Transmission of Substituent Effects through the Methyleneamino Group N=CH: Aldehyde Phenylhydrazones and Conjugate Anions

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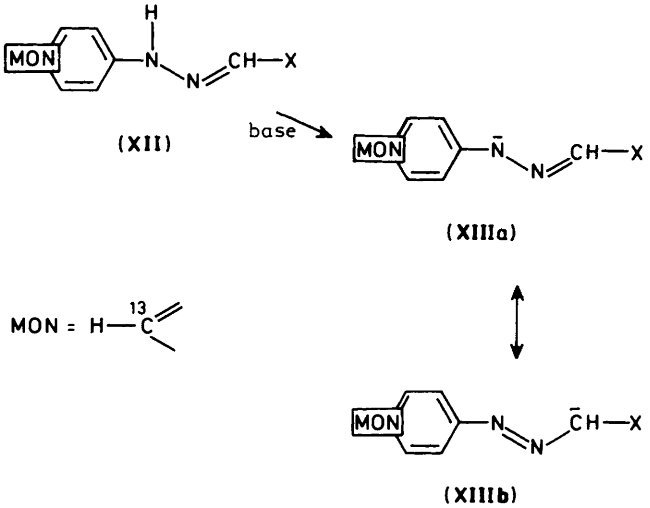
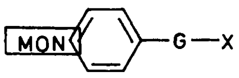
The *para* ^{13}C resonance of the phenyl ring of a series of phenylhydrazones PhNHN=CHX (**XII**) and of their conjugate anions (**XIII**) is taken as a monitor of the effects exerted by the substituent X: the chemical shift variations are treated by monoparametric relationships in terms of the previously defined, blended σ_C^- parameters (mixture of polar-inductive and mesomeric effects), and by biparametric relationships in terms both of the σ_{IB} parameter (representative of the polar inductive effect) and of the σ_R^- parameter (representative of the mesomeric effect exerted by the substituent X). Relative to the PhNHX systems, interposition of the methyleneamino group N=CH in phenylhydrazones (**XII**) induces a decrease to one-third of the transmission of substituent effects. Substituents X = 2-pyridyl, NO_2, CN, COMe, COPh do not correlate in the neutral species (**XII**) with the previously proposed σ constants. It is proposed that the methyleneamino group exerts a short-range electrostatic effect that alters the response of the monitor to the polar-inductive effect exerted by polar substituents X. In the phenylhydrazone anions (**XIII**) a sizeable amount of the negative charge is empirically calculated to be present on the aldehydic methine carbon, in line with the reported nucleophilic character of this centre.

Scales of electron demand of primary functionalities (COR, CN, NO_2, SOR, SO_2R, *etc.*),[1] of substituted aryls,[2] and of heterocycles of the pyridine series [1,3] contiguous to the reaction centre have been reported previously: such electron demand has been given in the form of polar-inductive constants σ_{IB}, as deduced from the response of the *para* ^{13}C shift C(*p*) in $PhCH_2X$ (I), of blended polar-inductive and mesomeric demands σ_C^-, as deduced from the response of C(*p*) in PhNHX (IV), and resonance σ_R^- constants as obtained by the biparametric treatment of the response of C(*p*) in PhNHX (**IV**). All sets of σ_{IB}, σ_C^-, and σ_R^- values have given satisfactory results when applied to a number of families other than (I) and (IV), and have provided insight into the nature and extent of interactions occurring between the two contiguous functionalities, the reacting group G (G = CH_2, NH, O, N^-, CH^-, *etc.*), and the substituent X.[4]





H—G—X

(I) G = CH_2
(III) G = O
(IV) G = NH
(VI) G = CH^-
(VII) G = N^-
(X) G = O
(XI) G = NH

(2) X = Ph
(5) X = COMe
(6) X = COPh
(9) X = NO_2
(10) X = CN
(19) X = 2-C_5H_4N
(20) X = 3-C_5H_4N
(21) X = 4-C_5H_4N
(26) X = Me
(42) X = *p*-BrC_6H_4
(44) X = *p*-$Me_2NC_6H_4$
(45) X = *p*-$MeOC_6H_4$
(46) X = *p*-$NO_2C_6H_4$

We have now investigated the response of the C(*p*) monitor to the electron demand of the substituent functionalities X in the two families (XII) and (XIII) of aldehyde phenylhydrazones and their conjugate anions. The reasons for the choice were the following: (i) the phenylhydrazones (XII) are methyleneamino homologues of the *N*-substituted phenylamines PhNHX (IV) and therefore the substituent X is displaced from the functionality NH or N^-: comparison of the sensitivies of families (XII) and (IV), and (XIII) and (VII) would give us the transmittance efficiency of the CH=N moiety. (ii) The conjugate anions (XIII) of phenylhydrazones (XII) are mesomeric with the α-substituted phenylazo carbanions (**XIIIb**) which, together with closely related systems derived from t-butylhydrazones,[5] have been shown to have interesting synthetic properties.[6] (iii) If supporting evidence is obtained that the anions of phenylhydrazones can indeed be regarded as *X*-substituted phenylazo carbanions (**XIIIb**), it would be possible to obtain the actual π charge residing on the methine carbon by applying the relationship $\delta_{\pm} = \delta_n - k(q - 1)$ given previously.[7] In this context, it would be possible also to obtain empirical, approximate charge maps in the case of anions (**XIII-2**) and (**XIII-26**). (iv) Families (**XII**) and (**XIII**) might be useful for obtaining the electron demand of other heterocycles, whose derivatives in families (**IV**) and (**VII**) are unstable.

To assess the above points, we report herein a ^{13}C n.m.r. study of compounds (**XII**) and their conjugate anions (**XIII**).

Table 1. Stereochemistry and ^1H n.m.r. data of phenylhydrazones of α-substituted formaldehydes PhNHN=CHX

			Literature data				^1H N.m.r. chemical shift δ						
No.	X	M.p. (°C)[a]	M.p. (°C) of *E*	Ref.	M.p. (°C) of *Z*	Ref.	Solvent	*t*/h[b]	Form (%)	Ph	CH	NH	X
(5)	COMe	149—150	148—150	*c*			$CDCl_3$	0	*E* 100	6.90—7.48	6.95	8.88	2.49
							$CDCl_3$	24	*E* 56	6.85—7.42	6.95	8.73	2.49
									Z 44		*d*	13.95	2.29
							Me_2SO	24	*E* 100	6.78—7.42	*d*	11.28	2.35
(6)	COPh	111—112			116—118	*e*	$CDCl_3$	0	*Z* 100	6.95—8.12	7.72	14.50	
					113—114	*f*							
							Me_2SO	24	*Z* 14	6.80—8.21	7.76	14.26	
									E 86		7.78	11.46	
		141—146	146—151	*f*			$CDCl_3$	2	*Z* 100	6.95—8.12	7.72	14.50	
(9)	NO_2	74—75			75—76	*f*	$CDCl_3$	0	*Z* 100	7.02—7.57	7.52	12.46	
							$CDCl_3$	6	*Z* 63	7.00—7.70	7.52	12.51	
									E 27		8.30	8.70	
			85—86	*f*									
			91—92	*g*									
			98—100	*h*									
(10)	CN	162	162	*i*			Me_2SO	0	*E* 100	6.81—7.45		11.79	
					82	*i*							
(26)	CH_3	88—90			90—98	*j*	$CDCl_3$	6	*Z* 55	6.51—7.49	6.68		2.05
									E 45		*d*		1.92
							Me_2SO	0	*Z* 100	6.40—7.30	6.54	9.0	1.92
							Me_2SO	12	*Z* 75	6.40—7.29	6.54	9.0	1.92
									E 25		*d*	9.6	1.95
					56	*j*							

[a] This work. [b] Time intervening between the solution of the sample and the ^1H n.m.r. recording. [c] Ref. 8 (product of unknown stereochemistry). [d] Covered by aromatic peaks. [e] Ref. 9(*a*). [f] Ref. 9(*b*). [g] Ref. 11. [h] Ref. 6(*b*). [i] Ref. 10. [j] Ref. 15.

Experimental

Varian EM 390, XL-200, and XL-300 instruments, operating at 90 (^1H), 50.21 (^{13}C), and 75.3 MHz (^{13}C) respectively were used to obtain n.m.r. spectra.

Materials.—The phenylhydrazones of α-substituted formaldehydes (**XII-5**),[8] (**XII-6**),[9] and (**XII-10**)[10] were prepared by coupling of benzenediazonium chloride with ethyl acetoacetate, ethyl benzoylacetate, and ethyl cyanoacetate respectively, followed by alkaline hydrolysis and decarboxylation. Compound (**XII-9**) was prepared analogously by coupling of benzenediazonium chloride with nitromethane.[11] All products were purified by column chromatography. Phenylhydrazones of acetaldehyde (**XII-26**), of aryl, and heteroaryl aldehydes were prepared from phenylhydrazine and the corresponding aldehyde. Deprotonation of phenylhydrazones (**XII**) to the corresponding anions (**XIII**) was performed by sodium dimsyl in dimethyl sulphoxide, directly in the n.m.r. tube, by a well established procedure.[4d,7]

β-*Phenylazostyrene.* This compound was prepared according to the reported procedure,[12] δ_C (75.30 MHz) 142.59 (α-C), 146.61 (β-C); styrene ring, 128.04 (*o*-C), 129.05 (*m*-C), 129.81 (*p*-C), 134.99 (*ipso*-C); phenylazo ring, 122.74 (*o*-C), 129.15 (*m*-C), 130.85 (*p*-C), and 152.95 (*ipso*-C).

Results

Stereochemistry of the Phenylhydrazones (**XII**).—Compounds (**XII-5**),[13] (**XII-6**),[13,14] (**XII-9**),[9,11] (**XII-10**),[10] and (**XII-26**)[15,16] are known to exist as both the *Z* and *E* isomers.* Interconversion of the isomers is also known to occur in solution, and in some cases the process is facile: the nature of the solvent often dictates which one of the two forms predominates at equilibrium. Criteria for the assignment of configuration have been given[16] and discussed, and are essentially based on different proton shifts of (i) the NH proton, (ii) the methine proton, and (iii) the X group when this is an alkyl chain. Since we had to record the ^{13}C n.m.r. spectra of compounds (**XII**) in Me_2SO to check with previous work,[1–4] and since recording the spectra required some time, it was essential for us to know which isomer was present at equilibrium, irrespective of the form in the solid state. The ^{13}C assignments reported in Tables 2 and 3 were thus made on the basis of the configurational assignment performed by ^1H n.m.r. spectroscopy, under conditions of thermodynamic control: data are reported in Table 1.

The phenylhydrazone of acetaldehyde was obtained as the *Z* isomer which slowly isomerizes into a mixture of the *Z* and *E* forms in Me_2SO and more rapidly in $CDCl_3$. The *Z* form, initially present in Me_2SO, has a distinctive feature in the ^{13}C n.m.r. spectrum which allows it to be discriminated from the *E* form: in the *Z* form the $^1J_{CH}$ of the 'aldehydic' methine carbon is larger ($^1J_{CH}$ 180 Hz) than in the *E* form ($^1J_{CH}$ 160 Hz). Although we believe that this parameter can be used successfully to discriminate between the *Z* and *E* forms of a given phenylhydrazone, it should be pointed out that it should not be used as an absolute measure because the actual size of ^1J also depends on the nature of the neighbouring group. In fact, it can be seen in Table 6 that in the phenylhydrazone of nitroformaldehyde (**XII-9**) and of cyanoformaldehyde (**XII-10**) the $^1J_{CH}$ coupling of the methine carbon is high, notwithstanding the fact that the configuration is *E*. However, when the ^1J couplings of both isomers of a phenylhydrazone are available, the larger coupling should be assigned to the *Z* isomer. Unfortunately, we could not check experimentally the predictive usefulness of this parameter in the case of the isomers present in Me_2SO for the phenylhydrazone of phenylglyoxal (**XII-6**) and nitroformaldehyde (**XII-9**). In fact, the percentage of the isomer present in minor amounts was so small (10 and 5%, respectively) that the CH resonance was barely observable for (**XII-6**) and the coupling constant could not be obtained due to the overcrowding of peaks in that area of the spectrum. Phenylhydra-

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* In the old literature the *cis*, or α, or *syn* form corresponds to the *Z* isomer, while the *trans*, or β, or *anti* form corresponds to the *E* isomer.

Table 2. ^{13}C Chemical shifts [δ (p.p.m.)] of α-substituted formaldehyde phenylhydrazones[a]

X		C_o	C_m	C_p	C_i	CH	Others
Me	(45%) *Z*	112.37	128.73	118.43	146.22	135.29[b]	CH_3, 13.48
	(55%) *E*	111.49	128.77	117.58	146.22	136.29[c]	CH_3, 17.98
COMe	(100%) *E*	113.44	129.31	121.53	143.26	134.65	CO, 196.3; CH_3, 24.06
COPh	(90%) *E*	113.69	129.45	121.79	143.26	133.73	CO, 189.22; $C_{o'}$, 129.45; $C_{m'}$, 128.12; $C_{p'}$, 131.93; $C_{i'}$, 137.44
	(10%) *Z*	116.44	129.45	123.60	137.37	133.32	CO, 182.17; $C_{o'}$, 128.98; $C_{m'}$, 129.45; $C_{p'}$[d]; $C_{i'}$, 142.67
CN	(100%) *E*	113.33	129.36	121.97	142.66	106.67	CN, 117.51
NO_2	(95%) *E*[e]	114.38	129.58	123.18	142.17	136.21	
	(5%) *Z*[e]	115.46	129.43	124.4	*d*	*d*	

[a] Shifts are relative to Me_4Si as external standard for 0.33M solutions in Me_2SO: coupling constants are in Hz. [b] Double doublet, ^1J 180.6, ^3J(C–C–N*H*) 6.5. [c] Doublet ^1J 160. [d] Not detectable. [e] Assumed.

Table 3. ^{13}C Chemical shifts [δ (p.p.m.)] of (hetero)arylaldehyde phenylhydrazones[a]

X	C_o	C_m	C_p	C_i	CH	C(1)	C(2)	C(3)	C(4)	C(5)	C(6)	Others
Ph	111.94	129.01	118.67	145.27	136.38	135.79	128.12	128.56	127.83	128.56	128.12	
p-$Me_2NC_6H_4$	111.63	128.93	117.84	145.80	137.70	123.72	126.15	112.09	150.18	112.09	126.15	Me, 39.88
p-$MeOC_6H_4$	111.77	128.96	118.27	145.50	136.53	128.47	126.96	114.11	159.23	114.11	126.96	Me, 55.17
p-BrC_6H_4	112.14	129.10	118.96	145.14	135.09	135.22	127.42	131.52	120.63	131.52	127.42	
p-$NO_2C_6H_4$	112.60	129.23	119.92	142.67	133.63	144.50	125.98	121.03	146.04	121.03	125.98	
2-C_5H_4N	112.19	129.13	119.38[b]	144.64	136.30[c]		154.61[d]	122.26[e]	136.63[f]	118.51[g]	148.99[h]	
3-C_5H_4N	112.18	129.06	119.12[i]	144.95	133.19		147.24[j]	131.68	131.89[k]	123.66[l]	148.47[m]	
4-C_5H_4N	112.46	129.13	119.70	144.51[n]	133.30		149.82	119.60	142.96[n]	119.60	149.82	

[a] Chemical shifts are relative to external Me_4Si for 0.33M solutions in Me_2SO: coupling constants are in Hz. C_o, C_m, C_p, C_i are relative to the phenyl ring of the phenylhydrazine while C(1), C(2), *etc.* are relative to the aryl ring of the aldehyde. [b] dt, ^1J 159.9, $^3J_{CH(o)}$ 8. [c] broad d, ^1J 166. [d] m, $^3J_{CH(6)}$ 10.6, $^3J_{CH(4)} \approx {}^2J_{C\text{–}CH} \approx 6$. [e] dt, ^1J 164.8, $^3J_{CH(5)} \approx {}^3J_{C\text{–}CH} \approx 8.2$. [f] dd, ^1J 162.2, $^3J_{CH(6)}$ 5.4. [g] ddd, ^1J 166.3, $^3J_{CH(3)}$ 7, $^2J_{CH(6)}$ 2.9. [h] dq. ^1J 177.1, $^3J_{CH(4)}$ 6.9, $^2J_{CH(5)}$ 2.6. [i] dt, ^1J 160, $^3J_{CH(o)}$ 6.4. [j] dquint, ^1J 177.7, $^3J_{C\text{–}CH} \approx {}^3J_{CH(4)} \approx 5$, $^3J_{CH(6)}$ 10. [k] ddd, ^1J 162.9, $^3J_{CH(6)} \approx {}^3J_{CH(2)} \approx {}^3J_{C\text{–}CH}$ 6; [l] dd, ^1J 164.3, $^2J_{CH(6)}$ 9. [m] dseptet, ^1J 180.3, $^3J_{CH(2)}$ 12.3, $^3J_{CH(4)}$ 6.8, $^2J_{CH(5)}$ 2.6. [n] The assignment can be reversed.

Table 4. ^{13}C Chemical shifts [δ (p.p.m.)] of anions of α-substituted formaldehyde phenylhydrazones[a]

X		C_o	C_m	C_p	C_i	CH	Others
Me	(55%) *E*	111.21	128.17	109.39	158.37	127.64[b]	Me, 18.69
	(45%) *Z*	112.29	127.97	109.23	156.77	126.66[c]	Me, 14.56
COMe		117.45	128.02	119.33	156.15	128.82	CO, 189.91; Me, 23.78
COPh		118.91	128.22	120.97	156.54	128.92	CO, 181.5; $C_{o'}$, 127.09; $C_{m'}$, 128.27; $C_{p'}$, 128.27; $C_{i'}$, 142.61
CN		116.64	128.01	117.61	157.19	89.14	CN, 126.60
NO_2		120.04	128.54	124.52	154.94	133.26	

[a] Chemical shifts are relative to external Me_4Si for 0.33M solutions of substrate and base in Me_2SO. [b] ^1J 155.6. [c] ^1J 173.

zones of formaldehydes α-substituted with groups X that can hydrogen bond intramolecularly with the NH proton (X = NO_2, COMe, COPh) are present as mixtures of the *Z* and *E* isomers in $CDCl_3$, once equilibration has been given enough time to occur. The same compounds are predominantly present as the *E* isomers in Me_2SO, under the same conditions. Evidently, hydrogen bonding to Me_2SO stabilizes the *E* form, while in $CDCl_3$, in the absence of hydrogen bonding to the solvent, the *Z* form, which can hydrogen bond intramolecularly, competes substantially with the inherently more stable *E* form.

Phenylhydrazones of substituted benzaldehydes and pyridinecarbaldehydes show only one isomer in the ^1H and ^{13}C n.m.r. spectra that is assumed to possess the *E* configuration.

^{13}C *N.m.r. Spectra.*—Tables 2 and 4 report ^{13}C n.m.r. data for the phenylhydrazones of α-substituted formaldehydes and for their conjugate anions, respectively: Tables 3 and 5 report ^{13}C n.m.r. data for the phenylhydrazones of substituted benzaldehydes and pyridine carbaldehydes and for their conjugate anions, respectively. Table 6 collects the $^1J_{CH}$ coupling constants of the aldehydic methine carbon in phenylhydrazones (**XII**) and their conjugate anions (**XIII**).

Assignment of the ^{13}C peaks to the various carbons of the phenylhydrazones (**XII**) and their anions (**XIII**) was based on proton-coupled spectra and analogies of chemical shifts, intensity ratios, coupling constants, and patterns of similarly substituted phenyl rings.[1–4]

Interpretation of the spectra was thus straightforward for the neutral and anionic phenylhydrazone derivatives of α-substituted formaldehydes (**5**), (**6**), (**9**), (**10**), and (**26**), and of substituted benzaldehydes (**2**), (**42**), and (**44**)—(**46**): in this latter case the assignment of peaks to carbons of the substituted aryl group was aided by the additivity of substituent effects on chemical shifts.[17] No details other than the carbon chemical shifts are reported herein and in the Tables, since they do not add anything new to data in textbooks. Instead, because of the crowding of peaks in a restricted area of the spectrum, more detailed analysis was necessary to interpret the spectra of the phenylhydrazones of pyridinecarbaldehydes and their conjugate anions. For these six cases (three neutral species and three anions), the $^1J_{CH}$ and long-range coupling constants of the carbons of the heterocyclic moiety are reported in Tables 3 and 5, along with the chemical shifts. In the majority of cases the assignments were based on shifts, multiplicity of peaks, and the size of the coupling constants for the unsubstituted pyridine[18] and for some derivatives,[19,20] but in a number of cases assign-

Table 5. ^{13}C Chemical shifts [δ (p.p.m.)] of the anions of (hetero)arylaldehyde phenylhydrazones[a]

X	C_o	C_m	C_p	C_i	CH	C(1)	C(2)	C(3)	C(4)	C(5)	C(6)	Others
Ph	113.91	127.96	111.60	159.10	126.85	141.25	122.60	127.87	121.62	127.87	122.60	
p-$Me_2NC_6H_4$	112.87	128.02	110.20	158.53	130.05	147.29	124.16	113.01	128.97	113.01	124.16	Me[b]
p-$MeOC_6H_4$	113.23	128.07	111.04	158.74	127.85	155.73	124.04	113.80	135.73	113.80	124.04	Me, 54.94
p-BrC_6H_4	114.77	127.98	112.75	159.75	124.37	141.03	123.72	130.55	112.52	130.55	123.72	
2-C_5H_4N	115.08	128.03	113.81[c]	158.66[d]	127.46		159.85[e]	115.53[f]	134.04[g]	115.81[h]	148.21[i]	
3-C_5H_4N	114.25	128.16	113.59[j]	157.26	127.98[k]		144.89[l]	136.59[m]	123.60[n]	123.26[o]	142.45[p]	
4-C_5H_4N	114.82	128.32	116.29[q]	154.65[r]	125.50		148.67[s]	116.91[t]	146.50[u]	126.91[t]	148.67[s]	

[a] See Table 3 for the recording conditions and explanatory notes. [b] Covered by the solvent. [c] dt, ^1J 158.3, $^3J_{CH(o)}$ 7.4. [d] t, $^3J_{CH(m)}$ 7.6. [e] dt, $^2J_{C-CH}$ 11, $^3J_{CH(4)} = J_{CH(6)}$ 7. [f] dt, ^1J 163.2, $^3J_{C-CH} \approx {}^3J_{CH(5)}$ 7.7. [g] dd, ^1J 158.3, $^3J_{CH(6)}$ 7.1. [h] dm, ^1J 162, $^3J_{CH(3)}$ 6, $^2J_{CH(6)}$ 3. [i] ddd, ^1J 172.6, $^3J_{CH(4)}$ 6.9, $^2J_{CH(5)}$ 3.3. [j] dt, ^1J 158.2, $^3J_{CH(o)}$ 7.4. [k] dt, ^1J 161, $^3J_{CH(2)} \approx {}^3J_{CH(4)} \approx 5$. [l] dm, ^1J 179.7, $^3J_{CH(6)}$ 12, $^3J_{CH(4)} \approx {}^3J_{C-CH} \approx 6.2$. [m] m, $^2J_{C-CH}$ 11.5, $^3J_{CH(5)}$ 8, $^3J_{CH(2)}$ 2.5. [n] dt, ^1J 159, $^3J_{CH(2)} \approx {}^3J_{CH(6)} \approx 4.6$. [o] dd, ^1J 159, $^3J_{CH(6)}$ 9. [p] dm, ^1J 181.6, $^3J_{CH(2)}$ 12.3, $^3J_{CH(4)}$ 8, $^2J_{CH(5)}$ 2.5. [q] dt, ^1J 158.3, $^3J_{CH(o)}$ 7.4. [r] t, $^3J_{CH(m)}$ 6. [s] dm, ^1J 173, $^3J_{C(2)H(6)} \approx {}^3J_{C(6)H(2)} \approx 11$, $^2J_{C(2)H(3)} \approx {}^2J_{C(6)H(5)} \approx 3$. [t] dquintet, ^1J 160, $^3J_{C-CH}$ 8, $^3J_{CH(3)} \approx {}^3J_{CH(5)}$ 5, $^2J_{C(5)H(6)} = {}^2J_{C(3)H(2)} = 5$. [u] m, $^2J_{C-CH}$ 11, $^3J_{CH(2)} \approx {}^3J_{CH(6)}$ 5.

Table 6. One-bond coupling constant $^1J_{CH}$ of the aldehydic methine carbon in (**XII**) and (**XIII**)

X	(**XII**) $^1J_{CH}$	(**XIII**) $^1J_{CH}$
Me (Z) (45%)	180.6	173
(E) 55%)	160	155.6
COMe	166.7	157.4
COPh	166.9	151
CN	184.5	172
NO_2	210	195
Ph	160	155
p-$Me_2NC_6H_4$	156.7	154
p-$MeOC_6H_4$	162	152.3
p-BrC_6H_4	162	156
2-C_5H_4N	166.1	159
3-C_5H_4N	161.9	161
4-C_5H_4N	162.9	158.7

Table 7. Shielding constants A_i for the X groups and π electron densities at the methine carbon in PhN^-–N=CHX (**XIII**), calculated by equation (1)

Substituent X	A_i	Ref.	$\delta^{\pm}$	δ_n	q_{CH}
COMe	14.90	a	128.82	172.01	1.27
COPh	9.30	a	128.92	166.41	1.23
CN	−14.60	a	89.14	142.51	1.33
NO_2	22.80	a	133.26	179.91	1.29
Ph	13	a	126.85	170.11	1.27
p-$Me_2NC_6H_4$	13.87	b	130.05	170.98	1.25(5)
p-$MeOC_6H_4$	13.49	b	127.85	170.6	1.27
p-BrC_6H_4	12.96	b	124.37	170.07	1.28(5)
2-C_5H_4N	13.82	a	127.4	170.93	1.27
Me	13		126.66 127.64	170.11 170.11	1.27[c] 1.26(5)[d]
PhN=N	34.31	e			

[a] Ref. 21. [b] This work, as a difference of arylsubstituted styrenes (ref. 22) and styrene. [c] For the Z isomer. [d] For the E isomer. [e] This work.

ment of the shifts and coupling constants had to be confirmed by heteronuclear selective decouplings.

In the phenylhydrazone of pyridine-2-carbaldehyde both C(3) and C(p) appear as double triplets: discrimination between the two is based upon the fact that ^1J for C(p) is smaller than in the pyridine ring. Discrimination between C(3) and C(5) is based upon the multiplicity due to long-range couplings: C(5) gives a double double doublet while C(3) yields a double triplet. In the phenylhydrazone of pyridine-3-carbaldehyde, C(2) can be distinguished from C(6) because of its multiplicity and particularly because of its coupling with the aldehydic methine proton. As usual, C(p) is a double triplet: the lower multiplicity of the aldehydic methine carbon relative to C(4) allows their distinction. In the phenylhydrazone of pyridine-4-carbaldehyde C(2) and C(6) are assigned to resonances at lower field than those of C(3) and C(5), in turn distinguished from C(p) because of their double intensity.

In the anion of the phenylhydrazone of pyridine-2-carbaldehyde C(p) of the phenyl ring and C(3) and C(5) of the heterocycle are shifted to higher field relative to the neutral precursor. While C(p) and C(3) are expected to give double triplets C(5) is expected to form a double multiplet: the different multiplicity thus distinguishes C(5) from C(3) and C(p). Since the long-range couplings of these two carbons are of the same size, no distinction was possible on this basis. The definite identification of C(p) was obtained by performing selective decoupling by irradiating H(p) in the ^1H n.m.r. spectrum. This was easily discernible as a double triplet and distinguishable from H(3) which was present as a doublet. C(*ipso*) was distinguished from C(2) as the former was present as a triplet while the latter was a multiplet because the various possible long-range coupling constants are all different from one another. In the anion of the phenylhydrazone of pyridine-3-carbaldehyde, C(2) can be distinguished from C(6) because of the different multiplicity and because of coupling with the aldehydic methine proton. In the anion of the phenylhydrazone of pyridine 4-carbaldehyde, the pyridine ring is symmetrical with regard to C(3) and C(5) and C(2) and C(6): these latter carbons have been assigned to the lower field peaks showing larger coupling constants. The quaternary carbons C(*ipso*) and C(4) are distinguished because the former is a triplet while the latter is a multiplet showing coupling to the aldehydic methine proton.

Inspection of Tables 2—5 discloses that deprotonation of the phenylhydrazones induces high-field shifts for all the carbons expected to carry some negative charge, not only of the phenyl ring bonded to N^- but also of the aryl ring of the aldehydic portion and the methine carbon. One important feature worth noting is that the $^1J_{CH}$ coupling constant of the aldehydic methine carbon generally decreases on going from the neutral (**XII**) to the anion (**XIII**). If the highfield displacement of this sp^2-hybridized carbon in anions (**XIII**) relative to the neutral species is associated primarily with the presence of the negative charge, it must be concluded then that the presence of such negative charge induces a decrease of the $^1J_{CH}$ coupling constant.

Charge Maps.—The extended form of the relationship that links through the proportionality constant k = 160 p.p.m. per electron of the actual shift of a charged carbon $\delta_{\pm}$ to the π electron density q residing thereon also contains the shielding constants A_i exerted by the groups directly bonded to the charged carbon: in the case of the anions Ph–N=N–CH^-–X (**XIIIb**) it is necessary to know the A_i values for a number

Table 8. Intersystem and Hammett-type monoparametric correlations

Entry	System(s)	*y*	*x*	Slope	Intercept	*r*	*n*	X
1	**(XII)**—**(IV)**	C(*p*) of **(XII)**	C(*p*) of **(IV)**	0.31 ± 0.02	81.90 ± 0.05	0.987	8	Ph,*p*-BrC_6H_4, *p*-$MeOC_6H_4$, *p*-$Me_2NC_6H_4$, *p*-$NO_2C_6H_4$, 3-C_5H_4N, 4-C_5H_4N, Me
2				0.31 ± 0.03	81.38 ± 0.07	0.972	9	As entry 1 + 2-C_5H_4N
3				0.52 ± 0.07	56.89 ± 0.22	0.904	13	As entry 2 + COMe, COPh, NO_2, CN
4	**(XII)**	C(*p*)	σ_C^-	3.09 ± 0.20	117.25 ± 0.04	0.989	7	Ph, *p*-BrC_6H_4, *p*-$MeOC_6H_4$, *p*-$Me_2NC_6H_4$, *p*-$NO_2C_6H_4$, 3-C_5H_4N, 4-C_5H_4N
5				3.11 ± 0.34	117.30 ± 0.07	0.967	8	As entry 4 + 2-C_5H_4N (0.55)[a]
6				3.07 ± 0.19	117.26 ± 0.04	0.989	8	As entry 4 + 2-C_5H_4N (0.71)[a]
7				3.89 ± 0.19	118.31 ± 0.08	0.996	5	COMe, COPh (90%), CN, NO_2 (95%), Me (0.04,[a] 118.43[b])
8				4.84 ± 0.60	116.70 ± 0.19	0.924	13	Entry 6 + entry 7
9	**(XIII)**—**(VII)**	C(*p*) of **(XIII)**	C(*p*) of **(VII)**	0.95 ± 0.07	8.58 ± 0.31	0.981	10	Ph, *p*-BrC_6H_4, *p*-$MeOC_6H_4$, *p*-$Me_2NC_6H_4$, 3-C_5H_4N, 4-C_5H_4N, COMe, COPh, NO_2, CN
10				0.93 ± 0.09	10.24 ± 0.41	0.958	11	As entry 9 + 2-C_5H_4N
11	**(XIII)**	C(*p*)	σ_C^-	10.94 ± 1.91	107.35 ± 0.33	0.944	6	Ph, *p*-BrC_6H_4, *p*-$MeOC_6H_4$, *p*-$Me_2NC_6H_4$, 3-C_5H_4N, 4-C_5H_4N
12				11.08 ± 1.73	107.34 ± 0.28	0.944	7	As entry 11 + 2-C_5H_4N (0.55)[a]
13				14.71 ± 1.14	105.80 ± 0.33	0.974	11	As entry 12 + COMe, COPh, NO_2, CN

[a] σ_C^-. [b] Selected chemical shift value.

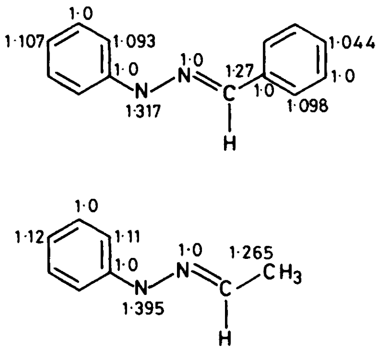

Figure 1. Empirical π electron density maps in phenylhydrazone anions obtained from equation (1)

of primary functionalities,[21] of substituted aryls, and of the phenylazo group (PhN=N–). It should be recalled that the A_i values are obtained as the difference of the chemical shift of C(1) in ethylenes substituted at position 1 with the *i*th group, and the chemical shift of ethylene itself: thus, the A_{Ar} values for the substituted aryl compounds have been obtained from the known shifts of aryl-substituted styrenes.[22] The $A_{PhN=N}$ value should be obtained from the shift of C(1) in phenylazoethene: actually, we obtained the value from the shift of C(2) of 2-phenylazostyrene by subtracting the shift of C(2) of styrene (δ 112.3 p.p.m.). Table 7 reports the A_i values for the X groups considered here and for the phenylazo group: Table 7 also reports the q_{CH} values relative to the aldehydic methine carbon. Since by applying equation (1) we cannot calculate the charge density residing on the non-iminyl nitrogen, complete charge maps cannot be obtained for those phenylhydrazone anions whose X groups contain heteroatoms capable of delocalizing the negative charge (NO_2, COR, CN, pyridyl). For the anions **(XIII-2)** and **(XIII-26)** approximate charge maps can be obtained however, provided that the charge density on the non-iminyl nitrogen is calculated as the difference between the total number of conjugated π electrons present in the molecule and the summation, extended over all the carbon atoms of the frame, of the local π electron densities q_C.* There are two possibilities for calculating the actual electron densities on each carbon of the phenyl ring(s) of **(XIII-2)** and **(XIII-26)**, depending upon the choice of the neutral δ_n: either the neutral δ_n values are assumed to be the carbons of the phenylhydrazone **(XII)** or δ_n is assumed to be that of benzene (δ 127.8 p.p.m.). Since in phenylhydrazones the delocalization of the nitrogen lone pair is already operative, we believe that the phenylhydrazone carbons would be a bad model for providing the chemical shifts δ_n. Therefore the charge maps reported in Figure 1 have been calculated assuming δ_n 127.8 p.p.m. for the *ortho* and *para* positions of the phenyl rings: by analogy with the Hückel computational method, we assumed a π electron density of 1 for the quaternary and *meta* carbons. The π electron density at the non-iminyl nitrogen [relative to structure **(XIIIa)**] was obtained as the difference from the total of 16π electrons in **(XIII-2)**, and of 10π electrons in **(XIII-26)**, respectively.

$$\delta_{\pm} = 122.8 + \Sigma A_i - k(q - 1) \qquad (1)$$

Correlation Analysis.—Data for intersystem and Hammett-type correlations are reported in Table 8, while the fitting parameters for the biparametric correlations are collected in

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* Since with equation (1) it is impossible to carry out empirical computations for the π charge density residing on heteroatoms, we have to assume that no extra negative charge resides on the iminyl nitrogen: this should not be too bad an approximation in view of the fact that the central carbon in allylic anions has q_C *ca.* 1.[7]

Table 9. Fitting parameters of biparametric correlations

Entry	System	y	ρ_I	ρ_R	Intercept	b[a]	r[a]	n	X
1	(XII)	C(p)	4.42 ± 1.17	3.71 ± 0.44	117.25 ± 0.07	0.999	0.997	8	Ph, p-BrC_6H_4, p-$OMeC_6H_4$, p-$Me_2NC_6H_4$, p-$NO_2C_6H_4$, 2-C_5H_4N (0.12, 0.41),[b] 3-C_5H_4N, 4-C_5H_4N
2	(XII)	C(p)	5.47 ± 1.10	5.56 ± 1.72	116.83 ± 0.62	1.00 ± 0.13	0.928	12	As entry 1 + COMe, COC_6H_4, NO_2, CN
3	(XIII)	C(p)	10.82 ± 1.80	22.65 ± 3.17	105.57 ± 0.99	1.00 ± 0.07	0.977	11	Ph, p-BrC_6H_4, p-$OMeC_6H_4$, p-$Me_2NC_6H_4$, 2-C_5H_4N (0.12, 0.31),[b] 3-C_5H_4N, 4-C_5H_4N, COMe, COC_6H_4, NO_2, CN

[a] b and r are respectively the slope and the correlation coefficient of the straight line obtained by plotting the experimental C(p) values against the values calculated using the reported fitting parameters. [b] σ_{IB}, σ_R^-.

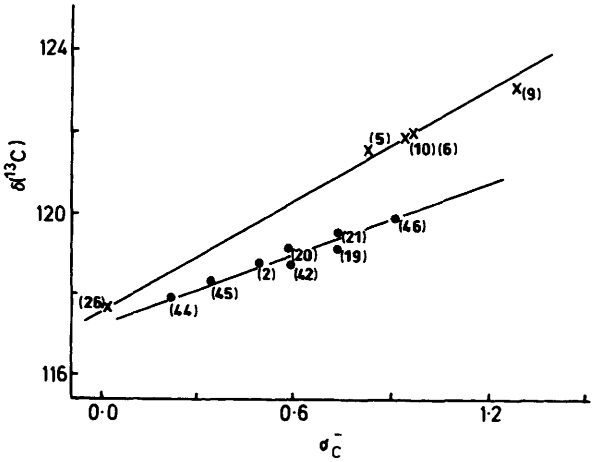


Figure 2. $^{13}C(p)$ of PhNHN=CHX as a function of σ_C^-. With reference to fitting parameters of Table 8, entry 6 pertains to the straight line formed by points designated ●; entry 7 to the line formed by points designated ×. Key to numbers in formulae

Table 9. Small substituent effects are shown by C(p) of the phenyl ring in phenylhydrazones: in fact the slope of the good correlation of the phenylhydrazones (**XII**) for aryl and heteroaryl aldehydes (with the exclusion of 2-pyridyl), and of the phenylamines (**IV**) (entry 1) indicates that $^{13}C(p)$ of the phenyl ring in (**XII**) is *ca.* 3 times less sensitive than in (**IV**). This means that the CH=N spacer present in between the NH group G and the substituent X reduces the transmission by 2/3. The correlation in entry 1 deteriorates by including the 2-pyridyl point (entry 2) and becomes even worse by including the COMe, COPh, NO_2, and CN points (entry 3). The incoherent substituent effect exerted by the 2-pyridyl group becomes evident on comparing entries 4—6 of Table 8. The σ_C^--constant for 2-pyridyl for the PhNHX (**IV**) system (0.55) produces a deterioration in the relationship of entry 4, while the enhanced value of 0.71 works quite well (entry 6). Astonishingly, the σ_C^- value required by the 2-pyridyl group in the anions of phenylhydrazones (**XIII**) is 0.55 and not 0.71, as indicated by comparing entries 11 and 12 of Table 8. The chemical shift of C(p) of phenylhydrazones (**XII**) with X = COMe, COPh, NO_2, CN, and Me appears to fit better a line (Figure 2) with a slope (3.89, entry 7) increased relative to that of entry 1. Again, as in the case of the 2-pyridyl substituent, the COMe, COPh, NO_2, and CN points also do not deviate particularly for the anions of phenylhydrazones (**XIII**), although their inclusion in the correlation of entry 12 leads to an increase in sensitivity (entry 13).

Entry 1 of Table 9 indicates that the sensitivity to polar-inductive and mesomeric components of the effects exerted by substituents X are similar: in this correlation we have used the increased σ_R^- value of 0.41 instead of 0.31 for the 2-pyridyl substituent. This choice was totally arbitrary since there is no evidence yet concerning which of the two components, polar-inductive or mesomeric, should be increased, in order to parallel the increased σ_C^- value of 0.71 instead of 0.55. As for the monoparametric relationship, the points for substituents X = COMe, COPh, NO_2, and CN, are deviant.

The sensitivity of C(p) of the phenyl ring of the anions of phenylhydrazones is only slightly decreased relative to that of PhN^-X (**VII**) (entry 9 of Table 8): the transmission of effects appears to be dominated in both cases by the resonance component (entry 3 of Table 9).

Discussion

Substituent Effects.—The use of σ_C^-, σ_{IB}, and σ_R^- scales to account for the effects exerted by substituents on the chemical shift C(p) of the phenylhydrazones meets with moderate success. While the aryl and the 3- and 4-pyridyl substituents are well behaved, 2-pyridyl is dichotomous and the COMe, COPh, NO_2, and CN groups appear to fit a different line or, alternatively would require substantially increased values. Since it seems that the phenylhydrazones of the α-substituted formaldehydes are stereochemically homogeneous with the phenylhydrazones of aryl and heteroaryl aldehydes, different geometries around the C=N bond cannot be invoked to explain the deviations.

Let us consider first the case of the 2-pyridyl group. It is not the first time that the pyridyl group has shown a dichotomy of effects: indeed, while a value of 0.55 was needed to account for the acidity of 2-hydroxypyridine,[4a] the 2-pyridyl-substituted parent oxygen acid XOH, an increased value of 0.71 was needed to account for (a) the C(p) shift in the anion of 2-anilinopyridine (**VII-19**);[4d] (b) the acidity of 2-aminopyridine, the 2-pyridyl-substituted parent nitrogen acid NH_2X.[4d] Perhaps some light is provided by the observation made over 20 years ago by Charton,[23] of the abnormal behaviour of substituents at position 2 of pyridine. Although in that case the context was totally different because reactions involving the heterocyclic nitrogen were involved, the conclusion was that a short-range localized electrostatic effect operates in these systems. In discussing substituent effects exerted by *ortho* substituents other than of steric nature, Hine[24] noted that the angular orientation of a dipole with respect to a charge in the reaction centre would vary more with the nature of the reaction centre than it would in the case of a *meta* or *para* substituent. In our case the nitrogen of the 2-pyridyl group can be regarded as an *ortho* aza-substitution relative to the reaction centre at position 2, that is the OH in 2-hydroxypyridine, the PhN^- residue in the anion of 2-anilinopyridine, the acidic NH_2 group in 2-aminopyridine. Therefore, according to this picture in the 2-pyridyl derivatives of **(IV)**, **(VII)**, and **(X)**—**(XIII)** the short-range electrical effect of the N=C system would interact variably with the functionality G present at position 2. A short-range electrical effect could also be invoked to explain the anomalous barrier to N–CO rotation in the *NN*-dimethylamide of 2-picolinic acid found[25] to be considerably higher than expected on the basis of data for the 3- and 4-isomers.

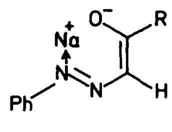
By a fortuitous coincidence the systems we chose to study at the outset of this investigation, the phenylhydrazones, also contain a N=CH group adjacent to the functionality X, which can be regarded as analogous to the C=N system in the 2-pyridyl derivatives. If the above reasoning for the 2-pyridyl group is accepted, then it seems logical that the CH=N group of the phenylhydrazones would also interact variably with the X functionality when this is constituted of heteroatoms and thus carries a dipole. The fact that no dichotomy whatsoever is found when *p*-substituted aryl and 3- and 4-pyridyl rings are involved, is in favour of the hypothesis of a localized short-range electrical effect: if an increased resonance effect were involved, dichotomy would also be expected for the 4-pyridyl group and for aryls substituted by an electron-withdrawing group (NO_2). As predicted by the proposal of Hine,[24] the charge at the reaction (or involved) centre changes on going from the neutral phenylhydrazones to their conjugate anions: it can be expected therefore that the deviations shown by substituents X containing doubly or triply bonded heteroatoms ($>$C=O, –N≡N) may disappear.

Finally, short-range electrostatic proximity effects have been recently recognized as reponsible for a variety of odd phenomena,[26] such as the basicity of pyrimidine *versus* pyridazine, relative to that of imidazole *versus* pyrazole.

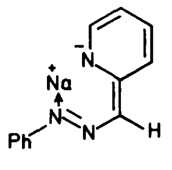
Phenylhydrazone Anions.—The ^{13}C n.m.r. data of the anions of phenylhydrazones are particularly informative: in fact, the approximate empirical charge mapping strongly suggests, beyond the precision of the calculation of the relative charge densities at the nitrogen N(1) and carbon atom of the diazaallylic moiety –N(1)–N=CH–, that the carbon atom should show some nucleophilic character, competitive with that of the N(1) nitrogen atom. The reaction of phenylhydrazone anions with alkyl nitrates[6b] and of t-butylhydrazones with a series of electrophiles[5] confirm the ambident nature of these species. However, despite substantial charge transfer from the nitrogen atom to the aldehydic methine carbon, the presence of both the *E* and *Z* isomers of the acetaldehyde phenylhydrazone anion as non-interconverting species at equilibrium clearly shows that the N=CH system essentially maintains considerable double-bond character.

Another relevant point concerns the effect of the negative charge in decreasing the actual $^1J_{CH}$ coupling constant of a trigonal carbanionic centre. This effect should be taken into account on considering the variation of $^1J_{CH}$ accompanying the deprotonation of an sp^3 carbon acid to an sp^2 carbanion.[21] The variation of $^1J_{CH}$ expected to be *ca.* 40 Hz, according to the equation $0.2\Delta^1J = \Delta(\%s)$ which links the variation of ^1J to the percentage variation of the *s* character of the orbitals of the carbon undergoing deprotonation, will actually be less, *ca.* 30 Hz, once the effect of charge has been taken into account.[21]

An important aspect of the phenylhydrazone anions is the stereochemical assignment of the species at equilibrium. Two isomers are distinctly discernible for the anion of acetaldehyde phenylhydrazone **(XIII-26)**: all the other phenylhydrazone anions give rise to a single set of peaks. The assignment of the *E* and *Z* configurations around the N=CH double bond in **(XIII-26)** is based on the different size of the $^1J_{CH}$ coupling constant of the aldehydic methine carbon, with the hypothesis that a large coupling in the neutral **(XII)** remains large in the anion. For the other phenylhydrazone anions the question arises whether the single set of signals should be ascribed to the presence of a single isomer or to the average of two rapidly (on the n.m.r. time scale) interconverting geometrical isomers. The experiment that would have possibly answered this question, *i.e.* the investigation of the spectral behaviour at low temperature, could not be performed since we were working in Me_2SO, a solvent with high m.p. However, since the $^1J_{CH}$ coupling constants of the aldehydic methine carbon atom in all the phenylhydrazone anions with the exception of **(XIII-9)** and **(XIII-10)** are in the range of 155—160 Hz, the same as for the *E* isomer of acetaldehyde phenylhydrazone anion, we suspect that the above species are present in solution only as the *E* isomers. This would also apply to the anions **(XIII-5)**, **(XIII-6)**, and **(XIII-19)**, the *Z* form of which could be stabilized by internal chelation of the metallic counterion.



(XIII-5) R = Me
(XIII-6) R = Ph



(XIII-19)

If indeed such species are present as *E* isomers, this would indicate that the co-ordinative capacity of Me_2SO would provide better stabilization to these systems than internal chelation that, moreover, would require preliminary *E*—*Z* isomerization. On these grounds it is quite possible that the anions **(XIII-9)** and **(XIII-10)** are also present as *E* isomers.

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