Tetrahedron Vol. 42, No. 17, pp. 4867 to 4872, 1986
Printed in Great Britain.

0040-4020/86 \$3.00+.00
© 1986 Pergamon Journals Ltd.

KINETICS AND MECHANISM OF OXIDATION OF SUBSTITUTED PHENYL METHYL SULPHIDES BY N-BROMOACETAMIDE

SUBBU PERUMAL*, SAKKIAH ALAGUMALAI, SANGAVANAICKER SELVARAJ AND NATESAN ARUMUGAM

School of Chemistry, Madurai Kamaraj University,
Madurai-625 021, India

(*Received in UK* 3 *April* 1986)

Abstract: The kinetics of oxidation of several substituted phenyl methyl sulphides by N-bromoacetamide (NBA) in 80%acetonitrile-20%water (v/v) mixture are presented. The reaction is first order with respect to both sulphide and NBA and second order in Hg(II). The rate of the reaction exhibits inverse dependence on both [acetamide] and [NBA]. Electron-releasing substituents present in the phenyl ring of the sulphides accelerate the rate while electron-withdrawing ones retard it. The results are in accord with a mechanism involving the reaction between NBA-Hg(II) and sulphide-Hg(II) complexes in the slow rate-limiting step affording a sulphonium ion which hydrolyses in a subsequent fast step to the sulphoxide.

The kinetics and mechanism of oxidation of organic sulphides with N-halo compounds like chloramine-T (CAT)[1-3] and bromamine-T (BAT)[4] have been reported. The preparative aspects of the reaction of sulphides by N-bromosuccinimide (NBS) have been investigated by Tagaki et al[5] and Harville and Reed.[6] The active oxidant species in these oxidations depend on the oxidant and the reaction conditions. The CAT oxidation of sulphides[1,2] involves both TsNHCl and $TsNCl_2$ (Ts=p-$CH_3C_6H_4SO_2$) while BAT[4] oxidation involves TsNHBr and HOBr as the active species. It is known that NBS and NBA oxidations of organic compounds is complicated by bromine oxidation. However, bromine oxidation is obviated by using Hg(II).[7,8] Interestingly, in some NBS reactions, Hg(II) also plays a catalytic role[9,10] although no such observation has yet been recorded in the reactions of NBA. These mechanistic features prompted us to investigate the kinetics and mechanism of oxidation of substituted phenyl methyl sulphides by NBA in presence of Hg(II).

EXPERIMENTAL

Materials. p-Methylthioacetophenone was prepared by the method of Burton and Hu.[11] All other sulphides were prepared by the methylation of the corresponding thiols.[12-14] Purity of all the sulphides were checked by TLC. NBA was prepared by a reported method.[15] Acetonitrile was purified by the method of Coetzee.[16] Doubly distilled water was used throughout the course of investigation. All other chemicals were of analytical grade.

Kinetics. Kinetic measurements were carried out in 80%acetonitrile-20%water (v/v) at constant concentrations of acetamide, mercuric acetate and at constant ionic strength under pseudo first order conditions with a large excess of [sulphide] over [oxidant]. To avoid photochemical reaction, all the kinetic runs were performed in blackened vessels. The initial concentrations of sulphide and NBA in the reaction mixture were 0.01-0.06M and 0.001M respectively unless stated otherwise. The kinetics were followed by determining the unreacted [NBA] iodometrically at different time intervals. For all the runs good first order plots of log [NBA] vs time with correlation coefficients (r) of atleast 0.996 were obtained. The pseudo first order rate constants (k_{obsd}) obtained by the method of least squares afforded the second order rate constants (k_2) when divided by [sulphide].

Stoichiometry. The stoichiometry of the reaction was determined by carrying out several sets of experiments with varying amounts of [NBA] largely in excess over [sulphide]. The estimation of unreacted [NBA] showed that one mole of each sulphide reacts with one mole of NBA.

Product analysis. After about 70% completion of the reaction, the reaction mixtures in actual kinetic runs were concentrated under reduced pressure. The residues when analysed by Co-TLC showed that sulphoxides were the products formed in the reaction. These results lead to the following stoichiometric equation (1).

$$\mathrm{ArSMe + CH_3CONHBr + H_2O \longrightarrow ArSOMe + CH_3CONH_2 + HBr} \qquad (1)$$

RESULTS AND DISCUSSION

The first order dependence of the reaction on NBA is obvious from the linearity of the plots of log [NBA] vs time (Fig.1A). The second order rate constants at different [methyl phenyl sulphide (MPS)] and [NBA] are listed in Table 1. The plot of k_{obsd} vs [MPS] (Fig. 1B) is linear passing through the origin showing that the reaction is first order in sulphide.

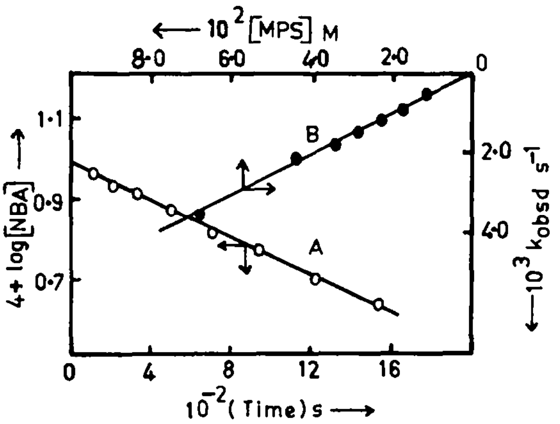


Fig. 1. A, Plot of log [NBA] vs t. [MPS] = 1.133×10^{-2}M, [NBA] = 1×10^{-3}M, [acetamide] = 2×10^{-2}M, [Hg(II)] = 5×10^{-3}M, I = 3.5×10^{-2}M, temp = 30°C, solvent = 80%CH_3CN-20%H_2O (v/v). B, Plot of k_{obsd} vs [MPS].

Table 1. Effect of varying [MPS] and [NBA] on the rate of reaction at 30°C.[a]

10^2[MPS] M	10^3[NBA] M	$10^4k^b_{obsd}$ s^{-1}	$10^2k_2^{b,c}$ $M^{-1}s^{-1}$
1.133	1.00	5.37±0.16	4.74±0.14
1.699	1.00	9.26±0.33	5.45±0.20
2.266	1.00	11.7 ±0.8	5.15±0.35
2.833	1.00	15.1 ±0.9	5.32±0.32
3.399	1.00	18.2 ±1.0	5.36±0.29
4.407	1.00	21.7 ±1.0	4.92±0.23
6.798	1.00	35.8 ±2.0	5.26±0.29
4.407	0.50	26.8 ±1.8	6.08±0.41
4.407	2.00	15.5 ±0.3	3.52±0.07
4.407	3.00	12.2 ±0.5	2.76±0.11
4.407	4.00	10.6 ±0.6	2.41±0.14

[a] [Acetamide] = 2×10^{-2}M, [Hg(II)] = 5×10^{-3}M, I = 3.5×10^{-2}M, Solvent:80%CH_3CN-20%H_2O(v/v);

[b] The error in rate constants is the 95% confidence limit(CL) of the student's t-test;

[c] $k_2 = k_{obsd}$ /[MPS].

The rate of oxidation is found to be an inverse function of [NBA] as evident from the linear plot of $1/k_{obsd}$ vs [NBA] (Fig.2) with a positive intercept.

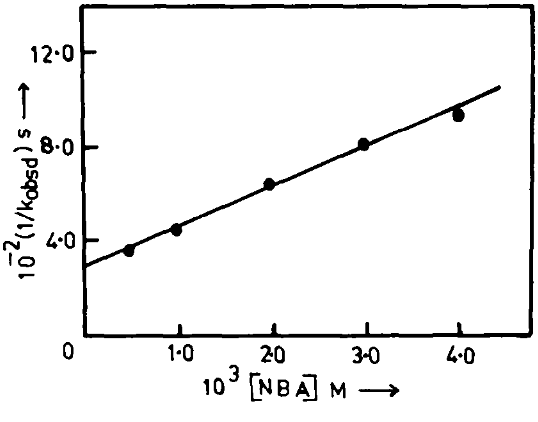


Fig. 2. Plot of $1/k_{obsd}$ vs [NBA].

Mercuric acetate introduced to trap the bromide ion catalyses the reaction. The plot of k_{obsd} vs $[Hg(II)]^2$ is linear (Fig. 3A) passing through the origin showing that the reaction is second order in [Hg(II)] and that the reaction proceeds entirely through the Hg(II) catalysed pathway.

The reaction exhibits an inverse dependence on the [acetamide]. A plot of $1/k_{obsd}$ vs [acetamide] is linear with a positive intercept (Fig.3B).

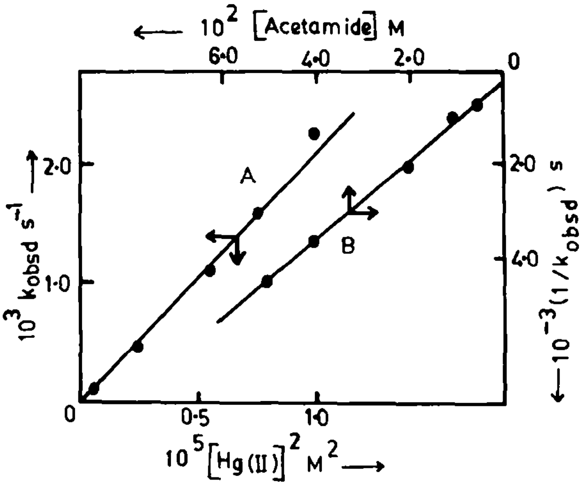


Fig. 3. A, Plot of k_{obsd} vs $[Hg(II)]^2$, [MPS] = 1.1×10^{-2}M, [acetamide] = 2×10^{-2}M. B, Plot of $1/k_{obsd}$ vs [acetamide]. [MPS] = 1.06×10^{-2}M, [Hg(II)] = 5.00×10^{-3}M. For both A and B, solvent: 80%CH_3CN-20%H_2O (v/v), [NBA] = 1×10^{-3}M, I = 3.5×10^{-2}M, temp = 30°C.

The rate data at different solvent compositions (Table 2) show that the reaction is facilitated by an increase in the polarity and/or nucleophilicity of the medium suggesting polar rate limiting transition state. The reaction shows a small positive salt effect as evident from the rate constants (Table 2) at different ionic strengths (maintained by adding $NaClO_4$). Similar kinetic results (dependence of rate on [sulphide], [NBA], [Hg(II)], solvent polarity and ionic strength) emerged in the NBA oxidation of several substituted phenyl methyl sulphides also.

The rate constants for NBA oxidation of substituted phenyl methyl sulphides at different temperatures and the activation parameters computed from the slope and intercept of the Eyring's plot are listed in Table 3. The negative entropy of activation ($\Delta S^{\neq}$) values indicate an ordered rate determining transition state relative to the reactants. The data in Table 3 reveal that the electron-releasing substitutes in the phenyl ring of the sulphides enhance the rate while electron-withdrawing substituents retard it. The plot of log k_2 (20°C) vs σ^{+}(Fig.4A) is linear affording a ρ value of -2.37. This suggests that the sulphide molecule becomes electron deficient in the rate limiting step. This is in consonance with the well documented nucleophilic role of the sulphides in several oxidations.[3,4,12]

The reaction series obeys the isokinetic relationship[17] as shown by the linearity of the plot of log k_2(30°C) vs log k_2(20°C) (Fig. 4B). From the slope of the above plot the isokinetic temperature, β , has been determined to be 505 K. The linear correlation in the isokinetic relationship indicates that all the sulphides undergo oxidation through the same mechanism.[18]

Mechanism and rate law. The reaction may involve either NBA or other products derived from it as the active oxidising species. The first order dependence of rate on [NBA] clearly rules out the involvement of N,N-dibromoacetamide (2) in the rate limiting step.

Table 2. Effect of solvent composition[a] and ionic strength[b] on reaction rate

CH_3CN-H_2O v/v (%)	10^4k_{obsd} s^{-1}	10^2I M	10^4k_{obsd} s^{-1}
50-50	36.6 ±1.4	2.5	4.93±0.26
60-40	17.0 ±1.1	3.5	4.59±0.28
70-30	8.33±0.36	5.5	5.03±0.20
80-20	5.52±0.20	9.5	5.77±0.28
90-10	2.92±0.20	13.5	6.29±0.23

[a] [MPS] = 1.102×10^{-2}M, [NBA] = 1.0×10^{-3}M, [Hg(II)] = 5.0×10^{-3}M, [acetamide] = 2.0×10^{-2}M, I = 3.5×10^{-2}M, temp = 30°C

[b] Solvent:80%CH_3CN-20% H_2O (v/v), [MPS] = 1.058×10^{-2}M, [NBA] = 1.0×10^{-3}M, [Hg(II)] = 5.0×10^{-3}M, [acetamide] = 2.0×10^{-2}M, temp = 30°C

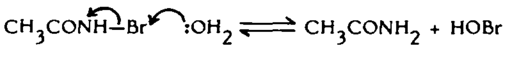
Table 3. Second order rate constants and activation parameters for the oxidation of substituted phenyl methyl sulphides by NBA[a]

No.	Substituent	10^2k_2 M^{-1} s^{-1} 10	20	30	40°C	$\Delta H^{\ddagger}$ kJ mol^{-1}	$-\Delta S^{\ddagger}$ $JK^{-1}mol^{-1}$
1	p-MeO	20.9 ±1.9	31.5 ±3.4	43.4 ±1.5	-	23.6	232
2	p-Me	5.85±0.35	9.82 ±0.56	13.7 ±1.1	-	28.0	265
3	m-Me	3.15±0.11	4.14 ±0.28	5.88 ±0.23	-	19.8	223
4	H	2.12±0.07	3.53 ±0.12	5.17 ±0.26	8.16 ±0.78	30.8	225
5	m-MeO	-	3.27 ±0.15	4.38 ±0.24	5.87 ±0.55	19.8	225
6	3,4-Benzo	-	1.67 ±0.08	2.52 ±0.10	3.90 ±0.15	29.8	177
7	p-Cl	-	1.13 ±0.05	1.60 ±0.07	2.32 ±0.07	24.9	255
8	p-COMe	-	0.211±0.012	0.380±0.04	0.651±0.020	40.5	139
9	p-NO_2	-	0.073±0.006	0.164±0.010	0.335±0.016	55.6	96

[a] Solvent :80%CH_3CN-20%H_2O (v/v), [sulphide] $\gg$ [NBA] = 1.0×10^{-3}M, [Hg(II)] =5.0×10^{-3}M, [acetamide] = 2.0×10^{-2}M, I = 3.5×10^{-2}M.

$$2CH_3CONHBr \rightleftharpoons CH_3CONH_2 + CH_3CONBr_2 \qquad (2)$$

In the neutral medium employed in the present study HOBr is not a probable oxidising species as the hydrolysis of NBA is likely to be very slow as water is a poor nucleophile (3).



$$CH_3CONH{-}Br \; :OH_2 \rightleftharpoons CH_3CONH_2 + HOBr \qquad (3)$$

The second order dependence of the reaction in Hg(II) and the first order dependence in both sulphide and NBA point to the following mechanistic possibilities involving the Hg(II) complexes of sulphides and NBA molecules: a sulphide-Hg(II) complex and an NBA-Hg(II) complex or a sulphide-$[Hg(II)]_2$ complex and an NBA molecule or a sulphide molecule and an NBA-$[Hg(II)]_2$ complex may react in the rate limiting step. Among the above pathways it seems reasonable to prefer the rate limiting reaction between sulphide-Hg(II) and NBA-Hg(II) complexes (4-6) as sulphide-$[Hg(II)]_2$ and NBA-$[Hg(II)]_2$ complexes are likely to be unstable.

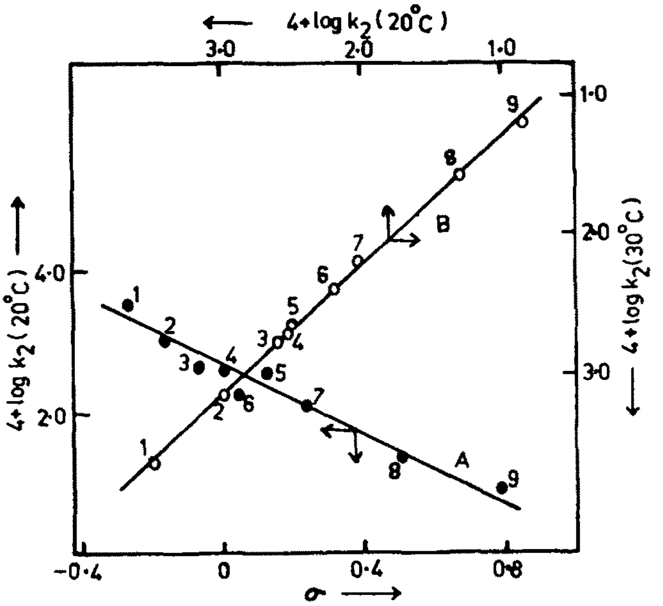
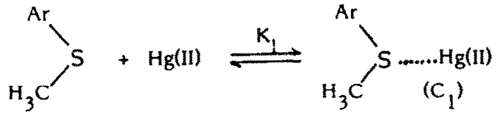
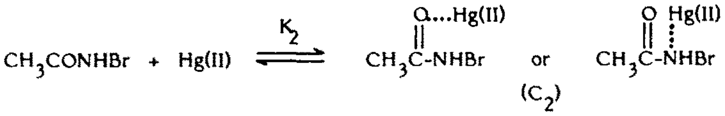


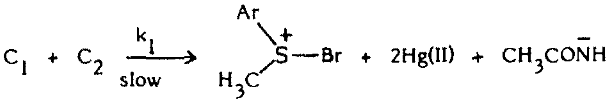
Fig. 4. A, Plot of log k_2(20°C) vs σ. B, plot of log k_2(30°C) vs log k_2(20°C). The numbers in both A and B correspond to substituents as given in Table 3.



(4)

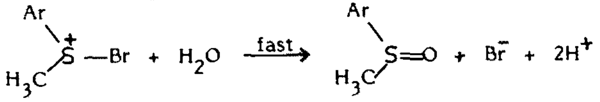


$$CH_3CONHBr + Hg(II) \xrightleftharpoons{K_2} \overset{O...Hg(II)}{\overset{\|}{CH_3C\text{-}NHBr}} \text{ or } \overset{O\ \ Hg(II)}{\overset{\|\ \ \vdots}{CH_3C\text{-}NHBr}}\ (C_2) \qquad (5)$$



(6)

The sulphonium ion formed in the slow step (6) is presumably converted to the sulphoxide in a fast step (7). Complexation of organic sulphides by Hg(II) has been established.[19] N-Bromosuccinimide has been reported to afford an active species [NBS-Hg(II)][9,10] with Hg(II). It is likely that a similar reactive complex NBA-Hg(II) is formed between NBA and Hg(II) as NBA can act as a better ligand than NBS.



(7)

The inverse dependence of the rate of the reaction on [acetamide] may probably be ascribed to the complexation of Hg(II) by acetamide (8) leading to a depletion in the $[Hg(II)_{free}]$ which will be reflected in the $[C_1]$ and $[C_2]$ causing rate retardation. It is known that amides and imides form complexes with Hg(II).[20]

$$CH_3CONH_2 + Hg(II) \xrightleftharpoons{K_3} CH_3CONH_2...Hg(II) \qquad (8)$$

The inverse dependence of the rate on [NBA] suggests that NBA is in equilibrium with a less reactive species, probably a dimer, $(NBA)_2$ or N,N-dibromoacetamide (9). It is pertinent to note that,

$$2\ \mathrm{NBA} \xrightleftharpoons{K_4} (\mathrm{NBA})_2 \text{ or } \mathrm{CH_3CONBr_2} \tag{9}$$

in solutions, N-halo compounds such as CAT[2] and BAT[21] exist in equilibrium with the corresponding N,N-dihalo compounds.

The foregoing equilibria and reactions lead to the rate law (10) after omitting the higher terms.

$$\frac{-d[\mathrm{NBA}]}{dt} = \frac{k_1K_1K_2\,[\mathrm{S}]\,[\mathrm{NBA}]_T\,[\mathrm{Hg(II)}]^2}{1 - 4K_4\,[\mathrm{NBA}]_T + 2K_3\left\{[\mathrm{CH_3CONH_2}] - [\mathrm{Hg(II)}]\right\}} \tag{10}$$

$$\text{where } k_{obsd} = \frac{k_1K_1K_2\,[\mathrm{S}]\,[\mathrm{Hg(II)}]^2}{1 + 4K_4\,[\mathrm{NBA}]_T + 2K_3\left\{[\mathrm{CH_3CONH_2}] + [\mathrm{Hg(II)}]\right\}} \tag{11}$$

The rate law accords well with the observed kinetic orders in sulphide, NBA and Hg(II) and explains the inverse dependence of the reaction in acetamide and NBA. The proposed mechanism also finds support from the dependence of rate on solvent polarity, negative entropy of activation and the negative ρ value. Both the sulphide-Hg(II) complex formation (4) and the rate-limiting reaction between sulphide-Hg(II) and NBA-Hg(II) complexes (6) would be facilitated by an increase in electron density at the sulphide sulphur leading to negative ρ values for each of these steps (4 and 6). Hence the observed ρ value which would be the sum[22] of the above ρ values should also be negative as observed.

REFERENCES

1. F. Ruff, K. Komoto, N. Furukawa and S. Oae, Tetrahedron, **32**, 2763 (1976).
2. F. Ruff and A. Kucsman, J. Chem. Soc. Perkin Trans. 2, 509 (1975).
3. A. Kucsman, I. Kapovits and B. Tanacs, Tetrahedron, **18**, 79 (1962).
4. F. Ruff and A. Kucsman, J. Chem. Soc. Perkin Trans. 2, 1075 (1982).
5. W. Tagaki, K. Kikukawa, K. Ando and S. Oae, Chem. and Ind., 1624 (1964).
6. R. Harville and S.F. Reed Jr., J. Org. Chem., **33**, 3976 (1968).
7. N. Venkatasubramanian and V. Thiagarajan, Tetrahedron Letters, **35**, 3349 (1967).
8. S.C. Negi and K.K. Banerji, Indian J. Chem., **21B**, 846 (1982).
9. T.S. Vivekanandam and M.S. Ramachandran, Indian J. Chem., **22A**, 629 (1983).
10. S.P. Srinivasan and N.S. Gnanaprakasam, J. Indian Chem. Soc., **LX**, 953 (1983).
11. H. Burton and P.F. Hu, J. Chem. Soc., 601 (1948).
12. C. Srinivasan, S. Perumal and N. Arumugam, J. Chem. Soc. Perkin Trans.2, 2065 (1984).
13. E.H. Huntress and F.H. Carten, J. Am. Chem. Soc., **62**, 511 (1940).
14. C.C. Price and G.W. Stacy, J. Am. Chem. Soc., **68**, 499 (1946).
15. E.P. Oliverto and C. Gerold, 'Organic Synthesis' Collect. Vol. IV, Edited by H. Gilman (John Wiley) 104 (1963).
16. J.F. Coetzee, Progr. Phys. Org. Chem., **4**, 45 (1967).
17. O. Exner, Nature (London), **210**, 488 (1964); **227**, 336 (1970); Collect. Czech. Chem. Commun., **29**, 1094 (1964).
18. J.E. Leffler, J. Org. Chem., **20**, 1202 (1955).
19. B.J. Aylett in 'Comprehensive Inorganic Chemistry', Edited by J.C. Bailer JR, H.J. Emeleus, Sir Ronald Nyholm and A.F. Trotman-Dickenson, Pergamon Press, Oxford, I edition, 326 (1973).
20. E. Lyons, J. Am. Chem. Soc., **47**, 830 (1925).
21. B. Singh and R. Chand, Tetrahedron, **41**, 2871 (1985).
22. J. Shorter, 'Correlation analysis in organic chemistry - an introduction to linear free energy relaltionships', Clarenden Press, Oxford (1973).