Substitution Effects on the Aza-di-π-methane Rearrangement of Imines

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The u.v. irradiation of several 1-aryl derivatives of 3,3-dimethyl-5,5-diphenyl-1-azapenta-1,4-diene has been carried out. All of them undergo the aza-di-π-methane rearrangement and yield a cyclopropylimine. The influence of substituents on the 1-aryl group has given support for the proposal that imines with a low ionization potential are less efficient at undergoing the aza-di-π-methane process than are imines with a higher ionization potential. This was demonstrated in a quantitative fashion. The involvement of an electron-transfer process in the reaction is discussed.

The photoreactivity of β,γ-unsaturated systems has received much detailed attention during the past fifteen years [1,2] and a good understanding of the reactions that these compounds undergo has been developed. We have studied the influence of nitrogen incorporation [3-7] into enone-like molecules. This reaction often leads to dramatic and surprising changes in the photoreactivity, such as seen in the cyclization of azadienes (1),[4,5] the cyclization of protonated azadienes (2),[6] and in the photochemical 1,5-benzoyl migration in the azaenones (3).[7]

We have also examined [8,9] the photochemical reactivity of the imines (4) derived from the aldehydes (5) and ketones (6). All of these, apart from (4d), are photochemically reactive to some extent and rearrange to (7) by a route interpreted by us as an example of the 1-aza-di-π-methane process, a reaction route

which has seldom been observed (Scheme).[10,11] The rearrangement of (4a, b) into (7a, b) is especially of interest since the aldehydes (5) do not undergo such a reaction but photodecarbonylate instead.[12] In addition ketone (6a) is unreactive in the di-π-mode and only undergoes decarbonylation on irradiation.[12] Thus the 1-aza-di-π-methane rearrangement provides a route whereby the Norrish type 1 process can be suppressed in favour of the alternative reaction path of C–C bridging.

(7)
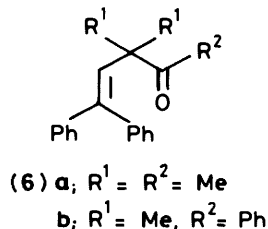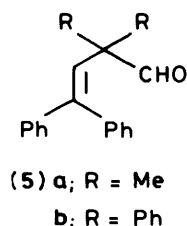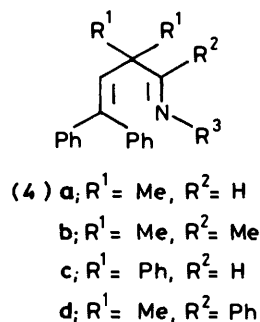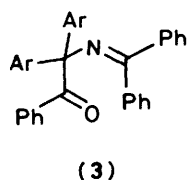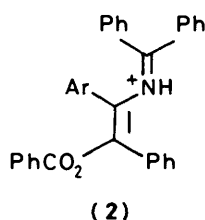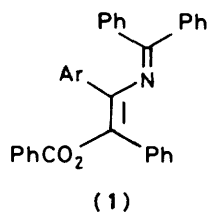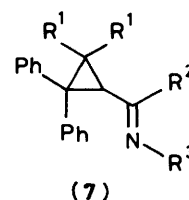
A semi-quantitative study of the imines (4a) identified that the efficiency of cyclization was dependent on the type of substitution on the imine nitrogen. This was most evident for the imine (4a; R^3 = Ph) and for imine (4a; R^3 = CH$_2$Ph). Both of these cyclized more efficiently than any of the alkyl-substituted imines (4a). The principal difference between the N-alkyl derivatives of (4a) and the N-phenyl derivative of the same is the ability of the phenyl group to conjugate with the lone pair on the nitrogen rather than with the imine π-bond.[13] The phenyl of the N-benzyl substituent in (4a; R^3 = CH$_2$Ph) can also interact with the nitrogen lone pair by a homoconjugative effect. Thus it seemed likely that the nitrogen lone pair was in some way involved in the cyclization step. It has been established that the lowest energy band in the photoelectron spectrum of simple imines arises by removal of an electron from the nitrogen lone pair.[14] Consequently, based on this observation, one hypothesis is that electron-transfer from the nitrogen lone pair to the alkene moiety, 1,1-diphenylethene is a known electron acceptor,[15] makes the cyclization less efficient. Thus if it is possible to increase the ionization potential of the imine then the cyclization should become more efficient.

(1)

(2)

(3)

(4) a; R^1 = Me, R^2 = H

b; R^1 = Me, R^2 = Me

c; R^1 = Ph, R^2 = H

d; R^1 = Me, R^2 = Ph

(5) a; R = Me

b; R = Ph

(6) a; R^1 = R^2 = Me

b; R^1 = Me, R^2 = Ph

Results and Discussion

In order to test the hypothesis in a quantitative fashion we have studied the efficiency of the cyclization of the series of imines (8). All of these compounds are readily prepared from the aldehyde (5a) by reaction with the appropriate amine. The spectral data for the new imines (8b—e) are all in accord with the proposed structure. These imines are stable under nitrogen and under rigorously anhydrous conditions. They are, however, readily

Table 1. Quantum yield (φ) for cyclization of imines (8)

Imine reactant	φ	Relative φ
(8a)	0.003 54	1.00
(8b)	0.000 445	0.13
(8c)	0.003 98	1.12
(8d)	0.003 90	1.10
(8e)	0.0147	4.15

hydrolysed, so much so that microanalytical results are unreliable. This behaviour is typical of imines of this class. All of the new imines (8b—e) have a large u.v. absorption maximizing at *ca.* 250 nm but with a long tail into the 330 nm region. From our previous observations acetophenone-sensitized irradiation was found to be effective and was used in the experiments described here. The photochemical reactivity of the imines was demonstrated in qualitative irradiations in an immersion well apparatus with a Pyrex filter whereby it was seen that they all afforded the cyclopropylaldehyde (9), after hydrolysis of the photolysate, by what we believe is a 1-aza-di-π-methane rearrangement. In this qualitative study it was observed that the imine (8e) yielded the cyclopropyl derivative more efficiently than any of the other imines studied.

(8) a; Ar = C_6H_5

b; Ar = $4 - MeOC_6H_4$

c; Ar = $4 - ClC_6H_4$

d; Ar = $3 - MeOC_6H_4$

e; Ar = $4 - CNC_6H_4$
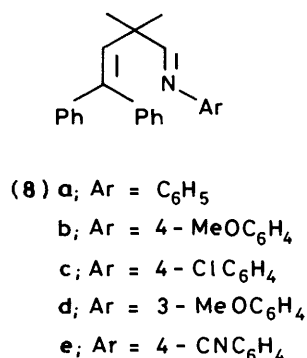
The quantum yield measurements were made on conversions ranging between 0.6—7.0% and are based on a minimum of four measurements for each sample. The results were plotted and extrapolated to zero time to give the optimum quantum yield in each case. These values are shown in Table 1 along with the relative quantum yields based on imine (8a) as unity.

These data fall into a distinct pattern where the imine (8b) is the least efficient and the imine (8e) is the most efficient.

It is interesting to note that other studies of the di-π-methane rearrangement have also examined the influence of substituents. Zimmerman and Swafford[16] have demonstrated, in a series of 3-methyl-3-(aryl)but-1-enes, that there is a range of quantum efficiencies with a *p*-cyano group more effective in the cyclization than a *p*-methoxy. Other researchers[17,18] have also observed ranges of quantum yields in the di-π-methane process. A spread of quantum yields has also been reported by Zimmerman and Welter[19] for the variously substituted tetraaryl divinyl system (10).

The mechanism of the reaction described presents some problems. There is no doubt that the reaction is of the 1-aza-di-π-methane type as outlined in the Scheme. In earlier work we proposed that the principal absorption involved in the process is that of the 1,1-diphenylalkene group. Indeed even phenyl-substituted imines do not absorb to any extent above 280 nm. The inclusion of substituents on the imine phenyl group will not alter this. However, the most important factor in the reaction is the fact that the *N*-aryl group overlaps more with the nitrogen

lone pair than with the imine π-system. Thus it is clear that the nature of the substituent on the aryl function will exercise some control over the availability of the nitrogen lone pair to undergo an electron-transfer to the 1,1-diphenylalkene. This ability will be greatest in imine (8b) and poorest in imine (8e). The other substituents, a *p*-chloro and a *m*-methoxy group in imines (8c) and (8d), have a very small effect on the quantum yield for the cyclization. This is borne out by our results shown in Table 1. In fact the enhancement in yield between the *p*-methoxy-substituted imine and the *p*-cyano-substituted imine is 32.

Further substantiation for the interaction between the aryl group and the nitrogen lone pair comes from Hammett plots of log φ against the substituent constants σ^+ and $\sigma.^{*,20}$ The graphs demonstrate that the plot of log φ against σ^+ gives a ρ value of 1.1 with a correlation coefficient of 0.998 whereas the plot of log φ against σ gives a ρ value of 1.5 with a correlation coefficient of 0.934.† These results give some confirmation to the conjugative effect of the aryl substituent with the lone pair.

Scheme.

(10)
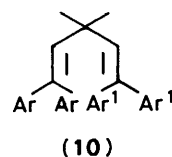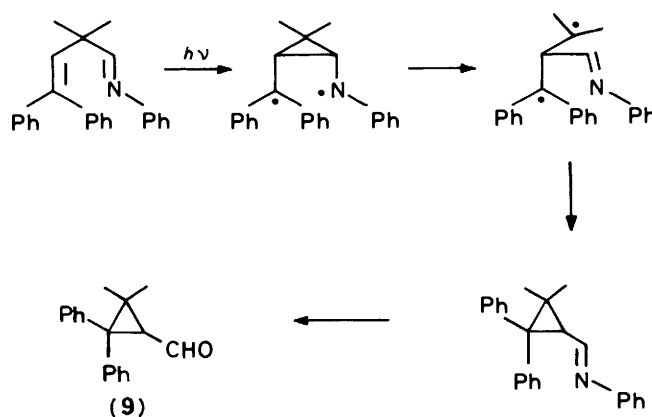
This, we believe, is evidence in support of our postulate that an electron-transfer from the imine nitrogen to the alkene group is detrimental to the cyclization. At this time the exact mechanism by which this process interferes is unknown. However, we are in the process of investigating the influence of aryl substituents on the 1,1-diphenylalkene group and this should shed some light on the matter.

Experimental

M.p.s were determined on a Buchi 510D apparatus in open capillaries and are uncorrected. I.r. spectra were recorded on a Perkin-Elmer 257 spectrophotometer and band positions are reported in wavenumbers. U.v. spectra were recorded on a Perkin-Elmer 124 spectrophotometer in methanol solutions. ^{1}H N.m.r. spectra were recorded on a Varian T60A spectrometer

with chemical shifts (δ) expressed in p.p.m. downfield from internal Me₄Si.

Synthesis of Imines (**8**).—Imine (**8a**) was synthesized by the previously reported route.[9] 2,2-Dimethyl-4,4-diphenylbut-3-enal (**5a**) was synthesized by the method of Zimmerman and Pratt.[21] The imines (**8b**—**e**) were synthesized by reaction of (**5a**) (1.5 g, 0.006 mol) with an equimolar amount of the corresponding amine in toluene (50 ml). The mixtures were refluxed for 3—8 h and the water produced during the reactions was removed in a Dean–Stark water separator. After the reaction was complete the solvent was evaporated under reduced pressure (*ca.* 15 mmHg). The i.r. and n.m.r. spectra of the crude product showed that the reaction was quantitative and had yielded the imine in each case. The products were purified by distillation at reduced pressure. The yields quoted for each imine are for the pure isolated product. 1-(p-*Methoxyphenyl*)-3,3-*dimethyl*-5,5-*diphenyl*-1-*azapenta*-1,4-*diene* (**8b**) (1.32 g, 67%); b.p. 132 °C/0.01 mmHg; $\nu_{max.}$(liq. film) 1 640 (C=N) and 1 240 (MeO) cm⁻¹; $\lambda_{max.}$(MeOH) 247 (ε = 15 500 dm³ mol⁻¹ cm⁻¹) nm; δ(CDCl₃) 1.31 (6 H, s, Me), 3.7 (3 H, s, OMe), 6.0 (1 H, s, C=CH), 6.48—6.53 (2 H, d, *J* = 8 Hz, ArH), 7.03—7.13 (12 H, m, ArH), and 7.33 (1 H, s, CH=N). 1-(p-*Chlorophenyl*)-3,3-*dimethyl*-5,5-*diphenyl*-1-*azapenta*-1,4-*diene* (**8c**) (1.38 g, 64%); b.p. 182—184 °C/0.01 mmHg; m.p. 66—69 °C; $\nu_{max.}$(liq. film) 1 640 (C=N) cm⁻¹; $\lambda_{max.}$(MeOH) 243 (26 200) nm; δ(CDCl₃) 1.31 (6 H, s, Me), 6.00 (1 H, s, C=CH), 6.26—6.41 (2 H, d, *J* = 9 Hz, ArH), 6.96—7.23 (12 H, m, ArH), and 7.33 (1 H, s, CH=N). 1-(m-*Methoxyphenyl*)-3,3-*dimethyl*-5,5-*diphenyl*-1-*azapenta*-1,4-*diene* (**8d**) (1.21 g, 57%); b.p. 172—174 °C/0.01 mmHg; $\nu_{max.}$(liq. film) 1 650 (C=N) and 1 260 (OMe) cm⁻¹; $\lambda_{max.}$(MeOH) 244 (14 760) nm; δ(CDCl₃) 1.31 (6 H, s, Me), 3.71 (3 H, s, OMe), 6.08 (1 H, s, C=CH), 6.18 (2 H, m, ArH), 6.95—7.33 (12 H, m, ArH), and 7.45 (1 H, s, CH=N). 1-(p-*Cyanophenyl*)-3,3-*dimethyl*-5,5-*diphenyl*-1-*azapenta*-1,4-*diene*

(**8e**) (1.28 g, 61%); b.p. 180 °C/0.01 mmHg; $\nu_{max.}$(liq. film) 2 220 (CN) and 1 640 (C=N) cm⁻¹; $\lambda_{max.}$(MeOH) 253 (22 600) and 274 (22 500) nm; δ(CDCl₃) 1.33 (6 H, s, Me), 6.08 (1 H, s, C=CH), 6.4—6.53 (2 H, d, *J* = 8 Hz, ArH), 7.25—7.36 (12 H, m, ArH), and 7.38 (1 H, s, CH=N).

Preparative Photolysis of Imines (**8b**—**e**).—All of the photolyses were carried out in an immersion well apparatus with a Pyrex filter and a 400 W medium-pressure Hg arc lamp. Solutions of the imines and acetophenone (1.40 g) in anhydrous benzene (400 ml) were purged for 1 h with nitrogen and irradiated under a positive pressure of nitrogen. None of these conversions have been optimized since these experiments were used to establish a qualitative order of reactivity. After completion of the irradiation the solvent was evaporated under reduced pressure and the sensitizer was removed by distillation. The crude photolysates of the imines were hydrolysed using a mixture of aqueous sulphuric acid (1%; 5 ml) in tetrahydrofuran (THF) (30 ml). These mixtures were stirred at ambient temperatures for 30 min and then were extracted with ether. The organic layer was separated, washed with aqueous NaHCO₃ (10%; 20 ml), dried (MgSO₄), filtered, and the ether was removed under reduced pressure. The crude mixtures were chromatographed on silica gel using hexane–ether (95:5) as the eluant.

Table 2. Yields from the preparative photolyses

Imine	Irradiation time (h)	Yield of (**5a**)	Yield of (**9**)
(**8b**) (385 mg)	4	161 mg (60%)	8 mg (3%)
(**8c**) (355 mg)	2	165 mg (67%)	37 mg (15%)
(**8d**) (370 mg)	2	158 mg (61%)	35 mg (13.5%)
(**8e**) (425 mg)	2	92 mg (33%)	137 mg (50%)

Table 3. Sensitized photolyses of imines (**8**)

Run	Quantity (**8a**) mmol	Light absorbed[a]	Conversion (%)	Product (**9**) mmol	φ
1	0.209	5.26	4.74	9.93 × 10⁻³	1.89 × 10⁻³
2	0.310	3.24	2.77	8.61 × 10⁻³	2.65 × 10⁻³
3	0.227	2.87	3.12	7.11 × 10⁻³	2.48 × 10⁻³
4	0.232	2.85	3.16	7.36 × 10⁻³	2.58 × 10⁻³
5	0.267	6.55	4.98	1.33 × 10⁻³	2.03 × 10⁻³
	(**8b**) mmol				
6	0.248	3.47	0.61	1.50 × 10⁻³	4.33 × 10⁻⁴
7	0.310	7.63	1.00	3.12 × 10⁻³	4.08 × 10⁻⁴
8	0.262	10.03	1.54	4.05 × 10⁻³	4.04 × 10⁻⁴
9	0.183	15.48	3.01	5.51 × 10⁻³	3.56 × 10⁻⁴
	(**8c**) mmol				
10	0.178	3.98	5.83	1.04 × 10⁻³	2.60 × 10⁻³
11	0.200	5.83	6.98	1.40 × 10⁻³	2.40 × 10⁻³
12	0.317	1.00	1.16	3.68 × 10⁻³	3.68 × 10⁻³
13	0.203	2.53	3.98	8.14 × 10⁻³	3.19 × 10⁻³
	(**8d**) mmol				
14	0.210	4.60	4.86	1.02 × 10⁻²	2.22 × 10⁻³
15	0.200	3.04	3.92	7.85 × 10⁻³	2.58 × 10⁻³
16	0.206	2.63	3.46	7.14 × 10⁻³	2.71 × 10⁻³
17	0.181	3.37	4.49	8.15 × 10⁻³	2.42 × 10⁻³
	(**8e**) mmol				
18	0.285	0.65	2.31	6.63 × 10⁻³	1.02 × 10⁻²
19	0.268	1.28	3.46	9.30 × 10⁻²	7.23 × 10⁻³
20	0.537	1.09	2.04	1.09 × 10⁻²	1.00 × 10⁻²
21	0.274	0.74	2.55	7.02 × 10⁻³	9.48 × 10⁻³

[a] = Light absorbed is in milli-einsteins.

Quantum Yield Measurements for Imines (**8a**—**e**).—Quantum yield determinations were carried out using a 200 W high-pressure Hg arc lamp in conjunction with a Bausch and Lomb model 33-86-07 grating monochromator. Sensitized irradiations were carried out using acetophenone (0.53M) as the sensitizer at 360 nm. Potassium ferrioxalate actinometry[22] was used to measure light output in all the experiments. The conversion into product was determined using g.l.c. of the crude hydrolysed photolysates with benzil as the internal standard. Solutions of the imine in anhydrous benzene (30 ml) were irradiated in cyclindrical quartz cells to 0.6—7% conversion under an atmosphere of nitrogen. The solutions were purged with nitrogen for 30 min prior to irradiation. The results obtained are tabulated.

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