide and Piperidine. Comparison with other 2-Halogeno-5-nitrothiophenes.

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2-Fluoro-5-nitrothiophene reacts with sodium thiophenoxide and piperidine much faster than other 2-halogeno-5-nitrothiophenes. In methanol the reactions with both nucleophiles follow overall second order kinetics, while in benzene the observed second order rate constants of the reaction with piperidine show a linear dependence by the piperidine concentration. Such a dependence, which is mild for the chloro, bromo and iodo derivative, becomes strong for the fluoro compound. Moreover, the reaction of 2-fluoro-5-nitrothiophene with $[1-^2H]$ piperidine shows the absence of a primary isotope effect. The results are interpreted within the framework of the two-stage, intermediate-complex mechanism, the first stage (attack of the nucleophile on the substrate) being rate determining for the reactions of 2-fluoro-, -chloro-, -bromo- and -iodo-5-nitrothiophene with thiophenoxide in methanol and of 2-chloro-, -bromo- and -iodo-5-nitrothiophene with piperidine in benzene. In the case of the reaction of 2-fluoro-5-nitrothiophene with piperidine in benzene the data are in agreement with a mechanism in which the rate determining step is the decomposition of the tetrahedral intermediate into products. The intervention of a second amine molecule in the transition state of the rate determining step can be rationalized in terms of bifunctional catalysis. A comparison of reactivity of thiophenoxide and piperidine towards 2-halogeno-5-nitrothiophenes (Hal = F, Cl, Br, I) indicates a greater sensitivity of the reaction with piperidine than that with thiophenoxide to the change of the leaving group.

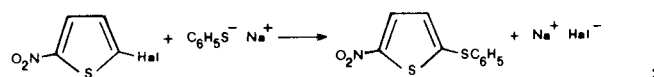
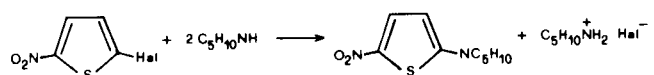
Kinetic behaviour of nitroactivated halogenothiophenes (Hal = Cl, Br, I) towards thiophenoxide has been studied in our laboratory in recent years (1a,b). Both mobility order and low reactivity variation on changing the leaving group strongly suggested the occurrence of a two-stage intermediate-complex mechanism generally accepted for aromatic nucleophilic substitutions, in which the intermediate complex formation is rate determining. Less data is available for reactions of the same substrates with amines (2), and nothing at all is reported for fluoronitrothiophenes.

Data on the reactivity towards nucleophiles of nitroactivated fluorothiophenes, beside those relative to the other halogenonitrothiophenes, are undoubtedly useful in confirming the occurrence of the S_N -Ar type mechanism in nucleophilic substitutions on thiophene derivatives. We here report kinetic data for the reactions of 2-fluoro-5-nitrothiophene with piperidine in methyl alcohol and in benzene, and with sodium thiophenoxide in methyl and ethyl alcohol. Rate constants for the reaction of 2-chloro-, -bromo- and -iodo-5-nitrothiophene with piperidine in

methyl alcohol and benzene were also measured in order to examine the effect of the leaving group on the reactivity of 2-X-5-nitrothiophenes towards thiophenoxide and piperidine.

Results and Discussion.

The reactions which were investigated are represented by equations 1 and 2:



Products show strong absorption maxima at about 380-440 nm, and reactions can be suitably followed photometrically. All rate determinations were carried out with a large excess of the nucleophile compared to the substrate. Good pseudo-first order kinetic plots were

Table I

Rates for the Reaction of 2-Fluoro-5-nitrothiophene with Piperidine in Methyl Alcohol and Benzene.
 k_{obs} is the Second-order Rate Coefficient: Rate/[Substrate][Pip] in $l \text{ mol}^{-1} \text{ s}^{-1}$.

Methyl Alcohol (a)					
Temperature 20.0°, unless otherwise stated					
$10^2 \times [C_5H_{10}NH]$	2.02	2.03	2.02	4.02	6.08
$10 \times k_{\text{obs}}$	1.10	1.10 (b)	1.14 (c)	1.09	1.09
$10^2 \times [C_5H_{10}NH]$	8.07	10.1	20.1	6.08	6.08
$10 \times k_{\text{obs}}$	1.14	1.12	1.20	2.07 (d)	3.66 (e)

(a) Initial concentration of substrate $1.2 \times 10^{-5} M$, unless otherwise stated; (b) $[substrate]_i = 2.4 \times 10^{-5} M$; (c) Piperidine hydrochloride, $0.02M$, also present; (d) At 30.0° ; (e) At 39.7° .

Benzene (a)					
Temperature 20.0°					
$10^2 \times [C_5H_{10}NH]$	5.02	10.1	20.2	30.3	30.3
$10^2 \times k_{\text{obs}}$	0.89	1.53	2.95	4.37	4.40 (b)
$10^2 \times [C_5H_{10}NH]$	29.8	40.5	50.6		
$10^2 \times k_{\text{obs}}$	4.56 (c)	5.70	7.03		

$k_c = 1.36 \times 10^{-1} l^2 \text{ mol}^{-2} \text{ s}^{-1}$; $k_u = 1.96 \times 10^{-3} l \text{ mol}^{-1} \text{ s}^{-1}$; $k_c/k_u = 69 l \text{ mol}^{-1}$.

Temperature 29.7°					
$10^2 \times [C_5H_{10}NH]$	5.07	10.1	20.3	30.4	40.5
$10^2 \times k_{\text{obs}}$	0.99	1.86	3.52	5.28	6.90

$k_c = 1.67 \times 10^{-1} l^2 \text{ mol}^{-2} \text{ s}^{-1}$; $k_u = 1.56 \times 10^{-3} l \text{ mol}^{-1} \text{ s}^{-1}$; $k_c/k_u = 107 l \text{ mol}^{-1}$.

Temperature 39.0°					
$10^2 \times [C_5H_{10}NH]$	5.02	10.0	20.1	30.1	40.1
$10^2 \times k_{\text{obs}}$	1.14	2.14	4.12	6.12	7.93

$k_c = 1.94 \times 10^{-1} l^2 \text{ mol}^{-2} \text{ s}^{-1}$; $k_u = 1.98 \times 10^{-3} l \text{ mol}^{-1} \text{ s}^{-1}$; $k_c/k_u = 98 l \text{ mol}^{-1}$.

(a) $[Substrate]_i = 1.9 \times 10^{-5} M$, unless otherwise stated; (b) $[Substrate]_i = 9.5 \times 10^{-6} M$; (c) $[1^{-2}H]$ piperidine was employed.

obtained (3). Second order rate constants were then computed by dividing the pseudo-first order rate constants by concentrations of the nucleophile. Photometric data showed, on the basis of the infinity absorbance of reactions, quantitative formation of the expected products. Reactions of 2-Fluoro-5-nitrothiophene with Piperidine in Methyl Alcohol and Benzene.

The reactions of 2-fluoro-5-nitrothiophene with piperidine in methyl alcohol and in benzene show different features (Table I). In methyl alcohol, runs carried out at diverse concentrations of the amine (0.02 - $0.2M$) and the substrate revealed an appreciable constancy of the second-order rate coefficients, within the limits of experimental error; thus the reaction is first-order both with respect to the fluoro derivative and piperidine. Moreover, the addition of piperidine hydrochloride did not affect

the kinetics. Rates were measured at three different temperatures, and the values which were calculated for activation enthalpy and entropy are $10.6 \text{ kcal mol}^{-1}$ and $-26.7 \text{ cal mol}^{-1} \text{ deg}^{-1}$ (at 20°), respectively. In contrast, in benzene second-order rate coefficients are fairly strongly dependent on the amine concentration in the range 0.05 - $0.5M$. Rate data are nicely represented by equation 3:

$$k_{\text{obs}} = k_u + k_c [C_5H_{10}NH]$$

where k_{obs} is the observed second-order rate coefficient. The values of k_u and k_c , which are second- and third-order coefficients (calculated by linear regression analysis of the data in Table I) respectively, and the ratios k_c/k_u at three different temperatures are also set forth in Table I. The disordered variations of the ratios k_c/k_u with

Table II

Reactions of 2-X-5-Nitrothiophene (X = Cl, Br, I) with Piperidine in Methyl Alcohol and Benzene at 20°. k_{obs} is the Second-order Rate Coefficient: Rate/ [Substrate][Pip] in $1 \text{ mol}^{-1} \text{ s}^{-1}$.

X	Methyl Alcohol (a)					
	Cl	$10^2 \times [\text{C}_5\text{H}_{10}\text{NH}]$ $10^5 \times k_{\text{obs}}$	2.02 3.20	2.03 3.19 (b)	5.02 3.25	
Br	$10^2 \times [\text{C}_5\text{H}_{10}\text{NH}]$ $10^5 \times k_{\text{obs}}$	2.0 1.63 (c)	2.02 1.64 (b)	4.99 1.65		
I	$10^2 \times [\text{C}_5\text{H}_{10}\text{NH}]$ $10^5 \times k_{\text{obs}}$	2.00 0.27	2.02 0.28 (b)	4.99 0.30		
	Benzene (d)					
Cl	$10^2 \times [\text{C}_5\text{H}_{10}\text{NH}]$ $10^6 \times k_{\text{obs}}$	2.0 1.22	17.2 2.53	32.0 3.82	50.8 5.38	50.8 5.39 (e)
$k_c = 8.53 \times 10^{-6} \text{ l}^2 \text{ mol}^{-2} \text{ s}^{-1}$; $k_u = 1.06 \times 10^{-6} \text{ l mol}^{-1} \text{ s}^{-1}$; $k_c/k_u = 8.0 \text{ l mol}^{-1}$.						
Br	$10^2 \times [\text{C}_5\text{H}_{10}\text{NH}]$ $10^6 \times k_{\text{obs}}$	2.0 0.97 (c)	16.9 1.65	34.4 2.43	50.8 3.21	50.6 3.20 (e)
$k_c = 4.58 \times 10^{-6} \text{ l}^2 \text{ mol}^{-2} \text{ s}^{-1}$; $k_u = 8.7 \times 10^{-7} \text{ l mol}^{-1} \text{ s}^{-1}$; $k_c/k_u = 5.2 \text{ l mol}^{-1}$.						
I	$10^2 \times [\text{C}_5\text{H}_{10}\text{NH}]$ $10^6 \times k_{\text{obs}}$	10.0 0.124	21.2 0.142	33.8 0.164	50.8 0.188	50.6 0.189 (e)
$k_c = 1.58 \times 10^{-7} \text{ l}^2 \text{ mol}^{-2} \text{ s}^{-1}$; $k_u = 1.09 \times 10^{-7} \text{ l mol}^{-1} \text{ s}^{-1}$; $k_c/k_u = 1.45 \text{ l mol}^{-1}$.						
(a) [Substrate] _i = 10^{-3} M , unless otherwise stated. (b) [Substrate] _i = $2 \times 10^{-3} \text{ M}$. (c) Data from reference (2). (d) [Substrate] _i = $2 \times 10^{-3} \text{ M}$, unless otherwise stated. (e) [Substrate] _i = $4 \times 10^{-3} \text{ M}$.						

increase in temperature can be ascribed to the substantial errors inherent to the k_u values. It does not appear to be possible to eliminate such errors because small values of k_u (if compared to the k_c values) made inaccuracy in their computation unavoidable. However, when the values of k_c/k_u are near 100, this can be taken, according to Bunnett's statement on base catalysis (4), as positive proof of piperidine catalysis. The activation parameters for the catalyzed part of the reaction have been calculated (at 20°), and are $\Delta H^\ddagger = 2.8 \text{ kcal mol}^{-1}$ and $\Delta S^\ddagger = -52.8 \text{ cal mol}^{-1} \text{ deg}^{-1}$. In Table I is also reported the second-order rate coefficient of the reaction of 2-fluoro-5-nitrothiophene with [$1\text{-}^2\text{H}$]piperidine. Since the value is very close (the difference is within the limits of experimental errors) to that relative to the undeuteriated amine, the existence of a primary isotope effect can be ruled out on a reasonable basis.

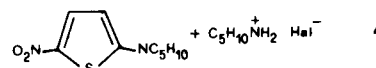
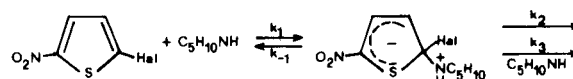
Reactions of 2-Chloro-, -Bromo- and -Iodo-5-nitrothiophene with Piperidine in Methyl Alcohol and Benzene.

Data are collected in Table II, examination of which reveals some interesting aspects:

i) The reactions of chloro, bromo and iodo derivatives with piperidine in methanol are first order both with respect to the substrate and the amine, while in benzene second-order rate constants are slightly dependent on the amine concentration. Such a dependence, which is very moderate for the iodo derivative ($k_c/k_u = 1.45$), becomes more marked for the bromo ($k_c/k_u = 5.2$) and for the chloro compound ($k_c/k_u = 8.0$).

ii) The reactivity is spread over a very limited range.
iii) The replaceability order is $\text{F} \gg \text{Cl} > \text{Br} > \text{I}$.

All these points can be easily fitted into the two-stage, intermediate-complex mechanism (4,5,6) shown by equation 4 and whose kinetic expression, derived on the basis



of steady-state treatment (7), is equation 5 (6c,f).

$$k_{\text{obs}} = \frac{k_1 k_2 + k_1 k_3 [\text{C}_5\text{H}_{10}\text{NH}]}{k_{-1} + k_2 + k_3 [\text{C}_5\text{H}_{10}\text{NH}]}$$

Two limiting cases must be considered:

i) When $k_{-1} \ll k_2 + k_3 [\text{C}_5\text{H}_{10}\text{NH}]$, *i.e.*, the intermediate yields products much faster than it reverts to reactants, then $k_{\text{obs}} = k_1$: the first stage is rate-determining.

ii) When $k_{-1} \gg k_2 + k_3 [\text{C}_5\text{H}_{10}\text{NH}]$, *i.e.*, the intermediate goes back to reactants much faster than it proceeds to products, then $k_{\text{obs}} = k_1 k_2 / k_{-1} + k_1 k_3 [\text{C}_5\text{H}_{10}\text{NH}] / k_{-1}$. Such equation is mathematically equivalent to equation 3, and k_c/k_u represents k_3/k_2 . In this case, a fast pre-equilibrium of intermediate formation is followed by its slow decomposition into products through a catalyzed and an uncatalyzed process, whose relative magnitudes at 1M piperidine concentration are represented by the ratio k_c/k_u .

The reactions of 2-chloro-, -bromo- and -iodo-5-nitrothiophene with piperidine in methyl alcohol and benzene and the reaction of 2-fluoro-5-nitrothiophene with piperidine in methyl alcohol can be ascribed to case (i): in fact, overall second-order kinetics (8), reactivity pattern, absence of element effect and lack of catalysis by the amine (8) require a bimolecular mechanism, and rule out that the carbon-halogen bond is broken in the rate-determining step of the reaction (6). The reactivity order $\text{F} \gg \text{Cl} > \text{Br} > \text{I}$ is typical for nucleophilic substitutions of activated aromatic derivatives (10). The greater reactivity of the fluoro derivative is usually explained (11) on the basis of the greater electronegativity of fluorine

with respect to other halogens, which increases the positive charge on the carbon bearing the leaving group, thus favouring attack of the nucleophile, *i.e.*, increasing k_1 . A comparison of the activation parameters of the reactions in methanol (calculated at 20°) of the fluoro- ($\Delta H^\ddagger = 10.6 \text{ kcal mol}^{-1}$; $\Delta S^\ddagger = -26.7 \text{ cal mol}^{-1} \text{ deg}^{-1}$) and bromo-derivative ($\Delta H^\ddagger = -15.3 \text{ kcal mol}^{-1}$; $\Delta S^\ddagger = -28.1 \text{ cal mol}^{-1} \text{ deg}^{-1}$) (2) indicates that the jump in reactivity on going from bromine to fluorine is mainly due to the enthalpic factor.

The lack of catalysis by piperidine deserves a brief comment. Inasmuch as the detachment of fluoride (provided that such a process is the slow step of the reaction) is known to be susceptible to acid catalysis (12), piperidine (or rather piperidinium ion formed in the removal of the ammonium proton from the addition intermediate to a piperidine molecule) should act as a catalyst (13). The absence of catalysis proves that the first stage is rate-limiting. On the contrary, catalysis effects which are apparent in the reaction of 2-fluoro-5-nitrothiophene in benzene reveal (case ii) that the overall reaction rate is governed, besides by the pre-equilibrium corresponding to the first stage (k_1/k_{-1}), by the uncatalyzed (k_2) and catalyzed ($k_3 [\text{C}_5\text{H}_{10}\text{NH}]$) progress from the intermediate to products. In benzene, the intervention of the catalytic amine molecule could be ration-

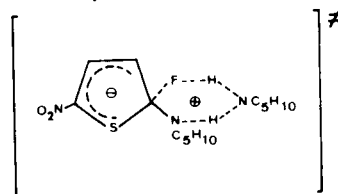


Table III

Second-order Rate Constants for the Reaction of 2-Fluoro-5-nitrothiophene with Sodium Thiophenoxide (a) in Methyl and Ethyl Alcohol. k_{obs} is the Second-order Rate Coefficient: $\text{Rate}/[\text{Substrate}][\text{Pip}]$ in $\text{l mol}^{-1} \text{s}^{-1}$.

Solvent	Temperature (°C)	$10^5 \times [\text{substrate}]$	$10^4 \times [\text{PhS}^-]$	k_{obs}
MeOH	20.0	4.76	10.7	10.1
	20.0	4.76	10.7 (b)	10.4
	20.0	4.76	10.6 (c)	10.3
	20.0	2.38	5.10	10.2
	10.2	2.38	5.35	4.87
	29.9	2.38	4.95	20.3
EtOH	20.0	2.38	4.95	54.1
	20.0	1.47	2.97	54.8

(a) Unless otherwise stated, thiophenol was four times in excess compared to sodium methoxide. The actual thiophenoxide concentration was taken as equal to methoxide concentration. (b) Thiophenol was eight times in excess compared to sodium methoxide. (c) Thiophenol was twelve times in excess compared to sodium methoxide.

Table IV

Second-order Rate Constants and Thiophenoxide/Piperidine Reactivity Ratios for the Reactions of 2-X-5-Nitrothiophenes with Piperidine and Sodium Thiophenoxide in Methanol at 20°.

X	$\frac{10^4 \times k_{\text{Pip}}}{\text{l mol}^{-1} \text{ s}^{-1}}$	$\frac{k_{\text{PhS}^-}}{\text{l mol}^{-1} \text{ s}^{-1}}$	$10^{-3} \times \frac{k_{\text{PhS}^-}}{k_{\text{Pip}}}$	$\log \frac{k_{\text{PhS}^-}}{k_{\text{Pip}}}$
Cl	0.32	0.126 (a)	3.94	3.60
Br	0.163 (b)	0.136 (a)	8.34	3.92
I	0.027	0.088 (a)	32.59	4.51
F	1100.00	10.1	0.092	1.96

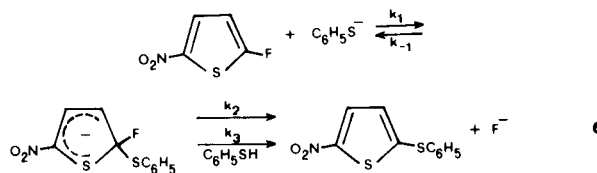
(a) Data from reference (1b). (b) Data from reference (2).

alized, on the basis of the collected results, in terms of "bifunctional catalysis" (14), *i.e.*, the simultaneous removal of the ammonium proton and fluorine. Creation of charge is thus avoided, which is most important in furnishing a low energy path for the intermediate decomposition in the apolar aprotic solvent used (6d). The large negative value of the activation entropy found for the catalyzed reaction ($\Delta S^\ddagger = -52.8 \text{ cal mol}^{-1} \text{ deg}^{-1}$) is in accordance with such transition state, whose formation implies the loss of translational and rotational entropy of two molecules of piperidine and one of fluoro-nitrothiophene (15).

The lack of a primary deuterium isotope effect is not so easily rationalized. However, it should be remembered that significant deuterium isotope effects have never been found in the reactions of amines with aromatic fluoro-nitro derivatives (9a,5,16). Causes have been tentatively attributed to the fact that processes involving a non-linear transition state (17), or simultaneous rupture and formation of bonds of different strength (18) might well fail to display a measurable isotope effect.

Reactions of 2-Fluoro-5-nitrothiophene with Sodium Thiophenoxide.

Results are listed in Table III. Second-order rate coefficients are not affected by changes in concentration of substrate, nucleophile and thiophenol, which was in a suitable excess over alkoxide in all runs, in order to ensure a quantitative conversion of the latter into the thiolate anion. The reaction is thus first-order with respect to both the reactants, and the possibility that thiophenol acts as a general acid catalyst is unequivocally excluded (19). In effect, if the second stage of the reaction (equation 6) were generally acid catalyzed, the rate law should include by implication a term proportional in part to the thiophenol concentration, which is not permitted by the experimental data. Therefore, lack of catalysis by thiophenol in the second step proves that the first



step is the rate-determining one (19). The activation parameters calculated (at 20°) from the rate data at three different temperatures are $\Delta H^\ddagger = 11.8 \text{ kcal mol}^{-1}$ and $\Delta S^\ddagger = -13.6 \text{ cal mol}^{-1} \text{ deg}^{-1}$.

A change of the solvent from methanol to ethanol was also studied, in order to test the effect of changing the the polarity of the medium on the reaction rate. Results listed in Table III show that at 20° the reaction is about fivefold faster in ethanol than in methanol. This effect is in complete agreement with the proposed mechanism, which predicts a greater charge dispersion in the transition state than in the ground state (20).

Comparison of Reactivity of Thiophenoxide and Piperidine towards 2-Halogeno-5-nitrothiophenes (Hal = F, Cl, Br, I).

Examination of Table IV, which summarizes the rate constants for the reactions of 2-fluoro-, -chloro-, -bromo- and -iodo-5-nitrothiophene with piperidine and with thiophenoxide ion in methyl alcohol at 20°, shows how the different polarizability of the nucleophile affects the reactivity of the substrates examined. Both with thiophenoxide and with piperidine the observed reactivity pattern is nearly the same ($\text{F} \gg \text{Cl} \sim \text{Br} > \text{I}$). On the other hand the increase in reactivity on passing from the less reactive iodo, through bromo and chloro, to the fluoro derivative is different in the two series, being much higher in the reaction with the amine ($k_{\text{F}}/k_{\text{I}} \approx 41000$) than with thiolate ($k_{\text{F}}/k_{\text{I}} \approx 115$). The greater sensitivity of the reaction with piperidine than that with thiophenoxide to the change of leaving group is in accordance with the theory of "symbiotic effect" on rates of nucleophilic displacement reactions (21). That is,

transition states with several soft or several hard ligands on the reaction center carbon atom are more stable than transition states with a mixture of soft and hard ligands.

In the same Table are also set forth the values of the ratios $k_{\text{PhS}}/k_{\text{Pip}}$ for all four halogenonitrothiophenes. Such ratios increase steadily with the size and weight of the halogen, i.e., with its polarizability (22). We have then attempted to correlate quantitatively our data using the equation 7 of Todesco (23). In accordance with this equation, the reactivity ratio (indicated by the values

$$\log \frac{k}{k_0} = A + B \log (R_{\text{C-X}})_D$$

of $\log k/k_0$ at a given temperature) between the more polarizable (thiophenoxide) and the less polarizable (piperidine) reagent for the same substrate and solvent, is linearly related to the polarizability of the leaving group, as measured, in the case of the halogens, by the logarithms of the refractivity constants $(R)_D$ of C-Hal bonds (24). In Figure 1 the values of $\log (k_{\text{PhS}}/k_{\text{Pip}})$ are plotted against $\log (R_{\text{C-X}})_D$. The good linearity found also confirms the validity of equation 7 for substitution reactions in the thiophene series. The value of B which we have found ($B = 2.48$) is higher than that found for the reactions of 1-X-2,4-dinitrobenzenes ($X = \text{F, Cl, Br, I}$) with thiophenoxide and piperidine ($B = 2.15$, calculated from data in reference 6b,g), as expected on the basis of the significance generally attached to this parameter (23). As it has been found in other series of reactions, the value of B increases as the efficiency of the substrate to remove the negative charge in the transition state decreases (23).

EXPERIMENTAL

Materials.

Methyl alcohol (Erba) was distilled over magnesium activated by iodine (25). Reagent grade ethyl alcohol (95%) (Erba) was purified by distillation of the azeotrope. Benzene (Erba) was purified from thiophene by the mercury acetate method (26), refluxed over sodium and distilled from sodium before use. Thiophenol (Fluka) was repeatedly distilled under reduced pressure, b.p. $55-56^\circ$ (10 mm.), only the central cuts being collected. Piperidine (Erba) was refluxed over sodium for two hours and distilled from sodium, b.p. $106-107^\circ$. Piperidine hydrochloride was prepared by passing hydrogen chloride into an ethereal solution of piperidine; it was twice crystallized from absolute ethanol (m.p. $245-246^\circ$, lit. 245° (6b), $[1-^2\text{H}]$ piperidine was prepared according to Hawthorne (27) and was α . 85% deuteriated (by ir analysis). 2-Chloro-(28), -bromo- (29) and -iodo-5-nitrothiophene (30) were prepared according to literature methods. 2-Fluoro-5-nitrothiophene was obtained by nitration of 2-fluorothiophene (31) according to Gronowitz (32). 2-(5-Nitrothienyl) phenyl sulfide (1b) and *N*-(5-nitrothienyl)piperidine (33) were obtained by literature methods.

Rate Measurements.

The photometric procedures described earlier (1b,34,35) were employed. Each k_{obs} value is the average of two or more separate runs, the mean deviation being $\pm 2.5\%$. The probable error of activation enthalpies is $\pm 0.3 \text{ kcal mol}^{-1}$, that of activation entropies is $\pm 1 \text{ cal mol}^{-1} \text{ deg}^{-1}$. The values of r (correlation coefficient) relative to the linear correlations between k_{obs} and piperidine concentration are in all cases equal to 1.

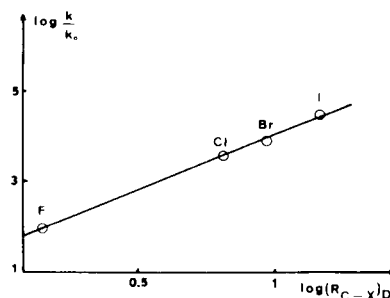


Figure 1. Plot of $\log k_{\text{PhS}}/k_{\text{Pip}}$ against $\log (R_{\text{C-X}})_D$ for 2-halogeno-5-nitrothiophenes. The calculated values of A and B constants are 1.58 and 2.48, respectively ($r = 0.9991$).

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