tion and vigorously stirred at the ether reflux temperature as 100 ml. of 20% hydrogen peroxide was added dropwise. After the oxidation step the ether layer was separated, washed with water, and then with a 5% ferrous ammonium sulfate solution until no further coloration of the aqueous layer occurred. The ether layer was then dried over magnesium sulfate and distilled through the spinning band column to yield the pure alcohol.

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The Basicities of Substituted Pyridine-1-oxides. A Reaction Series Requiring Use of σ^+ and σ^-[1]

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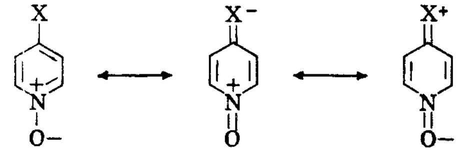
Some years ago we determined and examined the basicities of a series of substituted pyridine-1-oxides.[2] We recognized at that time that resonance between structures I, II, and III was important.[2a] II was expected to make a particularly important contribution when X was electron attracting by a tautomeric effect (*e.g.* $—NO_2$, —COOR), and in the treatment of the data by the Hammett equation[3] we consequently used σ^--values[4] for these substituents. Similarly, we recognized that structure III would make a particularly large contribution to the resonance hybrid when X was capable of electron release by a tautomeric effect (*e.g.* —OR, $—NR_2$), and we assumed that the failure of the experimental points for 4-hydroxypyridine-1-oxide, 4-aminopyridine-1-oxide, and isoquinoline-1-oxide to fall on the line defined by the plot of the pK_a's[5] of the other compounds *vs.* σ-values was due to this reason. At that time, however, no special substituent constants were available for tautomerically electron releasing substituents in conjugation with electron withdrawing side chains or reaction centers, and hence we were unable to adequately deal with the pK's of the three compounds mentioned in terms of the Hammett equation. The recent introduction of such constants (σ^+) by Brown and Okamoto[6] and by Deno and Evans[7] and the discussion of the tautomeric equilibria in 4-hydroxy- and 4-aminopyridine-1-oxides by Gardner and Katritzky[8] have prompted us to re-examine our data.



I II III

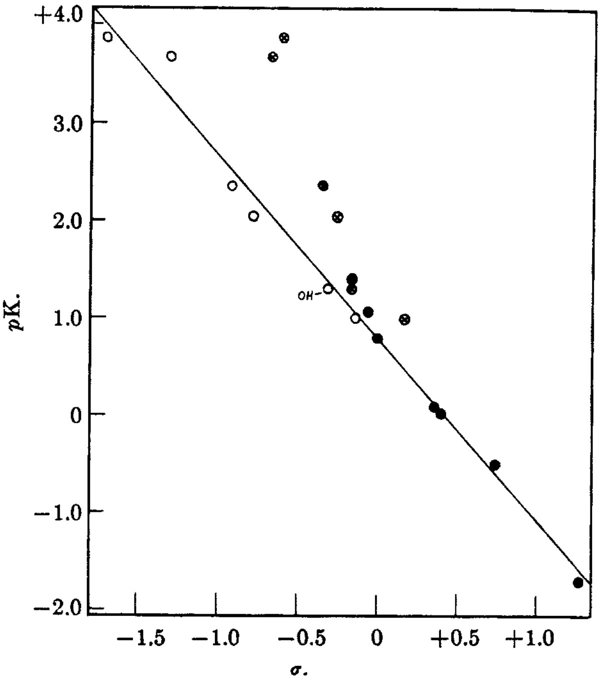


Fig. 1. Plot of the pK_a's of 1-hydroxypyridinium ions against σ. Open circles, σ^+ values; crossed circles, normal σ-values; full circles, normal σ-values or σ^--values for groups for which σ^+ is not applicable

Fig. 1 shows a plot of our pK_a-values against σ; σ^--values are used for electron withdrawing, σ^+-values for electron releasing substituents. Since the data of Gardner and Katritzky were in reasonable agreement with ours where comparison was possible, their data are included for those compounds which we had not examined. Fig. 1 also shows (as crossed circles) the points for electron releasing substituents using the normal σ-values. The tremendous improvement in the fit resulting from the use of σ^+-values is immediately apparent. The 13 data, which cover a range of more than 5 log units are correlated with $\rho = 1.893 \pm 0.071$, $r = 0.992$, $s = 0.201$ $(-\log k^\circ)_{calc.} = 0.812$ in excellent agreement with $pK^\circ = 0.79$. Although the ρ-value is slightly lower than that previously reported, it still bears a striking resemblance to the value applicable to the pK's of phenols. The data of Gardner

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[1] This work was supported by the office of Ordnance Research, U. S. Army.

[2] (a) H. H. Jaffé, *J. Am. Chem. Soc.*, **76**, 3527 (1954); (b) H. H. Jaffé and G. O. Doak, *J. Am. Chem. Soc.* **77**, 4441 (1955).

[3] (a) L. P. Hammett, *Physical Organic Chemistry*, McGraw-Hill Book Company, Inc., New York, 1940, Chapter VII; (b) H. H. Jaffé, *Chem. Revs.*, **53**, 191 (1953).

[4] By agreement between Prof. H. C. Brown, R. W. Taft, Jr., N. C. Deno, and the author, the constants designated as σ^* in ref. 3 b are now referred to as σ^-.

[5] As in earlier papers (ref. 2) all basicities are expressed as pK_a's of the conjugate acids.

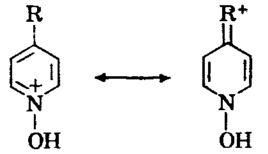
[6] Y. Okamoto and H. C. Brown, *J. Am. Chem. Soc.*, **79**, 1913 (1957); the σ^+ values used are the latest revised values of Prof. Brown.

[7] N. C. Deno and W. L. Evans, *J. Am. Chem. Soc.*, **79**, 5804 (1957).

[8] J. N. Gardner and A. R. Katritzky, *J. Chem. Soc.*, 4375 (1957).

and Katritzky[8] also permit the calculation of σ^+-values for two new groups: $—NHCH_3$, $\sigma^+ = -1.59$; $—OCH_2C_6H_5$, $\sigma^+ = -0.616$.

The basicities of the substituted pyridine-1-oxides are the first reaction series on record which, in the Hammett treatment, require the use of *both* σ^+- and σ^--values. A slightly more detailed discussion seems indicated. Although it was originally suggested that σ^--values were applicable to *all* reactions of anilines and phenols, evidence now appears to accumulate[9] that the requirement is an appreciable *difference* in conjugation of substituent and reaction site between initial and final (in the case of equilibria) or transition state (in the case of rates). Such a difference in conjugation between initial and final states obviously exists for electron releasing X, since it is impossible to write a plausible quinoid structure analogous to II for the conjugate acids. In the case of electron withdrawing X, however, it is suggested that the resonance IV↔V is sufficiently more important than I ↔ III to require use of σ^+-values.


IV V

In our previous paper[2b] we conclude that the tautomeric equilibria between 4-hydroxypyridine-1-oxide and 1-hydroxy-4-pyridone, and between 4-aminopyridine-1-oxide and 1-hydroxy-4-pyridone immine were overwhelmingly in favor of the pyridine rather than the pyridone structure. This conclusion was based on the estimation of the intrinsic basicities of the two pyridine structures by the Hammett equation, using standard σ-values, which lead to pK's for the conjugate acids appreciably *smaller* than the observed values, while in a tautomeric equilibrium of the type under investigation (single acid, tautomeric bases) the observed pK must be *at least as low* as the *lower* of tautomers. We doubted that the intrinsic pK's could have been underestimated by *more* than the discrepancy found.

Gardner and Katritzky[8] have examined the same tautomeric equilibria, and have confirmed our conclusion concerning 4-aminopyridine-1-oxide. They have used the pK's of 4-methoxypyridine-1-oxide ($pK = 2.04$) and of 1-methoxy-4-pyridone ($pK = 2.57$) and of the corresponding benzyl derivatives ($pK = 1.99$ and 2.58, respectively) to estimate the intrinsic basicities of the corresponding hydroxy compounds. These authors found themelves in the same dilemma as we had, since the 4-alkoxy compounds were weaker bases (their conjugate acids stronger acids) by 0.4–0.5 units than the hydroxy compound while the 1-alkoxy-4-pyridones were slightly stronger bases. From these data the authors conclude (rather unconvincingly) that 4-hydroxypyridine-1-oxide must exist as an equilibrium mixture of roughly comparable quantities of the pyridine and pyridone forms. Examination of Fig. 1 shows that the point for 4-hydroxypyridine-1-oxide lies well on the best straight line. Calculations indicate that omission of this datum does not improve the correlation with σ. The inherent accuracy of the Hammett equation is insufficient to accurately evaluate the tautomeric equilibrium constant, or to categorically state that the pyridone form makes no substantial contribution to the tautomeric equilibrium. However, the data lend no support to Gardner and Katritzky's thesis of an *important* contribution from the pyridone structure, but are best interpreted as indicating an equilibrium predominantly in favor of the pyridine form, in agreement with our theoretical calculations.[10]

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[9] R. W. Taft, Jr., private communication.

[10] H. H. Jaffé, *J. Am. Chem. Soc.*, 77, 4448 (1955).

Metalation of 1-Methylbenzimidazole with *n*-Butyllithium

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The reaction of 1-methyl-2-*t*-butylbenzimidazole with organolithium reagents has been reported[1] to involve addition across the azomethine linkage. Benzothiazole undergoes either metalation in the 2-position or addition across the azomethine linkage, depending upon the reaction temperature.[2,3] Benzoxazole apparently gives no metalation product with *n*-butyllithium.[3]

Treatment of 1-methylbenzimidazole with *n*-butyllithium at −60°, followed by carbonation, gave 1-methyl-2-benzimidazolecarboxylic acid in 45% yield. The high water solubility of the acid product, prepared previously from the reaction of glyoxylic acid and *N*-methyl-*o*-phenylenediamine,[4] prevented the quantitative isolation of the acid by precipitation with mineral acid from the aqueous layer of the carbonation mixture. A portion of the product was isolated in this manner, but the remainder was obtained as its water insoluble copper (II) complex. This complex is similar to the one

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[1] R. C. Elderfield and V. B. Meyer, *J. Am. Chem. Soc.*, 76, 1891 (1954).

[2] H. Gilman and J. A. Beel, *J. Am. Chem. Soc.*, 71, 2328 (1949).

[3] J. A. Beel, Doctoral Dissertation, Iowa State College, 1949; *Iowa State Coll. J. of Sci.*, 25, 161 (1951).

[4] E. H. Usherwood and M. A. Whitely, *J. Chem. Soc.*, 123, 1069 (1923).