Studies on the Scope of the Aza-di-π-methane Rearrangement of β,γ-Unsaturated Imines

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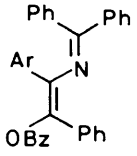
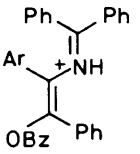
The syntheses of imines of 2,2,4,4-tetraphenylbut-3-enal, 3,3-dimethyl-5,5-diphenylpent-4-en-2-one, and 2,2-dimethyl-1,4,4-triphenylbut-3-en-1-one are described. The results of the irradiation of these and of 2,2-dimethyl-4,4-diphenylbut-3-enonitrile and 2,2-dimethyl-4,4-diphenylbut-3-enal oxime are discussed. The *N*-isopropyl imine of 2,2,4,4-tetraphenylbut-3-enal and the *N*-phenyl and benzyl imines of 3,3-dimethyl-5,5-diphenylpent-4-en-2-one undergo the 1-aza-di-π-methane rearrangement.

The photoreactivity of β,γ-unsaturated systems has received much detailed attention over the past 15 years[1,2] and is well understood. The effect of the incorporation of nitrogen in these compounds has not been investigated although the photochemistry of imines has been studied extensively.[3,4] We have observed that the influence of nitrogen incorporation into enone-like molecules often leads to dramatic and surprising changes in photoreactivity such as the cyclization of azadienes (**1**),[5] the cyclization of protonated azadienes (**2**),[6] and the photo-1,5-benzoyl migration in the enones (**3**).[7]



(**1**)



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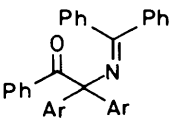
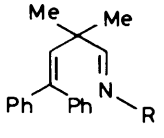
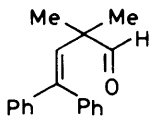


(**3**)

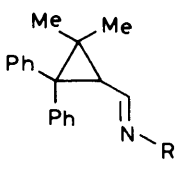
We have previously reported our observations[8,9] on the photochemical reactivity of the imines (**4**) derived from the aldehyde (**5**). All of these were photochemically reactive to some extent and rearranged to (**6**) by way of the aza-di-π-methane process, a reaction route which has seldom been observed.[10,11] The rearrangement of (**4**) into (**6**) is of special interest since the aldehyde (**5**) does not undergo such a reaction but instead photodecarbonylates.[12] Thus the aza-di-π-methane rearrangement provides a route whereby the Norrish Type I process can be suppressed. The present paper extends the scope of the process and investigates the influence of changes in substitution on the carbon skeleton.



(**4**)



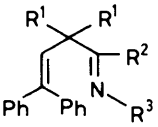
(**5**)



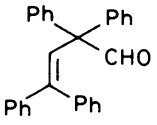
(**6**)

Results and Discussion

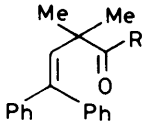
The imines (**7**) required for the study were readily synthezised from the corresponding aldehyde (**8**) or ketones (**9**) by standard procedures. The imines (**7**) were identified by i.r. spectroscopy which showed characteristic absorptions for C=N at *ca.* 1 645 cm^{-1} in agreement with reported[13] values for such compounds. ^1H N.m.r. spectroscopy of the imine (**7a**) was also helpful since the imine H was observable at δ 7.62, which is again in agreement with literature values[14] for such a functional group. All the imines were moisture sensitive and had to be stored at low temperature under an atmosphere of nitrogen. As a result of this moisture sensitivity microanalytical results were completely unreliable.



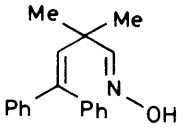
(**7**) a ; R^1 = Ph, R^2 = H, R^3 = Pr^i
b ; R^1 = R^2 = Me, R^3 = Ph
c ; R^1 = R^2 = Me, R^3 = $PhCH_2$
d ; R^1 = Me, R^2 = Ph, R^3 = $PhCH_2$



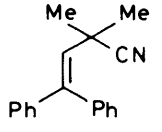
(**8**)



(**9**) a ; R = Me
b ; R = Ph



(**10**)



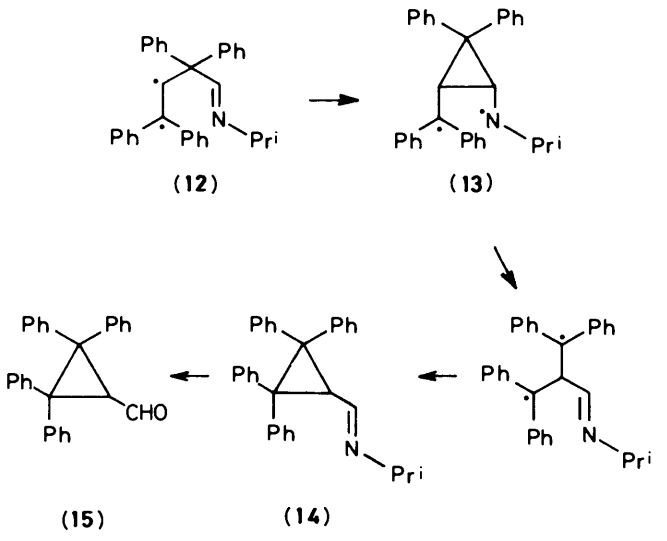
(**11**)

The colourless crystalline oxime (**10**) was readily prepared in high yield by condensation of the aldehyde (**5**) with hydroxylamine hydrochloride. The nitrile (**11**) was prepared by acetic anhydride dehydration of the oxime. The spectroscopic details of both of these compounds are in complete accord with the proposed structures.

All of the compounds prepared showed high extinction coefficient u.v. absorptions with a maximum around 250 nm and a long tail up to 320 nm. Such an absorption is characteristic for the 1,1-diphenylalkene moiety[15] with no apparent contribution from the C=N part of the molecule.

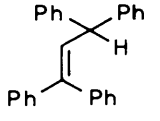
Previously[8,9] we demonstrated that the imines (**4**) undergo an aza-di-π-methane rearrangement on acetophenone- or phenanthrene-sensitized irradiation. Direct irradiation was shown to be less effective although reasonable chemical yields could be obtained by extending the irradiation time from 1 h to 20 h or more. Similar behaviour is seen on the acetophenone-sensitised irradiation of the imine (**7a**). After 1 h and subsequent hydrolysis of the photolysate, these conditions gave a good yield

of the cyclopropanecarbaldehyde (**15**) identical with an authentic sample. Direct irradiation was, in chemical yield, as efficient but required irradiation for 20 h to effect the conversion. The most likely route to the product is by way of the aza-di-π-methane path shown in the Scheme. The reaction



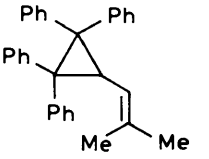
Scheme.

proceeds to the cyclized imine (**14**) which is deliberately hydrolysed before chromatography to afford (**15**). As in our previous study[8,9] there is no evidence that the aldehyde (**8**), the precursor to imine (**7a**), undergoes an oxa-di-π-methane reaction. Indeed, upon irradiation, this aldehyde undergoes an efficient decarbonylation to yield the alkene (**16**) which was identified by comparison with an authentic sample. This example of the aza-di-π-methane rarrangement confirms the use that can be made of our method to surmount the normal Norrish Type I behaviour of aldehydes. It is clear that either direct or sensitized irradiation will excite only the 1,1-diphenylalkene moiety ($\lambda_{max.}$ 252 nm[15]) of (**7a**) since the absorption of aldimines occurs at shorter wavelength.[3,17] Thus the excited state involved in the conversion of (**7a**) into biradical intermediate (**13**), the first step in the aza-di-π-methane rearrangement, can be identified as (**12**). It is this location of the excitation energy which permits the rearrangement to (**14**) to take place. With the aldehyde (**8**) the excited state produced is that of the carbonyl function which undergoes decarbonylation rather than intramolecular bonding.

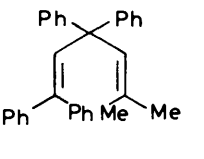


(**16**)

The efficiency of the cyclization of (**7a**) to (**14**) is considerably better, in qualitative terms, than the results with other imines (**4**). Indeed, when compared specifically with imine (**4**; R = Pr^i), there is a 15-fold enhancement in yield. Although it requires detailed study to identify fully the reasons for the enhancement this could be the result of the change form C–Me to C–Ph substitution on the central carbon. This is in accord with the work of Zimmerman *et al.*[16] who observed the enhanced formation of the tetraphenylcyclopropane (**17**) from the irradiation of (**18**). They[16] interpreted this efficiency in terms of efficient 'unzipping' of the intermediate due, no doubt, to the stabilizing influence of the phenyl groups on the intermediate biradical.



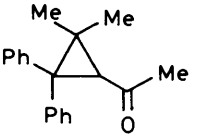
(**17**)



(**18**)

It also appears that the phenyl substitution on the central carbon substantially overcomes any inhibiting effect which we attributed[8] previously to the involvement of the nitrogen lone pair in an intramolecular electron transfer.

The influence of substitution on the imine carbon was also studied. Thus, the imine (**7b**) is also photoreactive and is converted in low yield (4.5% after 2 h sensitized irradiation) into the cyclopropyl ketone (**19**) after hydrolysis of the photolysate. It is clear that the reactivity of this ketimine is much less than that of the corresponding aldimine (**4**; R = Ph). The ketimine (**7c**) is also photoreactive but requires irradiation for 2 h under the standard conditions to bring about a 3% conversion into the same ketone (**19**). This result is comparable with the one obtained in the case of (**7b**).



(**19**)

The ketimine (**7d**) is totally unreactive in the aza-di-π-methane process and both direct and sensitized irradiation fail to yield product. The problem in this instance arises from the fact that the imine moiety in (**7d**) has phenyl substitution on the imine C-atom. This moves the imine absorbance to longer wavelength and thus this chromophore can compete with the 1,1-diphenylalkene group perhaps leading to photobehaviour analogous to the Norrish Type I behaviour of aldehydes and ketones. Indeed, in this instance, the direct irradiation afforded many products in low yield which could have arisen from such a reaction path.

Finally we have also demonstrated that the oxime (**10**) and the nitrile (**11**) are photochemically unreactive under our conditions.

The present study has shown to some extent the scope of the aza-di-π-methane process. It is clear that the aldimines are more efficient and that the phenyl substitution on the central carbon can enhance the chemical yield of product. Ketimines are, however, much less reactive with the success of the reaction dependent upon the substituent on nitrogen.

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 recorded in wavenumbers (cm^{-1}). ^{1}H N.m.r. spectra were recorded on a Varian T60A spectrometer with chemical shift values (δ) expressed in p.p.m. downfield from internal Me_4Si.

2,2-*Dimethyl*-4,4-*diphenylbut*-3-*enal* (**5**). This aldehyde was synthesized by the method of Zimmerman and Pratt.[18]

2,2,4,4-*Tetraphenylbut*-3-*enal* (**8**). This aldehyde was synthesized by the method of Zimmerman, Boettcher, and Braig.[16]

3,3-*Dimethyl*-5,5-*diphenylpent*-4-*en*-2-*one* (**9a**). This ketone was synthesized as previously described[12]

2,2-*Dimethyl*-1,4,4-*triphenylbut*-3-*en*-1-*one* (**9b**). This ketone (**9b**) was synthesized by the published method.[19]

2-*Methyl*-5,5,7,7-*tetraphenyl*-3-*azahepta*-3,6-*diene* (**7a**).—The imine (**7a**) was synthesized following a general procedure described by White *et al.*[20] 2,2,4,4-Tetraphenylbut-3-enal (8 mmol) and 1-methylethylamine (80 mmol) were dissolved in benzene (75 ml) under an atmosphere of nitrogen. The mixture was cooled to 0 °C in an ice-bath and titanium chloride (0.48 mmol) in benzene (30 ml, anhydrous) was added dropwise with stirring. The solution was stirred for 3 days at room temperature. After this time the mixture was filtered and the solvent and excess amine were removed from the filtrate by distillation under reduced pressure. Recrystallization of the residue from ethanol afforded the desired *imine* (**7a**) as a colourless solid (1.52 g, 61%), m.p. 86—87 °C; $\nu_{max.}$(KBr) 1 645 cm^{-1}; $\lambda_{max.}$(CH_2Cl_2) 255 nm (ε 22 910 dm^3 mol^{-1} cm^{-1}); δ_H(CCl_4) 1.05 (6 H, d, 2-Me), 3.05 (1 H, m, methine H), 6.7—7.3 (20 H, m, aryl and vinyl H), and 7.62 (1 H, s, CH=N).

2,3,3-*Trimethyl*-1,5,5-*triphenyl*-1-*azapenta*-1,4-*diene* (**7b**).—The ketone (**9a**) (0.5 g, 1.9 mol) was dissolved in aniline (15 ml) and the solution was heated at reflux for 5.25 h. The mixture was cooled and distilled under reduced pressure to remove the excess of aniline. The residual material was distilled to yield the *imine* (**7b**) as an oil (0.46 g, 70%), b.p. 120—122 °C/0.04 mmHg; $\nu_{max.}$ (liq. film) 1 655 (C=N) cm^{-1}; δ_H(CCl_4) 1.30 (6 H, s, 2-Me), 1.65 (3 H, s, Me), 6.10 (1 H, s, vinyl), 6.20—6.35 (2 H, m, *o*-aryl), and 6.80—7.30 (13 H, m, aryl); $\lambda_{max.}$(EtOH) 250 nm (20 417).

Imines (**7c**) *and* (**7d**).—These imines were synthesized from the ketones (**9a**) and (**9b**) respectively. The general method involves the treatment of the appropriate ketone (16 mmol) with an excess of the corresponding amine using zinc chloride (*ca.* 25 mg, anhydrous) as a catalyst. Mixtures were refluxed for 3 h and then the excess amine was removed by distillation at water pump pressure. The residue was treated with anhydrous ether and filtered. The solvent was then removed under reduced pressure. The i.r. and n.m.r. spectra of the crude products showed that the transformation from amine to imine was quantitative. The new imines were purified by distillation at reduced pressure.

3,4,4-*Trimethyl*-1,6,6-*triphenyl*-2-*azahexa*-2,5-*diene* (**7c**). The reaction yielded imine (**7c**) (3.27 g, 58%), b.p. 140—142 °C/0.04 mmHg; $\nu_{max.}$ (liq. film) 1 645 (C=N) cm^{-1}; δ_H(CCl_4) 1.3 (6 H, s, 2-Me), 1.55 (3 H, s, Me), 4.0 (2 H, s, CH_2), 6.12 (1 H, s, vinyl-H), and 7.0—7.3 (15 H, m, ArH); $\lambda_{max.}$(EtOH) 248 nm (16 220).

4,4-*Dimethyl*-1,3,6,6-*tetraphenyl*-2-*azahexa*-2,5-*diene* (**7d**). The reaction yielded the *imine* (**7d**) (3.45 g, 52%), b.p. 164 °C/0.05 mmHg; $\nu_{max.}$ (liq. film) 1 640 (C=N) cm^{-1}; δ_H(CCl_4) 1.15 (6 H, s, 2-Me), 4.25 (2 H, s, CH_2), 6.20 (1 H, s, vinyl-H), and 6.8—7.4 (20 H, m, ArH); $\lambda_{max.}$(EtOH) 249 nm (15 135).

2,2-*Dimethyl*-4,4-*diphenylbut*-3-*enal Oxime* (**10**).—The oxime (**10**) was synthesized following a general procedure described by Buck and Ide.[21] A hot solution of hydroxylamine hydrochloride (70 mg, 1 mmol) in water (2 ml) was added to a solution of the butenal (**5**) (250 mg, 1 mmol) in ethanol (95%; 5 ml). The mixture was stirred vigorously and a solution of NaOH (70 mg) in water (2 ml) was added. After 2 h at room temperature diethyl ether (20 ml) was added with stirring. The organic layer was separated and washed with water, dried ($MgSO_4$), filtered, and the solvent removed under reduced pressure. The solid product was crystallized from methanol to afford the *oxime* (**10**) (237 mg, 20%); m.p. 69—70 °C; $\nu_{max.}$(KBr) 3 260 (OH) and 1 600 (C=N) cm^{-1}; $\nu_{max.}$(CH_2Cl_2) 250 nm (16 980); δ_H($CDCl_3$) 1.16 (6 H, s, 2-Me), 5.98 (1 H, s, vinyl-H), 6.98 (1 H, s, CH=N), 7.1—7.35 (10 H, m, ArH), and 7.40 (1 H, s, NOH) (Found: C, 81.7; H, 7.25; N, 5.15. $C_{18}H_{19}NO$ requires C, 81.50; H, 7.17; N, 5.28%).

2,2-*Dimethyl*-4,4-*diphenylbut*-3-*enonitrile* (**11**).—The nitrile was synthesized following a general procedure.[21] A solution of the oxime (**10**) (1.16 g, 4.4 mmol) in acetic anhydride (10 ml) was refluxed for 20 min. Water (20 ml) was added with stirring and the aqueous phase was separated and extracted with ether. The organic layer was separated, dried ($MgSO_4$), filtered, and the ether was removed under reduced pressure. The residue was distilled to yield a colourless solid which was crystallized from ethanol to afford the *nitrile* (**11**) (0.86 g, 79%), m.p. 108—109 °C; $\nu_{max.}$(KBr) 2 235 cm^{-1} (CN); $\lambda_{max.}$(EtOH) 230 (13 180) and 249 nm (13 803); δ_H($CDCl_3$) 1.45 (6 H, s, 2-Me), 5.8 (1 H, s, vinyl-H), and 7.15—7.4 (10 H, m, ArH) (Found: C, 87.8; H, 7.05; N, 5.3. $C_{18}H_{17}NO$ requires C, 87.40; H, 6.93; N, 5.66%).

General Procedure for Photolyses.—All 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 compounds (*ca.* 2 mmol) in t-butyl alcohol or benzene (anhydrous; 400 ml) were purged for 1 h with nitrogen and irradiated for variable times. For the sensitized experiments acetophenone (15.5 mol) or phenanthrene (11.2 mmol) were added to the solutions prior to nitrogen purging. After completion of the irradiation the solvent was removed under reduced pressure and the sensitizer, if used, was removed by distillation for acetophenone or by chromatography for phenanthrene. The crude photolysates of the imines were then hydrolysed using a mixture of 1% H_2SO_4 (5 ml) in THF (30 ml). These mixtures were stirred at ambient temperature for 30 min and then extracted into ether. The organic layer was washed with aqueous sodium hydrogencarbonate (10%; 20 ml), dried ($MgSO_4$), filtered, and evaporated under reduced pressure. These crude mixtures were chromatographed on silica gel (150 mg) using hexane–ether (95:5) as the eluant.

2-*Methyl*-5,5,7,7-*tetraphenyl*-3-*azahepta*-3,6-*diene* (**7a**). Direct irradiation of (**7a**) (830 mg, 2 mmol) in t-butyl alcohol for 19 h gave on chromatography two fractions: (*a*) 2,2,4,4-tetraphenylbut-3-enal (374 mg, 50%) and (*b*) 2,2,3,3-tetraphenylcyclopropanecarbaldehyde (344 mg, 46%), m.p. 204—206 °C (lit.,[16] m.p. 205—207 °C). Sensitized irradiation of (**7g**) (830 mg, 2 mmol) for 1 h using acetophenone in benzene gave after chromatography two fractions: (*a*) 2,2,4,4-tetraphenylbut-3-enal (299 mg, 40%) and (*b*) 2,2,3,3-tetraphenylcyclopropanecarbaldehyde (413 mg, 55%).

2,3,3-*Trimethyl*-1,5,5-*triphenyl*-1-*azapenta*-1,4-*diene* (**7b**). Sensitized irradiation of (**7b**) (1.36 g, 4 mmol) for 2 h with acetophenone in benzene gave after chromatography two fractions: (*a*) 3,3-dimethyl-5,5-diphenylpent-4-en-2-one (**9a**) (1.04 g, 94%) and (*b*) 2,2-dimethyl-3,3-diphenylcyclopropyl methyl ketone (**19**) (50 mg, 4.5%). The physical and spectral properties of this compound were identical with those reported.[12]

3,4,4-*Trimethyl*-1,6,6-*triphenyl*-2-*azahexa*-2,5-*diene* (**7c**). Direct irradiation of (**7c**) (944 mg, 2.7 mmol) for 38 h in t-butyl alcohol gave on chromatography only 3,3-dimethyl-5,5-diphenylpent-4-en-2-one (671 mg, 95%). Sensitized irradiation of (**7c**) (2.5 g, 7.1 mmol) for 2 h with acetophenone in benzene gave after chromatography: (*a*) 3,3-dimethyl-5,5-diphenylpent-4-en-2-one (1.66 g, 89%) and (*b*) 2,2-dimethyl-3,3-diphenylcyclopropyl methyl ketone (56 mg, 3%). The spectral properties of this compound were identical with those reported.[12]

4,4-*Dimethyl*-1,3,6,6-*tetraphenyl*-2-*azahexa*-2,5-*diene* (**7d**). Direct irradiation of (**7d**) (830 mg, 2 mmol) for 19 h in t-butyl alcohol gave after chromatography only recovered 2,2-dimethyl-

1,4,4-triphenylbut-3-en-1-one (**9b**) (554 mg, 85%). Several minor products were also detected but not identified.

Sensitized irradiation of (**7d**) (830 mg, 2 mmol) for 20 h with phenanthrene in benzene gave on chromatography recovered 2,2-dimethyl-1,4,4-triphenylbut-3-en-1-one (630 mg, 97%).

2,2-*Dimethyl*-4,4-*diphenylbut*-3-*enal oxime* (**10**). Direct and acetophenone-sensitized irradiation of (**10**) (530 mg, 2 mmol) for 24 h in t-butyl alcohol and 18 h in benzene respectively gave recovery of starting material (100%).

2,2-*Dimethyl*-4,4-*diphenylbut*-3-*enonitrile* (**11**). Direct and acetophenone-sensitized irradiation of (**11**) (495 mg, 2 mmol) for 20 h in t-butyl alcohol and 65 h in benzene respectively gave only recovered starting material (100%).

2,2,4,4-*Tetraphenylbut*-3-*enal*. The aldehyde (55 mg, 0.15 mmol) was dissolved in t-butyl alcohol (8 ml) and placed in a quartz tube of 10 ml capacity which was then sealed with a serum cap. The sample was purgued with nitrogen introduced through a syringe needle for 20 min prior to photolysis. The sample was taped to the immersion well (Pyrex filter) of the conventional apparatus and irradiated for 4 h. After irradiation the solvent was removed to yield a white solid which crystallized from ethanol to afford 1,1,3,3-tetraphenylpropene (38 mg, 73%), shown to be identical with an authentic sample synthesized by the method of Zimmerman *et al.*[16]

Acknowledgements

We thank the British Council, the Ministerio de Educacion y Ciencia of Spain, and the Comisión Asesora de Investigación Científica y Tecnica for financial assistance.

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Received 13*th March* 1986; *Paper* 6/501