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# Thermodynamic Dissociation Constants of 2,4-Dichlorophenoxyacetic Acid (2,4-D) and Some Related Plant Growth Regulators

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The dissociation constants of four substituted aryloxyacetic acids in water at 25° C have been determined by the conductivity method. The acids belong to the group of plant growth regulators.

The biological activity of weak acids and bases is strongly influenced by the pH of the medium in which the activity is measured. In many cases it has been found that the activity of weak acids is independent of the acidity at pH levels below p$K$ but decreases rapidly when the pH is raised above p$K$ [1]. The aryloxyacetic acids, to which 2,4-D, 2,4,5-T and MCPA belong, is an important type of biologically active, weak acids for which similar relations have been found. It has been assumed that only the undissociated molecule is active in bringing about a physiological response [2]. This view is supported by the fact that undissociated organic acids appear to penetrate the plasma membranes more easily than their anions [3]. In contrast to this some cases have been reported where the physiological response appeared to be determined by the concentration of the anion [4,5].

In spite of these conflicting conclusions it is obvious that the degree of dissociation is of great importance for the growth regulating properties of weak acids. For a quantitative discussion of the influence of pH on the activity of 2,4-D and related growth regulators, the dissociation constants must be known with some accuracy. An examination of the literature has displayed that several determinations of dissociation constants of these compounds have been carried out (Table 1). Most of these refer to classical dissociation constants calculated from the pH of aqueous solutions of the acids, free or neutralized to 50 %. Such methods are only approximate, especially when the solubility of the acid investigated is small. Thus the discrepancies between values given by different authors are not surprising.

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Because of this need for more dependable data we have calculated thermodynamic dissociation constants from conductivity measurements of the phenoxyacetic acids recorded in Table 1.

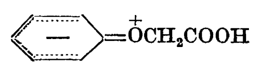
*Table 1.*

| Acid | $10^4$ $K$ | $10^4$ $K_0$ | Method | Reference |
|---|---|---|---|---|
| 4-Chlorophenoxyacetic | 9.62 | | Conductivity | 6 |
| | | 7.89 | E. m. f. | 7 |
| | | 9.79 | Conductivity | This investig. |
| 2,4-Dichlorophenoxy- | | | | |
| acetic (2,4-D) | 5.3 | | — | 8 |
| | 15.5 | | pH | 2 |
| | 10.9 | | pH | 9 |
| | 10 | | pH | 10 |
| | | 12.7 | Conductivity | This investig. |
| 2-Methyl-4-chloro- | 3.2 | | — | 11 |
| phenoxyacetic (MCPA) | 8.9 | | pH | 10 |
| | | 7.81 | Conductivity | This investig. |
| 2,4,5-Trichlorophenoxy- | 26.6 | | pH | 2 |
| acetic (2,4,5-T) | | 14.7 | Conductivity | This investig. |
| 2-Chlorobenzoic | 12.8—13.0 | | Conductivity | 12 |
| | | 11.4 | » | 13 |
| | | 12.0 | » | 14 |
| | 12.8—13.2 | 12.6 | » | This investig. |

The measurements were performed with a conductivity bridge, built according to the principles of Jones and Josephs [15]. The acids examined are rather strong and therefore the limiting conductivity at infinite dilution was not determined by the sodium salt method but from the conductivity of the aqueous acid solutions by the extrapolation method of Fuoss [16].

In order to test the bridge and the procedure, the dissociation constant of 2-chlorobenzoic acid was determined too. As seen from Table 1 the result is in fairly good agreement with data obtained from the literature.

The phenoxyacetic acids now studied, are rather strong, and their dissociation constants do not differ very much. This is a general feature of substituted phenoxyacetic acids as pointed out by Hayes and Branch [7]. The unusual strength is probably due to resonance structures of type I. In the phenoxyacetic acids there is no conjugation between the carboxylic group and the aromatic nucleus. Consequently, substituents will not affect the carboxyl group to the same extent as in the benzoic acids with resonance structures of type II.

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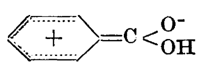


II

It was found by Hayes and Branch that the strength of phenoxyacetic acid was decreased by a methyl group in the nucleus but increased by a chlorine atom [7]. These rules were derived for monosubstituted acids but they seem to be valid also for the acids investigated here. However, the material is too small to permit a general statement.

## EXPERIMENTAL

*Materials. 2-Chlorobenzoic acid*, recrystallized three times from conductivity water, m. p. 140–141°.

*4-Chlorophenoxyacetic acid*, recrystallized twice from conductivity water, m. p. 157.2 –157.9°.

*2-Methyl-4-chlorophenoxyacetic acid*, recrystallized three times from toluene, m. p. 119.0–119.8°.

*2,4-Dichlorophenoxyacetic acid*, recrystallized once from formic acid and twice from toluene, m. p. 139.0–139.8°.

*2,4,5-Trichlorophenoxyacetic acid*, recrystallized once from formic acid, once from toluene and twice from benzene, m. p. 155.0–155.8°.

*Potassium chloride* (p. a.), recrystallized twice from conductivity water and fused in a platinum dish.

Melting points (corrected) were determined with a hot stage microscope. The conductivity water, which had a specific conductance of $0.8-0.9 \times 10^{-6}$ ohm$^{-1}$ cm$^{-1}$, was obtained by aeration of the distillate from a two-stage, all quartz still.

*Conductivity measurements.* The bridge network was based essentially on the bridge described by Jones and Josephs [15]. The ratio arms of the bridge were two equal, 1 000 $\Omega$, low-inductance resistances. The variable resistance was a calibrated, low-inductance, five-decade box of total resistance 11 111 $\Omega$, with a variable resistance, adjustable to 0.001 $\Omega$ (Leeds and Northrup, Cat. No. 43 256). The capacitances in the bridge were as follows: a variable capacitance (0–500 pF) across earth and either end of the bridge, a capacitance (200 pF) across the conductivity cell, two capacitances (500 pF, 1 000 pF) and a variable capacitance (0–500 pF) across the decade box. The detector was a high-resistance (2 000 ohms) telephone without amplifier. The earphone was covered with sheetmetal, connected to earth. The oscillator was an audion tube oscillator giving 4 V at 1 000 cycles per sec (Philips type GM 4260). The conductivity cells, of the type described by Jones *et al.*[17], had greyed platinum electrodes. During measurements the cells were immersed in a thermostat filled with oil and controlled within 0.005 °C. The whole assembly was placed in a constant temperature room at 20.0 ± 0.1 °C.

One of the conductivity cells was directly calibrated against M/100 potassium chloride solution, using the conductance data of Jones and Bradshaw [18]. This cell (constant 1.315) was used for calibration of the other (constant 0.3483).

The conductance at 25 °C of the pure acids dissolved in conductivity water was measured at different concentrations in the range 0.0003–0.003 M. The conductance of the acid solutions was not corrected for water conductance. All solutions were prepared by weighing and the weighings were corrected to *vacuo*.

The results of the conductivity measurements are found in Tables 2–6. The following symbols are used.

$C$ total concentration of acid
$\Lambda_0$ equivalent conductance at infinite dilution
$\Lambda_c$ equivalent conductance at concentration $C$
$K_0$ thermodynamic dissociation constant
$K$ classical dissociation constant.

*Table 2.* 2-Chlorobenzoic acid $\Lambda_0 = 373.4$.

| $10^3 C$ | $\Lambda_c$ | $10^4 K$ | $10^4 K_0$ | |
|---|---|---|---|---|
| 2.954 | 180.0 | 13.25 | 12.67 | |
| 2.459 | 190.6 | 13.08 | 12.56 | |
| 1.843 | 208.3 | 12.97 | 12.54 | $K_0 = (12.6 \pm 0.1)\ 10^{-4}$ |
| 1.288 | 231.2 | 12.96 | 12.65 | |
| 0.686 | 269.3 | 12.80 | 12.65 | |

*Table 3.* 4-Chlorophenoxyacetic acid. $\Lambda_0 = 370.8$.

| $10^3 C$ | $\Lambda_c$ | $10^4 K$ | $10^4 K_0$ | |
|---|---|---|---|---|
| 2.830 | 166.0 | 10.27 | 9.83 | |
| 2.308 | 177.6 | 10.16 | 9.76 | |
| 1.817 | 191.9 | 10.09 | 9.74 | $K_0 = (9.79 \pm 0.04)\ 10^{-4}$ |
| 1.416 | 207.6 | 10.10 | 9.80 | |
| 1.013 | 228.5 | 10.03 | 9.80 | |
| 0.6352 | 257.0 | 9.95 | 9.82 | |

*Table 4.* 2-Methyl-4-chlorophenoxyacetic acid $\Lambda_0 = 374.0$.

| $10^3 C$ | $\Lambda_c$ | $10^4 K$ | $10^4 K_0$ | |
|---|---|---|---|---|
| 2.616 | 158.4 | 8.14 | 7.80 | |
| 2.202 | 168.6 | 8.15 | 7.84 | |
| 1.788 | 180.8 | 8.08 | 7.80 | $K_0 = (7.81 \pm 0.03)\ 10^{-4}$ |
| 1.361 | 197.5 | 8.04 | 7.80 | |
| 0.9332 | 221.0 | 7.96 | 7.78 | |
| 0.5223 | 257.5 | 7.95 | 7.85 | |

*Table 5.* 2,4-Dichlorophenoxyacetic acid $\Lambda_0 = 361.1$.

| $10^3 C$ | $\Lambda_c$ | $10^4 K$ | $10^4 K_0$ | |
|---|---|---|---|---|
| 1.503 | 215.0 | 13.17 | 12.80 | |
| 1.265 | 225.0 | 13.04 | 12.71 | |
| 1.002 | 238.7 | 12.91 | 12.66 | $K_0 = (12.7 \pm 0.1)\ 10^{-4}$ |
| 0.7480 | 256.0 | 12.93 | 12.76 | |
| 0.5021 | 277.4 | 12.79 | 12.73 | |
| 0.3370 | 296.5 | 12.69 | 12.75 | |

*Table 6.* 2,4,5-Trichlorophenoxyacetic acid $\Lambda_0 = 362.7$.

| $10^3 C$ | $\Lambda_c$ | $10^4 K$ | $10^4 K_0$ | |
|---|---|---|---|---|
| 0.9860 | 249.5 | 14.95 | 14.69 | |
| 0.7822 | 262.9 | 14.95 | 14.77 | |
| 0.5171 | 284.4 | 14.75 | 14.72 | $K_0 = (14.7 \pm 0.1)\ 10^{-4}$ |
| 0.2592 | 314.0 | 14.46 | 14.69 | |

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