Effect of para Substituents on Decomposition Rates of
2-(N,N-Dimethylamino)ethyl Phenyl Phenylphosphonates

P. ANTTI MANNINEN

Department of Chemistry, University of Helsinki, Vuorikatu 20, SF-00100 Helsinki 10, Finland

Spontaneous decomposition of nineteen of the
title phosphonates to their 1,1,4,4-tetramethyl-
piperazinium salts was followed in 50 % aqueous
ethanol at different temperatures. The effect of
substituents of the phenyl group on reaction rates
was about twice as great as the effect substituents
of the phenoxy group and an electron attracting
substituent at either para position increase the
decomposition rate. A linear dependence was
found between logarithms of rate constants and
\( \sigma^p \) parameters of para substituents of the phenyl
group and a poorer linear correlation for para
substituents of the phenoxy group. The dual
substituent parameter approach using \( \sigma_l \) and \( \sigma^r \)
was applied.

In an earlier study the decomposition of dialkyl
2-(N,N-dimethylamino)ethyl phosphates was fol-
lowed in water and ethanol. Logarithms of rate
constants were plotted against \( \sigma^b \) parameters and
a reasonable linear correlation was found.
Substituent effects of phosphorus compounds are
studied further here, with the same reaction but
with substituents at a greater distance from the
phosphorus atom so that they do not have steric
effects on the other groups containing phosphorus.
The compounds are 2-(N,N-dimethylami-
no)ethyl phenyl phenylphosphonates (Scheme
1).

\[
\text{Scheme 1. 2-(N,N-Dimethylamino)ethyl phenyl}
\text{phenylphosphonates. } \text{X}=\text{Me}, \text{Y}, \text{Me, H,}
\text{F, Br and } \text{Y}=\text{MeO, Me, H, F, Cl, Br.}
\]

RESULTS AND DISCUSSION

Rate constants were determined at different
temperatures and activation parameters were
calculated as before (Table 1).

Aqueous ethanol was chosen as solvent be-
cause the studied compounds were not soluble in
water and some reactions were too slow in pure
ethanol. The X and Y substituents do not
interfere with the substituent properties of the
other as found also in NMR study, and therefore
the mean values of \( \log (k_{XY}/k_{HY}) \) and \( \log
(k_{XY}/k_{XH}) \) were used to express the effects of X
and Y, respectively (Table 2).

Thermodynamic parameters were determined
only for methoxy, methyl, hydrogen and bromine
substituents (not shown). The overall pattern of
the enthalpies of activation suggest that the
values decrease as substituents become more
electron attracting (range from 91 to 101 kJ
mol\(^{-1}\)), and entropies of activation are clearly
negative (range from -16 to -38 J K\(^{-1}\) mol\(^{-1}\)). The
Table 1. Rate constants and their logarithms for the decomposition of 2-(N,N-dimethylamino)ethyl phenyl phenylphosphonates (Scheme 1) in 50 % ethanol.

<table>
<thead>
<tr>
<th>X</th>
<th>Y</th>
<th>313.2 K (k/10^5\text{s}^{-1})</th>
<th>log (k)</th>
<th>323.2 K (k/10^5\text{s}^{-1})</th>
<th>log (k)</th>
<th>333.2 K (k/10^5\text{s}^{-1})</th>
<th>log (k)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Me₂N</td>
<td>Me</td>
<td>–</td>
<td>–</td>
<td>1.19(1)</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>MeO</td>
<td>MeO</td>
<td>1.07(1)</td>
<td>–4.971</td>
<td>3.67(4)</td>
<td>–4.435</td>
<td>11.8(1)</td>
<td>–3.928</td>
</tr>
<tr>
<td></td>
<td>Me</td>
<td>1.04(1)</td>
<td>–4.983</td>
<td>3.62(4)</td>
<td>–4.441</td>
<td>10.6(2)</td>
<td>–3.975</td>
</tr>
<tr>
<td></td>
<td>H</td>
<td>1.26(2)</td>
<td>–4.900</td>
<td>4.30(8)</td>
<td>–4.376</td>
<td>13.2(8)</td>
<td>–3.879</td>
</tr>
<tr>
<td></td>
<td>Br</td>
<td>2.17(2)</td>
<td>–4.664</td>
<td>7.25(8)</td>
<td>–4.140</td>
<td>22.0(3)</td>
<td>–3.658</td>
</tr>
<tr>
<td>Me</td>
<td>MeO</td>
<td>1.27(3)</td>
<td>–4.896</td>
<td>4.44(8)</td>
<td>–4.353</td>
<td>13.9(2)</td>
<td>–3.857</td>
</tr>
<tr>
<td></td>
<td>Me</td>
<td>1.21(1)</td>
<td>–4.917</td>
<td>4.12(5)</td>
<td>–4.385</td>
<td>12.6(3)</td>
<td>–3.900</td>
</tr>
<tr>
<td></td>
<td>H</td>
<td>1.55(2)</td>
<td>–4.810</td>
<td>5.14(6)</td>
<td>–4.289</td>
<td>15.9(2)</td>
<td>–3.799</td>
</tr>
<tr>
<td></td>
<td>F</td>
<td>–</td>
<td>–</td>
<td>6.61(7)</td>
<td>–4.180</td>
<td>–</td>
<td>–</td>
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<tr>
<td></td>
<td>Cl</td>
<td>–</td>
<td>–</td>
<td>8.31(6)</td>
<td>–4.081</td>
<td>–</td>
<td>–</td>
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<tr>
<td></td>
<td>Br</td>
<td>2.63(4)</td>
<td>–4.580</td>
<td>8.86(2)</td>
<td>–4.053</td>
<td>26.8(3)</td>
<td>–3.572</td>
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<tr>
<td>H</td>
<td>MeO</td>
<td>1.81(2)</td>
<td>–4.743</td>
<td>6.29(8)</td>
<td>–4.201</td>
<td>18.9(2)</td>
<td>–3.724</td>
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<tr>
<td></td>
<td>Me</td>
<td>1.70(6)</td>
<td>–4.770</td>
<td>5.94(8)</td>
<td>–4.226</td>
<td>18.3(3)</td>
<td>–3.738</td>
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<tr>
<td>F</td>
<td>Me</td>
<td>–</td>
<td>–</td>
<td>8.71(8)</td>
<td>–4.060</td>
<td>–</td>
<td>–</td>
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<tr>
<td>Br</td>
<td>MeO</td>
<td>3.95(9)</td>
<td>–4.403</td>
<td>12.7(2)</td>
<td>–3.896</td>
<td>37.6(5)</td>
<td>–3.425</td>
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<tr>
<td></td>
<td>Me</td>
<td>3.87(7)</td>
<td>–4.412</td>
<td>12.5(5)</td>
<td>–3.903</td>
<td>36.6(5)</td>
<td>–3.437</td>
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</tbody>
</table>

Table 2. Mean values of log \((k_{XY}/k_{HY})\) (effect of X) and log \((k_{XY}/k_{XH})\) (effect of Y) determined at different temperatures (the respective H-substituted derivative as reference compound). Standard deviations are shown in parentheses. Substituent constants from Ref. 5.

<table>
<thead>
<tr>
<th>X</th>
<th>log ((k_{XY}/k_{HY})) (10^5\text{s}^{-1})</th>
<th>313.2 K</th>
<th>323.2 K</th>
<th>333.2 K</th>
<th>Substituent constant (\sigma^o_p)</th>
<th>(\sigma_t)</th>
<th>(\sigma^o_R)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Me₂N</td>
<td>–</td>
<td>–0.699(^a)</td>
<td>–</td>
<td>–</td>
<td>–0.44</td>
<td>+0.10</td>
<td>–0.54</td>
</tr>
<tr>
<td>MeO</td>
<td>–0.251(45)</td>
<td>–0.228(23)</td>
<td>–0.226(20)</td>
<td>–0.226(20)</td>
<td>–0.16</td>
<td>+0.25</td>
<td>–0.41</td>
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<tr>
<td>Me</td>
<td>–0.172(39)</td>
<td>–0.153(18)</td>
<td>–0.150(13)</td>
<td>–0.150(13)</td>
<td>–0.12</td>
<td>–0.05</td>
<td>–0.10</td>
</tr>
<tr>
<td>F</td>
<td>–</td>
<td>0.166(^a)</td>
<td>–</td>
<td>–</td>
<td>+0.17</td>
<td>+0.52</td>
<td>–0.35</td>
</tr>
<tr>
<td>Br</td>
<td>0.334(28)</td>
<td>0.312(9)</td>
<td>0.286(24)</td>
<td>0.286(24)</td>
<td>+0.26</td>
<td>+0.45</td>
<td>–0.19</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Y</th>
<th>log ((k_{XY}/k_{XH})) (10^5\text{s}^{-1})</th>
<th>313.2 K</th>
<th>323.2 K</th>
<th>333.2 K</th>
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<tbody>
<tr>
<td>MeO</td>
<td>–0.075(17)</td>
<td>–0.054(13)</td>
<td>–0.049(21)</td>
<td></td>
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<tr>
<td>Me</td>
<td>–0.092(25)</td>
<td>–0.072(18)</td>
<td>0.076(31)</td>
<td></td>
</tr>
<tr>
<td>F</td>
<td>–</td>
<td>0.109(^b)</td>
<td>–</td>
<td></td>
</tr>
<tr>
<td>Cl</td>
<td>–</td>
<td>0.208(^b)</td>
<td>–</td>
<td>+0.27</td>
</tr>
<tr>
<td>Br</td>
<td>0.257(41)</td>
<td>0.247(27)</td>
<td>0.234(17)</td>
<td></td>
</tr>
</tbody>
</table>

\(^a\) Only the Y=Me series was studied. \(^b\) Only the X=Me series was studied.

Fig. 1. Dependence of the logarithm of the decomposition rate on substituent constants $\sigma_p^0$, (a) effect of $X$ and (b) effect of $Y$ (from Table 2).

variation in activation parameters from one substituent to another is small and without pattern, however, making further conclusions unreasonable.

Surprisingly the effect of $X$ on reaction rates was only about twice as great as that of $Y$ (Table 2), whereas the effect of $X$ on the phosphorus chemical shift of oxalates of these phosphonates was over five times as great as the effect of $Y$.\(^3\)

The plot of log $(k_{XY}/k_{HY})$ against the $\sigma_p^0$ parameter shows a reasonably good linear dependence (Fig. 1a) ($r=0.993$, $\rho=1.40(8)$, values from Table 3, 323.2 K). The weaker effect of $Y$ and the greater deviation of the plot from linearity [$r=0.974$, $\rho=0.70(80)$] is clearly seen in Fig. 1b. Some curving of the plot is evident in both correlations.

Despite claims that substituent constants may not be "fundamental" parameters describing "fundamental" effects,\(^4\) we continue for the present to use these when discussing substituent effects. The constants have a practical use and are successfully applied every day, at least qualitatively, by organic chemists when evaluating the reactivity of reagents in syntheses and reaction studies. Nevertheless the great number of substituent scales makes it difficult to select the "correct" and best scale for interpreting the observed results. When fitting with common substituent constants (e.g. $\sigma_p^0$) fails, the application of the dual substituent parameter method ($dsp$) using the equation log $k/k_o=\rho(\sigma_1+\lambda \sigma_p^0)$ would be the next best approach to the problem. However, when multiple parameter regressions are used the statistical significance of coefficients of regression need, of course, to be carefully evaluated before they are used to explain chemical phenomena.

The measured values fit reasonably well with $\sigma_p^0$ parameters and no significant improvement can be obtained by the $dsp$-method. Interestingly, however, when the latter method was applied to the data (Table 2, 323.2 K, $n=6$) using the above equation the regression gave $\lambda_X=1.18$ (F-test value 99.92 %) which is near to $\lambda_X=1.15$ obtained from NMR data,\(^3\) but $\lambda_Y=0.93$ (F-test 99.01 %) differs markedly.

An analogous reaction to the present decomposition reaction has been thoroughly investigated by Jentzsch et al.\(^6\) Alkylation of trimethylamine and 4-(4-nitrobenzyl)pyridine with substituted alkyl and aryl dimethyl phosphates was followed in acetone and good linear correlations between logarithms of rate constants and $\sigma_p^0$ constants were found (Scheme 2). This second-order reaction (actually pseudo first order, rate constant $k'$) correlates linearly with the first order spontaneous decomposition (rate constant $k$) studied here (substituents $Y=\text{MeO, Me, H, Cl}$).
diethyl 4-fluorophenylphosphonate (b.p. 150–151 °C/931 Pa, 67 %) was transformed with phosphoruspentachloride to 4-fluorophenylphosphonic dichloride (b.p. 123–125 °C/931 Pa, 64 %).

4-Methylphenylphosphonic dichloride. Use of the Friedel-Crafts reaction resulted in the formation of both the para and ortho isomers. To avoid this the triethyl phosphite method as above was applied. Diethyl 4-methylphenylphosphonate (b.p. 150–152 °C/1064 Pa, 76 %), 4-Methylphenylphosphonic dichloride (b.p. 150–153 °C/1064 Pa, 90 %).

4-Dimethylaminophenylphosphonic dichloride. Tricoordinated 4-dimethylaminophenylphosphonic dichloride was prepared from dimethylaniline and phosphorus trichloride (b.p. 140–150 °C/3 Pa, ca. 30 %) and was oxidized with dimethylsulfoxide to the desired product (b.p. 155–165 °C/3 Pa, low yield). 

Oxalates of 2-(N,N-dimethylamino)ethyl phenyl phenylphosphonates. The method used earlier was slightly modified because purification of high boiling phenyl phenylphosphonic chlorides by distillation is difficult. Substituted diphenyl phosphonophenylates were first prepared from phenylphosphonic dichlorides and were then by transesterification changed to the desired 2-(N,N-dimethylamino)ethyl phenyl phenylphosphonate using an equivalent amount of sodium salt of the amino alcohol. The yields of transesterification were low (ca. 30 %). The products were recrystallized and stored as oxalates as described earlier. Melting points and \( \delta^{31} \)P chemical shifts of the oxalate (dimethylsulfoxide-\( d_{6} \), reference (HO),P=OClO\(_{4}\)) (see Scheme 1) are: (X=Me, Y=Cl) 142–3 °C, \( \Delta \delta^{31} \)P 16.56 ppm; (Me, F) 138–9 °C, 16.63 ppm, J(P–F) 1.83 Hz; (Me\(_{2}\)N, Me) 108–9 °C, 19.00 ppm and (F, Me) 139–40 °C, 14.60 ppm, J(P–F) 1.53 Hz.

**EXPERIMENTAL**

**Preparations**

The preparation of most of the ammonium oxalates of the studied phosphonates has been described earlier. The structure and the purity of four additional compounds synthesized for this study were confirmed by NMR.

4-Fluorophenylphosphonic dichloride. This intermediate was prepared from 4-fluorobromobenzene and triethyl phosphate. The formed

**Table 3. Relationship between decomposition rates of studied compounds and phosphorus chemical shift of respective oxalates.**

<table>
<thead>
<tr>
<th>Y</th>
<th>A</th>
<th>B</th>
<th>r</th>
</tr>
</thead>
<tbody>
<tr>
<td>MeO</td>
<td>0.22(19)</td>
<td>-0.24(1)</td>
<td>0.998</td>
</tr>
<tr>
<td>Me</td>
<td>0.19(25)</td>
<td>-0.25(1)</td>
<td>0.997</td>
</tr>
<tr>
<td>H</td>
<td>0.02(29)</td>
<td>-0.24(2)</td>
<td>0.995</td>
</tr>
<tr>
<td>Br</td>
<td>0.46(37)</td>
<td>-0.24(2)</td>
<td>0.997</td>
</tr>
</tbody>
</table>

Decomposition reactions

The studied phosphonates were liberated from oxalates with sodium carbonate and extracted into ether, which was dried and evaporated. The remaining liquid phosphonates were used immediately in the decomposition reaction. The reaction was followed by titrating the samples with HCl solution. The end point of titration was determined by pH meter to pH 5.3–5.2. The basicity of the reaction medium during the reaction was typically about 8.5–9.5 owing to tertiary amino group. The 50 % ethanol solution was prepared by measuring exactly 50 cm\(^3\) of ethanol and filling the flask up to the 100 cm\(^3\) mark with water at 295 K.

Acknowledgements. The financial assistance of the Aaltonen Foundation and the Neste Oy Foundation is gratefully acknowledged.

REFERENCES


Received October 20, 1983.