Some Observations of Ultraviolet Absorption Spectra Involving Partial Chromophores in Di- and Trisubstituted Benzenes

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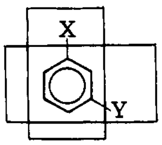
The ultraviolet absorption spectra of substituted benzenes in which absorption by more than one chromophore takes place are discussed. The term "hybrid spectra" is proposed for such cases. It is suggested that this type of absorption is a common feature of the spectra of those disubstituted benzenes in which mesomeric and other interactions are incomplete. The appearance of two high intensity bands at long wave lengths in the spectra of certain trisubstituted benzenes is explained.

It is generally accepted[2] that the mesomeric interactions of conjugated systems are largely responsible for the characteristics of their ultraviolet absorption spectra. If, therefore, a molecule contains two or more absorbing species or "partial chromophores" that are not conjugated with each other, its spectrum will be the sum of the separate absorptions of the partial chromophores. This has been shown for, *e.g.*, 1,4-diphenylbutane,[3] the spectrum of which resembles very closely that of ethylbenzene at twice the concentration.

In disubstituted benzenes, conjugation is at a maximum in the *para* isomer and the molecule generally absorbs as a single chromophore. Partial isolation of the chromophores, leading to local excitation, occurs in *meta*-disubstituted benzenes (I) because of the absence of classical conjugation, and in *ortho*-disubstituted benzenes (II) largely because of steric effects.[4] Although some features of the absorption of both chromophores in an *ortho*- or *meta*-disubstituted benzene will be retained, the spectrum of such a compound will not be a simple summation of the spectra of the two constituent monosubstituted benzenes. This follows firstly because it has been generally shown[5] (*cf.*, however, ref. 6) that separation of two chromophores by a single carbon atom, which is analogous to the separation of groups X and Y in structure I, does not result in complete loss of interaction; secondly because short-range interactions, such as inductive effects and hydrogen bonding, may affect the spectrum of an *ortho*-disubstituted benzene (II). For example, the ultraviolet absorption spectrum of *m*-nitrophenol consists of three bands[7] ascribed to nitrobenzene absorption and one band ascribed to phenol absorption[8-10]; the spectrum is not the sum of the spectra of the two parent compounds, as can be seen from Table I.



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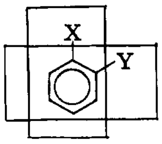


II

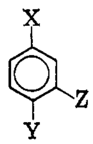
TABLE I

THE ABSORPTION MAXIMA OF NITROBENZENE, PHENOL, AND *m*-NITROPHENOL IN CYCLOHEXANE SOLUTION[a,b]

Bands in nitrobenzene spectrum		Bands in phenol spectrum		Corresponding bands in *m*-nitrophenol spectrum	
λ_{max} (mμ)	ϵ_{max}	λ_{max} (mμ)	ϵ_{max}	λ_{max} (mμ)	ϵ_{max}
206.2	13000[c]			210	10500
253	9000			258.5	6100
ca. 287	*1500*			311	2810
		211	6060	221	10200[d]
		265	1400		
		271	2070	. . .	. . .
		276	1960		

[a] Values italicized represent inflections. [b] From ref. 8-10. [c] A. Burawoy and J. P. Critchley, *Tetrahedron*, **5**, 340 (1959). [d] Partially fused band.

In the case of trisubstituted benzenes, Doub and Vandenbelt[11] have suggested that the absorption spectrum of a compound of type III (in which only one of the substituents is electron attracting) can be interpreted on the assumption that it is a composite of the absorption spectra of the three "constituent compounds," IV, V, and VI. They also stated that each of the bands appearing in the spectrum of the trisubstituted compound corresponded to that band which was at longest wave length among the corresponding bands of the "constituent compounds." This statement will be referred to as "Doub and Vandenbelt's rule."



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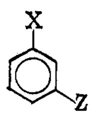

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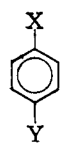
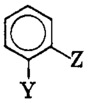


V



VI

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[1] "Shell" Research Limited, Thornton Research Centre, Chester, England.

[2] See, for example, W. F. Forbes and A. S. Ralph, *Can. J. Chem.*, **34**, 1447 (1956), and other papers in that series; B. M. Webster, "Steric Effects in Conjugated Systems," G. W. Gray, Ed., Butterworths Scientific Publications, London, 1958, p. 82; C. N. R. Rao, "Ultraviolet and Visible Spectroscopy," Butterworths Scientific Publications, London, 1961, Chapter 5; A. R. Katritzky and P. Simmons, *J. Chem. Soc.*, 490 (1960).

[3] P. Ramart-Lucas and P. Amagat, *Bull. soc. chim. France*, **51**, 965 (1932).

[4] W. F. Forbes and W. A. Mueller, *Can. J. Chem.*, **34**, 1340 (1956).

[5] P. Ramart-Lucas, *Bull. soc. chim. France*, **10**, 13 (1943); H. P. Koch, *J. Chem. Soc.*, 1111 (1948); E. A. Braude, *ibid.*, 1902 (1949).

[6] F. Yamada, *Kogyo Kagaku Zasshi*, **62**, 1389 (1959).

[7] The band nomenclature used in this paper is that proposed by A. Burawoy [*J. Chem. Soc.*, 1177 (1939) and references cited there] and E. A. Braude [*Ann. Rept. Progr. Chem.*, **42**, 105 (1945)] with the modification that a K band attributed to a chromophore containing an electron-attracting substituent is called a K_A band and one attributed to a chromophore containing only an electron-donating substituent is called a K_D band.

[8] W. F. Forbes, *Can. J. Chem.*, **36**, 1350 (1958).

[9] J. C. Dearden and W. F. Forbes, *ibid.*, **37**, 1294 (1959).

[10] J. C. Dearden and W. F. Forbes, *ibid.*, **38**, 896 (1960).

[11] L. Doub and J. M. Vandenbelt, *J. Am. Chem. Soc.*, **77**, 4535 (1955).

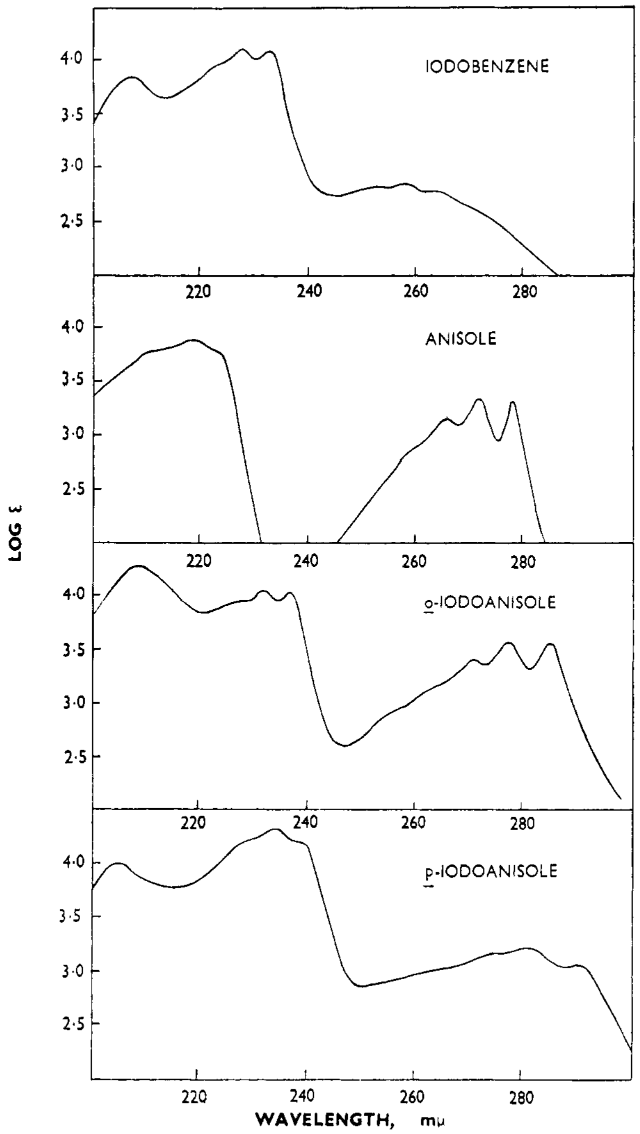

Fig. 1.—The spectra of iodobenzene, anisole, *o*-iodoanisole, and *p*-iodoanisole in cyclohexane solution.

The term "hybrid spectra" is proposed to describe spectra where absorption by more than one chromophore occurs.

The Spectra of Disubstituted Benzenes

The spectrum of a disubstituted benzene generally resembles the spectrum of the parent monosubstituted compound that absorbs at the longer wave length. For example, the spectrum of *p*-nitroanisole resembles that of nitrobenzene[8] rather than that of anisole, and the spectrum of *o*-aminophenol is similar to that of aniline.[12] In these examples, as with most disubstituted benzenes, all the bands in the spectrum of one of the parent monosubstituted compounds are at longer wave length than the corresponding bands in the spectrum of the other. However, some compounds, notably the halobenzenes, are anomalous. For example, the K band of iodobenzene is at longer wave length than that of anisole, but the B band is at shorter wave length (Table II). It would therefore be expected that the spectrum of *o*- or *m*-iodoanisole would exhibit an iodobenzene-type K band and an anisole-type B band.

TABLE II

THE ABSORPTION MAXIMA OF SOME PHENOLS, ANISOLES, AND HALOBENZENES IN CYCLOHEXANE SOLUTION[a]

	K band		B band	
Compound	λ_{max} (mμ)	ϵ_{max}	λ_{max} (mμ)	ϵ_{max}
Phenol[b]	211	6060	265	1400
			271	2070
			276	1960
Anisole[c]	220	7700	265	1400
	ca. 224	*6050*	271.5	2100
			277.5	2050
Iodobenzene[d]	*ca. 224*	*9500*	*ca. 248*	*590*
	228	12700	253	670
	233	12000	257.5	710
			263	620
Chlorobenzene[e]	211	7500	245	70
	215	7500	251	120
	ca. 219	*6000*	257	180
			261	170
			264	250
			270	190
o-Iodophenol[b]	218.5[f]	9250	*ca. 263*	*1350*
	225	8300	270.5	2220
	230	6550	276.5	3010
			284	2800
p-Iodophenol[b]	231.5	15050	276	1280
	ca. 236	*12400*	282	1430
			290.5	1090
o-Iodoanisole[c]	*ca. 213*[f]	*13000*	*ca. 257*[g]	*880*
	ca. 228	*8700*	*ca. 265*	*1540*
	232	10200	271.5	2390
	236.5	10050	278	3380
			285.5	3230
m-Iodoanisole[c]	213[f,h]	25600	*ca. 256*[g]	*860*
	ca. 225	*9200*	*ca. 264*	*1310*
	229.5	9550	270	1970
	ca. 235	*6900*	277	2720
			284.5	2550
p-Iodoanisole[c]	234	19000	276	1450
	ca. 238	*15800*	281.5	1600
			290.5	1200
o-Chlorophenol[b]	212.5	6450	*ca. 257*	*670*
			ca. 267	*1540*
			273.5	2350
			280.5	2440
o-Chloroanisole[c]	*ca. 213*	*7100*	*ca. 261*	*760*
	218.5	7500	*ca. 269*	*1600*
	222.5	7350	275	2400
			282.5	2440

[a] Values italicized represent inflections. [b] Ref. 9. [c] Ref. 13. [d] Ref. 10. [e] Ref. 15a. [f] Ascribed to residual phenol or anisole absorption. [g] Ascribed to residual iodobenzene absorption. [h] Partially fused with Rydberg band.

Table II and Fig. 1 show that this phenomenon is in fact observed. The possibility that steric interactions are responsible for this behavior can be discounted, since it has been shown[13] that even an *o*-*t*-butyl substituent does not cause a steric effect on the spectrum of anisole.

Close inspection of Fig. 1 shows that inflections at *ca.* 213 mμ (ϵ 13,000) and *ca* 257 mμ (ϵ 800) are present in the spectrum of *o*-iodoanisole but that these are not evident in the spectra of iodobenzene and anisole respectively. Since the inflection at 213 mμ is close to the K band of anisole [λ_{max} 220 mμ (ϵ 7700)] and that at 257 mμ is close to the B band of iodobenzene [λ_{max} 257.5 mμ (ϵ 710)], it is suggested that these inflections

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(12) W. F. Forbes and I. R. Leckie, *Can. J. Chem.*, **36**, 1371 (1958).

(13) J. C. Dearden and W. F. Forbes. *ibid.*, **37**, 1305 (1959).

TABLE III

THE ABSORPTION MAXIMA OF *o*-NITROPHENOL AND ITS 3-METHYL DERIVATIVE IN VARIOUS SOLVENTS[a,b]

	o-Nitrophenol				2-Nitro-3-methylphenol			
	K band		B band		K band		B band	
Solvent	λ_{max} (mμ)	ϵ_{max}	λ_{max} (mμ)	ϵ_{max}	λ_{max} (mμ)	ϵ_{max}	λ_{max} (mμ)	ϵ_{max}
Cyclohexane	*ca. 230*[c]	*4000*	346	3700	*ca. 234*[c]	*3350*	351	2900
	271	7400			278	6550		
Ether	*ca. 234*[c]	*3000*	346	3550	*ca. 236*[c]	*2640*	348	1410
	271	6900			278	3300		
Ethanol	*ca. 230*[c]	*3550*	347	3240	*ca. 241*[c]	*1730*	*ca. 277*[c]	*1640*
	272.5	6050			269.5	1730	*ca. 290*[c]	*1130*
							ca. 340	*740*

[a] Values italicized represent inflections. [b] From ref. 19. [c] Ascribed to residual phenol absorption.

represent residual anisole K-band absorption and residual iodobenzene B-band absorption, respectively.[14]

Figure 1 shows that the entire spectrum of *p*-iodoanisole is very similar to that of iodobenzene, that is, the relative positions of the K bands, rather than the relative positions of the B bands, of the parent compounds govern the spectral behavior of the *para*-disubstituted compound. This statement has been found to hold generally for *para*-disubstituted benzenes.

The data of Forbes,[15] and Ferguson and Iredale[16] indicate that other substituted iodobenzenes behave similarly to the iodoanisoles and iodophenols listed in Table II.

As the spectrum of iodobenzene is very different from that of any other monosubstituted benzene, substituted iodobenzenes are excellent model compounds for the study of hybrid spectra. For many other disubstituted benzenes, however, no unambiguous assignment of the absorption bands is possible. For example, Fig. 2 shows that the K band of *o*-chloroanisole resembles that of chlorobenzene and that of anisole. The K band of *o*-chlorophenol resembles that of phenol, in its lack of structure, rather than that of chlorobenzene, although the latter is at longer wave length than that of phenol. The K band of phenol is, however, at an anomalously shorter wave length than would be expected from mesomeric and other considerations[13]; the K band of *o*-chlorophenol is, therefore, probably of phenol type. By analogy, the K band of *o*-chloroanisole can probably be attributed to absorption by an anisole-type chromophore. Table II shows that the B band of *o*-chloroanisole is undoubtedly an anisole-type band.

The occurrence of hybrid spectra in *meta*-disubstituted compounds containing an electron-attracting group has already been mentioned in connection with *m*-nitrophenol (*cf.* also ref. 8,9,12). Evidence that hybridization can occur in the spectra of the corresponding *ortho*-disubstituted benzenes is provided by the spectrum of *o*-nitrophenol, data for which are given in Table III. The inflection at *ca.* 230 mμ in the spectrum of this compound is ascribed to phenol K_D-band absorption, by analogy with the spectrum of *m*-nitrophenol. Since *p*-nitrophenol absorbs as a single chromophore, there is no K_D band in its spectrum.

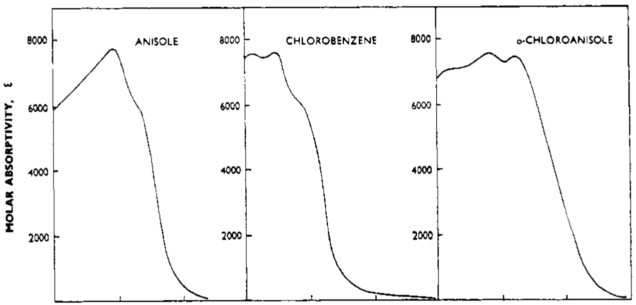
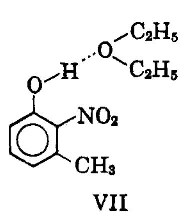
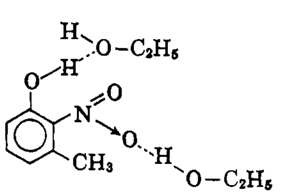


Fig. 2.—The K bands of anisole, chlorobenzene, and *o*-chloroanisole in cyclohexane solution.

It is to be expected that, in *ortho*- and *meta*-disubstituted benzenes, strong absorption by the chromophore containing the electron-attracting substituent will often completely submerge the residual absorption of the other chromophore. If absorption by the former chromophore could in some way be prevented, or greatly reduced, this residual absorption should become apparent. This can be shown to be so by a comparison of the spectra of 2-nitro-3-methylphenol[17] in different solvents, which are shown in Fig. 3 (taken from ref. 19). In cyclohexane solution the spectrum is very similar to that of *o*-nitrophenol (Table II) except for a slight decrease of molar absorptivity due to steric hindrance (*cf.* also ref. 18).

In ether solution a marked decrease in molar absorptivity occurs, which is attributed to an increase in the effective size of the hydroxy group due to competitive intermolecular hydrogen bonding (VII). In ethanol solution, at least two intermolecular hydrogen bonds can be formed (VIII) and the resulting steric interactions force the nitro group to be far from coplanar with the benzene ring. Absorption by the nitrobenzene chromophore is thus reduced to such an extent that the residual phenol B-band absorption becomes evident as fine structure. This phenomenon has been noted for several other substituted 2-nitro-3-methylphenols.[19]


VII


VIII

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[14] Forbes[15c] has pointed out that the B band of *m*-chloroiodobenzene is approximately a summation of the B bands of chlorobenzene and iodobenzene.

[15] (a) W. F. Forbes, *Can. J. Chem.*, **38**, 1104 (1960); (b) W. F. Forbes, *ibid.*, **39**, 1131 (1961); (c) W. F. Forbes, *ibid.*, **39**, 2295 (1961).

[16] J. Ferguson and T. Iredale, *J. Chem. Soc.*, 2959 (1953).

[17] Since the methyl group is only weakly electron donating, its electronic effect on the spectrum may be neglected here, and 2-nitro-3-methylphenol can therefore be regarded as a disubstituted benzene, for the purpose of this argument.

[18] B. M. Wepster, *Rec. trav. chim.* **76**, 335, 357 (1957).

[19] J. C. Dearden and W. F. Forbes, *Can. J. Chem.*, **38**, 1837, 1852 (1960).

TABLE IV

THE ABSORPTION MAXIMA OF SOME DERIVATIVES OF *o*-NITROPHENOL IN CYCLOHEXANE SOLUTION[a]

Compound	*K*$_D$ band λ$_{max}$ (mμ)	*K*$_D$ band ε$_{max}$	K$_A$ band λ$_{max}$ (mμ)	K$_A$ band ε$_{max}$	B band λ$_{max}$ (mμ)	B band ε$_{max}$
4-Nitroresorcinol	231.5	9000	298	12800	...	...
			337	10700		
2-Nitro-5-methoxyphenol[b]	233	5250	307	8500	...	...
	237	5150	340	9000		
3-Methoxy-4-nitrophenol[c,d]	238	6400	*ca. 285*	*4840*	...	...
			328	6900		
2,4-Dimethoxynitrobenzene[b]	231	8700	272	6000	...	...
			308	5450		
2-Nitro-5-phenoxyphenol[c,e]	238	8900	*ca. 315*[f]	*10700*[f]	...	...
			350	14100		
2-Nitro-4-methoxyphenol[b]	244	5900	276.5	6500	388	3900
2,5-Dimethoxynitrobenzene[b]	*ca. 237*	*6300*	*ca. 256*	*2100*	339	2660
2-Nitro-5-chlorophenol[b]	*ca. 228*	*4700*	*281*	9750	340	5170
2-Nitro-5-methylphenol[b]	*ca. 233*	*3000*	281	9000	347	4550
2-Nitroresorcinol[b]	*ca. 230*	*6440*	314	10750	405	1620

[a] Values italicized represent inflections. [b] Ref. 19. [c] In ethanol solution. [d] This compound is almost completely insoluble in cyclohexane; a saturated solution showed very low absorbance bands at *ca.* 270 mμ and *ca.* 310 mμ. [e] Ref. 22. [f] Estimated from graph.

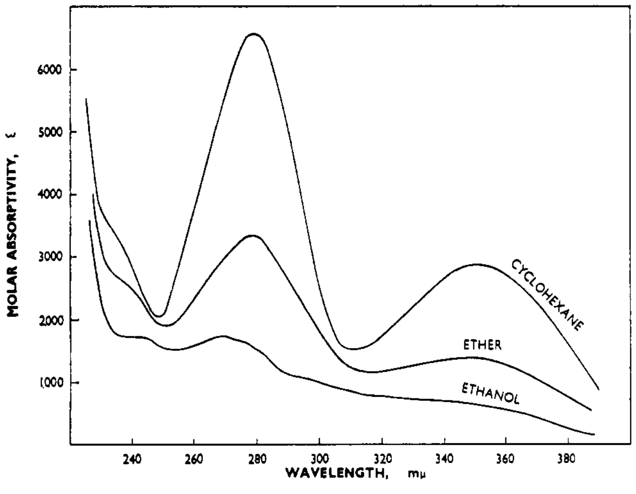


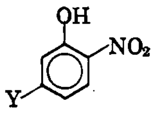
Fig. 3.—The spectra of 2-nitro-3-methylphenol in cyclohexane, ether, and ethanol solutions.

The existence of two absorbing species has thus been demonstrated in a number of *ortho*- and *meta*-disubstituted benzenes where both substituents are electron donating, and also where one of the substituents is electron attracting. There seems no reason why hybridization should not occur when both substituents are electron attracting. However, no conclusive evidence has been found for this. For example, the spectrum of *m*-nitroacetophenone in cyclohexane solution[8] shows an inflection at *ca.* 254 mμ (ε 7000) attributed to nitrobenzene-type absorption, and a peak at 224 mμ (ε 23000) which may be due to acetophenone-type absorption, but which may alternatively be a Rydberg band (possibly with acetophenone-type absorption submerged in it).

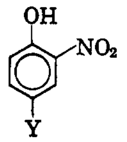
The above evidence suggests that hybrid spectra are by no means uncommon in disubstituted benzenes. It is unfortunate that the number of cases in which hybridization can be detected with certainty is very limited.

The Spectra of Trisubstituted Benzenes

The spectra discussed in this section are those of compounds containing one electron-attracting substituent,[20] since the observations made here arose initially from a previously reported study of the spectra of substituted *o*-nitrophenols.[19] It was noticed that the spectra of certain of these *o*-nitrophenols exhibited two K$_A$ bands (Table IV and Fig. 4). Specifically, this phenomenon occurred when two conditions were satisfied: the third substituent was (i) in the *para* position relative to the nitro group (IX) and was (ii) quite strongly electron donating (*e.g.*, -OH, -OCH$_3$).



IX



X

The phenomenon can be rationalized in terms of the present hypothesis of hybridization if it is assumed that (i) in compounds of type IX, interaction between the hydroxy group and the substituent Y is not complete, and (ii) only if Y is a strongly electron-donating group will it affect the electronic state of the molecule sufficiently for two K$_A$ bands to appear. The occurrence of two K$_A$ bands is therefore ascribed to absorption by two partial chromophores, a *para*-substituted nitrobenzene and an *ortho*-substituted nitrobenzene. In the spectra of compounds of type X, however, only one K$_A$ band is found (Table IV), because the two electron-donating substituents interact to the greatest extent, and act essentially as a single substituent.

In view of these considerations, the first condition for the spectrum of a trisubstituted benzene to display two K$_A$ bands can be generalized as follows: the two electron-donating substituents must not be *para* to each other. From this, it follows that the spectra of compounds of types XI to XV (in which X is electron-attracting and Y and Z are electron-donating substituents) can exhibit two K$_A$ bands, while those of type XVI cannot. Substituents Y and Z may be identical except in compounds of types XIII and XV, in which identical

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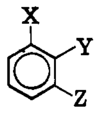
[20] After the completion of the present work, hybridization in the spectrum of 2,4-dinitroaniline, which contains two electron-attracting groups, was reported by E. E. Milliaresi and V. A. Izmail'skii [*Dokl. Akad. Nauk SSSR*, **146**, 1094 (1962)].

TABLE V

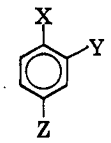
THE ABSORPTION MAXIMA OF SOME BENZENE DERIVATIVES WHICH EXHIBIT TWO K_A BANDS, AND OF THEIR REFERENCE COMPOUNDS[a]

Compound	Solvent or pH	K_A band λ_{max} (mμ)	K_A band ϵ_{max}	B band λ_{max} (mμ)	B band ϵ_{max}
2-Chloro-4-nitrophenol[b]	0.1 *N* HCl	317	8500	. . .	. . .
	0.1 *N* NaOH	265	4000	301	1400
		400	17400	. . .	. . .
m-Chloronitrobenzene[c]	Water	264	7100	313	1300
p-Nitrophenol[c]	pH 3	317.5	10000	. . .	. . .
	1 *N* NaOH	402.5	19200	. . .	. . .
β-Resorcylic acid[b]	pH 7	248	10800	292	4900
	pH 11	248	15400	. . .	. . .
		298	13000		
Salicylic acid[c]	pH 9	230.5	7200	296	3500
	pH 11	242	6900	306	3400
p-Hydroxybenzoic acid[c]	pH 8	245	11900	. . .	. . .
	1 *N* NaOH	280	16300	. . .	. . .
γ-Resorcylic acid[d]	Cyclohexane	263	8330	334	2300
3,4-Dimethyl-γ-resorcylic acid[d]	Cyclohexane	259[e]	14150[e]	356	5000
		272	10250		
3,5-Dimethyl-γ-resorcylic acid[d]	Cyclohexane	268	11250	353	1150
2,6-Dimethyl-4-nitro-N,N-dimethylaniline[f]	96% ethanol	267	5950	. . .	. . .
		380	5450		
4-Nitro-N,N-dimethylaniline[f]	96% ethanol	392	20000	314[g]	1870
2-*t*-Butyl-4-nitro-N,N-dimethylaniline[f]	96% ethanol	272	8650	. . .	. . .
		ca. 340[g]	*1530*		

[a] Values italicized represent inflections. [b] Ref. 11. [c] L. Doub and J. M. Vandenbelt, *J. Am. Chem. Soc.*, 69, 2714 (1947); **71**, 2414 (1949). [d] Ref. 21. [e] Estimated from graph. [f] Ref. 18. [g] Band assignment doubtful.



XI



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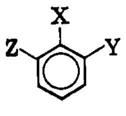

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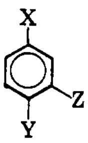

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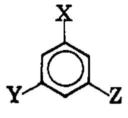

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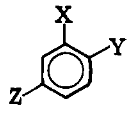

XVI

substituents would each exert exactly the same effect on the electron-attracting substituent. For example, the spectrum of 2-nitroresorcinol has only one K_A band (Table IV), while those of 4-nitrocatechol and 4-nitroresorcinol have two (Tables IV and VI). In addition, the data of Cram and Cranz,[21] which are given in Table V, show that while the spectra of γ-resorcylic acid and its 3,5-dimethyl derivative display only one K_A band, the spectrum of the 3,4-dimethyl derivative (in which the effects of the two hydroxy groups are no longer identical) exhibits two K_A bands.

The data of many workers[11,21-26] entirely bear out these findings. An examination of their results has shown that the spectra of compounds of type XVI never exhibit more than one K_A band. In compounds of types XI to XV, on the other hand, the data include numerous spectra that exhibit two K_A bands; some examples are listed in Table V. However, the phenomenon is not evident in every case. This may be because one of the K_A bands is so much weaker than the other that it is submerged or is mistaken for a B band. An interesting example of this is provided by the spectrum of 2-chloro-4-nitrophenol, the data for which are reproduced in Table V, together with the spectra of its "constituent compounds." In acid solution, this compound apparently exhibits only one K_A band, attributed to *p*-nitrophenol-type absorption. (A band at 231 mμ is ascribed to K_D-band absorption by the chlorobenzene or *o*-chlorophenol chromophore.) In alkaline solution, however, two more bands are evident in the spectrum; the band at 265 mμ can only be attributed to K_A-band absorption by a *meta*-substituted nitrobenzene chromophore, while the peak at 301 mμ is attributed to B-band absorption by the same chromophore. Clearly in acid solution these bands are submerged by *p*-nitro-

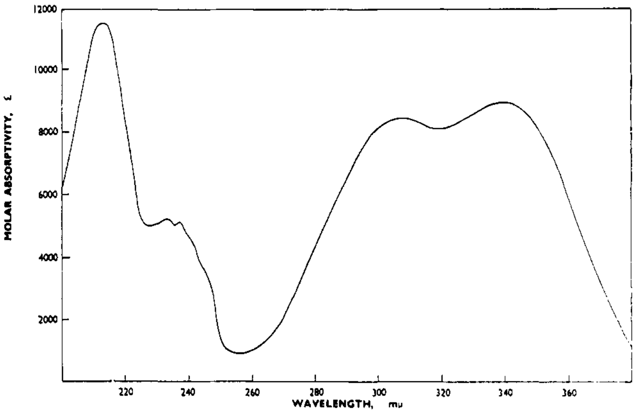

Fig. 4.—The spectrum of 2-nitro-5-methoxyphenol in cyclohexane solution.

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TABLE VI

THE EFFECT OF ALKALI ON THE K_A BANDS OF SOME PHENOLS WHICH EXHIBIT HYBRID SPECTRA[a]

Compound	Solvent or pH	1st K_A band		2nd K_A band[b]	
		λ_{max} (mμ)	ϵ_{max}	λ_{max} (mμ)	ϵ_{max}
2-Methoxy-4-nitrophenol[c]	0.1 *N* HCl	*310*	*5500*	345	7100
	0.1 *N* NaOH	*320*	*1450*	433	17400
3-Methoxy-4-nitrophenol	Ethanol	*ca. 285*	*4840*	328	6900
	0.1 *N* alcoholic NaOH	263	4100	393.5	21300
2-Nitro-5-methoxyphenol	Cyclohexane	340	9000	307	8500
	0.25 *N* NaOH	317	6350	403	7570
3-Methoxy-4-hydroxybenzaldehyde[d]	Ethanol	277[e]	10800[e]	310	10900
	Alkaline ethanol	294[e]	2800[e]	353	30200
3-Methoxy-4-hydroxyacetophenone[e]	Ethanol	276[e]	10100[e]	303	8500
	Alkaline ethanol	*ca. 295*[e]	*3300*[e]	348	24000
2-Amino-4-nitrophenol[f]	pH 5	256	9800	315	5100
	pH 11	275	6900	446	13400

[a] Values italicized represent inflections. [b] Corresponding to chromophore containing the hydroxy group. [c] Ref. 24. [d] Ref. 25. [e] Estimated from graph. [f] Ref. 11.

phenol-type absorption, and appear only when this strong absorption is displaced by the action of alkali. The ability of phenols to ionize in alkaline solution can thus be put to advantage in the identification of bands in hybrid spectra. Table VI gives a number of examples of band identification by this method.

Incomplete conjugation caused by steric hindrance can also lead to the appearance of hybrid spectra, as is shown by the data of Wepster[18] (*cf.* also ref. 23 and 27) on a series of *ortho*-substituted 4-nitro-N,N-dimethylanilines (Table V). The spectrum of 4-nitro-N,N-dimethylaniline itself exhibits only one K_A band; that of the *o-t*-butyl-substituted compound also exhibits only one K_A band (corresponding to nitrobenzene-type absorption, because the N,N-dimethylamino group is no longer conjugated). However, the spectrum of 4-nitro-2,6-dimethyl-N,N-dimethylaniline, which compound is only partially sterically hindered, exhibits two K_A bands, which are ascribed separately to 4-nitro-N,N-dimethylaniline- and nitrobenzene-type absorption.

Experimental

Spectra were determined in duplicate on a Unicam SP 500 spectrophotometer. The wave-length accuracy is estimated to be ±0.5 mμ at 270 mμ, and ±1 mμ at 350 mμ. The precision of ϵ_{max} values is ±5% or better. Values were generally reproducible to ±2%.

The compounds used in this work were mostly commercial materials. Others were prepared by standard methods. All compounds were purified until their melting points or refractive indices showed them to be pure.

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Isomerization and Decomposition Products of Methicillin[1]

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In weakly acidic media, methicillin (**1**) isomerizes to 2,6-dimethoxyphenylpenicillenic acid (**2**) which then decomposes spontaneously to 2,6-dimethoxyphenylpenicilloic acid (**3**), 2,6-dimethoxyphenylpenilloic acid (**4**), 2,6-dimethoxyhippuric acid (**5**), N-formyl-D-penicillamine (**6**), and 3,10-bis(2,6-dimethoxybenzamido)-6,6,13,13-tetramethyl-2,9-dioxo-5,12-dithia-1,8-diazatricyclo[9.3.0.0^{4,8}]tetradecane-7,14-dicarboxylic acid (**7**, see Scheme I). No penillic acid, penilloaldehyde, or penicillamine was detected as a product of this decomposition.

Methicillin (sodium 2,6-dimethoxyphenylpenicillinate, **1**) is a semisynthetic penicillin which has gained clinical importance because of its resistance to destruction by the enzyme penicillinase.[2] Although highly effective when given by injection, it is ineffective when administered orally, probably because of its extreme lability toward acid. We wish to report on the course of the acid decomposition reactions.

The chemistry of the natural penicillins has been exhaustively investigated.[3] Under various acidic conditions, benzyl- and 2-pentenylpenicillins were reported to isomerize to their respective penillic acids or to decompose to D-penicillamine and the appropriate penilloaldehyde. In a more recent study of the decomposition of natural and semisynthetic penicillins in acidic solutions, Dennen and Davis indicated that the penillic and penicilloic acids were the main products formed.[4] An excellent and comprehensive study of spontaneous benzylpenicillin decomposition under mild conditions was recently reported by Hitomi, who identified ten products.[5]

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[1] The trademark of Bristol Laboratories, a Division of Bristol-Myers Company, for methicillin is Staphcillin®.

[2] H. G. Steinman, *Proc. Soc. Exptl. Biol. Med.*, **106**, 227 (1961).

[3] "The Chemistry of Penicillin," H. T. Clarke, J. R. Johnson, and R. Robinson, Ed., Princeton University Press, Princeton, N. J., 1949.

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