thiophene was miscible above 60.8° and with ethylene glycol above 31.1°.

Enolization.—A drop of 2-acetylthiophene was diluted with 5 ml. of absolute alcohol and a dilute solution of ferric chloride was added dropwise. No color other than the light yellow of the ferric chloride was observed, whereas the enol form of carbonyl compounds (*e. g.*, ethyl acetoacetate) usually gives red or purple colors.[22,23] Hence, it was concluded that 2-acetylthiophene exists in the keto form.

Infrared Absorption Spectra.—The infrared absorption spectra of 2-acetylthiophene and other thiophene derivatives will be reported by other workers from this laboratory.

Chromatography.—2-Acetylthiophene lies between ethyl ether and benzene on the scale of adsorption on silica gel methanol > acetone > ethyl ether > benzene > chloroform > carbon tetrachloride > *n*-heptane. 2-Acetylthiophene is more strongly adsorbed than thiophene and less strongly adsorbed than acetic acid. 2-Acetylthiophene is more strongly adsorbed than acetophenone in the same way that thiophene is more strongly adsorbed than benzene. The experiments were all made by percolating an equal volume mixture of the pair being examined through a column of silica gel and analyzing the effluent refractometrically. The pale yellow color which existed in the distillation middle fraction was not completely removed by percolation through silica gel at room temperature.

Molar Refractivity.—The equation used was $R^{20}{}_{\mathrm{D}} = (n^2 - 1)/(n^2 + 2)\cdot(M/d)$ and the value found was 35.178. A calculated value was obtained by the method of Fajans[24] using $R^{20}{}_{\mathrm{D}}$ for thiophene 24.365,[19] CH_2 4.618, C 2.418, carbonyl oxygen 2.211 to give 33.612. Hence, 2-acetylthiophene shows marked exaltation when compared with thiophene. Furthermore, 2-acetylthiophene also shows exaltation but thiophene shows depression when compared with the usual values which are based on aliphatic compounds containing sulfide linkages, isolated double bonds and an isolated carbonyl group.

Specific Refractive Dispersion.—The calculations $10^4(n_{\mathrm{F}} - n_{\mathrm{C}})\cdot(1/d) = 213.4$ and $10^4\,(n_{\mathrm{g}} - n_{\mathrm{D}})(1/d) = 340.9$ show high values and indicate marked dispersion for 2-acetylthiophene, further indicating light absorption in the near ultraviolet.

Parachor.—From the equation $P = M\gamma^{1/4}/(D - d)$ a value of 281.9 at 30° was found. Sufficient data on thiophene derivatives are not available for a precise calculated value. The values of Mumford-Phillips[25] show 277.6.

Summary

1. Determinations of the physical properties of purified 2-acetylthiophene have been made, including m.p., b. p., change of b. p. with pressure, $n^{20}{}_{\mathrm{D}}$, $\Delta n_{\mathrm{D}}/\Delta T$, refractive dispersion, $d^{20}{}_4$, $\Delta d_4/\Delta t$, η^{30}, γ^{30} and water solubility. Derived values have been calculated for heat of fusion, heat of evaporation and molar refractivity.

2. An equation for the index of refraction at 20° as a function of wave length is presented.

PAULSBORO, N. J. RECEIVED JULY 18, 1946

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[22] Watson, "Modern Theories of Organic Chemistry," Oxford University Press, London, 1941, pp. 159–180.

[23] Huntress and Mulliken, "Identification of Pure Organic Compounds," John Wiley & Sons, Inc., New York, N. Y., 1941, p. 20.

[24] Fajans, *Additivity of Molar Refraction and Its Limitations*, in "Physical Methods of Organic Chemistry," Interscience Publishers, Inc., New York, N. Y., 1945, pp. 673, 680.

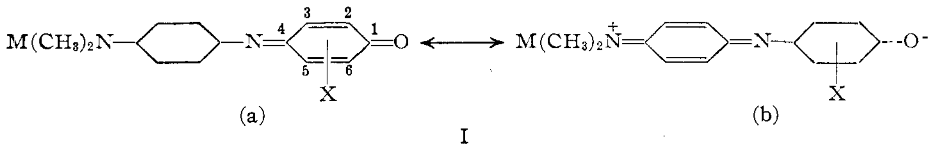
[25] Mumford-Phillips, *J. Chem. Soc.*, 2112 (1929).

[COMMUNICATION NO. 1109 FROM THE KODAK RESEARCH LABORATORIES]

Indoaniline Dyes. II.[1] The Effect of Multiple Substitution on the Absorption of Phenol Blue

BY PAUL W. VITTUM AND GORDON H. BROWN

Substituted phenol blue dyes (Ia ⟷ Ib) have been shown[1] to have markedly different absorptions, depending on the nature of the substituent groups (X) in the oxygen-containing ring. The change in absorption can be explained adequately in terms of the manner in which the substituents affect the contribution of the dipolar resonance structure, Ib. If X exerts an inductive or resonance effect which facilitates the separation of the charge in Ib, the substituted dye absorbs more strongly and has a higher $\lambda_{\max.}$ value. Conversely, if X renders the oxygen-containing ring less capable of accommodating the negative charge in Ib, both $\lambda_{\max.}$ and $\epsilon_{\max.}$ of the dye are lowered.



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The examination of indoaniline dyes has now been extended to some members having more than

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[1] Part I, THIS JOURNAL, **68**, 2235 (1946).

TABLE I

PHYSICAL PROPERTIES OF DYES FROM *p*-AMINODIMETHYLANILINE AND SUBSTITUTED PHENOLS

Substituents on phenol	M. p., °C.[a]	Crystallized from	Appearance	Carbon, % Calcd.	Carbon, % Found	Hydrogen, % Calcd.	Hydrogen, % Found	Nitrogen, % Calcd.	Nitrogen, % Found
2,6-Dimethyl-	119–120	Ligroin	Lustrous purple plates	75.59	75.52	7.08	7.20	11.02	11.29
2,5-Dimethyl-	122–123[b]	Ethanol	Long bronze needles	75.59	75.69	7.08	7.13	11.02	10.87
3,5-Dimethyl-	112–113	Ligroin	Dark bronze needles	75.59	75.78	7.08	6.93	11.02	11.31
2-Isopropyl-5-methyl	71–72[c]	Methanol	Dark purple plates	76.59	76.69	7.80	7.70	9.93	9.94
2,6-Dimethoxy-	182–183	Ligroin	Dark purple needles	67.13	67.42	6.29	6.47	9.79	9.94
2,5-Dichloro	169–170 (dec.)	*n*-Butanol	Dark purple crystals	56.95	57.02	4.07	4.02	9.49	9.64
2-Acetamino-4-chloro-5-methyl-[d]	207–208	*n*-Butanol	Lustrous bronze needles	68.69	68.55	6.40	6.40	14.14	14.23
2-Acetamino-4-chloro-3,6-dimethyl-[d]	182–183	CCl_4	Dark purple crystals	69.45	69.18	6.75	6.58	13.50	13.38

[a] Melting points determined with Fisher–Johns apparatus. [b] Bayrac[2] gives 125–126°. [c] Bayrac[2] gives 69.5°. [d] Chlorine is replaced in dye formation.

TABLE II

ABSORPTION OF INDOANILINE DYES FROM *p*-AMINODIMETHYLANILINE AND SUBSTITUTED PHENOLS[a]

Substituents on phenol	Cyclohexane $\lambda_{max.}$ Å.	Cyclohexane $\epsilon_{max.} \times 10^{-3}$	*n*-Butyl acetate $\lambda_{max.}$ Å.	*n*-Butyl acetate $\epsilon_{max.} \times 10^{-3}$	Methanol $\lambda_{max.}$ Å.	Methanol $\epsilon_{max.} \times 10^{-3}$	1:1 Acetone–water $\lambda_{max.}$ Å.	1:1 Acetone–water $\epsilon_{max.} \times 10^{-3}$
2,6-Dimethyl-	5450	13.7	5650	15.6	5870	17.7	6020	19.2
	(5460)	(15.2)	(5670)	(15.7)	(5900)	(15.7)	(5980)	(16.7)
2,5-Dimethyl-	5470	12.6	5690	14.7	5940	15.7	6130	17.0
	(5490)	(13.0)	(5720)	(13.9)	(5970)	(14.4)	(6110)	(14.8)
3,5-Dimethyl-	5620	8.3	5920	9.7	6350	11.5	6530	12.3
	(5520)	(10.8)	(5770)	(12.1)	(6040)	(13.1)	(6240)	(12.9)
2-*iso*-Propyl-5-methyl-	5470	13.3	5670	14.6	5950	15.3	6100	16.8
2,6-Dimethoxy-	5360	11.5	5590	12.5	5940	13.5	6110	15.0
	(5380)		(5590)	(12.1)	(5900)	(13.5)	(6060)	(13.3)
2,5-Dichloro-	5990	..[c]	6310	26.7	6630	29.0	6960	41.7
	(6040)		(6320)	(27.0)	(6630)	(30.0)	(7080)	(38.3)
2-Acetamino-4-chloro-5-methyl-[b]	5760	..[c]	5920	16.2	6090	17.2	6320	18.5
	(5800)		(5980)	(19.7)	(6110)	(19.1)	(6360)	(19.9)
2-Acetamino-4-chloro-3,6-dimethyl-[b]	5700	13.8	5820	14.3	6010	15.5	6200	16.5
	(5770)	(19.5)	(5940)	(17.9)	(6010)	(15.2)	(6180)	(13.9)

[a] Values in parentheses were calculated by adding the shifts of the individual substituents. [b] Chlorine is replaced in dye formation. [c] Solubility too low to permit determination.

one substituent on the oxygen-containing ring, with the object of determining whether the influence of one substituent on the absorption is modified by the presence of another. The dyes prepared for this study are listed in Table I, and data for their absorptions in four solvents are given in Table II.

In the absence of other factors affecting the absorption, it should be possible to calculate values of $\lambda_{max.}$ and $\epsilon_{max.}$ for a multi-substituted dye by totalling the shifts found[1] for the individual substituents. Calculated values arrived at in this way are included in Table II. In nearly all cases the calculated values for $\lambda_{max.}$ are in close agreement with those actually found. The agreement between calculated and determined values of $\epsilon_{max.}$ is not so close, but no very large discrepancies appear: the changes in $\epsilon_{max.}$ of the multi-substituted dyes are, in all cases, in the direction expected. It may be concluded, therefore, that, in general, the effects of the individual substituents on absorption in this series of dyes are more or less additive. Of the compounds studied, the only exception to this general rule is the 3,5-dimethyl dye, which has a *higher* value for $\lambda_{max.}$ than phenol blue itself, whereas the effect of only one methyl group, or of two methyl groups in either the 2,6- or 2,5-positions, is to reduce $\lambda_{max.}$ Further, 3,5-dimethyl substitution is seen to produce a greater lowering of $\epsilon_{max.}$ than was found for the 2,6- and 2,5-dimethyl dyes.

These deviations from the general behavior are shown more clearly by the absorption spectra of Figure 1. The spectrum of phenol blue in cyclohexane has, in addition to its absorption maximum in the visible region (λ = 5520 Å.), two maxima in the ultraviolet: one with a low extinction at 3490 Å., and another stronger maximum at 2700 Å.[3] The 3,5-dimethyl dye has two

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(2) Bayrac, *Ann. chim.*, [7] **10**, 18 (1897).

(3) In solvents more polar than cyclohexane (*e. g.*, methanol), the maximum at 3490 Å. becomes less sharply defined and appears as a "step-out." Schwarzenbach and Michaelis [THIS JOURNAL, **60**, 1667 (1938)] have reported ultraviolet absorption bands at 2900 and 3550 Å. for phenol blue in aqueous acid solutions.

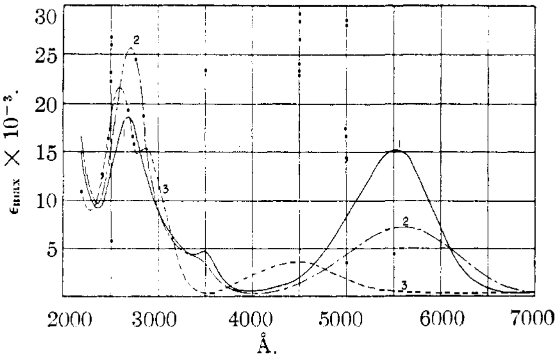

Fig. 1.—Absorption curves of cyclohexane solutions: (1) phenol blue; (2) 3,5-dimethyl phenol blue; (3) quinonanil.

very similar ultraviolet maxima, except that the 2700 Å. band is about 50% higher in extinction. For comparison, Fig. 1 includes the absorption spectrum of quinonanil, which may be considered the parent structure of the indoaniline dyes. With quinonanil, the contribution of a dipolar resonance structure, analogous to Ib, must be relatively small, because of the absence of the electron-donating dimethylamino group, present in the dyes. Accordingly, the absorption in the visible region is reduced and occurs at a much shorter wave length. The ultraviolet absorption bands both of quinonanil and of the dyes probably arise from excitation in the quinone-ring chromophore, since they bear a distinct resemblance to the ultraviolet absorption bands of quinone itself.[4]

These changes in visual and ultraviolet absorption brought about by the 3,5-dimethyl substitution in phenol blue probably result from mechanical interference with the planarity of the dye molecule. The scale drawing in Fig. 2 shows that, even in the unsubstituted dye, there is some interference between the hydrogen atoms in the two positions ortho to the central nitrogen if the dye is to retain its planar structure. With the dimethyl dye, a planar structure is seen to be possible only if very deep penetration of the van der Waals radii occurs, or the ring-N-ring bond angle or bond distances are greatly increased.

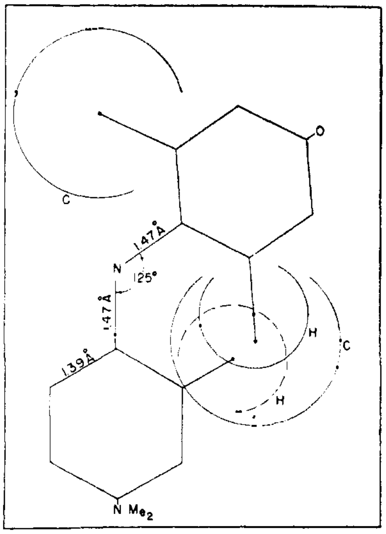

Fig. 2.—Scale model for phenol blue and its 3,5-dimethyl derivative, using dimensions given by Pauling.[7] The single-bond distances are used for the ring–N–ring bonds, although these would undoubtedly actually be shorter.

Many examples of changes in absorption spectra caused by steric effects have been reported,[5] and it has been pointed out[5,6] that frequently the decrease in absorption intensity is much more pronounced than the change in λ_{max}. In some cases, the introduction of hindering groups has caused an increase in $\lambda_{max.}$, and in others, a decrease. This unpredictability arises from the fact that knowledge is not usually at hand as to the effect of the hindering groups on the energies of the ground and excited states, respectively. The fact that $\lambda_{max.}$ is raised by the introduction of the 3,5-dimethyl groups in phenol blue, for example, shows only that the energy of the ground state is increased more than that of the excited state, without giving any indication of the actual amount of energy increase in either state. That the energy of the ground state is appreciably increased is shown by the low thermal stability of the dimethyl dye. It was necessary to prepare this dye under special conditions to avoid its decomposition, and its solutions, especially those in the more polar solvents, faded quite rapidly.

Experimental

Preparation of Dyes.—Except for the acetaminophenols, described below, all of the organic reagents for preparing the dyes were Eastman Kodak Co. chemicals, white label grade. Inorganic chemicals of reagent grade were employed. The procedure described previously[1] was used for preparing the dyes. The dye from 3,5-dimethylphenol proved quite unstable, and in this case it was necessary to extract the dye with ether immediately after its formation, to dry the ether solution rapidly, and to evaporate it under reduced pressure without heat. Attempts to recrystallize this dye from solvents other than ligroin resulted in its decomposition.

We are grateful to Dr. I. Salminen and Mr. C. O. Edens for preparing the samples of 2-acetamino-4-chloro-5-methylphenol and 2-acetamino-4-chloro-3,6-dimethylphenol, and for supplying the following descriptions for this paper.

2-Acetamino-4-chloro-5-methylphenol.—2-Amino-4-chloro-5-methylphenol[8] was acetylated with acetyl chloride and sodium acetate in acetic acid. The product was

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[4] Braude, *J. Chem. Soc.*, 490 (1945).

[5] See, for example, (a) O'Shaughnessy and Rodebush, This Journal, **62**, 2906 (1940); (b) Williamson and Rodebush, *ibid.*, **63**, 3018 (1941); (c) Sherwood and Calvin, *ibid.*, **64**, 1350 (1942); (d) Jones, *ibid.*, **65**, 1815, 1818 (1943); (e) Remington, *ibid.*, **67**, 1838 (1945); (f) Brunings and Corwin, *ibid.*, **64**, 593 (1942); (g) Rodebush and Feldman, *ibid.*, **68**, 896 (1946).

[6] Wheland, "The Theory of Resonance and Its Application to Organic Chemistry," John Wiley and Sons, Inc., New York, N. Y., 1944, p. 161.

[7] L. Pauling, "The Nature of the Chemical Bond," Cornell University Press, Ithaca, N. Y., 1940.

[8] von Walther and Zipper, *J. prakt. Chem.*, **91**, 364 (1915).

recrystallized from acetic acid, yielding white needles, m. p. 199–200°.

Anal. Calcd. for $C_9H_{10}ClNO_2$: Cl, 17.79. Found: Cl, 16.87.

2-Acetamino-4-chloro-3,6-dimethylphenol.—A mixture of 87.5 g. of 2-nitro-3,6-dimethylphenol, prepared according to von Auwers,[9] and 150 cc. of redistilled sulfuryl chloride was allowed to stand for one hour. Excess sulfuryl chloride was removed at the water pump to yield 104.5 g. (99.3%) of crude 2-nitro-4-chloro-3,6-dimethylphenol, yielding lemon yellow crystals, m. p. 54–55°. A solution was prepared of 42 g. of this crude nitro compound and 120 g. of sodium carbonate in 1.5 liters of water, and then was added, portionwise, with stirring at 75°, 175 g. of sodium hydrosulfite. The mixture was heated at 90° for twenty minutes, then cooled to room temperature. The amine was collected at the pump, washed with 1 liter of water, dissolved in 500 cc. of ether, dried over calcium chloride, treated with Darco, filtered, and, after concentration to 50 cc., precipitated with 100 cc. of ligroin; yield was 15 g. (42%) of 2-amino-4-chloro-3,6-dimethylphenol, forming buff crystals, m. p. 153–155°. The amine was acetylated with 1:1 acetic anhydride–acetic acid, giving light tan crystals, m. p., 169–171°. Recrystallized from acetic acid, m. p., 169–171°.

Quinonanil.—*p*-Hydroxydiphenylamine was oxidized in benzene solution with yellow mercuric oxide, as described by Calm.[10] The crude material was recrystallized once from ligroin, then twice from spectroscopically pure cyclohexane, producing fine orange needles (50% yield), m. p. 94°, with previous softening.

Anal. Calcd. for $C_{12}H_9ON$: N, 7.65. Found: N, 7.68.

Spectrophotometric Measurements.—All of the spectrophotometric measurements were made on 5.0×10^{-5} *M* solutions in 1-cm. cells. The ultraviolet absorption spectra were recorded photographically, using a Hilger rotating sector ultraviolet spectrograph with a photometer attachment, in conjunction with an iron spark. Some check readings were made with Beckman ultraviolet spectrophotometric equipment. Absorption spectra in the visual range were obtained with the General Electric Automatic Recording Spectrophotometer. Specially purified solvents, checked for their transparency down to 2100 Å., were used. We wish to thank Mr. E. E. Richardson and his associates for supplying these solvents, and for making all of the spectrophotometric measurements.

Summary

The effects of multiple substitution in the oxygen-containing ring of the indoaniline dye, phenol blue, on the absorption characteristics have been determined. In general, the shifts in $\lambda_{max.}$ and $\epsilon_{max.}$ brought about by two or more substituents agree quite closely with values calculated by totalling the shifts for the separate substituent groups.

An exception was noted in the dye from 3,5-dimethylphenol. In this dye, the resonance system is altered because the two methyl groups exert a mechanical interference with the planarity of the dye molecule.

ROCHESTER 4, N. Y. RECEIVED SEPTEMBER 23, 1946

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[9] von Auwers, Murbe, Sauerwein, Deines and Schornstein, *Fortschr. Chem., Physik. physik. Chem.*, **18**, No. 2, 37–77 (1924).

[10] Calm, *Ber.*, **16**, 2799 (1883); see, also, Uemura and Abe, *Bull. Chem. Soc. Japan*, **12**, 59 (1937).

[CONTRIBUTION FROM THE DEPARTMENT OF CHEMISTRY, UNIVERSITY OF CALIFORNIA, LOS ANGELES]

Flavanones and Related Compounds. IV. The Reduction of Some Naturally-Occurring Flavones at the Dropping Mercury Electrode

BY D. W. ENGELKEMEIR,[1] T. A. GEISSMAN, W. R. CROWELL AND S. L. FRIESS

Methods suitable for the analysis of small amounts of fresh plant tissue for their content of flavonoid substances are of particular interest in connection with studies on the genetical factors which control the synthesis of these substances in the organism. While spectroscopic and colorimetric methods are applicable to the anthocyanin pigments, their application to the analysis of acyanic tissues for flavone derivatives leaves much to be desired. An examination is being made of the behavior of compounds of this class (flavones, flavanones, chalcones and benzalcoumaranones) when they are reduced at the dropping mercury electrode. The only work of a related nature so far reported is the study of Adkins and Cox[2] on the polarographic reduction of a number of chromones, including flavone. Since the compounds in which we are interested are polyhydroxy compounds (and ethers and glycosides of these), further information was needed concerning the effect of the type and position of such substituents upon the reducibility of compounds of the classes mentioned above.

The results reported in the present paper deal with several naturally-occurring flavonols (3-hydroxyflavones) and some of their derivatives. These are quercitrin (I), quercetin (II), quercetin-3′,4′,5,7-tetramethyl ether (III), quercetin pentamethyl ether (IV), quercetin pentaacetate (V), apigenin (VI) and flavonol (VII). The aims of this phase of the study were as follows: (1) To determine the half-wave potentials, or $\pi_{1/2}$ values, at various *p*H's. (2) To determine the relationship between flavone concentrations (*C*) and wave heights (*h*) in the concentration range 10^{-3} to 10^{-4} molar. (3) To study the influence of the nature of the group in the 5-position (H, OH, OCH_3, $OCOCH_3$) on the half-wave potential. (4) To determine the values of the diffusion coefficients, *D*, in the Ilkovic equation $i_D = 605nD^{1/2}m^{2/3}t^{1/6}C$, where *n* is the number of electrons involved in the electrode reaction, *D* the diffusion coefficient and *C* the concentration of the diffusing substance, *m* the mass of mercury dropping per second, in

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[1] Present address: Box 1663, Santa Fe, New Mexico.

[2] Adkins and Cox, THIS JOURNAL, **60**, 1151 (1938).