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# X=Y-ZH Systems as Potential 1,3-Dipoles. Part 34.[1,2] Generation of Nitrones from Oximes. Tandem Michael Addition-1,3-Dipolar Cycloaddition Reactions. Class 2 Processes Utilising Bifunctional Michael Acceptor-Dipolarophile Components.

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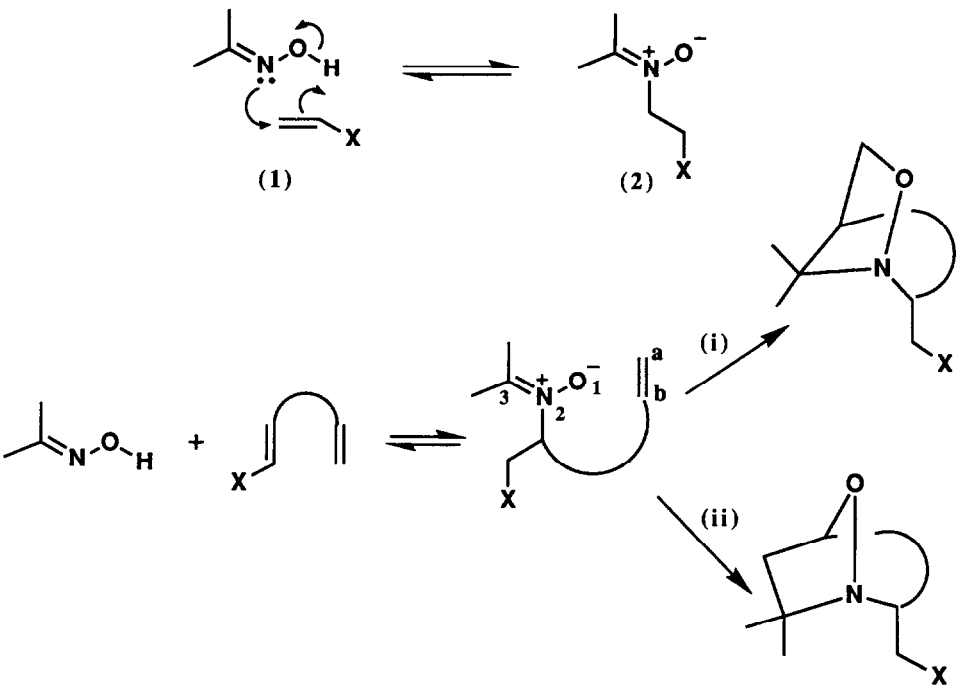
*Abstract: Aldoximes and ketoximes react with a range of bifunctional Michael acceptor-dipolarophile substrates comprising functionalised 1,3-, 1,4- and 1,5-dienes via a tandem process involving an N-alkenyl nitrone intermediate The 1,3-dienes react regio- and stereo-specifically to give 1-aza-7-oxabicyclo[2 2 1]heptanes whilst sterically unencumbered aryl aldoximes and 1,4-dienes give 1-aza-2-oxabicyclo[3 2 1]octane derivatives Ketoximes and 1,4-dienes give mixtures of 1-aza-2-oxa- and 1-aza-8-oxa-bicyclo[3 2 1]octanes 1,5-Dienes and ketoximes react regio- and stereo-specifically to give 1-aza-8-oxabicyclo[3 2 1]octane derivatives whilst benzaldoxime gives a 1 1 mixture of epimeric 1-aza-8-oxabicyclo[3 2 1]octanes together with traces of two epimeric 1-aza-2-oxabicyclo[3 2 1]octanes The regio- and stereo-chemical outcome of the tandem process is controlled by the length and nature of the linking chain in the bifunctional substrate and the steric interactions between substituents on the oxime and dipolarophile in the transition state A crystal structure of one of the 1-aza-7-oxabicyclo[2 2 1]heptanes is reported*

The oxime tandem Michael addition-1,3-dipolar cycloaddition process is capable of four broad synthetic variants (classes) depending on whether each component of the tandem process occurs in an inter- or intramolecular fashion.[3] Although our current data does not allow a distinction to be made between an initial Michael addition or ene- like process (1) → (2)[3,4] this uncertainty does not materially affect the analysis of the reaction's synthetic scope. Class 2 processes are particularly wide ranging and synthetically flexible because the dipolarophile can be located within the oxime (Class 2, type 1),[1] or the Michael acceptor and dipolarophile

can be combined in a bifunctional reagent (Class 2, type 2). The former methodology proceeds via a C-alkenyl nitrone and was discussed in the preceeding paper of this series.[1] The latter methodology involves an N-alkenyl nitrone intermediate (Scheme 1) and forms the subject of this paper. A further significant difference between the Class 2 type 1 and 2 processes is that the former can give rise to either a fused- or bridged-ring product (and invariably gives the fused-ring product)[1] whilst the latter process can only furnish bridged-ring products (Scheme 1). However, the class 2, type 2, process can furnish two different bridged-ring products depending on the regiochemistry of the cycloaddition step (Scheme 1). The regioselectivity of the cycloaddition step is dependent on the length and nature of the chain linking the Michael acceptor and dipolarophile as will become apparent below. In the cases considered herein (N- 3- and-4-alkenyl nitrones) only endo-transition states are stereochemically achievable and this greatly simplifies the potential stereochemical complexities of the products




**Scheme 1. Class 2, type 2 processes (i) 1,a / 3,b - bonding (ii) 1,b / 3,a - bonding.**

**N-(3-Alkenyl)nitrones.** The reaction of both aldoximes and ketoximes (3) with the 1,3-dienes (4a) and (4b) was studied. The initial Michael addition furnishes the N-(3-alkenyl)nitrone (5) ⇌ (6) which can undergo cycloaddition to either (7) [Scheme 1, path (i)] or (8) [Scheme 1, path (ii)]. In all cases studied (8) was the sole product (Table 1).

P.m.r studies of the cycloadducts from the reaction of (3) with (4) failed to distinguish unequivocally between the alternative structures (7) and (8). However, the $^{13}C$ n.m.r. spectra of the products clearly favoured structure (8), e.g. the chemical shift of the bridgehead tetrasubstituted carbon atom C(4) in (8d) occurs at 92.3 Hz The calculated chemical shift of C(4) in (8, X=P(O)$Ph_2$) is 93.4Hz whilst the calculated chemical shift for the analogous bridgehead carbon atom in (7) is 71 3Hz [5,6] Furthermore, a single crystal X-ray structure

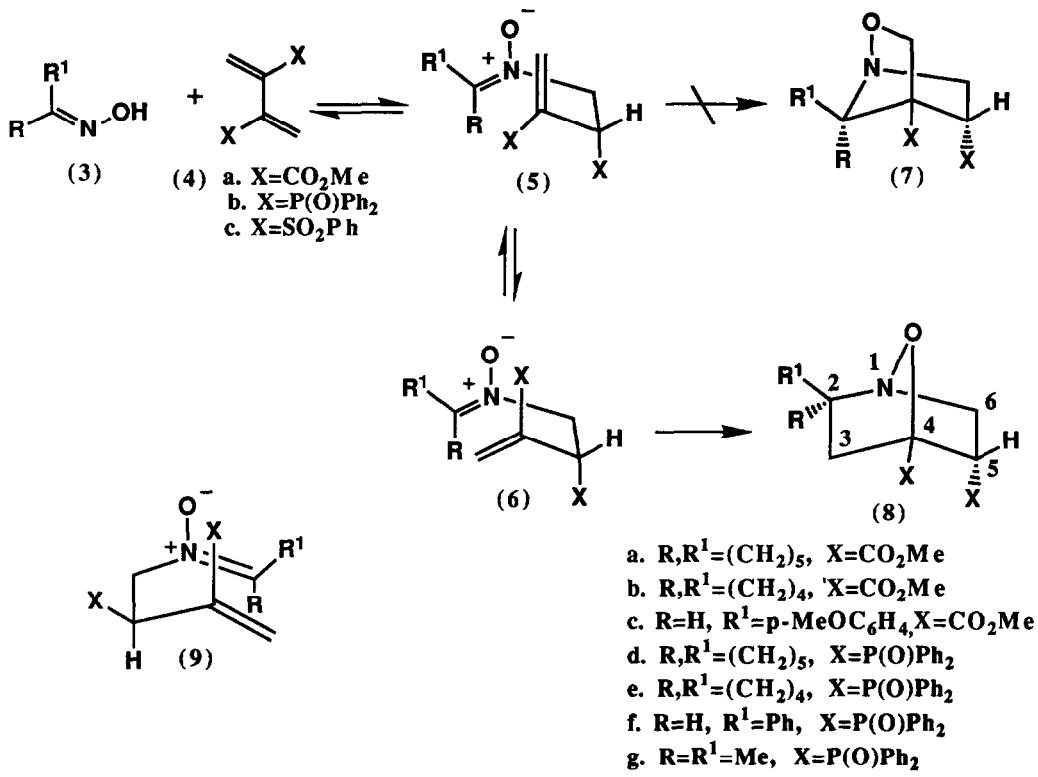



**Table 1. Reaction of oximes (3) with 1,3-dienes (4) to give 1-aza-7-oxabicyclo[2.2.1]heptanes(8).**

| Oxime | 1,3-Diene | Solvent | Temp(°C) | Time(h) | Product | Yield(%) |
|---|---|---|---|---|---|---|
| cyclohexanone | 4a | MeCN | 80 | 16 | 8a | 92 |
| cyclopentanone | 4a | MeCN | 80 | 16 | 8b | 65 |
| p-$MeOC_6H_4$ | 4a | xylene | 140 | 72 | 8c | 30 |
| cyclohexanone | 4b | xylene | 140 | 12 | 8d | 68[a] |
| cyclopentanone | 4b | xylene | 140 | 12 | 8e | 77[b] |
| $C_6H_5$ | 4b | xylene | 140 | 8 | 8f | 63 |
| acetone | 4b | xylene | 140 | 16 | 8g | 60[c] |

a. 75% conversion to products b. 80% conversion to products c. 60% conversion to products

determination shows the benzaldehyde oxime cycloadduct of (4b) has structure (8f) (Figure 1). Thus the intermediate nitrone derived from (E)-benzaldoxime has the (Z)-configuration, e.g. (5, R=H, $R^1$=Ph) rather than the (E)-configuration(5, R=Ph, $R^1$=H). This accords with observations from alkylation reactions of oximes that (Z)-aldonitrones are the observed products from E-aldoximes.[7]

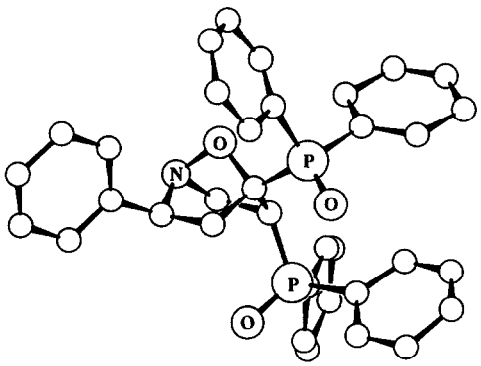


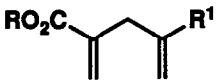

FIGURE 1

In neither of the two pre-transition state conformers (5) and (6) is it possible to superimpose the two pairs of reacting centres correctly for the desired cycloaddition without bond angle deformation. Thus the cycloaddition transition state will reflect a balance of angle deformation and the degree of asynchroniety of bond formation in the concerted process. Although it is possible to account for the observed regiochemistry in terms of overlap of the reacting centres with the highest FMO coefficients[8] it is believed that the key factor in determining the regiochemistry is the angle strain developing at the single atom bridges in transition states leading to the bicyclo[2.2.1] systems (7) and (8). The deformation is energetically less demanding for $sp^3$ oxygen with a smaller initial bond angle (but higher force constant) compared to $sp^3$ carbon. The endo-orientation of the X group in (8) reflects the lower energy transition state arising from conformer (6) as compared to conformer (9). Padwa has reported an example of a class 2, type 2, process involving the di(phenylsulphonyl) butadiene (4c) and leading to cycloadducts (8, X=$SO_2$Ph). His MMX calculations indicate that the transition state leading to (8) is ca. 2.5 kcal/mol below that leading to (7) [9]

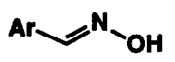
**N-(4-Alkenyl)nitrones.**

**a. From 1,4-Dienes.** A series of 1,4-dienes (10 a,b) and (11a-c) have been evaluated as bifunctional Michael acceptor/dipolarophile components with (10a) being the most extensively studied. The reaction of the aryl aldoximes (12a-d) and (17a) with (10a) occurs in boiling xylene to furnish a single cycloadduct (15a-e) in moderate to good yield (Table 2). Thus the aldoxime C-atom forms the single atom bridge. The intermediate N-(4-alkenyl)nitrones can undergo cycloaddition to give either (15) [scheme 1, path (i)] or (16)[scheme 1, path (ii)]. The incorporation of the $SO_2$ group into the chain linking the Michael component and dipolarophile allows reasonable alignment of the two pairs of reacting centres in both the pre-transition state conformers (13) and (14). Kinetic selection between the two appears finely balanced (see below) with developing non-bonded interactions in the transition state(s) responsible for the outcome of the cycloaddition. Thus the sterically most demanding aldoxime (17b) reacts with (10a) to give a 2:1 mixture of (15f) and (16a) and similarly the ketoximes of cyclopentanone, cyclohexanone, and acetone, and the 4-piperidone oximes (18a,b) give mixtures of the respective cycloadducts (15) and (16), and (19) and (20) (Table 2). Interestingly when cyclohexanone

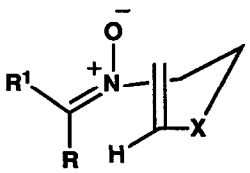
(10) a. X=$SO_2$
b. X=P(O)Ph



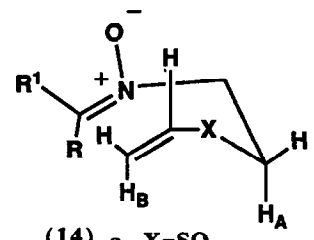
(11) a. R=Me, $R^1$=H
b. R=Me, $R^1$=$CO_2Me$
c. R=Et, $R^1$=$CO_2Et$



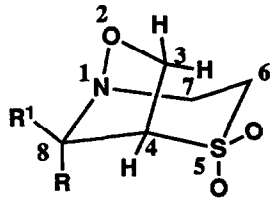
(12) a. Ar=Ph
b. Ar= 4-$MeOC_6H_4$
c. Ar= 4-$O_2NC_6H_4$
d. Ar= 2,4-$(MeO)_2C_6H_3$



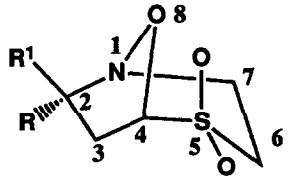
(13) a. X=$SO_2$
b. X=P(O)Ph
c. X=$CH_2$



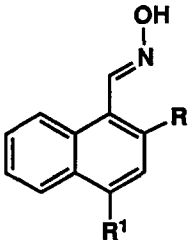
(14) a. X=$SO_2$
b. X=P(O)Ph
c. X=$CH_2$



(15) a. R=H, $R^1$=Ph
b. R=H, $R^1$=4-$MeOC_6H_4$
c. R=H, $R^1$=4-$O_2NC_6H_4$
d. R=H, $R^1$=2,4-$(MeO)_2C_6H_3$
e. R=H, $R^1$=1-(4-methoxynaphthyl)
f. R=H, $R^1$=1-(2-methoxynaphthyl)
g. R,$R^1$= $(CH_2)_4$
h. R,$R^1$= $(CH_2)_5$
i. R=$R^1$=Me

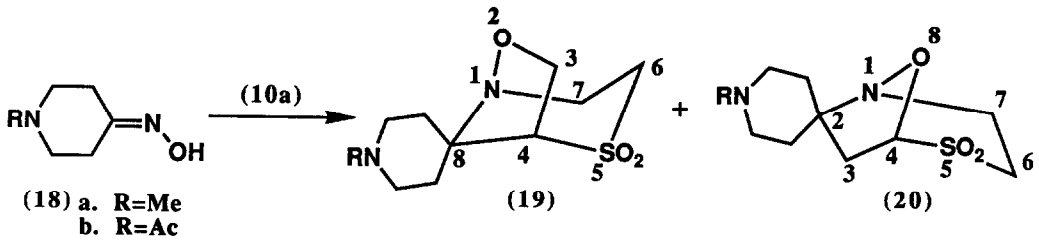


(16) a. R=H, $R^1$=1-(2-methoxynaphthyl)
b. R,$R^1$=$(CH_2)_4$
c. R,$R^1$=$(CH_2)_5$
d. R=$R^1$=Me



(17) a. R=H, $R^1$=MeO
b. R=OMe, $R^1$=H

oxime was allowed to react with (10a) in acetonitrile at room temperature over 10 days a slow reaction occurred to give (60%) essentially the same mixture of (15h) and (16c) as that obtained at 80°C (Table 2).




(18) a. R=Me
b. R=Ac

(19) (20)

**Table 2. Reaction of Oximes with Divinyl Sulphone (10a)**

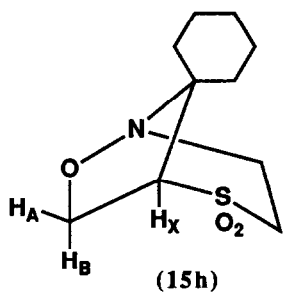
| Oxime | Solvent | Temp(°C) | Time(h) | Product(ratio) | Yield(%) |
|---|---|---|---|---|---|
| 12a | xylene | 140 | 6 | 15a | 60 |
| 12b | xylene | 140 | 7 | 15b | 55 |
| 12c | xylene | 140 | 34 | 15c | 55 |
| 12d | xylene | 140 | 2.5 | 15d | 75 |
| 17a | xylene | 140 | 16 | 15e | 84 |
| 17b | xylene | 140 | 18 | 15f(1.6),16a(1) | 72 |
| cyclopentanone | MeCN | 80 | 5 | 15g(3.5),16b(1) | 100 |
| cyclohexanone | MeCN | 80 | 6 | 15h(1),16c(1.8) | 78 |
| cyclohexanone | MeCN | 25 | 240 | 15h(1),16c(1.6) | 60 |
| 18a | MeCN | 80 | 12 | 19a(1),20a(1) | 70 |
| 18b | MeCN | 80 | 24 | 19b(1),20b(1) | 55 |
| acetone | MeCN | 80 | 6 | 15i(1),16d(1.4) | 88 |

The increased chain length in the N-alkenyl nitrone intermediate (13 ⇌ 14) compared to (5 ⇌ 6) results in the loss of the unfavourable angle strain at the single atom bridge in the transition states leading to (15) and (16).

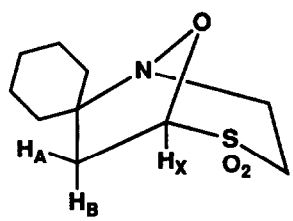
Moreover, both (15h) and (16c) were recovered unchanged on heating in xylene at 140°C for 20h. Making the assumption that this observation applies to the other isomeric mixtures of (15) and (16), or (19) and (20), we conclude that these isomer mixtures result from a kinetically controlled process. The explanation as to why aryl aldoximes (12a - d) and (17a) give a single product (15a - e), whilst ketoximes give mixtures of (15) and (16) is not immediately obvious although a study of molecular models is instructive. Assuming the aryl ring in (13a, R=H, $R^1$=aryl) and (14a, R=H, $R^1$=aryl) remains coplanar with the C=N-O moiety as these conformations transform into the respective transition states, then the transition state derived from (14a) experiences steric compression between protons $H_A$ and $H_B$ whilst that derived from (13a) does not. In the corresponding transition states of the cycloalkanone oximes, e.g. those derived from [13a, R, $R^1$=$(CH_2)_5$] and [14a, R, $R^1$=$(CH_2)_5$], significant non-bonded interactions develop between the psuedo axial C(8) R group and axial S-O moiety in the transition state derived from (13) thus offsetting the $H_A/H_B$ steric compression in the transition state derived from (14).

The observation that the rate of reaction of the arylaldoximes is in the order: 2,4-$(MeO)_2C_6H_3$>4-$MeOC_6H_4$>4-$O_2NC_6H_4$ (Table 2) reflects the importance of the nucleophilicity of the oxime nitrogen atom in the Michael addition (or ene-like) step. Padwa[9] has reported analogous and in some cases identical examples to those reported in our preliminary communications, of these tandem processes.[2,3,10] Interestingly our result with acetone oxime and (10a) (MeCN, 80°C) gives (16d) as the major product whilst reaction in methylene chloride affords a 3:2 mixture of (15i) and (16d).[9]

Isomers (15) and (16), or (19) and (20), are readily distinguished by their p.m.r. spectra. An illustrative example is provided by (15h) and (16c).




(15h)




(16c)

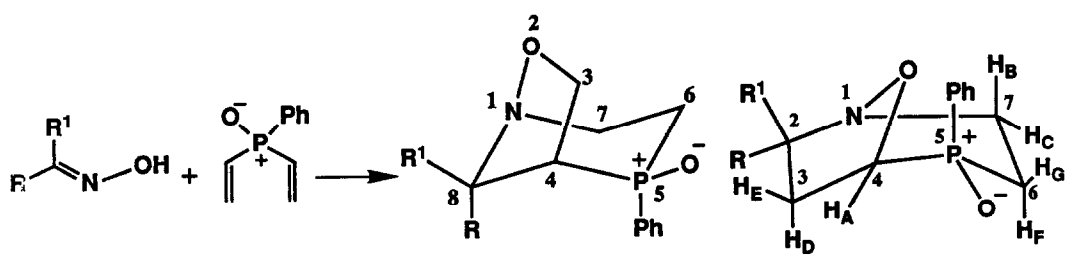
In both (15h) and (16c) the ABX systems are readily identified by decoupling experiments. In (15h) the signal for $H_X$ occurs as part of a multiplet of overlapping signals at δ 3.58, whilst $H_A$ occurs at δ 4.27(dd, J 10 and 6.1 Hz) and $H_B$ at δ 4.56(d, J 10 Hz). In (16c) the proton $H_X$(δ 4.90, dd) is deshielded by both the oxygen atom and the $SO_2$ moiety. Protons $H_A$ and $H_B$ occur at δ 2.69(dd, J 14.6 and 9Hz) and δ 2.41(dd, J 14 6 and 2.3 Hz) respectively. The coupling constant $J_{AX} > J_{BX}$ as expected from the Karplus equation.

Although a less extensive study of the reactions of oximes with (10b) was carried out it is clear that replacing the $SO_2$ moiety in (10a) by the P(O)Ph moiety in (10b) has a marked effect on the regioselectivity of the tandem cycloaddition processes (Table 4). Thus (10b) reacts (xylene, 140°C, 48h) with 4-methoxybenzaldoxime (12b) to give a 1:2 mixture of (21a) and (22a). In contrast aliphatic ketoximes derived from acetone, cyclopentanone, and cyclohexanone react (xylene, 140°C, 24-60h) to give only (22 b-d) in 70-73% yield The stereochemistry of the cycloadducts is based on their p.m.r. data. The chair conformation with an axial P-phenyl substituent for (22c) is derived from the data presented in Table 3.

**Table 3. Chemical Shifts and Coupling Constants ($CDCl_3$) for (22c).**

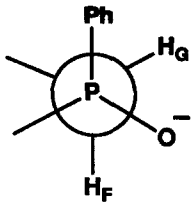
| Proton | δ | J(Hz) |
|---|---|---|
| A | 4.71 | AE 9.86, AD 3.48, AP small, AG 2.04 |
| B | 3.63 | BC 15.48, BG 5.35, BF 12.04, BP 1.01 |
| C | 3.48 | CG 2.04, CF 6.86, CP 22.63 |
| D | 2.78 | |
| E | 2.66 | |
| F | 2.20 | FG 15.39, FP 16.28 |
| G | 2.13 | GP 16.30 |

The chair conformation (22c), rather than a boat conformation with an equatorial P-Ph and axial P-O groups, is supported by the observation of a significant n.O.e. from the ortho-phenyl protons to the axial proton $H_B$ (not possible in the boat conformer). The 2-bond HP coupling constants for the H-C-P-O array are orientation dependant. For an H/O dihedral angle of $180^0$ the H/P coupling constant is very small (near zero) whilst for a dihedral angle of ca. $60^0$ a medium-sized HP coupling is expected.[11] In the chair conformation (22c) the P-C(6) conformation is as shown in Figure 2 (A) whilst that of corresponding boat conformer is shown in Figure 2(B). The observed coupling constants $J_{FP}$ and $J_{GP}$ are both 16.3Hz (Table 3) thus supporting conformer (22c). Finally calculations using the MOLOC program[12] suggest the chair conformer (22c) is at least 3 kcals/mole more stable than the corresponding boat conformer. Less extensive n.m.r. studies were carried out on (21a) but n.O.e. data again suggest the P-Ph group has an axial orientation. Thus irradiation of 8-H effects a 5.5% enhancement of the o-Ph protons.

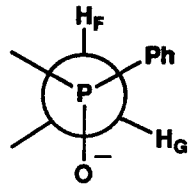


**(21) a. R=H, $R^1$= 4-$MeOC_6H_4$**

**(22) a. R=H, $R^1$= 4-$MeOC_6H_4$**
**b. R=$R^1$=Me**
**c. R,$R^1$=$(CH_2)_4$**
**d. R,$R^1$=$(CH_2)_5$**




(A)




(B)

**Figure 2**

The regiochemical outcome of the tandem processes involving (10a) and (10b) is summarised in Table 4

**Table 4. Regiochemistry of Tandem Cycloaddition Reactions of Oximes with (10a) and (10b).**

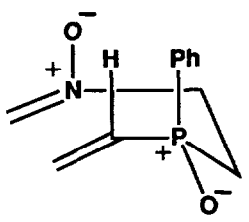
| Oxime type | Divinylsulphone | Divinyl phenylphosphine oxide |
|---|---|---|
| Aldoximes | Regiospecific C-bridged[a] | C- and O-bridged adducts[b] |
| Ketoximes | C- and O-bridged adducts | Regiospecific O-bridged |

a. C-bridged = (15) or (19), O-bridged = (16) or (20).

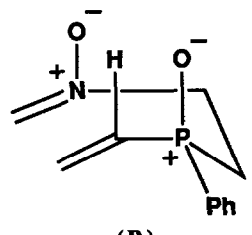
b. C-bridged = (21), O-bridged = (22).

The reversal of regiochemical trends evident in Table 4 reflects the steric demand of P(O)Ph versus $SO_2$.

The axial orientation of the P-Ph group in (22) is more easily accommodated due to the decreased 1,3-diaxial interactions consequent on replacing a ring methylene by an oxygen atom and suggests a role for internal dipole compensation in lowering the transition state energy.[13] Thus the preferred transition state is arises from the conformer in which the dipoles are opposed [Figure 3 (A)] rather than one in which they are aligned [Figure 3 (B)].



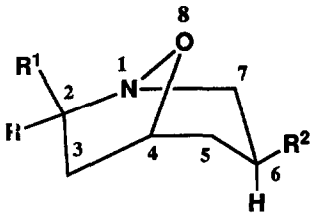

(A)



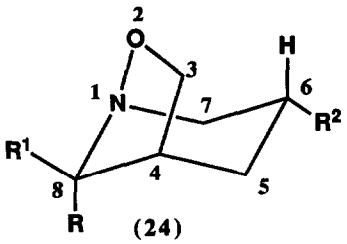

(B)

**Figure 3**

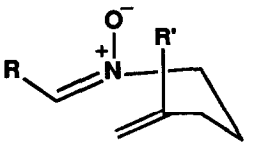
Only one example of a tandem process involving (11a) was studied. The reaction of cyclohexanone oxime with (11a) required severe conditions (mesitylene, 165°C, 4dy) and gave a 2:1 mixture (56%) of (23a) and (24a). This result is not inconsistant with the report that (25a) undergoes thermal cycloaddition (toluene, 110°C, 3h) to give a 1:2.3 mixture of (23b) and (24b).[14] Oppolzer has shown that certain N-alkenylnitrones (25) undergo regiospecific cycloadditions to give analogues of (23). In this latter case the nitrones were prepared from N-alkenyl hydroxylamines.[14] The conformations of (23a) and (24a) were assigned from p.m.r. studies. In particular the peak width of the multiplets for the 6-endo-H in (23a) and (24a) were >30Hz as expected for coupling to two adjacent equatorial and axial protons. We have calculated the energy difference between (23b) and (24b) and their respective boat conformers using the MOLOC program. The 1-aza-2-oxabicyclo [3.2.1]octane (24b) is 1.3 kcal/mole more stable than (23b) whilst the corresponding boat conformers are 3-4 kcal/mole less stable than (23b) and (24b).



(23) a. $R,R^1=(CH_2)_5$, $R^2=CO_2Me$
b. $R=R^1=R^2=H$

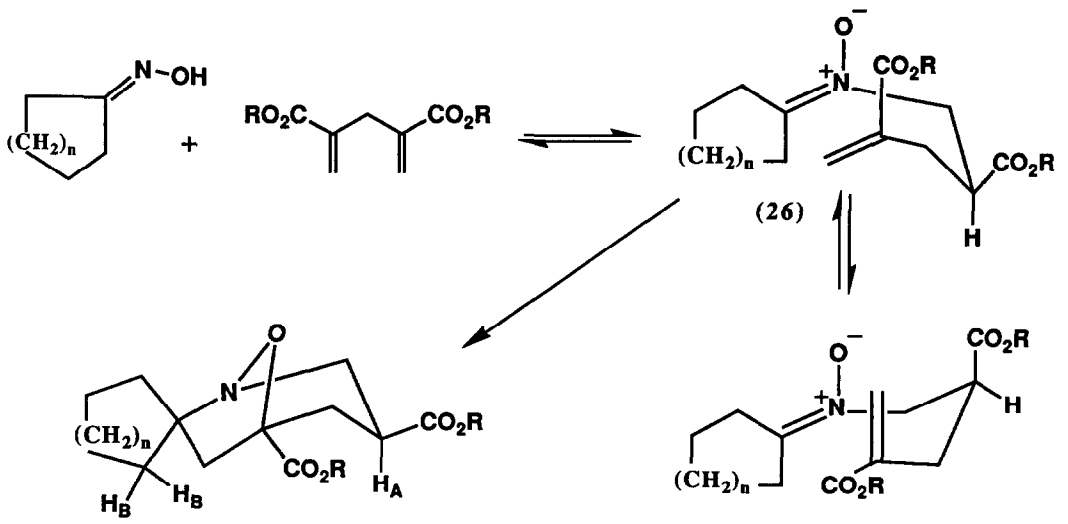


(24)



(25) a. R=R'=H

Two examples of the reaction of (11b,c) with oximes were studied. Thus cyclopentanone and cyclohexanone oximes and (11b) or (11c) react slowly (xylene, 140°C, 72h, 80% conversion) to give a single product (27a) and (27b) in each case in 72-76% yield. Thus the lowest energy transition state is derived from conformer (26) (Scheme 2).



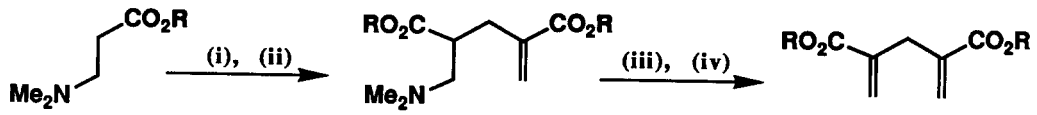
(26)

(27) a. n=1, R=Me
b. n=2, R=Et

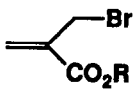
**Scheme 2.**

The stereochemistry of (27) was established by n.O.e. studies. For example irradiation of $H_A$ in (27a) resulted in enhancement of the signals for $H_B$ (5%).

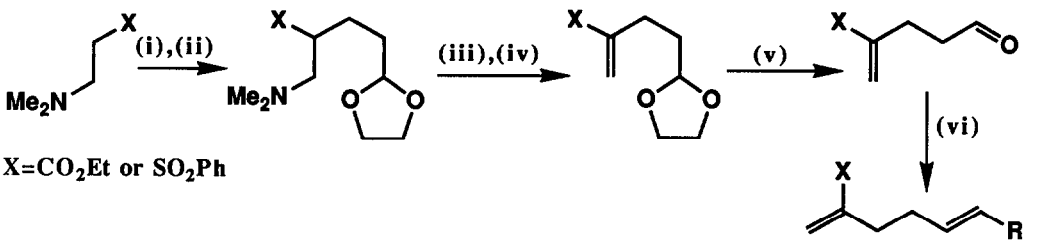
The synthesis of the diene diesters (11b) and (11c) are outlined in Scheme 3.




(11) b. R=Me
c. R=Et

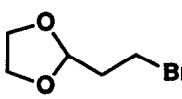
Scheme 3. (i) LDA / THF / HMPA / -78° C (ii)  (iii) MeI / MeOH / 25° C (iv) DBN / $C_6H_6$ / 80° C

**b. From 1,5-Dienes.** A series of bifunctional 1,5-diene substrates (28)-(30) was prepared as outlined in Schemes 4 and 5.




X=$CO_2Et$ or $SO_2Ph$

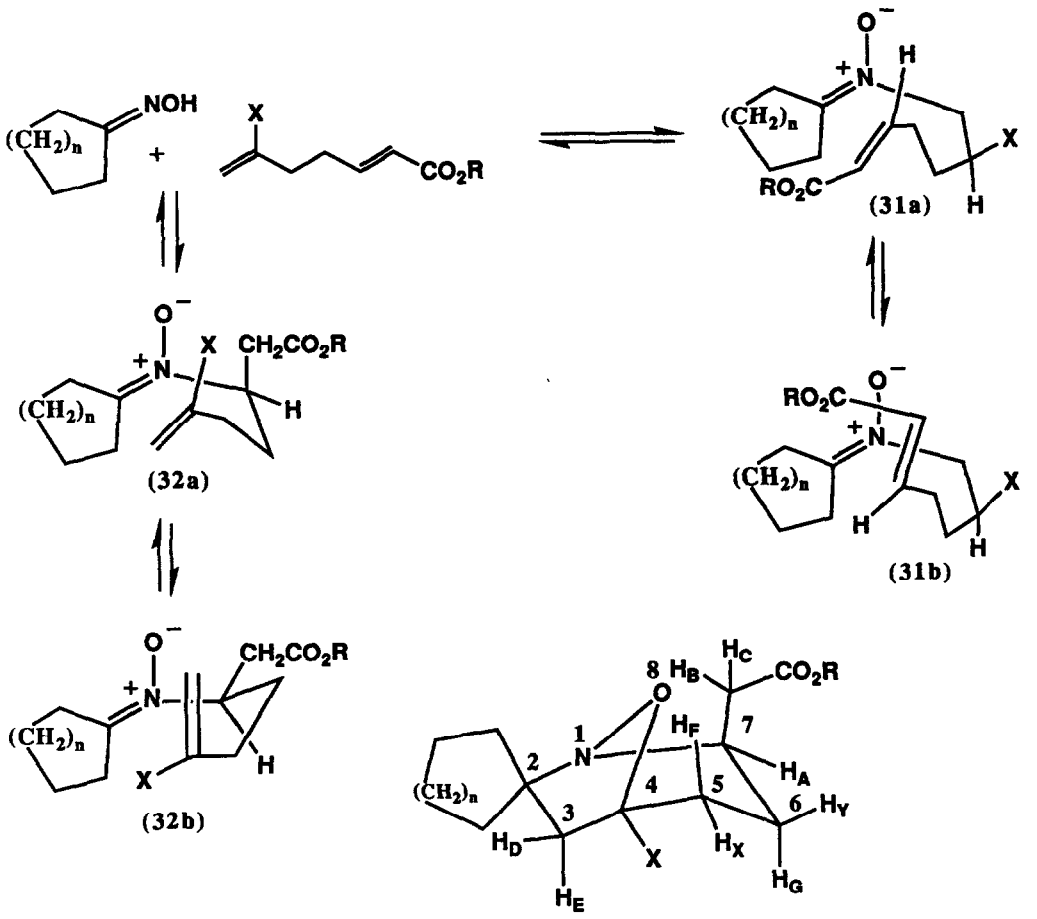
(28) X=R=$CO_2Et$
(29) X=$SO_2Ph$, R=$CO_2Me$

Scheme 4. (i) LDA / THF / HMPA / -78° C (ii)  (iii) MeI / MeOH / 25° C (iv) DBN / $C_6H_6$ / 80° C (v) 1 N HCl / 100° C (vi) $Ph_3P$=CHR / $CH_2Cl_2$ /25°C

Both (28) and (29) react slowly (xylene, 140°C, 48h, 70% conversion), but regio- and stereo-specifically, with cyclopentanone oxime to give (33a) and (33b) respectively, both in 61% yield (scheme 6). Cyclohexanone oxime reacts analogously (xylene, 140°C, 48h, 70% conversion) with (28) to give (33c)(57%). The initial Michael addition that leads to products thus occurs at the internal olefin leading to the N-alkenyl nitrones (32a,b). Products derived from the alternative Michael adduct (31a,b) are not observed (scheme 6).


(30)

Scheme 5. (i) $Ph_3P$=$CHCO_2Me$ / $CH_2Cl_2$ / 25° C

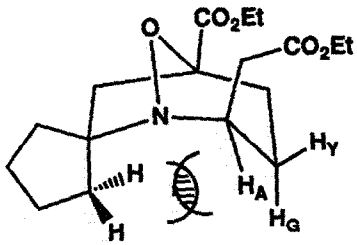



**(33)** **a. n=1, R=Et, X=$CO_2Et$**
**b. n=1, R=Me, X=$SO_2Ph$**
**c. n=2, R=Et, X=$CO_2Et$**

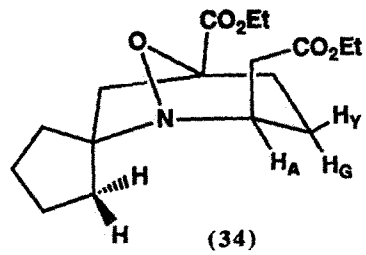
**Scheme 6.**

The structures of (33 a-c) are assigned on the basis of their p.m.r. spectra. A typical example is provided by the spectrum of (33a) which exhibits an AB pattern for protons $H_D$ and $H_E$ at δ 2.34 and 2.24, whilst $H_B$ and $H_C$ give rise to two double doublets at δ 2.89(J 15.9 and 6.1Hz) and δ2.65(J 15.9 and 8.3 Hz). Model building suggests a half-chair conformation (34) in the six membered ring of (33a) to relieve the steric hindrance between $H_A$, $H_G$ and the methylene protons of the cyclopentane ring. This conformational change results in an $H_AH_G$ dihedral angle of ca. 30° and an $H_AH_Y$ dihedral angle of ca. 80° in the model. This suggestion is supported by the observed coupling constants with $J_{AG}$=6 Hz, and $J_{AY}$=1Hz.

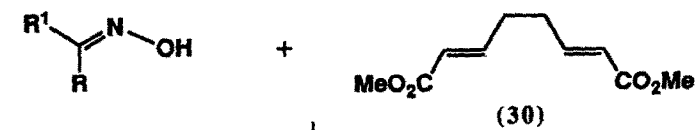
It is assumed that both Michael adducts (31) and (32) are formed but that the cycloaddition transition state derived from (32) is of significantly lower energy, i.e. cycloaddition is the rate determining step. In nitrone (31) the subsidiary ring forming in the transition state is 7-membered compared to the 6-membered subsidiary ring formed in (33).



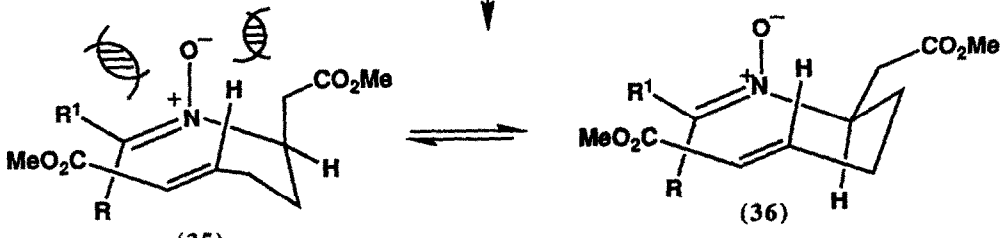
(33a)



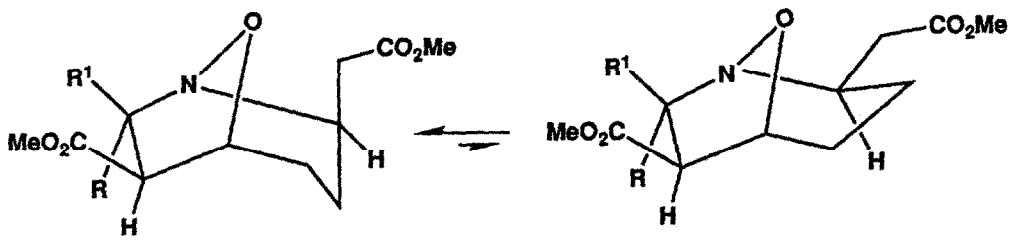
(34)



(30)

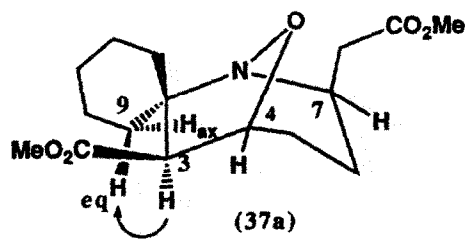


(35) (36)

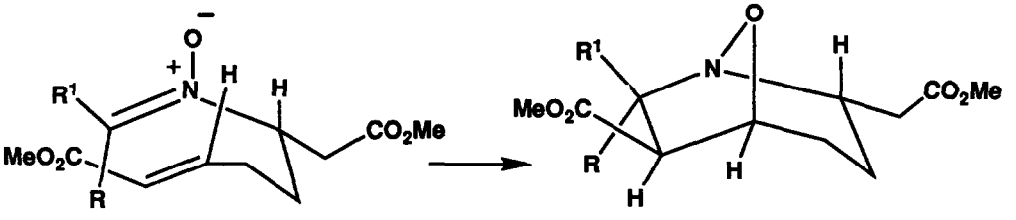


(37) a. R,R$^1$=(CH$_2$)$_5$
b. R=H, R$^1$=Ph

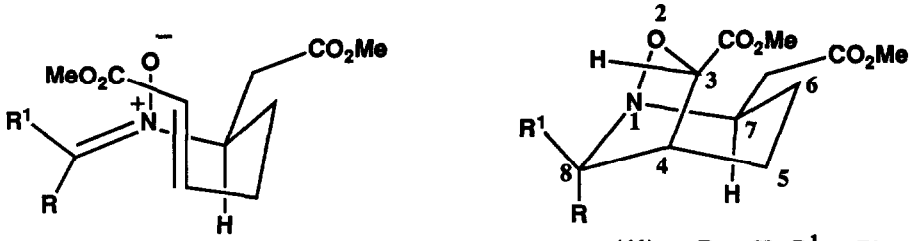
Scheme 7



(37a)



(38) (39) a. R = H, $R^1$ = Ph



(40) (41) a. R = H, $R^1$ = Ph

Cyclohexanone oxime reacts slowly (xylene, 140°C, 24h, 60% conversion) with the 1,5-diene (30) to give a single cycloadduct (37a) (80%) (scheme 7). The stereochemistry of (37a) was established by extensive p.m.r. studies involving decoupling, 2D-COSY and n.O.e. experiments. The chair conformation of the pyran ring and the axial orientation of the 7-$CH_2CO_2Me$ moiety could be interpreted as arising via a transition state derived from nitrone conformation (35) (scheme 7) and may reflect the reduced diaxial interactions consequent on replacing a ring methylene group by an oxygen atom. Alternatively, the steric compression resulting from the $R^1$/O and O/$CH_2CO_2Me$ interactions may favour the psuedo boat conformer (36) as the transition state precursor. Products arising from conformers (38) and (40) and their corresponding psuedo boat conformers are not observed in this case (scheme 7).

An analogous reaction between benzaldoxime and diene (30) also proceeds slowly (xylene, 140°C, 24h, 75% conversion) but affords a 1:1 mixture of (37b) and (39a) together with trace amounts of two minor isomers. One of the minor isomers was isolated and was shown to have structure (41a) by extensive p.m.r studies. The other minor isomer is presumably the C(3)-epimer of (37b). These two minor isomers are believed to arise from trace amounts of a cis-isomer of (30) produced in the Wittig reaction.

N.O.e. studies enabled the methylene protons of the cyclohexyl ring adjacent to the bridged ring to be identified in (37a). Thus irradiation of the 7-endo-H (δ 3.51) caused enhancements of the signal of the 9-axial-H (5%) (δ 2.05) and irradiation of the 3-H(δ2.94) results in enhancement of the signals for the 9-equatorial H(8%) (δ 1.93), the 9-axial-H(2%) and 4-H (2.5%).

**Experimental** General details were as previously described.[15] Divinyl Sulphone was obtained from Aldrich. 2,3-Di(methoxycarbonyl)buta-1,3-diene,[16] 2,3-diphenylphosphinylbuta-1,3-diene,[17] divinyl phenylphosphine oxide,[18] and methyl penta-1,4-diene-2-carboxylate[19] were prepared by the literature methods. Petroleum ether refers to the fraction with b.p. 40-60°C.

**Bifunctional Substrates.**

a. 2,4-Di(ethoxycarbonyl)-5-dimethylaminopent-1-ene. To a solution of diisopropylamine (11.0 ml, 78.6 mmol) in dry THF (180 ml) at -78°C (under nitrogen) was added 1.6M n-BuLi(49.1 ml, 78.6 mmol). After stirring at -78°C for 20 mins, ethyl 3-(dimethylamino) propionate (10.8 g, 74.8 mmol) was introduced and the mixture was stirred at -78°C for a further 30 mins. A solution of ethyl α-bromoethyl acrylate (15.1g, 78.6 mmol) in HMPA (13.6 ml, 78.6 mmol) was added slowly and the reaction mixture was left at 25°C for a further 2h. After quenching with saturated $NH_4Cl$ solution, the crude product was extracted with ether (3x) and the combined extracts were washed with water several times, dried over $MgSO_4$ and evaporated to dryness. The residual oil was distilled to give the product as a colourless oil (5.8g, 30%), b.p. 70-72°C/0.1mmHg. (Found: C, 60.15; H, 8.75; N, 5.55. $C_{13}H_{23}NO_4$ requires C, 60.65; H 9.0; N, 5.45%); δ 6.16 and 5.58(2 x d, 2 x 1H, $CH_2$=C), 4.20 and 4.11(2 x q, 2 x 2H, $OCH_2Me$), 2.98-2.19(m, 5H), 2.22(s, 6H, $NMe_2$), 1.31 and 1.22(2 x 3H, $OCH_2Me$); m/z(%) 257($M^+$, 5), 212(2), and 58(100); $\nu_{max}$ 3439, 1893, 1629, 688 and 604 $cm^{-1}$

b. 2,4-Di(ethoxycarbonyl)-5-dimethylaminopent-1-ene methiodide. To a solution of 2,4-di(ethoxycarbonyl)-5-dimethylaminopent-1-ene (5g, 19.5 mmol) in methanol (50 ml) at 25°C was added iodomethane (14.5 ml, 232.9 mmol). After being allowed to stand in the dark for 18h, the mixture was concentrated and the residue washed with ether, leaving the methiodide (7.0 g) which was used directly in the next step of the transformation.

c. 2,4-Di(ethoxycarbonyl)-1,4-pentadiene. Prepared from 2,4-di(ethoxycarbonyl)-5-dimethylaminopent-1-ene methiodide (9.0 g, 22.5 mmol) and 1,5-diazabicyclo[4.3.0]non-5-ene (DBN) (4.9g, 39.5 mmol) in boiling benzene for 2.5 h. The reaction mixture was washed with 1N HCl, water, saturated NaCl solution, and dried over $Na_2SO_4$. The benzene was evaporated (low temperature water bath) to give the product as a colourless oil (1 2 g, 25%) (Found: C, 62.0; H, 7.75. $C_{11}H_{16}O_4$ requires C, 62.25; H, 7.6%); δ 6.25 and 5.58(2 x s, 2 x 1H, $=CH_2$), 4.20(q, 4H, $OCH_2Me$), 3 38(s, 2H, $CH_2$), and 1.28(t, 2 x 3H, $OCH_2Me$); m/z(%) 212($M^+$, 13), 166(100) and 138(90)

Ethyl 6-ethoxycarbonylhepta-2,6-dienoate(28).

a. 2-(3′-Ethoxycarbonyl-4′-dimethylaminobutyl)-1,3-dioxolane. Obtained from the reaction of ethyl 3-(dimethylamino)propionate (10.85g, 74.8mmol) and 2-(2′-bromoethyl)-1,3-dioxolane (14.22g, 78.6mmol) in a manner analogous to that described above. The product distilled as a colourless oil (5.8 g, 31%), b.p. 86-88°C/0.1mmHg. (Found: C, 58.95; H, 9.6; N, 5.8. $C_{12}H_{23}NO_4$ requires C, 58.75; H, 9.45; N, 5.7%); δ 4.85(t, 1H, CHO), 4.16(dq, 2H, $OCH_2Me$), 3.94 and 3.84(2 x m, 2 x 2H, $O(CH_2)_2O$), 2.62(m, 2H, $CH_2N$), 2.21(s, 6H, $NMe_2$) which obscured multiplet of $CHCO_2Et$, 1.64(m, 4H, 2 x $CH_2$) and 1.25(t, 3H, $OCH_2Me$); m/z(%) 245($M^+$, 2), 200(2), 73(16) and 58(100).

b 2-(3′-Ethyoxycarbonylbut-3′-enyl)-1,3-dioxolane. Obtained in a manner similar to that described above as a colourless liquid (74%) from preparative t.l.c. eluting with 50% v/v ether-petroleum ether. (Found: C, 60.2; H, 8 15. $C_{10}H_{16}O_4$ requires C, 60.0; H, 8.05%); δ 6.16 and 5.56(2 x s, 2 x 1H, $=CH_2$), 4.90(t, 1H, CHO), 4.21(q, 2H, $OCH_2Me$), 3.96 and 3.86(2 x m, 2 x 2H, $O(CH_2)_2$), 2.45 and 1.86(2 x m, 2 x 2H, 2 x $CH_2$) and 1.30(t, 3H, $OCH_2Me$); m/z(%) 200($M^+$, 0.5), 171(2), 155(7), 127(1), 99(3), 86(5) and 73(100).

c. 4-Ethoxycarbonyl-4-pentenal. 1 N Hydrochloric acid (1.5 eq) was added to a solution of 2-(3′-ethoxycarbonylbut-3-enyl)-1,3-dioxolane in THF and the mixture was boiled under reflux for 2.5 h. The reaction mixture was extracted with ether, washed with water, dried over $Na_2SO_4$ and evaporated to dryness. The product was obtained as a colourless oil (71%) from preparative t.l.c. eluting with 50% v/v ether-petroleum ether. (Found: C, 61.45; H, 7.8. $C_8H_{12}O_3$ requires C, 61.5; H, 7.75%); δ 9.79(s, 1H, CHO), 6.22 and 5.61(2 x s, 2 x 1H, $=CH_2$), 4.22(q, 2H, $OC\underline{H}_2Me$), 2.67(s, 4H, 2 x $CH_2$) and 1.32(t, 3H, $OCH_2\underline{Me}$); m/z(%) 156($M^+$ 0.9), 127(2), 111(0.9), 83(25) and 73(100).

d. Ethyl (6-ethoxycarbonyl)-2,6-heptadienoate. Prepared from 4-ethoxycarbonyl-4-pentenal (3.0 g, 19.2 mmol) and (ethoxycarbonyl-methylene) triphenylphosphorane (8.0 g, 23.1 mmol) in methylene chloride at room temperature overnight. The methylene chloride was evaporated and the residue treated with ether to precipitate triphenylphosphine oxide which was removed by filtration. The filtrate was evaporated and the residual oil distilled to give the product as a colourless liquid (2.2g, 51%), b.p. 88-90°C/0.1mmHg, (Found: C, 63.95; H, 7.95. $C_{12}H_{17}O_4$ requires C, 63.95; H, 7.6%); δ 6.95(m, 1H, $=C\underline{H}CH_2$), 6.20 and 5.55(2 x s, 2 x 1H, $=CH_2$), 5.83(d, 1H, J 15.6Hz, $=C\underline{H}CO_2Et$), 4.22 and 4.17(2 x q, 2 x 2H, $OC\underline{H}_2Me$), 2.43(m, 4H, 2 x $CH_2$) and 1.28(2 x t, 2 x 3H, $OCH_2\underline{Me}$); m/z(%) 226($M^+$, 2), 181(43), 152(30) and 73(100).

Methyl 6-phenylsulphonylhepta-2,6-dienoate(29).

a 2-(3′-Phenylsulphonyl-4′-dimethylaminobutyl)-1,3-dioxolane. Obtained from the reaction of 2-(dimethylamino)ethyl phenyl sulphone (8g, 37.5mmol) and 2-(2′-bromoethyl)-1,3-dioxolane (7.13g, 39.4 mmol) according to previous procedure. The *product* formed colourless rods (7.1g, 60%) from methylene chloride-ether, m.p. 75-77° (Found: C, 57.25; H, 7.45; N, 4.55; S, 10.4. $C_{15}H_{23}NO_4S$ requires C, 57.5; H, 7.4; N, 4.45; S, 10.25%); δ 7.89(m, 2H, ArH), 7.59(m, 3H, ArH), 4.83(t, 1H, CHO), 3.79-3.94[m, 4H, $O(CH_2)_2O$], 3.24(m, 1H, $CHSO_2$), 2.65 and 2.42(2 x dd, 2 x 1H, $CH_2N$), 2.08(s, 6H, $NMe_2$) and 2.06-1.80(m, 4H, 2 x $CH_2$); m/z(%) 313($M^+$, 3), 255(8), 241(4), 172(4), 142(5), 73(45) and 58(100).

b. 2-(3′-Phenylsulphonylbut-3′-enyl)-1,3-dioxolane. Obtained as a colourless liquid (60%) from preparative t.l.c. eluting with ether. (Found: C, 58.45; H, 5.8. $C_{13}H_{16}O_4S$ requires C, 58.2; H, 6.0%); δ 7.88(d, 2H, ArH), 7.59(m, 3H, ArH), 6.40 and 5.77(2 x s, 2 x 1H, $=CH_2$), 4.82(t, 1H, CH-O), 3.85(m, 4H, $O(CH_2)_2O$), 2.38 and 1.82(2 x m, 2 x 2H, 2 x $CH_2$); m/z(%) 268($M^+$, 1), 127(2), 113(2) and 73(100).

c 4-Phenylsulphonyl-4-pentenal. Obtained from 2-(3′-phenylsulphonylbut-3′-enyl)-1,3-dioxolane in a manner analogous to that described above. The product was obtained as a colourless liquid (80%) by preparative t.l.c. eluting with ether. (Found: C, 58.8; H, 5.4; S, 14.35. $C_{11}H_{12}O_3S$ requires C, 58.9; H, 5.4; S, 14.3%); δ 9.71(s, 1H, CHO), 7.87(d, 2H, ArH), 7.60(m, 3H, ArH), 6.41 and 5.78(2 x s, 2 x 1H, $=CH_2$), 2.75 and 2.56(2 x t, 2 x 2H, 2 x $CH_2$); m/z(%) 224($M^+$, 0.5), 196(3), 143(6) and 83(100).

d. Methyl (6-phenylsulphonyl)-2,6-heptadienoate. Prepared from 4-phenylsulphonyl-4-pentenal (0.9g, 4 mmol) and (methoxycarbonylmethylene) triphenylphosphorane (1.4g, 4.2 mmol) in an analogous manner to that described above. The crude product was purified by flash chromatography eluting with 50% v/v ether-petroleum ether to give a colourless oil (0.8g, 71%). (Found: C, 60.1; H, 5.95; S, 11.5. $C_{14}H_{16}O_4S$ requires C, 59.75; H, 6.1; S, 11.4%); δ 7.88(m, 2H, ArH), 7.54-7.68(m, 3H, ArH), 6.81(m, 1H, $=C\underline{H}CH_2$), 6.42 and

5.75(2 x s, 2 x 1H, $=CH_2$), 5.76(d, 1H, J 15.6 Hz, $=CHCO_2Me$), 3.72(s, 3H, OMe) and 2.39(m, 4H, 2 x $CH_2$); m/z(%) 281($M^+$ + 1, 2.6), 249(4), 221(0.7), 141(11), 139(6), 12(15), 110(34), 85(15) and 77(100).

Dimethyl trans, trans-octa-2,6-diene-1,8-dioate(30). A solution of carbomethoxymethylenetriphenylphosphorane (38.8g, 116 mmol) in dry methylene chloride (100 ml) was added at room temperature to a stirred solution of succinaldehyde (5.0g, 58 mmol)[20] in dry methylene chloride (50 ml). The resulting solution was stirred at room temperature for 18 hrs, solvent removed and the residue triturated with ether to remove the crystalline triphenylphosphine oxide. The ether solution was concentrated and purified by flash chromatography ($SiO_2$) eluting with 1:9 v/v ether-petroleum ether followed by distillation. The product (8.4g, 73%) distilled as a colourless oil, b.p. 95-100°C/0.2 mm Hg (Found: C, 60.5; H, 7.3. $C_{10}H_{14}O_4$ requires, C, 60.6; H, 7.1%); δ: 6.94(m, 2H, 2 x $CH=CHCO_2Me$), 5.87(d, 2H, J 15.5 Hz, 2 x = $CHCO_2Me$), 3.73(s, 6H, 2 x $CO_2Me$) and 2.39(m, 4H, 2 x $CH_2$). m/z(%): 198($M^+$, 3), 167(53), 166(27), 139(23), 138(100), 134(28), 107(47), 106(23), 99(59), 79(82), 78(23), 75(28), 71(31), 68(60) and 59(39).

## Cycloaddition Reactions

### A. With 2,3-di(methoxycarbonyl)buta-1,3-diene.

Cycloadduct (8a). A solution of cyclohexanone oxime (500 mg, 4.4 mmol) and 2,3-di(methoxycarbonyl)buta-1,3-diene(750mg; 4.4 mol) in acetonitrile (15ml) was boiled under reflux under a nitrogen atmosphere for 16 hrs. The solvent was removed under reduced pressure and the residue purified by flash chromatography ($SiO_2$) eluting with 1:1 ether-petroleum ether to give the *product* (1.15g, 92%) as colourless prisms, m.p. 72°C, form ether-petroleum ether (Found: C, 59.2; H, 7.55;N, 4.85. $C_{14}H_{21}NO_5$ requires, C, 59.35; H, 7.45 and N, 4.95%); δ 3.82(s, 3H, 4-$CO_2Me$), 3.72(dd, 1H, J 4.3 and 12.1 Hz, 6- exo -H), 3.69(s, 3H, 5-$CO_2Me$), 3.59(dq, 1H, J 2.1, 4.2 and 10.6 Hz, 5-H), 3.39(dd, 1H, J 10.6 and 12.1 Hz, 6- endo -H), 2.05(dd, 1H, J 2.2 and 12.5 Hz, 3- exo -H), 1.71(d, 1H, J 12.4 Hz, 3- endo -H), 1.47-1.79(m, 8H, 4 x $CH_2$), and 1.27(m, 2H, $CH_2$); m/z(%), 283($M^+$,33), 252(17), 224(52), 189(15), 188(17), 171(9), 139(39), 126(100), 113(11), 110(13), 86(17) and 84(25).

Cycloadduct (8b). A solution of 2,3-di(methoxycarbonyl)buta-1,3-diene(0.32g, 1.88mmol) and cyclopentanone oxime (0.18g, 1.88 mmol) in acetonitrile was boiled under reflux for 16h. The solvent was then evaporated under reduced pressure and the residue purified by preparative t.l.c. eluting with 50% v/v ether-petroleum ether The *product* formed colourless prisms (0.3g, 65%) from ether-petroleum ether, m.p. 75-77°C (Found: C, 58.25, H, 6.85; N, 5.0. $C_{13}H_{19}NO_5$ requires C, 57.95; H, 7.1; N, 5.2%); δ 3.83 and 3.71(2 x s, 2 x 3H, OMe), 3 54(m, 3H, 5-H and 2 x 6-H), and 2.18 and 1.99(2 x d, 2 x 1H, J 12 5Hz, 2 x 3-H), 1.57-1.79(m, 8H, 4 x $CH_2$); m/z(%) 269($M^+$, 22), 238(14) and 210(100).

Cycloadduct (8c). A solution of 2,3-di(methoxycarbonyl)buta-1,3-diene (0.34g, 2mmol) and p-methoxybenzaldehyde(0.30g, 2mmol) in xylene was boiled under reflux for 3 d. After work up as above the residue was purified by preparative t.l.c. eluting with 50% v/v ether-petroleum ether to afford the *product* as a colourless thick oil (0.19g, 31%) (Found: C, 59.6; H, 6.1; N, 4.55. $C_{16}H_{19}NO_6$ requires C, 59.8; H, 5.95; N, 4.35%); δ 7.30 and 6.88(2 x m, 2 x 2H, ArH), 4.17(dd, 1H, J 8.1 and 5.4 Hz, 2-H), 3.86, 3.78 and 3.77(3 x s, 3 x 3H, OMe), 3.64(m, 2H, $CH_2N$), 3.40(dd, 1H, J 8.7, and 1.6Hz, 5-H) and 2.74 and 2.31(2 x dd, 2 x 1H,

$CH_2$); m/z(%) 321($M^+$, 93), 276(42), 262(42), 151(43) and 134(100).

**B. With 2,3-di[bis(phenylphosphinyl)]buta-1,3-diene**

General Procedure. A solution of the oxime (10 mmol) and 1,3-diene (4b) (10 mmol) in xylene (40ml) was boiled under reflux for 8-16h. Removal of the solvent afforded the crude product which was analysed by its p.m.r. spectra and purified according to the procedures detailed below. Yields and reaction times are listed in Table 1.

Cycloadduct (8d). The crude reaction product, a colourless gum (100%), was found to comprise (8d) (75%), together with unchanged starting materials (25%). Crystallisation of the gum from benzene afforded (8d) (2.8g, 68%) (based on 75% conversion of reactants) as colourless plates, m.p. 189-190°C. (Found: C, 69.95; H, 6.4; N, 2.55. $C_{34}H_{35}NO_3P_2$. $H_2O$ requires C, 69.7; H, 6.3; N, 2.4%); δ($CDCl_3$ + 1 drop $C_6D_6$); 7.45(m, 20H, ArH), 3.78(ddd, 1H, J 13.7, 11.7 and 5.3Hz, 6-exo-H), 3.55(m, 1H, 5-H), 3.48(d, 1H, J 12.0, Hz, 3-endo-H) 3.45(ddd, 1H, J 11.3, 7 3 and 11.3Hz, 6-endo-H), 1.98(dd, 1H, J 12.0 and 1.9Hz, 3-exo-H), 1.82, 1.60, 1.44 and 1.16(4 x m, 10H, 5 x $CH_2$); these proton assignments are based on the 2D-$^1$H-COSY spectrum; $^{13}$C($CDCl_3$ + drop $C_6D_6$), 130.0(m, ArC), 92.4(d, J 6.56Hz, C-4), 70.75(s, C-2), 52.63(d, J 5.1 Hz, C-6), 44.50(dd, J 7.7 and 69.0 Hz, C-5), 40.97(d, J 3.61Hz, C-3), 38.04(d, J 3.61, cyclohexane-C), 31.13, 25.13, 24.02 and 21.74(4 x s, 4 x cyclohexane-C). The assignment of secondary (s), tertiary (t) and quaternary (q) carbon atoms was confirmed by a DEPT spectrum; m/z(%) 567($M^+$, 1), 454(37), 377(14), 113(100) and 72(47).

Cycloadduct (8e). The p.m.r. spectrum of the crude reaction product indicated 80% conversion to product Crystallisation from benzene afforded (8e) (1.65g, 77%) (based on 80% conversion of starting materials), as colourless rods, m.p. 189-190°C. (Found: C, 74.45; H, 6.3; N, 2.0. $C_{33}H_{33}NO_3P_2$. $H_2O$ requires C, 74.15; H, 6.2; N, 2.2%); δ 7.56(m, 20H, ArH), 3.55(d, 1H, J 12.0Hz, 3-endo-H), 3.34(m, 3H, 5-H and 2 x 6-H), 1.87(m, 1H, CH), and 2.16, 1.62 and 0.83(3 x m, 8H, 4 x $CH_2$). m/z(%): 553($M^+$, 2), 454(60), 377(20), 201(48) and 55(100).

Cycloadduct (8f). The p.m.r. spectrum of the crude reaction product indicated 90% conversion to product. Crystallisation from benzene afforded (8f) as chunky colourless cubes (1.9g, 63%), m.p. 145-146°C. (Found: C, 70.65; H, 5.4; N, 2.55. $C_{35}H_{31}NO_3P_2$. $H_2O$ requires C, 70.55; H, 5.6; N, 2.35%); δ 7.35(m, 20H, ArH), 4.23(dd, 1H, J 8.0 and 4.4Hz, 2-H), 4.07(dd, 1H, J 12.0 and 8.0 Hz, 3-endo-H), 3.50(m, 2H, 2 x 6-H), 3.28(dd, 1H, J 13 6 and 5.4Hz, 5-H), and 2.16(m, 1H, 3-exo-H), $^1$H NOEDS(%). irradiation of 3-endo-H causes enhancement of the 6-endo-H(2%), 2-H(2.5) and 3-exo-H(31). The complete stereochemistry was unambiguously determined by a single crystal X-ray structure (Fig. 1).

Cycloadduct (8g). The p.m.r. spectrum of the crude product indicated 60% conversion to product. Fractional crystallisation from benzene afforded (8g) (0.6g, 60%) (based on 60% conversion) as colourless plates, m.p. 194-196°C; (Found: C, 69.8; H, 5.95; N, 2.65. $C_{31}H_{31}NO_3P_2$ requires C, 70.05; H, 6.25; N, 2.65%); δ($CDCl_3$ + $C_6D_6$), 7.84 and 7.20(2 x m, 20H, ArH), 3.61(d, 1H, J 11.7Hz, 3-endo-H), 3.20 and 3 45(2 x m, 3H, 5-H and 2 x 6-H), 1.80(ddd, 1H, J 11.4, 11.4 and 1.5Hz, 3-exo-H), 1.36 and 0.82(2 x s, 2 x 3H, 2 x Me); m/z(%), 527($M^+$, 4), 454(100), 377(31), 253(35), and 201(41).

**C. With divinylsulphone**

General Procedure. A solution of the oxime (10 mmol) and divinyl sulphone (10 mmol) was boiled under reflux in xylene or acetonitrile (20ml) for the time shown in Table . Removal of the solvent in vacuo afforded the crude product which was purified according to the procedures detailed below. Yields and product ratios are collected in Table 2.

Cycloadduct (15a). The *product* crystallised from benzene as fine colourless needles, m.p. 171-172°C. (Found: C, 55.5; H, 5.5; N, 5.65. $C_{11}H_{13}NO_3S$ requires C, 55.25; H, 5.5; N, 5.85%); δ 7.31(m, 5H, ArH), 5.15(s, 1H, 8-H), 4.56(d, 1H, J 8.0Hz, 3-exo-H), 3.9(m, 3H, 3-endo-H, 4-H, and NCH), 3.41(m, 2H, $SO_2CH$ and NCH), and 3.12(m, 1H, $SO_2CH$); m/z(%) 239($M^+$, 58), 148(10), 121(100), 117(53), and 77(35).

Cycloadduct (15b). The *product* crystallised from benzene as colourless plates, m.p. 155-156°C(Found: C, 53.85; H, 5.35; N, 5.4. $C_{12}H_{15}NO_4S$ requires C, 53.55; H, 5.6; N, 5.2%); δ 7.35 and 6.89(2 x m, 2 x 2H, ArH), 5.11 s, 1H, 8-H), 4.55(d, 1H, J 8.8Hz, 3-exo-H), 3.84(m, 6H, inc. 3.81, s, 3H, OMe, 3-endo-H, 4-H, and NCH), 3.44(m, 2H, NCH and $SO_2H$), and 3.10(m, 1H, $SO_2CH$); m/z(%) 269($M^+$, 99), 177(4), 151(100) and 134(51).

Cycloadduct (15c). The *product* crystallised from benzene as chunky colourless rods, m.p. 239-241°C (Found: C, 46.6; H, 4.2; N, 10.05. $C_{11}H_{12}N_2O_5S$ requires C, 46.5; H, 4.25; N, 9.85%); δ 8.24 and 7.65(2 x m, 2 x 2H, ArH), 5.22(s, 1H, 8-H), 4.53(d, 1H, J 9.8Hz, 3-exo-H), 3.92(dd, 1H, J 5.6 and 2.8Hz, 4-H), 3.78(m, 2H, 3-endo-H and NCH), 3.45(m, 2H, NCH and $SO_2CH$) and 3.15(m, 1H, $SO_2CH$); $^1H$ NOEDS(%): Irradiation of 4-H causes enhancement of the signal for 8-H (2) and O-ArH(5); irradiation of 8-H effects enhancement 4-H(2), O-ArH(4) and the 6-exo-H(5.5); irradiation of the 3-endo-H causes enhancement of 8-H(0.5), 6-exo + 7-exo-H(5) and the 3-exo-H(28); m/z(%) 284($M^+$, 25), 193(10), 166(13), 149(24), and 54(100).

Cycloadduct (15d). The *product* crystallised from benzene as colourless plates, m.p. 193-194°C (Found: C, 52.45; H, 5.9; N, 4.6. $C_{13}H_{17}NO_5S$ requires C, 52.15; H, 5.75; N, 4.7%); δ 7.45 and 6.46(2 x m, 3H, ArH), 5 21(s, 1H, 8-H), 4.45(d, 1H, J 9.3Hz, 3-exo-H), 3.84(m, 9H, inc. 3.86 and 3.80, 2 x s, 2 x 3H, 2 x OMe, 3-endo-H, 4-H, and NCH), 3.41(m, 2H, NCH, $SO_2H$), and 3.06(m, 1H, $SO_2CH$); m/z(%) 299($M^+$, 51), 268(23), 171(27) and 149(100).

Cycloadduct (15e). The *product* crystallised from ether-hexane as fine colourless needles, m.p. 232-233°C. (Found. C, 60.05; H, 5.3; N, 4.65. $C_{16}H_{17}NO_4S$ requires C, 60.2; H, 5.35; N, 4.4%); δ 8.37, 7 96, 7.75 and 6.84(4 x m, 6H, ArH), 5.70(s, 1H, 8-H), 4.53(d, 1H, J 8.9Hz, 3-exo-H), 3.98(m, 6H, inc. 3.00, s, 3H, OMe, 3-endo-H, 4-H, and NCH), 3.62(m, 2H, NCH and $SO_2CH$), and 3.25(m, 1H, $SO_2CH$); m/z(%) 319($M^+$, 100), 301(7), 201(20) and 185(19).

Cycloadducts (15f) and (16a). Trituration of the crude reaction product with ether gave a pale yellow solid (72%) which comprised a 1.6:1 mixture of (15f) and (16a). The isomers were separated by flash chromatography ($SiO_2$) eluting with a 3:3:17 v/v mixture of ether-acetone-petroleum ether (Found (mixed isomers): C, 59.8; H, 5.5; N, 4.15. $C_{16}H_{17}NO_4S$ requires C, 60.15; H, 5.35; N, 4.4%).

(15f) Obtained as buff prisms from benzene, m p. 204-205°C. δ 8.75, 7.85, 7.75, 7.50, 7.35 and 7.25(6 x m,

6H, ArH), 5.84(s, 1H, 8-H), 4.61(d, 1H, J 9.5Hz, 3-endo-H), 4.22(dd, 1H, J 5.5 and 2.8Hz, 4-H), 4.09(dd, 1H, J 9.5 and 5.5Hz, 3-exo-H), 4.00(s, 3H, OMe), 3.85(m, 1H, 7-exo-H), 3.62(m, 1H, 6-endo-H), 3.54(m, 1H, 6-exo-H), and 3.20(m, 1H, 7-endo-H); m/z(%) 321(M + 2, 17), 320(18), 319($M^+$, 100), 288(69), 227(11), 158(11), and 127(32).

(16a) Obtained as fawn plates from benzene, m.p. 252-254°C. δ 8.32, 7.90, 7.75, 7.40 and 7.30(6 x m, 6H, ArH), 5.39(dd, 1H, J 10.0 and 8.0Hz, 2-H), 5.13(m, 1H, 4-H), 4.63(m, 1H, 7-endo-H), 4.00(s, 3H, OMe), 3.84(m, 2H, 6-exo-H and 7-exo-H), 2.90(d of t, 1H, J 14.6, 9.4 and 9.4Hz, 6-endo-H), 2.82(dd, 1H, J 13.7 and 4.2Hz, 3-endo-H) and 2.85(dd, 1H, J 13.2 and 5.3Hz, 3-exo-H).

The stereochemistry of these adducts is based on NOEDS data (Table 5).

**Table 5. NOEDS results ($CDCl_3$) for cycloadducts (15f) and (16a)**

| | | % Enhancement | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Cycloadduct | Proton irradiated | ArH | 4-H | 8-H | 7-endo | 3-endo | OMe | 6-exo | 3-exo |
| | 4-H | | | 5 | | 1.5 | | | |
| (15f) | 8-H | 8.5 | 6.3 | | 9 | | | | |
| | 6-endo | | | | | | 5 | 27 | |
| | 3-exo | | 4 | | | 19 | | | |
| | 3-endo | | | | | | | | 16 |
| | | | | 2-H | | | | | |
| | 2-H | 14.8 | | | | -2.3 | | | 8.6 |
| (16a) | 3-exo | | 7.9 | 7.9 | | 20 | | | |
| | 4-H | | | | | 4.5 | | | |
| | 3-endo | | | | | | | | 11.6 |

Cycloadducts (15g) and (16b). The p.m.r. spectrum of the crude reaction product, a viscous orange oil, showed it to comprise a 3.5:1 mixture of (15g) and (16b). The mixture was separated by flash chromatography ($SiO_2$) eluting with a 19:1 v/v mixture of ether-ethyl acetate. [Found (mixed isomers): C, 50.05; H, 7.1; N, 6.45. $C_9H_{15}NO_3S$ requires C, 49.75; H, 6.95; N, 6.45%].

(15g) Obtained as colourless prisms from acetone, m.p. 125-128°C. δ 4.53(d, 1H, J 9.7Hz, 3-endo-H), 4.18(dd, 1H, J 9.7 and 5.8Hz, 3-exo-H), 3.53(m, 2H, 7-exo-H and 7-endo-H), 3.40(m, 1H, 4-H), 3.31(m, 1H, 6-endo-H), 3.00(m, 1H, 6-exo-H), 2.47(m, 1H, CH), 2.06(m, 2H, $CH_2$), 1.77(m, 4H, 2 x $CH_2$), 1.47(m, 1H, CH); m/z(%) 217($M^+$, 100), 188(12), 189(5), 126(16), 112(93), 99(73) and 67(83).

(16b) Obtained as colourless prisms, m.p. 98-99°C from ether-petroleum ether. (Found: C, 49.8; H, 7.1; N, 6.25; S, 14.9. $C_9H_{15}NO_3S$ requires C, 49.75; H, 6.95; N, 6.45 and S, 14.75%). δ 4.94(dm, 1H, J 8.4 Hz, 4-H), 3.99(ddd, 1H, J 4.4, 12.7 and 15.6 Hz, 7-exo-H), 3.45(dd, 1H, J 5.2 and 15.6 Hz, 7-endo-H), 3.29(ddd, 1H, J 5.4, 13.1 and 14.0 Hz, 6-endo-H), 3.03(dm, 1H, J 14.3 Hz, 6-exo-H), 2.77(dd, 1H, J 8.4 and 14.6 Hz, 3-exo-H), 2.68(dd, 1H, J 2.5 and 14.6 Hz, 3-endo-H), and 1.56-2.06(m, 8H, 4 x $CH_2$). m/z(%) 219(M + 2,6), 218(M + 1, 39), 174(6), 152(24), 136(57), 124(100), 110(75), 97(72), 96(78), 82(81) and 67(98).

Cycloadducts (15h) and (16c). The crude product was a pale brown semisolid Flash chromatography ($SiO_2$) eluting with 1:9 v/v ethyl acetate-ether afforded both isomers.

(15h) Colourless plates from ether, m.p. 175-176°(Found: C, 52.05; H, 7.55; N, 6.15; S, 13.75. $C_{10}H_{17}NO_3S$ requires C, 51.9; H, 7.4; N, 6.05; S, 13.85%); δ 4.56(d, 1H, J 10 Hz, 3-endo-H), 4.27(dd, 1H, J 6.1 and 10 Hz, 3-exo-H), 3.58(m, 3H, 4-H, $SO_2CH$ and NCH), 3.38(m, 1H, NCH), 3.04(m, 1H, $SO_2CH$), 2.33 and 2.01(2 x m, 2 x 1H, 2 x CH), and 1.41-1.82(m, 8H, 4 x $CH_2$); m/z(%) 231($M^+$, 96), 214(16), 202(13) and 188(5).

(16c) Colourless prisms from ether, m.p,. 143-144°C (Found: C, 52.05; H, 7.6; N, 6.05; S, 13.9%); δ 4.90(dd, 1H, J 2.3 and 8.97 Hz, 4-H), 4.01(m, 1H, 7-exo-H), 3.49(dd, 1H, J 5.6 and 15.6 Hz, 7-endo-H), 3.29(ddd, 1H, J 5.7, 5.8 and 13.1 Hz, 6-endo-H), 3.05(m, 1H, 6-exo-H), 2.69(dd, 1H, J 8.97 and 14.6Hz, 3-exo-H), 2.41(dd, 1H, J 2.3 and 14.6Hz, 3-endo-H) and 1.41-1.76(m, 10H, 5 x $CH_2$); m/z(%) 232(M + 1, 20), 231($M^+$, 2), 188(6), 166(7), 150(19), 138(36), 124(100), 110(34), 96(56) and 81(91).

Cycloadducts (19a) and (20a). The crude product was a pale yellow semisolid which upon flash chromatography ($SiO_2$) eluting with 2:1 v/v methanol-acetone afforded a colourless solid which still comprised a mixture of isomers, m.p. 168-170°(Found: C, 48.75; H, 7.4; N, 11.35. $C_{10}H_{18}N_2O_3S$ requires C, 48.75; H, 7.35; N, 11.35%). The spectra of the two isomers were assigned from that of the mixture. m/z(%) (mixed isomers) 246($M^+$, 9), 247(2), 229(10), 139(12), 128(21), 124(17) and 70(100).

(19a) δ 4.57(d, 1H, J 10.0Hz, 3-exo-H), 4.26(dd, 1H, J 10.0 and 6.0 Hz 3-endo-H), 3.57(m, 2H, 2 x 7-H), 3.40(m, 2H, 4-H and 6-H), 3.07(m, 1H, 6-H), 2.60(m, 4H, 2 x $NCH_2$), 2.31(s, 3H, NMe) and 1.81(m, 4H, 2 x $CH_2$).

(20a) δ 5.00(d, 1H, J 8.8Hz, 4-H), 4.00(m, 1H, NCH), 3.52(m, 2H, NCH and $SO_2CH$), 3.22(m, 1H, $SO_2CH$), 3 10(m, 1H, 3-exo-H), 2.71(m, 2H, $NCH_2$), 2.38(m, 1H, 3-endo-H), 2.30(s, 3H, NMe), and 1.81(m, $NCH_2$ and 2 x $CH_2$)

Cycloadducts (19b) and (20b). The crude reaction mixture was separated by flash chromatography ($SiO_2$) eluting with 1:9 v/v chloroform-methanol [Found (mixed isomers): C, 48.2; H, 6.75; N, 10.0. $C_{11}H_{18}N_2O_4S$ requires C, 48.15; H, 6.6; N, 10.2%]; m/z(mixed isomers) 274($M^+$, 25), 257(52), 215(41), 167(32), 121(39),

82(47) and 43(100).

(19b) Colourless plates from ether-methanol, m.p. 194-196°C. δ 4.59(dd, 1H, J 10.1 and 1.3Hz, 3-exo-H), 4.27(m, 1H, 3-endo-H), 3.53(m, 8H, 3 x $NCH_2$, $SO_2CH$ and 4-H), 3.11(m, 1H, $SO_2CH$), 2.11(s, 3H, Me), 2.35, 1.82 and 1.61(3 x m, 4H, 2 x $CH_2$).

(20b) Colourless plates from ether-methanol, m.p. 207-209°C. δ 4.88(dd, 1H, J 2.5 and 6.2Hz, 4-H), 3.98(m, 2H, $NCH_2$), 3.81(m, 1H, $SO_2CH$), 3.33(m, 1H, $SO_2CH$), 3.08(m, 1H, 3-exo-H), 2.51 and 2.73(2 x m, 3H, $NCH_2$ and 3-endo-H), 2.05(s, 3H, NMe), and 1.78 and 1.52(2 x m, 6H, $NCH_2$ and 2 x $CH_2$).

Cycloadducts (15i) and (16d). The crude product was a pale brown solid. Flash chromatography ($SiO_2$) eluting with 1:9 v/v methanol-chloroform afforded both isomers.

(15i) Colourless plates from methylene chloride-ether, m.p. 155-156°C. (Found: C, 43.75; H, 6.85; N, 7.25; S, 16.55. $C_7H_{13}NO_3S$ requires C, 43.95; H, 6.85; N, 7.35; S, 16.8%). δ 4.58(d, 1H, J 9.9 Hz, 3-endo-H), 4.31(dd, 1H, J 5.9 and 9.9 Hz, 3-exo-H), 3.57(m, 2H, 7-endo-H and 7-exo-H), 3.37(m, 2H, 4-H and 6-endo-H), 3.01(dq, 1H, J 3.1 and 14.4 Hz, 6-exo-H), 1.70(s, 3H, Me) and 1.35(s, 3H, Me). m/z(%), 191($M^+$, 22), 163(11), 119(43), 100(54), 83(39), and 69(100).

(16d) Colourless prisms from ether, m.p. 116-117°C. (Found: N, 7.0, S, 16.5%). δ 4.95(dt, 1H, J 2.5 and 8.8 Hz, 4-H), 4.02(ddd, 1H, J 4.9, 12.7 and 15.6 Hz, 7-exo-H), 3.48(dd, 1H, J 5.6 and 15.6 Hz, 7-endo-H), 3.30(ddd, 1H, J 5.7, 13.6 and 13.6 Hz, 6-endo-H), 3.04(dm, 1H, J 14.3, 6-exo-H), 2.69(dd, 1H, J 8.8 and 14.6 Hz, 3-exo-H), 2.56(dd, 1H, J 2.5 and 14.6 Hz, 3-endo-H), 1.44(s, 3H, Me), and 1.34(s, 3H, Me); m/z(%), 191($M^+$, 5), and 149(5), 119(9), 112(24), 99(16), 84(96), 71(32) and 70(32).

**D. With divinyl phenyl phosphine oxide.**

Cycloadducts (21a) and (22a). A solution of p-methoxybenzaldehyde oxime (0.76g, 5 mmol) and divinyl phenyl phosphine oxide (0.89g, 5 mmol) was boiled under reflux in xylene (15ml) under $N_2$ for 48h. Evaporation of the solvent afforded a colourless gum whose p.m.r. spectrum indicated it comprised a 1:2 mixture of (21a) and (22a), and that 75% conversion to products had occurred. Pure samples of each isomer were obtained by flash chromatography ($SiO_2$) eluting with 95:5 v/v ether-methanol in 54% combined yield (0.67g), based on 75% conversion [Found (mixed isomers): C, 65.85; H, 6.0; N, 4.1. $C_{18}H_{20}NO_3P$ requires C, 65.65: H, 6.05; N, 4.2%]; m/z(%) (mixed isomers) 330(M + 1, 18), 329($M^+$, 81) 312(82), 257(28), 204(100), 178(33) and 160(57).

(21a) Colourless needles from ether-petroleum ether, m.p. 176-179°C. δ 7.79 and 7 57(2 x m, 5H, ArH), 7.40 and 6.87(2 x d, 2 x 2H, ArH), 5.33(d, 1H, J 8.2Hz, 8-H), 4.01(dd, 1H, J 18.6 and 8.3Hz, 6-exo-H), 3.92(ddd, 1H, J 26.4, 14.7 and 6.6Hz, 7-endo-H), 3.78(s, 3H, OMe), 3.74(dd, 1H, J 8.1 and 6.5Hz, 7-exo-H), 3.64(m, 1H, 3-exo-H), 3.02(ddd, 1H, J 10.9, 6.1 and 2.3Hz, 4-H), 2.55(m, 1H, 6-endo-H), and 1.94(m, 1H, 3-endo-H).

(22a) Colourless prisms from benzene-petroleum ether, m.p. 135-137°C. δ($C_6D_6$), 8 16, 7.25, 7.15 and 6.81(4 x m, 9H, ArH), 4.31(d, 1H, J 9.6Hz, 2-endo-H), 3.89(dd, 1H, J 9.2 and 4.6 Hz, 4-H), 3.30(s, 3H, OMe), 3.32(m,

2H, 7-endo-H and 3-exo-H), 2.61(m, 1H, 7-exo-H), 2.55(m, 1H, 3-endoH), 1.84(m, 1H, 6-exo-H), and 1.42(m, 1H, 6-endo-H).

Cycloadduct (22b). A solution of acetone oxime (0.51g, 7mmol) and divinyl phenyl phosphine oxide (1.26g, 7 mmol) in xylene (25ml) was boiled under reflux for 24h. Removal of the solvent in vacuo afforded a fawn coloured solid which upon crystallisation from benzene-petroleum ether-ethyl acetate furnished (22b) (1.25g, 70%) as cream prisms, m.p. 152-155°C. (Found: C, 62.4; H, 6.95; N, 5.8. $C_{13}H_{18}NO_2P$ requires C, 62.15; H, 7.15; N, 5.55%); δ 8.03 and 7.50(2 x m, 5H, ArH), 4.71(m, 1H, 4-H), 3.58(m, 2H, 2 x 7-H), 2.62(m, 2H, 2 x 3-H), and 2.16(m, 2H, 2 x 6-H); m/z(%) 251($M^+$, 80), 252(12), 234(25), 179(100) and 104(34).

Cycloadduct (22c). A solution of cyclopentenone oxime (396mg, 4 mmol) and divinyl phenylphosphine oxide (712 mg, 4 mmol) in xylene (80 ml) was boiled under reflux for 2.5 dy. The solvent was then removed and the residue crystallised from methylene chloride-hexane to afford the *product* (800 mg, 73%) as colourless prisms, m.p. 204-205°C (Found: C, 64.9; H, 7.3; N, 5.2. $C_{15}H_{20}NO_2P$ requires C, 65.0; H, 7.2; N, 5.05%); δ 8.0-7.48(m, 5H, ArH), 4.71(br d, 1H, J 9.7 Hz, 4-H), 3.65-3.46(m, 2H, 2 x 7-H), 2.69(m, 2H, 2 x 3-H), 2.19(m, 2H, 2 x 6-H), and 1.99-1.61(m, 8H, 4 x $CH_2$); m/z(%) 277($M^+$, 68), 260(36), 179(100), 110(20) and 77(15).

Cycloadduct (22d). Prepared in an analogous manner to that described above from cyclohexanone oxime and divinyl phenylphosphine oxide. The *product* (70%) crystallised from methylene chloride-petroleum ether as colourless prisms, m.p. 120-122° (Found: C, 66.1; H, 7.8; N, 4.8. $C_{16}H_{22}NO_2P$ requires C, 65.95; H, 7.55; N, 4.8%); δ 8.01-7.46(m, 5H, ArH), 4.64(dd, 1H, J 2.93 and 9.62Hz, 4-H), 3.62(m, 2H, 2 x 7-H), 2.70-2.42(m, 2H, 2 x 3-H), 2.20(m, 2H, 2 x 6-H), and 1.84-1.4(m, 10H, 5 x $CH_2$); m/z(%) 291($M^+$, 82), 274(27), 220(24), 205(55), 179(100), 113(52) and 81(33).

**E. With methyl penta-1,4-diene-2-carboxylate**

Cycloadducts (23a) and (24a) Cyclohexanone oxime (0.71g, 6.3 mmol) and methyl penta-1,4-diene-2-carboxylate (0.8g, 6.3mmol) were boiled under reflux in mesitylene (25ml) for 4dy. The solvent was removed and n.m.r. analysis of the crude brown oil remaining showed it to comprise a 2:1 mixture of (23a) and (24a) together with some uncharacterised material. Preliminary flash chromatography (silica gel, $Et_2O$) gave a clean mixture of (23a) and (24a) (0.85g, 56%) as a pale yellow oil. The isomers were separated by further flash chromatography ($SiO_2$) eluting with 3:2 hexane-ether and were obtained as colourless oils. [Found (mixture) C, 65 1; H, 8.9; N, 6.05 $C_{13}H_{21}NO_3$ requires C, 65.245; H, 8.85; N, 5.85%].

(23a) δ 4.46(m, 1H, 4-H), 3.65(s, 3H OMe), 3.44(dd, 1H, J 14.8 and 12 Hz, 7-exo-H), 3.22(dd, 1H, J 5.7 and 14.8Hz, 7-endo-H), 2.86(m, 1H, 6-endo-H), 2.19(dd, 1H, J 12.2 and 7.9 Hz, 3-endo-H), 2.16(m, 1H, 5-exo-H), 1.87-1 7(m, 2H, 3-exo-and 5-endo-H), and 1.65-1.25(m, 10H, 5 x $CH_2$), assignments are supported by a 2D COSY spectrum; m/z (%) 239($M^+$, 40), 208(14), 180(9), 127(17), 110(100), 81(26), and 67(26); $\nu_{max}$(film) 2630, 1725, 1439, 1201, 1042, 957 and 732$cm^{-1}$.

(24a) δ 3 97 and 3.92(2 x m, 2 x 1H, 2 x 3-H), 3.65(s, 3H, OMe), 3.38(dd, 1H, J 14.7 and 7.1Hz, 7-exo-H), 3 21(dd, 1H, J 14.7 and 10.8Hz, 7-endo-H), 3.01(m, 1H, 6-endo-H), 2.44(m, 1H, 4-H), 2.08(m, 1H, 5-endo-H), 1 75(m, 1H, 5-exo-H), and 1.84-1.30(m, 10H, 5 x $CH_2$), assignments are supported by a 2D COSY spectrum;

m/z (%) 239(44), 222(21), 208(14), 183(18), 180(8), 110(100), 81(17), 67(19), 57(20), 55(26) and 41(28); $\nu_{max}$(film) 2910, 1720, 1429, 1197, 1015, 791 and 755 $cm^{-1}$.

**F. With dimethyl trans, trans-octa-2,6-diene-1,8-dioate.**

Cycloadduct (37a). A solution of cyclohexanone oxime (300 mg, 2.65 mmol) and dimethyl trans, trans-octa-2,6-diene-1,8-dioate(510mg, 2.57 mmol) in dry xylene (10 ml) was stirred and boiled under reflux for 24 hrs. The solvent was removed under reduced pressure. The p.m.r. spectrum of the residue showed only 60% conversion to product. This was purified by flash chromatography ($SiO_2$) eluting with 3:7 v/v ether-petroleum ether to give the *product* (395 mg, 80%), as colourless rods from ether-petroleum ether m.p. 73°C. (Found: C, 61.75; H, 8.15; N, 4.6. $C_{16}H_{25}NO_5$ requires; C, 61.7; H, 8.1; N, 4.5%); δ 4.68(br.s, 1H, 4-H), 3.69(S, 3H, $CO_2Me$), 3.67(S, 3H, $CO_2Me$), 3.51(m, 1H, 7-endo-H), 3.04(dd, 1H, J 8.8 and 15.0 Hz, $CH_\alpha CO_2Me$), 2.94(d, 1H, J 2.0 Hz, 3-H), 2.51(dd, 1H, J 6.4 and 15.0 Hz, $CH_\beta CO_2Me$), 2.12(m, 1H, 5-exo-H), 2.05(m, 1H, 9-Hax), 1.93(m, 1H, 9-Heq), 1.89(m, 1H, 6-endo-H), 1.84(m, 1H, CH), 1.66-1.35(m, 7H, cyclohexyl-H), 1.17(m, 1H, CH), and 0.86(m, 1H, CH); 2D-COSY and decoupling experiments were used to assign the signals. m/z (%) 311($M^+$, 43), 294(28), 280(21), 238(11), 198(11), 183(13), 182(100), 135(10), 107(14), 96(11), 81(33), 80(12), 79(32), 68(13), 67(25) and 59(32); $\nu_{max}$ 2920, 2840, 1730, 1450, 1430, 1380, 1300, 1210, 1180, 1130, 1080, 980, 860 and 760 $cm^{-1}$.

Cycloadducts (37b), (39a) and (41a). A solution of benzaldehyde oxime (2.0g, 16.5 mmol) and dimethyl trans, trans-oct-2,6-diene-1,8-dioate (3.28g, 16.5mmol) in dry xylene (20 ml) was boiled under reflux for 24 hrs. The solvent was removed under reduced pressure and the p.m.r. spectrum of the residue indicated only 75% conversion to products which comprised a 1:1 mixture of two major isomers together with trace amounts of two minor isomers. The mixture was separated by flash chromatography ($SiO_2$) eluting with 1:2 v/v ether-petroleum ether to afford (37b), (39a), and (41a) (2.82g, 71%). One minor isomer was not isolated in the pure form. [Found (mixed isomers): C, 64.0; H, 6.4; N, 4.25. $C_{17}H_{21}NO_5$ requires C, 63.95; H, 6.65; N, 4.4%].

(37b) Obtained (1.23g, 31%) as colourless prisms, m.p. 141-143°C from ether-petroleum ether. δ 7.14-7.30(m, 5H, ArH), 4.85(s, 1H, 4-H), 4.73(d, 1H, J 9.4 Hz, 2-endo-H), 3.79(d, 1H, J 9.4 Hz, 3-endo-H), 3.66(s, 3H, $CO_2Me$), 3.37(m, 1H, 7-endo-H), 3.03(s, 3H, $CO_2Me$), 3.00(dd, 1H, J 5.2 and 16.0 Hz, $CH_\beta CO_2Me$), 2.82(dd, 1H, J 9.2 and 15.9 Hz, $CH_\alpha CO_2Me$), 2.19(m, 1H, 5-exo-H), 2.02(m, 1H, 6-endo-H), 1.50(m, 2H, 5, 6-exo-H); n.O.e. experiments were used to assign the stereochemistry. Irradiation of the signal at δ 4.85(4-H) showed enhancements on the signals at δ 3.79(3-endo-H; 1.7%), 2.19(5-exo-H; 3.9%) and 1.50(5-endo-H; 2.2%). Irradiation of the signal at δ 4.73(2-endo-H) showed enhancements on the signals at δ 3.79(3-endo-H; 5.9%), 3 37(7-endo-H; 8.6%), 2.02(6-endo-H; 3.1%) and on the aromatic signals (7.8%). Irradiation of the signal at δ 3.79(3-endo-H) showed enhancements on the signals at δ 4.85(4-H; 2.2%), 4.73(2-endo-H; 6.0%), 2 02(6-endo-H; 5.2%) and 1.50(6-exo-H; 1.5%). Irradiation of the signal at δ 3.37(7-Heq) showed enhancements on the signals at δ 4.73(2-endo-H; 8.7%), 2.02(6-endo-H; 2.4%) and 1.50(6-exo-H; 1.6%). Irradiation of the signal at δ 3.00($CH_\beta CO_2Me$) showed an enhancement on the signal at δ 2.82($CH_\alpha CO_2Me$; 17.6%). Irradiation of the signal at δ 2.82($CH_\alpha CO_2Me$) showed enhancements on the signals at δ 3.37(7-endo-H; 2 0%), 2.19(5-exo-H; 2.0%), 1.50(1.2%) and δ 3.0($CH_\beta CO_2Me$; 20.2%). Irradiation of the signal at δ 2.19(5-exo-H) showed enhancements on the signals at δ 4.85(4-H; 6.8%), 2.82($CH_\alpha CO_2Me$; 3.1%) and 1.50(5-exo-H ; 22 7%). Irradiation of the signal at δ 2.02(6-endo-H) showed enhancements on the signals at δ 4.73(2-endo-H; 5.0%),

3.79(3-endo-H; 8.8%), 3.37(7-endo-H; 4.4%) and at δ 1.50(6-exo-H; 25.3%). Finally irradiation on the signals at δ 1.50(5-endo-H and 6-exo-H) showed enhancements on the signals at δ 4.85(4-H; 1.5%), 2.19(5-exo-H; 13.4%) and 2.02(6-endo-H; 11.6%). m/z(%) 319($M^+$, 51), 303(8), 302(45), 288(25), 260(8), 246(18), 191(14), 190(100), 158(13), 132(10), 131(15), 130(19), 115(15), 107(8), 104(17), 91(18), 79(10) and 77(7),

(39a) Obtained (1.24g, 31%) as colourless needles from ether-petroleum ether, m.p. 124°C; δ 7.14-7.32(m, 5H, ArH), 4.92(s, 1H, 4-H), 4.64(d, 1H, J 9.4 Hz, 2-endo-H), 3.91(m, 1H, 7-exo-H), 3.65(d, 1H, J 9.4 Hz, 3-endo-H), 3.52 and 3.04(2 x s, 2 x 3H, OMe), 2.48(dd, 1H, J 6.2 and 14.9 Hz, $CH_\alpha CO_2Me$), 2.21(dd, 1H, J 9.0 and 14 9 Hz, $CH_\beta CO_2Me$), 2.13(m, 1H, 5-exo-H ), 1.80(dt, 1H, J 4.6 and 14.4 Hz, 6-exo-H), 1.61(m, 1H, 5-endo-H), 1.47(m, 1H, 6-endo-H). N.O.e. experiments were used to assign the stereochemistry of the molecule. Irradiation of the signal at δ 4.92 (4-H), showed enhancements on the signals at δ 3.65(3-endo-H; 2.1%), 2.13(5-exo-H; 3.6%) and 1 61(5-endo-H; 2.1%). Irradiation of the signal at δ 4.64(2-endo-H) showed enhancements on the signals at δ 3.65(3-endo-H; 7.1%), 2.48($CH_\alpha CO_2Me$; 2.6%), 2.21($CH_\beta CO_2Me$, 5.8%) and 1.47(6-exo-H; 3.2%). Irradiation of the signal at δ 3.91(7-exo-H) showed enhancements on the signal at δ 2 48($CH_\alpha CO_2Me$; 1.8%), 2.13(5-exo-H; 2.2%) and 1.80(6-endo-H , 3.1%). Irradiation of the signal at δ 3.65(3-endo-H) showed enhancements on the signals at δ 4.92(4-H; 2.4%), 4.64(2-endo-H; 6.1%), 1.61(5-endo-H; 3.1%) and 1.47(6-exo-H; 4.9%). Irradiation of the signal at δ 2.48($CH_\alpha CO_2Me$) showed enhancements on the signals at δ 4.64(2-endo-H; 2.8%), 3.91(7-exo-H; 3.8%) and 2.21($CH_\beta CO_2Me$; 16.6%). Irradiation of the signal at δ 2.21($CH_\beta CO_2Me$) showed enhancements on the signals at δ 4.64(2-endo-H; 5.2%), 3.91(7-exo-H; 2.9%) and 2.48($CH_\alpha CO_2Me$, 16.9%). Irradiation of the signal at δ 2.13(5-exo-H) showed enhancements on the signals at δ 4.92(4-H, 6.1%), 3.91(7-exo-H; 3.3%), 1.61(5-endo-H; 19.9%) and 1.80(6-exo-H ; 2.8%). Irradiation on the signal at δ 1.80(6-exo-H) showed enhancements on the signals at δ 3.91(7-exo-H; 5.9%) and 1.47(6-endo-H; 17.1%) Finally irradiation on the signal at δ 1.47(6-endo-H) showed enhancements on the signals at δ 4.64(2-endo-H, 5 1%), 3.65(3-endo-H; 8.6%) and 1.80(6-exo-H; 17.1%); m/z(%): 319($M^+$, 63), 302(45), 288(44), 246(24), 230(20), 191(13), 190(100), 158(10), 131(30), 130(19), 104(12), 103(10), 91(11) and 79(11).

(41a) Obtained (290 mg, 10%) as colourless needles, m.p. 136-138°C, from ether-petroleum ether δ 7.47(d, 2H, J 7 5Hz, ArH), 7.32(t, 2H, J 7.6Hz, ArH), 7.25(m, 1H, ArH), 4.31(s, 1H, 8-H), 4.23(d, 1H, J 4.7Hz, 3-endo-H), 3.74 and 3.69(2 x s, 2 x 3H, OMe), 3.46(m, 1H, 7-exo-H), 2.99(m, 1H, 4-H), 2.91(dd, 1H, J 7.1 and 15.6 Hz, $CH_\alpha CO_2Me$), 2.51(dd, 1H, J 6.8 and 15.6Hz, $CH_\beta CO_2Me$), 1.96(m, 2H, 5-exo-H and 5-endo-H), 1.73(m, 2H, 6-endo-H and 6-exo-H) N.O.e. difference spectroscopy was used to assign the stereochemistry. Irradiation at δ 4.31(8-H ) caused enhancements at δ 3.46(7-exo-H; 10.5%), 2.99(4-H; 2.9%), 1.96(5-exo-H; 2.9%) and on the phenyl protons (4.7%). Irradiation at δ 4.23(3-endo-H) showed an enhancement at δ 2.99(4-H, 5.1%). Irradiation at δ 3.46(7-exo-H) caused an enhancement at δ 4.31(8-H; 10.7%). Irradiation at δ 2.99(4-H) caused enhancements at δ 4.31(8-H; 3.8%), 4.23(3-endo-H; 7.5%), 1.96(5-exo-H; 4.4%) and of ArH(5.6%); m/z(%) 319(29), 302(43), 288(25), 246(18), 230(17), 191(14), 190(100), 158(10), 143(19), 132(13), 131(37), 130(23), 107(11), 104(14), 103(12), 91(12) and 79(12).

Crystal Data for (8f): $C_{35}H_{31}NO_3P_2.H_2O$, M=593.6, triclinic, a=14.136(13), b=12.390(11), c=10.057(9)Å, α=100.4(1), β=98.3(1), γ=115.8(1)°, U=1510.3Å$^3$, Z=2, $D_x$=1.31 mg m$^{-3}$, F(000)=624, space group P1, (No. 1), Mo-Kα radiation, λ=0.71069Å, μ(Mo-Kα)=1.39 cm$^{-1}$. Colourless blocks; dimensions 0.25 x 0.80 x 1.0 mm. Data were recorded on a Stöe STADI-2 two-circle diffractometer using the background - ω scan - background technique, scan range 2°, 6 20 50°; 3148 unique reflections were measured. The structure was solved by direct methods (SHELXS86) and refined by least squares (SHELX76); non-hydrogen atoms were anisotropic

except the atoms of the phenyl groups attached directly to the central bicyclic ring nucleus. Hydrogen atoms were ignored. In the final cycles the 3006 data with $F > 2\sigma(F)$ gave $R = 0.085$. The two crystallographically independent molecules in the unit cell are chemically equivalent enantiomers and, except for the conformations of some phenyl rings, the whole structure approximates to the centrosymmetric space group $P\bar{1}$ (No. 2). A projection of one molecule is shown in Figure 1. A water molecule of crystallization per formula unit is bound to the phosphite oxygen atoms of two adjacent molecules leading to a hydrogen-bonded chain through the crystal. The full structural data has been deposited with the Cambridge Crystallographic Data Centre.

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