# Kinetics of Oxidation of Epimeric Piperidin-4-ols by Vanadium(v) [1]

**Kuppusamy Selvaraj and Kondareddiar Ramalingam** *
*Department of Chemistry, PSG College of Arts and Science, Coimbatore 641014, India*
**Krishnasamy Ramarajan** *
*Department of Chemistry, C.B.M. College, Coimbatore 641042, India*

The kinetics of oxidation of six epimeric pairs of piperidin-4-ols by vanadium(v) in the presence of sulphuric and perchloric acids in aqueous acetic acid have been investigated. The corresponding deuteriated piperidin-4-ols have been prepared in most cases and their rates of oxidation by $V^V$ have been measured. The reaction is first order in both oxidant and substrate at constant acid concentration. The order with respect to $[H_3O^+]$ is found to be unity at constant ionic strength in perchloric acid. The primary kinetic isotope effect is suggestive of the involvement of the C–H or C–D bond of the hydroxy-bearing carbon in the rate-determining step of the oxidation. A mechanism involving a free radical intermediate has been proposed. However, a different rate-determining step is suggested for *c*-2,*c*-6-diphenyl-*t*-3,*t*-5,*N*-trimethylpiperidin-*r*-4-ol which has no isotope effect. The reactivities of piperidin-4-ols towards oxidation have been discussed on the basis of conformational differences. Activation parameters have also been determined.

Although the oxidation of alcohols by quinquevalent vanadium in acid solution had been the subject of a number of publications,[2-8] no attempt seems to have been made to study the oxidation of heterocyclic epimeric alcohols by vanadium(v). This study is an attempt in this direction and has enabled us to correlate the rate with conformation.

## Results and Discussion

The kinetics of oxidation of piperidin-4-ols (7)—(11), (16)—(20), (25), and (27) by vanadium(v) have been investigated in aqueous acetic acid in the presence of sulphuric or perchloric acid and the results are recorded in Tables 2—6. The first-order dependence of the rate on piperidinol concentration can be seen from Table 2. The data in Table 3 show the effect of acids on the rate of oxidation. The rate of oxidation is found to be faster in $H_2SO_4$ than in $HClO_4$ for the same molar concentration of acid, indicating that the active species of $V^V$ is different in different acids and that the $V^V$ species in $H_2SO_4$ is much more effective in bringing about the oxidation than that in $HClO_4$. The active species of $V^V$ may be taken as $V(OH)_3^{2+}$ and $V(OH)_3HSO_4^+$ in $HClO_4$ and $H_2SO_4$ respectively.[9,10]

Owing to the difficulties in maintaining a constant ionic strength in $H_2SO_4$, $HClO_4$ was used to find out the order with respect to $[H_3O^+]$. Analysis of the data in Table 4 reveals a first-order dependence on $[H_3O^+]$.

Examination of the data in Table 5 shows that the reaction is susceptible to variation in solvent polarity. The rate decreases with increase in polarity, suggesting that the transition state is less polar than the initial state. Kinetic parameters obtained for various piperidinols are given in Table 6. The negative entropy of activation ($\Delta S^{\ddagger}$) is suggestive of an orderly arrangement of the reacting species in the transition state.

It is evident from Table 7 that the deuteriated piperidinols react at a slower rate than the corresponding undeuteriated piperidinols. The $k_H/k_D$ values are moderate (1.60—4.76), indicating the participation of a C–H or C–D bond in the rate-determining step. However, no kinetic isotope effect is observed for the piperidinol (20).

A deep yellow solution is formed immediately after the admixture of the pale yellow acid solution of $V^V$ with piperidinols. This colour persists until it is masked by the blue colour of $V^{IV}$ resulting from the oxidation, so one can visualize the reaction as taking place through the formation of an intermediate complex between piperidinol and the $V^V$ species in an equilibrium step. However, the complex formation is not kinetically detectable, since the plot of $1/k_1$ *versus* 1/[Piperidinol] gives no intercept (Michaelis–Menten plot).

The reaction mixture for the piperidinols is found to induce polymerisation of acrylamide. This indicates the formation of free radical intermediates during oxidation.

*Mechanism and Rate Law.*—From the foregoing observations, we suggest the mechanism in Scheme 1 for the oxidation of piperidin-4-ol. The rate equation for this mechanism can be written as (1) where $[V^V]_T$ is the total $V^V$ concentration.

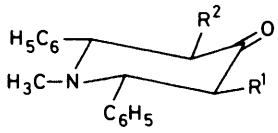
$$\text{Rate} = \frac{k_s K_1 K_2[\text{Piperidinol}][H_2SO_4][V^V]_T}{1 + K_1[H_2SO_4] + K_1K_2[\text{Piperidinol}][H_2SO_4]} \quad (1)$$

**Table 1.** Composition of the products from $LiAlD_4$ reduction of 4-piperidones

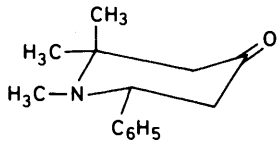
| Piperidone | Total crude product (%) | Yield (%) Axial | M.p. (°C) | Equatorial | M.p. (°C) |
|---|---|---|---|---|---|
| (2) | 94 | 20 (12) | 71—72 | 56 (21) | 72—74 |
| (3) | 96 | 26 (13) | 139—140 | 52 (22) | 74—75 |
| (4) | 96 | 30 (14) | 105—106 | 40 (23) | 112—113 |
| (5) | 94 | 38 (15) [a] | 99—100 | 46 (24) [b] | 133—134 |
| (6) | 84 | 60 (26) | 123—124 | | |

[a] Mass spectrum, *m/e* 296.2000 ($M^+$), calc. 296.1999. [b] Mass spectrum, *m/e* 296.2005 ($M^+$), calc. 296.1999.

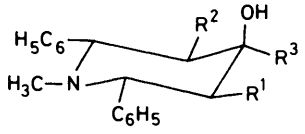
Since $K_1$ is very small,[11] the second term in the denominator, $K_1[H_2SO_4]$, is $\ll 1$. If it is assumed that $K_2$ is small, the third term is also negligible since the concentration of piperidinol is low. Hence, equation (1) reduces to (2). With the substrate



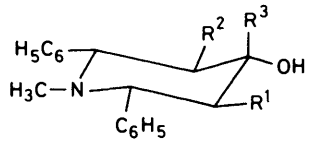
(1) $R^1 = R^2 = H$
(2) $R^1$ = Me, $R^2$ = H
(3) $R^1$ = Et, $R^2$ = H
(4) $R^1$ = $Pr^i$, $R^2$ = H
(5) $R^1 = R^2$ = Me



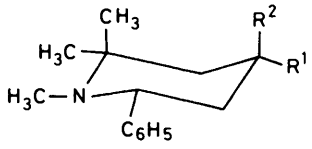
(6)



(7) $R^1 = R^2 = R^3 = H$
(8) $R^1$ = Me, $R^2 = R^3$ = H
(9) $R^1$ = Et, $R^2 = R^3$ = H
(10) $R^1$ = $Pr^i$, $R^2 = R^3$ = H
(11) $R^1 = R^2$ = Me, $R^3$ = H
(12) $R^1$ = Me, $R^2$ = H, $R^3$ = D
(13) $R^1$ = Et, $R^2$ = H, $R^3$ = D
(14) $R^1$ = $Pr^i$, $R^2$ = H, $R^3$ = D
(15) $R^1 = R^2$ = Me, $R^3$ = D



(16) $R^1 = R^2 = R^3 = H$
(17) $R^1$ = Me, $R^2 = R^3$ = H
(18) $R^1$ = Et, $R^2 = R^3$ = H
(19) $R^1$ = $Pr^i$, $R^2 = R^3$ = H
(20) $R^1 = R^2$ = Me, $R^3$ = H
(21) $R^1$ = Me, $R^2$ = H, $R^3$ = D
(22) $R^1$ = Et, $R^2$ = H, $R^3$ = D
(23) $R^1$ = $Pr^i$, $R^2$ = H, $R^3$ = D
(24) $R^1 = R^2$ = Me, $R^3$ = D



(25) $R^1$ = H, $R^2$ = OH
(26) $R^1$ = D, $R^2$ = OH
(27) $R^1$ = OH, $R^2$ = H

$$\text{Rate} = k_s K_1 K_2[\text{Piperidinol}][H_2SO_4][V^V]_T \quad (2)$$

taken in large excess, thus maintaining its concentration virtually constant and the concentration of $H_2SO_4$ remaining constant during the run, equation (2) reduces to (3) where the

$$\text{Rate} = k_1[V^V]_T \quad (3)$$

$$k_1 = k_s K_1 K_2[\text{Piperidinol}][H_2SO_4] \quad (4)$$

pseudo-first-order rate constant is given by equation (4). At constant acid concentration equation (5) holds where $k'$ is given by (6). When $k_1$ is plotted against [Piperidinol], a

$$k_1 = k'[\text{Piperidinol}] \quad (5)$$

$$k' = k_2 K_1 K_2[H_2SO_4] \quad (6)$$

straight line passing through the origin is obtained. This is consistent with the proposed rate equation. A similar rate equation can be derived for the oxidation in $HClO_4$.

The mechanism proposed above should result in a large CH(CD) isotope effect and this is found to be so (Table 7) for piperidinols (8)—(10) and (17)—(19). An alternative mechanism can be suggested (Scheme 2) for the oxidation of piperi-

**Table 2.** Dependence of rate on piperidin-4-ol concentration

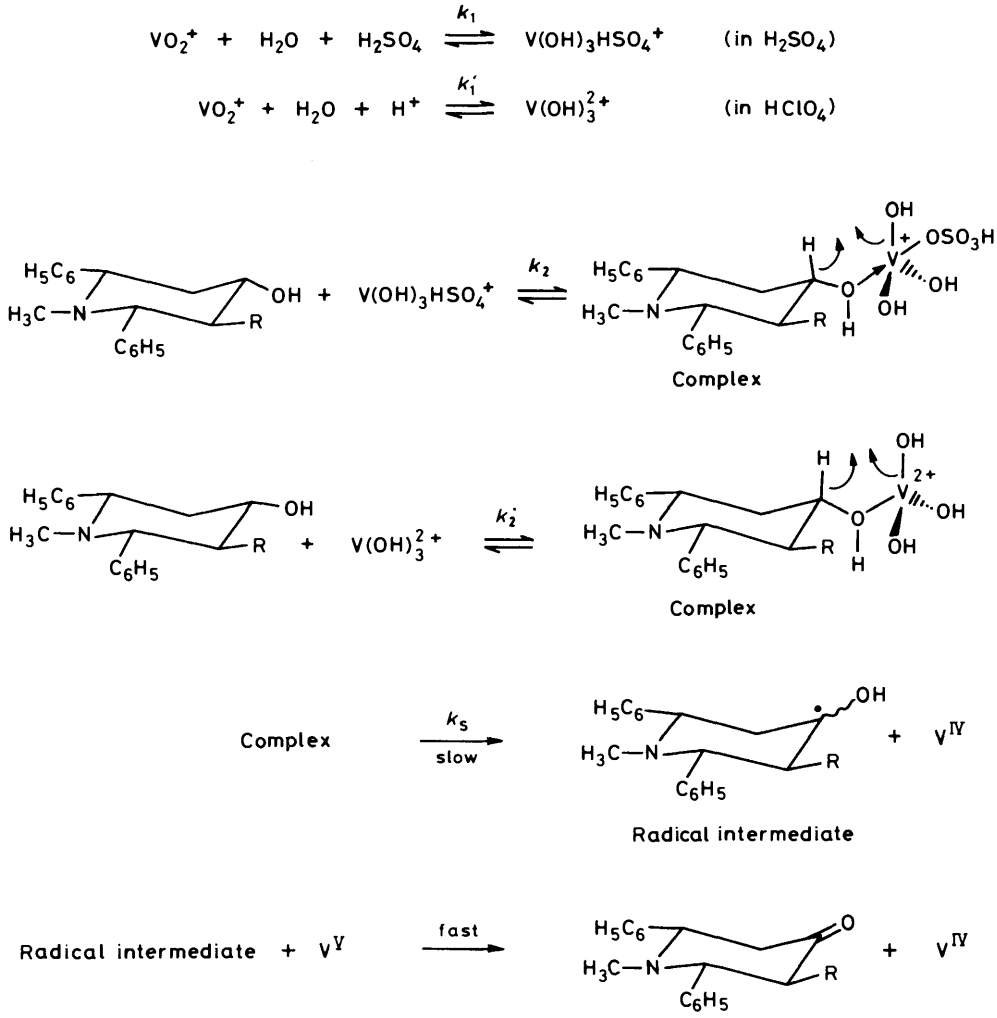
[Vanadium(v)] $2.5 \times 10^{-3}$M; $T$ 60 °C; Solvent 60% HOAc–40% $H_2O$ (v/v); Substrate (10)

| $10^3$[S]/mol $l^{-1}$ | $10^5k_1/s^{-1}$ | $10^4k_2$/l $mol^{-1}$ $s^{-1}$ |
|---|---|---|
| [Perchloric acid] 4M | | |
| 25.21 | 15.29 | 60.64 |
| 38.50 | 23.12 | 60.04 |
| 49.45 | 29.12 | 58.88 |
| 70.25 | 41.97 | 59.74 |
| | | Mean 59.83 ± 0.73 |
| [Sulphuric acid] 3M | | |
| 26.12 | 14.64 | 56.04 |
| 39.22 | 21.70 | 55.33 |
| 50.66 | 28.28 | 55.83 |
| 75.73 | 42.22 | 55.75 |
| | | Mean 55.74 ± 0.30 |

**Table 3.** Effect of varying acid concentration on reaction rate

[Vanadium(v)] $2.5 \times 10^{-3}$M; $T$ 60 °C; Solvent 60% HOAc–40% $H_2O$ (v/v)

| | $10^4k_2$/l $mol^{-1}$ $s^{-1}$ | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | [$H_2SO_4$]/mol $l^{-1}$ | | | | [$HClO_4$]/mol $l^{-1}$ | | | |
| Piperidin-4-ol | 2.5 | 3.0 | 3.5 | 4.0 | 2.5 | 3.0 | 3.5 | 4.0 |
| (7) | 11.89 | 20.00 | 29.84 | 43.26 | 5.15 | 7.97 | 11.68 | 16.22 |
| (8) | 37.54 | 47.03 | 52.06 | 59.77 | 8.65 | 14.80 | 22.27 | 32.45 |
| (9) | 28.34 | 39.84 | 53.31 | 67.30 | 5.08 | 13.06 | 25.23 | 51.51 |
| (10) | 39.98 | 56.04 | 79.08 | 96.41 | 8.04 | 17.46 | 32.87 | 60.65 |
| (11) | 5.08 | 7.54 | 11.00 | 14.47 | 0.86 | 2.15 | 4.64 | 10.14 |
| (16) | 5.20 | 8.93 | 14.63 | 20.71 | 0.89 | 2.56 | 6.82 | 15.15 |
| (17) | 10.93 | 17.10 | 24.31 | 34.96 | 5.90 | 9.84 | 14.73 | 22.30 |
| (18) | 6.87 | 10.67 | 15.36 | 22.77 | 2.17 | 3.74 | 5.66 | 9.50 |
| (19) | 4.25 | 6.95 | 10.71 | 14.99 | 1.00 | 1.98 | 3.50 | 5.85 |
| (20) | 1.78 | 2.90 | 4.61 | 6.76 | 0.85 | 1.30 | 1.78 | 2.46 |
| (25) | 33.10 | 45.49 | 64.35 | 92.26 | 7.03 | 12.49 | 19.81 | 37.49 |
| (27) | 7.38 | 9.71 | 14.90 | 26.60 | 1.46 | 3.13 | 5.31 | 9.04 |




**Scheme 1.**

**Table 4.** Dependence of rate on acid concentration at constant ionic strength

[Vanadium(v)] 2.5 × $10^{-3}$M; $T$ 60 °C; Solvent 60% HOAc–40% $H_2O$ (v/v); ionic strength 4M; Substrate (7)

| $[HClO_4]$/ mol $l^{-1}$ | $10^3[S]$/ mol $l^{-1}$ | $10^5k_1$/ $s^{-1}$ | $10^4k_2$/ l $mol^{-1}$ $s^{-1}$ | $10^4k_3$/ $l^2$ $mol^{-2}$ $s^{-1}$ |
|---|---|---|---|---|
| 3.25 | 25.98 | 3.38 | 13.01 | 4.00 |
| 3.50 | 26.97 | 3.82 | 14.16 | 4.05 |
| 3.75 | 26.21 | 3.95 | 15.07 | 4.02 |

**Table 5.** Effect of varying solvent composition on reaction rate

Substrate (10); [Vanadium(v)] 2.5 × $10^{-3}$M; [Substrate] 2.6 × $10^{-2}$M; [$H_2SO_4$] 3.0M; $T$ 60 °C

| % HOAc–% $H_2O$ (v/v) | $10^4k_2$/l $mol^{-1}$ $s^{-1}$ |
|---|---|
| 50—50 | 29.83 |
| 55—45 | 41.12 |
| 60—40 | 56.04 |
| 65—35 | 77.51 |

dinols (11) and (25) to account for their low isotope effects ($k_H/k_D$ 2.55 and 1.60, respectively). A similar mechanism has been proposed for the oxidation of cyclohexanol by manganese(III) ($k_H/k_D$ 1.6),[12,13] cerium(IV) ($k_H/k_D$ 1.9),[14] and cobalt(III) ($k_H/k_D$ 1.6).[13,15]

The mechanism in Scheme 3 is consistent with the observed isotope effect ($k_H/k_D$ = 1.00) for the oxidation of the piperidinol (20).

*Structure and Reactivity.*—Piperidinols (7)—(10), (16)—(19), (25), and (27) have been shown to exist in the chair conformation with the alkyl and phenyl groups in the most stable equatorial positions.[16–18] The difference in the oxidation rates of piperidin-4-ols is strikingly similar to numerous observations for the oxidation of epimeric alicyclic alcohols by chromic acid.[19–21] The second-order rate constants in Table 8 indicate that the axial piperidin-4-ols (7)—(11) and (25) are oxidised at a faster rate than the corresponding equatorial piperidin-4-ols (16)—(20) and (27). The data also indicate that axial and equatorial piperidinols behave differently when there is an alkyl group at the 3-position.

We shall deal with the axial piperidin-4-ols (7)—(10) and (25) first, since they are somewhat easier to rationalise. An interesting observation in the present study is the effect of the

**Table 6.** Activation parameters for the oxidation of piperidin-4-ols by vanadium(v) in the presence of $H_2SO_4$ (3.0M) in 60% aqueous acetic acid

| Piperidin-4-ol | $\Delta H^{\ddagger}$/kJ mol$^{-1}$ | $\Delta S^{\ddagger}$/J mol$^{-1}$ K$^{-1}$ |
|---|---|---|
| (7) | 83.6 | −46.5 |
| (8) | 80.7 | −48.2 |
| (9) | 76.7 | −52.6 |
| (10) | 79.4 | −50.8 |
| (11) | 84.2 | −52.9 |
| (16) | 99.7 | −5.0 |
| (17) | 90.4 | −27.5 |
| (18) | 94.7 | −18.6 |
| (19) | 87.7 | −43.3 |
| (20) | 75.2 | −87.8 |
| (25) | 72.8 | −71.8 |
| (27) | 86.2 | −45.1 |

**Table 7.** Kinetic isotope effect on the oxidation of piperidin-4-ols

[Vanadium(v)] 2.5 × 10$^{-3}$M; $T$ 60 °C; 60% HOAc–40% $H_2O$ (v/v); [$H_2SO_4$] 3.0M

| Piperidin-4-ol | $10^4k_2$/l mol$^{-1}$ s$^{-1}$ | Piperidin-4-ol | $10^4k_2$/l mol$^{-1}$ s$^{-1}$ | $k_H/k_D$ |
|---|---|---|---|---|
| (8) | 46.81 | (12) | 12.59 | 3.72 |
| (9) | 39.31 | (13) | 11.44 | 3.44 |
| (10) | 55.74 | (14) | 11.69 | 4.76 |
| (11) | 7.53 | (15) | 2.95 | 2.55 |
| (17) | 17.21 | (21) | 5.14 | 3.35 |
| (18) | 10.76 | (22) | 2.87 | 3.75 |
| (19) | 6.93 | (23) | 1.77 | 3.92 |
| (20) | 2.93 | (24) | 2.91 | 1.00 |
| (25) | 45.12 | (26) | 28.25 | 1.60 |

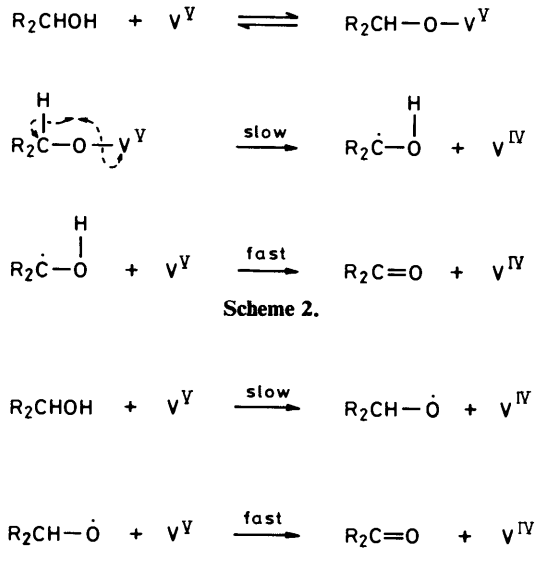
**Table 8.** Second-order rate constants for the oxidation of piperidin-4-ols by vanadium(v)

[Vanadium(v)] 2.5 × 10$^{-3}$M; $T$ 60 °C; Solvent 60% HOAc–40% $H_2O$ (v/v); [$HClO_4$] 3.5M; ionic strength 4.0M

| Piperidin-4-ol | $10^4k_2$/l mol$^{-1}$ s$^{-1}$ |
|---|---|
| (7) | 14.16 |
| (8) | 28.64 |
| (9) | 33.77 |
| (10) | 49.07 |
| (11) | 4.92 |
| (16) | 9.80 |
| (17) | 19.51 |
| (18) | 11.83 |
| (19) | 5.87 |
| (20) | 3.02 |
| (25) | 28.40 |
| (27) | 6.29 |

alkyl group, situated adjacent to the reaction centre, on the rate of oxidation. An alkyl group vicinal to hydroxy can produce non-bonded steric interactions with the latter. The resulting increase in strain is relieved during oxidation. Hence, 3-alkyl-2,6-diphenylpiperidin-4-ols (8)—(10) react at a faster rate than the 2,6-diphenylpiperidin-4-ol (7). An increase in the size of the 3-alkyl substituent results in an increase in the oxidation rate. *t*-2,*t*-6-Diphenyl-*c*-3-ethyl-*N*-methylpiperidin-*r*-4-ol (9) and *t*-2,*t*-6-diphenyl-*c*-3-isopropyl-*N*-methylpiperidin-*r*-4-ol (10) react at a much higher rate than *t*-2,*t*-6-diphenyl-*N*-methylpiperidin-*r*-4-ol (7) or its 3-methyl derivative (8).

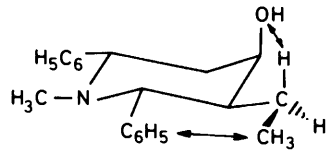
In *t*-2,*t*-6-diphenyl-*c*-3-ethyl-*N*-methylpiperidin-*r*-4-ol (9), the ethyl group has the preferred conformation with respect to



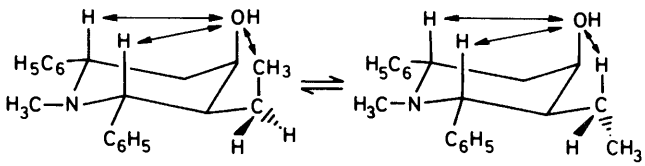

**Scheme 2.**




**Scheme 3.**




(9a)

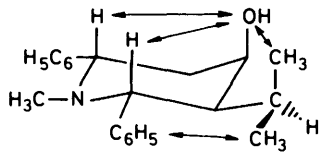



(9b) (9c)

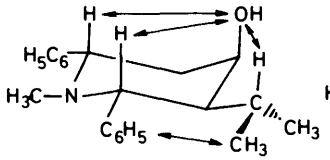
the C(3)–alkyl bond. Conformations (9a—c) are possible for the ethyl group in piperidinol (9). Conformation (9a) is precluded because there is a severe interaction between the phenyl and methyl groups. The other two conformations (9b and c) place the methyl group away from the phenyl side and should exist as an equilibrium mixture. Conformation (9b) has got one $CH_3$–OH interaction (with a higher energy) in addition to two H–OH interactions and (9c) has got three H–OH interactions. Hence the rate of oxidation of (9) is higher than that of either the 3-methyl or the 3-H alcohol.

*t*-2,*t*-6-Diphenyl-*c*-3-isopropyl-*N*-methylpiperidin-*r*-4-ol (10) shows an even greater rate enhancement. Like the ethyl group, the 3-isopropyl group can also attain the preferred orientation of its methyl groups by rotation about the C(3)–alkyl bond. Of the three possible conformations of (10), forms (10a and b) are analogous to (9a) in having the phenyl–methyl interaction and therefore need not be considered. The further increase of the rate constant of the 3-isopropyl derivative is attributable to the presence of $CH_3$–OH interactions in all the reacting species (10c).

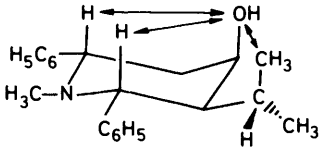
In *c*-2,*t*-2,*N*-trimethyl-*t*-6-phenylpiperidin-*r*-4-ol (25), the hydroxy-group has a non-bonded steric interaction with the axial methyl group at the C(2) and hence reacts much faster ($2.840 \times 10^{-3}$ l mol$^{-1}$ s$^{-1}$) than the 2,6-diphenylpiperidin-4-ol (7) ($1.416 \times 10^{-3}$ l mol$^{-1}$ s$^{-1}$).



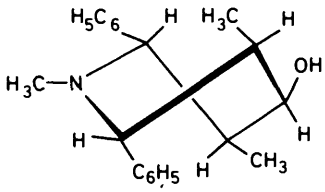
(10a)



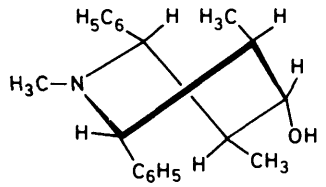
(10b)



(10c)



(11a)



(20a)

Upon considering the rate constants of piperidin-4-ols (7)—(10) with an axial hydroxy-group it can be seen that the rate falls in the order: (10) > (9) > (8) > (7). The relative order of reactivity of these piperidin-4-ols is in perfect agreement with the relative degree of steric compression of the hydroxy-group.

Unfortunately, no such straightforward interpretation can be given for the equatorial series and in fact, despite a considerable literature search, we have not been able to come up with a complete explanation of the data in the equatorial series.

The decelerating factor is operative in the all-equatorial series where all but (17) react slower than the equatorial standard (16). Piperidinols (18) and (19) react significantly slower than *c*-2,*c*-6-diphenyl-*t*-3,*N*-dimethylpiperidin-*r*-4-ol (17) which is of like conformation. The lowering in rate for the piperidinols (18) and (19) is presumably steric in origin. For these piperidinols, the initial formation of the complex itself is made more difficult due to the equatorial 3-alkyl group.

The behaviour of the epimeric 2,6-diphenyl-3,5-dimethylpiperidin-4-ols (11) and (20) appears to be still more complex. Since the higher oxidation rates of 2,6-diphenyl-3-methylpiperidin-4-ols compared with those of 2,6-diphenylpiperidin-4-ols (both axial and equatorial) are mainly due to the *gauche*-interaction of the hydroxy-group with the 3-methyl group, one would expect the oxidation rates of the epimeric 2,6-diphenyl-3,5-dimethylpiperidin-4-ols to be higher than those of the corresponding 2,6-diphenyl-3-methylpiperidin-4-ols (because in the chair conformation of the 2,6-diphenyl-3,5-dimethylpiperidin-4-ols, the hydroxy-group has *gauche*-interactions with both the adjacent equatorial methyl groups). But the rate constants for the oxidation of the epimeric 2,6-diphenyl-3,5-dimethylpiperidin-4-ols (11) and (20) are less than those of the corresponding 2,6-diphenyl-3-methylpiperidin-4-ols (8) and (17). The rate constants also indicate that the epimeric 2,6-diphenyl-3,5-dimethylpiperidin-4-ols (11) and (20) react slower than the 3,5-unsubstituted piperidinols (7) and (16).

In the chair conformation of (11) and (20), there exist *gauche*-interactions (two $C_6H_5$–$CH_3$ and two $CH_3$–OH) which seem to be relieved if these molecules exist in the twist conformations (11a) and (20a). Since in such a non-chair conformation the interactions between the hydroxy-group and methyl group are greatly reduced in the ground state, the rates of oxidation are slower.

Balasubramanian and Padma proposed a boat-chair equilibrium for (20) on the basis of i.r. spectral data.[17] The i.r. spectrum of (20) gave two bands in the O–H stretching region (3 627 and 3 587 $cm^{-1}$). The lower frequency band was thought to be due to a hydroxy hydrogen atom intramolecularly bonded with nitrogen.

The possibility that the piperidinol (20) exists partly in a twist conformation was also discussed in the light of the observed coupling constants and chemical shift data by LeFèvre.[18]

The behaviour of the 2,6-diphenyl-3,5-dimethylpiperidin-4-ols included in the present study is not in conformity with a chair conformation. The much lower rates of oxidation than expected are indicative of decreased non-bonded interactions of the hydroxy-group with adjacent methyl groups which is possible only in a highly distorted chair or twist conformation.

## Experimental

*Materials.*—The piperidin-4-ols (7)—(11), (16)—(20), (25), and (27) included in the present study were prepared by reducing the 4-piperidones (1)—(6).[22-25] The deuteriated piperidinols (12)—(15), (21)—(24), and (26) were prepared by reducing 4-piperidones with lithium aluminium deuteride.

*General procedure for the lithium aluminium deuteride reduction of 4-piperidones.* To a stirred suspension of $LiAlD_4$ (0.02 mol) in dry ether (25 ml) was added dropwise a solution of 4-piperidone (0.02 mol) in dry ether (175 ml). The mixture was stirred under gentle reflux under nitrogen for 24 h. The excess of deuteride was decomposed by the careful addition of ice-cold water. The ether layer was separated and precipitated hydroxides were washed with ether (4 × 15 ml). The ethereal washings and the ether extract were combined and dried ($MgSO_4$). Removal of ether in a rotary evaporator gave a mixture of axial and equatorial alcohols in >90% yield. The epimeric alcohols were separated by column chromatography by adopting the procedure already reported.[22] The yields and m.p.s are recorded in Table 1. The deuteriated piperidinols were recrystallized from light petroleum (b.p. 60—80 °C).

Acetic acid (AnalaR; B.D.H.) was refluxed over $CrO_3$ and used as solvent.[26] Other chemicals used were of AnalaR grade.

*Kinetic Measurements.*—Pseudo-first-order conditions were maintained for all the kinetic runs by keeping the substrate and acid concentrations always in excess of that of vanadium. The ionic strengths of the reaction mixtures were kept constant by the addition of sodium perchlorate. The reaction was followed by taking portions (2 ml) of the mixture at suitable intervals, pouring into a known excess of $Fe^{II}$ solution and titrating the unused $Fe^{II}$ against potassium dichromate using barium diphenylamine sulphonate as indicator. The reactions were followed to at least 60% conversion of the oxidant and the results were found to be reproducible to within ±3% error.

The reactions were carried out at 60, 65, 70, and 75 °C. A plot of log ($k_2/T$) *versus* $1/T$ gave a straight line. The enthalpy of activation ($\Delta H^{\ddagger}$) and the entropy of activation ($\Delta S^{\ddagger}$) were calculated from the slope and intercept respectively, the slope being $-\Delta H^{\ddagger}/2.303R$ and intercept being log ($k/h$) + $\Delta S^{\ddagger}/2.303R$ according to equation (7).

$$\log (k_2/T) = \log (k/h) + \Delta S^{\ddagger}/2.303R - (1/T)\Delta H^{\ddagger}/2.303R \quad (7)$$

*Product Analysis.*—In the oxidation of piperidin-4-ol by vanadium(v), the corresponding 4-piperidone was identified as the product. A solution (25 ml) containing piperidinol (0.25 mol), ammonium metavanadate (0.025 mol), and sulphuric acid (3M) in aqueous acetic acid (60% v/v) was kept in a thermostat (60 °C). The solution after completion of the reaction was neutralised with aqueous ammonia (1 : 1). The resulting blue solution was extracted with ether (3 × 50 ml) and the combined ether extract was dried ($Na_2SO_4$) and evaporated. The residue was dissolved in the minimum amount of cold benzene and chromatographed over a column of neutral alumina. Evaporation of light petroleum (b.p. 60—80 °C)–benzene eluates gave a solid. This product was found to be identical with the corresponding 4-piperidone. Product analysis was done for the oxidation of all piperidinols.

## Acknowledgements

We thank Professor D. K. P. Varadarajan, Principal, PSG College of Arts and Science, Coimbatore, and Mr. G. Varadaraj, Managing Trustee, PSG Institutions, for the constant encouragement and facilities provided. K. S. thanks the U.G.C., New Delhi, India, for the award of a Research Grant.

## References

1 Taken from the Ph.D. Thesis of K. Selvaraj, University of Madras, India, 1981.
2 J. S. Littler and W. A. Waters, *J. Chem. Soc.*, 1959, 4046.
3 J. S. Littler, A. I. Mallet, and W. A. Waters, *J. Chem. Soc.*, 1960, 2761.
4 J. R. Jones and W. A. Waters, *J. Chem. Soc.*, 1960, 2772.
5 K. Julien and W. A. Waters, *J. Chem. Soc.*, 1962, 818.
6 J. R. Jones and W. A. Waters, *J. Chem. Soc.*, 1962, 2068.
7 G. V. Bakore and R. Shankar, *Indian J. Chem.*, 1968, **6**, 699.
8 P. S. Radhakrishnamurti and S. Devi, *Indian J. Chem.*, 1976, **14A**, 319.
9 R. N. Mehrotra, *J. Chem. Soc. B*, 1968, 642.
10 G. Chithambarathanu Pillai, J. Rajaram, and J. C. Kuriacose, *Indian J. Chem.*, 1977, **15A**, 608.
11 C. F. Wells and L. V. Kuritsyn, *J. Chem. Soc. A*, 1970, 1372.
12 F. H. Westheimer, *Chem. Rev.*, 1961, **61**, 265.
13 J. S. Littler, *J. Chem. Soc.*, 1962, 2190.
14 J. S. Littler, *J. Chem. Soc.*, 1959, 4135.
15 D. G. Hoare and W. A. Waters, *J. Chem. Soc.*, 1962, 965.
16 K. Ramalingam, K. D. Berlin, N. Satyamurthy, and R. Sivakumar, *J. Org. Chem.*, 1979, **44**, 471.
17 M. Balasubramanian and N. Padma, *Tetrahedron Lett.*, 1963, 49.
18 C. Y. Chen and R. J. W. LeFèvre, *J. Chem. Soc.*, 1965, 3467.
19 E. L. Eliel, S. H. Schroeter, T. J. Brett, F. J. Biros, and J. C. Richer, *J. Am. Chem. Soc.*, 1966, **88**, 3327.
20 J. C. Richer and Gilardeau, *Can. J. Chem.*, 1965, **43**, 538.
21 H. Kwart and P. S. Francis, *J. Am. Chem. Soc.*, 1959, **81**, 2116.
22 M. Balasubramanian and N. Padma, *Tetrahedron*, 1963, **19**, 2135.
23 C. R. Dharmaraj, R. Sivakumar, V. Devarajan, and K. Ramalingam, *Indian J. Chem.*, 1976, **14B**, 140.
24 T. R. Radhakrishnan, M. Balasubramanian, and V. Baliah, *Indian J. Chem.*, 1973, **11**, 318.
25 T. R. Radhakrishnan, M. Balasubramanian, and V. Baliah, *Indian J. Chem.*, 1973, **11**, 562.
26 S. Sundaram and N. Venkatasubramanian, *Indian J. Chem.*, 1971, **9**, 1102.

*Received* 1*st September* 1982; *Paper* 2/1496