Experimental

Typical Procedure.—The ketone (0.5 mole) and phosphorus pentachloride (1.0 mole) were sealed in a stainless steel autoclave, and the mixture was heated at 275–300° for 5 hr. with shaking. The vessel was then cooled to room temperature and the contents were transferred to a separatory funnel containing 1 kg. of crushed ice. The mixture was shaken and the lower layer was withdrawn. It was washed three times with 50-ml. portions of 5% sodium hydroxide solution, dried over calcium chloride, and distilled.

The Effects of Hydrogen Bonding on the Absorption Spectra of Some Substituted Benzaldehyde Tosylhydrazone Anions

HELEN W. DAVIES AND MEYER SCHWARZ

Harry Diamond Laboratories, Washington, D. C. 20438

Received August 19, 1964

The decomposition reaction of the anions of aryl- and alkylsulfonylhydrazones, referred to as the Bamford–Stevens reaction, has attracted considerable attention in the past few years.[1-4] The reaction affords a convenient way of generating carbenes when it is carried out in aprotic media (eq. 1–3), while the decomposition in protic solvents leads to products formed *via* an ionic mechanism (eq. 1, 2, and 4). The intermediates in both cases are aryl- or alkyldiazomethanes. In the case of the tosylhydrazones of some aromatic aldehydes and ketones, the alkaline decomposition reaction proceeds at sufficiently low temperatures that the diazo compound may be conveniently isolated.[5] During the course of some synthetic work using this reaction we observed large differences between the absorption spectra of the anion of the tosylhydrazone of *p*-nitrobenzaldehyde in protic and nonprotic solvents. Similar observations had been made earlier by Burawoy and co-workers[6,7] in their studies of the effects of hydrogen bond formation on the absorption spectra of many aromatic substances having hydrogen bond donor and acceptor sites. They showed that where the effect of hydrogen bonding with the solvent is to reduce the polarity of the solute molecule a blue shift of the $\pi \rightarrow \pi^*$ absorption band (K-band) is observed. A relevant example is the blue shift which occurs in the absorption spectrum of the *p*-nitrophenol anion on changing the solvent from pyridine to water.[7] In this case hydrogen bonding localizes the negative charge on the oxygen, thereby decreasing the dipole moment of the anion and stabilizing its ground state and causing a shift of the primary band to shorter wave lengths.

Brealey and Kasha[8] have also discussed the effect of hydrogen bonding on electronic absorption spectra. They showed that the blue shifts observed in the $n \rightarrow \pi^*$ absorption bands (R-bands) of pyridazine and benzophenone upon changing from hydrocarbon to hydroxylic solvents are mainly due to hydrogen bonding, which stabilizes the ground state more than the excited state of the molecule.

This paper reports our findings of a hypsochromic shift of the primary absorption bands of several anions of substituted benzaldehyde tosylhydrazones upon changing from aprotic to protic solvents. It was also found that the rate at which the anions decompose is retarded by the same solvent changes.

Experimental

Spectra.—Spectra were measured on a recording spectrophotometer, using 1-cm. quartz cells.

Solvents.—Solvents used were all Spectroquality, with the exception of N,N-dimethylformamide (DMF), which was reagent grade. Distilled water was used.

Toluene-*p*-sulfonylhydrazones.—The toluene-*p*-sulfonylhydrazones were prepared in ethanol solutions and were recrystallized from methanol–water mixtures. The *p*-diethylamino compound was prepared in an ethanol–acetic acid solution. The aldehyde tosylhydrazones which are shown in Table I were prepared.

Excess diethylamine was added to 10^{-4} *M* solutions of the tosylhydrazones to obtain the anion solutions, except in solutions of the *p*-diethylamino compound, in which alcoholic NaOH was used.

The spectral absorption data are given in Tables II and III where λ_{max} refers to the wave length of the primary absorption band. The *p*-nitrobenzaldehyde tosylhydrazone was studied most thoroughly, since it displayed the greatest shift.

***p*-Nitrophenyldiazomethane.**—*p*-Nitrobenzaldehyde tosylhydrazone (1 g.) was dissolved in 10 ml. of DMF. Diethylamine (1 ml.) was added and the solution was allowed to stand at room temperature for about 1 hr. On the addition of water, *p*-nitrophenyldiazomethane, m.p. 80° dec., separated and was recrystallized from acetone; yield 59%, λ_{max}^{EtOH} 370 mμ (log ε 4.29). In the infrared spectrum a strong band at 4.84 μ (>CN_2[9]) was observed. The identical compound was also prepared by the oxidation of p-$O_2NC_6H_4CH{=}NNH_2$ with active manganese dioxide.

Anal. Calcd. for $C_7H_5N_3O_2$: C, 51.5; H, 3.1. Found: C, 51.6; H, 3.1.

***p*-Nitrobenzaldehyde N-Methyltoluene-*p*-sulfonylhydrazone.**—*p*-Nitrobenzaldehyde N-methyltosylhydrazone was prepared in 80% yield according to Dornow and Bartsch,[2] by alkylation of the tosylhydrazone with diazomethane. It melted at 165°

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(2) A. Dornow and W. Bartsch, *Ann.*, **602**, 23 (1957).
(3) J. W. Powell and M. C. Whiting, *Tetrahedron*, **7**, 305 (1959).
(4) L. Friedman and H. Shechter, *J. Am. Chem. Soc.*, **81**, 5512 (1959); **82**, 1002 (1960); **83**, 3159 (1961).
(5) (a) D. G. Farnum, *J. Org. Chem.*, **28**, 870 (1963); (b) G. L. Closs and R. A. Moss, *J. Am. Chem. Soc.*, **86**, 4042 (1964).
(6) A. Burawoy, "Hydrogen Bonding," D. Hadzi, Ed., Pergamon Press, Ltd., London, 1959, p. 259.
(7) W. A. Lees and A. Burawoy, *Tetrahedron*, **19**, 419 (1963), and references cited therein.
(8) G. J. Brealey and M. Kasha, *J. Am. Chem. Soc.*, **77**, 4462 (1955).
(9) P. Yates, *et al.*, *ibid.*, **79**, 5756 (1957).

Table I
Aldehyde Tosylhydrazones

Aldehyde	M.p., °C.	Calcd. % C	Calcd. % H	Found % C	Found % H	λ_{max} (EtOH), mμ	log ε
p-$O_2NC_6H_4CHO$	158 dec.	52.7	4.1	52.7	4.2	317	4.20
m-$O_2NC_6H_4CHO$	160–161 dec.	52.7	4.1	52.4	4.3	265	4.34
2,4-$Cl_2C_6H_3CHO$	184 dec.	49.0	3.5	49.2	3.7	285	4.29
o-HOC_6H_4CHO	155 dec.	57.9	4.8	57.7	4.9	273	4.15
p-$(C_2H_5)_2NC_6H_4CHO$	172–173 dec.	62.6	6.7	62.5	6.7	341	4.37
C_6H_5CHO	127 dec. (lit.[a] m.p. 128)					273	4.24

[a] See ref. 1.

Table II
Absorption Maxima of the p-Nitrobenzaldehyde Tosylhydrazone Anion

Solvent	λ, mμ	log ε[a]
$HCON(CH_3)_2$	475	4.15
C_5H_5N	475	4.14
CH_3COCH_3	473	4.18
CH_3CN	450	4.02
CH_3COCH_3–H_2O (9:1)	427	4.25
$(CH_3)_2CHOH$	411	4.20
n-C_4H_9OH	405	4.18
C_2H_5OH	403	4.23
$HCONH_2$	403	4.25
C_6H_6	403	4.02
$CHCl_3$	400	3.97
CCl_4	395	3.97
C_2H_5OH–H_2O (7:3)	395	4.22
CH_3OH	387	4.24
CH_3OH–H_2O (9:1)	386	4.25
H_2O	373	4.22

[a] Estimated by extrapolation to zero time.

with decomposition after recrystallization from ethanol; λ_{max}^{EtOH} 323 mμ (log ε 4.24).

Anal. Calcd. for $C_{15}H_{15}N_3O_4S$: C, 54.0; H, 4.5. Found: C, 54.1; H, 4.6.

Results and Discussion

As reference to Tables II and III shows, all of the anions studied exhibited qualitatively the same behavior. As observed with the p-nitrophenol anion,[7] in each case replacement of a nonhydrogen-bonding by a hydrogen-bonding solvent resulted in a blue shift of the primary absorption band. That these shifts occur with the anions only was shown by the fact that the parent compounds showed only very minor shifts with changes of solvents. Neither was the spectrum of p-nitrobenzaldehyde N-methyltosylhydrazone, in which anion formation is precluded, affected by the addition of base or change of solvent. The effect of protic solvents is to localize the negative charge at its original position on the nitrogen atom through hydrogen bonding, thereby inhibiting the redistribution of electrons required in the excitation process. The transition energy is thus increased in hydrogen-bonding solvents, as manifested by a shift of the absorption maximum to shorter wave length. It would seem reasonable then that in any solvent where hydrogen bonding is possible the amount of shift of the absorption maximum should be related to the hydrogen-bonding ability of the solvent. Indeed we find that for each solvent the hypsochromic shift parallels the hydrogen-bonding ability[10,11] in the order $H_2O > CH_3OH > C_2H_5OH > n$-$C_4H_9OH$. The absorption maximum of the p-nitro compound in formamide, which has approximately the same proton-donating power for hydrogen-bond formation as ethanol[12] was found to be at the same wave length as in the latter solvent. Thus it would appear that for the solvents studied here the shifts in the absorption maxima of the tosylhydrazone anions can also be viewed as a measure of their relative abilities to function as hydrogen-bond donors.

In benzene and carbon tetrachloride which cannot act as proton donors but which at the same time are nonionizing solvents we find that absorption takes place at the shorter wave lengths. This could be due to the formation of ion pairs, in which the proximity of the cation prevents the distribution of charge throughout the anion and localizes it on the nitrogen. In the case of chloroform, which has some proton-donating ability for hydrogen-bond formation,[13] and at the same time is a poor ionizing solvent, both effects may be operative.

Another possible explanation of the observed blue shift suggested itself, namely that this shift might simply be the consequence of the different polarities of the solvents in question. If one assumes that the dipole moment of the excited state is less than that of the ground state, a blue shift would be expected on changing from nonpolar to polar solvents. Kosower[14] has been successful in relating many solvent-dependent shifts to the solvent polarity using his Z-values. A plot of our transition energies *vs.* Z-values gives us a fair correlation for the hydrogen-bonding solvents only; however, in the aprotic solvents (DMF, C_6H_6, CH_3COCH_3, CH_3CN, C_5H_5N) and also in chloroform this is not the case.

It has also been found that with these compounds the total energy shift in changing to a nonhydrogen-bonding solvent from the best hydrogen-bonding solvent (H_2O) is related to the electron-donating or electron-withdrawing ability of the substituent in the benzaldehyde moiety of the molecule. Thus it can be seen in Tables II and III that the relative spectral shifts are the largest for the p-nitro compound. We believe that the reason for this is that while hydrogen bonding stabilizes the resonance form with the negative charge on the nitrogen adjacent to the tosyl group (O_2N–C_6H_4–CH=N–N^-–tosyl), in the absence of hydrogen-bonding resonance forms involving the nitro

(10) G. C. Pimentel, *J. Am. Chem. Soc.*, **79**, 3323 (1957).
(11) E. D. Becker, *Spectrochim. Acta*, **17**, 436 (1961).
(12) S. Mizushima, *et al.*, *ibid.*, **7**, 100 (1955).
(13) A. Allerhand and P. von R. Schleyer, *J. Am. Chem. Soc.*, **85**, 1715 (1963).
(14) E. M. Kosower, *ibid.*, **80**, 3253, 3261 (1958).

TABLE III
ABSORPTION MAXIMA OF TOSYLHYDRAZONE ANIONS

RCH=N–$\bar{N}$-tosyl

Solvent	R: 2,4-$Cl_2C_6H_3$	R: *m*-$O_2NC_6H_4$	R: C_6H_5	R: *o*-HOC_6H_4	R: *p*-$(C_2H_5)_2NC_6H_4$
	λ, mμ (log ε[a])			λ, mμ (log ε)	
$HCON(CH_3)_2$	368.5 (4.13)	351 (4.18)	345 (4.23)	342 (4.34)	337 (4.40)
CH_3CN	355 (4.28)	342 (4.30)	334 (4.15)	337 (4.37)	332 (4.42)
C_2H_5OH	334.5 (4.25)	321 (4.25)	313 (4.12)	325 (4.23)	325 (4.53)
CH_3OH	329 (4.29)	315 (4.25)	310.5 (4.26)	322 (4.23)	325 (4.41)
H_2O	313 (4.27)	297 (4.29)	303 (4.24)	322 (4.19)	325 (4.36)

[a] Estimated by extrapolation to zero time.

group (*e.g.*, $^{-}O_2N{=}C_6H_4{=}CH{-}N{=}N$-tosyl) contribute greatly to the excited state. The increased resonance stabilization in these latter forms is manifested by the large energy shift in changing from a protic to a nonprotic solvent. On the other hand, the effect of an electron-donating substituent such as the diethylamino group would be to favor resonance forms with high electron density at the nitrogen atom (*e.g.*, $Et_2N{-}C_6H_4{-}CH{=}N{-}N^{-}$-tosyl). The contribution of resonance forms in which the negative charge is delocalized ($Et_2N{-}{}^{-}C_6H_3{=}CH{-}N{=}N$-tosyl) will be small even in nonhydrogen-bonding solvents, hence leading to only small transition energy differences between protic and nonprotic solvents. The total energy changes observed range from 16.6 kcal./mole for the *p*-nitro compound to 3.6 kcal./mole for the *p*-diethylamino compound. These energies are for the most part much larger than those observed for the energy of the hydrogen bond, which is on the order of 2 to 10 kcal./mole.[15] Therefore, the total energy shifts should be related to the energy gained through stabilization of the ground state plus the energy gained through the destabilization of the excited state in the hydrogen-bonding solvents.[16]

The effect of solvents manifests itself also in the rate at which the tosylhydrazones decompose. At room temperature the *p*-nitrobenzaldehyde derivative anion decomposed in aprotic dissociating solvents approximately 15 times as fast as in the hydrogen-bonding solvents, confirming the spectroscopically observed stabilization of the ground state by the latter solvents. The half-life of a 10^{-4} *M* solution was about 2 min. in DMF *vs.* about 30 min. in ethanol. In the cases of the 2,4-dichlorobenzaldehyde, *m*-nitrobenzaldehyde, and benzaldehyde derivatives, the rates of decomposition in nonprotic solvents were also faster than in protic solvents. The rates were, however, considerably slower than for the *p*-nitro compound in the expected order: 2,4-dichloro- > *m*-nitro- > benzaldehyde. These decomposition reactions were followed spectroscopically by observing the rate of disappearance of the anion bands. The *o*-hydroxy and *p*-diethylamino tosylhydrazone anions appeared to be stable at room temperature indefinitely. In the case of the *p*-nitro compound, *p*-nitrophenyldiazomethane could be isolated as a stable solid.

(15) L. Pauling, "The Nature of the Chemical Bond," 3rd Ed., Cornell University Press, Ithaca, N. Y., 1960, p. 449.

(16) This situation appears to be similar to the n → π* carbonyl transition discussed by Kosower.[14] We wish to thank the referee for pointing this out to us.

Conversion of Methyl 17β-Acetoxy-5-oxo-3,5-seco-4-norestran-3-oate to Δ⁹⁽¹¹⁾-Testosterone[1]

JULIUS A. VIDA AND MARCEL GUT

Worcester Foundation for Experimental Biology, Shrewsbury, Massachusetts

Received October 19, 1964

A review of recent total syntheses shows that most of them, especially the most efficient ones, led to 19-norsteroids. A recently published total synthesis[2] commanded our attention because an intermediate seemed to be a good starting material to produce analogs possessing a 19-methyl group. We had a further interest in this problem because of our desire to introduce a radioactive label at C-19.[3]

The key intermediate in our synthesis of adrenosterone, 17β-hydroxy-5-oxo-3,5-seco-4-norestr-9-en-3-oic acid (I),[4] had already been obtained by total synthesis. As an alternative, a partial synthesis makes use of the known methyl 17β-acetoxy-5-oxo-3,5-seco-4-norestran-3-oate[5] which was brominated selectively at C-10 with N-bromosuccinimide and the resulting crude bromide was dehydrobrominated with lithium chloride in N,N-dimethylformamide to give 17β-hydroxy-5-oxo-3,5-seco-4-norestr-9-en-3-oic acid (I).

There remained the introduction of the angular methyl group at C-10, already mentioned without disclosure of details, in a review article by Velluz, *et al.*,[2a] in a closely related case. To the solution of I in N,N-dimethylformamide sodium hydride was added, followed by the addition of a catalytic amount of methanol and then by a large excess of methyl iodide. The absence of any α,β-unsaturated ketone in the isolated crude product demonstrates that the methylation had taken place at C-10, thus making it unnecessary to block C-6.[6] Simultaneous methylation of the

(1) Supported, in part, by National Institutes of Health Grant H-5266. Presented, in part, before the Division of Organic Chemistry at the 148th National Meeting of the American Chemical Society, Chicago, Ill., Sept. 1964, Abstracts of Papers, p. 40S.

(2) (a) L. Velluz, G. Nomine, and J. Mathieu, *Angew. Chem.*, **72**, 725 (1960); (b) L. Velluz, G. Nomine, G. Amiard, V. Torelli, and J. Cerede, *Compt. rend.*, **257**, 3086 (1963); (c) British Patent 914,738 (Jan. 2, 1963).

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(5) Free acid described by J. A. Hartman, A. J. Tomasewski, and A. S. Dreiding, *J. Am. Chem. Soc.*, **78**, 5662 (1956).

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