



Quinolines from Oximes

A Thesis Presented for the Degree of Doctor of Philosophy

By

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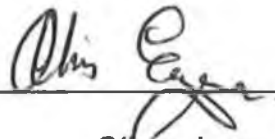
School of Chemical Sciences

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TO MAM AND DAD

Declaration

I, the undersigned, hereby declare that this thesis, which I now submit for assessment on the programme of study leading to the award of Ph.D., represents the sole work of the author and has not been taken from the work of others save and to the extent that such work has been cited and acknowledged within the text.



Oliver James Egan

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ABSTRACT

The photochemistry of a number of arylidenecyclopentanone oxime O-acetates and methyl ethers has been investigated. Irradiation of several of these compounds in methanol leads to initial E-Z geometrical isomerisation and ultimately to the formation of nitrogen containing heterocycles via a 6π -electron photocyclisation process followed by an elimination.

The photocyclisation has been investigated for aryl groups containing both electron withdrawing and electron donating substituents. Cyclisation is not observed in the case of electron withdrawing groups such as 2-(4-cyanobenzylidene)cyclopentanone oxime O-acetate, 2-(3-cyanobenzylidene)cyclopentanone oxime O-acetate, 2-(3-fluorobenzylidene)cyclopentanone oxime O-acetate and 2-(3-chlorobenzylidene)cyclopentanone oxime O-acetate, whereas the presence of electron donating groups such as 2-(3-methoxybenzylidene)cyclopentanone oxime O-acetate and 2-(3-methylbenzylidene)cyclopentanone oxime O-acetate facilitates the reaction.

The regiospecificity of the reaction has also been investigated, and in all cases where the photocyclisation proceeds, only one product is isolated. Both acetates and methyl ethers yield the same cyclised photoproducts.

The photoreactivity of the arylidenecyclopentanone oxime O-acetates has also been investigated in natural sunlight at the Plataforma Solar de Almeria (PSA) in the south of Spain. The photoreactions proceed in the same manner as in the laboratory yielding the desired products. Reasonable conversions are achieved, and the apparatus available at the PSA makes large scale and inexpensive heterocycle syntheses achievable.

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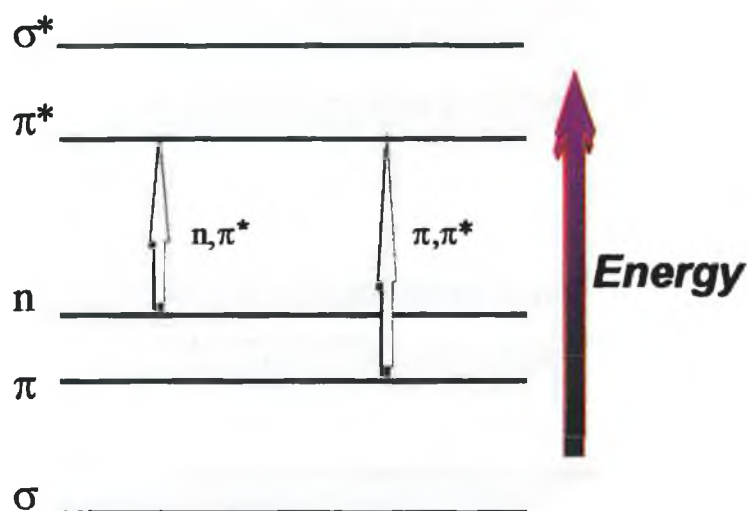
Special thanks go to my fellow postgrads, past and present without whom this work would not have been nearly as enjoyable. I would like to particularly thank Shane, James, Cormac, Mark, Colm, Ben, Orla, Collette, Rory, Joe, Siobhan, Ciara, Mary, Peter and Mairead for their continued good humour and from whom I have learned a great deal.

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1. The Photochemistry of the Carbon-Nitrogen Double Bond

1.1 Spectroscopy

The structure of the imino group makes possible two frequently observed transitions into orbitals of a higher energy level from the ground state on excitation; that of an n, π^* and a π, π^* transition. This stems from the fact that the imine entity (which is the C=N system) contains a double bond (i.e. a π -system) and a nitrogen atom, which has a non-bonded pair of electrons which are denoted 'n'. A representation of the relative energies of the respective orbitals in organic molecules is shown below.

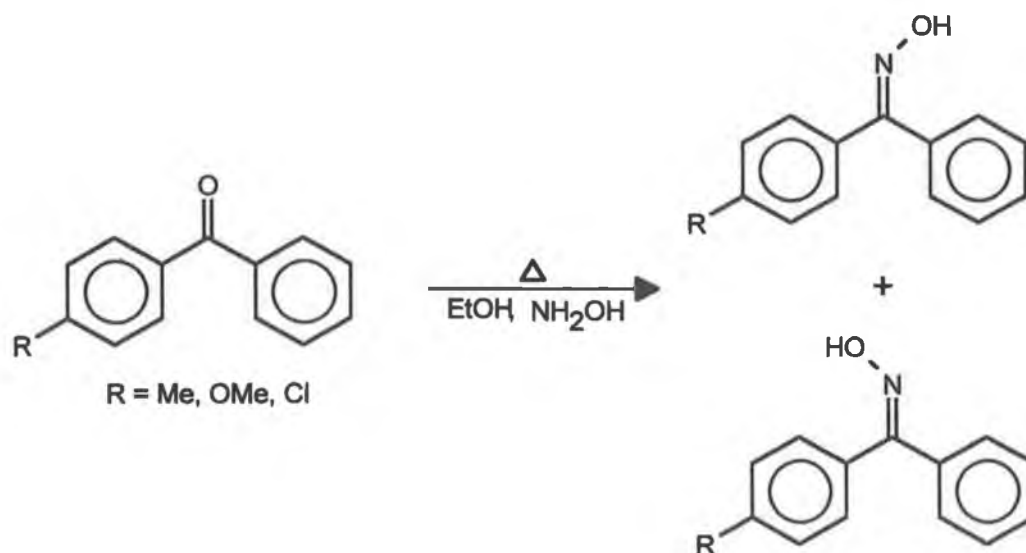


For imines, two distinct bands are visible in the u.v. spectrum due to the two frequently observed transitions of imines discussed above. The π, π^* band appears at shorter wavelength than the n, π^* band, because of the higher energy required for a π, π^* transition and in unconjugated imines is usually a more intense band. In highly conjugated molecules, the π, π^* band often submerges the n, π^* band completely. Both types of transition can result in either a triplet or a singlet excited state.

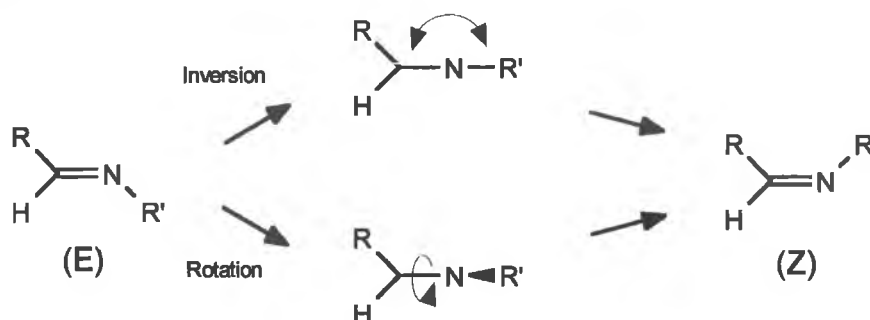
1.2 Photoisomerisation

As early as 1890 it was observed that isomerisation occurs around the carbon-nitrogen double bond.^{1,2} On conversion of a *p*-tolylketone to its oxime

derivative, Hantzsch isolated two different isomers of product under different recrystallisation conditions. This was observed for a number of different ketones, as shown below;



It was not until 1903 that photochemical isomerisation around the carbon-nitrogen double bond³ was observed. The papers published on this subject were quite sporadic^{4,5} up to the late 1960's, since when the wealth of new techniques available to the chemist has increased enormously. The photochemistry of the carbon-nitrogen double bond has been investigated extensively over this period, although not in as much detail mechanistically as qualitatively.⁶ For many years the mechanism of syn-anti isomerisation about the carbon-nitrogen double bond was attributed to one of three possible mechanisms⁶ (Scheme 1).



SCHEME 1

It could be due to a planar inversion, a rotational process, or a combination of the two. In the ground state (S_0) the favoured mechanism is inversion because the rotational mechanism involves scission of the double bond. In the excited state, the double bond character is reduced, allowing the rotational mechanism to become a possibility.

From work carried out by Bonacic-Koutecký and Perisco⁷ it now seems clear that the rotational mechanism is the favoured process for isomerisation in the excited states.

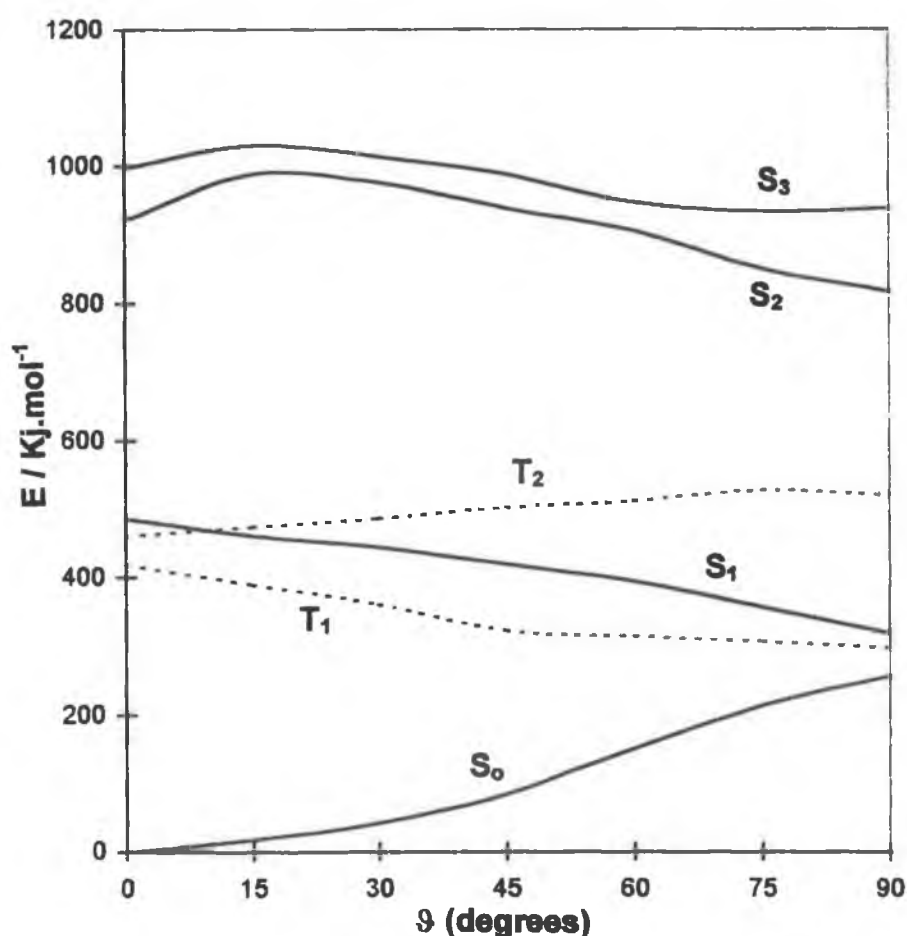


Fig 1. Averaged extrapolated energies of the four singlet states S_0 , S_1 , S_2 , S_3 and the two triplet states T_1 , T_2 of formaldehyde as a function of the twist, ϑ , of the C=N bond.⁷

They have theoretically calculated energy barriers between planar and torsional (up to 90°) arrangements of the carbon-nitrogen double bond and found that in

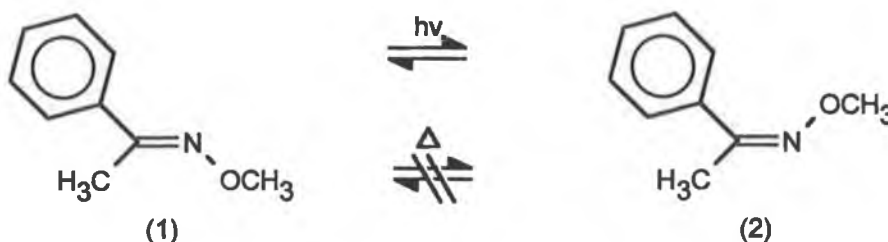
the first excited state S_1 the energy for 90° torsion is actually 138 kJ.mol^{-1} lower than at planar geometry (Fig 1). This situation is opposite to that of the molecule in the ground state S_0 , where it is calculated that the energy barrier for torsion of 90° is approximately 251 kJ.mol^{-1} higher than that of planar inversion (values quoted are for formaldimine, but analogous results were obtained for allylidenimine).

Photochemical reactions about the carbon-nitrogen double bond such as Beckmann or Beckmann-like rearrangements are frequently observed,^{8,9,10} but a more frequently encountered phenomenon is the high rate and efficiency with which excited states undergo radiationless decay.^{11,12} This deactivation of the chromophore can be attributed to rotation about the π -bond in the excited state thereby allowing dissipation of electronic energy. The thermal interconversion energy barrier between syn and anti isomers has been shown to be very sensitive to the attached substituent groups;¹³ indeed the difference in rates of isomerisation between imines with differing substituents on the carbon and nitrogen has been shown to range over at least 16 powers of 10. At room temperature, oxime ethers have been shown to have great configurational stability (a property contrary to that of the N-aryl- and N- alkyl-imines,¹³ which may interconvert readily to their syn or anti isomers at room temperature) and thus are very suitable candidates for mechanistic photostudies since the presence of the methoxy group reduces greatly the rate of thermal interconversion. Each oxime ether isomer should be stable at room temperature to facilitate mechanistic investigation of the system.

The stability of the oxime ether isomers (1) and (2) to be investigated by Padwa and Albrecht¹⁴ was tested before photolysis by heating each isomer separately at 150°C for 168 hrs in benzene and noting the absence of any isomerisation. On irradiation, photoisomerisation occurred, and this could not be quenched by high concentrations of a triplet quencher (piperylene). This indicated that the reaction proceeded either from a singlet excited state or from a triplet excited state at a rate exceeding the rate of diffusion. Direct irradiation of the isomers resulted in a photostationary state close to that theoretically

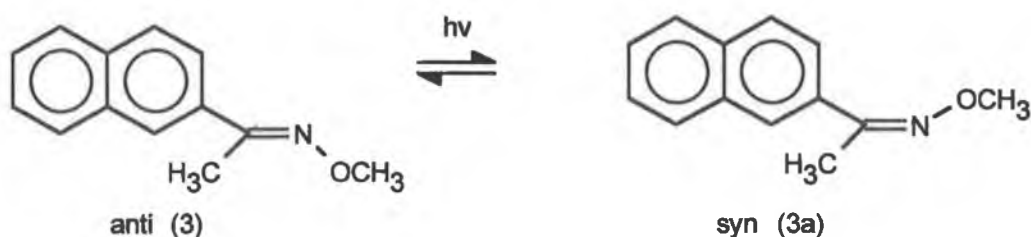
predicted. Triplet sensitised experiments were also carried out, but in these cases the photostationary states observed were very different to those predicted theoretically.

This is an indication that the rate constants for quenching sensitizer triplets by the two oxime ethers were different. To determine whether the isomerisation

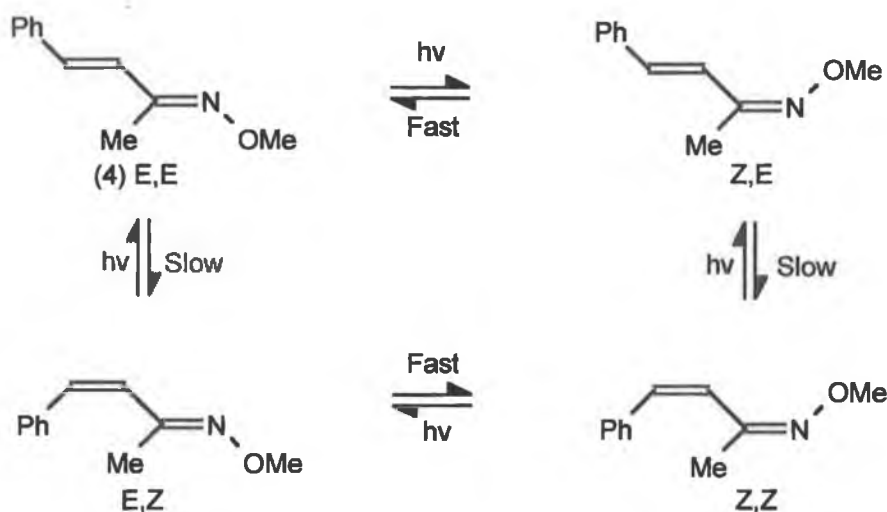


occurred from a singlet state or a very reactive triplet intermediate, double sensitisation experiments were carried out. These were based on the irradiation of the oxime ether in the presence of a suitable triplet sensitizer such as benzophenone and a triplet quencher; in this case trans-stilbene. Before this double sensitisation experiment was carried out, the relative triplet quenching abilities of the two oxime ethers and trans stilbene were assessed. Cyclohexanol was photoreduced by benzophenone in the presence of each of the two oxime ethers and the stilbene in three separate experiments. It was found that the trans-stilbene was actually a much more efficient quencher of benzophenone than either of the oxime ethers. In the double sensitisation experiment with the stilbene, one of the oxime ethers and benzophenone, it was found that the ratio $\Phi_{\text{conversion of trans to cis stilbene}} / \Phi_{\text{conversion of syn oxime ether to anti or vice versa}}$ was actually greater than that theoretically calculated. Because this is so, energy transferred from the benzophenone to the oxime ether is, in turn, being transferred to the stilbene molecule. This being the case, then it is clear that the triplet photoisomerisation cannot proceed at a rate which is faster than the diffusion controlled rate. Taking this fact into account along with the absence of a quenching effect by piperylene, it follows that the reactive state involved in the direct irradiation is an electronically excited singlet state.

In certain olefinic systems, excimers have been reported to play an important role in their photoisomerisation.^{15,16,17} This has also been reported for the syn and anti isomers (3) and (3a).¹⁸ These isomers were irradiated revealing a photostationary state which is dependent on two factors. When the concentrations of the oxime ethers are increased, the fraction of anti isomer increases. However, if the temperature of photolysis is raised, the concentration of anti isomer (which is the thermodynamically more stable of the two) is diminished. No evidence for ground state complexing was found by any spectroscopic methods. This indicated the presence of interaction between ground and excited state molecules, i.e. excimers. This correlates with the observations made on certain olefinic systems where an increase in olefin concentration enhances the concentration of the trans isomer in the photostationary state.

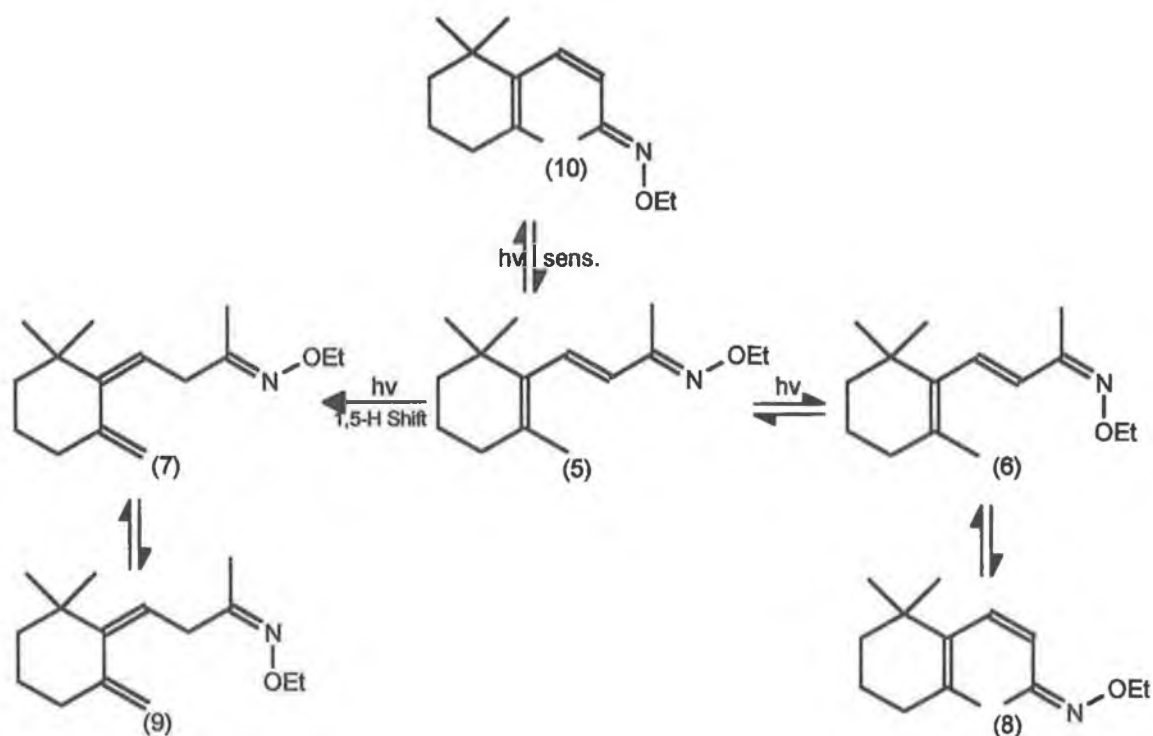


Reports have also appeared in the literature concerning the isomerisation of systems containing olefinic and imino groups in the same molecule, such as



α,β -unsaturated oxime ethers.¹⁹⁻²³ Sato previously reported²³ that the conjugated oxime ether E-[E-benzylideneacetone]oxime O-methyl ether (4) underwent carbon-carbon double bond isomerisation, but not carbon-nitrogen double bond isomerisation. This was disputed in a later paper¹⁹ in which the photochemistry of the ether (4) was reinvestigated. It was shown that the carbon-nitrogen double bond in this system does isomerise and in fact undergoes isomerisation more easily than the carbon-carbon double bond, both under direct and triplet sensitised irradiation.

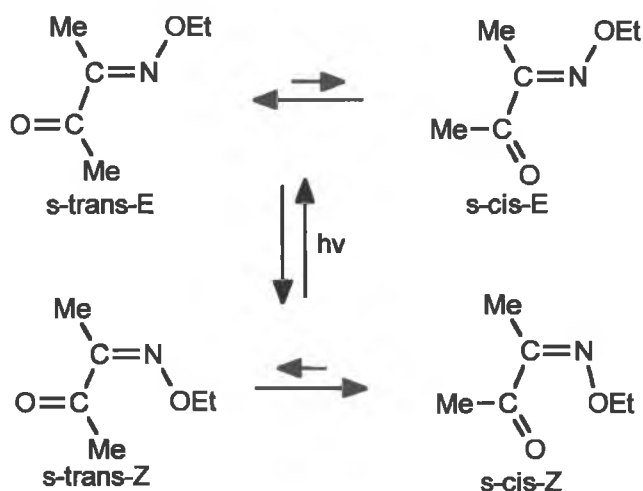
Direct irradiation of E- β -ionone oxime O-ethyl ether (5) yields (6) and (7) as primary photoproducts, while prolonged irradiation leads to a mixture of (6), (7), (8) and (9).²²



The products (6) and (8) are geometrical isomers, whereas (7) and (9) are the result of a 1,5 hydrogen shift. Triplet sensitisation of (5) yields a mixture of the four geometrical isomers (5), (6), (8) and (10), with varying photostationary state ratios, depending on the sensitiser used. Formation of neither (7) or (9) was observed on triplet sensitisation. It was concluded from this that the 1,5-hydrogen

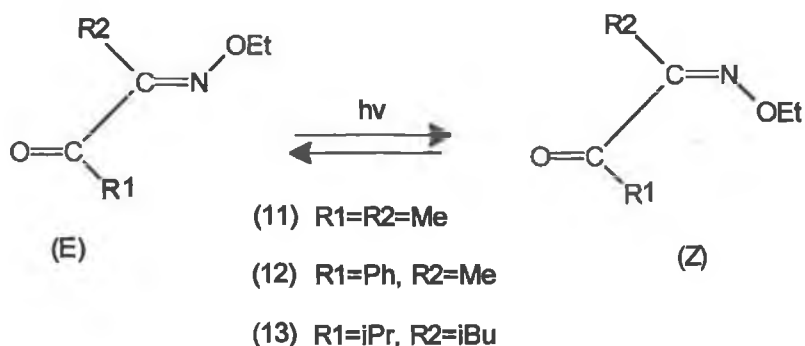
shift occurs exclusively from the singlet state on direct irradiation. It was also concluded that E,Z-photoisomerisation occurs from the singlet excited state, since the triplet sensitised product (10) was not formed on direct irradiation. The addition of ethyl iodide (to enhance singlet to triplet intersystem crossing) affected the E,Z-photoisomerisation and 1,5-hydrogen shift of (6) and (5) to the same extent. Because it was already known that the 1,5-hydrogen shift occurs exclusively from the singlet excited state, this was further evidence which inferred that E,Z-photoisomerisation occurs from the singlet excited state.

The photochemistry of α -oxo oximes, oxime ethers and oxime acetates has been investigated for several systems.²⁴⁻²⁸ The direct and sensitised irradiation at $\lambda > 300\text{nm}$ of E- and Z-3-ethoxyiminobutan-2-one²⁴ leads to solely E,Z-photoisomerisation, the E-isomer existing predominantly in the *s-trans* and the Z- isomer predominantly in the *s-cis* conformation (s here signifies rotation around the C-C single bond). The photostationary state ratio obtained on irradiation in acetonitrile solution at 366nm was found to be 6.0 (± 0.3):1 in favour of (E). The isomerisation was not quenched by Z-penta-1,3-diene, even in high concentrations (up to 1.5M). This indicated that the reaction proceeded from an excited singlet or from a very short lived triplet state. Also on triplet

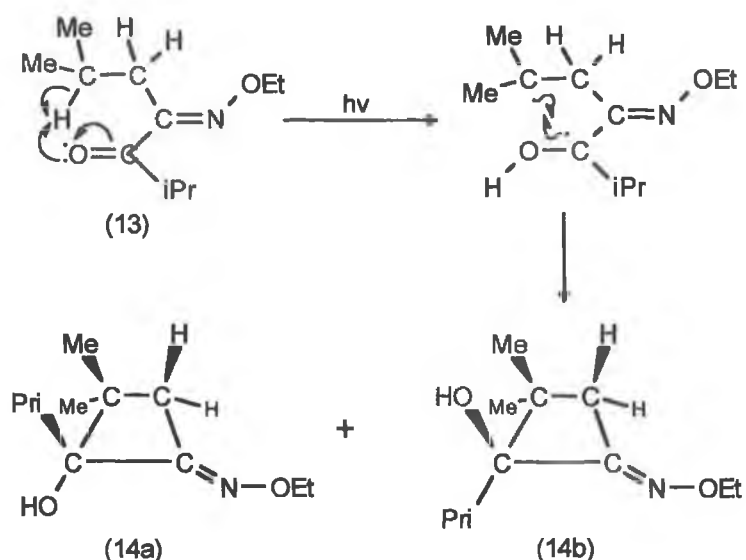


*Geometrical isomers of
3-ethoxyiminobutan-2-one*

sensitisation a photostationary state was obtained, the ratio of isomers depending on the sensitizer used. More recent publications have shown that the photoreactions of α -oxo oximes and their derivatives can be divided into photoisomerisation and photodecomposition.²⁵⁻²⁸ In compounds (11)-(13) from spectroscopic studies it has been possible to work out their structures.

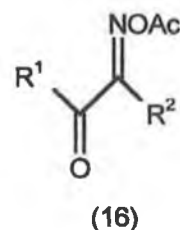
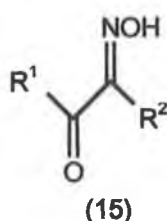


Both upon direct and triplet sensitised irradiation, E,Z-photoisomerisation takes place from the T_1 ($\pi-\pi^*$) state. The Z-isomer of (11) is thought to exist in a slightly twisted *s-cis* conformation, by analogy with the slightly non-planar *s-cis* conformation of Z-3-methylpent-3-ene-2-one.²⁹ It is unlikely that the Z isomers of (12) and (13) exist in the planar *s-cis* conformation, because of steric interactions between R1 and R2, but in an *s-trans* conformation. Upon direct irradiation at 313nm, isomerisation is also accompanied by photodecomposition, which is



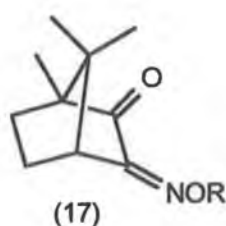
thought to proceed via the S_1 ($n-\pi^*$) state, because of the absence of photodecomposition in triplet sensitised reactions. In the case of (13) photodecomposition results in a Norrish type II γ -hydrogen abstraction which is followed by ring closure, resulting in the formation of two cyclobutanol derivatives, (14a) and (14b).

Irradiation of the α -oxo oximes (15a-e) and (17a) and the α -oxo oxime acetates (16a-e) and (17b) at 366 nm led to E,Z-isomerisation with



- a: $R^1 = R^2 = \text{Ph}$
 b: $R^1 = \text{Ph}, R^2 = \text{Me}$
 c: $R^1 = \text{Me}, R^2 = \text{Ph}$

- d: $R^1 = \text{Me}, R^2 =$
 e: $R^1 =$ $, R^2 = \text{Ph}$
 f: $R^1 = \text{Et}, R^2 = \text{Me}$
 g: $R^1 = \text{Me}, R^2 = \text{H}$
 h: $R^1 = \text{Me}, R^2 = \text{Et}$
 i: $R^1 = \text{Me}, R^2 = \text{CH}_2\text{Ph}$
 j: $R^1 = R^2 = \text{Me}$



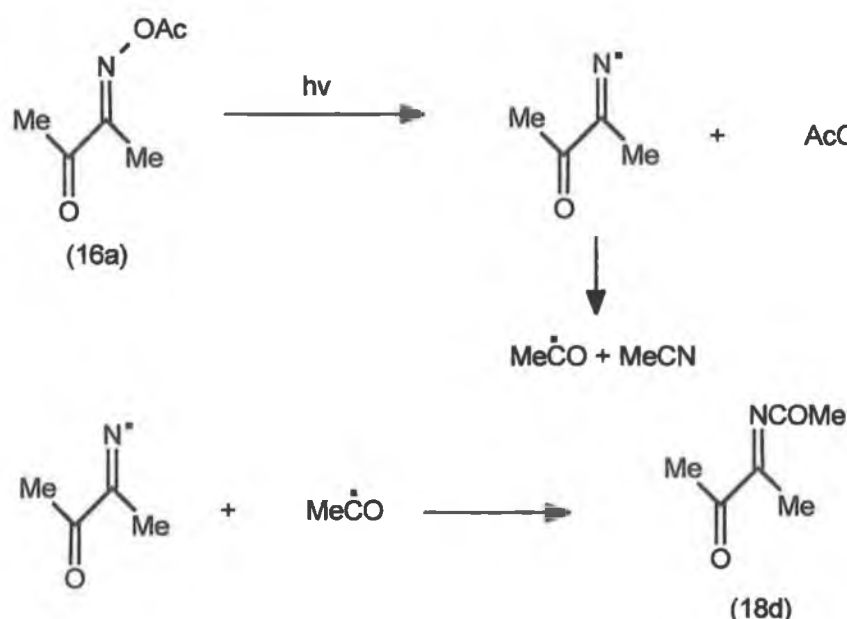
- a: $R = \text{H}$
 b: $R = \text{Ac}$
 c: $R = \text{Et}$



- a: $R^1 = \text{Me}, R^2 = \text{Et}$
 b: $R^1 = \text{Me}, R^2 = \text{Ph}$
 c: $R^1 = \text{CH}_2\text{Ph}, R^2 = \text{Et}$

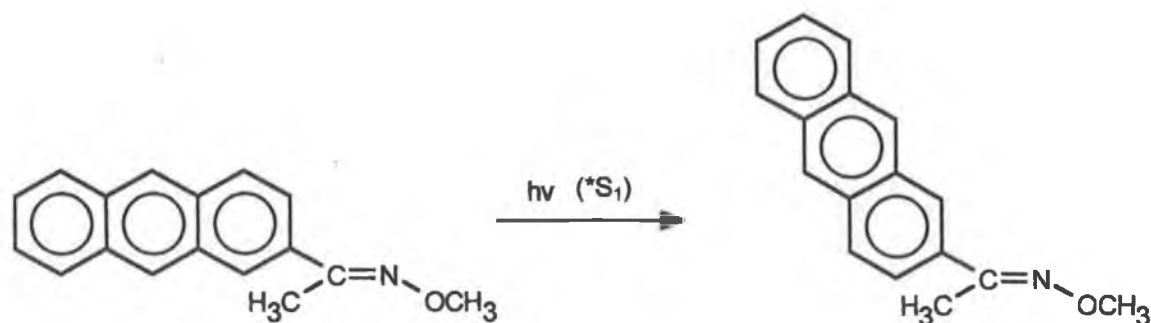
eventual formation of a photostationary state, the ratio of which depends on the substituent on the oxime function. The same ratio is obtained whether starting

with the E or Z isomer. The E-isomers of the α -oxo oximes (15f-j) did not photoisomerise. Photodecomposition was not seen to any great extent in the case of the α -oxo oximes, but in the case of all the oxime esters (16a-j, 17b and 18a-c), photodecomposition occurred rapidly. In the case of (16b) and (17b) the rate of photodecomposition is of the same order of magnitude as the rate of E,Z photoisomerisation. On irradiation at 254 nm however, decomposition of all of the α -oxo oxime esters is a much faster process than photoisomerisation. Photolyses of α -oxo oxime esters were carried out in the presence of a spin trapping agent (2-methyl-2-nitrosopropane) and e.s.r. spectroscopy was used to determine the presence of alkyl and acyl radicals. This aided the investigation into the reaction mechanism of photodecomposition. It was seen that after excitation, N-O bond homolysis occurs with formation of an α -oxo-iminyl and an acyloxyl radical. The α -oxo iminyl radical undergoes β -scission with formation of acetonitrile, or recombines with an acetyl radical to yield the N-acetyl- α -oxo-imine (18);



Decomposition of acyloxyl radicals leads also to the formation of carbon dioxide and alkyl radicals. However, irradiation of cyclic α -oxo imino compounds such as compound (17c), can lead to much more complex reactions resulting in several products, some of which are due to radical based cage recombination;

the 2-anthryl substituted carbon-nitrogen double bond in the excited singlet state can be attributed to the localisation of excitation on the anthracene nucleus.

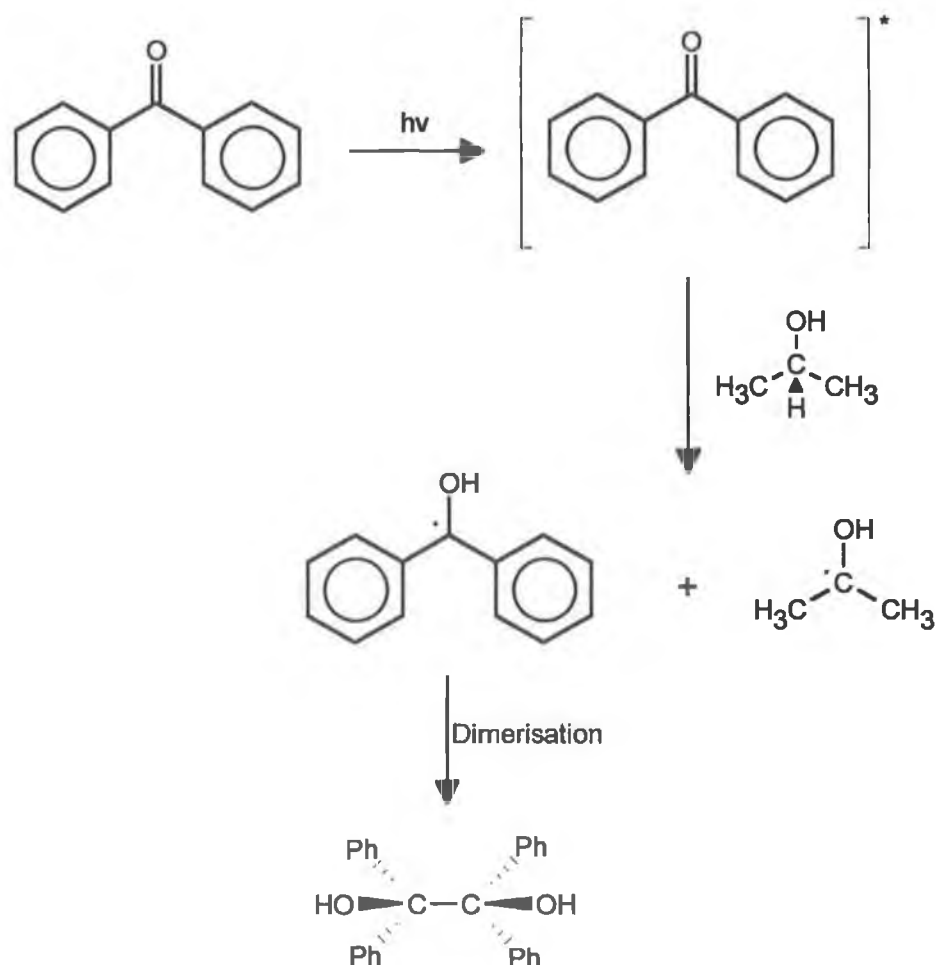


This localisation of excitational energy results in the rotational isomerisation of the anthracene nucleus around the single bond in the excited state in preference to the isomerisation from E to Z around the double bond. The localisation of excitation on the anthracene has been attributed to the low energy of the E isomer. A more recent publication by the same authors³⁴ in which the same system was investigated via transient and fluorescence studies, rules out the participation of an excited singlet state in the isomerisation around the C=N bond for the following reasons. The Z- and E-isomers exhibit different fluorescence spectra. If the Z-isomer underwent isomerisation from the excited singlet state, its fluorescence spectrum would become similar to that of the E-isomer as observed in the isomerisation of 1-styrylpyrene.^{35,36} This is simply because excitation of the Z-isomer to its excited singlet state (from which fluorescence occurs) would convert the molecule into its isomeric E-form, if isomerisation occurred from the singlet excited state. The fluorescence spectrum would then begin to assume the appearance of the E-isomer because the E-isomer in the sample would be replacing the Z-isomer. Since no detectable isomerisation to the E-isomer accompanied the fluorescence studies, it was concluded that the singlet excited state of the Z-isomer must undergo intersystem crossing to the excited triplet state, $^3Z^*$, which subsequently isomerises to $^3E^*$. The mode of C=N isomerisation has been postulated to be either a rotational or an inversion mechanism, although as discussed earlier, the weight of evidence lies in favour of a rotational mechanism. Arai and co-workers^{37,38} in this case conclude that the mechanism

is rotational, due to the similarity between the theoretical potential energy surfaces of isomerisation of the anthryl compound and 3,3-dimethyl-1-butenylanthracene, a compound which also has been seen to undergo one way C-N double bond isomerisation.

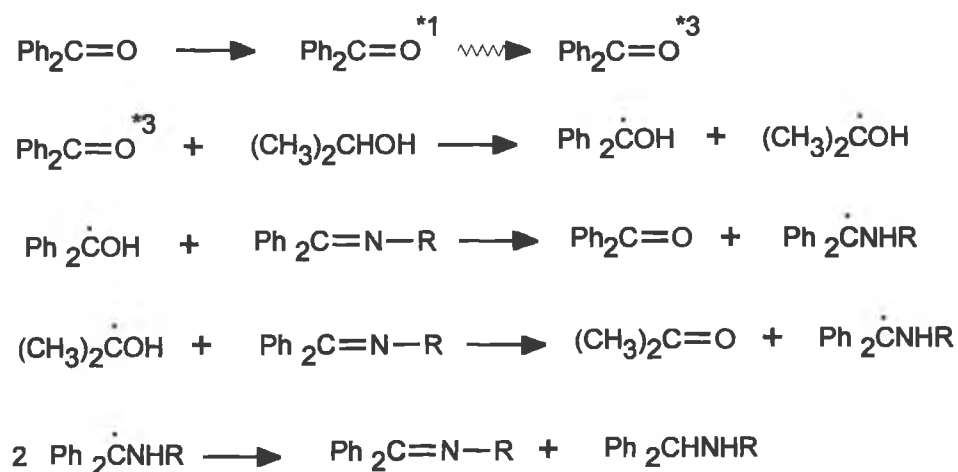
1.3 Photoreduction and Hydrogen Abstraction

The photochemistry of the carbonyl group is wide and varied, the principal modes of action being hydrogen abstraction and Norrish type I (α -cleavage) processes. The imino group, which shows many analogies to the carbonyl group, also has a tendency to undergo many of the reactions commonly seen in carbonyl chemistry, although in lower degree. This alternate reactivity of the imino group may be attributed to a reduced π -bond order in the (π, π^*) excited



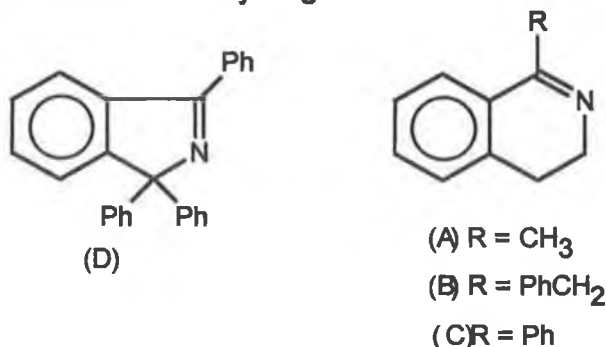
state of the C=N chromophore allowing facile *syn-anti* isomerisation, a pathway not available to carbonyl compounds. *Syn-anti* conversion is not the only reason for the alternate photochemical activity of the imino chromophore. In certain cases where the imino group is part of a ring system which inhibits C=N isomerisation, the inefficiency of hydrogen abstraction has been shown to be comparable to that of acyclic analogues. The photoreduction of benzophenone was investigated by Pitts and co-workers in the late 1950's,³⁹ the mechanism of which was proposed to proceed via the ketone's triplet excited state, resulting in a pinacolisation reaction among others (shown on the previous page).

The photoreduction of benzophenone imine⁴⁰ was thought to proceed via a similar mechanism where absorption of light by the imine yielded the excited singlet species and decayed to the triplet state, abstracting a hydrogen. An earlier and a subsequent paper^{41,42} (the earlier one being disputed by the authors of ref. 40) however showed that imine photoreductions did not involve the excited state of the imine at all. Several papers were published on the photoreduction of imines up to 1972, when a paper was published⁴⁶ illustrating how the photoreduction of imines actually took place from the ground state of the imine. The imine is first converted to an α -amino radical which is formed by hydrogen atom transfer to the ground state imine from a ketyl radical. The ketyl radical is derived from carbonyl compounds present in starting material as an impurity, an added sensitizer, or as a photogenerated species (see scheme 2).

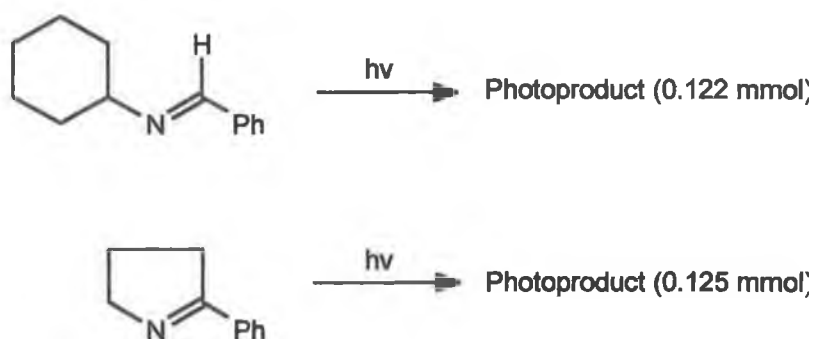


SCHEME 2

Ohta and Tokumaru⁴⁷ have investigated the phosphorescence of several cyclic imines and concluded that the unreactive nature of excited imines is attributable to the high π,π^* character of their triplet states as well as to the low energy of the N-H bond which would result from hydrogen transfer to imines. This conclusion

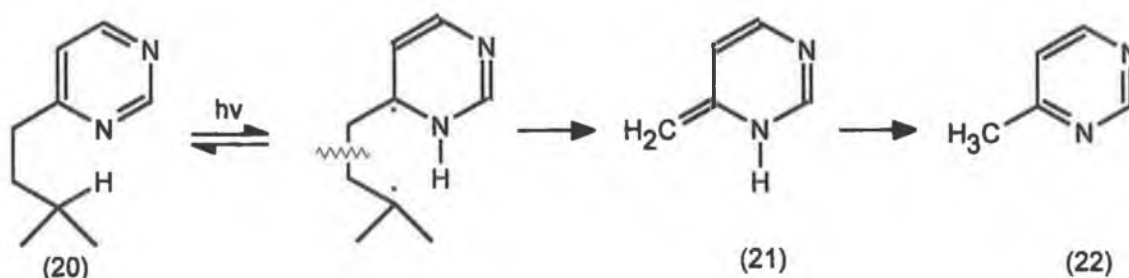


was reached after observation of triplet energy transfer from the above (A-D) imines to trans-1,3-pentadiene resulting in its geometrical isomerisation and the absence of hydrogen abstraction by the imines from alcoholic solvents. Also the reactivity of triplet carbonyl compounds (such as methyl and trifluoromethyl-substituted acetophenones) for hydrogen abstraction decreases with the increase of π,π^* character at the expense of n,π^* character in their triplet states.^{47a} Comparative photolyses of cyclic and acyclic analogues have also been investigated⁴⁸ which illustrate how *syn-anti* isomerisation does not play a key role in the unreactivity of imines in hydrogen abstraction reactions;

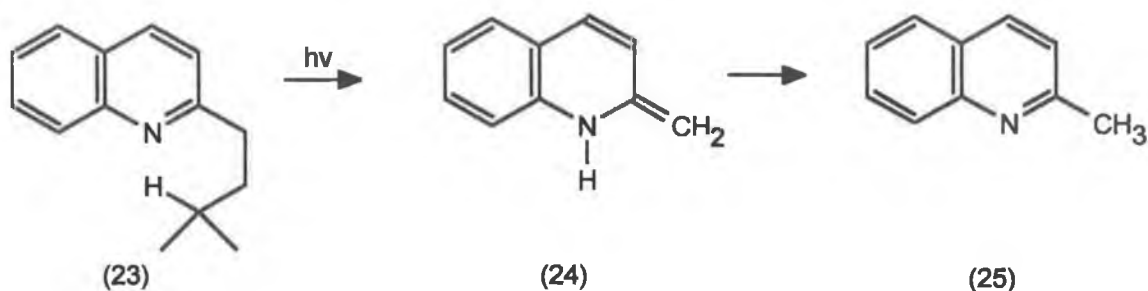


In separate experiments, photolyses of equimolar amounts of acyclic and cyclic imines yielded equivalent amounts of product as shown above.

Hydrogen abstraction reactions have also been observed in other nitrogen containing cyclic compounds and their derivatives such as pyrazines, pyrimidines, pyridines and quinolines.⁴⁹⁻⁵³ Pyrimidine (20) undergoes intramolecular hydrogen abstraction from an n,π^* triplet state to form (22) via methide (21).

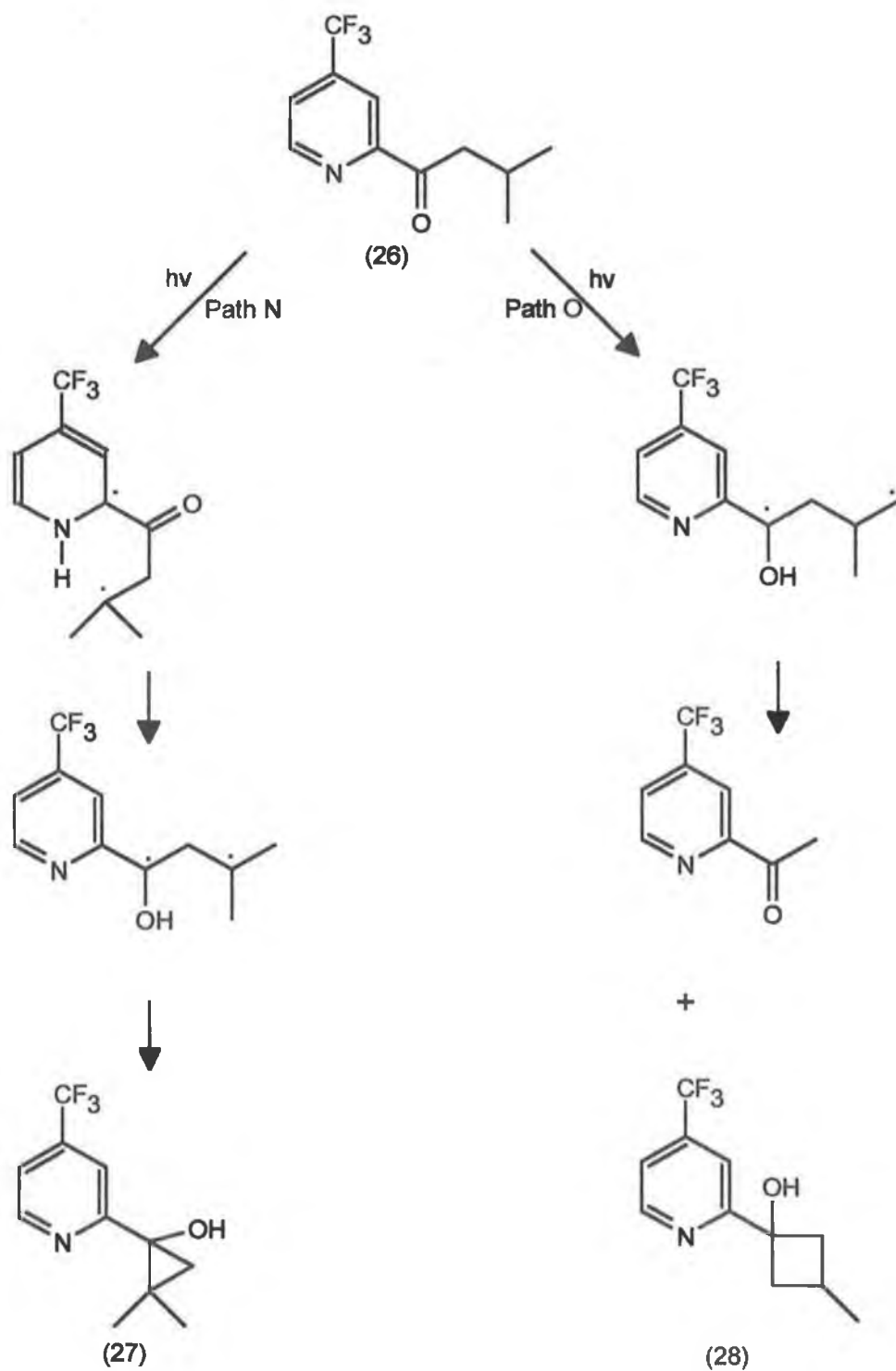


Quinoline (23) undergoes a similar reaction but from an n,π^* singlet state. The methide (24) has been identified spectroscopically as a transient on flash photolysis of (23). Quantum yields for product formation (Φ_{22} and Φ_{25}) and Stern-Volmer quenching studies on these reactions have shown that, unlike Φ for abstraction by carbonyl triplets, Φ_{22} and Φ_{25} do not increase in hydrogen donating solvent

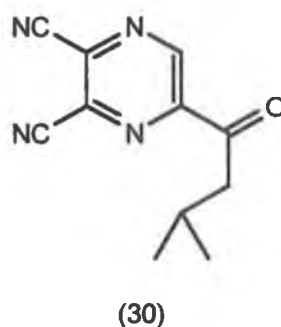
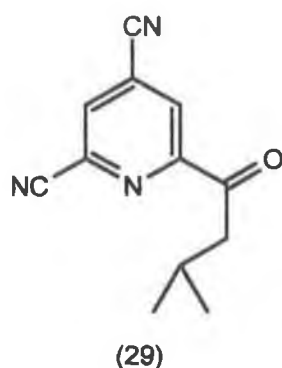


and there is little rate difference in transferring primary, secondary and tertiary hydrogen in the initial step. Investigation into systems which contain both a carbonyl group and an imine group^{50,51,53} has shown that competing hydrogen abstraction processes take place between nitrogen and oxygen atoms. Some

examples of these compounds are the acyl heterocycles, acylpyrimidines, acylpyridines, acylpyrazines and acylpyridazines.

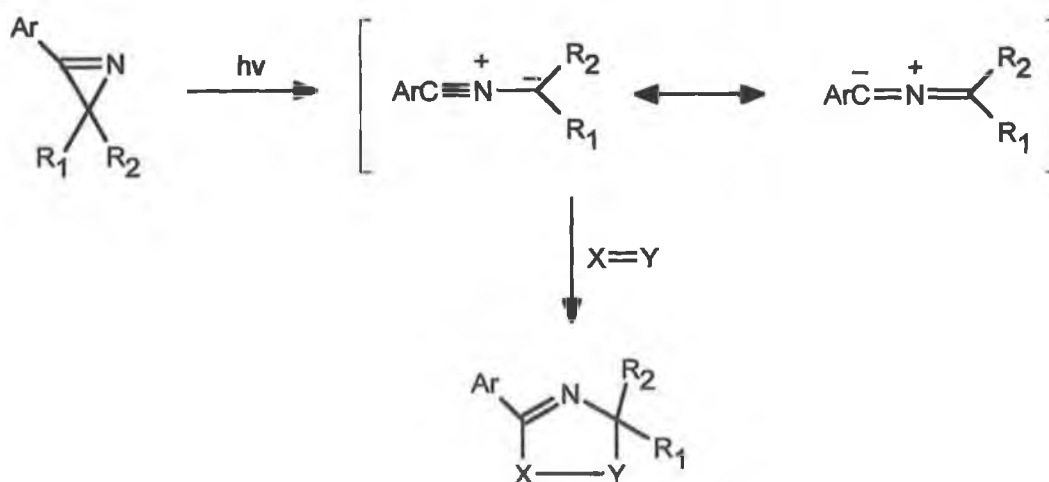


The 2-pyridyl ketone 4-trifluoromethyl-2-isovalerylpyridine (26) undergoes hydrogen abstraction by nitrogen (path N) and/or oxygen (path O) yielding cyclopropanol (27) via the former reaction and cyclobutanol (28) via the latter.⁵¹ Stern-Volmer quenching data indicates that two distinct n,π^* triplet states of (26) mediate abstraction of hydrogen. A correlation between the observed photochemistry and the triplet energy (E_T) of T_1 (n,π^*) of the parent heterocyclic ring was also found. The excited state or states responsible for these reactions result from interaction of the ring π,π^* state and the oxygen and nitrogen n,π^* states, all of whose triplet energies lie in the range 290-350 kJ/mol and competition between O- and N-abstraction is affected by ring substituents. Substituents on the aromatic ring of simple aromatic ketones (phenones) can shift the energies of both carbonyl (n,π^*) and ring (π,π^*) states and thereby influence the reactivity of T_1 in O-abstraction of hydrogen.⁵³ Three different ring substituents on acylpyrazines, acylpyridines and acylpyrimidines were investigated: cyano, methyl and trifluoromethyl groups, and results show direct correlation with earlier results.⁵⁴⁻⁵⁸ A methyl substituent caused a marked reduction in Φ_N , consistent with increased n,π^* character in the nitrogen triplet. In (29) and (30), hydrogen abstraction is suppressed completely, suggesting that the cyano groups lower the ring π,π^* energy well below that of the nitrogen n,π^* triplet, making the latter state inaccessible; i.e. in (29) and (30) the ring π,π^* triplet is T_2 and the nitrogen n,π^* triplet is T_3 . T_1 is then the carbonyl n,π^* triplet.



1.4 The Photochemistry of Azirines

Azirines are three membered rings containing the imino group. As we have seen earlier, the low reactivity of the imino chromophore has been, in many circumstances, attributed to the energy dissipated during facile *syn-anti* isomerisation. Because this mode of action is constrained within a ring system, these molecules have a greater opportunity to undergo reaction from an excited state. The photochemistry of azirines is dominated by an irreversible ring opening reaction to form nitrile ylides (scheme 3).⁵⁹ These dipolar compounds are easily trapped by a wide variety of dipolarophiles yielding five membered heterocyclic rings. Consequently azirines are useful in a variety of synthetic areas.

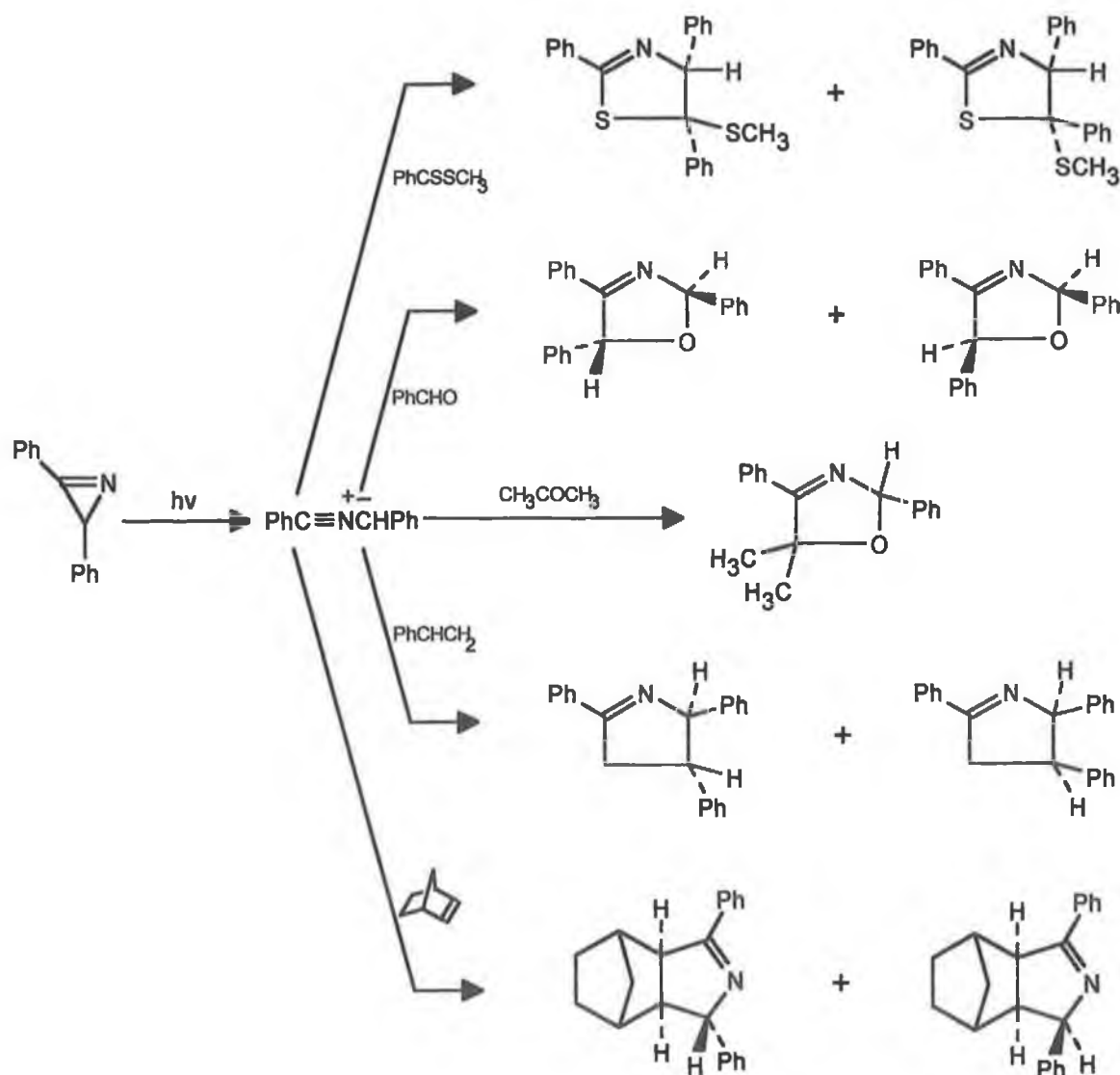


SCHEME 3

Initial cleavage of the C-C bond on irradiation proceeds from the n,π^* excited singlet state of the azirine.⁶⁰ Padwa and co-workers demonstrated that ground state azirines can themselves act as dipolarophiles, reacting with azirines^{61,62,63} which have undergone photochemical ring opening to form the ylides. Indeed there are many possible photochemical reaction paths for the azirines to follow depending on the dipolarophile used (scheme 4).⁶⁴

The addition of these 1,3 dipolar compounds to dipolarophiles is believed to occur from interaction of the highest occupied molecular orbital (HOMO) of the

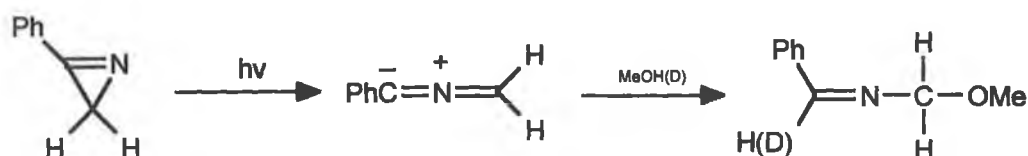
nitrile ylide with the lowest unoccupied molecular orbital (LUMO) of the dipolarophile.⁶⁵



SCHEME 4

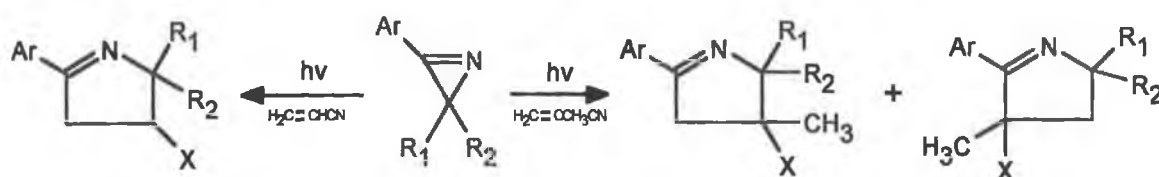
This interaction is the most important governing factor in stabilisation of the transition state. The favoured cycloadduct will be that formed between the atoms with the largest coefficient in the dipole HOMO and the dipolarophile LUMO. To determine the relative magnitudes of the coefficients in the HOMO of the nitrile ylide, irradiation of a number of arylazirines was carried out in protic solvents.⁶⁵ Deuterium labelling (scheme 5) showed that the coefficient at the disubstituted

carbon atom of the nitrile ylide is greater than that at the trisubstituted carbon atom. This result can explain the regiochemistry of any photoadditions of arylazirines to dipolarophiles.



SCHEME 5

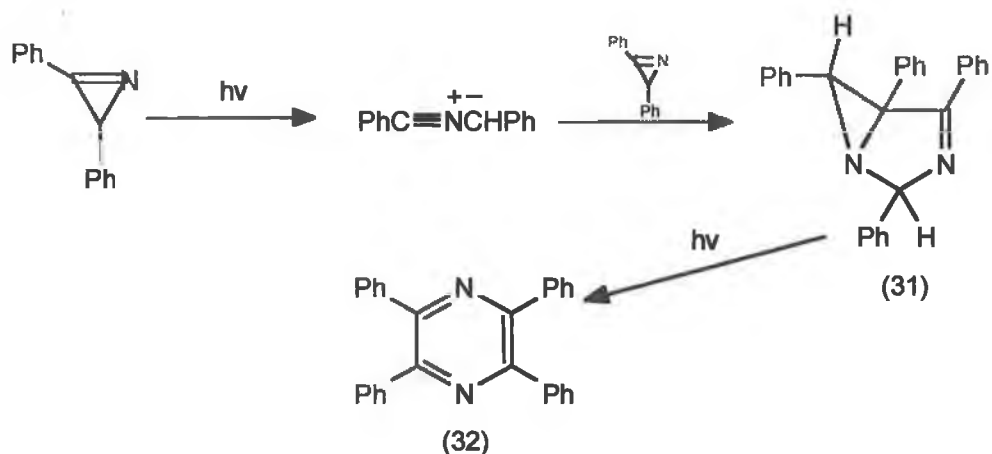
An example of this regioselectivity is shown in scheme 6, where differences in substituents on the dipolarophile in an analogous reaction to that shown in scheme 5 affect the reaction products.^{65,66} Photocycloadditions of various azirines with acrylonitrile result in 4-substituted isomers only. The reaction however, of methylacrylonitrile with the same azirines results in two different isomers in a 3:2 ratio.



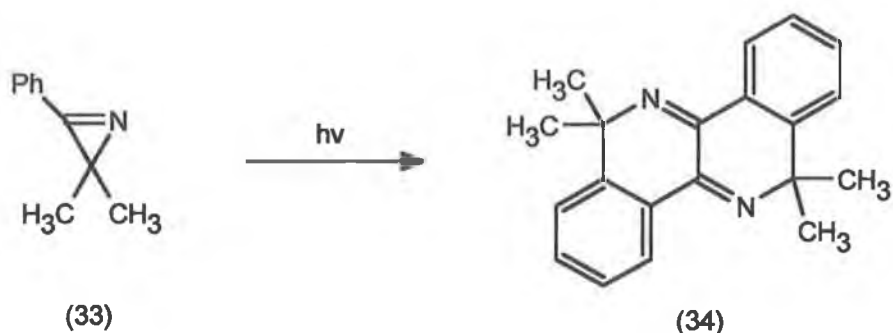
SCHEME 6

The difference in reaction products was attributed to the fact that the cyano group enhances the LUMO coefficient at the unsubstituted carbon atom, whereas the methyl group has an opposite effect, negating the effect of the cyano group. As has been shown above,⁶¹⁻⁶³ azirines on photolysis can react to form dimers, i.e. when a ground state azirine reacts with a ring opened azirine. It has been shown in several publications^{59,67} that this does not only happen when azirines are photolysed alone, but also occurs in the presence of olefins of low

dipolarophilic activity (e.g. β -methylcrotonate).⁶⁷ On extended irradiation some azirines have been shown to form six and seven membered heterocycles.⁶⁸⁻⁷¹

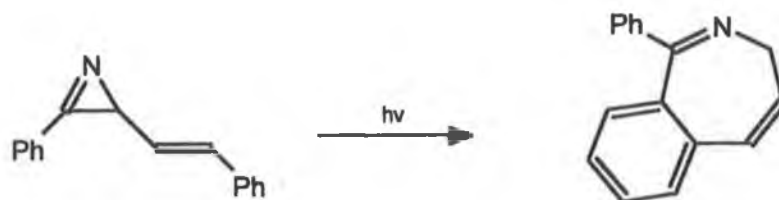


Padwa has photolysed the azirine above and on extended irradiation has obtained the six membered heterocycle (32), tetraphenylpyrazine. Confirmation of the reaction was obtained when (31) was irradiated alone. The same product resulted. From quenching and sensitisation experiments, Padwa and co-workers showed that formation of both (31) and (32) proceed via the excited singlet manifold. The same authors have shown that the products formed are dependent on the substituent groups on the azirine, the time of irradiation and the particular solvent employed. Irradiation of compound (33) over a period of five hours generates the diazachrysene (34).



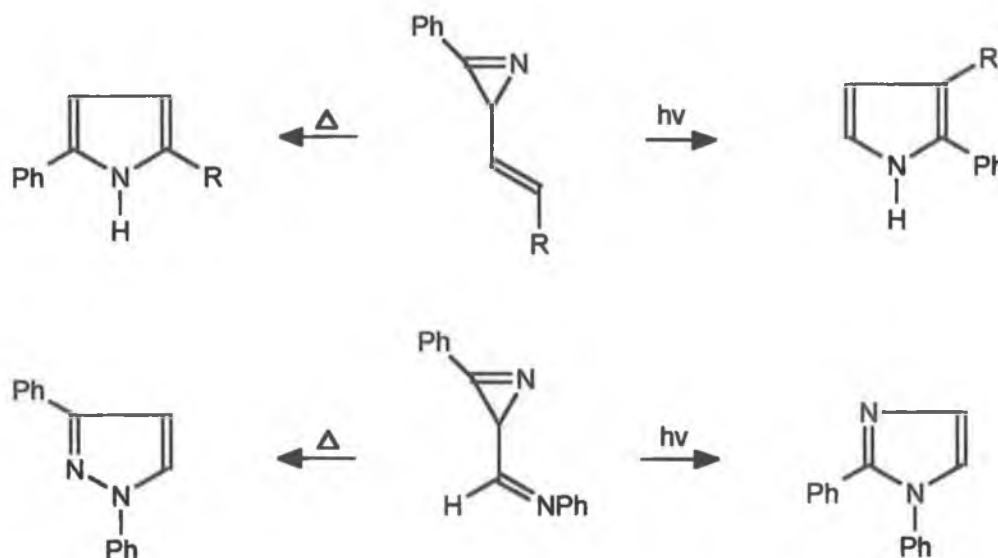
This demonstrates the ability of azirines to form a multitude of highly complex heterocyclic compounds on irradiation. Padwa has also illustrated the

ability of azirines to form substituted benzazepines⁶⁹ by placing a styryl substituent on the azirine ring (scheme 7).



SCHEME 7

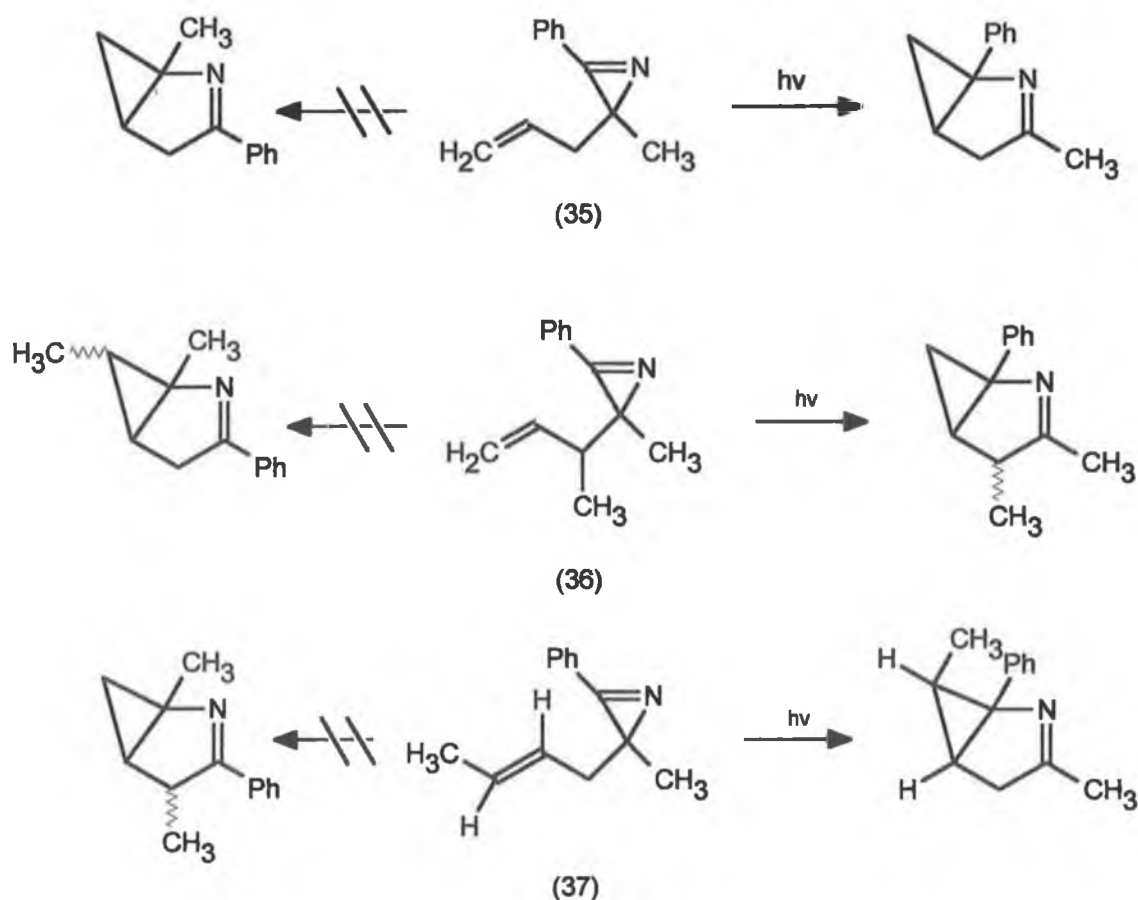
More evidence for the mechanism of photoreaction of azirines being one in which a nitrile ylide is produced was presented by Padwa,⁷² where compounds were synthesised containing the azirine and alkene moieties in the same molecule. In scheme 8 it can be seen that the photoreactions carried out yield products which are isomeric to those produced by thermal reactions;



SCHEME 8

The thermal reactions above are selective yielding only the products shown, while the photoreactions yield only the products shown. Neither of the photoreactions yields either of the thermal products giving clear evidence that a nitrile ylide is the intermediate.

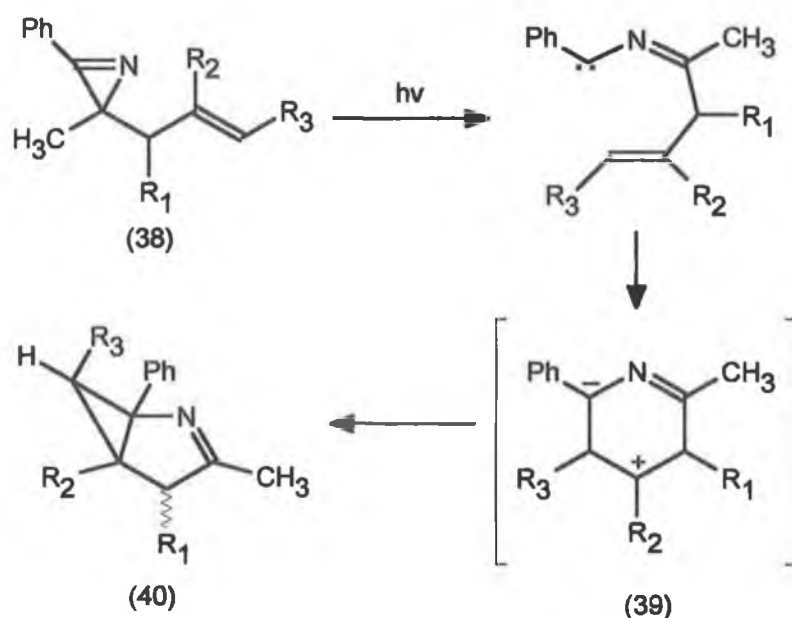
An ab initio computation carried out by Salem⁷³ in 1974 on the ground and excited state energy surfaces of the 2*H*-azirine molecule indicated that the ring opened intermediate of the azirine molecule should be capable of dual reactivity when intercepted by an added dipolarophile. He deduced that opening of the ring to an intermediate with linear geometry results in the formation of a 1,3-dipolar like species having closed shell zwitterionic character. This correlates with all of the photocycloadditions seen so far. His calculations also indicated that if the ring is opened to give an intermediate with bent geometry, a diradical state with partial dipolar character is obtained.



SCHEME 9

Among the possible resonance forms of a nitrile ylide postulated is a carbene like structure which makes conceivable a 1,1 cycloaddition reaction. Padwa reported the first example of such a cycloaddition.⁷¹ On photolytic investigation of three separate azirines he found that the products formed were in

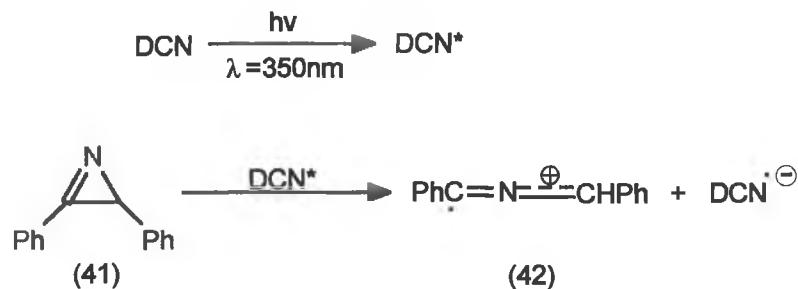
theory the thermodynamically less favoured, but by applying the logic inferred by Salems' investigations the results were correct (scheme 9). The cycloaddition of azirines (35), (36) and (37) afford the Δ^1 -pyrrolines as shown as the primary photoadducts. Inspection of molecular models of the allyl substituted nitrile ylides indicated that the normal "two-plane" orientation approach of the linear nitrile ylide and the allyl π system is impossible as a result of the geometric restrictions imposed on the system. Product formation was found to be possible, however, if the linear nitrile ylide underwent rehybridisation to give a species of bent geometry. This contorted nitrile ylide then undergoes cycloaddition with the neighbouring double bond. The most favourable transition state for the 1,1-cycloaddition reaction is one in which the π orbitals of the nitrile ylide and olefinic bond are orthogonal. These results also correlate with other publications on the same subject.^{74,75} In one such publication,⁷⁴ the authors reported the first example of a stepwise 1,3-dipolar cycloaddition reaction.



The azirine (38) undergoes intramolecular cycloaddition via a six membered 1,3-dipole (39), to form the azabicyclohexene (40). Competitive rate studies have been carried out using different external dipolarophiles such as fumaronitrile,

methyl crotonate and aliphatic olefins. Fumaronitrile undergoes cycloaddition at a much faster rate than methyl crotonate, and aliphatic olefins were found to be ineffective dipolarophiles. A study of the quantum yield for azabicyclohexene formation as a function of added dipolarophile shows, however, that the internal photocyclisation of the allyl azirine system occurs readily with these aliphatic substituted olefins. This is consistent with the bent nitrile ylide form since carbenes are known to react readily with electron-rich double bonds.

More recent publications on azirines have shown their use as reagents in the synthesis of N-substituted imidazoles⁷⁶ under photosensitised electron transfer irradiation conditions. The n,π^* transition of azirines such as (41) occurs at a wavelength of 280 nm. Irradiation with light of wavelength 350 nm does not lead to the direct excitation of the azirine. However, DCN (dicyanonaphthalene), when present in the same solution is excited and abstracts an electron from the azirine. As observed for direct excitation, the C-C bond is broken. Instead of the nitrile ylide, a radical cation (42) is formed.

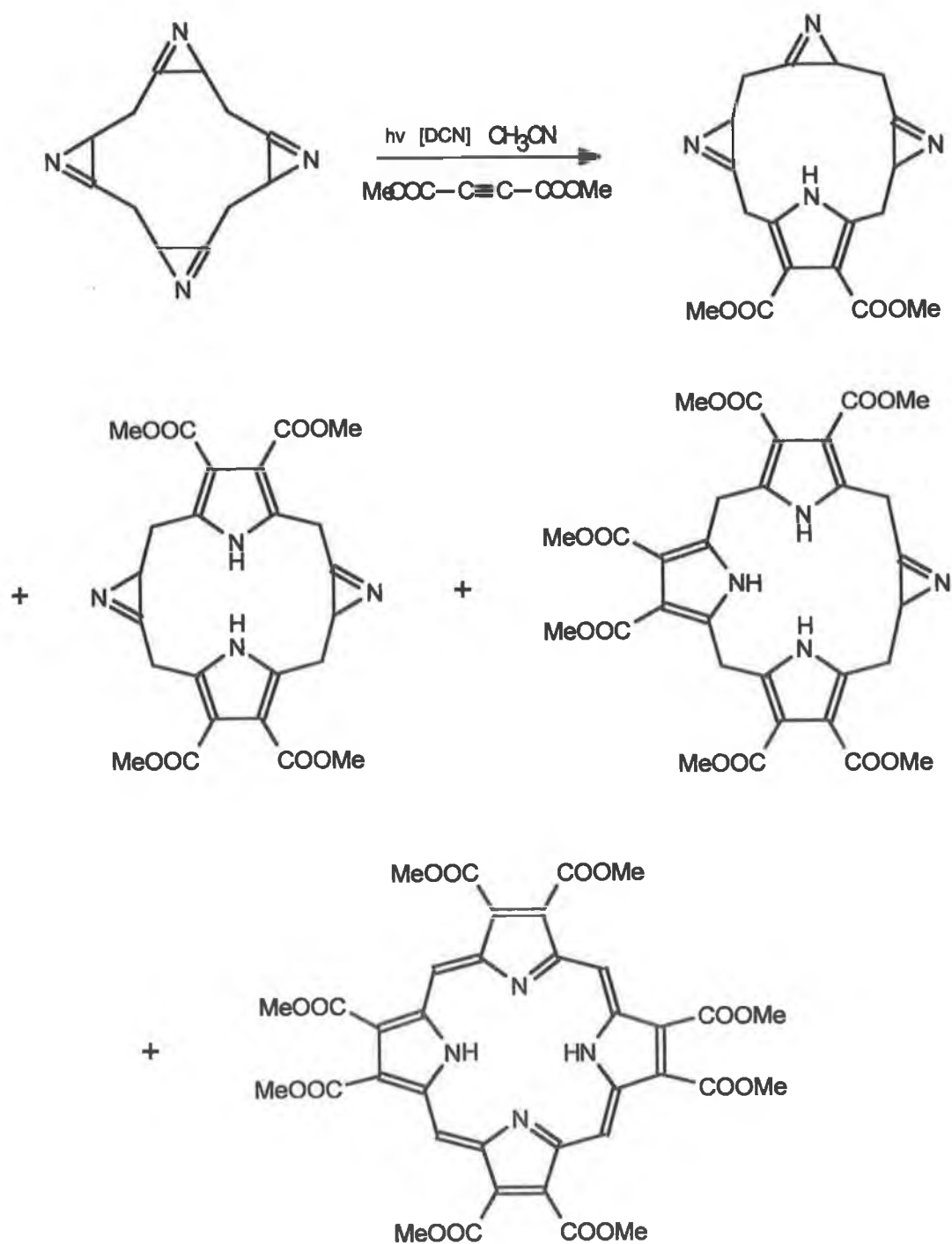


This radical cation (42) is able to attack the C-N double bond in imines in an intermolecular fashion, a reaction not possible for photochemical 1,3-dipolar cycloaddition. Addition of the radical cation to the imine is followed by ring closure to form a dihydroimidazole. Under these conditions the dihydroimidazole is not stable and undergoes subsequent aromatisation to the N-substituted imidazole. Since the C-N double bond of the azirine competes with the C-N double bond of the imino group, yields vary widely (from 3% to 87%). More

recent publications have shown applications of azirines in the photochemical synthesis of peptides, porphyrins and pyrrolophanes.⁷⁷⁻⁷⁹

3-Amino-2*H*-azirines have been shown to be possible synthons for the synthesis of oligopeptides,⁷⁷ but since 3-amino-2*H*-azirines absorb at shorter wavelengths than the corresponding 3-phenyl-2*H*-azirines, their excitation requires short wave U.V. light and therefore their photolysis is of less preparative importance. The author has shown that these reactions are possible, but has devoted most of the publication to more standard methods of synthesis. Müller and co-workers have reported the photochemical synthesis of a porphyrin system built up from four consecutive [3+2] cycloadditions between a cyclododecane functionalised with four azirine units and an acceptor-substituted ethyne derivative under conditions of photoinduced electron transfer (PET). The reaction proceeds as above, in the conversion of (41) to (42). Dicyanonaphthalene (DCN) is irradiated at 350nm and the DCN in its excited state abstracts an electron from the azirine system causing it to ring open. The linear 2-azaallenyl radical cation then reacts in a two step process with a double or triple bond to form a five membered ring. This happens sequentially around the system as shown in scheme 10. Another publication by the same authors⁷⁹ provides a method for the photochemical synthesis of heterocyclophanes. Once again the reaction is carried out under PET conditions using DCN. Short bridged [n](2,5)pyrrolophanes have been known for a long time and are readily available via different synthetic routes such as the Paal-Knorr method. The PET promoted method enables the preparation of 3,4-substituted pyrrolophanes in acceptable yields.

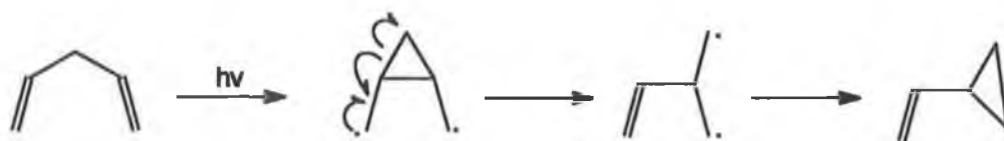
Experiments have also been carried out investigating the lifetime and kinetics of 2-azaallenyl radical cation intermediates using electron pulse radiolysis and γ -radiolysis.^{80, 81} γ -Radiolysis of diphenylazirines in *n*-butyl chloride leads to the same products formed in PET reactions, i.e. N-alkylated imidazoles.



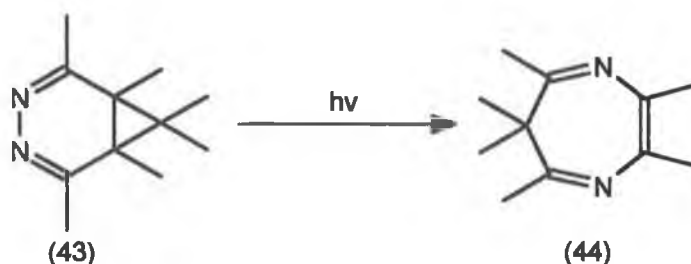
SCHEME 10

1.5 The Aza-di- π -Methane Rearrangement

The di- π -methane rearrangement occurs in molecules having 1,4-diene units and for allylbenzene derivatives and has been well documented.⁸² The overall process can formally be considered as a 1,2 shift of one of the π units to the other moiety with concomitant ring closure to form the cyclopropane ring between the methylene group and the other end of the nonmigrating π moiety;

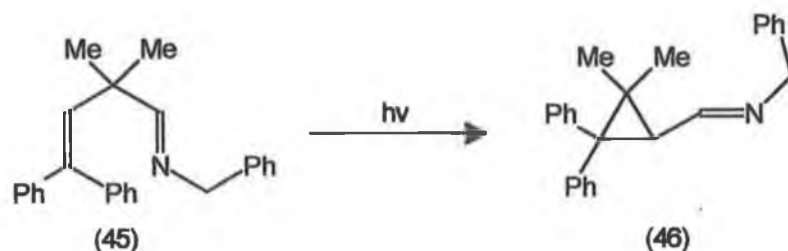


Likewise the analogous oxa-di- π -methane reaction has been well documented since the early 1970's.⁸³ The aza-di- π -methane (ADPM) reaction, however, had not been thoroughly investigated until the eighties, although Armesto and co-workers^{84a} have pointed out that the first publication of the reaction is thought to have been the one by Reissenweber and Sauer in 1977.^{84b} They showed that the 3,4-diazanorcaradiene (43) on irradiation is converted to the 6H-1,4-diazepine (44). No evidence was given for the proposed mechanism. The photoproduct could have been formed by an alternative path such as 1,3-migration followed by ring opening of a cyclobutene.

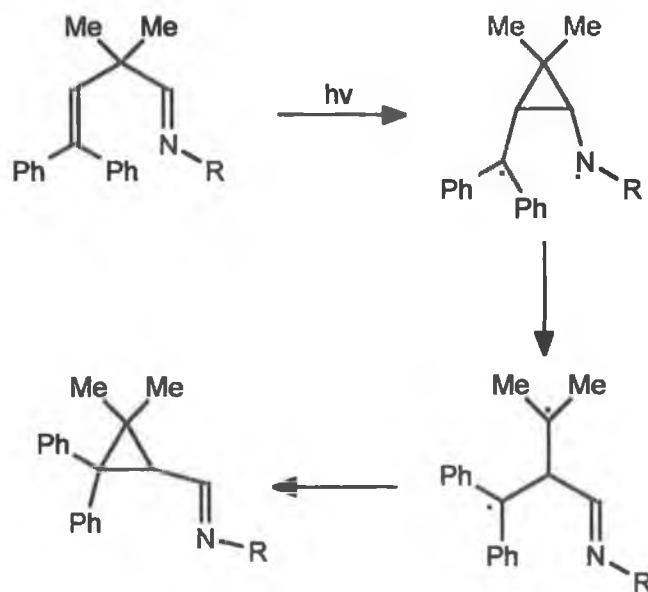


Armesto and co-workers have carried out extensive studies on the aza-di- π -methane rearrangement.⁸⁴⁻⁹⁷ Little was known about what would happen if a heteroatom other than oxygen was introduced into the di- π system until Armesto

and co-workers synthesised the imine (45) and irradiated it directly and in the presence of a triplet sensitiser, acetophenone.⁸⁴ One major product (46) resulted. Studies with triplet quenchers indicated that the reaction proceeds



from the triplet state. This is unusual from acyclic 1,4-diene photochemistry where the formation of the normal di- π -methane product is mainly a singlet state reaction. The overall reaction for the conversion of imine (45) to cyclised product (46) seems to proceed via the mechanism shown in scheme 11.



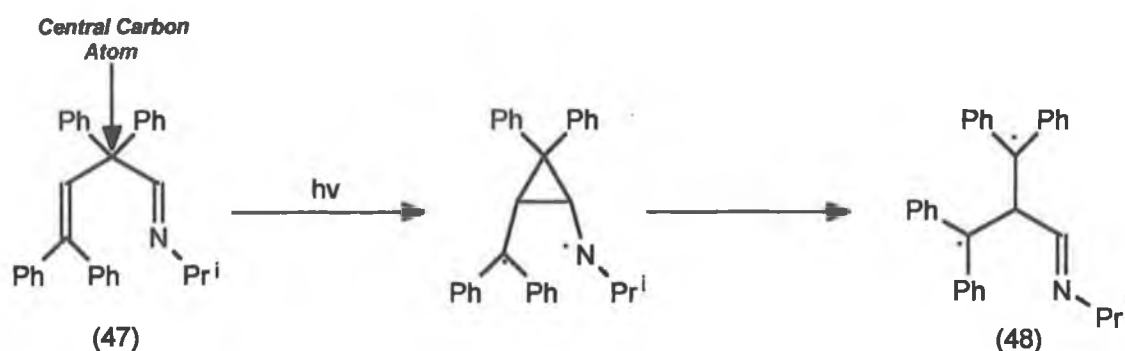
SCHEME 11

The actual details of the mechanism were unclear at this stage, although the 1,1-diphenyl moiety on the starting material in scheme 11 was thought to be the principal chromophore because it absorbs at a higher wavelength than the imine moiety. The excitation energy was thought to reside on this part of the

molecule. Thus sensitisation favours the excitation of the alkene moiety to the triplet state leading to what is thought to be a normal di- π -methane process. Another interesting aspect of the reaction was the fact that under identical conditions, different yields of products resulted due to differences in nitrogen substituent. Where the substituent, R, on the nitrogen was a phenyl group, quantum yields were enhanced compared to aliphatic groups. Armesto attributed this to the fact that orbital overlap could occur between the nitrogen lone pair and the phenyl group, thus removing the lone pair from direct involvement in the reaction.

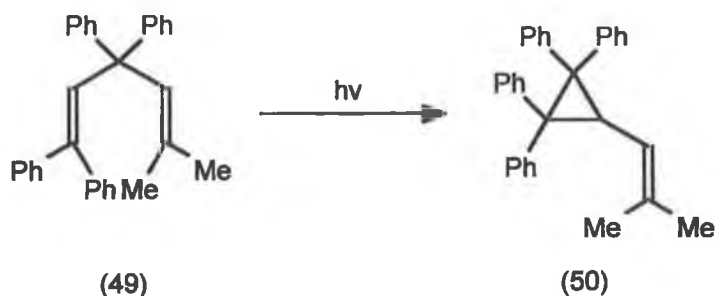
The aza-di- π -methane reaction provides a route⁸⁶ whereby the Norrish Type I process can be suppressed in favour of the alternative reaction path of C-C bridging. Lone pair involvement in the reaction was thought to stem from the fact that the lowest energy band in the photoelectron spectrum of simple imines arises by removal of an electron from the nitrogen lone pair. 1,1-Diphenylethene is a known electron acceptor, and consequently electron transfer from the nitrogen lone pair to the alkene moiety seemed to make the cyclisation less efficient.

Subsequent work by Armesto and co-workers has shown that the substituents present on the central carbon atom in the imine system such as (47) also have an effect on the rearrangement. There was a fifteen fold enhancement



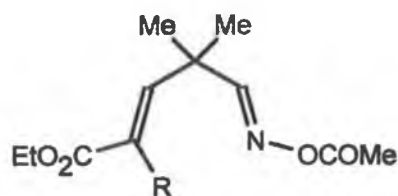
in quantum yield when the central carbon atom of (47) had phenyl groups as substituents as opposed to earlier synthesised molecules containing methyl

groups in the same position. Zimmerman and co-workers observed analogous behaviour⁹⁸ in the rearrangement of (49) to (50). They interpreted this efficiency



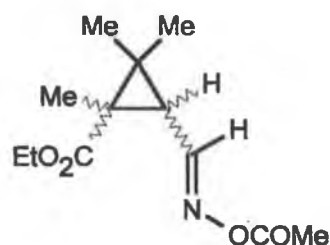
in terms of efficient 'unzipping' of the intermediate due to the stabilising influence of the phenyl groups on the intermediate biradical such as that of (48). Phenyl substitution on the central carbon atom also appeared to overcome any inhibiting effect which was previously attributed to nitrogen lone pair involvement in an intramolecular electron transfer. Phenyl substitution on the imino carbon atom on the other hand resulted in absolutely no rearrangement taking place. This is thought to arise from the fact that with a phenyl group attached to the imino group, the absorption of the imino group is shifted to longer wavelength. At this wavelength the chromophore competes with the 1,1-diphenylethene moiety perhaps leading to behaviour analogous to Norrish type I reactions of aldehydes and ketones. In the same publication Armesto and co-workers showed that oximes would not undergo the aza-di- π -methane rearrangement. Later on this was postulated to be due⁸⁸ to the fact that success of cyclisation in the reaction depended on the ionisation potential of the imine nitrogen. This theory was supported by an earlier paper¹⁹ which showed that oxime ethers also failed to undergo the ADPM rearrangement but simply isomerised about the C=C and C=N bonds. By placing an acetate group on the nitrogen, the ionisation potential of the nitrogen is increased, although direct irradiation failed to bring about rearrangement. Triplet sensitisation using acetophenone however, did bring about rearrangement indicating a triplet excited state. In a more recent publication,⁸⁹

the involvement of a free rotor effect has been thought to be responsible for a dissipation of energy in the molecule, deactivating the excited triplet state and thereby preventing reaction from taking place. Compound (51a) rearranges to form the cyclopropane (52).



(51)

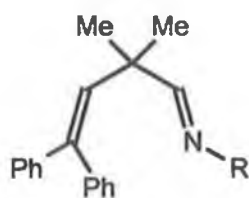
(a) R = Me
(b) R = H



(52)

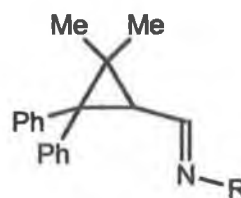
Compound (51b) on the other hand does not undergo rearrangement. The failure of the monosubstituted compound (51b) to undergo the rearrangement was interpreted by Armesto and co-workers as an example of triplet state deactivation by a free rotor, since the energy from the sensitizer will be transferred solely to the alkene moiety. This process of triplet state deactivation by a free rotor has been seen in many di- π -methane reactions.⁸³ Other carbonyl compound derivatives have also been investigated such as semicarbazones and benzoylhydrazones.

The photolyses of (53a), (53b) and (53c) gave good chemical yields⁹⁰ of cyclopropanes (54), with the efficiency of the reaction being highest for (53c), at 90%.



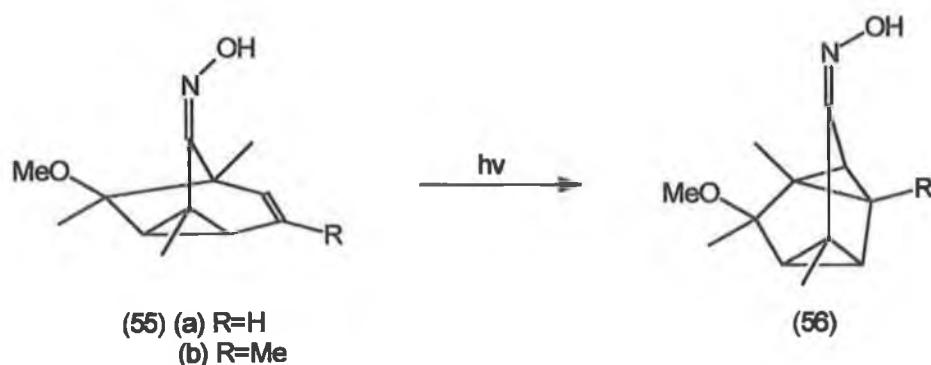
(53)

(a) R = NHCONH₂
(b) R = NHBz
(c) R = OBz

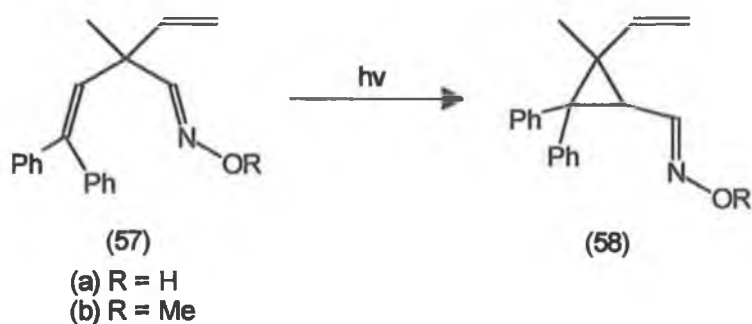


(54)

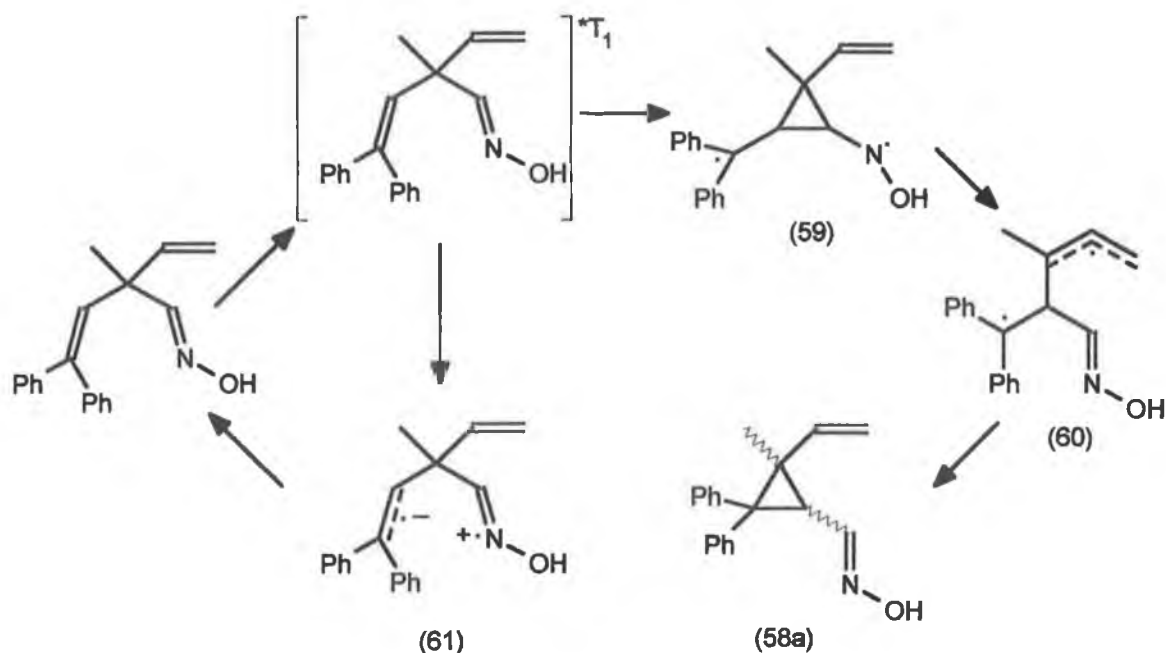
It is clear from these results that the ADPM rearrangement is not restricted to imines and oxime acetates, but can be readily extended to other common derivatives of carbonyl compounds. The success of these reactions also indicates that there is no adverse effect in incorporating a nitrogen in the system adjacent to the imine nitrogen.



The aza-di- π -methane reaction has also been reported to occur in some cyclic systems such as the bridged oxime (55).⁹⁹ Photolysis of (55a) and (55b) yield the cyclic compound (56). This reaction, in contrast to the other ADPM reactions has been shown to proceed via the excited singlet state. Another incidence of an oxime and indeed an oxime ether undergoing the ADPM rearrangement has also been reported. In earlier studies by Zimmerman and co-workers,¹⁰⁰ systems containing the 1,4-diene moieties such as that shown in compound (57) undergo the DPM rearrangement. On irradiation of (57) however,⁹⁵ the cyclopropane (58) is isolated as the major product. This is a very unexpected result and is the first example of the ADPM reaction of an acyclic β,γ -unsaturated oxime.



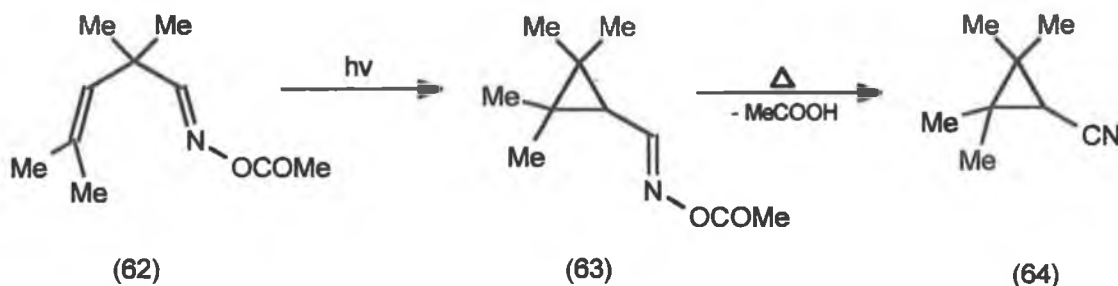
The reason for this reaction occurring was unclear. It was originally attributed to hydrogen bonding between the hydroxyl group and the 2-vinyl substituent in oxime (57a). That this is not so is obvious from the analogous reaction occurring with the oxime methyl ether (57b). A possible explanation for the successful rearrangements could be related to differences between the energy barriers for the various processes open to the excited state of the molecule. The principal processes are the conversion of the excited state via the bridging biradical (59) to the biradical (60) or single electron transfer to the zwitterionic biradical (61) as shown in scheme 12. If the energy barrier for conversion of the excited state to the 1,3-biradical and thence to the ADPM product is lower than that for the SET process, ultimately leading back to starting material, then the ADPM process dominates. In the opposite situation SET will dominate and no rearrangement will be observed. If the rearrangement of oximes is to be a general process, then the biradical (60) has to be sufficiently stable so that SET, the energy wasting step, is unfavoured.



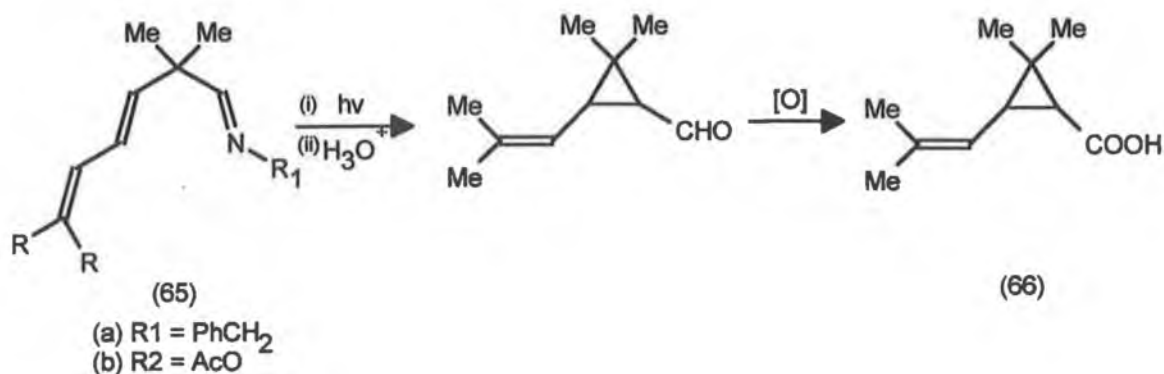
SCHEME 12

This reaction demonstrates that acyclic β,γ -unsaturated oximes that were previously thought to be inert towards the ADPM reaction can undergo reaction, provided the intermediate 1,3-biradical is sufficiently stabilised.

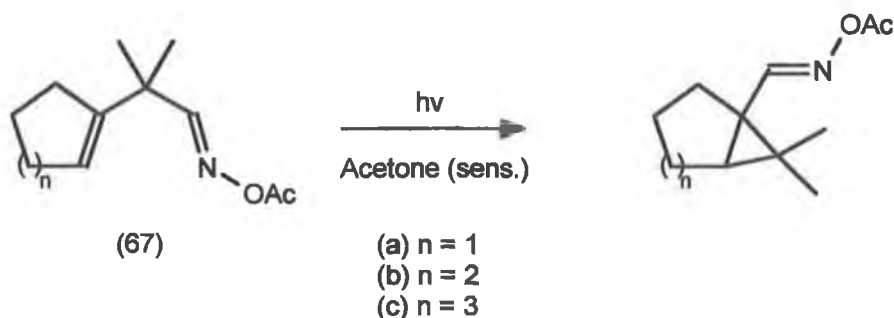
The di- π -methane reaction has been studied and is a reasonable route for the synthesis of cyclopropane derivatives. Practically this is not feasible since the DPM reaction process is not applicable to molecules where the double bonds in the compound do not absorb above 220nm. Addition of a chromophore which causes a bathochromic shift in the molecule would be a way around this, but the aza-di- π -methane rearrangement seems to be a much more general reaction and has been shown to be more feasible as a mode of pyrethroid synthesis. The principal advantage of the ADPM reaction is that it permits the photochemical transformation of aldehydic and ketonic compounds via stable C=N derivatives in an efficient manner which is regiospecific. Two such recent publications illustrate the versatility of the reaction in the synthesis of potential pyrethroid components.^{91,92} These pesticides are very important in agriculture due to their low mammalian toxicity and biodegradability. An example of this is the azadiene (62) which was converted photochemically into the cyclopropane oxime acetate (63). This also affords the nitrile (64) by thermal elimination of acetic acid from (63). This is readily converted into the acid component of the pyrethroid *terallethrin*.



Photochemical cyclisation of the trienes (65a) and (65b) to the corresponding cyclopropanes has been investigated by Armesto and co-workers. The resultant cyclopropylimines are readily transformed into the cyclopropyl carboxylic acids (66). This reaction also provides a general route to the synthesis of cyclopropyl aldehydes and acids that can be readily converted into pyrethroid derivatives.



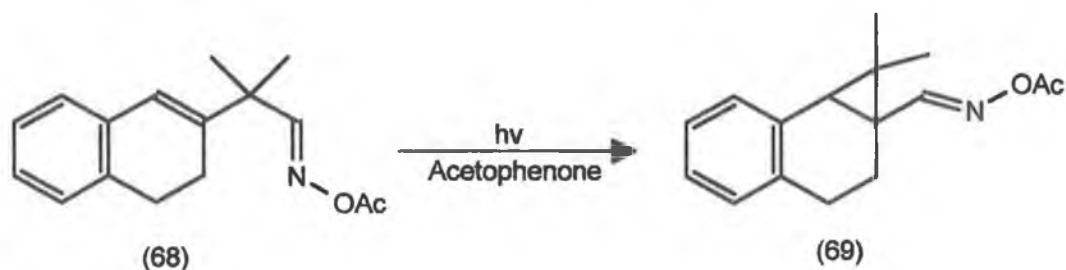
The synthetic potential of the ADPM rearrangement has further been demonstrated in the photochemical synthesis of naturally occurring bicyclic compounds such as the caranes.



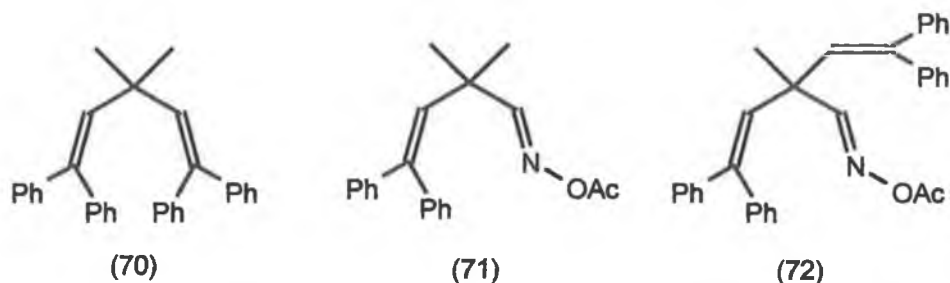
The oxime acetate derivatives of 1-carbaldehydebicyclo[n.1.0]alkanes⁹⁴ were photochemically synthesised by irradiation of (67) in the presence of acetone as sensitizer. The yield of product decreased as n increased. For n=3, no product was isolated. The mechanism of reaction was thought to be that of the conventional formation of the alkene triplet followed by bridging as seen in the earlier discussed reactions. The decrease in photoproduct resulting from the ADPM rearrangement as ring size increases could be attributed to the triplet energy located on the alkene moiety being dissipated through a twisting of the cycloalkene ring as its size increases. This relaxation of the ring as size increases is well established in, for example, the sensitised addition of alcohols to cycloalkenes. To test whether this ring flexibility was responsible for the deactivation of the excited state of the alkene, Armesto and Ramos irradiated the dihydronaphthalene derivative (68). Another possible benefit of using this

compound was the enhanced stability of the ADPM bridged biradical intermediate by participation of the phenyl ring. Acetophenone was used as sensitiser because (68) was likely to have a lower triplet energy than (67). Irradiation of (68) for twenty minutes brought about the formation of the tricyclic compound (69) in 90% yield. It is unsure whether the decrease in flexibility of the cyclohexenyl compound has as much importance in the increased yield as enhanced intermediate biradical stabilisation.

A study has been carried out aimed at detecting intramolecular competition between the di- π -methane rearrangement and the aza-di- π -methane process.⁹⁶ Molecules were designed to contain an alkene moiety which underwent the DPM rearrangement on its own in a molecule and an imino moiety which underwent the ADPM process if in a molecule alone. The two separate moieties were chosen so as to have relatively close quantum efficiency values.

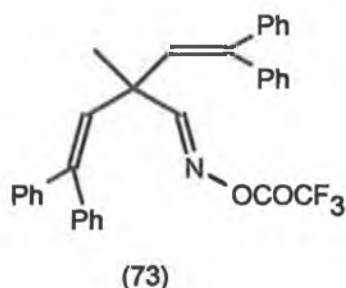


For example, the tetraphenyl-1,4-diene (70) underwent the DPM rearrangement¹⁰¹ with a quantum yield of 0.08, whereas the diphenyl oxime acetate (71) underwent the ADPM reaction with a similar efficiency of 0.12. Combining these components pointed to the azatriene (72). On direct irradiation,



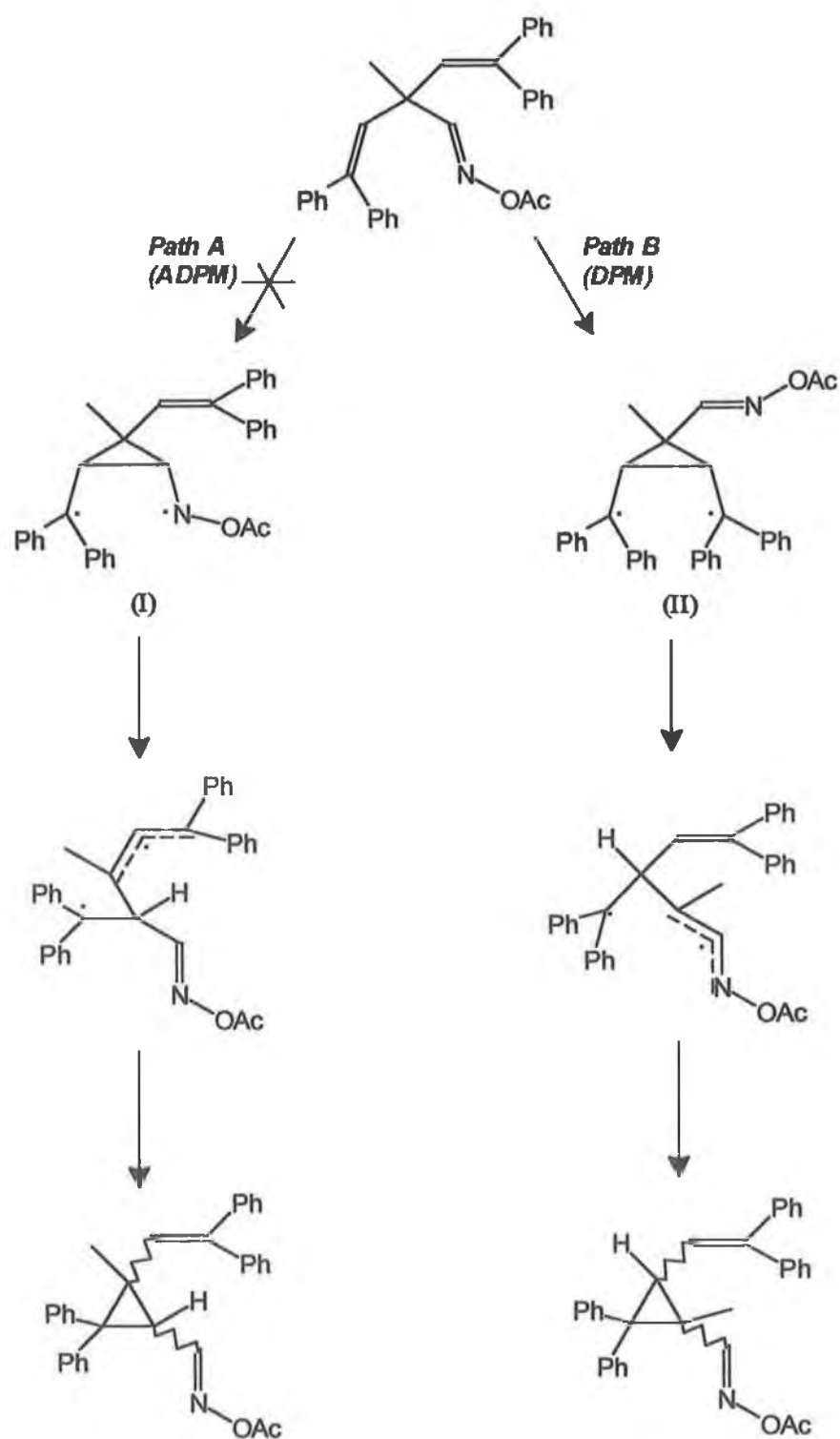
the product formed was due exclusively to the DPM rearrangement. No product was seen forming due to the ADPM rearrangement. This was not too surprising,

since the ADPM rearrangement works best under triplet sensitised irradiation and the DPM process normally operates via an excited singlet state in acyclic systems. However, sensitised irradiation with acetophenone resulted in the same reaction occurring, but in even greater yield. A similar system was also irradiated under direct and sensitised conditions. Compound (73) was irradiated because the trifluoroacetate oxime derivatives show enhanced activity towards the ADPM rearrangement. When products were isolated after irradiation, it was discovered that the same reaction had occurred again. From these experiments it appears that the DPM rearrangement always takes precedence over the ADPM process even in situations where the quantum yield for the latter, in the isolated system, is marginally better than the corresponding quantum yield for the DPM rearrangement. A possible reason for this given by Armesto and co-workers is due to the difference in stability of the 1,4-bridged biradical, or subsequent 1,3-biradical obtained after bond rupture, for the two possible

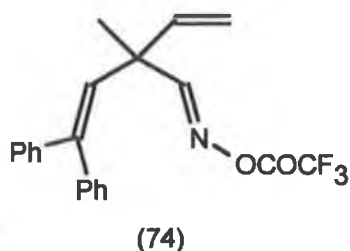


rearrangement paths A and B shown in scheme 13.⁹⁶

The DPM process involving biradical II will be preferred to the ADPM rearrangement, involving biradical I, since biradical II is more stable. This argument applies to compounds (72) and (73) and suggests that a decrease in stability of biradical II might lead to a situation where the rearrangement would follow the ADPM path. This is precisely what Armesto and co-workers have done by synthesising compound (74).



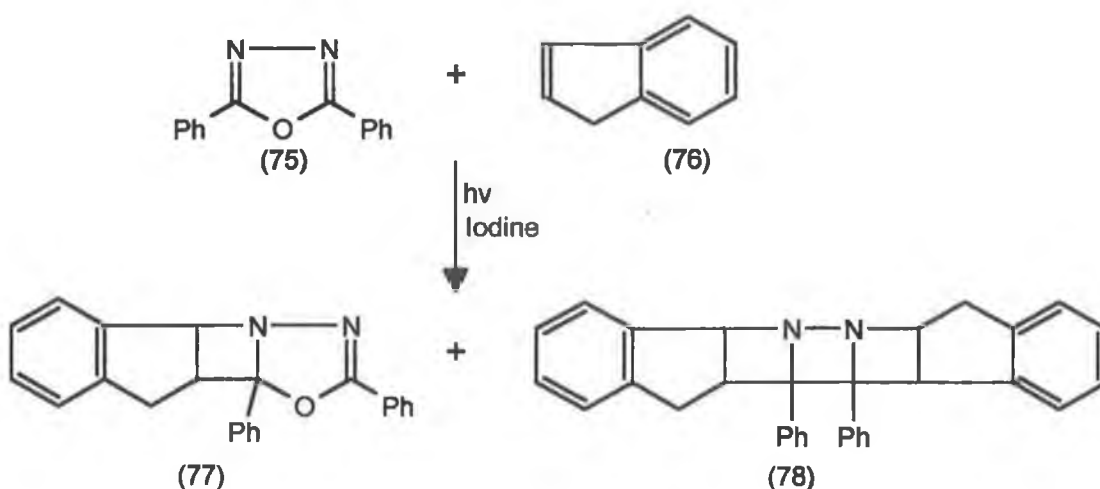
SCHEME 13



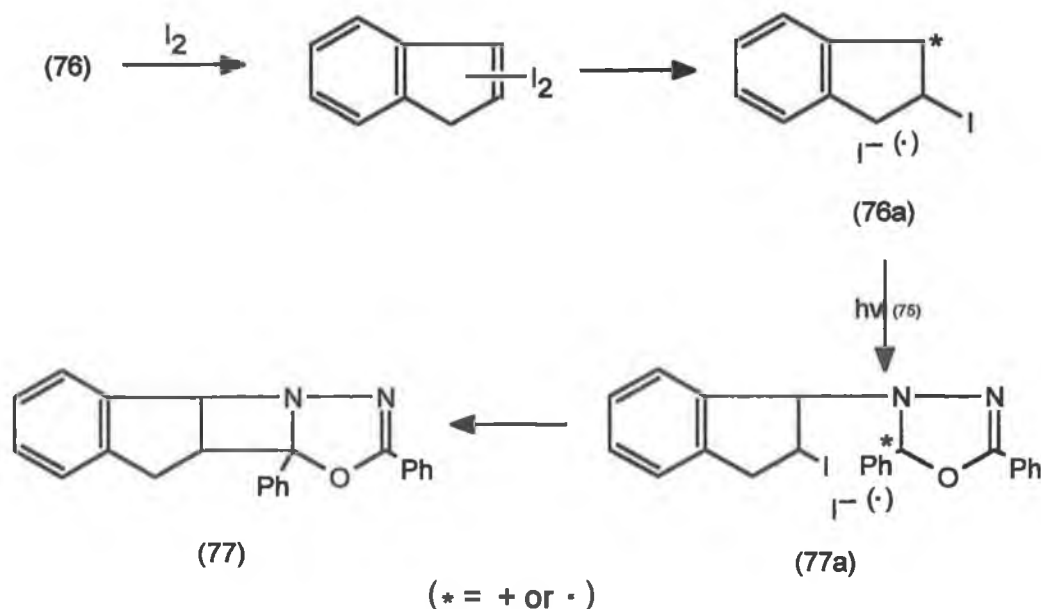
When split into its separate components as in the design of molecule (73), it is found that the quantum yield for the DPM reactivity is 0.02, while that of ADPM reactivity is 0.12. This greater efficiency for the ADPM rearrangement gives it a better chance of competing. On sensitised irradiation of (74) it was found that the ADPM rearrangement occurred exclusively. It was not possible to observe competition between the ADPM and the DPM rearrangements. However, by changing the relative stability of the bridging 1,4-cyclopropyl radical it is possible to selectively bring about either the DPM or the ADPM rearrangement. It has also been seen that the same factors which control the competition between the ADPM and DPM reactions are also operative in controlling the competition between the DPM and ADPM rearrangement of aldehydes.¹⁰²

1.6 Photocycloaddition

The [2+2] photochemical cycloaddition reactions of olefins to form cyclobutanes date back to 1908 and have been well documented as a frequently encountered process in alkene chemistry.⁸²

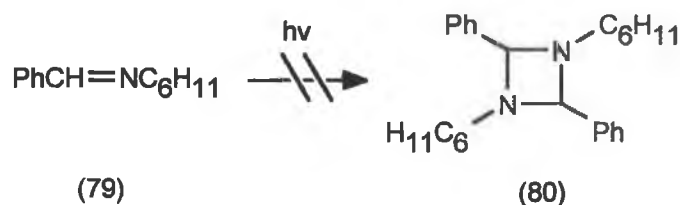


Analogous reactions of the imino chromophore had not been documented however, until the photochemical addition of an imine to an alkene was described by Tsuge and co-workers in 1968.¹⁰³ They observed that 2,5-diphenyl-1,3,4-oxadiazole (75) in the presence of iodine adds to indene (76) to form compounds (77) and (78). When iodine is not used, (78) alone is isolated as product. In a later publication by the same authors,¹⁰⁴ a more thorough investigation was carried out to investigate the mode of participation of iodine in the reaction. The iodine was observed to form the complex (76a) with indene (scheme 14) which on photolysis formed (77a). This then resulted in the formation of (77).

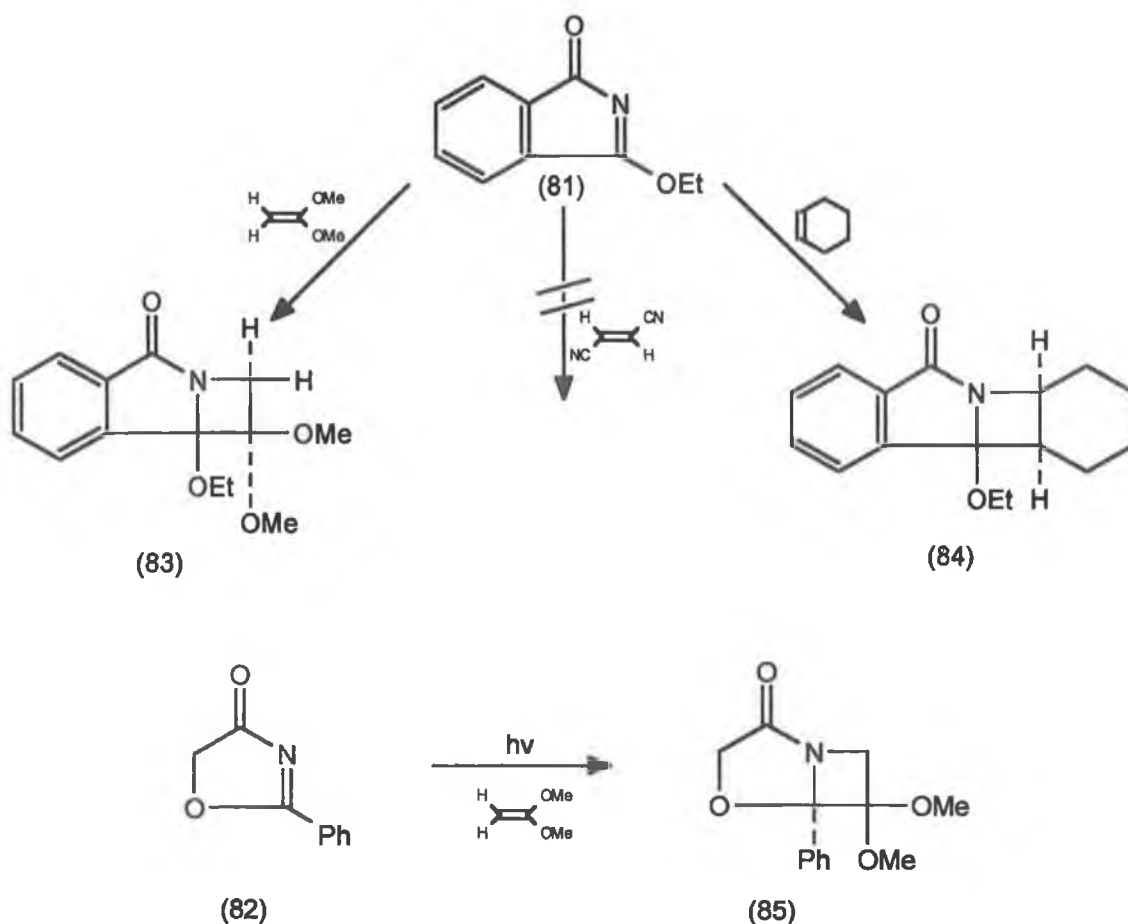


SCHEME 14

A photodimerisation was reported by Kan and Furey¹⁰⁵ in which the photodimerisation of imine (79) resulted in the azetidine (80). This was later

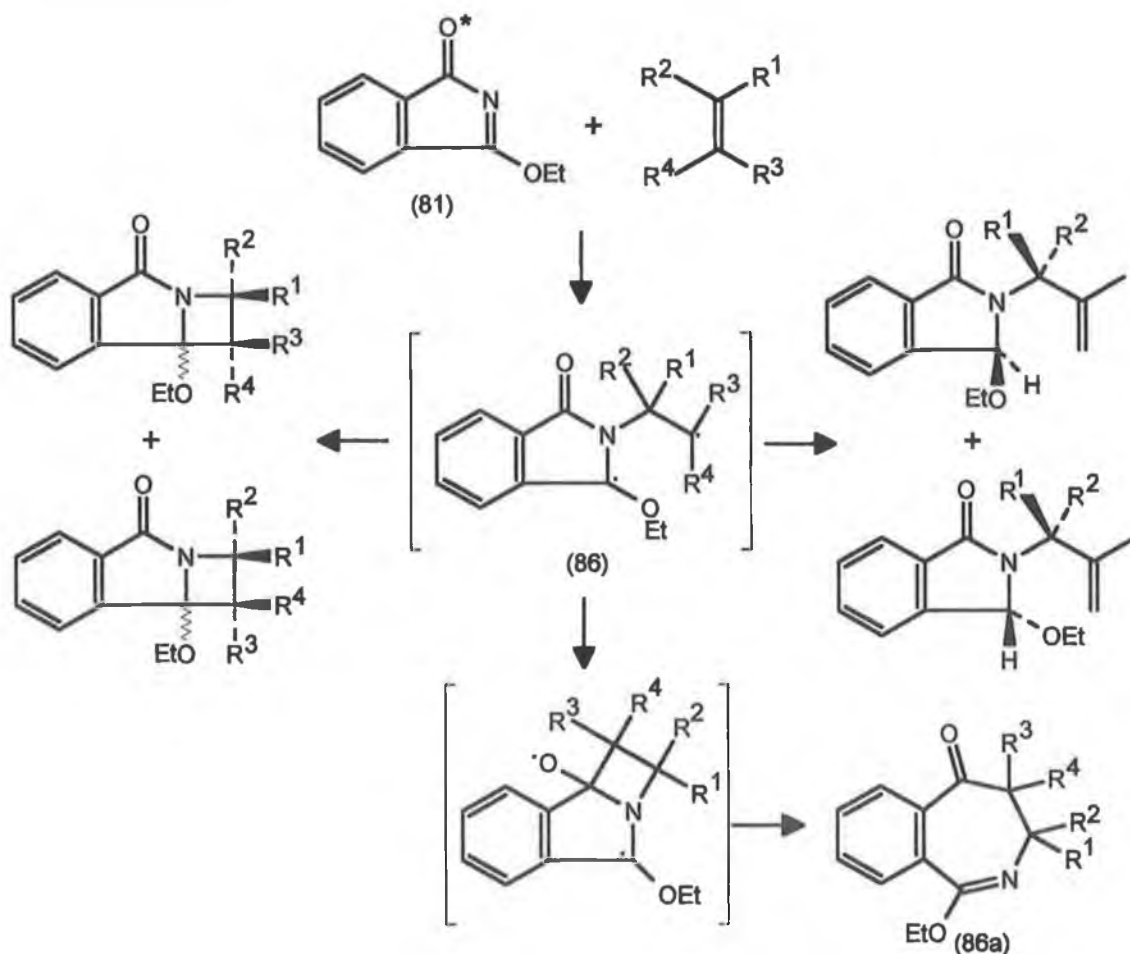


shown to be false by Padwa and co-workers,¹² and that the product was in fact a reductive dimer. Koch and co-workers^{106,107} have reported the photochemical [2+2] cycloaddition of 3-ethoxyisoindolone (81) and 2-phenyl-2-oxazolin-4-one (82) to various alkenes. Irradiation of the isoindolone (81) in the presence of 1,1-dimethoxyethylene and cyclohexene yields products (83) and (84) respectively. Irradiation of (81) in the presence of fumaronitrile yields no photoproduct. Similarly, irradiation of the oxazolinone (82) in the presence of 1,1-dimethoxyethylene yields photoproduct (85) due to a [2+2] cycloaddition.



Koch and co-workers deduced from the above reactions that [2+2] cycloaddition of imino groups do not occur with electron deficient olefins such as fumaronitrile, but with electron rich olefins the reactions proceed. In a more thorough investigation,¹⁰⁸ the isoindolone (81) was irradiated in the presence of

several different olefins including furan, isobutylene, *cis* and *trans*-2-butene and tetramethylethylene.



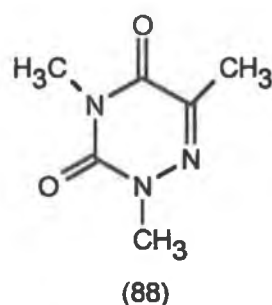
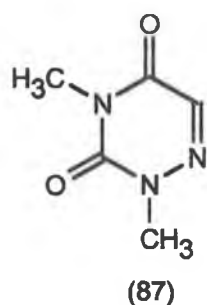
SCHEME 15

Several different products were observed due to [2+2] cycloaddition reactions, ene type reactions and carbon-nitrogen bond fragmentation reactions. From quantum yield data and product analysis, it was thought that the general reaction mechanism was based on formation of a long lived 1,4-biradical intermediate (86). Formation of products is shown in scheme 15.

They theorised that a 1,4-biradical such as (86), formed from reaction of excited (81) with an olefin could cyclise with complete loss of the stereochemistry of the starting olefin to give azetidine products, undergo intramolecular hydrogen transfer to give the ene products, or cyclise at the carbonyl carbon with subsequent or simultaneous carbon-nitrogen bond fragmentation to give the

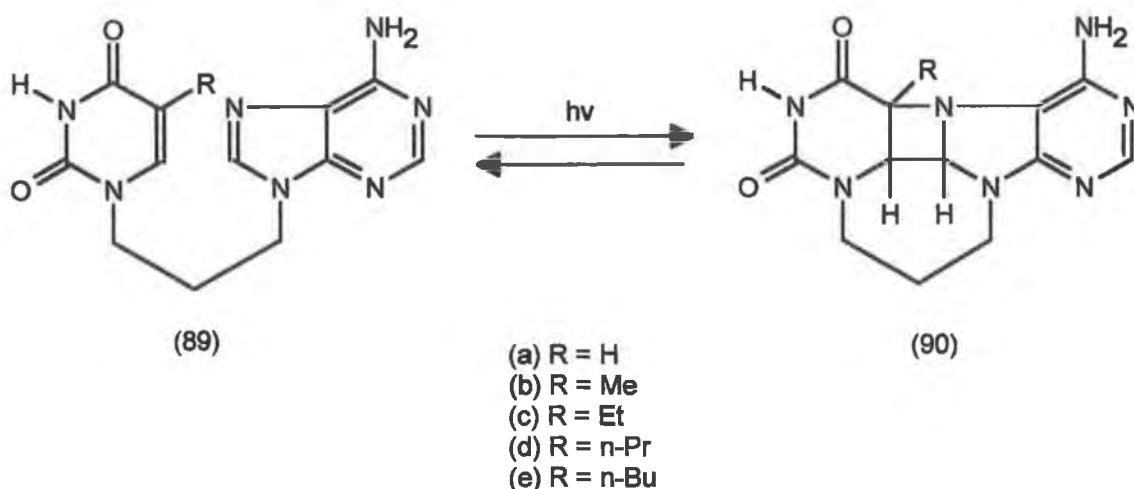
azepinone (86a). Similar 1,4-biradical intermediates have been proposed for both the photoreactions of α,β -unsaturated ketones with olefins and the triplet state Paterno-Büchi reaction. The authors concluded that all of the above photoreactions occur from a common isoindolone triplet state, and the olefins are quenchers of the isoindolone singlet state. The authors concluded that molecules which are reactive in the [2+2] photocycloaddition with carbon-nitrogen double bonds have low energy $\pi-\pi^*$ states, and those which are unreactive have low energy $n-\pi^*$ states.

Swenton and Hyatt have reported the successful acetone sensitised photocycloaddition of the azapyrimidine analogues (87) and (88) to a variety of unsaturated linkages in high yield.¹⁰⁹ Azauracil (87) forms cycloadducts with ethylene, tetramethylethylene, isobutylene, cyclohexene, cyclooctene, ethyl vinyl ether, vinyl acetate and isopropenyl acetate. The reactivity of (88) was similar.

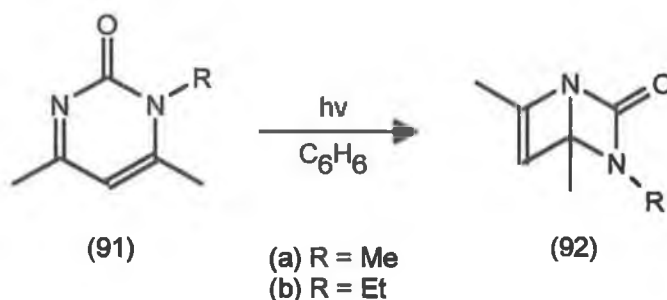


The authors discussed the structural features of the molecules which permit facile cycloaddition of the alkenes to the generally unreactive imine linkage. One possibility proposed was the presence of the imine moiety in (87) and (88) in a six membered ring, leading to decreased deactivation processes arising from bond rotations and nitrogen inversion mechanisms. The authors also stated that the situation of the imino group in a six membered ring might not be sufficient grounds alone for reaction, as attempted cycloadditions to cyclic imines lacking the carbonyl group had failed up to the time of this publication. They proposed that a conjugated electron withdrawing group may need to be present for maximum reactivity.

Other biological molecules containing the imino group have shown similar reactivity. The pyrimidine-purine dinucleotide analogues (89a-e) in which the sugar-phosphate group has been replaced by a trimethylene bridge were irradiated in aqueous solution at 254nm. The products were isolated and identified as the photoadducts (90a-e). Irradiation of aqueous solutions of each of the compounds (89a-e) leads to a photostationary state.^{109a} Isolation of the photoadducts (90a-e) and subsequent irradiation of each adduct leads to their partial decomposition, regeneration of starting materials (89a-e) and establishment of a photostationary state. Stereochemistry was not discussed.

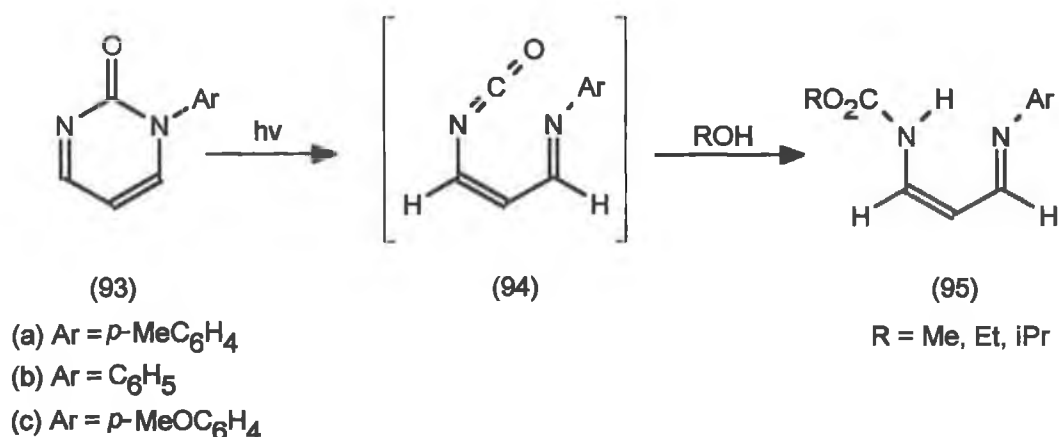


Nishio and co-workers have reported on the intramolecular photocyclisation of a pyrimidin-2-one (91) to give a diazabicyclohexene (92) in benzene solution.¹¹⁰ Different behaviour however, has been seen in analogous systems.¹¹¹

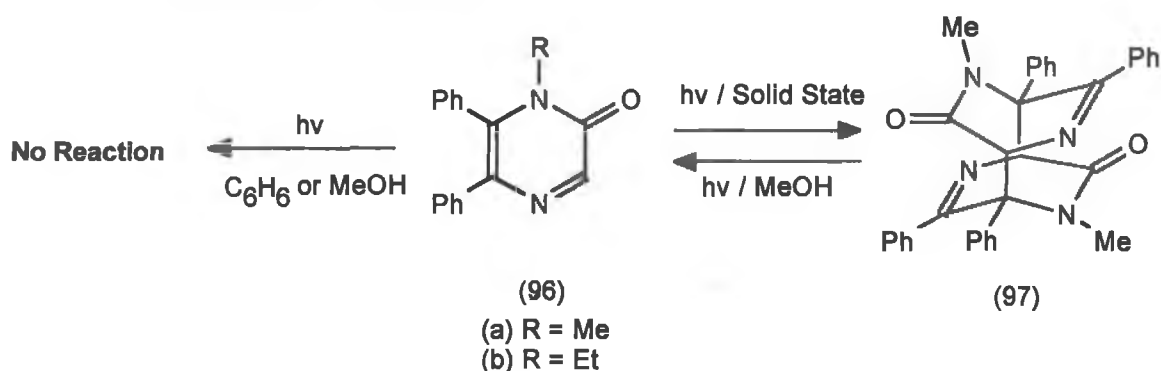


Irradiation of the analogues (93a-c) in a mixed benzene-alcohol solution does not result in a cyclisation reaction, but a cleavage. The reaction is thought to proceed

via an unstable isocyanate intermediate (94) which arises from Norrish type I cleavage. This intermediate then traps an alcohol molecule from solution to form product (95).

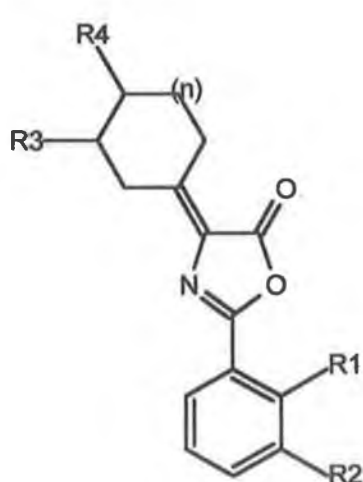


A more recent publication¹¹² has reported the first case of the photochemical [4+4] cyclodimerisation in the solid state photochemistry of monocyclic heteroaromatic compounds containing nitrogen atoms. Irradiation of (96a) produces the anti dimer (97) on irradiation in the solid state in 100% yield. Irradiation of the same compound in either benzene or methanol solution results in no new products. Irradiation of (96b) also results in no new products. Irradiation of the dimer (97) in a methanol solution, however, results in regeneration of (96a) in 100% yield.

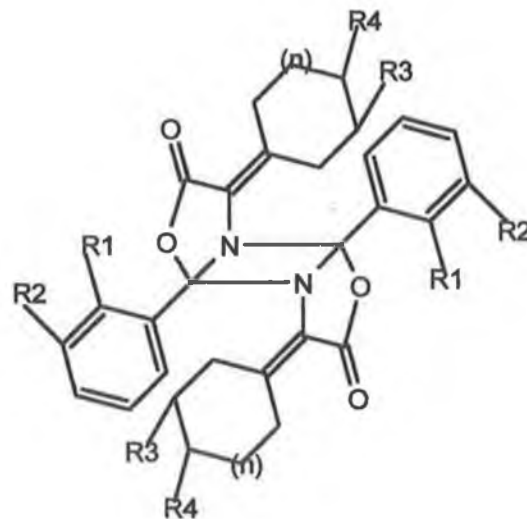


Lawrenz and co-workers have also reported¹¹² a solid state dimerisation reaction which produces remarkably high yields of azetidines; also up to 100%

yield via a dimerisation reaction of oxazolones. This is the first publication demonstrating the formation of azetidines in the solid state via a cycloaddition reaction. The oxazolones (98a) and (98b) on irradiation undergo dimerisation reactions to form adducts of the type (99).

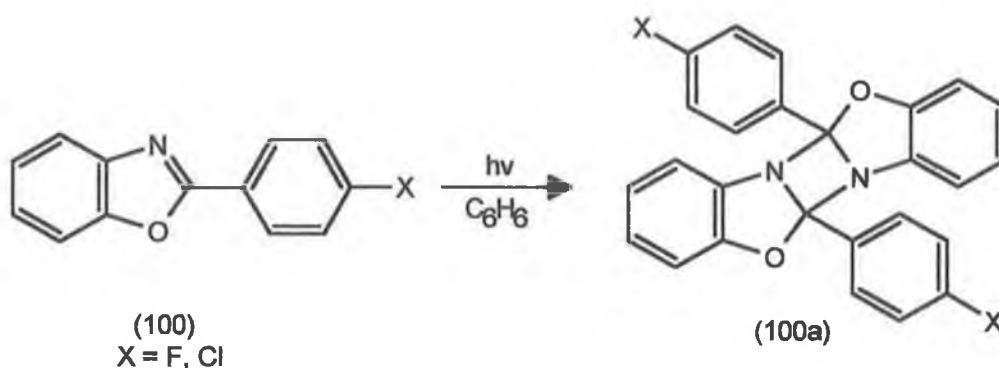


(98)
(a) $n = 1$
(b) $n = 2$

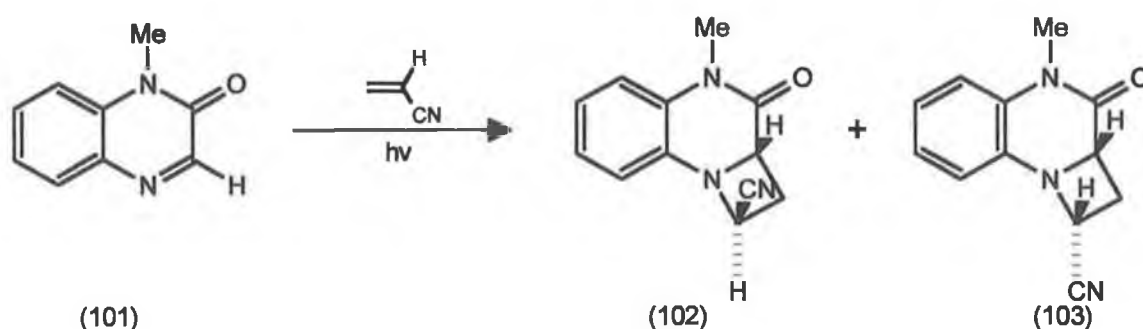


(99)
(a) $n = 1$
(b) $n = 2$

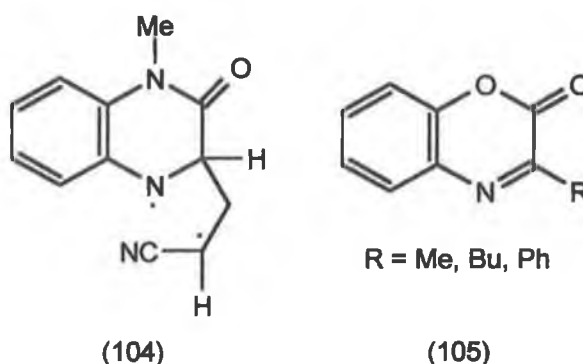
The substituents R1-R4 were either hydrogen, methoxy, methyl or butyl groups. Similar results have been reported for the irradiation of solutions of substituted benzoxazoles to form azetidines by Fery-Forgues, Paillous and co-workers.^{113,114} Irradiation of (100) in benzene yields dimer (100a).¹¹³ The authors have proposed a mechanism of dimerisation proceeding via the excited singlet state and probably involving the formation of an excimer. That the formation of product proceeds via a head to tail process has been shown by X-ray crystallography.



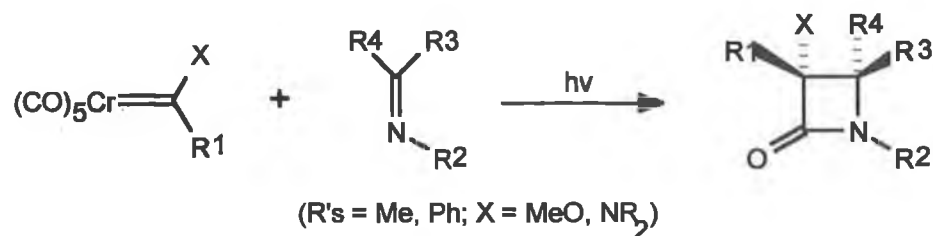
Nishio has investigated the photocycloaddition reaction of quinoxalinones to electron deficient olefins.¹¹⁵ Irradiation of the quinoxalinone (101) in the presence of acrylonitrile produced the adducts (102) and (103) in almost equivalent amounts. The author has investigated a series of quinoxalinones and olefins and has found through quenching and triplet sensitisation experiments that the photocycloaddition may occur from the excited triplet state. The regiochemistry of the photoproduct and the nonstereospecificity of the cycloaddition have suggested that the formation of 1:1 cycloadducts may arise by initial interaction of the quinoxalinone triplet with the electron deficient olefin to give an excited complex or exciplex, which proceeds



to give the 1,4-biradical intermediate (104). This intermediate then cyclises to give the 1:1 cycloadduct. Similar 1,4-biradical intermediates have been proposed by Koch and Howard in the photocycloaddition reactions of isoindolones¹⁰⁸ and the triplet state Paterno-Büchi reactions. Similar results have been found in the irradiation of benzoxazinones (105) with electron deficient olefins.¹¹⁶

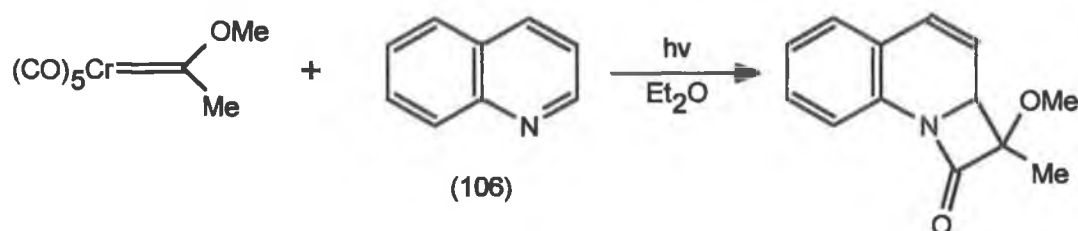


A number of more recent publications have been concerned with the synthesis of β -lactams via the photocycloaddition reactions of imines and chromium carbene complexes.¹¹⁷⁻¹²¹ The process is quite general and tolerates wide variations in the structure of both the carbene and the imine. The reactions proceed in high yield under very mild conditions (photolysis in natural sunlight; THF, Et₂O, or CH₃CN as solvent; 25°C), and are quite stereoselective, producing a single diastereoisomer in almost all cases. The β -lactam forming process does not occur under thermal conditions. The reaction proceeds according to scheme 16. Reactions have also been carried out where the



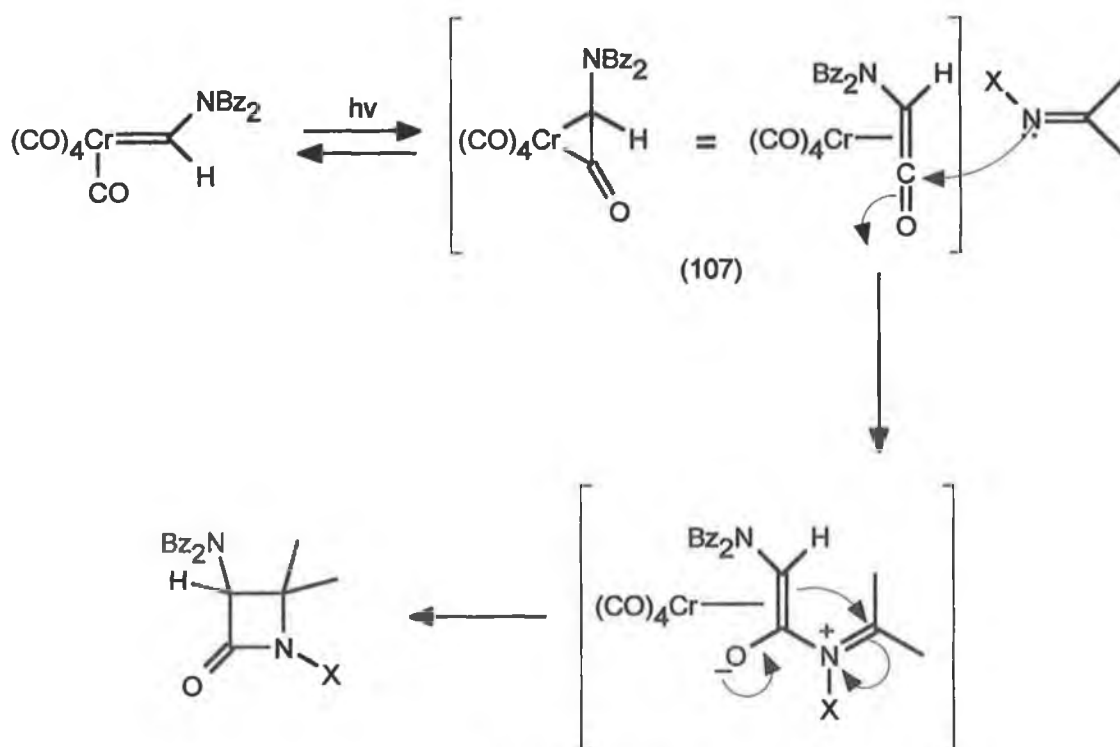
SCHEME 16

imino group is part of a ring system such as in quinoline (106). A reasonable mechanism for the β -lactam formation has been proposed in scheme 17. The β -lactam forming reaction is thought to involve the reaction of the imine substrate with a photogenerated metal-bound ketene (107).

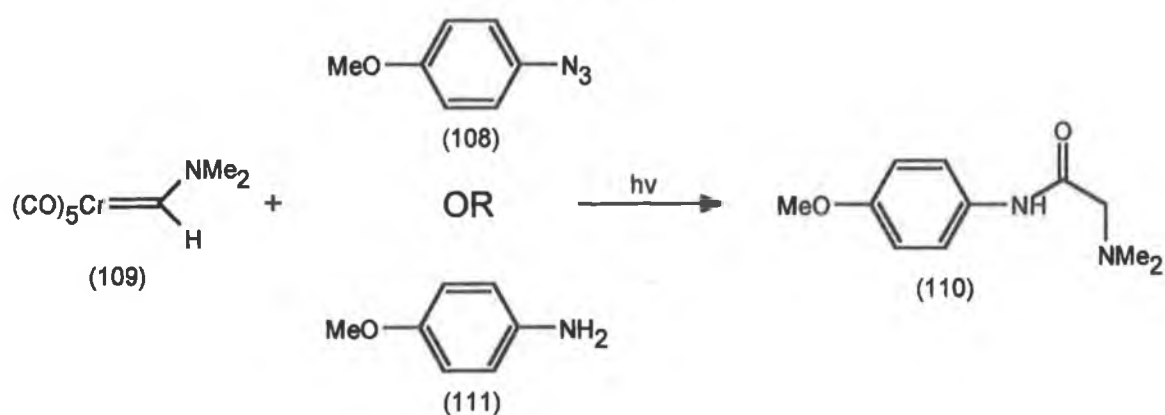


The first indication of the formation of chromium-ketene complexes upon irradiation of chromium-carbene complexes came from unsuccessful attempts to effect a dipolar 1,3-cycloaddition of *p*-methoxyphenyl azide (108) to chromium carbene complex (109). Instead of the expected cycloadduct, glycineamide (110)

was obtained in ~40% yield. When (109) was irradiated in the presence of *p*-anisidine (111), ~70% yield of (110) was obtained. A number of different nucleophiles have been used as trapping agents for the ketenes. The excited state of the imine is not thought to be involved in the photoreaction.

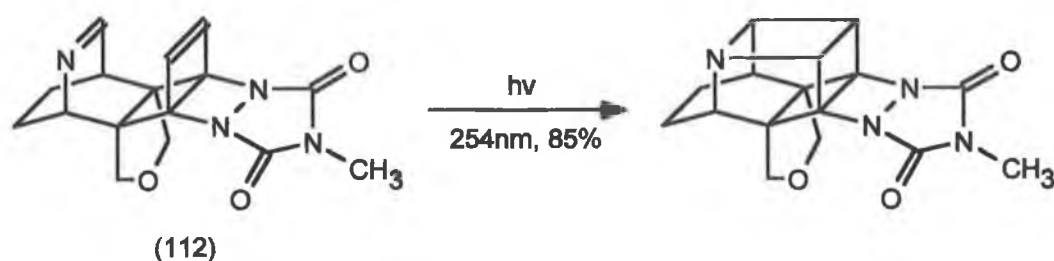


SCHEME17



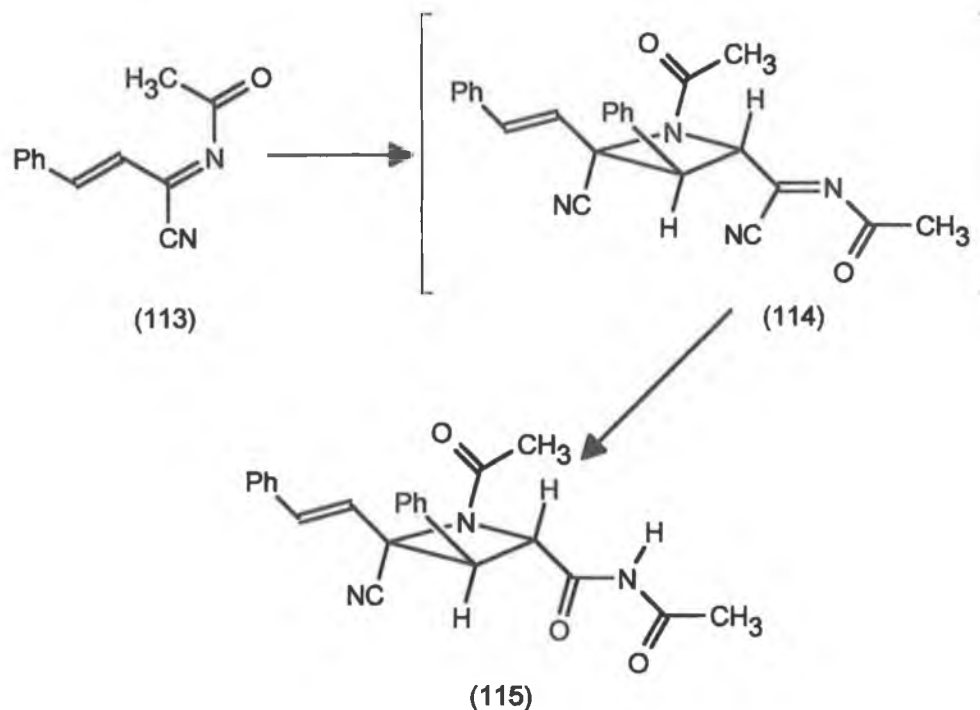
Up to now it has been seen that almost all imine systems which undergo photocycloaddition reactions require conjugation with an electron withdrawing

group. Fischer and co-workers have reported a system in which intramolecular [2+2] photocycloaddition reactions occur in excellent yield between an alkyimine moiety and an olefinic system of type (112).^{121a} Yields of product obtained were

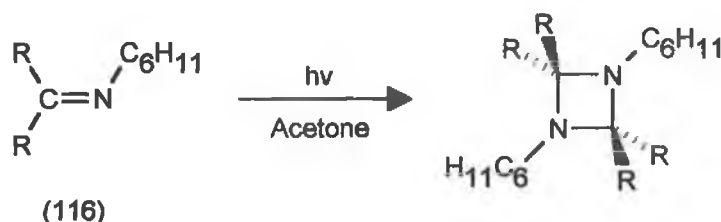


equivalent under direct or sensitised irradiation in the presence of a triplet sensitiser (acetone). Triplet quenching reactions have not been carried out and no mechanism has yet been proposed by the authors.

A publication has appeared which reports the photochemical reactivity of a 1-aza diene both in solution and in the solid state.¹²² Because of the instability of the *N*-acyl-1-aza dienes the authors have investigated the reactivity of the analogous *N*-acyl-2-cyano-1-aza dienes.

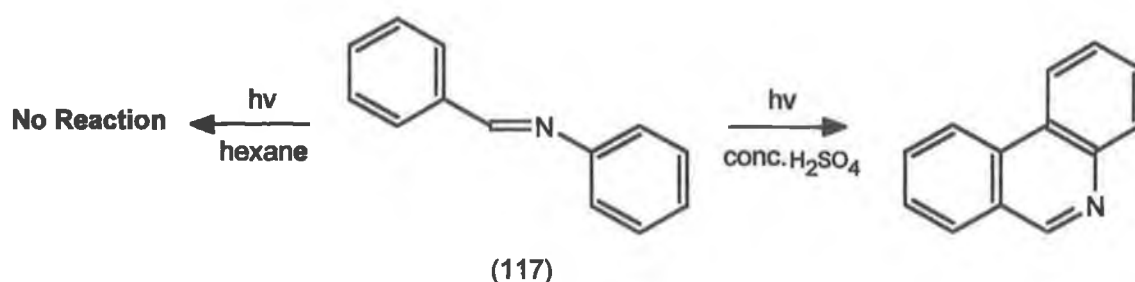


Irradiation of (113) leads to a [2+2] cycloaddition yielding product (114). This is unstable and quickly converts to the imide (115). This reaction, i.e. the [2+2] photocycloaddition of an acyclic imine is a rare occurrence and has only been reported once before in the literature, by Margaretha in the early 1980's.¹²³ Here the dimerisation of (116) is reported to occur readily when R is fluoromethyl group ($-\text{CH}_2\text{F}$). Earlier the failure of this reaction to proceed when R is an alkyl or phenyl group¹⁰⁵ had been shown by Padwa.¹²

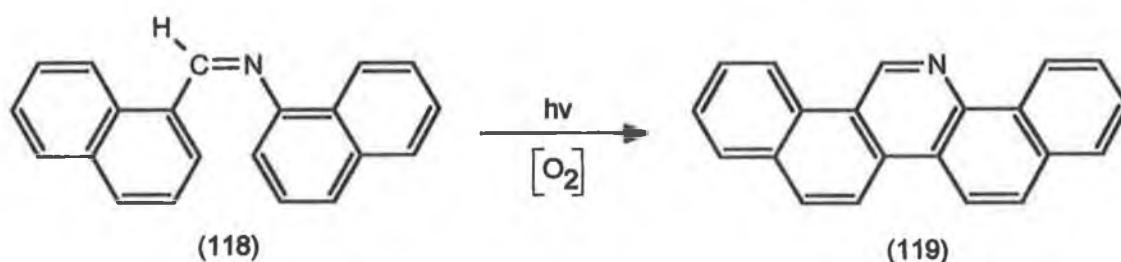


1.7 Photocyclisations

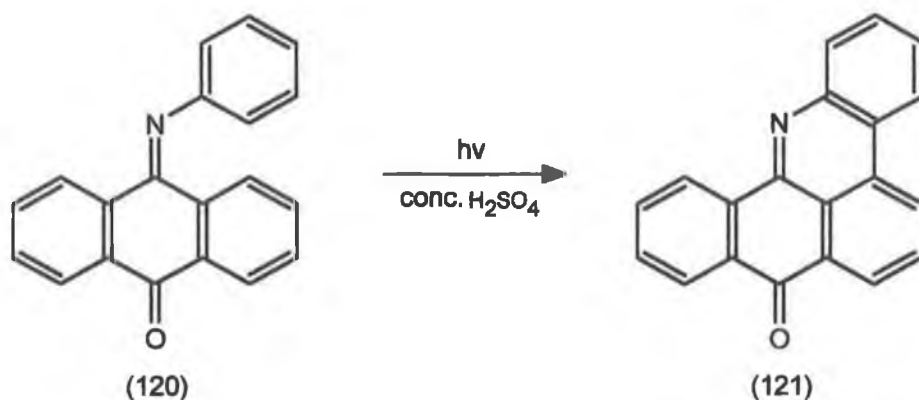
The formation of polycyclic systems by intramolecular photocyclisation is a common process for several different types of aromatic compound and is a reaction which has been used as a key step in a variety of synthetic pathways. In olefins the singlet (π, π^*) excited state cyclisation of stilbenes to dihydrophenanthrenes is a well documented process.¹²⁴ Less well documented are the analogous reactions of C-N double bond containing systems. An early experiment demonstrated the absence of reaction on irradiation of the benzaniline (117).¹²⁵ Irradiation in concentrated acid, however, yielded the phenanthridine derivative.



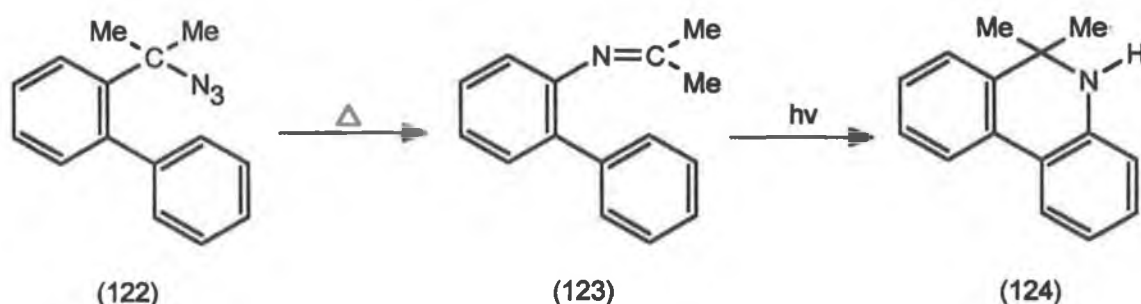
A similar reaction was investigated by Mallory and Wood which demonstrated that the anil (118) underwent cyclisation readily to form the corresponding phenanthridine (119). This was surprising, considering



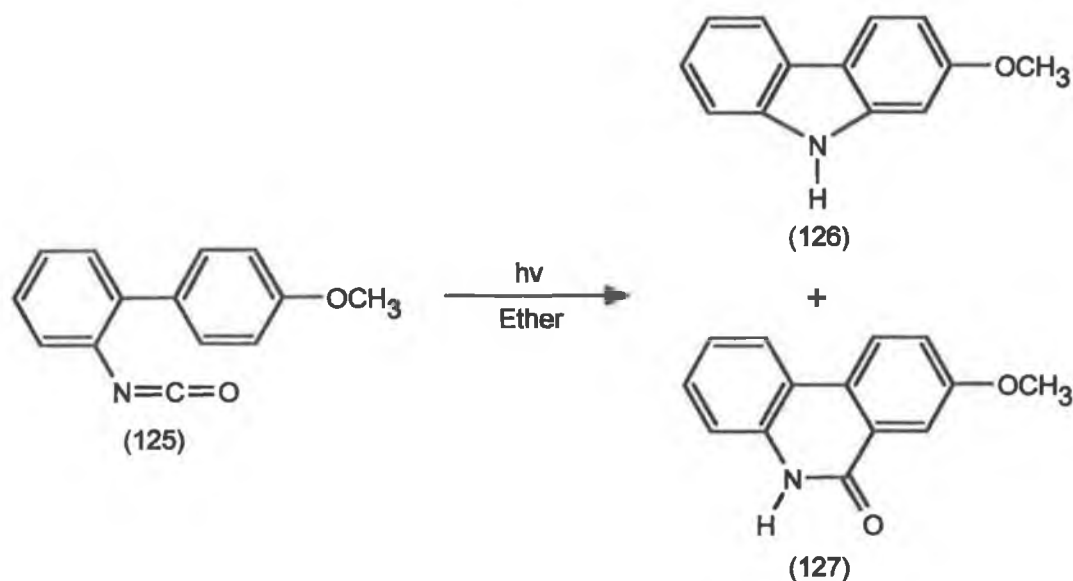
the absence of reaction on irradiation of the stilbene-analogous benzalaniline (117). When the authors investigated, it was discovered that the failure of (117) to cyclise could be satisfactorily explained stereochemically. This is analogous to the photocyclisation of stilbene which has been demonstrated to occur only following excitation of the cis isomer and not the trans isomer. It had been shown shortly before this publication that the photochemical isomerisation of (117) brings about a photostationary state in which the ratio of cis/trans isomers was extremely small, except at lower temperatures.¹²⁶ By irradiating (117) at low temperatures, cyclisation was seen to occur. An analogous reaction was shown to occur in a larger heterocyclic system by Scholtz and co-workers.^{127a} This occurred, once again, in the presence of concentrated acid. The anil (120) was observed to cyclise to form (121).



In an investigation of the reactions of alkyl nitrenes, it was found that thermolysis of the azide (122) yielded the imine (123), which on irradiation afforded the phenanthridine (124).^{127b} No mechanism was proposed by the authors.



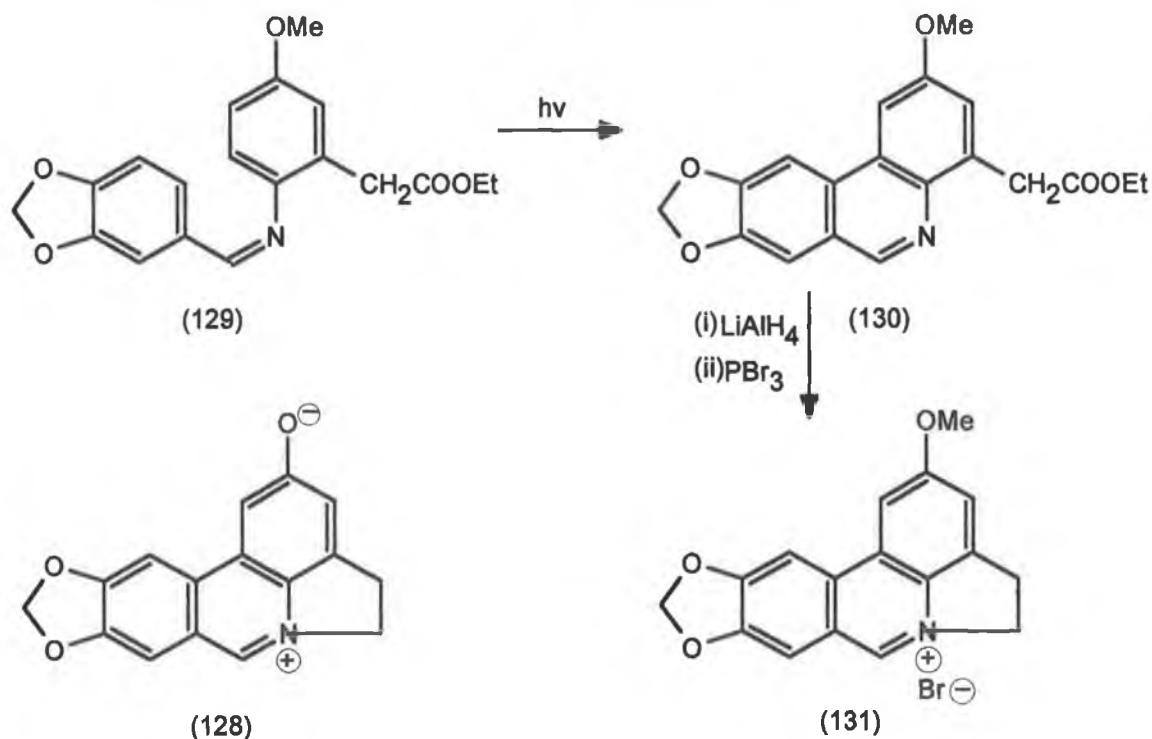
A publication by Swenton and co-workers has appeared in which they investigate the synthetic potential of nonoxidative cyclisation in suitable 2-substituted biphenyls.¹²⁸ They carried out a thorough investigation into the photoreactions of 2-biphenyl isocyanates and imines, and the influence of substituents and biphenyl geometry on the efficiency and multiplicity of these processes. On direct irradiation of the isocyanate (125), a mixture of carbazole (126) and phenanthridinone (127) were afforded as products.



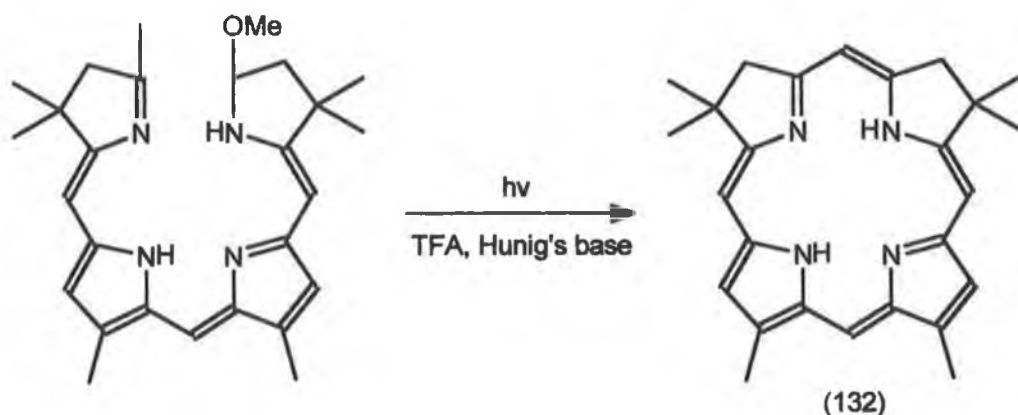
The authors concluded that because of the high triplet energy of carbazole, its moderate intersystem crossing efficiency, and its strong absorption in the near

uv, the carbazole (126) itself could be acting as a triplet sensitiser producing the phenanthridinone (127). Triplet sensitisation and quenching studies using acetone and piperylene respectively, showed that the reaction does in fact proceed via the triplet manifold. Triplet sensitisation reactions yielded primarily the phenanthridinones, with reactions being 20-40 times more efficient than direct irradiation experiments. Quenching with high concentrations of piperylene stopped reaction almost completely.

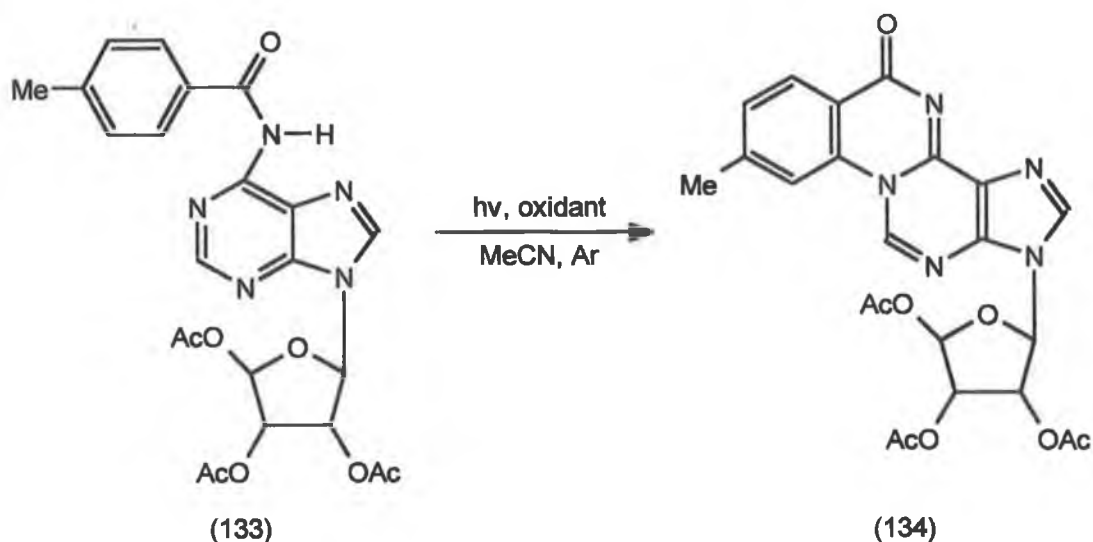
In the search for useful syntheses of natural products, photochemistry has played an important part. Onaka and co-workers have demonstrated a useful synthesis based on the earlier work on benzalaniline (117) in which they have synthesised the methobromide of the phenanthridine alkaloid ungerimine (128).¹²⁹ Irradiation of (129) yields the cyclised product (130), which on reduction with LiAlH_4 and treatment with PBr_3 yields the methobromide salt (131).



A photocyclisation has been shown to occur in a publication by Harrison and co-workers, in which the crucial cyclisation step involves irradiation in a solution of TFA and Hunig's base.¹³⁰ The product is the isobacteriochlorin macrocycle (132), an essential element in the biosynthesis of vitamin B_{12} .

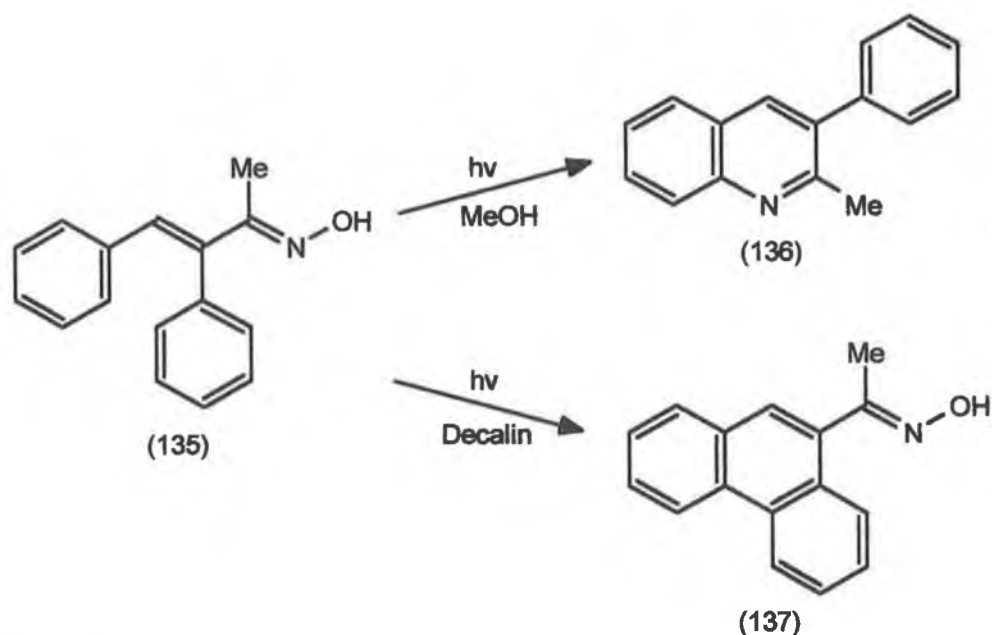


The authors concluded that the reaction proceeded via a tautomerisation step. An oxidative photocyclisation has been shown to be of use in the synthesis of a quinazolinopurine ring system in a more recent paper, and affords product in yields varying from 60 to 95% depending on oxidant.¹³¹ The benzoyladenine derivative (133) undergoes photocyclisation to form the purine (134). Different

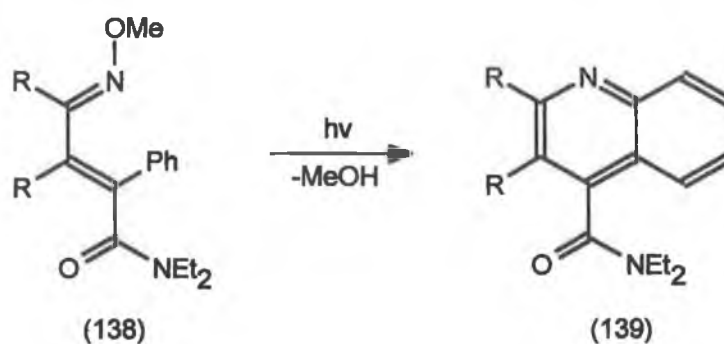


oxidants were used, such as *p*-dinitrobenzene, iodine or tetracyanoethylene. It was also observed by the authors that thermal oxidation under the same conditions did not occur.

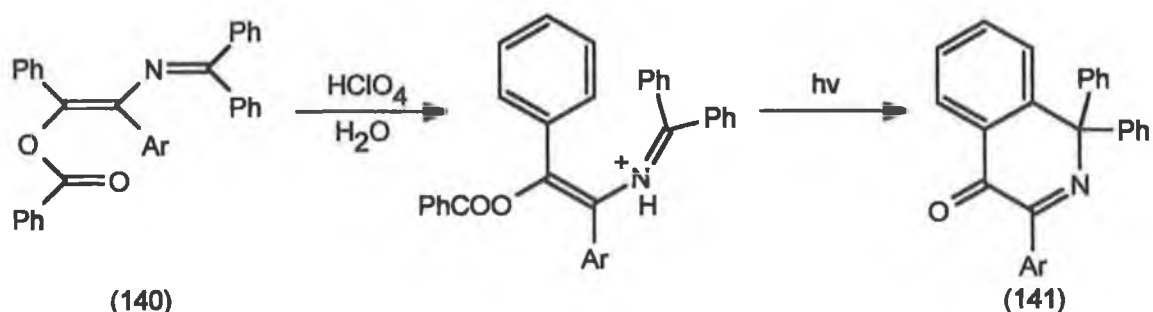
An important aspect of the photochemistry of the C-N double bond is the photochemical synthesis of quinoline systems and their derivatives.¹³²⁻¹⁴⁰ Glinka demonstrated that *trans*- α -phenylbenzylideneacetone oxime (135), undergoes a photocondensation reaction to a quinoline system (136) in methanol, whereas in



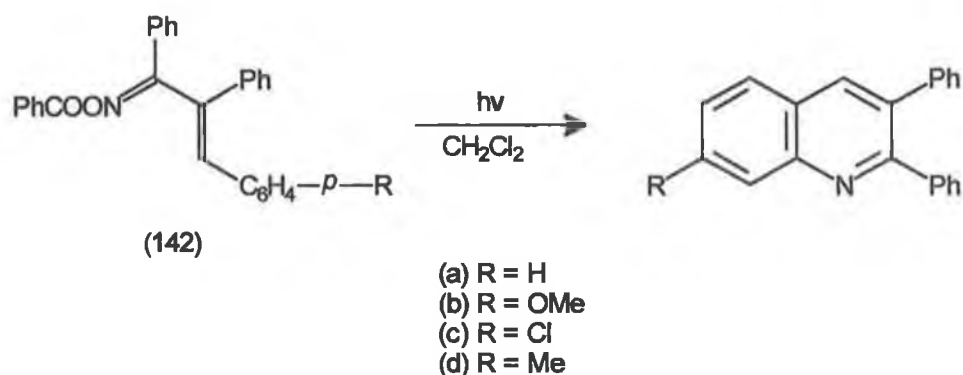
a non polar solvent such as decalin, cyclisation occurs around the C-C double bond yielding the phenanthrene derivative (137).¹³² When sulphuric acid is added the quinoline cyclisation reaction is enhanced. Conversion of the oxime to its acetate and subsequent irradiation of this acetate yields primarily the quinoline in both methanolic and decalin solutions. Elferink and Bos¹³³ have reported the photochemical synthesis of fused quinoline systems in c.80% yield. The carboxamide (138) on irradiation yields the fused quinoline system (139) following initial cyclisation and subsequent elimination of methanol.



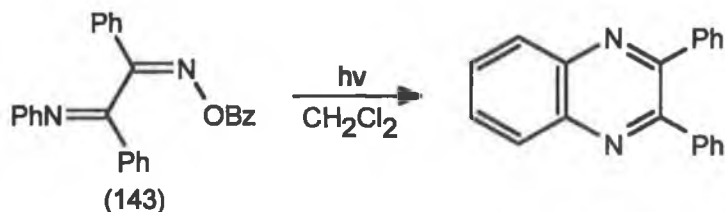
Armesto and co-workers¹³⁴ have reported a novel approach to the synthesis of isoquinolin-4-ones in which they protonate an azadiene (140) using perchloric acid and subsequently irradiate the salt obtained, yielding an isoquinolin-4-one



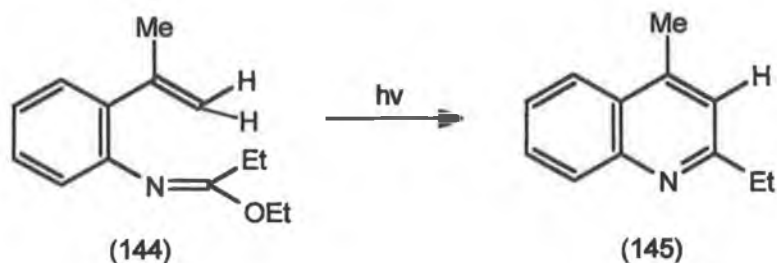
(141). Cyclisation is thought to occur via attack of the iminium carbon by the phenyl group followed by loss of H^+ and subsequent hydrolysis to the ketone and loss of benzoic acid. The resultant ketone is then oxidised during irradiation to the product (141). In experiments where azabuta-1,3-dienes were irradiated, good yields of quinolines were also obtained.¹³⁵ Irradiation of dienes (142a-d) afforded the corresponding quinolines in varied yield (33-70%). A similar



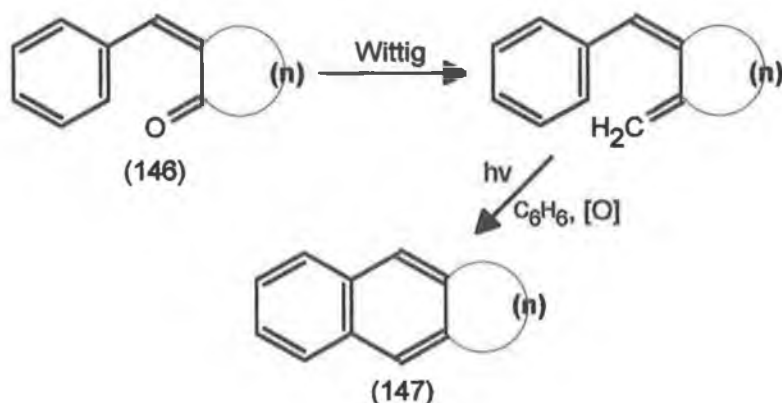
reaction is observed in the irradiation of the diazadiene (143) in dichloromethane which cyclises to form the corresponding quinoxaline derivative.¹³⁷ The yield of product is improved if the reaction is carried out in acetone, indicating a reaction which proceeds via the triplet state.



Qiang and Baine have also reported a facile synthesis of quinolines in high yield by the irradiation of imidates.¹³⁶ The imidate (144) on irradiation in cyclohexane yields the quinoline (145) in 91% yield, without the formation of any side products. Several of these quinolines have been synthesised with varying substituents.

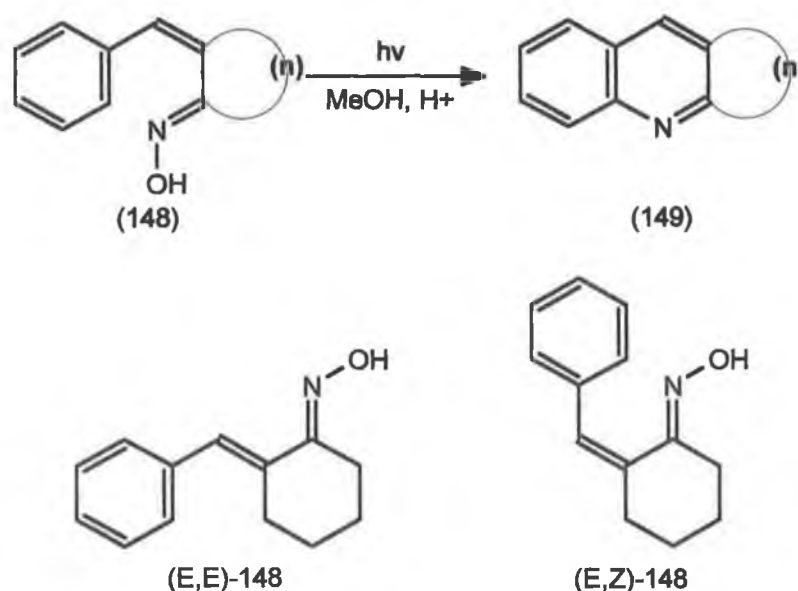


Photoannulations to naphthalenes and quinoline derivatives have been investigated by Olsen and co-workers for several systems.¹³⁸⁻¹⁴⁰ Ketone (146) is first converted to a diene via a Wittig reaction. This is then irradiated in benzene yielding the cyclised product (147).



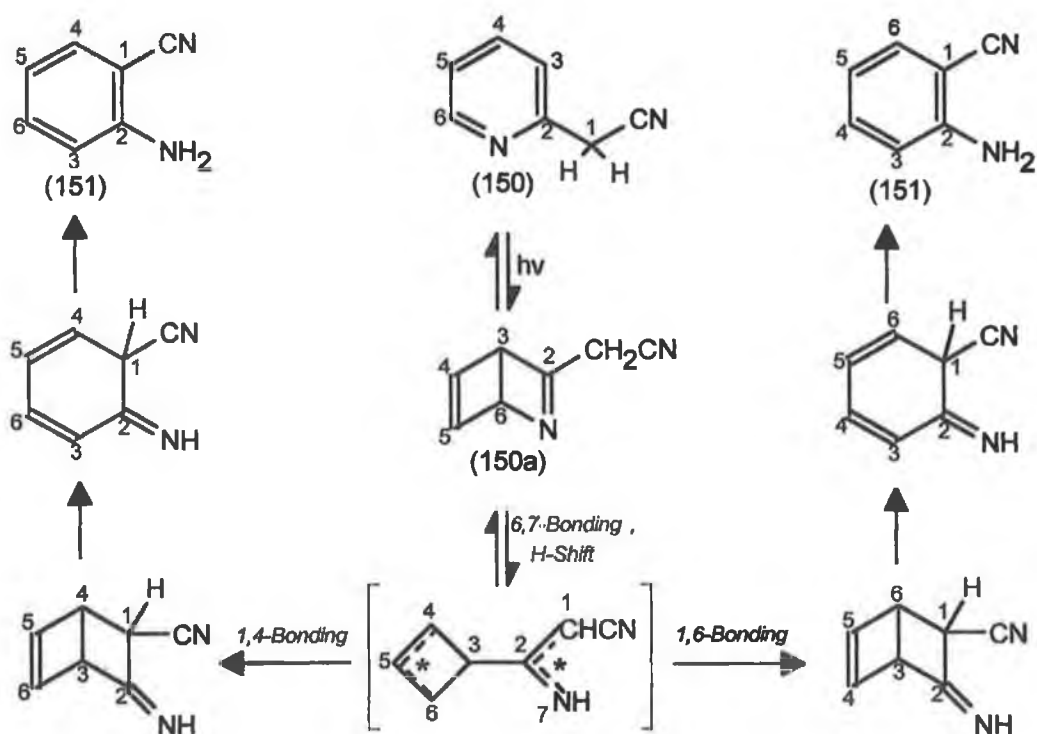
The photocyclisation has been shown to proceed via the triplet state, with enhanced yields on irradiation in the presence of a triplet sensitizer, such as benzophenone. Successful cyclisations occur from saturated ring sizes of $n=5$ to $n=8$. The mechanism of reaction is similar to that of the analogous arylidene cycloalkanone oximes which have been investigated by the same authors. Oxime (148) on irradiation cyclises to form quinoline (149). The reaction proceeds once

again for values of n from $n=5$ to $n=8$, with best results in six and seven membered rings, affording yields of 84 and 70% respectively. The triplet state behaviour of the oximes E,E- and E,Z- (148), where the cycloalkane is hexane, was studied by carrying out sensitisation experiments in benzene using a variety of sensitisers with different triplet energies. Triplet state isomerisation reactivity was localised almost exclusively at the C=C bond, giving photostationary state mixtures of E,E- and E,Z-isomers. Direct irradiation of



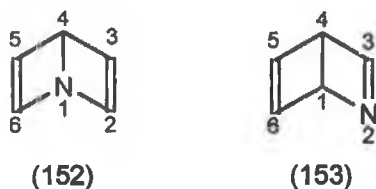
E,E-148 gives isomerisation primarily at the C=N bond, a result which is similar to those which have been described for other α,β -unsaturated oxime derivatives. Because triplet sensitisation experiments give almost exclusive isomerisation about the C=C bond, it is apparent that the cyclisation of the oxime arises from the excited singlet state.

Several publications have appeared since the late seventies regarding the intramolecular cyclisation and subsequent rearrangement of pyridines and their analogues. Indeed the intramolecular cyclisation of pyridines to their Dewar forms seems to be the phenomenon which has been observed as being responsible for the majority of these rearrangements.¹⁴¹⁻¹⁵⁹ Takagi and Ogata, on irradiation of 2-pyridylacetonitrile (150), isolated anthranilonitrile (151) as product.^{141,142}



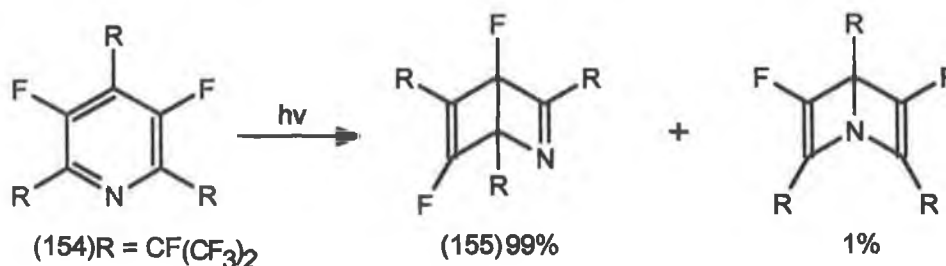
SCHEME 18

The authors have suggested the mechanism outlined in scheme 18. Intramolecular cyclisation of (150) to Dewar (150a) leads to ring opening and subsequently ring closure can occur on a different part of the molecule. The authors have carried out triplet sensitisation experiments, but have seen no enhancement in reactivity. Triplet quenching had no effect either. They did however propose that a triplet quencher might not have effect here because of the short triplet lifetime of these species. *para*-Bonded isomers of the pyridine system such as type

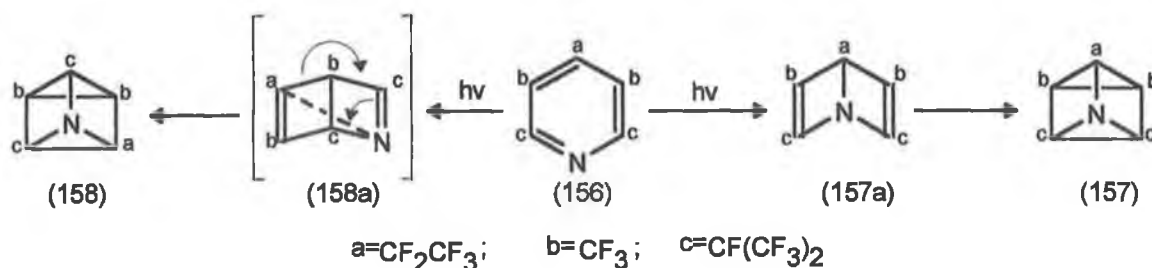


(152) have been isolated and are quite stable, whereas isomers of type (153) have been described as unstable and very short lived, until Chambers and

Middleton isolated what is thought to be the first stable derivative of this type.^{143,144} Irradiation of (154) affords an isomer of this type (155) in 99% yield.

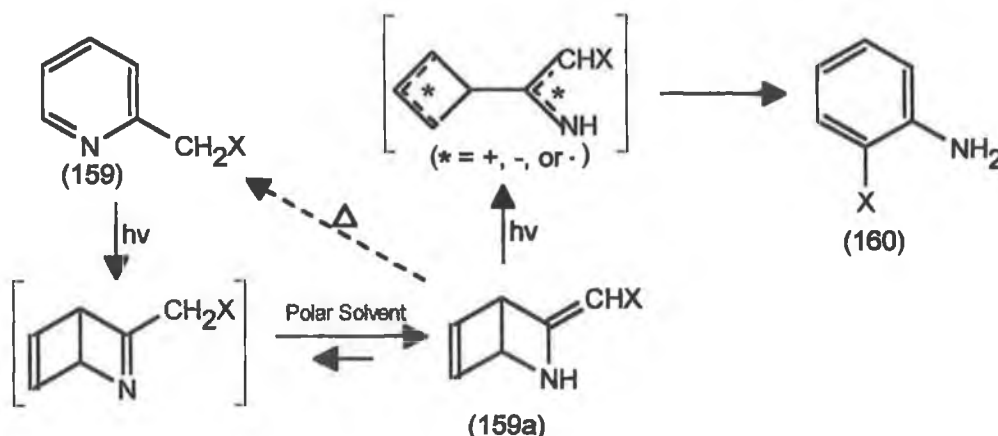


In general it appears that the 2-aza skeleton (153) is preferred over the 1-aza skeleton (152), although the former is sometimes very unstable. Here however, it is demonstrated that it is the more preferred of the two by the addition of the fluoro groups which act as stabilising substituents, allowing isolation of the product. In a subsequent publication irradiation of pyridine (156) has been shown to produce not only these Dewar isomers, but azaprismanes (157) and (158).¹⁴⁴

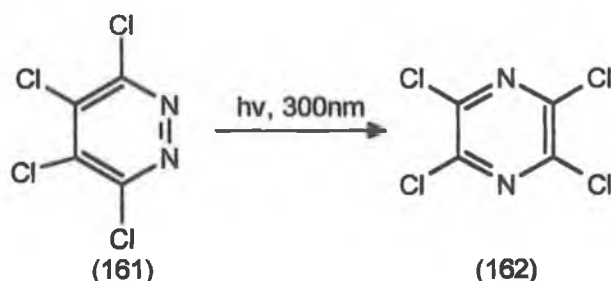


The authors had the problem of accounting for the formation of (158) from pyridine (156). They proposed that the structure (158) is produced by the initial formation of the 2-azabicyclohexadiene derivative (158a) followed by immediate rearrangement to the 1-azabicyclohexadiene derivative and cyclisation to (158). Ogata and Takagi have investigated the photochemistry of substituted pyridines, namely 2-picoline derivatives, and have isolated Dewar isomers as reaction intermediates towards formation of anilines.¹⁴⁶ They have also investigated the role of pH on the reaction. On irradiation of (159) in polar solvent, (160) is produced. As the pH of the solvent is increased the yield of (160) is increased. Reaction reaches a max at pH=12. The authors have attributed this increase in

yield accompanying an increase in pH to the formation of the intermediate (159a), the production of which depends on the solvent being alkaline.

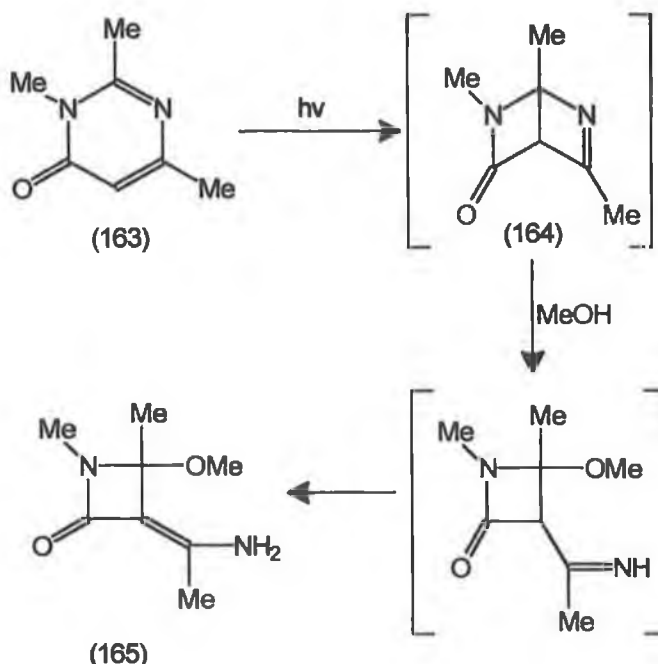


The reaction is thought to proceed via a zwitterionic or diradical intermediate formed from (159a) which cyclises to form (160) as was thought to be the mechanism in an earlier reaction investigated by the same authors (shown in scheme 18).¹⁴² Chlorinated pyridazines have been shown on irradiation to rearrange to chlorinated pyrazines via a reactive n,π^* singlet state.¹⁵¹ U.V. absorption spectra of pyridazine (161) show two bands at 300 and 253nm due to n,π^* and π,π^* states respectively. Irradiation of pyridazine (161) at 300nm yields pyrazine (162) in 80% yield, whereas irradiation of the same compound at 253nm affords product in 15% yield. The number of quanta absorbed in all cases was observed using ferrioxalate actinometry.

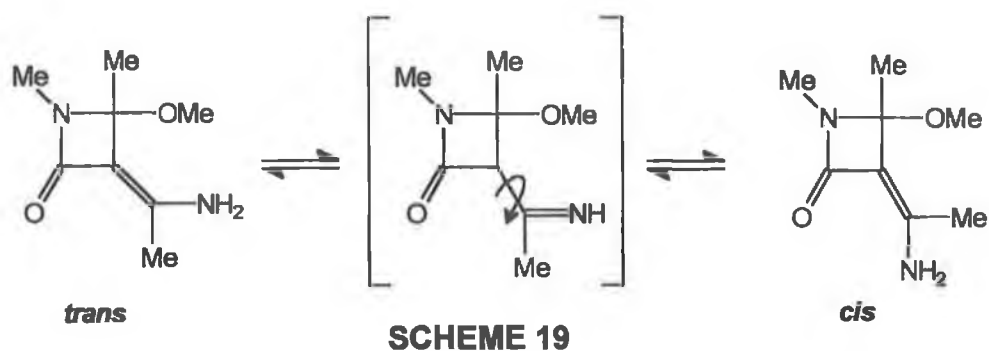


The use of Dewar analogues as reagents for producing biologically active systems has been documented in a number of publications since the late seventies. Their uses as lactam and nucleoside precursors have been

highlighted, particularly during the investigation of pyrimidinone systems and their analogues.^{147-150, 152-159}

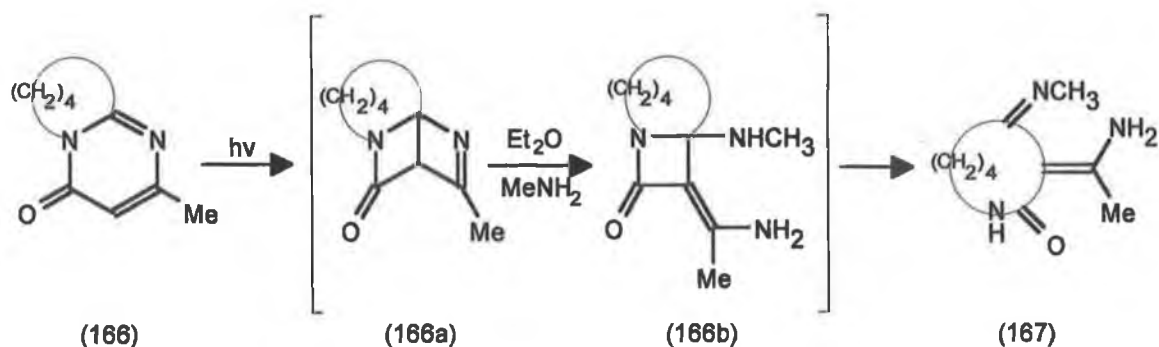


Irradiation of pyrimidinone (163) yields β -lactam (165) via Dewar intermediate (164). Both *cis* and *trans* isomers were isolated. *Trans* isomers were isolated in excess with most compounds investigated having *cis:trans* ratios ~60:40. Their presence is explained via intermediate single bond rotation, as shown in scheme 19.

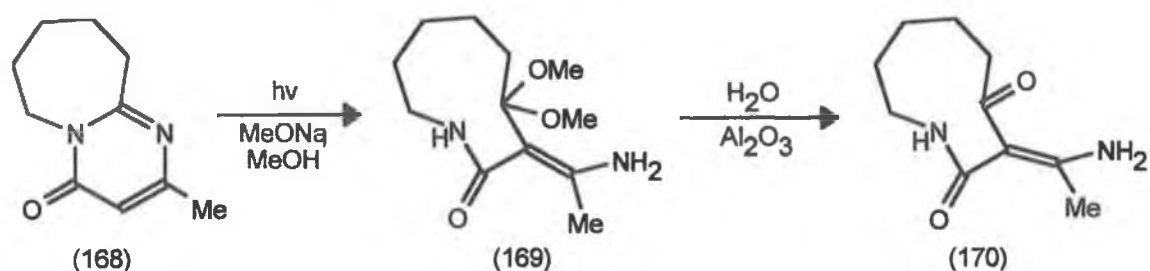


Hirai and Yamakazi¹⁴⁸ reported a synthesis of 8 and 9 membered lactams containing the reactive di-imine system by carrying out the photochemical reaction of fused 4(3H)-pyrimidin-4-ones in a mixed methylamine-ether solution.

The reaction proceeds according to the mechanism shown below. Irradiation of the pyrimidinone (166) in benzene followed by addition of a mixed solution of methylamine and diethylether yields the lactam (167). The Dewar type intermediate (166a) formed by irradiation reacts with methylamine to give β -lactam (166b). This is followed by cleavage of the bridgehead N-C to afford the final product.

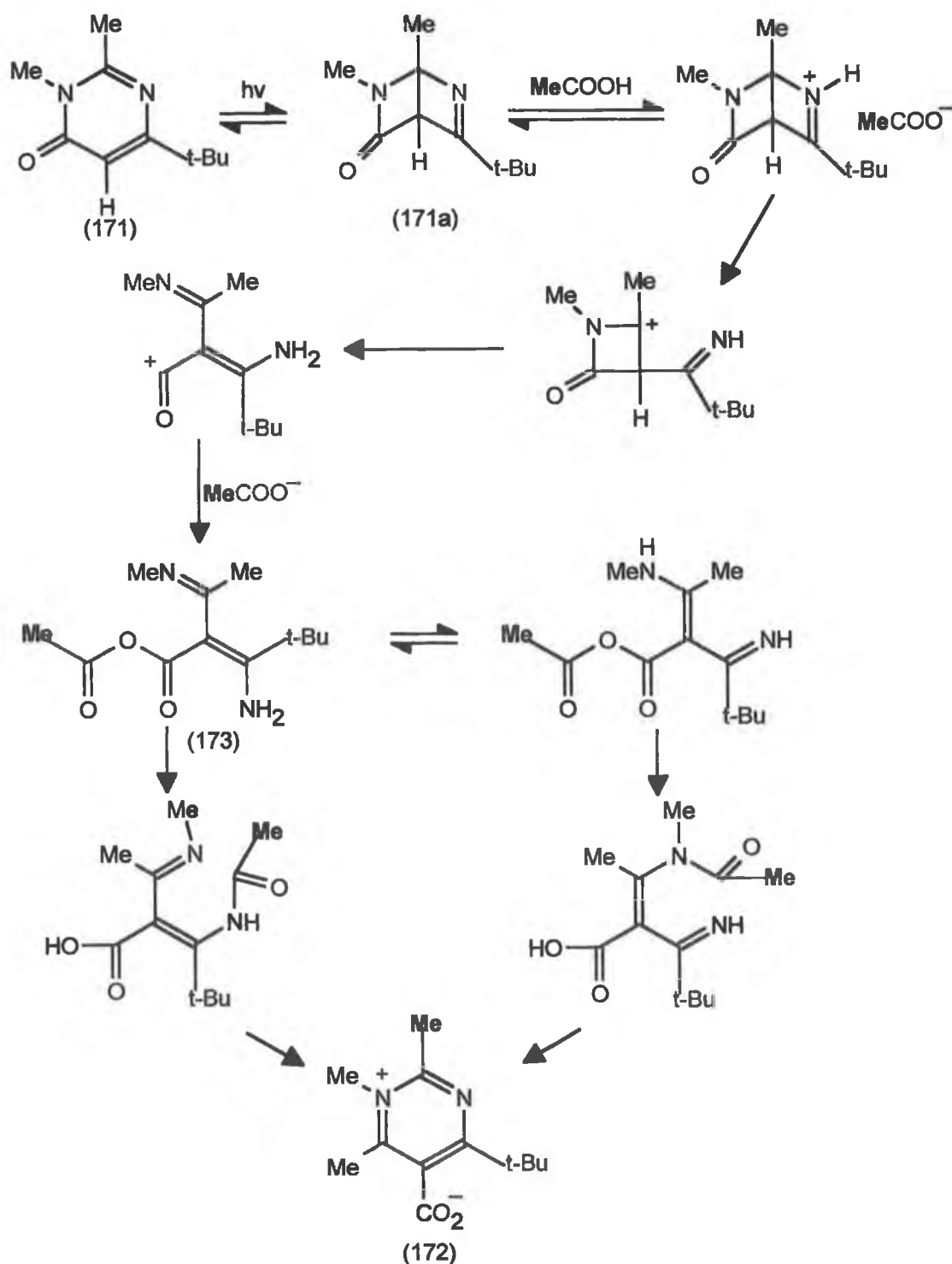


Similarly, in another publication by the same authors, photolysis of the fused pyrimidinone (168) in methanol and sodium methoxide undergoes rearrangement to the ketal (169) which on hydrolysis converts to the enamino ketone derivative (170).¹⁵⁰ Once again the participation of Dewar intermediates



in the reaction has been shown. The formation of zwitterionic betaines via Dewar intermediates has also been reported.^{152,157}

Irradiation of the pyrimidinone (171) in an acetic acid solution yields a crystalline compound which was identified as being betaine (172). The mechanism proposed by the authors is shown in scheme 20. Pyrimidinone (171) on irradiation closes to the Dewar (171a). This Dewar intermediate reacts with

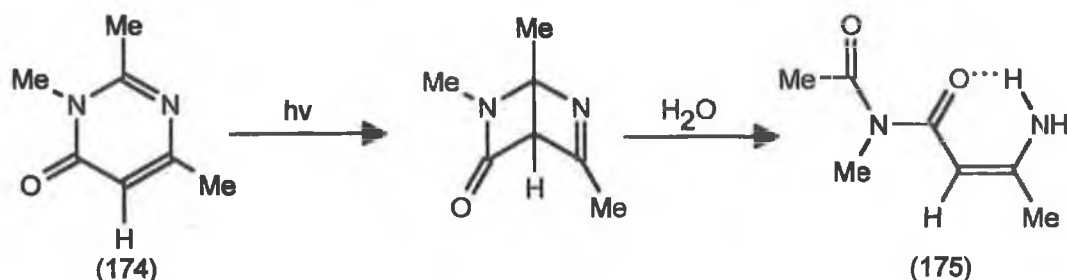


SCHEME 20

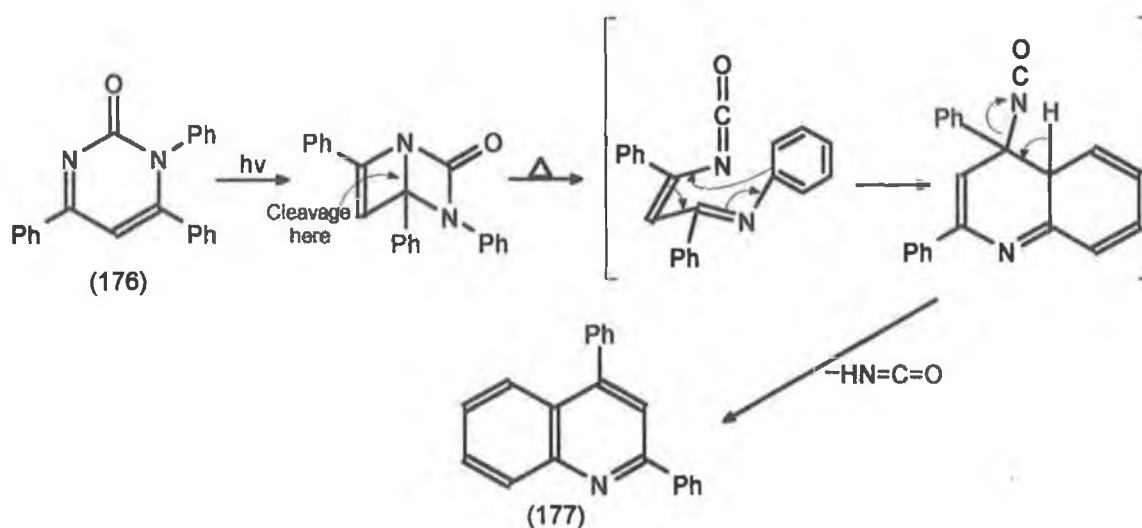
the acetic acid in solution to yield mixed anhydride (173). The primary amino group in the anhydride (173) undergoes an intramolecular acylation, cyclising to form the betaine (172). Irradiation of certain pyrimidinones in aqueous solution

afford the corresponding photohydrates which are isolable in crystalline form.^{155,159}

Photohydrates are known to play important roles in the inactivation and mutation of living organisms by ultraviolet radiation. The pyrimidinones examined by Takahashi and co-workers are model compounds closely related to nucleic acid pyrimidine bases. Irradiation of pyrimidinone (174) yields photohydrate (175) via a Dewar intermediate, which is itself isolable. The reversion of photohydrate (175) to starting material (174) occurs in the dark at room temperature.

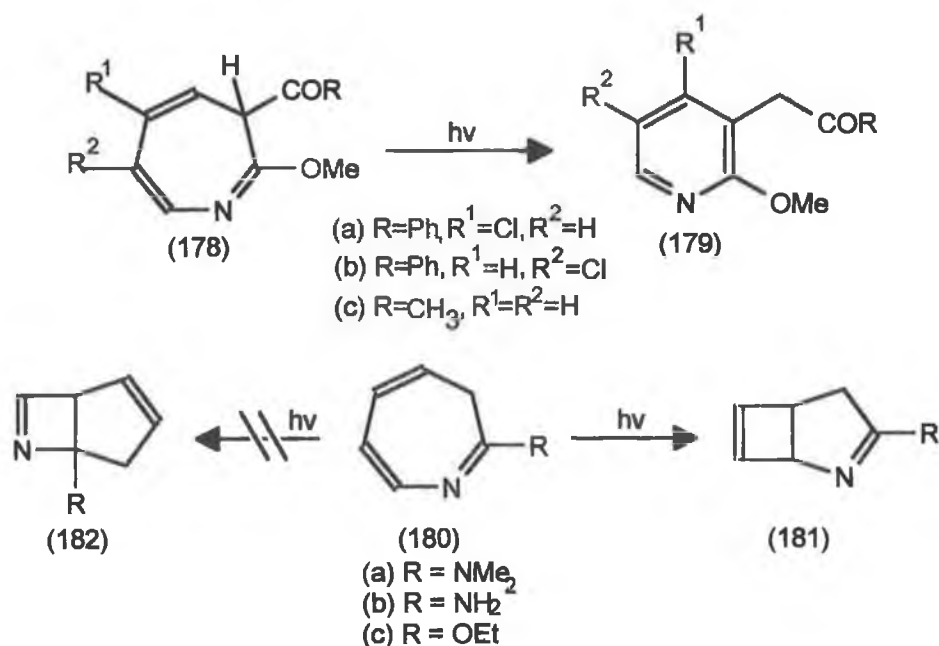


The irradiation of triarylpyrimidinones (176) has been shown to be of use in the synthesis of quinolines (177). The reaction is thought to proceed via a Dewar isomer which on heating undergoes C-N bond cleavage and loss of isocyanic acid, (scheme 21).

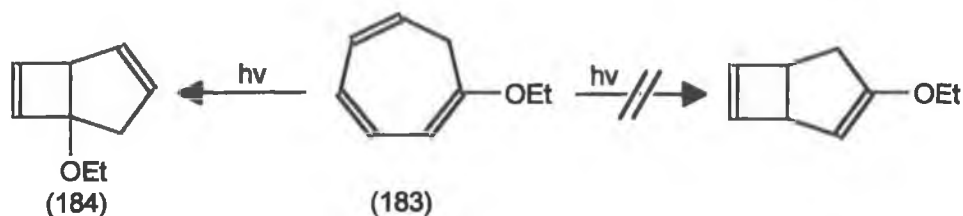


SCHEME 21

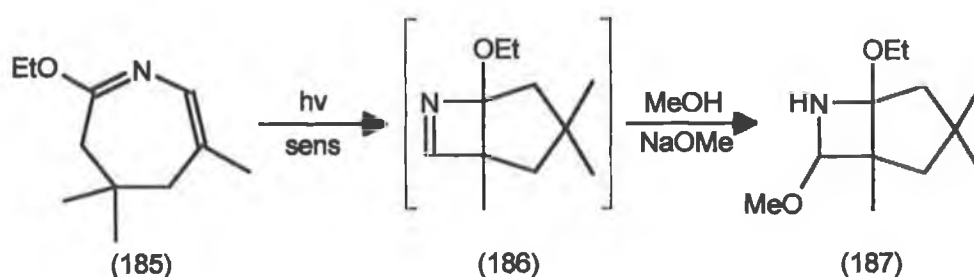
Another ring system which undergoes many different types of reaction including ring expansion and contraction, is that of the azepine system. Azepines (178a-c) undergo ring contraction when irradiated to form the corresponding pyridines (179a-c).¹⁶⁰ Irradiation of azepines (180a-c) results in regioselective photorearrangement to form the azabicyclodienes (181a-c). Formation of the isomeric products (182a-c) did not occur.¹⁶¹ No mechanism is proposed by the authors. Chapman has reported the photorearrangement of



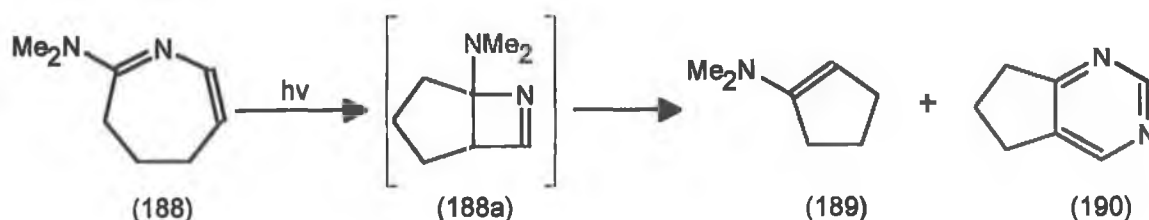
1-ethoxycyclohepta-1,3,5-triene (183) to the diene (184) in direct contrast to the mode of reaction of azepine (180),¹⁶² its heterocyclic analogue. Koch and co-workers have also observed this mode of reaction



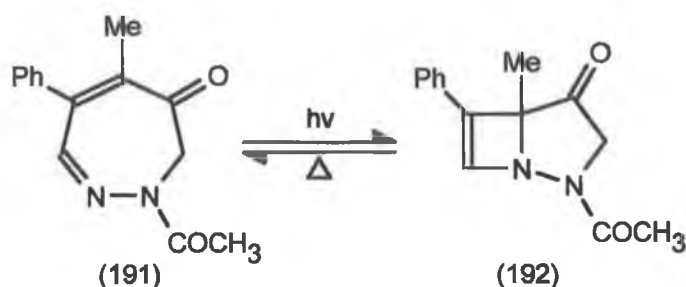
on acetophenone sensitised irradiation of (185). The reaction yields the unstable azetine derivative (186), which is trapped by methanol and sodium methoxide to yield (187).^{163,164}



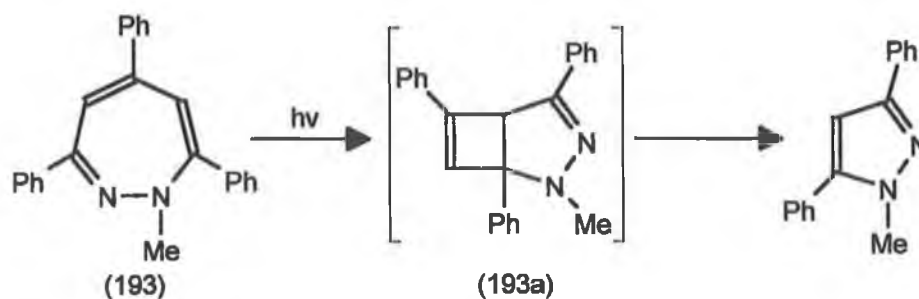
Irradiation of (188) without triplet sensitisation is a novel reaction, yielding (189) and (190) as products. The authors have proposed a reaction path which proceeds via the formation of intermediate (188a).^{165,166}



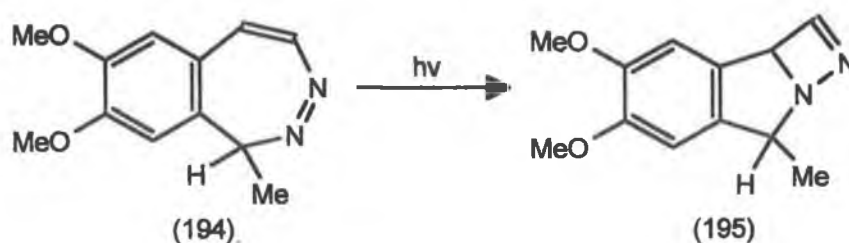
Publications have appeared concerning the photochemistry of diazepines, which in many cases show analogous behaviour to azepines.¹⁶⁷⁻¹⁷⁰ Irradiation of the diazepinone (191) yields the crystalline bicyclic ketone (192) in 90% yield.¹⁶⁷



The reaction is reversible on heating. Kan and co-workers have shown an analogous reaction which occurs on irradiation of a highly substituted diazepine (193). Once again a five membered ring compound is isolated as product (as occurred in the irradiation of 188) in 82% yield.

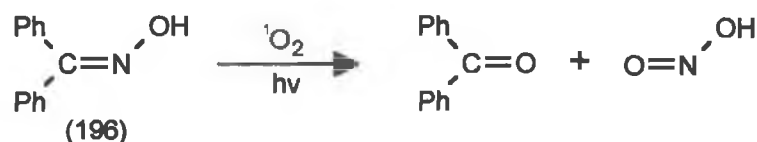


The reaction is thought to proceed via the intermediate (193a). Reid and co-workers investigated this intramolecular cyclisation using benzodiazepines.¹⁷⁰ Irradiation of benzodiazepine (194) at 0°C yielded the stable tricyclic compound (195).



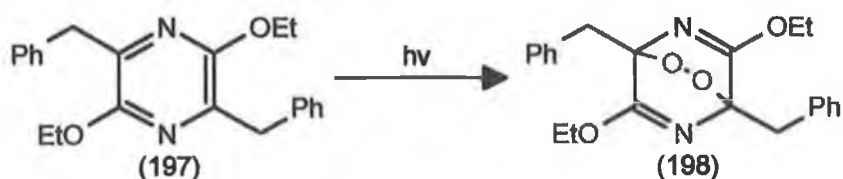
1.8 Photooxygenation

The first report of the addition of singlet oxygen to a π -bond other than a C=C bond demonstrated the sensitised (Rose Bengal) addition of oxygen to the C=N bond in benzophenone oxime (196), although in small yield.¹⁷¹ A known singlet oxygen quencher, 1,4-diazabicyclo[2.2.2]octane (DABCO), suppressed reaction.

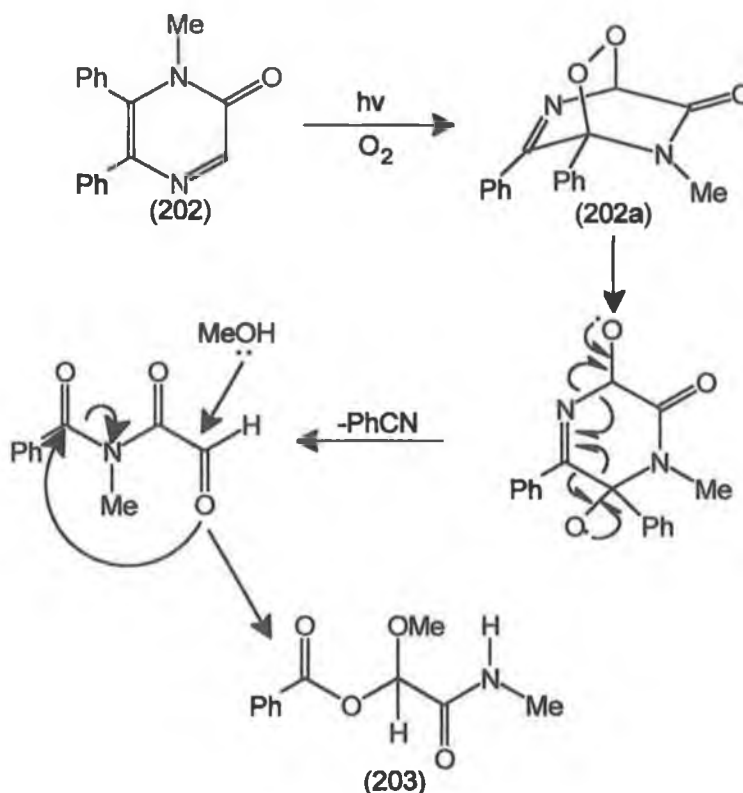
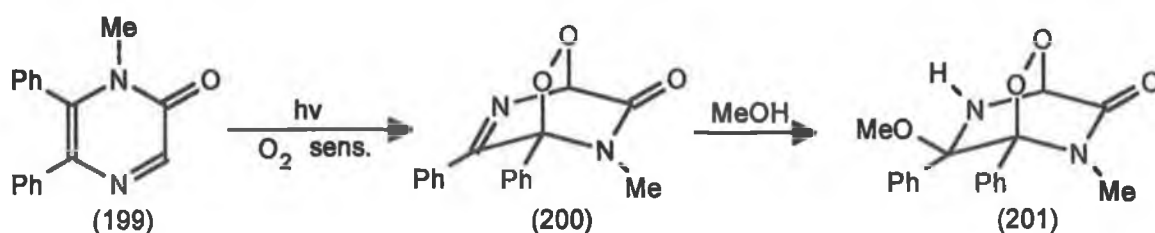


Several publications have appeared in the literature regarding the photooxygenation of pyrazines and their derivatives.¹⁷³⁻¹⁷⁵ Irradiation of pyrazine

(197) with methylene blue as sensitiser, yielded the stable peroxide (198) as a colourless oil.¹⁷²

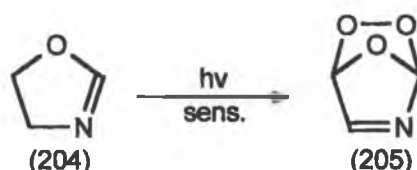


Irradiation of pyrazinone (199) yields the endoperoxide (200).¹⁷³ In methanol solution the adduct (201) is formed. The formation of endoperoxide (200) is a photochemical reaction, as no reaction occurs in the presence of oxygen in the dark. Formation of (201) does, however, occur in the dark when (200) is dissolved in methanol.



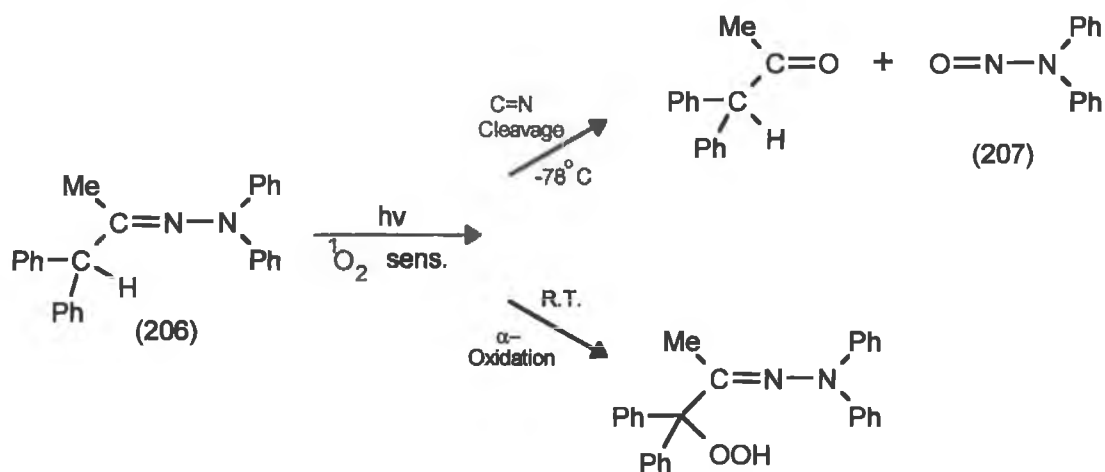
Further investigations into the photooxygenation of pyrazinones reveal that some of the reactions proceed with an accompanying cleavage, with the elimination of nitriles and formation of acetamides. Irradiation of pyrazinone (202) in the presence of methylene blue as sensitiser yields the acetamide (203), via initial formation of the endoperoxide (202a), elimination of benzonitrile and nucleophilic attack of methanol, which in this case is the solvent.

Oxazoles (204) are believed to undergo photooxygenation reactions to form oxazole endoperoxides (205), although the evidence published is circumstantial only. Gollnick and Koepler have, however isolated products by using highly substituted oxazoles.¹⁷⁶



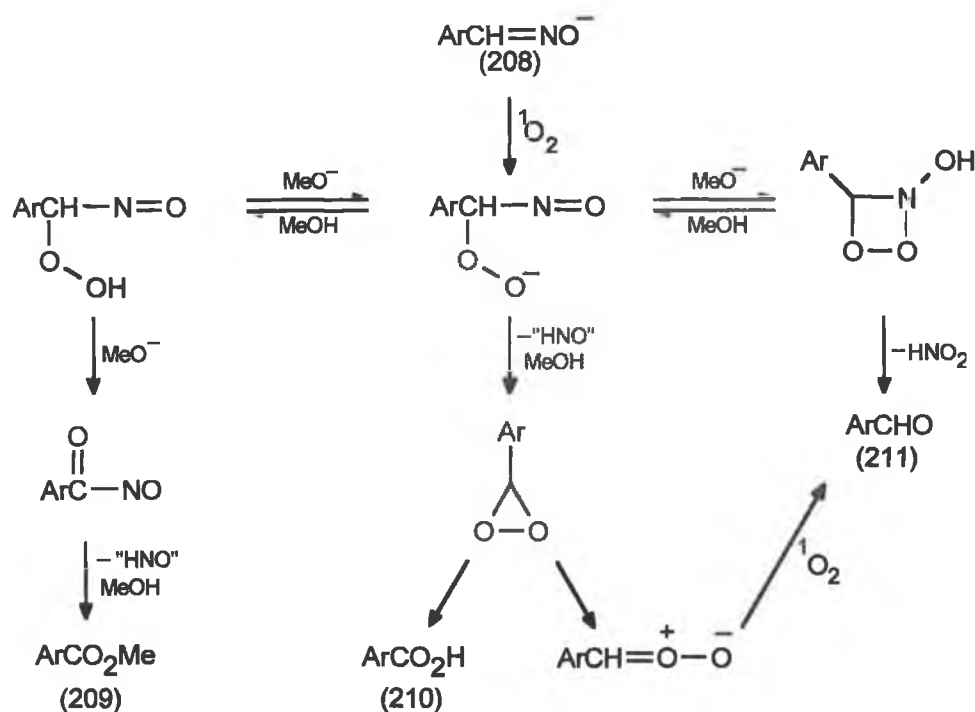
By placing substituents such as methyl groups and phenyl groups on different carbons on the oxazoles and irradiating in the presence of sensitiser such as Rose Bengal, endoperoxides were identified by ¹³C and ¹H-nmr spectroscopy. None of the products were isolated in the pure form, as reaching room temperature caused explosion.

A publication by Ito and co-workers has reported that the reaction of



N,N-disubstituted hydrazones with singlet oxygen shows a unique dependence on the substituents at the nitrogen atom and on reaction temperature and solvent. At room temperature, N-phenyl-substituted hydrazones (206) were oxidised in dichloromethane solution affording α -oxidation products. At -78°C however, these hydrazones underwent carbon-nitrogen double bond cleavage to afford the parent ketones and N-nitrosodiphenylamine (207). That the singlet state of oxygen was responsible for reaction was shown by quenching of the reactions by DABCO, a known singlet quencher which has been described earlier.

Although the photooxygenated cleavage of benzophenone oxime has been shown to occur, it is in contrast to the reaction of most oximes. Indeed the oximes of cyclohexanone, cinnamaldehyde, *p*-tolualdehyde, and several others are unchanged after 7-12h illumination at room temperature in the presence of oxygen.¹⁷⁷ Oxime esters and ethers are much more reactive in comparison, affording greater yields of the parent ketone.¹⁷⁸



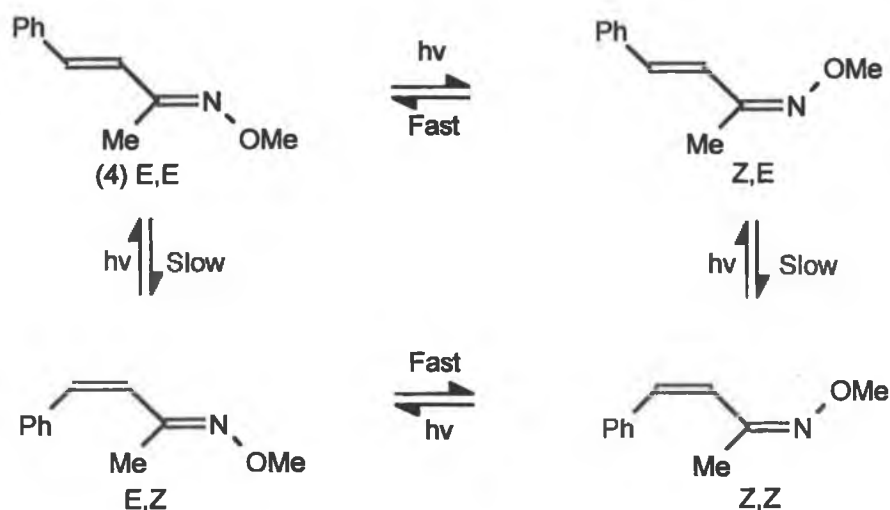
SCHEME 22

Oximate anions are even more reactive to photooxygenation. Oximes of *p*-tolualdehyde and *p*-methylacetophenone were photooxygenated in methanol in the presence of Rose Bengal as sensitiser and two equivalents of sodium methoxide. After 3h, the starting materials had totally disappeared.¹⁷⁷ In the case of the ketoximate, workup gave *p*-methylacetophenone, whereas in the case of the aldoximate (208), three different products were obtained, methyl *p*-toluate (209), *p*-toluic acid (210) and *p*-tolualdehyde (211) in the ratio 9:7:1 respectively. The mechanism of their formation is shown in scheme 22.

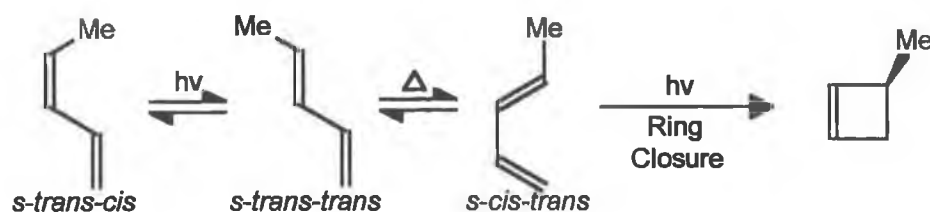
2. The Photochemistry of
2-Arylidene-cyclopentanone Oxime O-Acetates
and Methyl Ethers

2.1 Introduction

The photochemistry of α,β -unsaturated compounds containing the carbon-nitrogen double bond has been investigated by several authors.^{19-23,132,133,135,140} The number of papers published on this subject has been small, however, in comparison to the number of similar publications on 1,3-dienes.⁸² On irradiation of the conjugated oxime ether E-(E-benzylideneacetone)oxime O-methyl ether (E,E-4), Pratt and Majid found that the carbon-nitrogen double bond isomerises more rapidly than the carbon-carbon double bond both under direct and triplet sensitised irradiation.¹⁹

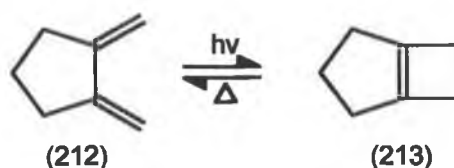


Buta-1,3-dienes in the cisoid conformation undergo electrocyclic ring closure to yield cyclobutenes on irradiation (scheme 23).¹⁷⁹

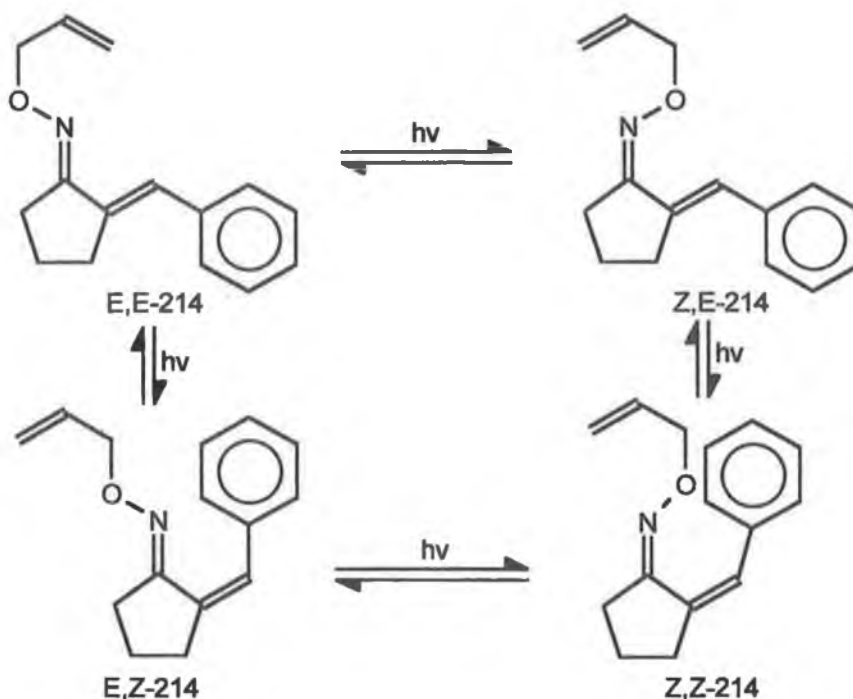


SCHEME 23

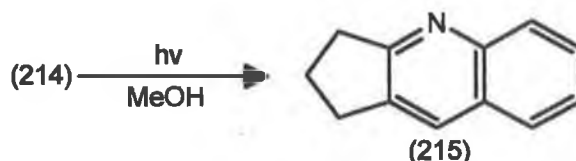
Constraining the buta-1,3-diene chromophore in the cisoid conformation facilitates the electrocycatisation.¹⁸⁰ Thus 1,2-dimethylenecyclopentane (212) yields bicycloheptene (213) in quantitative yield.



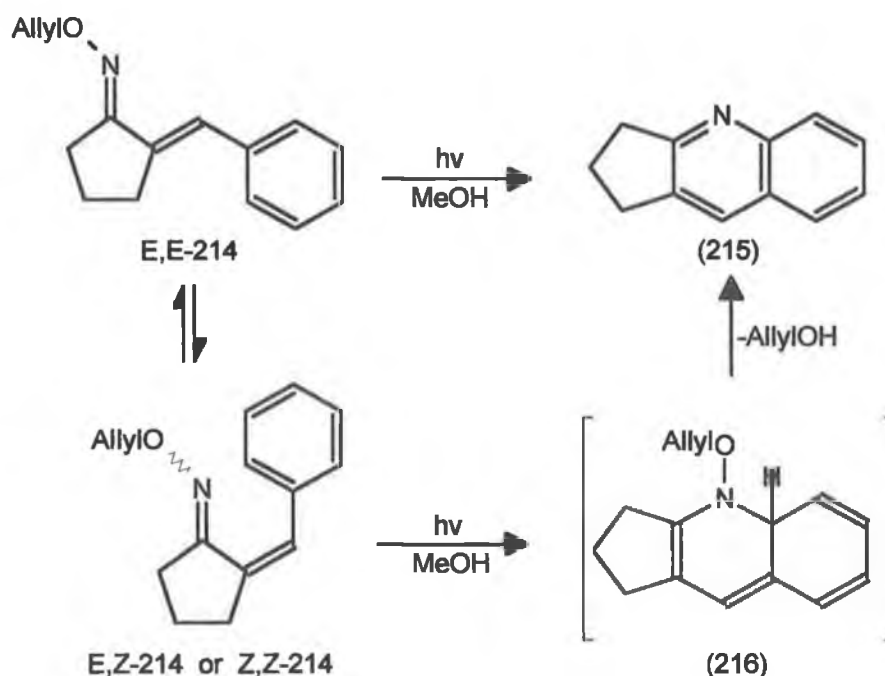
It was therefore of interest to study the effects of irradiation on a system containing an α,β -unsaturated carbon-nitrogen double bond constrained in the cisoid conformation by placing a ring system such as that in (212) in the molecule. An investigation into such systems was carried out by Austin.¹⁸¹ 2-Benzylidenecyclopentanone oxime O-allyl ether (214) was irradiated in ethyl acetate, resulting in a photostationary state on prolonged irradiation. The allyl group remained intact throughout.



In methanol however, an additional product was formed. After preparative chromatography, the product was isolated and was shown to be the quinoline (215).



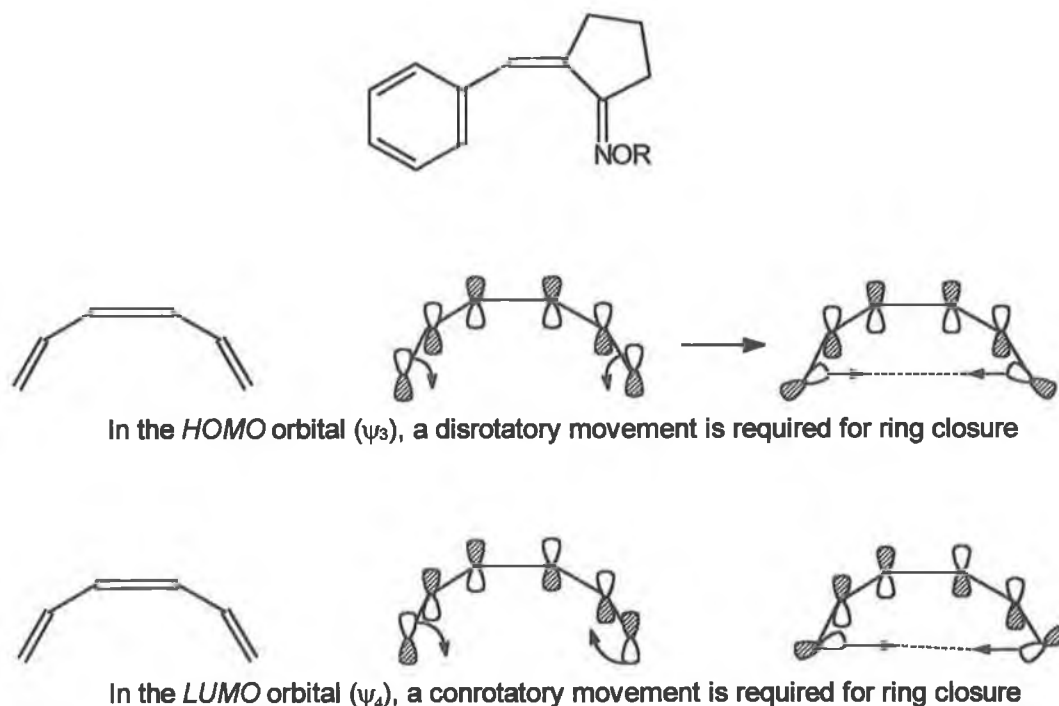
Formation of (215) on irradiation was accounted for by initial carbon-carbon double bond isomerisation followed by 6π -electron electrocyclic ring closure of E,Z-(214) or Z,Z-(214) to the intermediate nonaromatic heterocycle (216) followed by spontaneous elimination of allyl alcohol (scheme 24).



2.2 Mechanism of Reaction

The cyclisation reaction is thought to proceed via a π,π^* singlet excited state, since product formation is not affected by the presence of a triplet quencher (isoprene).¹⁸¹ The mode of ring closure is theorised using the frontier

orbital approach. The structure which cyclises to form the ring involves three π -bonds (scheme 26). Therefore there are altogether six atomic orbitals, three bonding and three antibonding. The highest energy bonding orbital is the *HOMO* (Highest Occupied Molecular Orbital), ψ_3 . To form the C-N bond on cyclisation in the ground state, the orbital lobes on the terminal atoms (in this case on the nitrogen atom of the NOR group and the carbon atom in position 2 on the phenyl ring) must each rotate through 90° in opposite directions (a disrotatory movement).¹⁸⁸

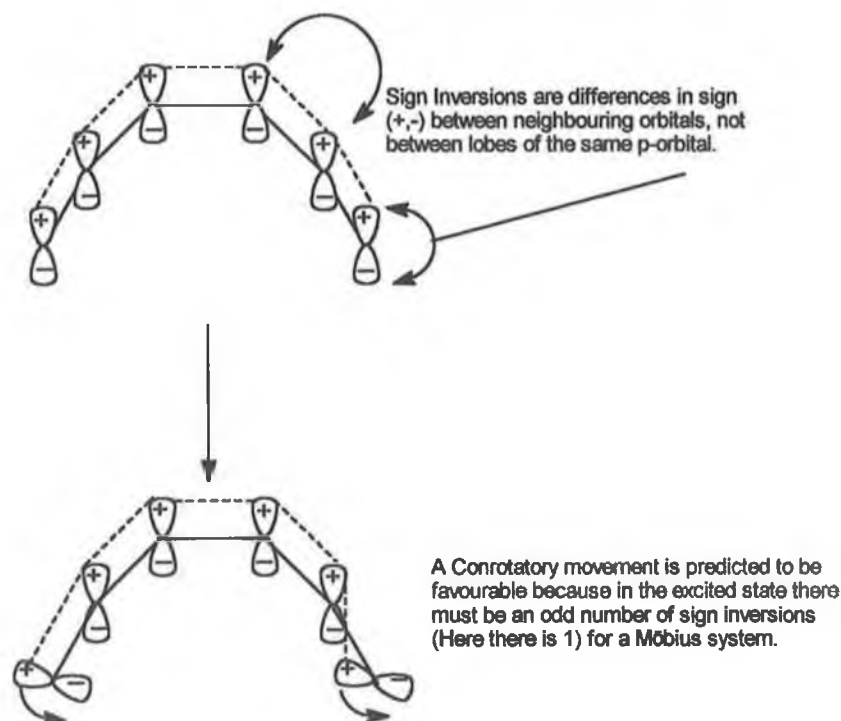


SCHEME 26

However, when in the excited state, an electron is promoted into the lowest unoccupied molecular orbital (*LUMO*), ψ_4 . It can be seen from scheme 26 that in this state, a conrotatory movement is required for overlap of orbital lobes which are in phase. Therefore, it is thought that cyclisation proceeds via a conrotatory movement of the terminal atom orbitals.

An alternative approach to predicting the mode of photochemical electrocyclicalisation is the Möbius-Hückel method.¹⁸⁹ In using this method, we do not examine the molecular orbitals themselves, but rather the *p*-orbitals before they overlap to form the molecular orbitals. Such a set of *p*-orbitals is called a

basis set. The basis set for the molecule discussed in scheme 26 is shown below (scheme 27).

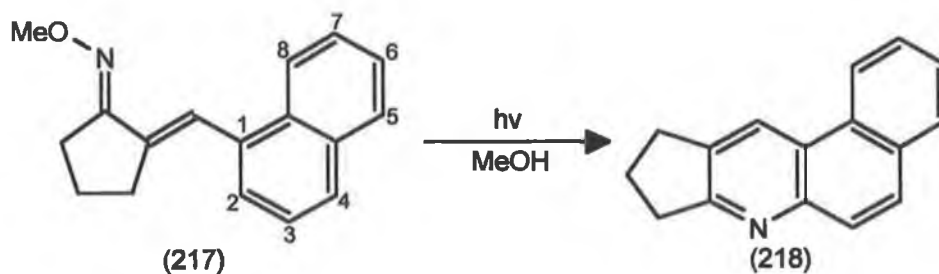


SCHEME 27

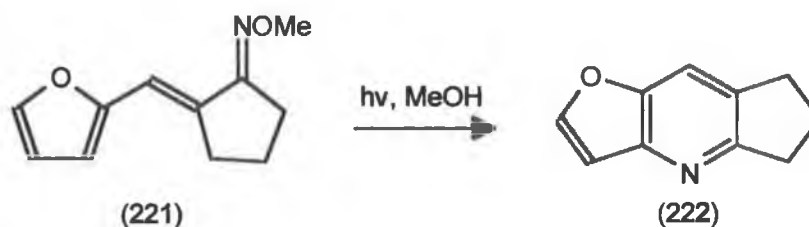
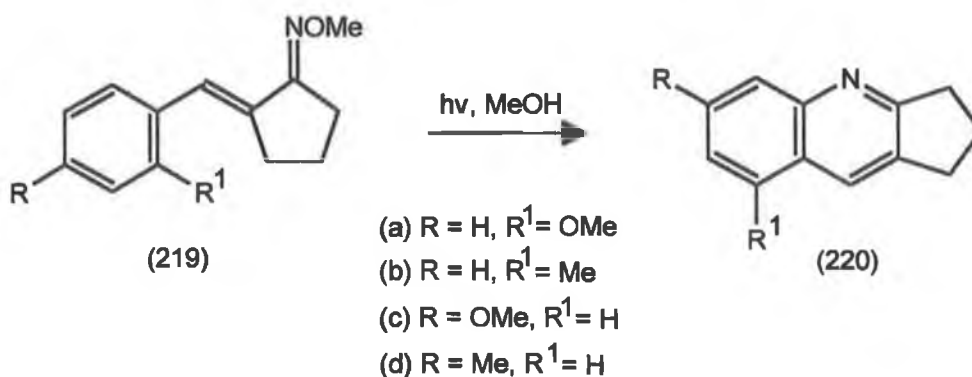
Another name for this method is the aromatic transition state method. The transition state is drawn; one having an even number of sign inversions (such as zero) is called a Hückel system whereas one having an odd number of sign inversions is called a Möbius system. In the ground state for a Hückel system, a thermal pericyclic reaction is allowed only if the total number of participating π -electrons is $4n+2$. A photochemical (excited state) reaction of this type is forbidden for a Hückel system but is allowed for a Möbius system. Therefore for 6π -electron ring closure by the conrotatory mode, the system is of the Möbius type. According to the Möbius-Hückel rule this is predicted to be favourable.

Since the allyl group did not participate in the photocyclisation reaction, a series of oxime O-methyl ethers with different aryl substituents was synthesised by Austin¹⁸¹ and the photochemistry of each investigated. One of the first investigated was 2-(1-naphthylidene)cyclopentanone oxime O-methyl ether

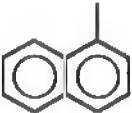
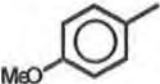


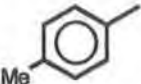
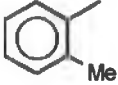
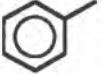
(217). This was irradiated in methanol and the product isolated was quinoline (218) in c.70% yield.



Irradiation of oxime ethers (219a-d) and (221) in methanolic solution also yielded the corresponding cyclised photoproducts (220a-d) and (222) respectively.

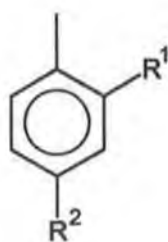


Yields of cyclised product for each of the reactions carried out by Austin are shown in the following table:

Aryl Group	Yield of Cyclised Product
	70%
	53%
	48%
	45%
	37%
	35%
	29%

2.3 Photochemistry of the Arylidencyclopentanone Oxime O-Acetates

It is clear from the above table that the synthetic yield of cyclised photoproduct is dependent on the aryl group present in the molecule. For example, the replacement of a *para* substituted methoxy group by a *para* methyl group causes a decrease in yield of cyclised photoproduct by 16%. A range of other substituents was investigated by Austin, (223-226). The cyclisation process for each of these compounds was ineffective, only complex mixtures being obtained on irradiation. Possible reasons given for this are intersystem crossing or intervention of radical processes.



(223) $R^1=NO_2$, $R^2=H$

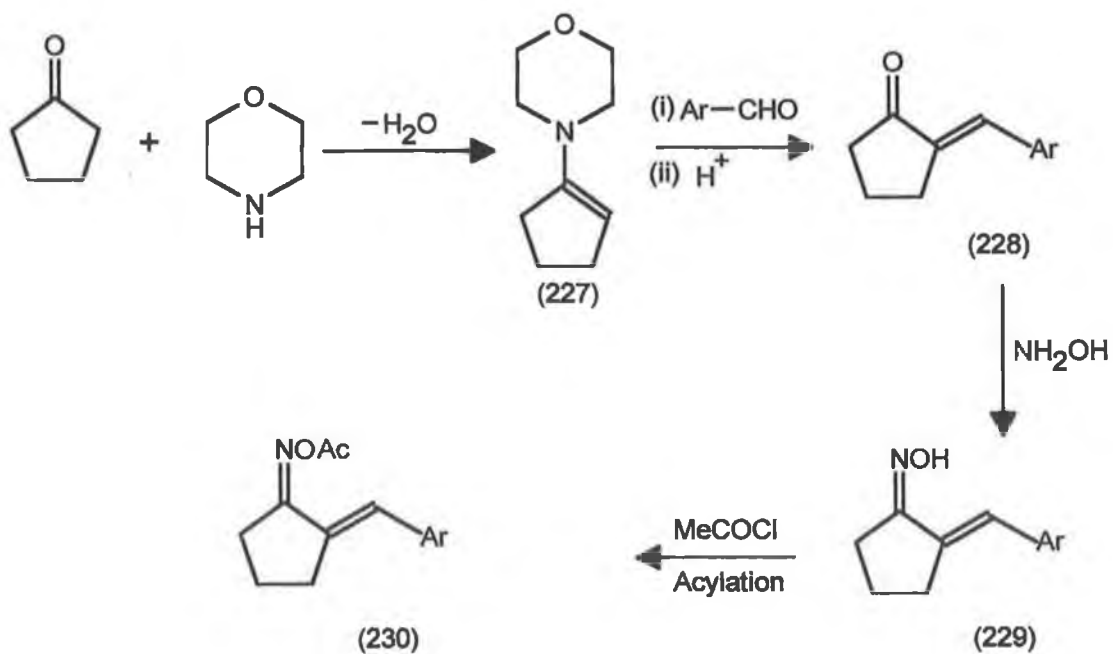
(224) $R^1=H$, $R^2=NO_2$

(225) $R^1=Cl$, $R^2=H$

(226) $R^1=H$, $R^2=Cl$

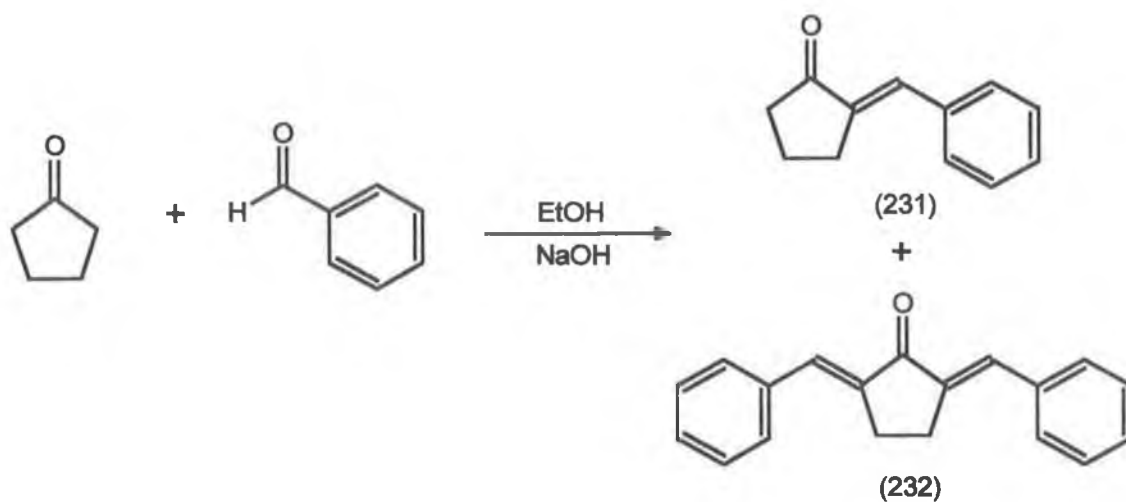
Such complications might not be anticipated for the electron withdrawing cyano group or indeed the fluorine group, which forms very strong bonds with aromatic rings. For this reason it was decided to investigate the photochemistry of some new systems containing cyano and fluorine substituted aryl groups.

The oxime ethers synthesised by Austin were usually initially isolated as liquids and were therefore inconvenient to handle. This, coupled with the fact that dimethyl sulphate, the reagent used for methylation of the oximes, is a hazardous reagent, prompted the synthesis of the corresponding oxime acetates (of general structure 230), compounds which are generally crystalline and relatively easier to synthesise. The acetates were synthesised by a route parallel to that for synthesis of (217), (scheme 28). Reaction of the morpholine enamine (227) of cyclopentanone with the desired aromatic aldehyde followed by acid hydrolysis yielded the arylidenecyclopentanone (228). The synthetic method is essentially the same as that used by Birkofer and co-workers for the synthesis of alkylidene cycloketones,¹⁸² with the exceptions that the enamine was not isolated in this case and toluene was used as solvent instead of benzene. This method is more useful than that reported by House and Wasson¹⁸³ for benzylidenecyclopentanone (231), which simply involved reaction of cyclopentanone with benzaldehyde in an ethanolic solution of sodium hydroxide (scheme 29). However this tends to lead to the accompanying formation of the disubstituted cyclic ketones such as 2,5-dibenzylidenecyclopentanone (232).



SCHEME 28

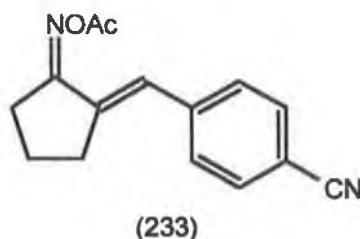
The enamine route does not lead to formation of the dibenzylidene ketones to any significant extent.



SCHEME 29

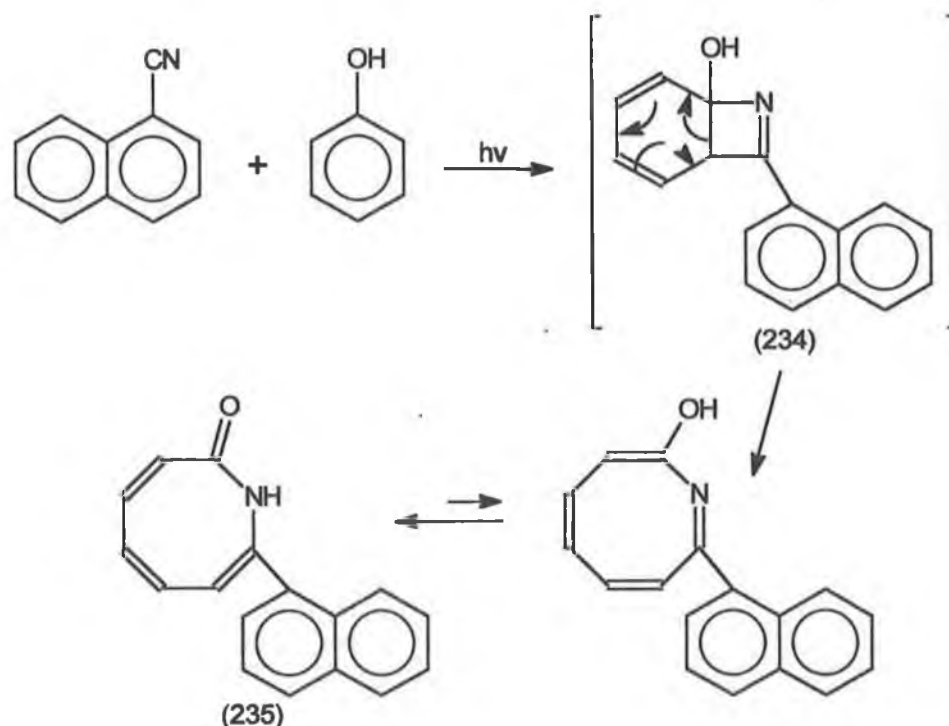
2.3.1 Photochemistry of 2-(4-Cyanobenzylidene)cyclopentanone Oxime O-Acetate (233)

2-(4-Cyanobenzylidene)cyclopentanone oxime O-acetate (233), the first of the oxime O-acetates investigated, was synthesised from *p*-cyanobenzaldehyde using the general method shown in scheme 28.



2-(4-Cyanobenzylidene)cyclopentanone oxime O-acetate (233) was irradiated in methanol, with Pyrex filtered light ($\lambda > 300\text{nm}$). The photochemical reaction was followed by thin layer chromatography (TLC). After ten minutes of irradiation, two additional spots appeared on TLC. On prolonged irradiation the number of spots on TLC increased with no single product being formed in excess. Isolation of the complex mixture was not attempted.

Publications have appeared which show that aryl cyanides¹⁹⁶⁻¹⁹⁹ may undergo photoreaction involving photocycloaddition between the cyano groups and the aromatic ring. For example, the reaction of 2-cyanonaphthalene with phenol is thought to proceed via the mechanism shown in scheme 30 to yield an unstable intermediate (234) which, after ring opening and tautomerisation, yields the azocinone (235). Photocycloaddition of aryl cyanides with aromatic rings may be a more facile reaction than the desired intramolecular cyclisation reaction. A recent publication¹⁹⁸ has shown that this cycloaddition reaction most commonly occurs for *para*-substituted benzonitriles. The complex mixture observed on TLC due to the irradiation of (233) may or may not contain the desired quinoline photoproducts.



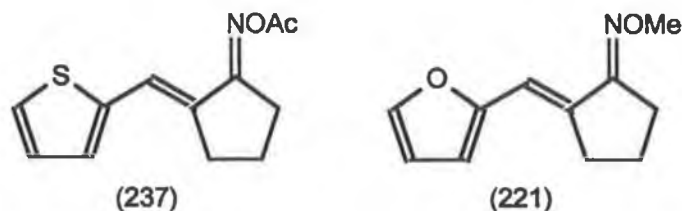
SCHEME 30

2.3.2 Photochemistry of 2-(2,4-Difluorobenzylidene)cyclopentanone Oxime O-Acetate (236)

2-(2,4-Difluorobenzylidene)cyclopentanone oxime O-acetate (236) was prepared from 2,4-difluorobenzaldehyde by the method shown in scheme 28. The irradiation of 2-(2,4-difluorobenzylidene)cyclopentanone oxime O-acetate (236) was followed by TLC. The number of components in the photolysis mixture increased steadily with no single product being formed in excess. After prolonged irradiation the photolysis was halted but, because of the complexity of the photolysis mixture, no attempt was made to isolate the products formed. The formation of cyclised product may have occurred in minor amounts, but was not detected.

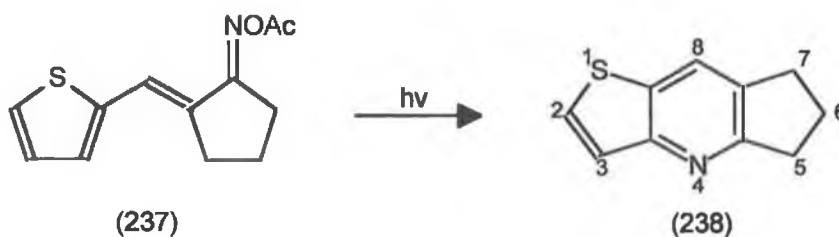
2.3.3 Photochemistry of 2-(2-Thienylidene)cyclopentanone Oxime O-Acetate (237)

The photochemistry of 2-(2-thienylidene)cyclopentanone oxime O-acetate (237), a system analogous to an oxime ether investigated by Austin,¹⁸¹ i.e. 2-(2-furylidene)cyclopentanone oxime O-methyl ether (221), was next explored.



2-(2-Thienylidene)cyclopentanone oxime O-acetate (237) was prepared from thiophene-2-carboxaldehyde by a route analogous to that shown in scheme 28.

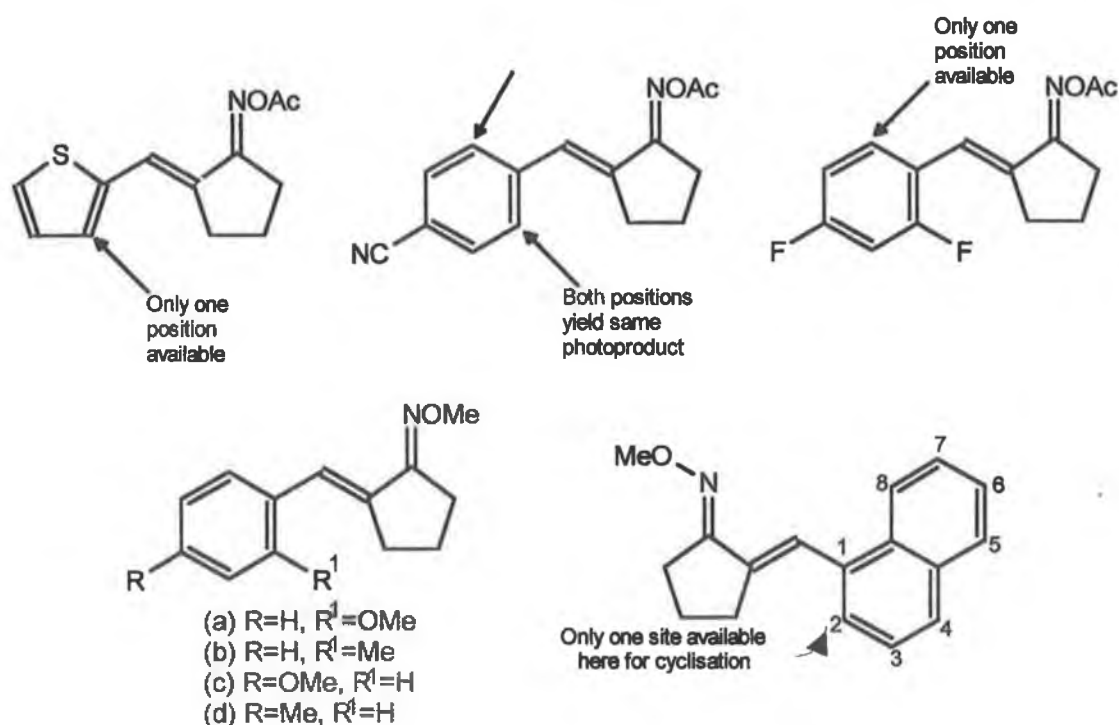
2-(2-Thienylidene)cyclopentanone oxime O-acetate (237) was found to undergo cyclisation to the corresponding quinoline on irradiation. Initially, three new spots appeared on TLC, one of which became the major product on prolonged irradiation. Separation and characterisation of this product showed it to be the previously unreported heterocycle 6,7-dihydro-5*H*-thieno[3,2-*b*]cyclopenta[*e*]pyridine (238).



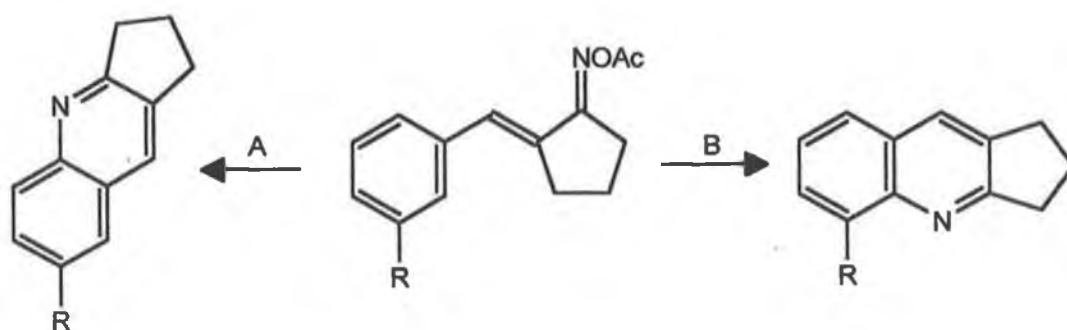
The $^1\text{H-NMR}$ spectrum of (238) was consistent with the proposed structure. A multiplet at δ 2.21ppm corresponds to the methylene group at C-6. Triplets at δ 3.03 and 3.11ppm correspond to the protons on the methylene groups at C-5 and C-6. In the aromatic region three one-proton signals are observed for the protons at C-2, C-3 and C-8, doublets (J 5.9Hz) at δ 7.47 and 7.52ppm for the thienyl protons at C-2 and C-3 and a singlet at δ 7.95ppm for the pyridyl proton at C-8.

The $^{13}\text{C-NMR}$ spectrum was also consistent with the proposed structure, with three signals in the range δ 23-34ppm corresponding to the three methylene carbons at C-5, C-6 and C-7. A further seven signals are observed in the range δ 124-165ppm corresponding to the seven aromatic carbons present in (246).

Combining the above results and those obtained by Austin,¹⁸¹ it is clear that, since the oxime substituent plays no part in the cyclisation reaction, the best yields of cyclised product are obtained when the aryl group has substituents which are electron donating or when there is no aryl substituent. When the aryl substituent is electron withdrawing, such as for the difluoro phenyl substituted acetate, the cyano phenyl substituted acetate and the chloro phenyl substituted methyl ethers investigated by Austin, cyclisation is not competitive. Although it may have occurred to some minor extent, other processes competed to produce complex reaction mixtures in all cases. For the compounds studied thus far only one possible cyclised product could have resulted in each case:



For this reason it was decided to investigate the regioselectivity of this cyclisation. As shown in scheme 31, irradiation of a meta substituted oxime acetate derivative can result in either of two possible heterocycles via path A or B. This prompted the study of a number of these analogues.

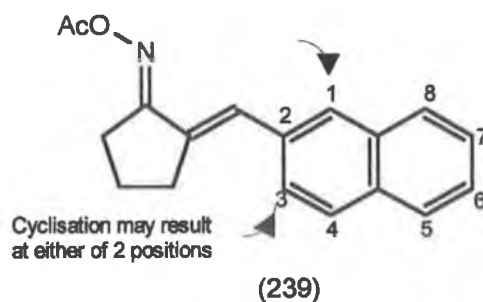


SCHEME 31

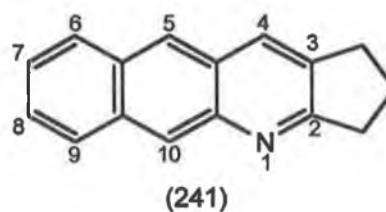
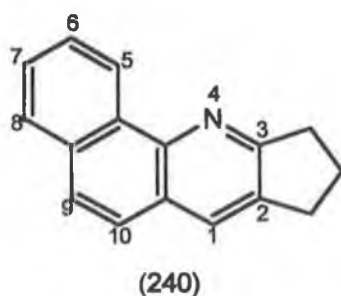
The oxime acetates were prepared using the standard method described in scheme 28.

2.3.4 Photochemistry of 2-(2-Naphthylidene)cyclopentanone Oxime O-Acetate (239)

2-(2-Naphthylidene)cyclopentanone oxime O-acetate (239) has two different sites available for cyclisation and it was irradiated in methanol with Pyrex filtered light ($\lambda > 300\text{nm}$).



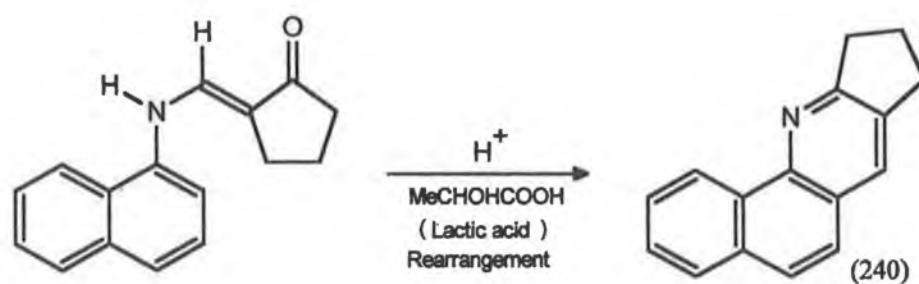
The reaction was followed by thin layer chromatography (TLC) and, after ten minutes, three new spots had appeared. On further irradiation one of these compounds became the major component of the photolysis mixture, while the concentration of the other spots diminished. When the reaction was halted, isolation of the major photoproduct afforded the quinoline 4-azacyclopenteno[b]phenanthrene (240).¹⁸⁶ The isomeric azaphenanthrene (241) is the other possible photoproduct from this cyclisation reaction.



The carbon-NMR spectrum is consistent with the proposed structure. Three signals between δ 23.6 and δ 34.7ppm correspond to the cyclopentane ring carbons and there are thirteen aromatic carbon signals in the range δ 124.1-166.1ppm.

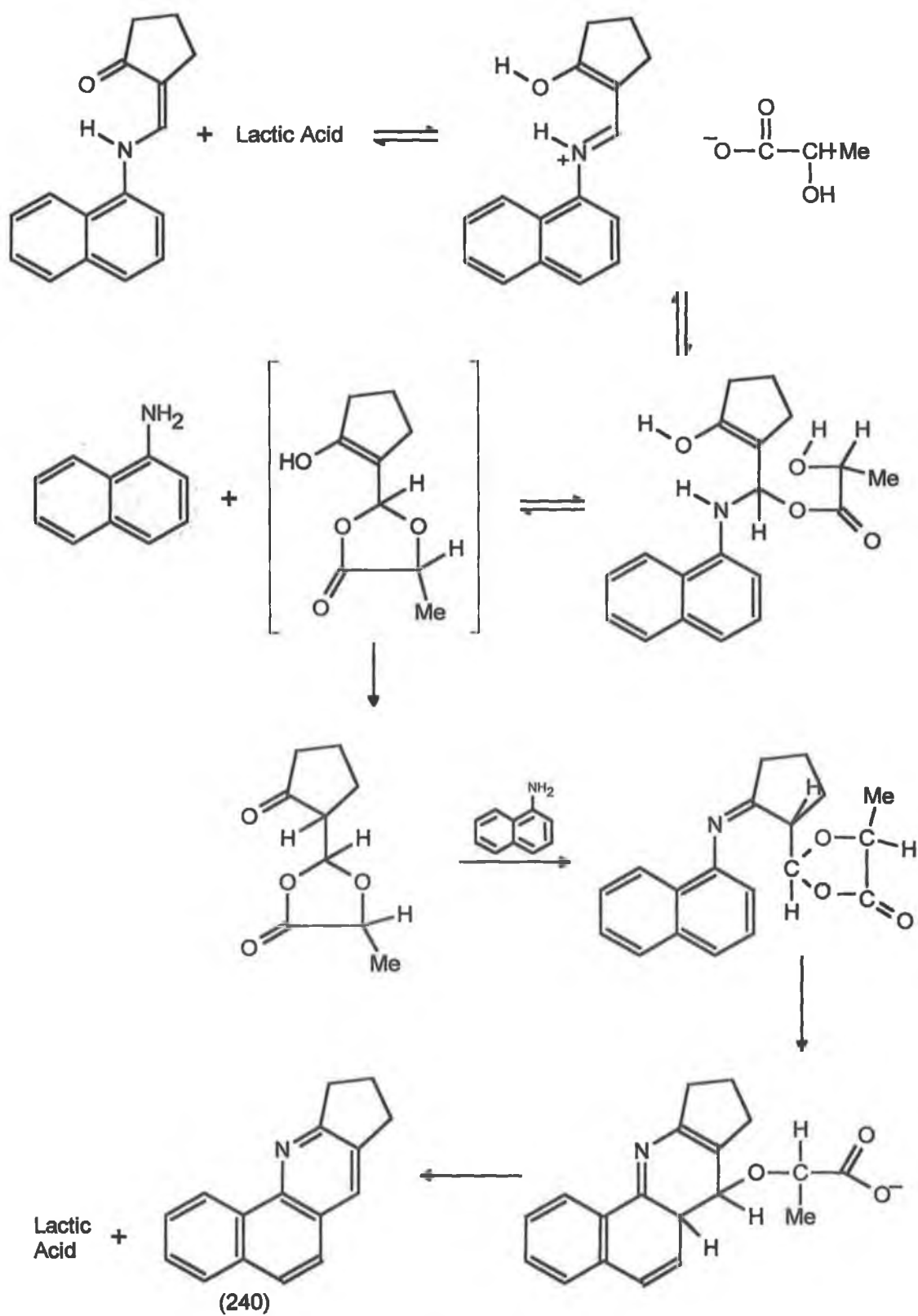
The ^1H -NMR spectrum of the isolated photoproduct shows a two-hydrogen multiplet and two two-hydrogen triplets corresponding to the three cyclopentane ring methylene groups. The aromatic region of the spectrum shows signals as follows: a one-hydrogen doublet at δ 7.59 (J 8.9Hz), a three hydrogen multiplet at δ 7.70, a one-hydrogen singlet at δ 7.84, a one-hydrogen doublet of doublets at δ 7.89 (J_1 7.9Hz, J_2 0.9Hz) and a one-hydrogen doublet at δ 9.35ppm (J 8.4Hz). That the structure of the photoproduct is (240) and not (241) is clear from the spectrum. For photoproduct (241) there should be three aromatic one-hydrogen singlets visible for the hydrogens attached to carbons 4, 5 and 10. The spectrum shows only one, as expected for H-1 of (240). Also highly diagnostic is the one-hydrogen doublet obtained at δ 9.35ppm. This signal could only be seen for structure (240) and not (241), because this requires a hydrogen being present with only one ortho neighbour such as H-9 and H-10 in (240), none of which are present in structure (241).

The quinoline (240) has been reported previously,^{186a} produced by the cyclodehydration reaction shown in scheme 32. The melting point of the photoproduct was identical to the literature value reported for (240). Heterocycle (241) has also been prepared more recently¹⁸⁷ and has a melting point $\sim 70^\circ\text{C}$ higher than that of (240).



SCHEME 32

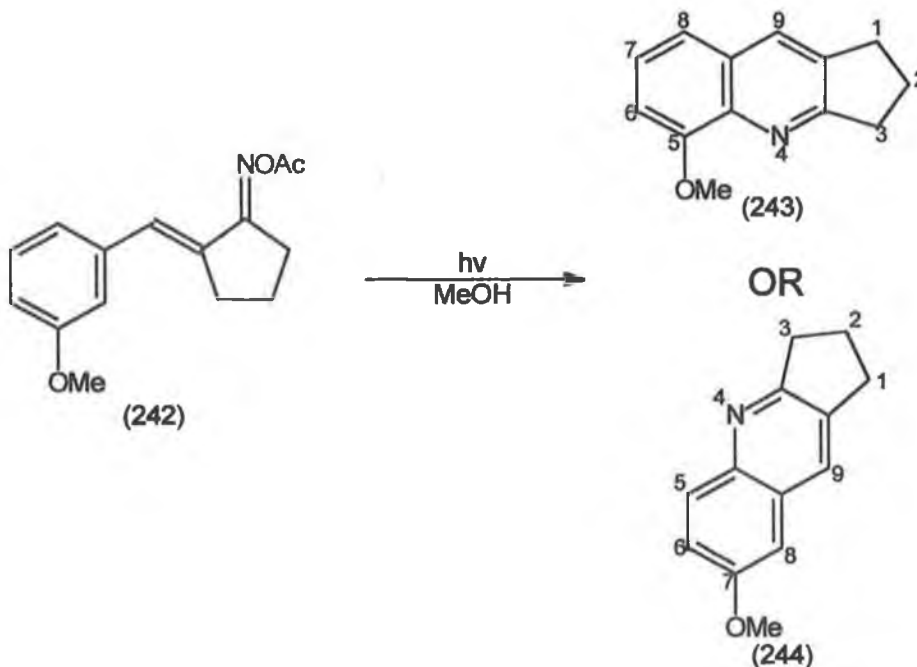
The reaction used to prepare (240) is an unusual rearrangement reaction. The mechanism proposed is shown in scheme 33.^{186b} The yields reported^{186a} for (240) are poor (30%), and compare unfavourably to the 70% obtained by the photochemical cyclisation method, suggesting that the latter may be a useful method of synthesising such compounds.



SCHEME 33

2.3.5 Photochemistry of 2-(3-Methoxybenzylidene)cyclopentanone Oxime O-Acetate (242)

To further investigate the regioselectivity of the photocyclisation reaction, another compound, oxime acetate (242) was chosen which on irradiation could possibly give two products.



On photolysis of (242) in methanol for a short period, three new spots appeared on TLC. On further irradiation, one of these became the major component of the mixture at the expense of the starting material and the other products formed. When TLC showed no further change the reaction was halted. Isolation and characterisation of the major photoproduct showed it to be the previously unreported heterocycle, 7-methoxy-2,3-dihydro-1H-cyclopenta[b]quinoline (244). Once again a single quinoline resulted, the cyclisation occurring regiospecifically *para* to the methoxy group. The regiospecificity will be discussed later.

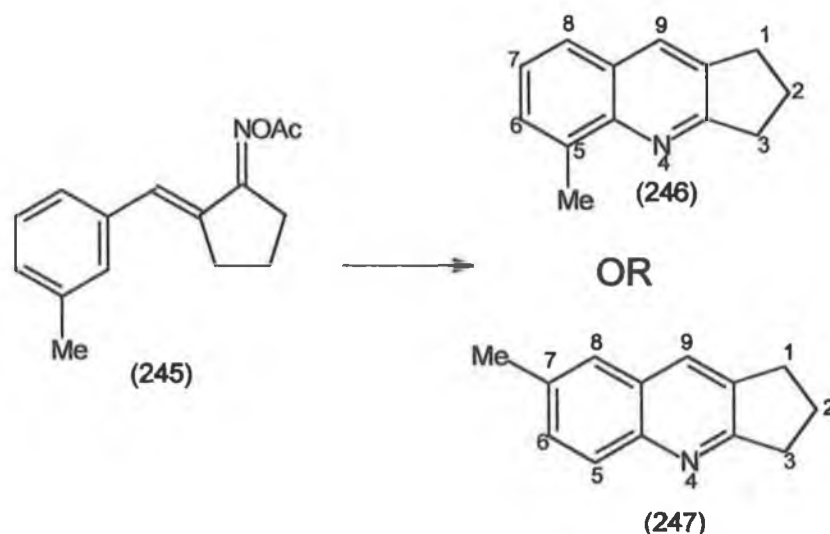
The ^{13}C -NMR spectrum of (244) is consistent with the proposed structure, with three signals in the range δ 23-34ppm corresponding to the three methylene carbons C-1, C-2 and C-3. A signal at δ 55.06ppm corresponds to the carbon of the methoxy group, and nine signals appear in the range δ 105-165ppm corresponding to the nine aromatic carbons present.

As required for (244) the ^1H -NMR spectrum showed four signals in the range δ 2.72-4.42ppm. A two-hydrogen multiplet at δ 2.72ppm corresponds to the central methylene group at C-2. Two two-hydrogen triplets at δ 3.58 and 3.65ppm correspond to the methylene groups at C-1 and C-3, and a three-hydrogen singlet at δ 4.42ppm corresponds to the methoxy group. Four well resolved signals appeared in the aromatic region of the spectrum, each of which integrated for one proton. A doublet at δ 7.53ppm (J , 2.0Hz; meta coupled) may be assigned to the proton at C-8. A doublet of doublets at δ 7.81 (J_1 , 8.9Hz; ortho coupled, J_2 , 2.9Hz; meta coupled) may be assigned to the proton at C-6. A doublet at δ 8.45ppm (J , 8.9Hz; ortho coupled) corresponds to the proton at C-5 and a singlet at δ 8.32ppm corresponds to the proton at C-9.

That the structure of the isolated quinoline is not (243) is evident from this information. Compound (243) would be expected to display a different pattern in the aromatic region, specifically two hydrogens, each showing both ortho and meta coupling and one hydrogen showing coupling to two ortho hydrogens. The aromatic signals for the photoproduct are well resolved and it is clearly visible that such a pattern is not present.

2.3.6 Photochemistry of 2-(3-Methylbenzylidene)cyclopentanone Oxime O-Acetate (245)

On irradiation of 2-(3-methylbenzylidene)cyclopentanone oxime O-acetate (245), two regioisomeric products (scheme 34) were possible. Initially, formation of three new spots was observed on TLC, one of which became the major component on prolonged irradiation. Isolation by column chromatography and characterisation showed it to be the previously unreported heterocycle 5-methyl-2,3-dihydro-1H-cyclopenta[b]quinoline (246).



SCHEME 34

The ^{13}C -NMR spectrum is consistent with the proposed structure. Four signals appear in the range δ 18-35ppm arising from the methylene carbons at C-1, C-2 and C-3 and from the methyl group carbon. Between δ 125 and 167ppm there are nine aromatic carbon signals visible due to the nine aromatic carbons present in (246).

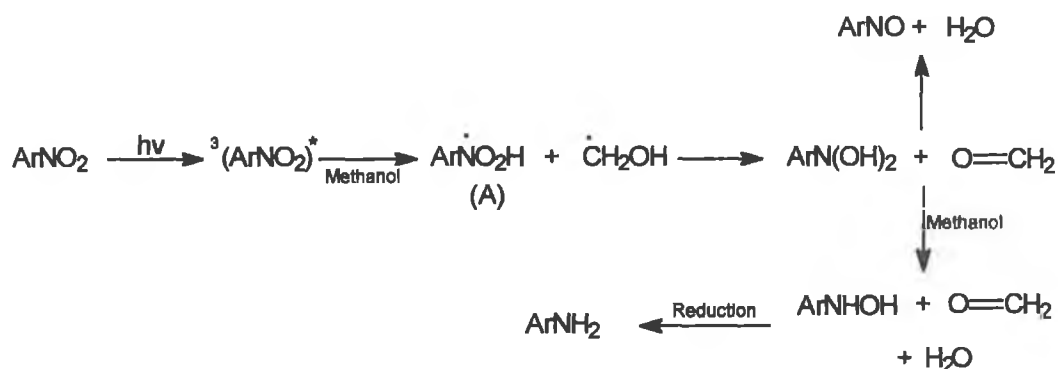
The ^1H -NMR spectrum of this product is consistent with the structure (246) proposed. Four signals appear in the range δ 2.19-3.16ppm. A two-hydrogen multiplet at δ 2.19ppm corresponds to the methylene protons at C-2, a three-hydrogen singlet at δ 2.80ppm corresponds to the methyl protons and two two-hydrogen triplets at δ 3.05 and 3.16ppm to the two methylene groups at C-1 and C-3. Four well resolved aromatic signals are visible. A one-hydrogen triplet at δ 7.32ppm (J , 8.3Hz) corresponds to the proton at C-7; two one-hydrogen doublets at δ 7.44 and 7.55ppm (J , 8.3Hz each) correspond to the two protons at C-6 and C-8 and a one-hydrogen singlet at δ 7.8ppm corresponds to the proton at C-9. A regular well resolved "triplet" at δ 7.32ppm corresponding to the hydrogen at C-7, provides evidence that the structure of the photoproduct is not that of the isomeric (247), the spectrum of which would not be expected to contain a "triplet". The presence of a well resolved singlet (at δ 7.8ppm) indicating the presence of a single aromatic proton which is not coupled to any neighbouring protons also

rules out the cyclised product having structure (247) which would have one one-hydrogen singlet in its spectrum due to the hydrogen at C-9 and a meta coupled one-hydrogen doublet corresponding to the hydrogen at C-8 similar to that observed for the hydrogen at position C-8 in (244).

2.3.7 Photochemistry of 2-(3-Nitrobenzylidene)cyclopentanone Oxime O-Acetate (248)

Irradiation for a short period of 2-(3-nitrobenzylidene)cyclopentanone oxime O-acetate (248) gave rise to a number of spots on TLC. On prolonged irradiation the number of spots increased with no single product being formed in excess. After three hours, irradiation was halted. Due to the complexity of the photolysis mixture, no attempt was made to separate its components.

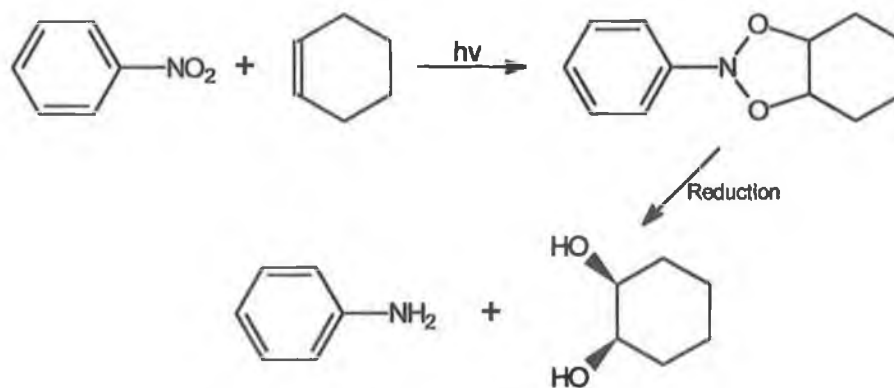
A possible explanation for the complexity of the photoreaction in this case can be attributed to alternative paths available to aromatic nitro compounds. For example nitrobenzene has a triplet n,π^* lowest excited state and on irradiation in propan-2-ol readily abstracts hydrogen.¹⁹⁰ This hydrogen abstracting ability of excited state nitro-compounds has been demonstrated in many publications,¹⁹¹⁻¹⁹³ with the products of photoreduction generally being hydroxylamines. However depending on the structure of the compound, the reaction conditions and the hydrogen-donating ability of the solvent, anilines, nitrosoarenes and minor amounts of azo and azoxybenzenes can also be formed.^{194,195}



SCHEME 35

A possible mechanistic pathway for what happens on irradiation in methanol is shown in scheme 35.⁸² The key step in the reaction is believed to be the formation of the radical (A).

Photoaddition processes have also been observed among the many photoreactions of nitro compounds. Attack of triplet excited n,π^* nitroarenes on alkenes and methoxyarenes have been observed to yield dioxazolidines.¹⁹⁰ These oxazolidines are thermally labile, but those resulting from alkenes can be isolated at low temperatures or reduced to aniline and 1,2-dihydroxyalkanes, as shown in scheme 36. This fact, coupled with the above reactions in scheme 35 indicate that there are a number of different pathways open to the nitro substituted benzylidene compound (248). It has been shown above that the lowest excited state in nitrobenzene and other nitro compounds is the n,π^* triplet state. A π,π^* singlet excited state is required for concerted electrocycisation, and this may not be possible for the nitrobenzylidene compound if its lowest excited state is a triplet excited n,π^* state.



SCHEME 36

2.3.8 Photochemistry of 2-(3-Cyanobenzylidene)cyclopentanone Oxime O-Acetate (249)

2-(3-Cyanobenzylidene)cyclopentanone oxime O-acetate was irradiated in methanol under standard conditions and the reaction monitored by TLC. After ten minutes, two new spots appeared on TLC. As was seen with the *para* substituted

cyano compound (233), on more prolonged irradiation the number of spots increased with no single product being formed in excess. The reaction was stopped and no attempt was made to separate the complex product-mixture formed.

2.3.9 Photochemistry of 2-(3-Fluorobenzylidene)cyclopentanone Oxime O-Acetate (250)

As on irradiation of the *para*- and *meta*- cyano substituted derivatives of 2-benzylidenecyclopentanone oxime O-acetate (233) and (249), none of the expected quinoline derivative was isolated on irradiation of 2-(3-fluorobenzylidene)cyclopentanone oxime O-acetate. The reaction was followed by TLC and the number of components in the photolysis mixture increased steadily with no single product being formed in excess. After prolonged irradiation the mixture was very complex and no attempt was made to separate and isolate the products formed.

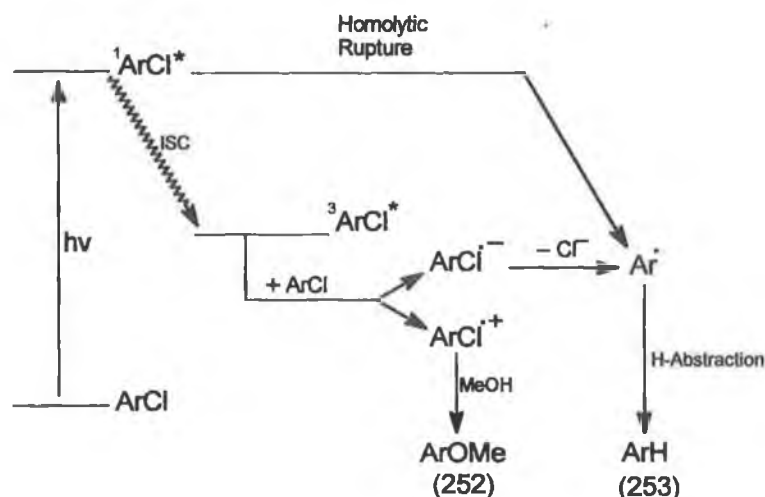
2.3.10 Photochemistry of 2-(3-Chlorobenzylidene)cyclopentanone Oxime O-Acetate (251)

The irradiation of 2-(3-chlorobenzylidene)cyclopentanone oxime O-acetate (243) proceeded in a similar fashion to that of 2-(3-fluorobenzylidene)cyclopentanone oxime O-acetate (250) and 2-(2,4-difluorobenzylidene)cyclopentanone oxime O-acetate (236). The reaction was closely monitored over its course by TLC, and a steadily increasing number of spots was observed. The product mixture was so complex that no attempt was made to separate the components.

The irradiation of halogenated aromatic compounds has been discussed in several publications.²⁰¹⁻²⁰⁷ Soumillion and De Wolf specifically investigated the photochemistry of chloroaromatic compounds in methanol.²⁰⁶ They found that both photoreduction and photosubstitution occur simultaneously with methanol acting both as a hydrogen donor and a nucleophile. Photoreduction is the main process in the majority of cases. From triplet sensitisation and quenching

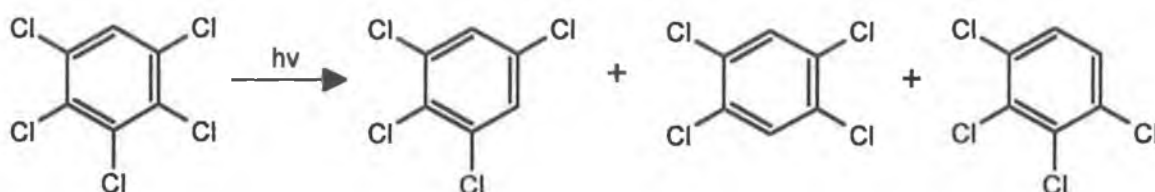
experiments, it was concluded that the excited state species involved is the triplet and the mechanism shown in scheme 37 has been proposed. The key step is formation of a pair of radical ions via a triplet excimer. Formation of the substituted product (252) is rationalised in terms of addition of a methanol molecule to the radical cation, whereas formation of the reduction product (253) is rationalised via loss of chlorine from the radical anion and hydrogen abstraction.

The presence of alkenes increases the tendency of aromatic halides such as chloronaphthalene to undergo photoreductive reactions.²⁰² The formation of an excimer has also been proposed here as the mode of reaction. Smothers and co-workers have shown the involvement of an excimer in the photochemical dechlorination of 9,10-dichloroanthracene.²⁰⁴



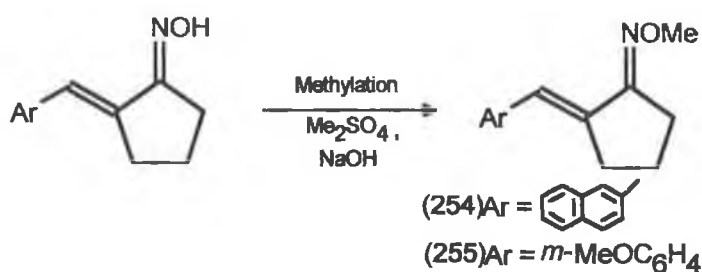
SCHEME 37

The photodechlorination of pentachlorobenzene (scheme 38) has also been investigated, the authors concluding that the mode of dechlorination proceeds via fragmentation of a triplet excimer.^{208,209}



SCHEME 38

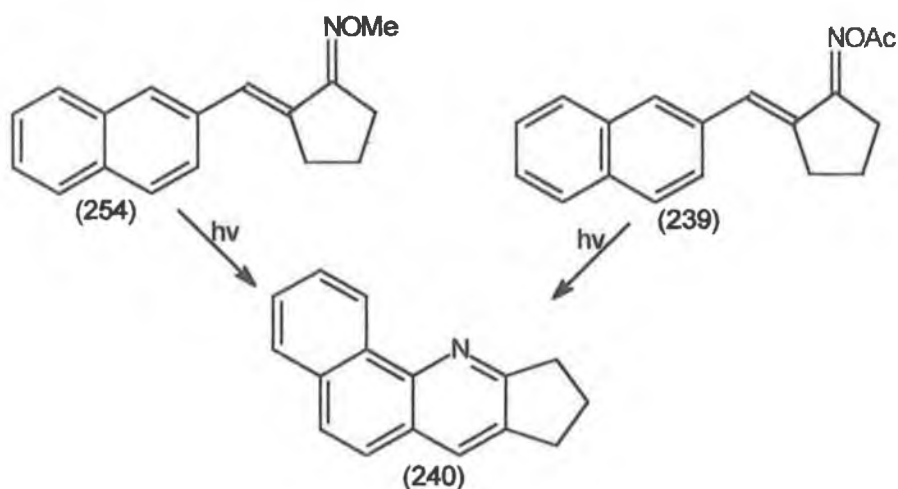
To further investigate the regioselectivity in terms of yield and involvement of the oxime substituent, two oxime methyl ethers were synthesised analogous to the two oxime acetates which cyclised most successfully; namely the 2-naphthylidene and 3-methoxy derivatives. The oxime O-methyl ethers were prepared by the standard method from the corresponding oximes using dimethyl sulphate and sodium hydroxide as base (scheme39).¹⁸⁵



SCHEME 39

2.3.11 Photochemistry of 2-(2-Naphthylidene)cyclopentanone Oxime O-Methyl Ether (254)

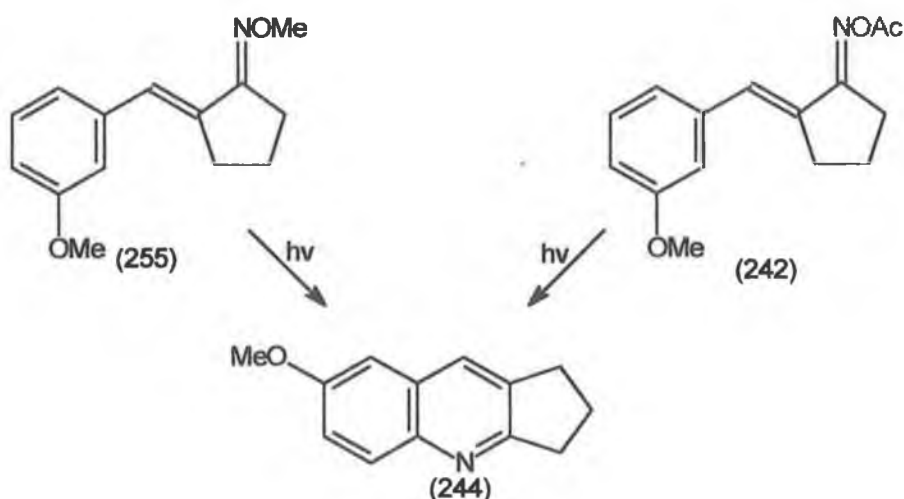
Irradiation of 2-(2-naphthylidene)cyclopentanone oxime O-methyl ether proceeded in the same way as that of the corresponding oxime acetate. Initially three new spots were visible on TLC, one of which ultimately became the sole photoproduct. When isolated it proved to be 4-aza-cyclopenta[*b*]phenanthrene (240), identical to that which resulted from irradiation of oxime acetate (239).



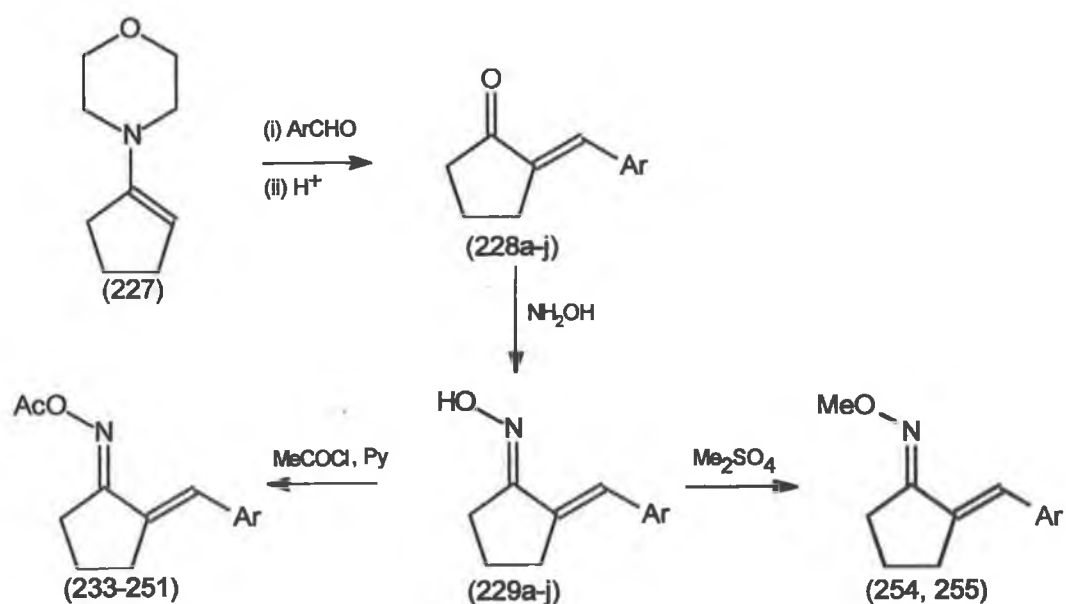
The yield of photoproduct was also the same as that obtained on irradiation of the oxime acetate.

2.3.12 Photochemistry of 2-(3-Methoxybenzylidene)cyclopentanone Oxime O-Methyl Ether (255)

Irradiation of 2-(3-methoxybenzylidene)cyclopentanone oxime O-methyl ether was carried out in methanol under the standard conditions and the reaction proceeded in the same way as that of the corresponding oxime acetate. After a short while three new spots were visible on TLC, one of which became the major photoproduct. Isolation and characterisation of the major photoproduct showed it to be 7-methoxy-2,3-dihydro-1H-cyclopenta[b]quinoline (244), previously isolated from photolysis of the corresponding oxime acetate (242). The yield of cyclised photoproduct was the same as that obtained from cyclisation of the corresponding oxime acetate.



A summary of all compounds synthesised and photolysed is shown below (scheme 40).



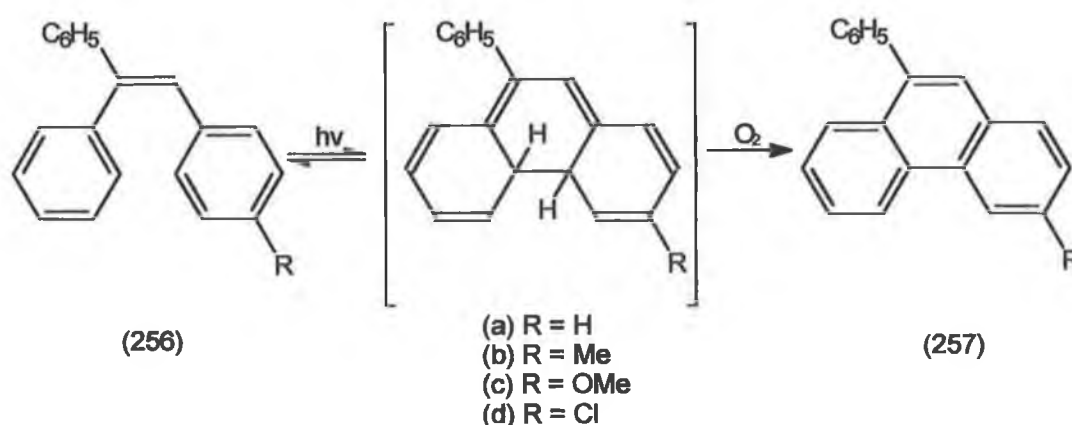
SCHEME 40

(228a), (229a), (233)	Ar = 3-CNC ₆ H ₄
(228b), (229b), (236)	Ar = 2,4-F ₂ C ₆ H ₃
(228c), (229c), (237)	Ar =
(228d), (229d), (239), (254)	Ar =
(228e), (229e), (242), (255)	Ar = 3-MeOC ₆ H ₄
(232f), (229f), (245)	Ar = 3-MeC ₆ H ₄
(228g), (229g), (248)	Ar = 3-NO ₂ C ₆ H ₄
(228h), (229h), (249)	Ar = 3-CNC ₆ H ₄
(228i), (229i), (250)	Ar = 3-FC ₆ H ₄
(228j), (229j), (251)	Ar = 3-ClC ₆ H ₄

2.4 The Efficiency and Regiospecificity of the Photocyclisation Reaction

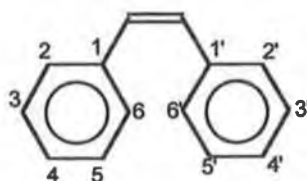
On irradiation of different substituted stilbenes (256 a-d), Mallory and co-workers found that the quantum efficiency of cyclisation to the corresponding

phenanthrenes (257a-d) was dependent on the substituent present.^{210, 211} The formation of the chloro-substituted phenanthrene was the most inefficient reaction observed. Because of the similarity in reactivity between the halogens, it is expected that fluorine-substituted compounds would act similarly to their chlorine substituted analogues.



The presence of a methyl group on the stilbene (256b) enhanced reactivity (compared to the unsubstituted 256a) whereas substitution by a methoxy group (256c) stimulated the cyclisation reaction the most. These results are consistent with the chemical yields observed for cyclisation of the arylidene cyclopentanone oxime acetates and methyl ethers. The substituents which enhance photocyclisation are electron donating such as methyl and methoxy groups whereas electron withdrawing groups such as chlorine inhibit the reaction.

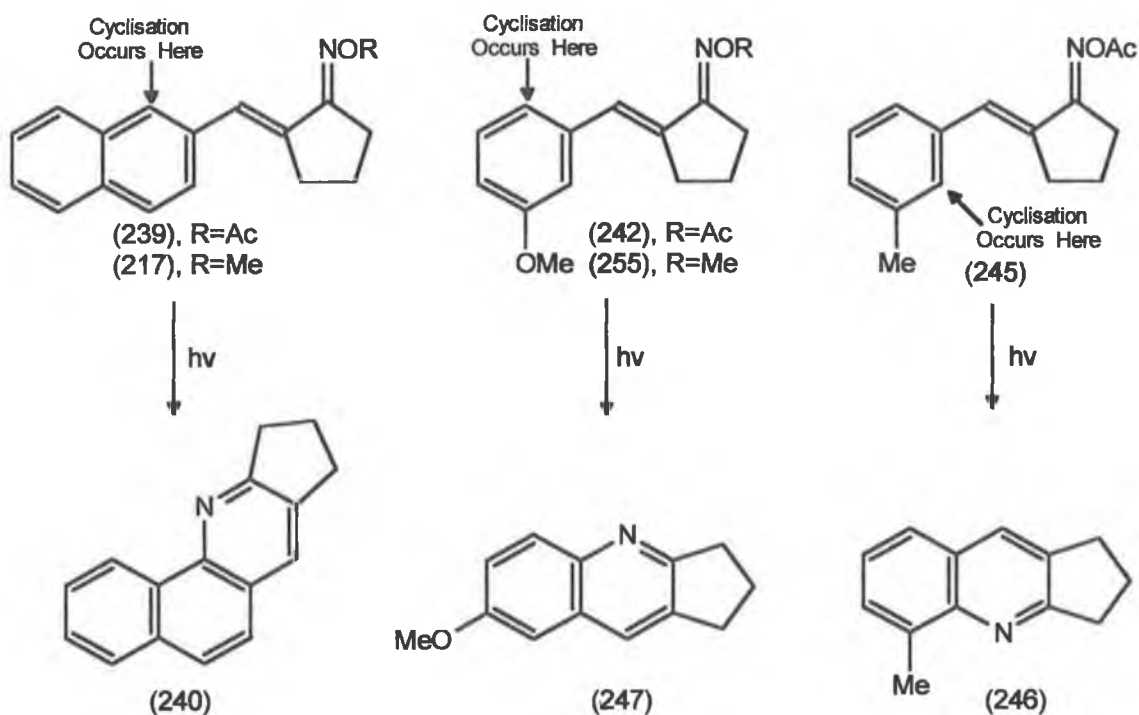
In a publication by Muszkat and co-workers, electronic population analysis was applied to the photocyclisation reactions of substituted stilbenes.²¹² A series of stilbenes having different substituents was synthesised and irradiated in an attempt to correlate the experimental photocyclisation quantum yield with the theoretical excited state electronic overlap population for the atom pair forming the new bond, $n^*_{6,6'}$, in (258). The molecular geometries were theoretically derived using an energy minimisation computer program (CONFI). The new bond forms between C centers 6 and 6'. The first excited state total electronic overlap population is denoted as $n^*_{6,6'}$ and $\Delta n_{6,6'}$ is the difference in $n_{6,6'}$ (the ground state electronic overlap population) due to one electron excitation.



(258)

The following conclusions were reached. Both strong electron donating and electron attracting groups attached to the 4 (*para*) position in (258) lower strongly the cyclisation quantum yield. Strong electron attracting substituents such as nitro groups in this position show the most prominent effects. Substituents attached to the 3 and 5 (*meta*) positions produce twofold effects. A strongly attracting nitro group stops the cyclisation altogether and a cyano group lowers the cyclisation yield, while a methoxy group in the 3 or 5 positions enhances the overall cyclisation yield by a factor of ~4. The experimental results obtained correlated strongly with the theoretical results.

On examination of the photoproducts formed from irradiation of the oxime

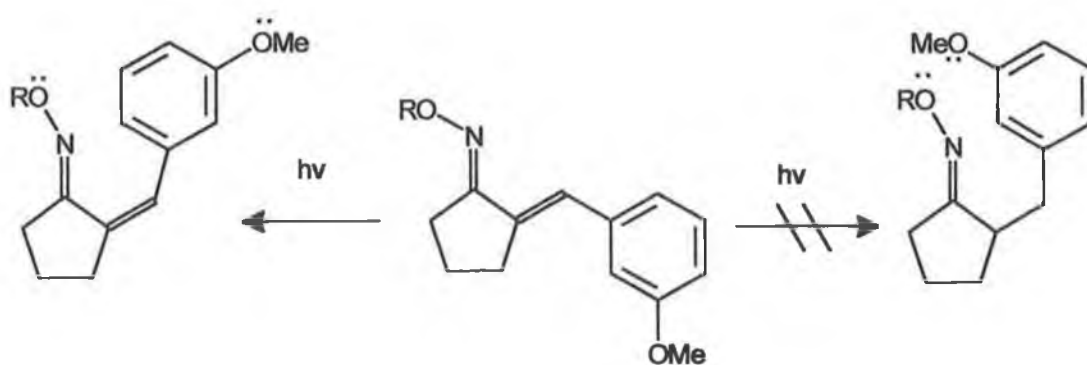


acetates, it is observed that the cyclisations are regiospecific. The reactions are summarised below. The cyclisation of the naphthylidene oxime acetate (239) in

such high yield can be explained in terms of aromaticity of the naphthyl system and stability of the intermediate. Because the naphthalene system is less aromatic than benzene, there is a smaller loss in aromatic character and therefore less energy expended in the cyclisation step than in the analogous benzylidene system (the oxime O-methyl ether system of which was irradiated by Austin¹⁸¹). Similar behaviour was observed in the photolysis of the 1-naphthylidene oxime ether (217) irradiated by the same author. Therefore this may go to some length in explaining the high yield obtained in this particular cyclisation reaction. The regiospecificity of this cyclisation at the 1 position is expected. For example, photocycloaddition of ethenes to the 1,2-positions of naphthalenes, rather than the 2,3-positions is a general reaction.^{211a} Also ground state electrophilic substitutions to naphthalene occur preferentially to the 1 position,^{211b} due to the stability of the intermediate carbocation. In the excited state, cyclisation at this position may be due to the stability of the cyclised intermediate.

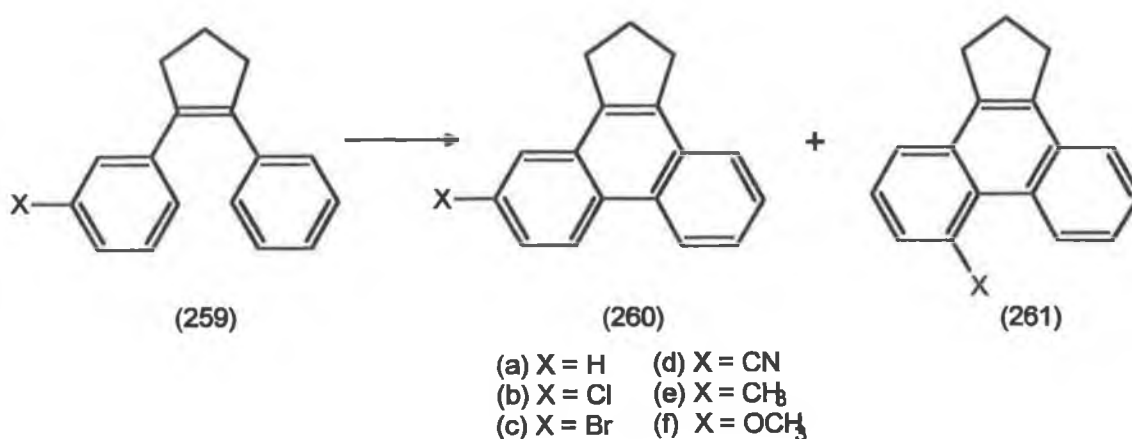
The chemical efficiency in cyclisation of the methoxy substituted oxime acetate correlates with the results obtained by previous authors, as discussed above. That the molecule cyclises at this position is also analogous to the behaviour of the *meta*-substituted stilbenes investigated by Muszkat and co-workers.²¹² They report that cyclisation in *meta*-substituted methoxy stilbenes occurs predominantly at a position on the aromatic ring *para*- to the position of the methoxy group. They also report that in nitro and cyano substituted stilbenes, photocyclisation fails to occur or occurs very slowly. This is also consistent with the observations of the nitro and cyano substituted oxime acetates. Methyl substituents were not investigated.

Somers and Laarhoven^{213, 214} report that in principle, a *meta* substituent may exert its electronic property more directly in the ring closure reaction, because the substituent is in a conjugated *para* or *ortho* position with respect to the carbon atom involved in the cyclisation. Another possible reason for the cyclisation of the *meta*-methoxy substituted compounds at this ring position may be due to the stability of the initial geometrical isomers formed on irradiation.



Repulsion between the methoxy oxygen lone pair and the oxime derivative lone pair may prevent the molecule from maintaining this configuration long enough, if at all for cyclisation to occur *ortho* to the methoxy group.

The influence of both *meta* and *para* substituents on the photocyclisation of 1,2-diphenylcyclopentenes (259a-f) in methanol has also been investigated extensively in these publications.^{213,214} In almost all cyclisation reactions



the yield of (260) exceeded the yield of (261). This correlates with results discussed by previous authors. It does not, however, explain the regioselectivity of the *meta* substituted methyl oxime acetate. Because compounds (259a-f) have no substituents which may interact spatially with substituent 'X', this may be further evidence that the cyclisation of the 3-methyl oxime acetate cyclises via the most stable spatial arrangement of its isomers. That steric effects may come into play in the photocyclisations of stilbenes has been demonstrated by

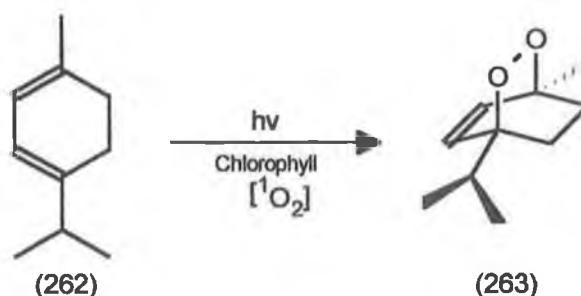
Dickerman and Zimmerman.²¹⁵ Irradiation of (259) where X is a phenyl group, yields (260) in a large excess over (261).

3. The Photochemistry of
2-Arylidene-cyclopentanone Oxime O-Acetates
in Natural Sunlight

3.1 Introduction

Since the dawn of time, nature has used natural sunlight as a reagent in the conversion of starting materials to products. The utilisation of this natural source of energy had not, however, been explored up until the beginning of this century when Ciamician began to investigate the photochemistry of several compounds which he irradiated on the roof of his chemical research laboratory in Bologna.²¹⁶

One of the first milestones in solar photochemistry was the synthesis of the drug ascaridol (263) by Schenck and co-workers in 1943.²¹⁷ After world war II a large pilot plant was built to synthesise the compound. This was the first solar chemical plant ever built. Terpinene (262) was irradiated in the presence of oxygen and chlorophyll yielding product.

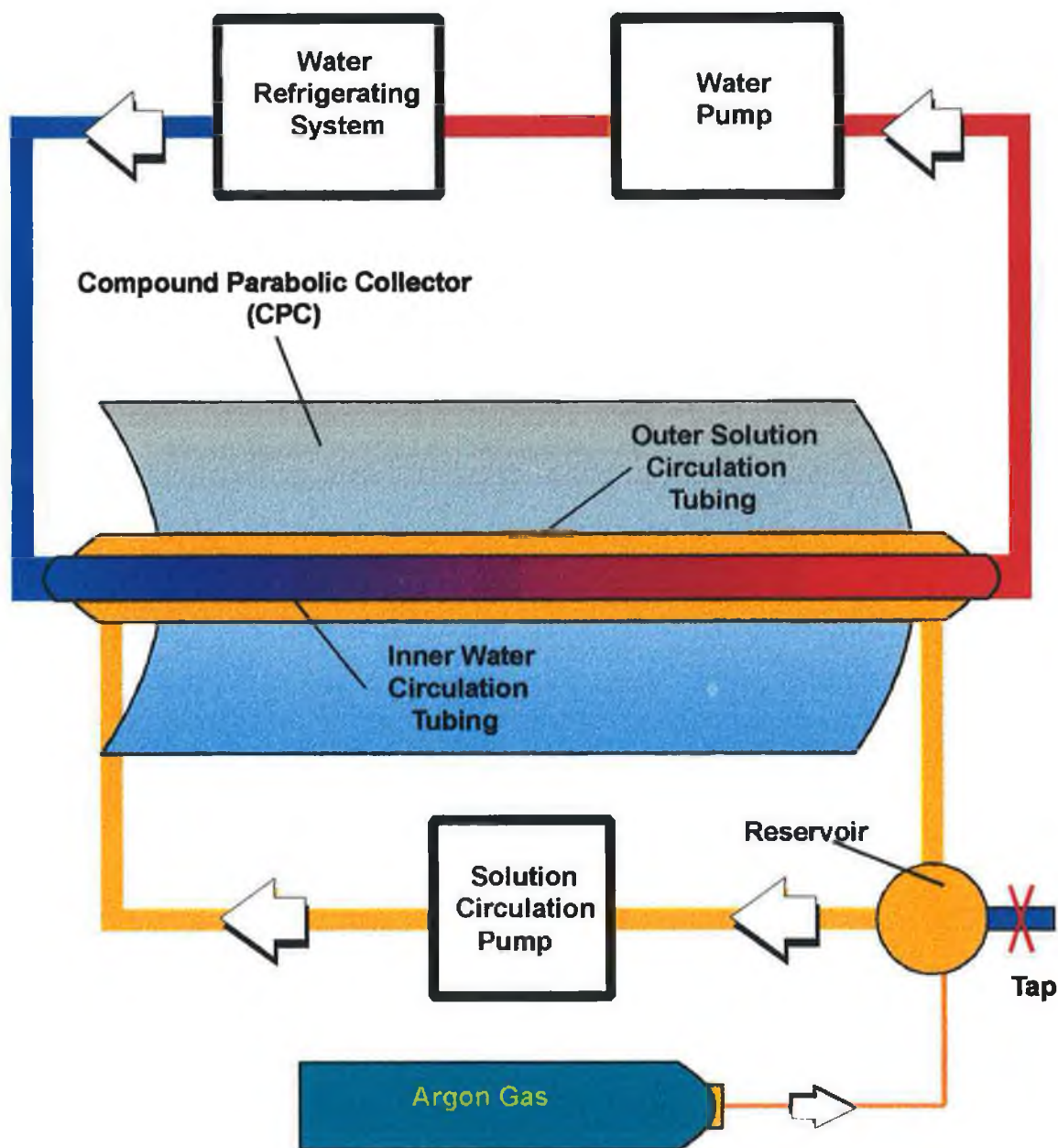


The development of high power lamps subsequent to this, especially high and low pressure mercury lamps and then lasers, enabled photochemical reactors to be moved from the rooftops to the laboratories. This evolution in photochemical investigative method led to a revolution in photochemical information acquired. Photochemistry became a funded scientific area and many areas of chemistry benefited from this research. The photochemical investigation of free radicals by Norrish²¹⁸ and Porter led to the award of a Nobel prize in 1967. While there was great interest at this time in laboratory photochemistry however, there was a lull in investigation of natural sunlight derived photochemistry. Research into the use of the sun as a source of energy was revitalised and intensified during the 1970's, after the oil crisis. Following the tightening of

ecological standards in the 1980's, intensive investigations into the solar detoxification of halogenated hydrocarbons have taken place. Since the beginning of the 1990's, experiments on the use of solar photons for fine chemical synthesis have been in progress. Most of this research, for European countries, is carried out at the Plataforma Solar de Almeria (PSA, latitude 37.1°N, 500m above sea level) in the south of Spain. This is an area which has more sunlight hours on average than anywhere else in Europe. For photochemical synthesis by natural sunlight, starting materials must absorb light above 300nm, as light below this wavelength is absorbed by the earth's ozone layer. All of the oxime acetates discussed in the previous section have absorptions which tail off well into the 300nm region. As part of the TMR (Training and Mobility of Researchers) programme, several of these oxime acetates were taken to the Plataforma Solar de Almeria and irradiated under natural sunlight using the Solfin (SOLar FINE chemical synthesis) solar reactor.

3.2 The Solfin Solar Reactor

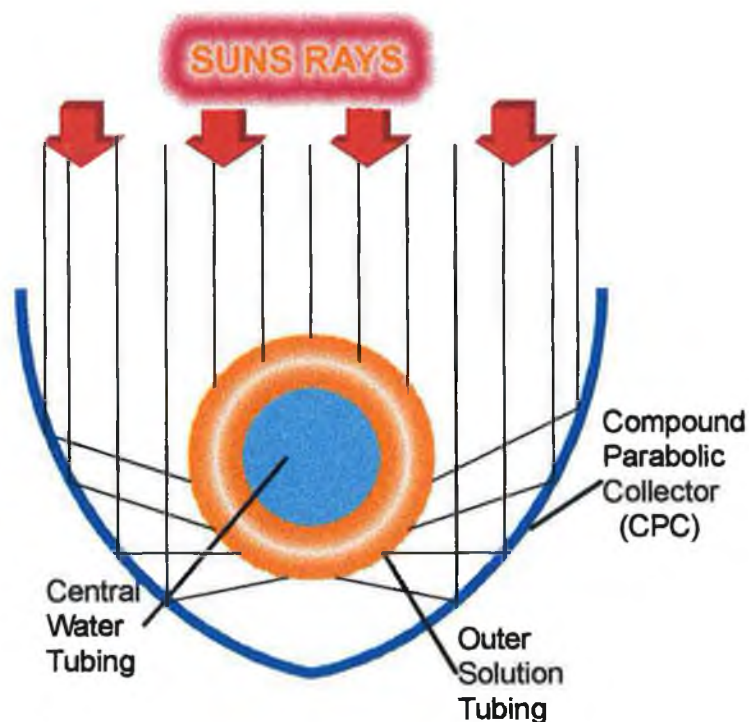
The Solfin solar reactor (scheme 41) consists of a one metre long highly polished aluminium compound parabolic collector (CPC). Running along the centre of the CPC is a Pyrex tube of similar length. Within this tube the reaction solution is circulated via a pump. Enclosed within this tube is a smaller tube in which the refrigerant, in this case water, is circulated. The tube structure is analogous to a large reflux condenser, but with the water running through the centre and the reaction solution being pumped around the outside. The water is pumped through a refrigerator on each circulation cycle and maintained at 13°C. This in turn maintains the reaction solution at a cool temperature. Samples are withdrawn via the reservoir. The system is purged with argon to free the solution from any oxygen present, and an atmosphere of argon gas is maintained over the solution. This is done via the reservoir, which is vented to inhibit any pressure build up due to the presence of excess gas. The Solfin solar reactor is a much more efficient system of irradiation than using an ordinary laboratory vessel for several reasons. The Pyrex tube through which the solution flows



SCHEME 41

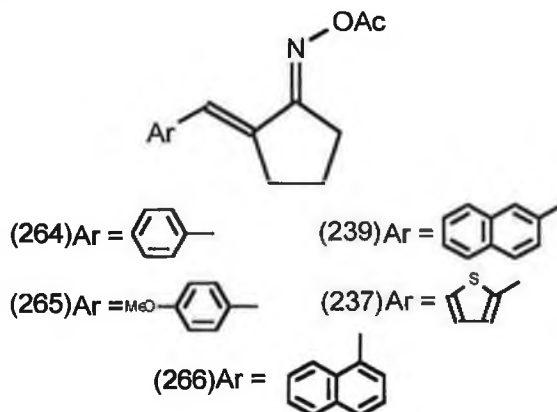
is positioned in the focal plane of a CPC. The CPC is a highly efficient solar photon collector, as its name implies. A cross-sectional view of the CPC is shown in scheme 42. All photons impinging on the CPC surface are reflected incident to the reaction tube. This is said to increase efficiency of reaction ~3 fold. In all, the photochemistry of five compounds was investigated using the Solfin solar

reactor. They were chosen on the basis of their success in laboratory scale photoreactions involving cyclisation to yield the quinoline photoproducts.

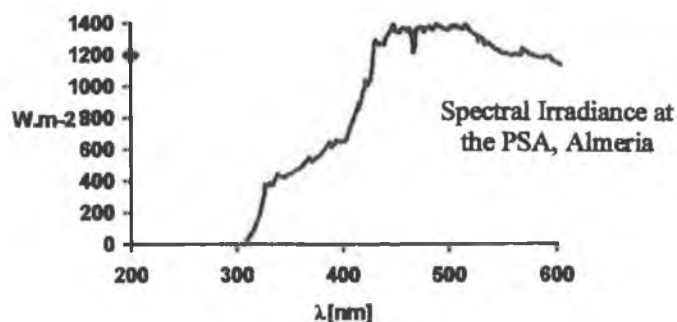
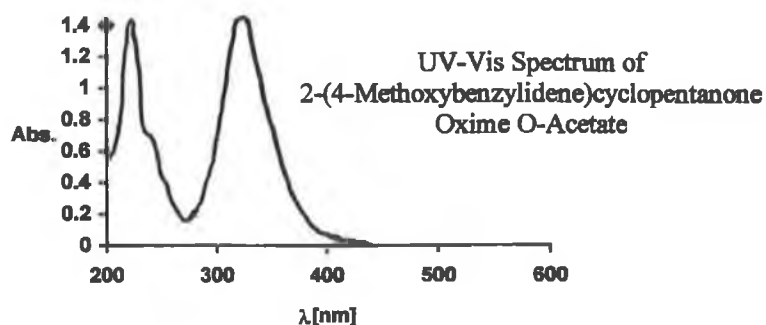


SCHEME 42

The compounds chosen were 2-benzylidenecyclopentanone oxime O-acetate (264), 2-(4-methoxybenzylidene)cyclopentanone oxime O-acetate (265), 2-thienylidenecyclopentanone oxime O-acetate (237), 2-(2-naphthylidene)cyclopentanone oxime O-acetate (239), and 2-(1-naphthylidene)cyclopentanone oxime O-acetate (266). The synthesis of acetates (237) and (239) and their laboratory scale photoreactions has been described earlier.



To investigate the photochemistry of a compound in natural sunlight, it is first of all necessary that its absorption spectrum overlaps with the irradiance spectrum of the incident sunlight. An absorption spectrum of one of the

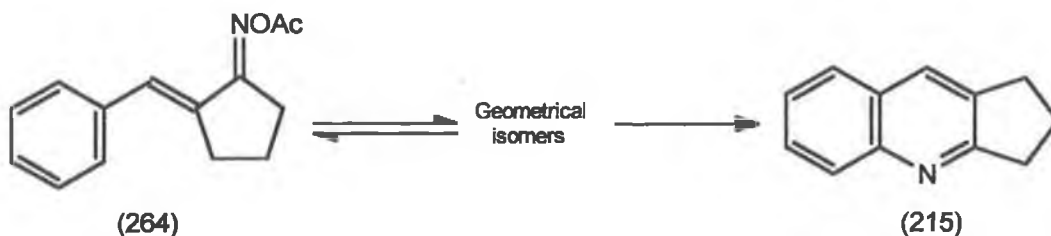


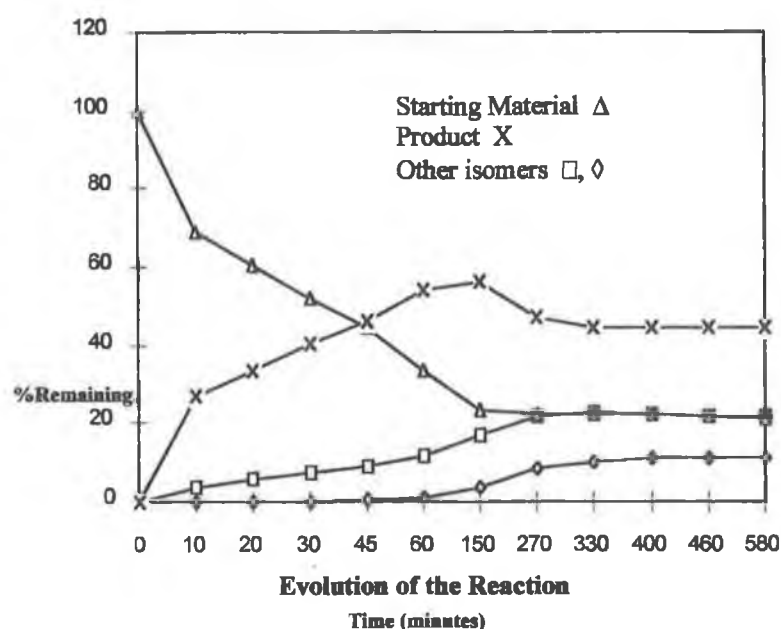
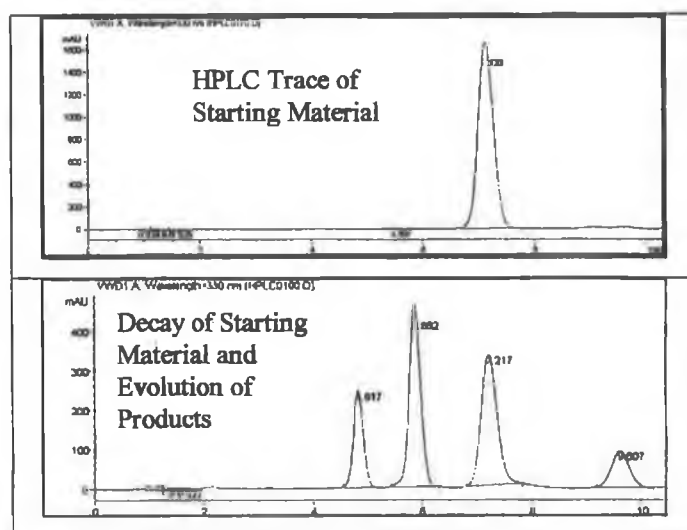
compounds chosen, 2-(4-methoxybenzylidene)cyclopentanone oxime acetate (265) is shown above. A graph of spectral irradiance against wavelength is shown below it for the PSA. It can be clearly seen that below 300nm almost no solar photons are detectable at the earth's surface. For this reason, all compounds chosen had to absorb light above 300nm. Even so it can be seen that the compounds chosen are absorbing only a small fraction of sunlight due to the low intensity of incident radiation at these wavelengths. The photocyclisation reaction is at minimum a two-photon process, one photon causing geometrical isomerisation and another causing ring closure. This, coupled with the fact that the intensity of incident sunlight at these wavelengths is relatively low, stimulated the use of concentrated solutions in photoreactions ($4\text{-}5\text{g.l}^{-1}$). The main aim of this investigation was to test the feasibility of using natural sunlight as an inexpensive source of energy in the large-scale synthesis of quinolines and their

analogues. The first compound investigated was 2-benzylidenecyclopentanone oxime O-acetate (264).

3.3 Irradiation of 2-Benzylidenecyclopentanone Oxime O-Acetate (264)

2-Benzylidenecyclopentanone oxime O-acetate (264) was irradiated in the Solfin reactor under natural sunlight. The reaction progress was followed by withdrawing samples from the reservoir every ten minutes and examining each one using high pressure liquid chromatography (HPLC). After irradiating for 20 minutes two new peaks were observed on the HPLC trace, indicating the presence of isomers in the solution. Irradiation was continued and when 45 minutes had elapsed a third new peak had appeared on the HPLC trace. After 580 minutes irradiation was halted and purification of the brown gum obtained by column chromatography gave a 45% yield of white crystalline product. ^1H and ^{13}C -NMR spectroscopy confirmed it to be the previously isolated heterocycle 2,3-dihydro-1*H*-cyclopenta[*b*]quinoline (215).¹⁸¹ The HPLC traces and graph show the decay of starting isomer, the evolution of two of the remaining three geometrical isomers, and the quinoline photoproduct. The top HPLC trace shows starting material (in this case acetate 264). The other HPLC trace shows the decay of starting material and the evolution of product. The decay in reactant concentration and the evolution of isomers and product is plotted in the above graph.

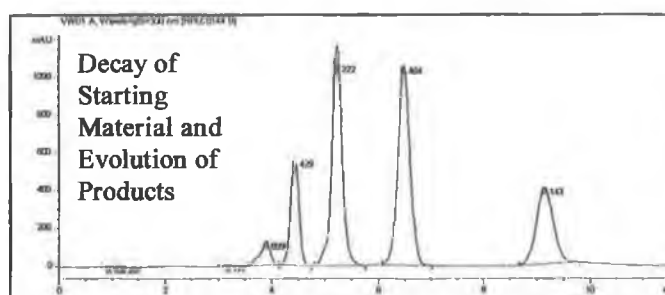
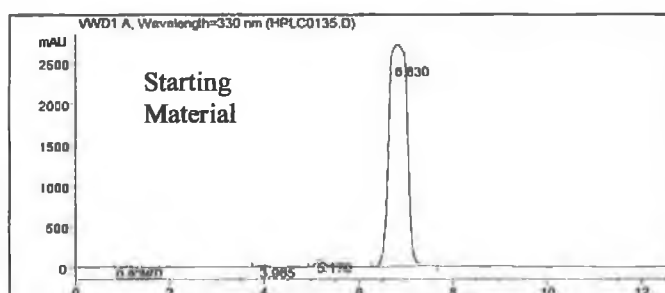
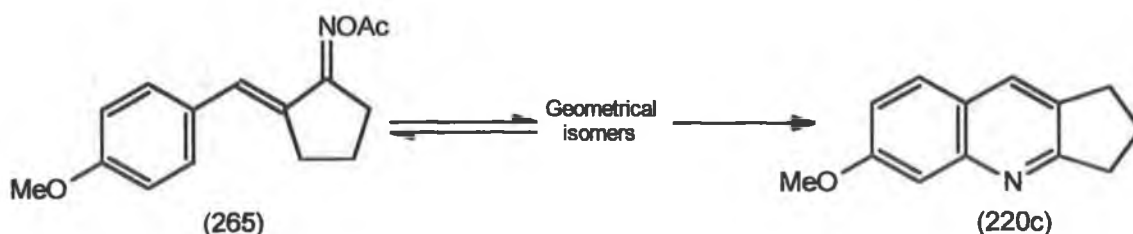




The HPLC system used a single wavelength u.v. detector. Since the starting material and the product have different extinction coefficients at this wavelength, the peak areas are corrected for this difference to permit the graph of reaction composition vs. time to be drawn. For this purpose, the extinction coefficients of the starting material and final product were determined. As an approximation, those of the geometrical isomers were assumed to be the same as that of the starting material. These calculations were carried out for all starting materials used.

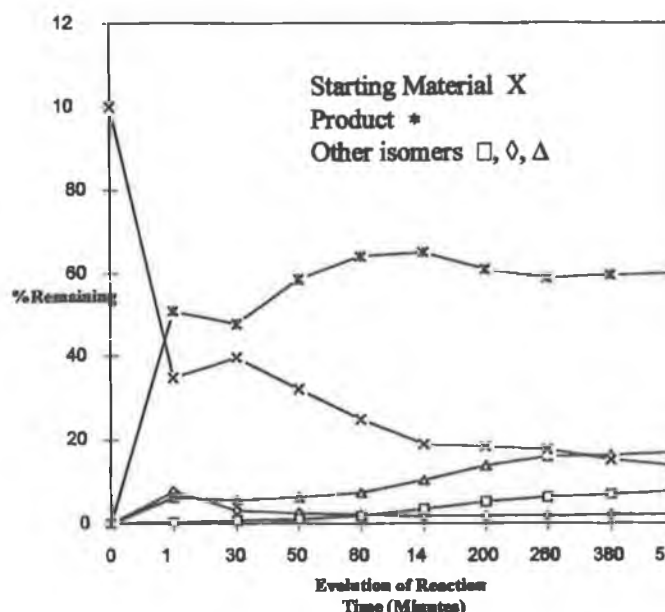
3.4 Irradiation of 2-(4-Methoxybenzylidene)cyclopentanone Oxime O-Acetate (265)

2-(4-Methoxybenzylidene)cyclopentanone oxime O-acetate was irradiated using the Solfin reactor. After 10 minutes, 4 new peaks were visible on the HPLC trace, corresponding to the three additional geometrical isomers and the cyclised photoproduct. For the duration of the reaction the concentration of these products were seen to increase at the expense of starting material. After 515 minutes, the irradiation was stopped and purification of the brown gum obtained gave a 63% yield of the off-white crystalline product.



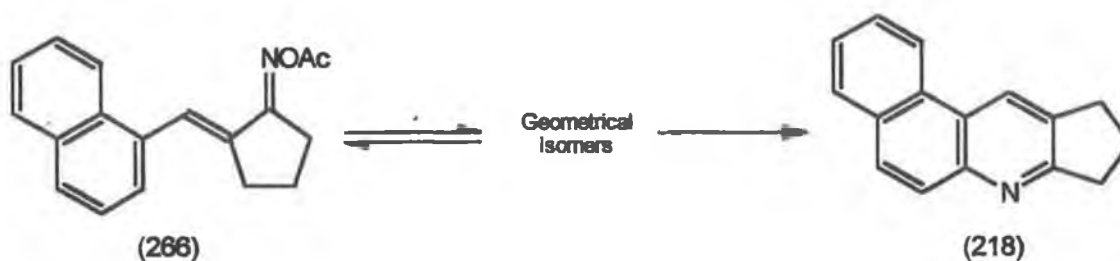
^1H and ^{13}C -NMR confirmed it to be the previously isolated heterocycle 6-methoxy-2,3-dihydro-1H-cyclopenta[b]quinoline (220c).¹⁸¹ The HPLC traces and corrected graph overleaf show the decay of the starting isomer and evolution of the remaining three geometrical isomers during photolysis. Also shown is

formation of the quinoline photoproduct. The top HPLC trace is of starting material alone. The second trace shows the evolution of remaining isomers and quinoline heterocycle.

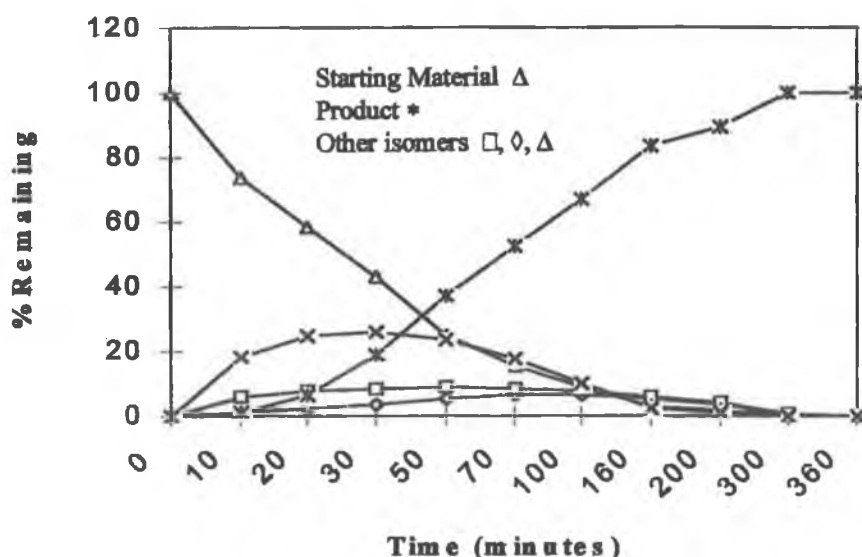


3.5 Irradiation of 2-(1-Naphthylidene)cyclopentanone Oxime O-Acetate (266)

2-(1-Naphthylidene)cyclopentanone oxime O-acetate (266) was irradiated using the Solfin reactor. After 10 minutes, four new peaks had appeared on the HPLC trace corresponding to the other three geometrical isomers of starting material and the quinoline photoproduct (218). After 360 minutes all starting material had been consumed and the reaction was stopped.

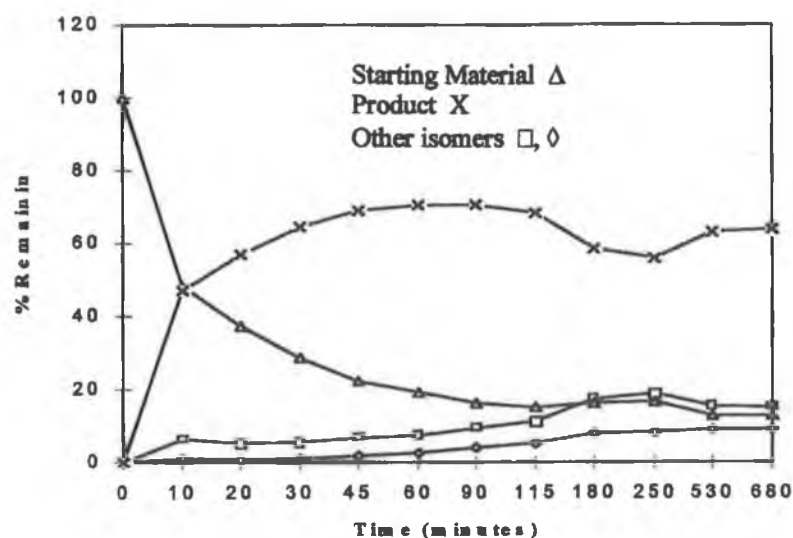


Recrystallisation of the brown gum (light petroleum b.p. 60-80°C) gave a >95% yield of a white crystalline compound. ^1H and ^{13}C -NMR confirmed it to be the previously reported heterocycle 1-aza-cyclopenteno[b]phenanthrene (255).^{181,186} A graph showing decay of starting material and formation of quinoline photoproduct is shown.



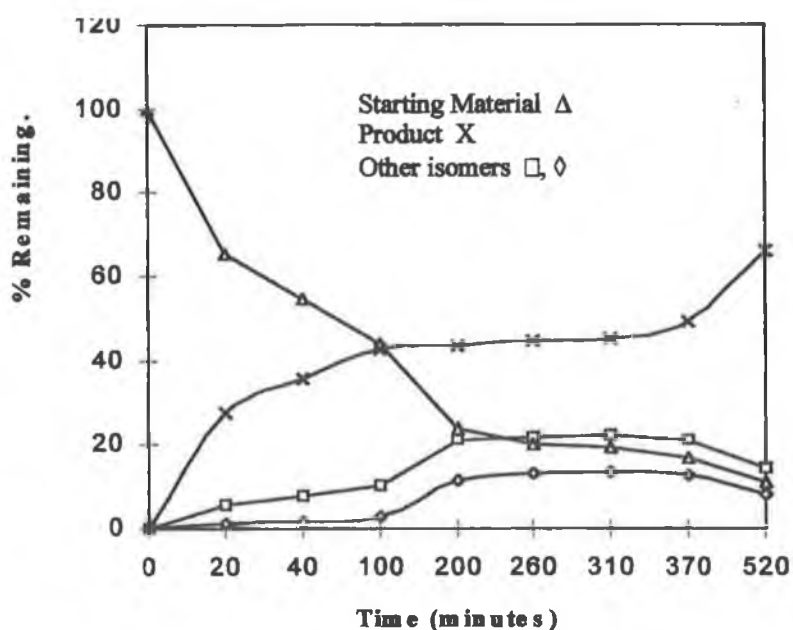
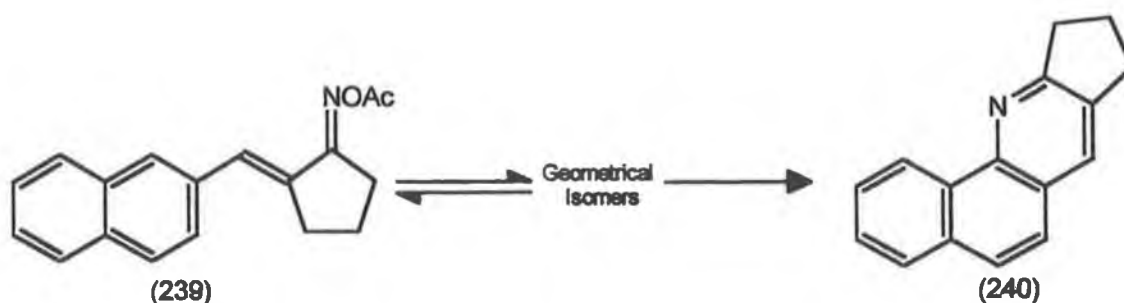
3.6 Irradiation of 2-Thienylidenecyclopentanone Oxime O-Acetate (237)

2-Thienylidenecyclopentanone oxime O-acetate (237) was irradiated using the Solfin reactor. After 10 minutes of irradiation 4 new peaks were visible on the HPLC trace corresponding to 3 additional geometrical isomers of the starting material and quinoline photoproduct. Over the course of the reaction the concentration of these isomers increased at the expense of starting material. After 680 minutes the photolysis was stopped and purification of the brown gum obtained gave a 62% yield of an off-white crystalline product. ^1H and ^{13}C -NMR confirmed that the product had structure (238) previously isolated in the laboratory in Dublin. A plot of decay of starting material vs. time is shown. Also shown is the evolution of the additional isomers and quinoline photoproduct.



3.7 Irradiation of 2-(2-Naphthylidene)cyclopentanone Oxime O-Acetate (239)

2-(2-Naphthylidene)cyclopentanone oxime O-acetate (239) was irradiated using the Solfin reactor. After 20 minutes of irradiation, 4 new peaks were visible on the HPLC trace, corresponding to the three additional geometrical isomers of the starting material and the quinoline photoproduct. The concentration of these isomers increased over the course of the photolysis at the expense of the starting material. After 520 minutes, irradiation was stopped and purification of the brown gum obtained gave a 65% yield of the quinoline photoproduct. ^1H and ^{13}C -NMR identified it to be (240).



it can be clearly seen from the photoreactions investigated in Almeria that the results obtained are consistent with those found in the laboratory using a conventional immersion well with medium pressure vapour lamp. All heterocyclic photoproducts obtained from photoreactions in Almeria were identical to those obtained on the laboratory scale. It is difficult to discuss the efficiency of the photoreactions in natural sunlight because of variations in photon concentration due to time of day, weather conditions, and concentrations of dust in the atmosphere on a particular day. What is clear from the results however, is that the small-scale Solfin reactor can be used to convert significant quantities of substrate on a reasonable timescale. Whereas the Solfin reactor allows ~800 ml of solution to be exposed to the sun at any one time via the CPC, the reservoir can theoretically be made to accommodate any volume of solution.

This is not an ideal situation for high reservoir volumes however, as reaction times would be quite prolonged. There is however a larger multi-tube photoreactor in Almeria , a photo of which is shown below, in which 50 litres of solution at a time are exposed to the suns radiation, and there is no reason why the reactions investigated using this apparatus could not be scaled up to handle amounts on the kilogram scale.



Multi-tube photoreactor at the PSA in Almeria in which ~50L of solution are exposed to the sun at any one time. The apparatus basically consists of a number of Solfin reactors connected in series. The CPCs are seen running from top to bottom in the photo.

In the case of 2-(1-naphthylidene)cyclopentanone oxime O-acetate (266), conversion was essentially complete and yielded a high purity product without the necessity for chromatography. It is possible that the 2-substituted analogue (239) may show similar reactivity in the photoreactor, because on the day of its photolysis weather conditions were extremely unfavourable; cloudy with slight drizzle. Even in these conditions a respectable 65% yield of product was

obtained. The regioselectivity of this reaction was also preserved on photolysis in natural sunlight, the sole product isolated being the heterocycle (240).

As discussed earlier, the systems discussed above have an inherent photochemical inefficiency in that at least 2 discrete excitation steps are required for conversion of substrate to product. The first of these requires photoconversion of the E-arylidene unit to its Z-isomer required for ring closure, and the ring closure itself is a separate excitation step. In spite of this drawback, reasonable conversions are achieved in reasonable irradiation periods.

4. Experimental

4.1 Introductory remarks

Nuclear Magnetic Resonance (NMR) spectra were recorded on a Bruker AC-400 instrument operating at 400Mhz for ^1H -NMR and 100Mhz for ^{13}C -NMR. Spectra were recorded using deuterated chloroform as solvent unless otherwise stated (d=doublet, t=triplet, q=quartet, qn=quintet, m=multiplet).

Infrared(IR) spectra were recorded on either a Perkin Elmer 983G infrared spectrometer or a Nicolet 205 FT-IR spectrophotometer.

Ultraviolet(UV) spectra were recorded on a Hewlett Packard 8452A diode array UV-Vis. Spectrophotometer.

Melting ranges were recorded using a Gallenkamp melting point apparatus and are uncorrected.

Elemental analyses were carried out by the Microanalytical Laboratory at University College Dublin.

Thin layer chromatography (TLC) was carried out on silica gel TLC plates containing a fluorescent indicator (Riedel-de-Haen, DC-cards SiF, layer thickness 0.2mm).

Radial centrifugal chromatography (RCC) was carried out using a Harrison Research model 7942T Chromatotron system using rotors coated with silica gel PF₂₅₄ containing calcium sulphate (5%) as binder. Light petroleum for mobile phase had b.p. 40-60°C.

Laboratory photochemical reactions were carried out using a water-cooled immersion well containing a Photochemical Reactors 400W medium pressure mercury lamp fitted with a Pyrex filter ($\lambda > 300\text{nm}$). All solvents for photochemical reactions were high purity grade. All solutions for photochemical reaction were

deoxygenated by passing a stream of nitrogen through the solution for 30 minutes prior to irradiation and an atmosphere of nitrogen was maintained over the solutions for the duration of irradiation.

Photochemical reactions under natural sunlight were carried out using a one metre long Pyrex tube equipped with inlet and outlet Teflon tubing connected in series with a 300 ml reservoir and a circulation pump. This pyrex tube also contained a smaller Pyrex inner tube for circulation of refrigerant through the reaction mixture. The reaction tube was positioned in the focal plane of a compound parabolic collector (CPC).

All solutions for irradiation under natural sunlight were degassed for thirty minutes prior to irradiation under argon. An atmosphere of argon was maintained over reaction mixtures for the duration of irradiation.

All methanol used for photochemical reactions under natural sunlight was u.v.-vis grade methanol of 99.8% purity.

All HPLC analysis was carried out using a C₁₈ chromatography column and a Hewlett Packard HP1050 isocratic pumping system. The mobile phase used for HPLC was acetonitrile:water in the ratio 50:50, except the acetates (230) and (254) for which acetonitrile:water in the ratio of 55:45 was used.

Manipulation of the HPLC apparatus and management of data was carried out using a P.C. equipped with "HP Chemstation" software by Hewlett Packard.

Purification of crude photoproducts was carried out using column chromatography with silica gel as stationary phase unless otherwise stated.

4.2 General Procedure for the Preparation of Arylidenecyclopentanones (228a-i)

Cyclopentanone (3.45 g, 0.04 mole) and morpholine (3.5 g, 0.04 mole) were placed in a 100 ml round bottom flask containing toluene (40 ml). The mixture was heated under reflux with continuous azeotropic removal of water using a Dean and Stark distillation apparatus until a constant volume of water had been collected (0.7 ml, 45 minutes). The reaction mixture was allowed to cool and the desired aldehyde (0.04 mole) was added. The mixture was again heated under reflux with removal of water, until a constant volume of water had again been collected (0.7 ml, 75 minutes). The reaction mixture was allowed to cool and transferred to a 100 ml conical flask. A 1:1 mixture of conc. HCl / water (20 ml) was added dropwise to the flask with stirring and the mixture was then stirred for a further 30 minutes. The contents of the flask were then transferred to a 100 ml separating funnel and the lower acid layer was removed. The upper organic layer was washed first with a 10% aqueous sodium carbonate solution (50 ml) and then with water (2 × 30 ml). The organic layer was dried over anhydrous magnesium sulphate and the toluene was removed by rotary evaporation yielding the required arylidenecyclopentanone. The arylidenecyclopentanones were recrystallised from methanol unless otherwise stated.

4.3 Preparation of 2-(4-Cyanobenzylidene)cyclopentanone (228a)

2-(4-Cyanobenzylidene)cyclopentanone was prepared from 4-cyano benzaldehyde (3.9 g, 0.03 mol), yielding yellow needles of product (4.25 g, 72%), melting range 112-113°C.

IR (KBr pellet): 3140, 2961, 2904 (aromatic and aliphatic CH), 2228 (CN), 1708 (C=O), 1630, 1502, 1466, 1410, 1289, 1232, 1182, 1011, 926, 840 and 733 cm⁻¹.

¹H-NMR: δ 2.03 (qn, 2H, J=7.9Hz, CH₂-CH₂-CH₂), 2.40 (t, 2H, J=7.9Hz, CH₂-C=O), 2.95 (t of d, 2H, J_t=7.87, J_d=2.95, CH=C-CH₂), 7.29 (t, 1H, J=2.95, vinylic

proton), 7.56 (d, 2H, $J=8.9\text{Hz}$, aryl H-2 and H-6) and 7.65 (d, 2H, $J=8.9\text{Hz}$, aryl H-3 and H-5) ppm.

^{13}C -NMR: δ 19.90, 29.19, 37.49 (cyclopentane ring saturated carbons), 112.04 (CN), 118.38, 129.57, 130.43, 132.18, 139.16, 139.82 (aromatic and vinylic carbons) and 207.32 (C=O) ppm.

Found: C, 78.87; H, 5.66; N, 7.34%. $\text{C}_{13}\text{H}_{11}\text{NO}$ requires: C, 79.17; H, 5.62; N, 7.10%.

4.4 Preparation of 2-(2,4-Difluorobenzylidene)cyclopentanone (228b)

2-(2,4-Difluorobenzylidene)cyclopentanone was prepared from 2,4-difluorobenzaldehyde (3.9 g, 0.03 mol), yielding white needles of product (4.0 g, 67%), melting range 76-78°C.

IR (KBr pellet): 3090, 2961, 2904 (aromatic and aliphatic CH), 1716 (C=O), 1630, 1594, 1502, 1431, 1274, 1210, 1139, 1090, 968, 911, 854, 812 and 726 cm^{-1} .

^1H -NMR: δ 1.98 (qn, 2H, $J=7.88\text{Hz}$, $\text{CH}_2\text{-CH}_2\text{-CH}_2$), 2.35 (t, 2H, $J=7.88\text{Hz}$, $\text{CH}_2\text{-C=O}$), 2.83 (t of d, 2H, $J_t=7.88\text{Hz}$, $J_d=2.95\text{Hz}$, CH=C-CH_2), 6.79 (t of d, 1H $J_t=8.88$, $J_d=2.95$, aromatic proton), 6.88 (t of d, 1H, $J_t=7.88\text{Hz}$, $J_d=1.97\text{Hz}$, aromatic proton), 7.41-7.50 (m, 2H, aromatic and vinylic protons) ppm.

^{13}C -NMR: δ 19.97, 29.13, 37.57 (cyclopentane ring saturated carbons), 104.10 (t, $J=26\text{Hz}$, aromatic C-3), 111.50 (d of d, $J_{d1}=21\text{Hz}$, $J_{d2}=4.6\text{Hz}$, aromatic C-5), 120.01 (d of d, $J_{d1}=12\text{Hz}$, $J_{d2}=3.1\text{Hz}$, aromatic C-1), 122.80 (d, $J=4.6\text{Hz}$, vinylic carbon), 137.62 (s, CH-C-CH_2), 162.10 (d of d, $J_{d1}=253\text{Hz}$, $J_{d2}=12\text{Hz}$, aromatic C-4), 163.32 (d of d, $J_{d1}=256\text{Hz}$, $J_{d2}=11\text{Hz}$, aromatic C-2) and 207.34 (C=O) ppm.

Found: C, 69.11; H, 4.84%. $\text{C}_{12}\text{H}_{10}\text{F}_2\text{O}$ requires C, 69.23; H, 4.84%.

4.5 Preparation of 2-(2-Thienylidene)cyclopentanone (228c)

2-(2-Thienylidene)cyclopentanone was prepared from thiophene-2-carboxaldehyde (9.0 g, 0.08 mol), yielding pale yellow plates of product, (8.6 g, 60%) melting range 77-78°C (lit.²²², 79°C).

IR (KBr pellet): 3082, 2968, 2911 (aliphatic and aromatic CH), 1701 (C=O), 1616, 1509, 1466, 1417, 1303, 1239, 1182, 1054, 1011, 904, 854 and 748 cm⁻¹.

¹H-NMR: δ 2.05 (qn, 2H, J=7.4Hz, CH₂-CH₂-CH₂), 2.40 (t, 2H, J=7.4Hz, CH₂-C=O), 2.85 (t, 2H, J=7.4Hz, C=C-CH₂), 7.12 (t, 1H, J=3.7Hz, thienyl H-4), 7.32 (d, 1H, J=3.7Hz, thienyl H-3), 7.51 (d, 1H, J=3.7Hz, thienyl H-5), and 7.56 (s, 1H, CH=C-CH₂) ppm.

¹³C-NMR: δ 19.63, 29.01, 38.01 (cyclopentane ring saturated carbons), 124.93, 127.89, 129.92, 132.60, 133.58, 139.90 (vinyl and thienyl carbons), and 207.50 (C=O) ppm.

Found: C, 67.34; H, 5.45; S, 17.84%; C₁₀H₁₀OS requires: C, 67.38; H, 5.65; S, 17.99%.

4.6 Preparation of 2-(2-Naphthylidene)cyclopentanone (228d)

2-(2-Naphthylidene)cyclopentanone was prepared from 2-naphthaldehyde (6.00g, 0.04mole) yielding yellow crystals of the product (7.02g, 79%), melting range 128-129°C.

IR (KBr pellet): 3056, 2956, 2894 (aromatic and aliphatic CH), 1707 (C=O), 1617 (C=C), 1199, 1172, 821 and 749 cm⁻¹.

¹H-NMR: δ 2.04 (qn, 2H, J=7.4Hz, CH₂-CH₂-CH₂), 2.42 (t, 2H, J=7.2Hz, CH₂-C=O), 3.05 (t of d, 2H, J_t = 7.2Hz, J_d = 2.4Hz, CH₂-C=C), 7.48 (m, 4H, aromatic and vinylic protons) and 7.80 ppm (m, 4H, aromatic protons).

^{13}C -NMR: δ 19.73, 28.99, 37.34 (cyclopentane ring saturated carbons), 126.11, 126.63, 126.71, 127.22, 127.84, 128.07, 130.57, 131.96, 132.60, 132.73, 132.96, 135.80 (aromatic and vinylic protons) and 207.64 (C=O) ppm.

Found: C, 86.23; H, 6.43; $\text{C}_{16}\text{H}_{14}\text{O}$ requires: C, 86.46; H, 6.35%.

4.7 Preparation of 2-(3-Methoxybenzylidene)cyclopentanone (228e)

2-(3-Methoxybenzylidene)cyclopentanone was prepared from *m*-anisaldehyde (4.7 g, 0.03 mol). Recrystallisation from light petroleum yielded yellow crystals of product (4.5 g, 74%), melting range 57-58°C (lit. ²²³, 57°C).

IR (KBr pellet): 2965, 2894, 2842 (aromatic and aliphatic CH), 1707 (C=O), 1620, 1550, 1488, 1430, 1270, 1205, 1183, 1037, 928, 884, 819, 782 and 688 cm^{-1} .

^1H -NMR: δ 2.02 (qn, 2H, $J=7.2\text{Hz}$, $\text{CH}_2\text{-CH}_2\text{-CH}_2$), 2.39 (t, 2H, $J=7.3\text{Hz}$, $\text{CH}_2\text{C=O}$), 2.96 (t of d, 2H, $J_t=7.2\text{Hz}$, $J_d=2.7\text{Hz}$), 3.83 (s, 3H, OMe), 6.89 (m, 1H, aromatic proton), 7.03 (s, 1H, vinylic proton), 7.10 (d, 1H, $J=7.3\text{Hz}$, aromatic proton) and 7.29 (m, 2H, aromatic protons) ppm.

^{13}C -NMR: δ 19.99, 29.19, 37.63 (cyclopentane ring saturated carbons), 55.08 (OMe), 114.79, 115.54, 122.88, 129.49, 131.99, 136.14, 136.65, 159.43 (aromatic and vinylic carbons) and 207.97 (C=O) ppm.

Found: C, 77.04; H, 7.06; $\text{C}_{13}\text{H}_{14}\text{O}_2$ requires C, 77.20; H, 6.98%.

4.8 Preparation of 2-(3-Methylbenzylidene)cyclopentanone (228f)

2-(3-Methylbenzylidene)cyclopentanone was prepared from 3-tolualdehyde (3.6 g, .03mol). Recrystallisation from dichloromethane yielded fine yellow needles of product (4.2 g, 75%), melting range 30-31°C.

IR (KBr pellet): 3020, 2962 (aromatic and aliphatic CH), 2364, 2344, 1713 (C=O), 1630, 1488, 1411, 1295, 1256, 1192, 1160, 1024 and 928 cm^{-1} .

$^1\text{H-NMR}$: δ 2.01 (qn, 2H, $J=6.2\text{Hz}$, $\text{CH}_2\text{-CH}_2\text{-CH}_2$), 2.38 (t, 2H, $J=6.5\text{Hz}$, $\text{CH}_2\text{-C=O}$), 2.39 (s, 3H, Me), 2.95 (t of d, 2H $J_t=6.3\text{Hz}$, $J_d=2.4\text{Hz}$, C=C-CH_2), 7.15 (d, 1H, $J=2.4\text{Hz}$, aromatic proton) and 7.25 (m, 4H, aromatic and vinylic protons) ppm.

$^{13}\text{C-NMR}$: δ 22.40, 26.25, 34.32 (cyclopentane ring saturated carbons), 49.23 (Me), 113.15, 116.82, 122.92, 126.92, 132.3, 137.3, 139.40, 155.62 (aromatic and vinylic carbons) and 161.3 (C=O) ppm.

Found: C, 83.58; H, 7.58%; $\text{C}_{13}\text{H}_{14}\text{O}$ requires: C, 83.83; H, 7.58%.

4.9 Preparation of 2-(3-Nitrobenzylidene)cyclopentanone (228g)

2-(3-Nitrobenzylidene)cyclopentanone was prepared from 3-nitrobenzaldehyde (4.5 g, 0.03 mol) to yield off white crystals of product (4.3 g 67%), melting range 111-112°C.

IR (KBr pellet): 3110, 2982, 2903 (aromatic and aliphatic CH), 1715 (C=O), 1630, 1523, 1409, 1353, 1175, 1089, 919, 869, 811, 741, 677 and 641 cm^{-1} .

$^1\text{H-NMR}$: δ 2.11 (qn, 2H, $J=7.9\text{Hz}$, $\text{CH}_2\text{-CH}_2\text{-CH}_2$), 2.45 (t, 2H, $J=7.9\text{Hz}$, $\text{CH}_2\text{-C=O}$), 3.05 (t of d, 2H, $J_t=7.9\text{Hz}$, $J_d=2.9\text{Hz}$, CH=C-CH_2), 7.38 (t, 1H, $J=2.95\text{Hz}$, vinylic proton), 7.62 (t, 1H, $J=7.9\text{Hz}$, aryl H-5), 7.82 (d, 1H, $J=7.9\text{Hz}$, aryl H-6), 8.2 (d, 1H, $J=7.9\text{Hz}$, aryl H-4) and 8.35 (s, 1H, phenyl H-2) ppm.

$^{13}\text{C-NMR}$: δ 19.94, 29.10, 37.53 (cyclopentane ring saturated carbons), 123.43, 124.10, 129.06, 129.62, 136.02, 137.06, 138.73, 148.27 (aromatic and vinylic carbons) and 207.32, (C=O) ppm.

Found: C, 66.07; H, 5.11; N, 6.33. $C_{12}H_{11}NO_3$ requires C, 66.35; H, 5.10; N, 6.45%.

4.10 Preparation of 2-(3-Cyanobenzylidene)cyclopentanone (228h)

2-(3-Cyanobenzylidene)cyclopentanone was prepared from 3-cyano benzaldehyde (3.9 g, 0.03 mol), yielding yellow needles of product (4.0 g, 68%), melting range 72-74°C.

IR (KBr pellet): 3074, 2968 (aromatic and aliphatic CH), 2235 (CN), 1730 (C=O), 1629, 1481, 1424, 1253, 1189, 1018, 919, 797, 732 and 691 cm^{-1} .

1H -NMR: δ 2.05 (qn, 2H, $J=7.87Hz$, $CH_2-CH_2-CH_2$), 2.39 (t, 2H, $J=7.87Hz$, $CH_2-C=O$), 2.91 (t of d, 2H, $J_t=7.87Hz$, $J_d=2.95Hz$, $CH=C-CH_2$), 7.22 (t, 1H, $J=2.95Hz$, vinylic proton), 7.49 (t, 1H, $J=7.87Hz$, aryl H-5 proton), 7.58 (d, 1H, $J=7.87Hz$, aryl H-6 proton), 7.68 (d, 1H, $J=7.87Hz$, aryl H-4 proton) and 7.72 (s, 1H, aryl H-2 proton) ppm.

^{13}C -NMR: 19.85, 29.01, 37.43 (cyclopentane ring saturated carbons), 112.76 (CN), 118.15, 129.10, 129.40, 131.97, 132.92, 134.23, 136.53, 138.31 (aromatic and vinylic carbons) and 207.29 (C=O) ppm.

Found: C, 79.16; H, 5.69; N, 7.10%. $C_{13}H_{11}NO$ requires C, 79.17; H, 5.62; N, 7.10%.

4.11 Preparation of 2-(3-Fluorobenzylidene)cyclopentanone (228i)

2-(3-Fluorobenzylidene)cyclopentanone was prepared from 3-fluoro-benzaldehyde (3.7 g, 0.03 mol). Recrystallisation from light petroleum yielded white needles of product (4.4 g, 77%), melting range 58-60°C.

IR (KBr pellet): 3072, 2968, 2907, 2886, 2850 aromatic and aliphatic CH), 1715 (C=O), 1633, 1582, 1486, 1465, 1445, 1409, 1365, 1290, 1277, 1186, 1149, 1078, 1016, 787, 686 and 640 cm⁻¹.

¹H-NMR: δ 1.95 (qn, 2H, J=7.87Hz, CH₂-CH₂-CH₂), 2.34 (t, 2H, J=7.87Hz, CH₂-C=O), 2.87 (t of d, 2H, J_t=7.87Hz, J_d=2.95, CH=C-CH₂), 6.98 (t of d, 1H, J_t=8.9Hz, J_d=2.95, aromatic proton), 7.13 (d, 1H, J=8.9Hz, aromatic proton) and 7.25 (m, 3H, aromatic and vinylic protons) ppm.

¹³C-NMR: 19.83, 29.00, 37.43 (cyclopentane ring saturated carbons), 115.78, 115.99 (d, J=21Hz, aromatic C-4), 116.16, 116.37 (d, J=21Hz, aromatic C-2), 126.21 (vinylic carbon), 129.90, 129.97 (d, J=7.0Hz, aromatic C-5) ppm.

Found: C, 75.61; H, 5.86; F, 10.20. C₁₂H₁₁FO requires C, 75.77; H, 5.83; F, 9.99%.

4.12 Preparation of 2-(3-Chlorobenzylidene)cyclopentanone (228j)

2-(3-Chlorobenzylidene)cyclopentanone was prepared from 3-chloro benzaldehyde (4.2 g, 0.03 mol). Recrystallisation from dichloromethane yielded golden plates of product (3.9 g, 63%), melting range 47–48°C (lit. ¹⁸⁴, 178°C).*

IR (KBr pellet): 3065, 2965, 2884 (aromatic and aliphatic CH), 1715 (C=O), 1627, 1529, 1562, 1475, 1410, 1307, 1284, 1267, 1234, 1175, 1125, 1098, 1007, 921, 890, 881, 826, 788, 685 and 638 cm⁻¹.

¹H-NMR: δ 2.03 (qn, 2H, J=7.88Hz, CH₂-CH₂-CH₂), 2.41 (t, 2H, J=7.88Hz, CH₂-C=O), 2.94 (t of d, 2H, J_t=7.88Hz, J_d=2.96Hz, CH=C-CH₂) and 7.25–7.48 (m, 5H, aromatic and vinylic protons) ppm.

* The experimental procedure quoted in the reference was carried out in the laboratory and the compound was found not to have structure 228j.

¹³C-NMR: 19.92, 29.09, 37.52 (cyclopentane ring saturated carbons), 128.48, 128.98, 129.70, 129.80, 130.34, 130.45, 134.39, 137.12 (aromatic and vinylic carbons) and 207.65 (C=O) ppm.

Found: C, 69.81; H, 5.41; Cl, 17.47. C₁₂H₁₁ClO requires C, 69.74; H, 5.36, Cl, 17.15%.

4.13 General Procedure for the Preparation of Arylidenecyclopentanone Oximes (229a-i)

The desired arylidenecyclopentanone (0.03 mol) was added to a solution containing pyridine (0.04 mol, 3.2 g) and hydroxylamine hydrochloride (0.04 mol, 2.8 g) in ethanol (50 ml) in a 250 ml round bottomed flask. The reaction mixture was then heated under reflux for 30 minutes and allowed to cool. The ethanol was removed by rotary evaporation, chloroform (100 ml) was added to the flask and its contents transferred to a 300ml conical flask. A 200 ml aliquot of 1M hydrochloric acid was then added to the flask and the mixture was stirred vigorously for 15 minutes. Half of this mixture was then transferred to a 250 ml separating funnel and the acid layer was removed. This was repeated for the other half of the mixture and the organic layers were combined. The organic layer was then added to a 250 ml separating funnel, washed with water (2×100 ml) and dried over anhydrous magnesium sulphate. The chloroform was then removed by rotary evaporation yielding the required oxime.

4.14 Preparation of 2-(4-Cyanobenzylidene)cyclopentanone Oxime (229a)

2-(4-Cyanobenzylidene)cyclopentanone oxime was prepared from 2-(4-cyanobenzylidene)cyclopentanone (5.9 g, 0.03 mol), yielding yellow needles of product (6.3 g, 80%) melting range 130-133°C (decomp.).

IR (KBr pellet): 3260 (OH), 2968, 2900, 2850 (aromatic and aliphatic CH), 2226 (C≡N), 1602 (C=N), 1502, 1417, 1289, 1260, 1061, 1054, 947, 919 and 731 cm⁻¹.

$^1\text{H-NMR}$: δ 1.88 (qn, 2H, $J=7.4\text{Hz}$, $\text{CH}_2\text{-CH}_2\text{-CH}_2$), 2.66 (t, 2H, $J=7.4\text{Hz}$, $\text{CH}_2\text{-C}\equiv\text{N}$), 2.78 (t of d, 2H, $J_t=7.4\text{Hz}$, $J_d=2.5\text{Hz}$, CH-C-CH_2), 7.14 (t, 1H, $J=2.5\text{Hz}$, C=CH-Ph), 7.42 (d, 2H, $J=8.4\text{Hz}$, aromatic protons), 7.60 (d, 2H, $J=8.4\text{Hz}$, aromatic protons) and 9.9 (broad s, 1H, OH) ppm.

$^{13}\text{C-NMR}$: δ 22.28, 26.99, 31.55 (cyclopentane ring saturated carbons), 118.77 ($\text{C}\equiv\text{N}$), 110.16, 121.30, 129.43, 132.01, 140.38, 141.44 (aromatic and vinylic carbons) and 163.22 (C=N) ppm.

Found: C, 73.11; H, 5.72; N, 12.97%. $\text{C}_{13}\text{H}_{12}\text{N}_2\text{O}$ requires C, 73.58; H, 5.70; N, 13.20%.

4.15 Preparation of 2-(2,4-Difluorobenzylidene)cyclopentanone Oxime (229b)

2-(2,4-Difluorobenzylidene)cyclopentanone oxime was prepared from 2-(2,4-difluorobenzylidene)cyclopentanone (6.2 g, 0.03 mol), yielding white needles of product (6.25 g, 76%), melting range 155-158°C (decomp.).

IR (KBr pellet): 3258 (OH), 2950, 2918, 2880 (aromatic and aliphatic CH), 1614 (C=N), 1498, 1419, 1275, 1268, 1138, 1095, 965, 936 and 920 cm^{-1} .

$^1\text{H-NMR}$: δ 1.88 (qn, 2H, $J=7.4\text{Hz}$, $\text{CH}_2\text{-CH}_2\text{-CH}_2$), 2.70 (m, 4H, $\text{CH}_2\text{-C=N}$ and CH=C-CH_2), 6.82 (m, 2H, aromatic protons), 7.22 (s, 1H, vinylic proton), 7.38 (m, 1H, aromatic proton) and 8.70 (broad s, 1H, OH) ppm.

$^{13}\text{C-NMR}$: δ 22.26, 26.93, 31.31 (cyclopentane ring saturated carbons), 103.80 (t, $J=26\text{Hz}$, aromatic carbon), 110.90 (d of d, $J_{d1}=18\text{Hz}$, $J_{d2}=3.0\text{Hz}$, aromatic carbon), 114.04 (d, $J=4.6\text{Hz}$, CH-C-CH_2), 121.25 (t, $J=4.6\text{Hz}$, aromatic C-1), 130.35 ("q", $J=4.6\text{Hz}$, aromatic C-6), 138.44 (CH-C-CH_2), 159.31 (d, $J=252\text{Hz}$, aromatic C-F), 159.43 (d, $J=252\text{Hz}$, aromatic C-F) and 163.02 (C=N) ppm.

Found: C, 64.44; H, 4.97; N, 6.11; F, 16.58%. $C_{12}H_{11}NOF_2$ requires C, 64.57; H, 4.97; N, 6.27; F, 17.02%.

4.16 Preparation of 2-(2-Thienylidene)cyclopentanone Oxime (229c)

2-(2-Thienylidene)cyclopentanone oxime was prepared from 2-(2-thienylidene)cyclopentanone (5.3 g, 0.03mol), yielding pale yellow plates of product, (4.9 g, 85%), melting range 122-123°C.

IR (KBr pellet): 3274 (OH), 3217, 3096, 2925 (aromatic and aliphatic CH), 1602 (C=N), 1466, 1416, 1259, 1196, 1040, 933, 883, 854 and 698 cm^{-1} .

1H -NMR: δ 1.95 (qn, 2H, $J=7.9Hz$, $CH_2-CH_2-CH_2$), 2.70 (t, 2H, $J=7.9Hz$, $CH_2-C=N$), 2.79 (t of d, 2H, $J_t=7.9Hz$, $J_d=1.97$, $C=C-CH_2$), 7.05 (t, 1H, $J=5.0 Hz$, thienyl H-4), 7.13 (d, 1H, $J=3.8Hz$, thienyl proton), 7.35 (d, 1H, $J=5.2Hz$, thienyl proton), 7.40 (s, 1H, vinylic proton) and 8.78 (broad s, 1H, OH) ppm.

^{13}C -NMR: δ 22.13, 27.48, 31.32 (cyclopentane ring saturated carbons), 116.35, 126.68, 127.36, 128.84, 134.21, 141.28 (vinylic and thienyl carbons), and 163.46 (C=N) ppm.

Found: C, 62.24; H, 5.68; N, 7.13; S, 16.47%. $C_{10}H_{11}NOS$ requires C, 62.15; H, 5.74; N, 7.25; S, 16.59%.

4.17 Preparation of 2-(2-Naphthylidene)cyclopentanone Oxime (229d)

2-(2-Naphthylidene)cyclopentanone oxime was prepared from 2-(2-naphthylidene)cyclopentanone (5.0 g) yielding yellow crystals of product (4.1 g, 75%), melting range 196-198°C.

IR (KBr pellet): 3271 (broad, OH), 2955, 2924 (aromatic and aliphatic CH), 1591 (C=N), 1505, 1465, 1420, 1371, 1244, 1177, 1044, 938, 911, 816 and 749 cm^{-1} .

$^1\text{H-NMR}$ (DMSO-d_6): δ 1.88 (qn, 2H, $J=7.3$ Hz, $\text{CH}_2\text{-CH}_2\text{-CH}_2$), 2.60 (t, 2H, $J=7.3$ Hz, $\text{CH}_2\text{-C=N}$), 2.93 (t of d, 2H, $J_t=7.3\text{Hz}$, $J_d=2.3\text{Hz}$ $\text{CH}_2\text{-C=C}$), 7.33 (s, 1H, aromatic proton), 7.58 (m, 2H, aromatic and vinylic protons), 7.67 (d, 1H, aromatic proton), 8.01 (m, 4H, aromatic protons) and 11.20 (s, 1H, -OH) ppm.

$^{13}\text{C-NMR}$ (DMSO-d_6): δ 22.19, 26.78, 31.27 (cyclopentane ring saturated carbons), 120.57, 126.18, 126.39, 127.07, 127.50, 127.84, 127.88, 128.06, 131.98, 133.11, 134.68, 138.32 (aromatic and vinylic carbons) and 160.82 (C=N) ppm.

Found: C, 80.76; H, 6.33; N, 5.65; $\text{C}_{16}\text{H}_{15}\text{NO}$ requires: C, 80.98; H, 6.37; N, 5.90%.

4.18 Preparation of 2-(3-Methoxybenzylidene)cyclopentanone Oxime (229e)

2-(3-Methoxybenzylidene)cyclopentanone oxime was prepared from 2-(3-methoxybenzylidene)cyclopentanone (6.1 g, 0.03 mol), yielding yellow crystals of product (5.27 g, 81%), melting range 98-100°C.

IR (KBr pellet): 3274 (OH), 2950, 2925 (aromatic and aliphatic CH), 1580 (C=N), 1486, 1465, 1431, 1289, 1239, 1168, 1047, 960, 919, 791, 741 and 691 cm^{-1} .

$^1\text{H-NMR}$: δ 1.87 (qn, 2H, $J=7.4\text{Hz}$, $\text{CH}_2\text{-CH}_2\text{-CH}_2$), 2.68 (t, 2H, $J=7.4\text{Hz}$, $\text{CH}_2\text{C=N}$), 2.81 (t of d, 2H, $J_t=7.4\text{Hz}$, $J_d=2.9\text{Hz}$), 3.82 (s, 3H, OMe), 6.81 (m, 1H, aromatic proton), 6.95 (s, 1H, aromatic proton), 7.01 (d, 1H, $J=7.3\text{Hz}$, aromatic proton), 7.18 (t, 1H, $J=2.9\text{Hz}$, vinylic proton), 7.26 (t, 1H, $J=7.3\text{Hz}$, aromatic proton) and 9.5 (broad s, 1H, OH) ppm.

$^{13}\text{C-NMR}$: δ 22.43, 27.09, 31.51 (cyclopentane ring saturated carbons), 55.15 (OMe), 113.02, 114.63, 121.91, 123.13, 129.23, 136.92, 138.38, 159.38 (aromatic and vinylic carbons) and 163.67 (C=N) ppm.

Found: C, 71.50; H, 6.97; N, 6.64%; $C_{13}H_{15}NO_2$ requires C, 71.87; H, 6.96; N, 6.45%.

4.19 Preparation of 2-(3-Methylbenzylidene)cyclopentanone Oxime (229f)

2-(3-Methylbenzylidene)cyclopentanone oxime was prepared from 2-(3-methylbenzylidene)cyclopentanone (5.6 g, 0.03 mol), to yield fine yellow needles of product (4.9 g, 82%), melting range 147-149°C.

IR (KBr pellet): 3288 (OH), 3046, 2968, 2875 (aromatic and aliphatic CH), 1609 (C=N), 1460, 1289, 1224, 1054, 946, 912, 890, 784 and 705 cm^{-1} .

1H -NMR: δ 1.87 (qn, 2H, $J=7.4Hz$, $CH_2-CH_2-CH_2$), 2.37 (s, 3H, Me), 2.65 (t, 2H, $J=7.4Hz$, $CH_2-C=N$), 2.95 (t, 2H $J=7.4Hz$, $C=C-CH_2$), 7.07 (d, 1H, $J=7.4Hz$, aromatic proton), 7.16 (s, 1H, vinylic proton), 7.25 (m, 3H, aromatic protons) and 8.95 (broad s, 1H, OH) ppm.

^{13}C -NMR: δ 21.44, 22.49, 27.05, 31.50 (cyclopentane ring saturated carbons and methyl carbon), 123.29, 126.33, 128.21, 130.09, 136.43, 136.99, 137.86 (aromatic and vinylic carbons) and 163.77 (C=N) ppm.

Found: C, 77.39; H, 7.45; N, 6.68%; $C_{13}H_{15}NO$ requires: C, 77.58; H, 7.51; N, 6.96%.

4.20 Preparation of 2-(3-Nitrobenzylidene)cyclopentanone Oxime (229g)

2-(3-Nitrobenzylidene)cyclopentanone was prepared from 2-(3-nitrobenzylidene)cyclopentanone (6.5 g, 0.03 mol) to yield off white crystals of product (7.4 g, 87%), melting range 175-176°C.

IR (KBr pellet): 3110, 2982, 2903 (aromatic and aliphatic CH), 1715 (C=O), 1630, 1523, 1409, 1353, 1175, 1089, 919, 869, 811, 741, 677 and 641 cm^{-1} .

$^1\text{H-NMR}$: δ 2.11 (qn, 2H, $J=7.9\text{Hz}$, $\text{CH}_2\text{-CH}_2\text{-CH}_2$), 2.45 (t, 2H, $J=7.9\text{Hz}$, $\text{CH}_2\text{-C=N}$), 3.05 (t of d, 2H, $J_t=7.9\text{Hz}$, $J_d=2.9\text{Hz}$, CH=C-CH_2), 7.38 (t, 1H, $J=2.95\text{Hz}$, vinylic proton), 7.62 (t, 1H, $J=7.9\text{Hz}$, aryl H-5), 7.82 (d, 1H, $J=7.9\text{Hz}$, aryl H-6), 8.2 (d, 1H, $J=7.9\text{Hz}$, aryl H-4) and 8.35 (s, 1H, aryl H-2) ppm .

$^{13}\text{C-NMR}$: δ 19.94, 29.10, 37.53 (cyclopentane ring saturated carbons), 123.43, 124.10, 129.06, 129.62, 136.02, 137.06, 138.73, 148.27 (aromatic and vinylic carbons) and 207.32 (C=O) ppm.

Found: C, 61.65; H, 5.16; N, 11.98; $\text{C}_{12}\text{H}_{12}\text{N}_2\text{O}_3$ requires C, 62.06; H, 5.21; N, 12.06%.

4.21 Preparation of 2-(3-Cyanobenzylidene)cyclopentanone Oxime (229h)

2-(3-Cyanobenzylidene)cyclopentanone oxime was prepared from 2-(3-cyanobenzylidene)cyclopentanone (5.9 g, 0.03 mol), yielding yellow needles of product (5.76 g, 73%), melting range 134-136°C (decomp.).

IR (KBr pellet): 3369 (OH), 2968, 2957, 2943 (aromatic and aliphatic CH), 2231 ($\text{C}\equiv\text{N}$), 1600 (C=N), 1580, 1481, 1424, 1288, 1263, 1217, 1054, 950, 913, 799, 733 and 683 cm^{-1} .

$^1\text{H-NMR}$: δ 1.90 (qn, 2H, $J=7.4\text{Hz}$, $\text{CH}_2\text{-CH}_2\text{-CH}_2$), 2.66 (t, 2H, $J=7.4\text{Hz}$, $\text{CH}_2\text{-C=N}$), 2.78 (t of d, 2H, $J_t=7.4\text{Hz}$, $J_d=2.5\text{Hz}$, CH=C-CH_2), 7.12 (t, 1H, $J=2.5\text{Hz}$, vinylic proton), 7.5 (m, 4H, aromatic protons) and 9.8 (broad s, 1H, OH) ppm.

$^{13}\text{C-NMR}$: δ 22.30, 27.00, 31.37 (cyclopentane ring saturated carbons), 118.60 ($\text{C}\equiv\text{N}$), 112.42, 120.73, 129.11, 130.42, 132.22, 133.21, 138.11, 139.33 (aromatic and vinylic carbons) and 163 (C=N) ppm.

Found: C, 73.45; H, 5.81; N, 13.08%. $\text{C}_{13}\text{H}_{12}\text{N}_2\text{O}$ requires C, 73.58; H, 5.70, N, 13.20%.

4.22 Preparation of 2-(3-Fluorobenzylidene)cyclopentanone Oxime (229i)

2-(3-Fluorobenzylidene)cyclopentanone oxime was prepared from 2-(3-fluorobenzylidene)cyclopentanone (5.7 g, 0.03 mol), yielding white needles of product (6.1 g, 80%), melting range 110-112°C.

IR (KBr pellet): 3221 (OH), 2950, 2918 (aromatic and aliphatic CH), 1606 (C=N), 1578, 1483, 1426, 1275, 1217, 1152, 1051, 965, 936, 785 and 684 cm⁻¹.

¹H-NMR: δ 1.91 (qn, 2H, J=7.4Hz, CH₂-CH₂-CH₂), 2.70 (t, 2H, J=7.4Hz, CH₂-C=N), 2.81 (t of d, 2H, J_t=7.4Hz, J_d=2.5Hz, CH=C-CH₂), 7.20 (m, 5H, aromatic and vinylic protons) and 9.8 (broad s, 1H, OH) ppm.

¹³C-NMR: δ 22.31, 27.03, 31.37 (cyclopentane ring saturated carbons), 114.10 (d, J=21Hz, aromatic C-4), 115.50 (d, J=23Hz, aromatic C-2), 122.10 (d, J=3.0Hz, vinylic carbon), 125.10 (d, J=3.0Hz, aromatic C-6), 129.60 (d, J=9.1Hz, aromatic C-5), 137.83 (CH-C-CH₂), 139.20 (aromatic quaternary carbon), 161.36 (d, J=244Hz, aromatic C-3) and 163.51 (C=N) ppm.

Found: C, 70.23; H, 5.93; N, 6.78; F, 9.55%. C₁₂H₁₂NOF requires C, 70.23; H, 5.89; N, 6.82; F, 9.26%.

4.23 Preparation of 2-(3-Chlorobenzylidene)cyclopentanone Oxime (229i)

2-(3-Chlorobenzylidene)cyclopentanone oxime was prepared from 2-(3-chlorobenzylidene)cyclopentanone (6.2 g, 0.03 mol), yielding yellow plates of product (6.9 g, 84%), melting range 122-123°C.

IR (KBr pellet): 3274 (OH), 2960, 2930, 2907 (aromatic and aliphatic CH), 1590 (C=N), 1563, 1557, 1475, 1418, 1286, 1257, 1198, 1095, 1079, 1051, 996, 944, 909, 887, 790, 788, 733 and 691 cm⁻¹.

$^1\text{H-NMR}$: δ 1.90 (qn, 2H, $J=7.4\text{Hz}$, $\text{CH}_2\text{-CH}_2\text{-CH}_2$), 2.72 (t, 2H, $J=7.4\text{Hz}$, $\text{CH}_2\text{-C=N}$), 2.80 (t of d, $J_t=7.4\text{Hz}$, $J_d=2.5\text{Hz}$, CH=C-CH_2), 7.16 (t, 1H, $J=2.5\text{Hz}$, vinylic proton), 7.25 (m, 3H, aromatic protons), 7.39 (s, 1H, aromatic proton) and 10.05 (broad s, 1H, OH) ppm.

$^{13}\text{C-NMR}$: δ 22.33, 27.08, 31.40 (cyclopentane ring saturated carbons), 121.83, 127.22, 127.33, 128.89, 129.45, 134.12, 138.00, 138.80 (aromatic and vinylic carbons) and 163.43 (C=N) ppm.

Found: C, 65.03; H, 5.48; N, 6.20; Cl, 15.94%. $\text{C}_{12}\text{H}_{12}\text{NOCl}$ requires C, 65.02; H, 5.46; N, 6.32; Cl, 15.99%.

4.24 General Procedure for the Preparation of Arylidene-cyclopentanone Oxime O-Acetates

The desired arylidenecyclopentanone oxime (0.02 mol) was added to pyridine (20 ml, 0.25 mol) with stirring at room temperature until it was totally dissolved. The resulting solution was then cooled to 5°C in an ice bath. While the cooled solution was stirred vigorously and maintained at 5°C , acetyl chloride (2.3 g, 0.03 mol) was added dropwise. When all the acetyl chloride had been added, the solution was stirred at room temperature for one hour, and then crushed ice (50 g) was added with stirring. When all the ice had melted, the resulting arylidenecyclopentanone oxime acetate suspension was filtered on a Buchner funnel. The crude ester was dissolved in chloroform (50 ml), washed twice with a 1:1 solution of water and hydrochloric acid (60 ml) until neutral to litmus, then dried over magnesium sulphate. The solvent was removed by rotary evaporation, yielding the desired ester.

4.25 Preparation of 2-(4-Cyanobenzylidene)cyclopentanone Oxime O-Acetate (233)

2-(4-Cyanobenzylidene)cyclopentanone oxime acetate was prepared from 2-(4-cyanobenzylidene)cyclopentanone oxime (4.0 g, 0.02 mol) yielding yellow needles of product (3.95 g, 81%), melting range 120-121°C.

IR(KBr pellet): 3053, 2968, 2925, 2897, 2854 (aromatic and aliphatic CH), 2228 ($\text{C}\equiv\text{N}$), 1765 ($\text{C}=\text{O}$), 1650, 1602 ($\text{C}=\text{N}$), 1502, 1474, 1417, 1367, 1296, 1267, 1217, 1004, 939, 926, 890, 826 and 691 cm^{-1} .

$^1\text{H-NMR}$: δ 1.95 (qn, 2H, $J=7.9\text{Hz}$, $\text{CH}_2\text{-CH}_2\text{-CH}_2$), 2.24 (s, 3H, -OMe), 2.75 (t, 2H, $J=7.9\text{Hz}$, $\text{CH}_2\text{-C}=\text{N}$), 2.82 (t of d, 2H, $J_t=7.9\text{Hz}$, $J_d=2.9\text{Hz}$, $\text{CH}_2\text{-C}=\text{CH}$), 7.51 (m, 3H, aromatic and vinylic protons) and 7.66 (d, 2H, $J=8.9\text{Hz}$, aromatic proton) ppm.

$^{13}\text{C-NMR}$: δ 19.69 (Me), 22.44, 28.96, 31.43 (cyclopentane ring saturated carbons), 111.17 (aromatic carbon), 118.79 ($\text{C}\equiv\text{N}$), 125.14, 129.92, 132.24, 138.70, 140.85 (aromatic and vinylic carbons), 168.70 ($\text{C}=\text{N}$) and 169.49 ($\text{C}=\text{O}$) ppm.

UV (methanol): λ_{max} 308nm ($\epsilon=30,000$), 228nm ($\epsilon=8,666$), 204nm ($\epsilon=7,877$).

Found: C, 70.89; H, 5.60; N, 11.01%. $\text{C}_{15}\text{H}_{14}\text{N}_2\text{O}_2$ requires C, 70.85; H, 5.55; N, 11.02%.

4.26 Preparation of 2-(2,4-Difluorobenzylidene)cyclopentanone Oxime O-Acetate (236)

2-(2,4-Difluorobenzylidene)cyclopentanone oxime acetate was prepared from 2-(2,4-difluorobenzylidene)cyclopentanone oxime (4.5 g, 0.02 mol), yielding white needles of product (3.7 g, 70%), melting range 117-118°C.

IR(KBr pellet): 3088, 2968, 2925, 2896, 2854 (aromatic and aliphatic CH), 1766, 1659, 1616 (C=N), 1502, 1466, 1424, 1367, 1267, 1225, 1196, 1146, 1097, 1040, 1004, 968, 940, 883, 862, 819, 719 and 691 cm^{-1} .

$^1\text{H-NMR}$: δ 1.85 (qn, 2H, $J=6.9\text{Hz}$, $\text{CH}_2\text{-CH}_2\text{-CH}_2$), 2.20 (s, 3H, CH_3), 2.70 (m, 4H, CH=C-CH_2 and N=C-CH_2), 6.82 (m, 2H, aromatic protons), 7.35 (m, 1H, aromatic proton) and 7.51 (s, 1H, CH=C-CH_2) ppm.

$^{13}\text{C-NMR}$: δ 19.60, 22.22, 28.92, 31.19 (cyclopentane ring saturated carbons and methyl carbon), 104.60 (t, $J=26\text{Hz}$, aromatic C-3), 111.70 (d of d, $J_{d1}=21\text{Hz}$, $J_{d2}=3\text{Hz}$, aromatic carbon), 118.30 (d, $J=3\text{Hz}$, CH=C-CH_2), 120.75 (d, $J=17\text{Hz}$, aromatic C-1), 131.50 (d of d, $J_{d1}=6\text{Hz}$, $J_{d2}=3\text{Hz}$, aromatic carbon), 136.92 (CH=C-CH_2), 162.51 (d, $J=252\text{Hz}$, aromatic C-F), 162.53 (d, $J=252\text{Hz}$, aromatic C-F), 168.90 and 169.45 (C=O and C=N) ppm.

UV (methanol): λ_{max} 292 nm ($\epsilon=19,922$), 218 nm ($\epsilon=7758$).

Found: C, 63.28; H, 4.91; N, 5.18; F, 14.48%. $\text{C}_{14}\text{H}_{13}\text{NO}_2\text{F}_2$ requires C, 63.39; H, 4.94; N, 5.28; F, 14.32%.

4.27 Preparation of 2-(2-Thienylidene)cyclopentanone Oxime O-Acetate (237)

2-(2-Thienylidene)cyclopentanone oxime acetate was prepared from 2-(2-thienylidene)cyclopentanone (3.9 g, 0.02 mol), yielding golden plates of product (3.9 g, 82%), melting range 120-121°C.

IR(KBr pellet): 3117, 2968, 2942 (aromatic and aliphatic CH), 1758 (C=O), 1651 (C=N), 1594, 1424, 1367, 1267, 1203, 1045, 1003, 954, 883, 862 and 712 cm^{-1} .

$^1\text{H-NMR}$: δ 1.96 (qn, 2H, $J=7.9\text{Hz}$, $\text{CH}_2\text{-CH}_2\text{-CH}_2$), 2.22 (s, 3H, $\text{H}_3\text{C-C=O}$), 2.75 (t, 2H, $J=7.9\text{Hz}$, $\text{CH}_2\text{-C=N}$), 2.80 (t of d, 2H, $J_t=7.9\text{Hz}$, $J_d=2.9\text{Hz}$, CH=C-CH_2),

7.08 (t, 1H, J=4.9Hz, thienyl proton), 7.20 (d, 1H, J=4.9Hz, thienyl proton), 7.41 (d, 1H, J=4.9Hz, thienyl proton) and 7.75 (t, 1H, J=2.9Hz, CH₂-C-CH) ppm.

¹³C-NMR: δ 19.69, 22.05, 29.47, 31.05 (cyclopentane ring saturated carbons and methyl carbon), 120.22, 127.56, 127.93, 130.22, 131.99, 140.56 (aromatic and vinylic carbons), 168.84 (C=N) and 169.72(C=O) ppm.

UV (methanol): λ_{max} 324 nm (ε=25,390), 202 nm (ε=17,240).

Found: C, 61.17; H, 5.58; N, 5.91; S, 13.65; C₁₂H₁₃NOS requires C, 61.25; H, 5.57; N, 5.95; S, 13.63%.

4.28 Preparation of 2-(2-Naphthylidene)cyclopentanone Oxime O-Acetate (239)

2-(2-Naphthylidene)cyclopentanone oxime acetate was prepared from 2-(2-naphthylidene)cyclopentanone oxime (4.7 g, 0.02 mol) yielding yellow plates of product (4.1 g, 73%), melting range 95-96°C.

IR(KBr pellet): 3055, 3010, 2963, 2881 (aromatic and aliphatic CH), 1764 (C=O), 1649 (C=N), 1592 1503, 1463, 1435, 1420, 1365, 1334, 1307, 1296, 1264, 1250, 1199, 1126, 1040, 1001, 940, 880, 865, 817, 748 and 689 cm⁻¹.

¹H-NMR: δ 1.92 (qn, 2H, J=7.9Hz, CH₂-CH₂-CH₂), 2.23 (s, 3H, H₃C-C=O), 2.73 (t, 2H, J=7.9Hz, CH₂-CH₂-C=N), 2.92 (t of d, 2H, J_t=7.9Hz, J_d=2.9Hz, CH=C-CH₂), 7.51 (m, 3H, aromatic protons), 7.70 (d, 1H, J=2.9Hz, vinylic proton) and 7.85 (m, 4H, aromatic protons) ppm.

¹³C-NMR: δ 19.64, 22.36, 28.93, 31.31 (cyclopentane ring saturated carbons and methyl carbon), 126.26, 126.46, 126.96, 127.16, 127.38, 127.90, 128.22, 129.25 (naphthyl hydrogen bearing carbons and vinylic carbon), 132.74, 133.12, 133.84,

135.01 (naphthyl and cyclopentane ring quaternary carbon), 168.86 ($\text{C}=\text{N}$) and 170.05 ($\text{C}=\text{O}$) ppm.

UV (methanol): λ_{max} 322 nm ($\epsilon=33,480$), 282 nm ($\epsilon=35,712$), 222 nm ($\epsilon=48,800$).

Found: C, 77.35; H, 6.16; N, 4.96%. $\text{C}_{18}\text{H}_{17}\text{NO}_2$ requires C, 77.39; H, 6.13; N, 5.01%.

4.29 Preparation of 2-(3-Methoxybenzylidene)cyclopentanone Oxime O-Acetate (242)

2-(3-Methoxybenzylidene)cyclopentanone oxime acetate was prepared from 2-(3-methoxybenzylidene)cyclopentanone oxime (4.3 g, 0.02 mol), yielding white needles of product (4.1 g, 80%), melting range 69–70°C.

IR(KBr pellet): 2961, 2950, 2836 (aromatic and aliphatic CH), 1767 ($\text{C}=\text{O}$), 1652, 1596 ($\text{C}=\text{N}$), 1575, 1490, 1464, 1432, 1365, 1299, 1275, 1244, 1228, 1200, 1158, 1038, 1001, 940, 878, 778, 758, 697, 686 and 667 cm^{-1} .

^1H -NMR: δ 1.91 (qn, 2H, $J=7.8\text{Hz}$, $\text{CH}_2\text{-CH}_2\text{-CH}_2$), 2.23 (s, 3H, $\text{H}_3\text{C-C}=\text{O}$), 2.72 (t, 2H, $J=7.8\text{Hz}$, $\text{CH}_2\text{-C}=\text{N}$), 2.85 (t of d, 2H, $J_t=7.8\text{Hz}$, $J_d=1.9\text{Hz}$, $\text{CH}=\text{C-CH}_2$), 3.82 (s, 3H, $\text{H}_3\text{C-O-Ph}$), 6.86 (d of d, 1H, $J_{d1}=8.8\text{Hz}$, $J_{d2}=1.9\text{Hz}$, aromatic proton), 6.98 (s, 1H, aromatic proton), 7.05 (d, 1H, $J=7.8\text{Hz}$, aromatic proton), 7.30 (t, 1H, $J=7.8\text{Hz}$, aromatic proton,) and 7.52 (t, 1H, $J=1.9\text{Hz}$, $\text{CH}=\text{C-CH}_2$) ppm.

^{13}C -NMR: δ 19.75 (H_3C), 22.48, 29.12, 31.42 (cyclopentane ring saturated carbons), 55.47 (OMe), 113.78, 114.95, 122.12, 127.04, 129.34, 135.02, 137.67, 159.44 (aromatic and vinylic carbons), 168.86 ($\text{C}=\text{N}$) and 170.02 ($\text{C}=\text{O}$) ppm.

UV (methanol): λ_{max} 298nm ($\epsilon=23,153$), 210nm ($\epsilon=11,771$).

Found: C, 69.67; H, 6.57; N, 5.61; $C_{15}H_{17}NO_3$ requires C, 69.48; H, 6.61; N, 5.40%.

4.30 Preparation of 2-(3-Methylbenzylidene)cyclopentanone Oxime O-Acetate (245)

2-(3-Methylbenzylidene)cyclopentanone oxime acetate was prepared from 2-(3-methylbenzylidene)cyclopentanone oxime (4.0 g, 0.02 mol), yielding off-white needles of product (3.65 g, 75%), melting range 78-79°C.

IR(KBr pellet): 3032, 2961, 2890 (aromatic and aliphatic CH), 1765 (C=O), 1651, 1602 (C=N), 1488, 1431, 1366, 1296, 1274, 1196, 1040, 1004, 939, 883, 790 and 705 cm^{-1} .

1H -NMR: δ 1.88 (qn, 2H, $J=7.4Hz$, $CH_2-CH_2-CH_2$), 2.20 (s, 3H, H_3C-Ph), 2.37 (s, 3H, $H_3C-C=O$), 2.72 (t, 2H, $J=7.4Hz$, $CH_2-C=N$), 2.83 (t, 2H, $J=7.4Hz$, $CH=C-CH_2$), 7.11 (d, 1H, $J=5.6Hz$, aromatic proton), 7.25 (m, 3H, aromatic and vinylic protons) and 7.50 (d, 1H, $J=3.7Hz$, aromatic proton) ppm.

^{13}C -NMR: δ 19.61 ($H_3C-C=O$), 21.34 (H_3C-Ar), 22.32, 28.92, 31.21 (cyclopentane ring saturated carbons), 126.65, 127.20, 128.22, 128.85, 130.26, 134.45, 136.24, 137.87 (aromatic and vinylic carbons), 168.84 (C=N) and 170.07 (C=O) ppm.

UV (methanol): λ_{max} 282nm ($\epsilon=22,234$), 206nm ($\epsilon=13,728$)

Found: C, 74.02; H, 7.04; N, 5.70; $C_{15}H_{17}NO_2$ requires C, 74.05; H, 7.04; N, 5.76%.

4.31 Preparation of 2-(3-Nitrobenzylidene)cyclopentanone Oxime O-Acetate (248)

2-(3-Nitrobenzylidene)cyclopentanone oxime acetate was prepared from 2-(3-nitrobenzylidene)cyclopentanone oxime (4.6 g, 0.02 mol), yielding white needles of product (4.3 g, 78%), melting range 119-121°C.

IR(KBr pellet): 3084, 2965, 2882 (aromatic and aliphatic CH), 1768 (C=O), 1654, 1601 (C=N), 1528, 1420, 1301, 1263, 1196, 1098, 1001, 940, 881, 816, 736 and 669 cm^{-1} .

$^1\text{H-NMR}$: δ 1.92 (qn, 2H, $J=7.4\text{Hz}$, $\text{CH}_2\text{-CH}_2\text{-CH}_2$), 2.20 (s, 3H, $\text{H}_3\text{C-C=O}$), 2.73 (t, $J=7.4\text{Hz}$, 2H, $\text{CH}_2\text{-C=N}$), 2.86 (t of d, 2H, $J_t=7.4\text{Hz}$, $J_d=2.4\text{Hz}$, CH=C-CH_2), 7.52 (m, 2H, aromatic protons), 7.68 (d, 1H, $J=7.9\text{Hz}$, aromatic proton), 8.10 (m, 1H, aromatic proton) and 8.25 (t, 1H, $J=2.4\text{ Hz}$, vinylic proton) ppm.

$^{13}\text{C-NMR}$: δ 19.53 ($\text{H}_3\text{C-C=O}$), 22.27, 28.79, 31.10 (cyclopentane ring saturated carbons), 122.41, 123.37, 124.24, 129.37, 135.32, 137.83, 138.02, 148.19 (aromatic and vinylic carbons), 168.56 (C=N) and 169.24 (C=O) ppm.

UV (methanol): λ_{max} 288nm ($\epsilon=27,283$), 214nm ($\epsilon=15,182$).

Found: C, 61.07; H, 5.21; N, 10.16%. $\text{C}_{14}\text{H}_{14}\text{N}_2\text{O}_4$ requires C, 61.31; H, 5.14; N, 10.21%.

4.32 Preparation of 2-(3-Cyanobenzylidene)cyclopentanone Oxime O-Acetate (249)

2-(3-Cyanobenzylidene)cyclopentanone oxime acetate was prepared from 2-(3-Cyanobenzylidene)cyclopentanone oxime (4.0 g, 0.02 mol), yielding yellow plates of product (3.7 g, 76%), melting range 111-112°C.

IR(KBr pellet): 3075, 3039, 2968, 2890 (aromatic and aliphatic CH), 2235 ($\text{C}\equiv\text{N}$), 1773 (C=O), 1659 (C=N), 1601 1488, 1424, 1366, 1274, 1232, 1203, 1047, 938, 883, 805 and 683 cm^{-1} .

$^1\text{H-NMR}$: δ 1.91 (qn, 2H, $J=7.4\text{Hz}$, $\text{CH}_2\text{-CH}_2\text{-CH}_2$), 2.19 (s, 3H, $\text{H}_3\text{C-C=O}$), 2.72 (t, 2H, $J=7.4\text{Hz}$, $\text{CH}_2\text{-CH}_2\text{-C=N}$), 2.79 (t of d, 2H, $J_t=7.4\text{Hz}$, $J_d=2.9\text{Hz}$,

CH=C-CH₂), 7.44 (t, 1H, J=2.9Hz, CH=C-CH₂), 7.54 (m, 1H, aromatic proton), 7.60 (d, 1H, J=7.9Hz, aromatic proton) and 7.66 (s, 1H, aromatic proton) ppm.

¹³C-NMR: δ 19.53 (H₃C-C=O), 22.26, 28.79, 31.10 (cyclopentane ring saturated carbons), 112.58 (C=N), 118.45, 124.40, 129.28, 131.05, 132.25, 133.63, 137.42, 137.61 (aromatic and vinylic carbons), 168.60 (C=N) and 169.33 (C=O) ppm.

UV (methanol): λ_{max} 294 nm (ε=25,570), 226 nm (ε=14,415).

Found: C, 70.90; H, 5.61; N, 11.03%. C₁₅H₁₄N₂O₂ requires C, 70.85; H, 5.55; N, 11.02%.

4.33 Preparation of 2-(3-Fluorobenzylidene)cyclopentanone Oxime O-Acetate (250)

2-(3-Fluorobenzylidene)cyclopentanone oxime acetate was prepared from 2-(3-fluorobenzylidene)cyclopentanone oxime (4.1 g, 0.02 mol), yielding off-white needles of product (3.6 g, 74%), melting range 84-85°C.

IR(KBr pellet): 3082, 3032, 2968, 2890, 2847 (aromatic and aliphatic CH), 1773 (C=O), 1659 (C=N), 1616, 1579, 1488, 1445, 1374, 1303, 1274, 1232, 1203, 1153, 1047, 1004, 947, 890, 790, 769 and 684 cm⁻¹.

¹H-NMR: δ 1.88 (qn, 2H, J=7.4Hz, CH₂-CH₂-CH₂), 2.20 (s, 3H, H₃C-C=O), 2.71 (t, 2H, J=7.4Hz, CH₂-CH₂-C=N), 2.80 (t of d, 2H, J_t=7.4Hz, J_d=2.9Hz, CH=C-CH₂), 6.75 (t of d, 1H, J_t=8.4Hz, J_d=2.5Hz, aromatic proton), 7.11 (d of t, 1H, J_d=10.3Hz, J_t=2.0Hz, aromatic proton), 7.18 (d, 1H, J=7.9Hz, aromatic proton), 7.30(m, 1H, aromatic proton) and 7.46 (t, 1H, J=2.5Hz, vinylic proton) ppm.

¹³C-NMR: δ 19.53, 22.26, 28.84, 31.10 (cyclopentane ring saturated carbons and methyl carbon), 114.72, (d, J=21Hz, aromatic carbon), 115.58, (d, J=23Hz, aromatic carbon), 125.46 (CH₂-C-CH), 125.72 (d, J=3.0Hz, aromatic carbon),

129.75, (d, $J=9.1\text{Hz}$, aromatic carbon), 136.09 ($\text{CH}_2\text{-C=CH}$), 138.36, (d, $J=8.0\text{Hz}$, aromatic carbon), 161.33, 163.77 (d, $J=244\text{Hz}$, C-F), 168.67 and 169.67 (C=O and C=N) ppm.

UV (methanol): λ_{max} 298nm ($\epsilon=25,843$), 220nm ($\epsilon=9732$).

Found: C, 68.04; H, 5.73; N, 5.72; F, 7.87%. $\text{C}_{14}\text{H}_{14}\text{NO}_2\text{F}$ requires C, 68.00; H, 5.71; N, 5.66; F, 7.68%.

4.34 Preparation of 2-(3-Chlorobenzylidene)cyclopentanone Oxime O-Acetate (251)

2-(3-Chlorobenzylidene)cyclopentanone oxime acetate was prepared from 2-(3-chlorobenzylidene)cyclopentanone oxime (4.4 g, 0.02 mol), yielding yellow plates of product (3.6 g, 69%), melting range 77-78°C.

IR(KBr pellet): 3068, 2968, 2890, 2840(aromatic and aliphatic CH), 1773(C=O), 1659, 1602(C=N), 1566, 1481, 1424, 1367, 1274, 1210, 1203, 1082, 1004, 947, 890, 790, 719 and 684cm^{-1} .

$^1\text{H-NMR}$: δ 1.87 (qn, 2H, $J=7.9\text{Hz}$, $\text{CH}_2\text{-CH}_2\text{-CH}_2$), 2.18 (s, 3H, $\text{H}_3\text{C-C=O}$), 2.68 (t, 2H, $J=7.9\text{Hz}$, $\text{CH}_2\text{-CH}_2\text{-C=N}$), 2.77 (t of d, 2H, $J_t=7.9\text{Hz}$, $J_d=2.9\text{Hz}$, CH=C-CH_2), 7.23 (m, 3H, aromatic protons), 7.36 (s, 1H, aromatic H-2) and 7.41 (t, $J=2.9\text{Hz}$, vinylic proton) ppm.

$^{13}\text{C-NMR}$: δ 19.56 ($\text{H}_3\text{C-C=O}$), 22.26, 28.84, 31.11 (cyclopentane ring saturated carbons), 125.45, 127.73, 127.90, 128.95, 129.56, 134.18, 136.26, 138.03 (aromatic and vinylic carbons), 168.67 (C=N), and 169.61 (C=O) ppm.

UV (methanol): λ_{max} 298 ($\epsilon=22588$), 222nm ($\epsilon=9746$), 206nm ($\epsilon=11,663$).

Found: C, 63.79; H, 5.37; N, 5.26; Cl, 13.57%. $C_{14}H_{14}NO_2Cl$ requires C, 63.76; H, 5.35; N, 5.31; Cl, 13.44%.

4.35 General Procedure for the Preparation of Arylidenecyclopentanone Oxime O-Methyl Ethers (254-255)

The desired arylidenecyclopentanone oxime (2 g) was dissolved in acetone (50 ml), in a 250 ml three necked round bottom flask fitted with a reflux condenser and two 25 ml dropping funnels. A solution containing dimethyl sulphate (5 ml) and acetone (20 ml) was placed in one dropping funnel and 40%w/v aqueous sodium hydroxide solution (12 ml) was placed in the other. The two solutions were then slowly added simultaneously, dropwise with stirring to the oxime solution and the resulting solution was then heated under reflux. The reaction was monitored by TLC using a mobile phase of light petroleum/ethyl acetate (90:10) until all the oxime had been used up (approx. one hour). A further 10 ml of the 40% sodium hydroxide solution was then added to the reaction mixture to hydrolyse any unreacted dimethyl sulphate, and the acetone was removed by rotary evaporation. Diethyl ether (70 ml) was added to the reaction mixture and this was then transferred to a 100 ml separating funnel. The aqueous layer was run off and the ether layer was washed with dilute hydrochloric acid (2×50 ml), water (2×50 ml) and dried over anhydrous magnesium sulphate. The ether was then removed by rotary evaporation. A 90:10 mixture of light petroleum/ethyl acetate (100 ml) was added to the resulting oil and the mixture was passed through a sintered glass crucible covered with a small layer of silica to remove impurities. The light petroleum/ethyl acetate was removed by rotary evaporation, yielding the arylidene cyclopentanone oxime O-methyl ether which was recrystallised from methanol.

4.36 Preparation of 2-(2-Naphthylidene)cyclopentanone Oxime O-Methyl Ether (254)

2-(2-Naphthylidene)cyclopentanone oxime O-methyl ether was prepared from 2-(2-naphthylidene)cyclopentanone oxime (7.1 g, 0.03 mol), yielding white needles of product (4.37 g, 58%), melting range 113-114°C.

IR(KBr pellet): 3061, 2955 (aromatic and aliphatic CH), 1643, 1594 (C=N), 1171, 1051, 917, 889, 861, 813, 770, 739, 646 and 622 cm⁻¹.

¹H-NMR: δ 1.90 (qn, 2H, J=7.9Hz, CH₂-CH₂-CH₂), 2.63 (t, 2H, J=7.9Hz, CH₂-C=N), 2.92 (t of d, J_t=7.9Hz, J_d=2.9Hz, CH=C-CH₂), 4.03 (s, 3H, -CH₃), 7.42 (t, 1H, J=2.9Hz, CH₂-C-CH), 7.49 (m, 2H, aromatic protons), 7.59 (m, 1H, aromatic proton) and 7.85 (m, 4H, aromatic protons) ppm.

¹³C-NMR: δ 22.62, 27.42, 31.46 (cyclopentane ring saturated carbons), 62.03 (N-O-CH₃), 122.85, 126.07, 126.16, 127.12, 127.52, 127.77, 128.09, 128.45, 132.42, 133.30, 134.74, 137.15 (aromatic and vinylic carbons) and 162.47 (C=N) ppm.

UV (methanol): λ_{\max} 322nm (ϵ =27,343), 282nm (ϵ =22,812), 224nm (ϵ =21,875), 210nm (ϵ =21,093).

Found: C, 81.19; H, 6.70; N, 5.52; C₁₇H₁₇NO requires C, 81.24; H, 6.82; N, 5.57%.

4.37 Preparation of 2-(3-Methoxybenzylidene)cyclopentanone Oxime O-Methyl Ether (255)

2-(3-Methoxybenzylidene)cyclopentanone oxime O-methyl ether was prepared from 2-(3-methoxybenzylidene)cyclopentanone oxime (6.51 g, 0.03 mol) yielding a pale yellow liquid of product (4.5 g, 64%).

IR (KBr pellet): 2954, 2903, 2839 (aromatic and aliphatic CH), 1600 (C=N), 1588, 1492, 1467, 1429, 1300, 1251, 1162, 1054 and 882 cm^{-1} .

^1H -NMR: δ 1.81 (qn, 2H, $J=7.4\text{Hz}$, $\text{CH}_2\text{-CH}_2\text{-CH}_2$), 2.56 (t, 2H, $J=7.4\text{Hz}$, $\text{CH}_2\text{-C=N}$), 2.76 (t, 2H, $J=7.4\text{Hz}$, CH=C-CH_2), 3.75 (s, 3H, $-\text{CH}_3$), 3.95 (s, 3H, $-\text{CH}_3$), 6.79 (m, 1H, aromatic proton), 6.93 (s, 1H, aromatic proton), 7.01 (d, 1H, $J=2.0\text{Hz}$, aromatic proton), 7.19 (s, 1H, vinylic proton) and 7.25 (t, 1H, $J=2.0\text{Hz}$, aromatic proton) ppm.

^{13}C -NMR: δ 22.67, 27.50, 31.46 (cyclopentane ring saturated carbons), 55.21 (C-O- CH_3), 62.07 (C=N-O- CH_3), 112.98 (aromatic C-4), 114.71 (aromatic C-2), 121.93 (CH-C-CH_2), 122.78 (aromatic C-6), 129.31 (aromatic C-5), 137.15 (aromatic C-1), 138.62 (aromatic C-3), 159.51 (CH-C-CH_2) and 162.45 (C=N) ppm.

UV (methanol): λ_{max} 302nm ($\epsilon=18,041$), 224nm ($\epsilon=10,061$), 210nm ($\epsilon=13,608$).

Found: C, 73.10; H, 7.51; N, 6.09. $\text{C}_{14}\text{H}_{17}\text{NO}$ requires C, 72.70; H, 7.41; N, 6.06%.

4.38 Irradiation of 2-(4-Cyanobenzylidene)cyclopentanone Oxime O-Acetate (233)

2-(4-Cyanobenzylidene)cyclopentanone oxime acetate (500 mg, 1.84×10^{-3} moles) was dissolved in methanol (350 ml) and the solution was irradiated under standard conditions, the reaction being monitored by TLC with mobile phase 70:30 light petroleum/ethyl acetate. A complex mixture of components appeared on TLC, the concentration of which did not appear to change for the duration of the reaction. After two hours of irradiation, the reaction was stopped. No attempt was made to separate any of the considerable number of components present in the reaction mixture.

4.39 Irradiation of 2-(2,4-Difluorobenzylidene)cyclopentanone Oxime O-Acetate (236)

2-(2,4-Difluorobenzylidene)cyclopentanone oxime O-acetate (500 mg, 1.89×10^{-3} moles) was dissolved in methanol (350 ml), and the solution was irradiated under standard conditions, the reaction being monitored by TLC with mobile phase 70:30 light petroleum/ethyl acetate. Over the course of the reaction it was observed on TLC that the number of components in the photolysis mixture increased steadily. After two hours irradiation was stopped, a complex mixture of products resulted and no attempt was made to separate the components.

4.40 Irradiation of 2-(2-Thienylidene)cyclopentanone Oxime O-Acetate (237)

2-(2-Thienylidene)cyclopentanone oxime acetate (400 mg, 1.70×10^{-3} moles) was dissolved in methanol (350 ml) and irradiated under standard conditions, the photolysis being followed by TLC with mobile phase of 70:30 light petroleum/ethyl acetate. After irradiation for 15 minutes three new spots had appeared on TLC. The irradiation was continued and after 45 minutes one of the new spots had become the major component of the mixture. After 2 hours, all starting material had disappeared and only one major component remained. The photolysis was halted and the contents of the photolysis cell were transferred to a 500 ml round bottomed flask. The solvent was removed by rotary evaporation yielding a dark gum which was triturated with light petroleum b.pt. 60-80°C. The light petroleum was removed by rotary evaporation. Recrystallisation from light petroleum (b.pt. 60-80°C) yielded off-white plates of 6,7-dihydro-5*H*-thieno[3,2-*b*]cyclopenta[*e*]pyridine (238), (152mg, 51%), melting range 84-85°C.

IR (KBr pellet): 3089, 3039, 2968, 2918, 2854 (aromatic and aliphatic CH), 1545, 1538, 1431, 1395, 1381, 1310, 1232, 1075, 1033, 919, 890, 833, 833, 776, 691 and 684 cm^{-1} .

¹H-NMR: δ 2.21 (qn, 2H, J=7.4Hz, CH₂-CH₂-CH₂), 3.03 (t, 2H, J=7.4Hz, CH₂), 3.11 (t, 2H, J=7.4Hz, CH₂), 7.47 (d, 1H, J=5.9Hz, thienyl proton), 7.52 (d, 1H, J=5.9Hz, thienyl proton) and 7.95 (s, 1H, pyridyl proton) ppm.

¹³C-NMR: δ 23.83, 30.45, 33.87 (saturated carbons), 124.43, 125.70, 128.66, 131.24, 133.10, 154.64 and 164.39 (aromatic carbons) ppm.

UV (methanol): λ_{max} 302nm (ε=9,845), 228nm (ε=29,760), 202nm (ε=38,290).

Found: C, 68.44; H, 5.18; N, 7.94; S, 18.68. C₁₀H₉NS requires C, 68.54; H, 5.18; N, 7.99; S, 18.29%.

4.41 Irradiation of 2-(2-Naphthylidene)cyclopentanone Oxime O-Acetate (239)

2-(2-Naphthylidene)cyclopentanone oxime O-acetate (560 mg, 2.0×10⁻³ moles) was dissolved in methanol (350 ml) and irradiated under standard conditions, the photolysis being monitored by TLC using a mobile phase of 90:10 light petroleum/ethyl acetate. After irradiation for fifteen minutes, three new spots had appeared on TLC at the expense of starting material. After forty five minutes, the starting material and two of the other spots had disappeared, the other photoproduct now being the major component of the photolysis mixture. At this stage the photolysis was stopped. The contents of the photolysis cell were transferred to a 500 ml round bottomed flask and the methanol was removed by rotary evaporation yielding a brown gum. The residue was triturated using light petroleum (b.p. 60-80), and the resulting white solid recrystallised from light petroleum of b.pt. 80-100°C, yielding white needles of (240), (325 mg, 74%), melting range 115-116°C (lit.^{186a}, 114-116°C).

IR (KBr pellet): 3040, 2968, 2840 (aromatic and aliphatic CH stretch), 1616, 1573, 1516, 1438, 1395 (C=C and C=N ring stretching), 1260, 1196, 1033, 904, 797, 748 and 712 cm⁻¹.

¹H-NMR: δ 2.23 (qn, 2H, $J=7.9\text{Hz}$, $\text{CH}_2\text{-CH}_2\text{-CH}_2$), 3.07 (t, 2H, $J=7.9\text{Hz}$, cyclopentane ring protons), 3.26 (t, 2H, $J=7.9\text{Hz}$, N=C-CH_2), 7.59 (d, 1H, $J=8.9\text{Hz}$, aromatic proton), 7.70 (m, 3H, aromatic protons), 7.84 (s, 1H, aromatic proton), 7.89 (d of d, 1H, $J_1=7.9\text{Hz}$, $J_2=0.9\text{Hz}$, aromatic proton) and 9.35 (d, 1H, $J=8.4\text{Hz}$, aromatic proton) ppm.

¹³C-NMR: δ 23.57, 30.49, 34.70 (cyclopentane ring saturated carbons), 124.12, 124.90, 125.52, 126.30, 126.48, 127.34, 127.55, 130.60, 131.42, 133.20, 135.85, 145.32 and 166.14 (aromatic carbons) ppm.

UV (methanol): λ_{max} 352nm ($\epsilon=7212$), 336nm ($\epsilon=6422$), 272nm ($\epsilon=19,320$), 238nm ($\epsilon=37,415$), 202nm ($\epsilon=43,104$).

Found: C, 87.63; H, 5.97; N, 6.52; $\text{C}_{16}\text{H}_{13}\text{N}$ requires: C, 87.64; H, 5.98; N, 6.39%.

4.42 Irradiation of 2-(3-Methoxybenzylidene)cyclopentanone Oxime O-Acetate (242)

2-(3-Methoxybenzylidene)cyclopentanone oxime O-acetate (500 mg, 1.93×10^{-3} moles) was dissolved in methanol (350 ml) and the resulting solution was irradiated under standard conditions. The reaction was monitored closely by TLC with a mobile phase of 70:30 light petroleum/ethyl acetate. During the first twenty minutes of irradiation, three new spots appeared on TLC. Over the next thirty minutes one of these spots became the major component of the photolysis mixture at the expense of the starting material and the other initially formed products. After three hours, when there appeared to be no further change in the concentration of these spots on TLC, the irradiation was ceased and the contents of the flask were transferred to a 500ml round bottomed flask. The solvent was removed by rotary evaporation yielding a brown gum. The brown gum was then dissolved in a small volume of dichloromethane ($\approx 20\text{ml}$) and filtered through a thin layer of silica gel. The dichloromethane was then removed by rotary evaporation and the resulting white solid was recrystallised from light petroleum

(b.pt. 60-80°C) yielding white needles of 7-methoxy-2,3-dihydro-1*H*-cyclopenta[*b*]quinoline (244), (242 mg, 63%), melting range 96-97°C.

IR(KBr pellet): 3040, 2960, 2882, 2840 (aromatic and aliphatic CH), 1619, 1500 (C=C and C=N ring stretching), 1388, 1366, 1299, 1217, 1158, 1118, 1090, 1032, 902, 874, 828 and 616 cm⁻¹.

¹H-NMR: δ 2.72 (qn, 2H, J=7.9Hz, CH₂-CH₂-CH₂), 3.58 (t, 2H, J=7.9Hz, cyclopentane ring protons), 3.65 (t, 2H, J=7.9Hz, cyclopentane ring protons), 4.42 (s, 3H, OMe), 7.53 (d, 1H, J=2.0Hz, aromatic proton), 7.81 (d of d, 1H, J₁=8.9Hz, J₂=2.9Hz, aromatic proton), 8.32 (s, 1H, aromatic proton), and 8.45 (d, 1H, J=8.9Hz, aromatic proton) ppm.

¹³C-NMR: δ 23.28, 30.18, 33.93 (cyclopentane ring saturated carbons), 55.06 (OMe), 105.16, 120.07, 127.87, 128.93, 129.46, 135.52, 143.05, 156.70 and 164.98 (aromatic carbons) ppm.

UV (methanol): λ_{max} 334nm (ε=1,228), 236nm (ε=8,420), 208nm (ε=26,210).

Found: C, 78.45; H, 6.74; N, 6.98; C₁₃H₁₃NO requires C, 78.36; H, 6.58; N, 7.03%.

4.43 Irradiation of 2-(3-Methylbenzylidene)cyclopentanone Oxime O-Acetate (245)

2-(3-Methylbenzylidene)cyclopentanone oxime O-acetate (300 mg, 1.23×10⁻³ moles) was dissolved in methanol (350 ml) and irradiated under standard conditions, the photolysis being followed by TLC using a mobile phase of 70:30 light petroleum/ethyl acetate. After forty minutes three new spots were observed on TLC. Irradiation was continued for a further six hours when there was no further change in the concentration of the individual components on TLC. During this time one component was present which exceeded the concentration

of each of the other components. The photolysis was halted and the solvent was removed by rotary evaporation yielding a dark coloured oil. The major photoproduct was separated using a silica gel column with mobile phase 80:20 light petroleum/ethyl acetate. Recrystallisation from light petroleum (b.pt.60-80°C) yielded white crystals of 5-methyl-2,3-dihydro-1*H*-cyclopenta[*b*]quinoline (246), (72mg, 32%), melting range 92-94°C.

IR (KBr pellet): 3025, 2954, 2925, 2854 (aromatic and aliphatic CH), 1623, 1495, 1473, 1409, 1352, 918, 776 and 769 cm⁻¹.

¹H-NMR: δ 2.19 (qn, 2H, J=7.4Hz, CH₂-CH₂-CH₂), 2.80 (s, 3H, -Me), 3.05 (t, 2H, J=7.4Hz, CH₂), 3.16 (t, 2H, J=7.4Hz, CH₂), 7.32 (t, 1H, J=8.4Hz, aromatic proton), 7.44 (d, 1H, J=8.3Hz, aromatic proton), 7.55 (d, 1H, J=8.3Hz, aromatic proton) and 7.81 (s, 1H, aromatic proton) ppm.

¹³C-NMR: δ 18.32 (CH₃), 23.72, 30.43, 34.87 (cyclopentane ring saturated carbons), 125.04, 125.52, 127.22, 128.54, 130.46, 135.08, 136.20, 146.63 and 166.88 (aromatic carbons) ppm.

UV (methanol): λ_{max} 322nm (ε=4322), 305nm (ε=3872), 240nm (ε=28,412), 207nm (ε=22,338).

Found: C, 85.20; H, 7.51; N, 6.98. C₁₃H₁₃N requires C, 85.21; H, 7.15; N, 7.64%.

4.44 Irradiation of 2-(3-Nitrobenzylidene)cyclopentanone Oxime O-Acetate (248)

2-(3-Nitrobenzylidene)cyclopentanone oxime O-acetate (500 mg, 1.82×10⁻³ moles) was dissolved in methanol (350 ml) and irradiated under standard conditions, the reaction being monitored by TLC for its duration with mobile phase 70:30 light petroleum/ethyl acetate. During irradiation a number of different products appeared on TLC. The number of products increased during irradiation

with no single product being formed in excess. After three hours, when TLC showed no further change, the photolysis solution contained a complex mixture of products. Irradiation was stopped and no attempt was made to separate the products.

4.45 Irradiation of 2-(3-Cyanobenzylidene)cyclopentanone Oxime O-Acetate (249)

2-(3-Cyanobenzylidene)cyclopentanone oxime O-acetate (500 mg, 1.84×10^{-3} moles) was dissolved in methanol (350 ml) and the resulting solution was irradiated under standard conditions, the reaction being monitored by TLC with mobile phase 70:30 light petroleum/ethyl acetate. During irradiation it was observed on TLC that the number of components in the photolysis mixture increased steadily. After two hours irradiation was halted and no attempt was made to separate the components.

4.46 Irradiation of 2-(3-Fluorobenzylidene)cyclopentanone Oxime O-Acetate (250)

2-(3-Fluorobenzylidene)cyclopentanone oxime O-acetate (500 mg, 2.0×10^{-3} moles) was dissolved in methanol (350 ml) and the solution was irradiated under standard conditions, the reaction being monitored by TLC with a mobile phase of 70:30 light petroleum/ethyl acetate. During irradiation, as was noted with the *m*-chloro derivative, a steadily increasing number of products was observed on TLC. The photolysis reaction was allowed to run for four hours and was closely monitored over this time on TLC. A complex mixture of components resulted and no attempt was made to separate the components.

4.47 Irradiation of 2-(3-Chlorobenzylidene)cyclopentanone Oxime O-Acetate (251)

2-(3-Chlorobenzylidene)cyclopentanone oxime O-acetate (500 mg, 1.89×10^{-3} moles) was dissolved in methanol (350 ml) and the solution was irradiated under standard conditions, the reaction being monitored by TLC with

mobile phase 70:30 light petroleum/ethyl acetate. During irradiation a steadily increasing number of products appeared on TLC with no appreciable accumulation of any one product. The reaction was allowed to proceed for two hours. A complex mixture of products resulted and no attempt was made to separate the components.

4.48 Irradiation of 2-(2-Naphthylidene)cyclopentanone Oxime O-Methyl Ether (254)

2-(2-Naphthylidene)cyclopentanone oxime O-methyl ether (500 mg, 2.0×10^{-3} moles) was dissolved in methanol (350 ml) and irradiated under standard conditions, the photolysis being monitored by TLC using a mobile phase of 90:10 light petroleum/ethyl acetate. After irradiation for ten minutes, three new spots had appeared on TLC at the expense of starting material. After forty minutes, the starting material and two of the other spots had disappeared, the other photoproduct now being the major component of the photolysis mixture. The major photoproduct was distinguishable from starting material on TLC by its fluorescence under u.v. light compared to the starting material's dark colour. At this stage the photolysis was stopped. The contents of the photolysis cell were transferred to a 500 ml round bottomed flask and the methanol was removed by rotary evaporation yielding a dark brown gum. The major photoproduct was purified on a 4mm Chromatotron plate with a mobile phase of 90:10 light petroleum/ethyl acetate, and recrystallised from light petroleum of b.pt. 80-100°C, yielding white needles of (240), (314 mg, 72%), melting range 115-116°C (lit.^{186a}, 114-116°C).

4.49 Irradiation of 2-(3-Methoxybenzylidene)cyclopentanone Oxime O-Methyl Ether (255)

2-(3-Methoxybenzylidene)cyclopentanone oxime O-methyl ether (500 mg, 2.16×10^{-3} moles) was dissolved in methanol and irradiated under standard conditions, the photolysis being followed on TLC by a mobile phase of 90:10 light petroleum/ethyl acetate. During the first twenty minutes of irradiation three new

spots were seen to appear on TLC at the expense of starting material. Over the next fifty minutes one of these new spots became the major component of the photolysis mixture after which no further change was observed on TLC. At this stage the photolysis was stopped and the contents of the photolysis cell were transferred to a 500ml round bottomed flask. The methanol was removed by rotary evaporation yielding a dark brown gum. The major photoproduct was separated using a 4mm Chromatotron plate with a mobile phase of 90:10 light petroleum/ethyl acetate and was then recrystallised using light petroleum of b.pt. 40-60°C, yielding yellow needles of (244), (271 mg, 63%), melting range 96-97°C.

IR(KBr pellet): 3040, 2960, 2882, 2840 (aromatic and aliphatic CH), 1619, 1500 (C=C and C=N ring stretching), 1388, 1366, 1299, 1217, 1158, 1118, 1090, 1032, 902, 874, 828 and 616 cm^{-1} .

^1H -NMR: δ 2.72 (qn, 2H, $J=7.9\text{Hz}$, $\text{CH}_2\text{-CH}_2\text{-CH}_2$), 3.58 (t, 2H, $J=7.9\text{Hz}$, cyclopentane ring protons), 3.65 (t, 2H, $J=7.9\text{Hz}$, cyclopentane ring protons), 4.42 (s, 3H, OMe), 7.53 (d, 1H, $J=2.0\text{Hz}$, aromatic proton), 7.81 (d of d, 1H, $J_1=8.9\text{Hz}$, $J_2=2.9\text{Hz}$, aromatic proton), 8.32 (s, 1H, aromatic proton), and 8.45 (d, 1H, $J=8.9\text{Hz}$, aromatic proton) ppm.

^{13}C -NMR: δ 23.28, 30.18, 33.93 (cyclopentane ring saturated carbons), 55.06 (OMe), 105.16, 120.07, 127.87, 128.93, 129.46, 135.52, 143.05, 156.70 and 164.98 (aromatic carbons) ppm.

UV (methanol): λ_{max} 334nm ($\epsilon=1,228$), 236nm ($\epsilon=8,420$), 208nm ($\epsilon=26,210$).

Found: C, 78.45; H, 6.74; N, 6.98; $\text{C}_{13}\text{H}_{13}\text{NO}$ requires C, 78.36; H, 6.58; N, 7.03%.

4.50 Preparation of 2-Benzylidenecyclopentanone Oxime O-Acetate (264)

2-Benzylidenecyclopentanone oxime O-acetate was prepared by the standard method (pg.143) from 2-benzylidenecyclopentanone oxime²¹⁹ (5.6g, 0.03mol). Recrystallisation from light petroleum (b.p. 80-100) yielded white needles of product (6.2g, 90%), melting range 114-115°C.

IR (KBr pellet): 3030, 2960, 2850 (aromatic and aliphatic CH), 1766 (C=O), 1650 (C=N), 1600, 1580, 1493, 1460, 1292, 1276, 1199, 1154, 1033, 1006, 942, 867, 778, 752, 705, 685 and 665cm⁻¹.

¹H-NMR: δ 1.82(qn, 2H, J=7.4Hz, CH₂-CH₂-CH₂), 2.15(s, 3H, -CH₃), 2.66(t, 2H, J=7.4Hz, CH₂-C=N), 2.77(t of d, 2H, J_t=7.4Hz, J_d=2.5Hz, CH=C-CH₂), 7.22(m, 1H, aromatic proton), 7.30(m, 2H, aromatic protons), 7.37(m, 2H, aromatic protons), 7.47ppm(t, 1H, J=2.5Hz, vinylic proton).

¹³C-NMR: δ 19.60, 22.33, 28.92, 31.18(cyclopentane ring saturated carbons and methyl carbon), 127.22, 128.13, 128.46, 129.66, 134.80, 136.42(aromatic and vinylic protons), 168.99 and 170.20ppm (C=N and C=O).

UV (methanol): λ_{\max} 302nm (ϵ =22,672); 200nm (ϵ =28286).

Found: C, 73.44; H, 6.65; N, 6.10. C₁₄H₁₅NO₂ requires: C, 73.34; H, 6.59; N, 6.11%.

4.51 Preparation of 2-(4-Methoxybenzylidene)cyclopentanone Oxime O-Acetate (265)

2-(4-Methoxybenzylidene)cyclopentanone oxime O-acetate was prepared from 2-(4-methoxybenzylidene)cyclopentanone oxime (6.5g, 0.03mol) using the standard method (pg. 143). Recrystallisation from light petroleum (b.p. 60-80) yielded off-white needles of product (6.4g, 83%), melting range 88-89°C.

IR (KBr pellet): 2961, 2952, 2832(aromatic and aliphatic CH), 1765(C=O), 1650(C=N), 1593, 1575, 1492, 1466, 1434, 1365, 1290, 1240, 1235, 1201, 1155, 1043, 945, 880, 777, 752, 694 and 687cm⁻¹.

¹H-NMR: δ 1.89(qn, 2H, J=7.4Hz, CH₂-CH₂-CH₂), 2.23(s, 3H, -CH₃), 2.71(t, 2H, J=7.4Hz, CH₂-C=N), 2.82(t of d, 2H, J_t=7.4Hz, J_d=2.5Hz, C=C-CH₂), 6.90(d, 2H, J=6.4Hz, aromatic protons), 7.41(d, 2H, J=6.4Hz, aromatic protons) and 7.50ppm (s, 1H, vinylic proton).

¹³C-NMR: δ 19.63, 22.33, 28.96, 31.11(cyclopentane ring saturated carbons and acetyl group methyl carbon), 55.23(-OCH₃), 113.98, 126.93, 129.24, 131.26, 132.29, 159.60(aromatic and vinylic carbons), 169.52 and 170.52ppm (C=N and C=O).

UV (methanol): λ_{\max} 322nm (ϵ =27142), 226nm (ϵ =11,253), 202nm (ϵ =27212).

Found: C, 69.58; H, 6.65; N, 5.37. C₁₅H₁₇NO₃ requires C, 69.48; H, 6.61; N, 5.40%.

4.52 Preparation of 2-(1-Naphthylidene)cyclopentanone Oxime O-Acetate (266)

2-(1-Naphthylidene)cyclopentanone oxime O-acetate was prepared using the standard method (pg. 143) from 2-(1-naphthylidene)cyclopentanone oxime (7.1g, 0.03mol). Recrystallisation from light petroleum (b.p. 80-100) yielded white needles of product (7.2g, 86%), melting range 102-103°C.

¹H-NMR: δ 1.85(qn, 2H, J=7.4Hz, CH₂-CH₂-CH₂), 2.27(s, 3H, -CH₃), 2.73(t of d, 2H, J_t=7.4Hz, J_d=2.5Hz, C=C-CH₂), 2.80(t, 2H, J=7.4Hz, -CH₂-C=N), 7.50(m, 4H, aromatic protons), 7.82(m, 2H, aromatic protons) and 8.15ppm (m, 2H, aromatic and vinylic protons).

^{13}C -NMR: δ 19.66, 22.23, 29.24, 31.43(cyclopentane ring saturated carbons and methyl carbon), 124.55, 125.11, 126.06, 126.31, 126.84, 128.53, 128.70, 131.91, 133.48, 137.16(aromatic and vinylic carbons), 169.11 and 169.68ppm ($\text{C}=\text{N}$ and $\text{C}=\text{O}$).

UV (methanol): λ_{max} 330nm ($\epsilon=13875$), 254nm ($\epsilon=11592$), 224nm ($\epsilon=27156$), 208nm ($\epsilon=30504$).

Found: C, 77.53; H, 6.17; N, 4.89. $\text{C}_{18}\text{H}_{17}\text{NO}_2$ requires C, 77.39; H, 6.13; N, 5.01%.

4.53 General Procedure for the Photolysis of Arylidene cyclopentanone Oxime O-Acetates using the "Solfin" Apparatus.

The desired arylidene cyclopentanone acetate (18×10^{-3} moles) was dissolved in methanol (500cm^3) in a volumetric flask. This solution was poured into the reservoir on the Solfin apparatus. To this was added an additional 700cm^3 of methanol giving the solution an overall volume of 1200cm^3 . A large black cloth was then draped across the whole apparatus, excluding light. The pump was then switched on and the solution allowed to circulate and mix thoroughly. During circulation, the refrigeration system was started and the thermostat set at 13°C . Argon gas was then bubbled through the solution in the reservoir for thirty minutes, after which the black cloth was removed allowing the reaction to start. An atmosphere of argon was maintained over the reaction mixture for the duration of the reaction. Samples of reaction mixture (1cm^3) were removed via the solvent reservoir at ten minute intervals for the first twenty minutes and at designated intervals after this, depending on how the reaction seemed to be progressing, using HPLC analysis as a guide. When the reaction was complete, the apparatus was emptied and the solvent was removed from the reaction mixture by rotary evaporation. The photoproducts were isolated by column chromatography using silica gel as stationary phase and a light

petroleum-ethyl acetate mix in the ratio of 80:20 as eluent unless otherwise stated.

4.54 Irradiation of 2-Benzylidenecyclopentanone Oxime O-Acetate (264)

2-Benzylidene cyclopentanone oxime acetate (264) (4.12 g), was irradiated for 580 minutes. Rotary evaporation of the reaction mixture yielded a brown gum, which on purification by chromatography and recrystallisation from light petroleum (bp 60-80°C) gave white crystals of 2,3-dihydro-1*H*-cyclopenta[*b*]quinoline (215), melting range 60-61°C (1.4 g, 45%) (lit.²²⁰, 60-61°C).

4.55 Irradiation of 2-(4-Methoxybenzylidene)cyclopentanone Oxime O-Acetate (265)

2-(4-Methoxybenzylidene)cyclopentanone oxime O-acetate (265), (4.37 g), was irradiated for 515 minutes. Rotary evaporation of the reaction mixture yielded a brown gum, which on purification by chromatography and recrystallisation from light petroleum (bp 60-80°C) gave white crystals of 6-methoxy-2,3-dihydro-1*H*-cyclopenta[*b*]quinoline (220c), melting range 58-60°C (2.1 g, 63%) (lit.²²¹, 58-60°C).

4.56 Irradiation of 2-(1-Naphthylidene)cyclopentanone Oxime O-Acetate (266)

2-(1-Naphthylidene) cyclopentanone oxime acetate (266), (5.02 g), was irradiated for 360 minutes. Evaporation of the reaction mixture yielded a brown crystalline solid, which on recrystallisation from light petroleum 60/80 yielded white crystals of 1-aza-cyclopenteno[*b*]phenanthrene (218), melting range 119-120°C (3.7 g, 96%), (lit.^{186a} 118-120°C).

4.57 Irradiation of 2-Thienylcyclopentanone Oxime O-Acetate (237)

2-Thienylcyclopentanone oxime O-acetate (237), (4.23g), was irradiated for 680 minutes. Removal of solvent yielded a brown gum, which

on purification by column chromatography and recrystallisation from light petroleum (bp 60-80°C) yielded off-white crystals of 6,7-dihydro-5H-thieno[3,2-b]cyclopenta[e]pyridine (238), (1.9 g, 62%).

4.58 Irradiation of 2-(2-Naphthylidene)cyclopentanone Oxime O-Acetate (239)

2-(2-Naphthylidene) cyclopentanone oxime O-acetate (239), (5.02g), was irradiated for 520 minutes. Removal of solvent by rotary evaporation yielded a brown gum, which on purification by column chromatography and recrystallisation in light petroleum (bp 60-80°C) gave white crystals of 4-aza-cyclopenteno[b]phenanthrene (240), (2.6 g, 65%) melting range 115-116°C (lit.^{186a}. 114-116°C).

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