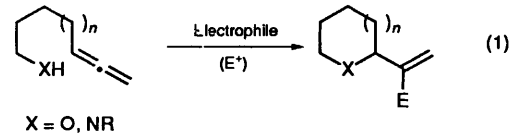
Allene-based Electrophile-mediated Cyclisations: Efficient Synthesis of Medium Ring Azacycles

Robert W. Shaw[a,b] **and Timothy Gallagher***[a,c]
[a] *School of Chemistry, University of Bath, Bath BA2 7AY, UK*
[b] *Shell Research Ltd., Sittingbourne Research Centre, Sittingbourne ME9 8AG, UK*
[c] *School of Chemistry, University of Bristol, Bristol BS8 1TS, UK*

While Ag^{I}- and Pd^{II}-based electrophiles have limited application in cyclisations of allenic amines leading to 7-membered and larger azacycles, these rings may be obtained using iodine as the electrophilic trigger. Iodination of the *N*-benzyl derivative **5** gives hexahydroazepine **9** either directly or *via* the isolable allylic iodide **10**. The sulfonamide-based allylic iodides **11a–e**, produced by direct iodination of allenic sulfonamides **4a–e**, cyclise in the presence of NaH, and the product distribution—**12** *vs.* **13**—which depends on the size of rings involved, shows a preference towards formation of the larger ring **13**. This chemistry provides a relatively efficient synthesis of 8-, 9-, 10- and 11-membered azacycles **13a–e** and ^{13}C and ^{1}H NMR correlations have been applied to assign the (*E*)/(*Z*)-alkene geometry of both **13** and related macrocycles **14**.

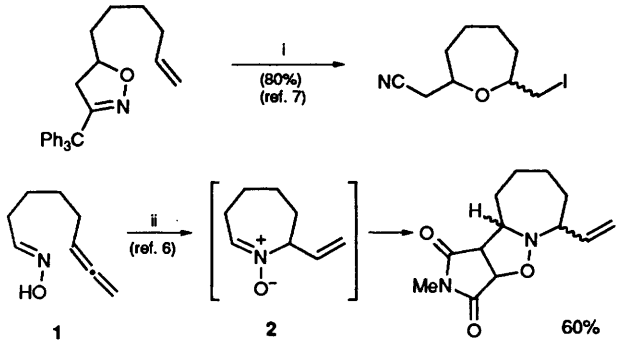
Electrophile-mediated cyclisations involving the activation of C–C π-bonds provide an important and flexible entry into N- and O-containing heterocycles.[1] While this class of reaction is most commonly exploited with an alkenyl moiety serving as the nucleophilic π-bond, alkynyl[2] and, in particular, allenyl-based substrates[3–6] have also been widely used and our interest in this area has centred primarily on the applicability of the allene π-bond array. The reactivity of this unit facilitates the electrophilic addition process and, more importantly, imparts—*via* the 'second' π-bond that is retained after cyclisation has occurred—an exploitable level of functionality to the resulting heterocyclic product [eqn. (1)].[4]



X = O, NR (1)

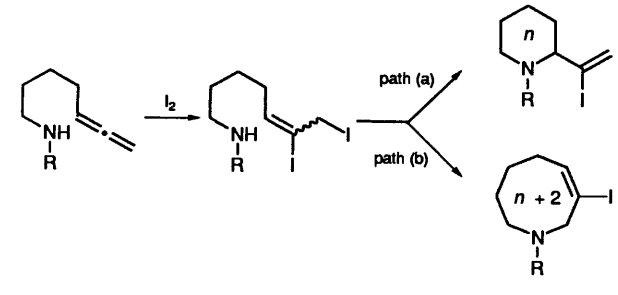
To date, most studies have involved the synthesis of either 5- or 6-membered rings, though electrophile-mediated cyclisations involving alkenes (but **not** allenes†) can also provide access to 3- and 4-membered heterocyclic rings. However, the scope of this process is more limited in terms of larger (>6) ring sizes. Kurth and co-workers[7] have successfully generated 7-ring oxygen heterocycles, and Ag^{I}-catalysed cyclisation of the allenyl oxime **1**[6] provides, *via* the nitrone **2**, efficient access to the hexahydroazepine skeleton (Scheme 1).‡

To overcome this obstacle and provide a general route to larger (≥7) rings is a worthwhile objective, but necessitates an appreciation of the mechanistic requirements and limitations associated with what are, in essence, intramolecular alkylations.



Scheme 1 *Reagents:* i, I_2; ii, $AgOSO_2CF_3$, *N*-methylmaleimide

It is well-known that the efficiency of such reactions is very sensitive to the size of ring involved, but yields can be improved by incorporation of a better leaving group or a more reactive nucleophile and restricting competing bimolecular alkylation.[9] We reasoned that addition of a suitable electrophile, for example I_2, across the allene π-system would generate a reactive allylic iodide better able to undergo efficient cyclisation (Scheme 2).[10]



Scheme 2

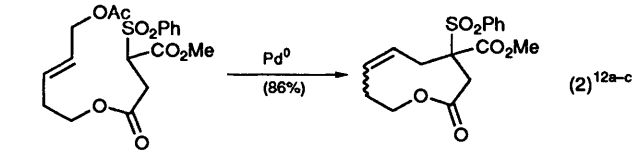
This sequence can lead to different products depending on whether nucleophilic attack takes place at the proximal [path (a)] or distal [path (b)] site of the ambident allyl system. The preference for ring size (*n vs.* *n* + 2) must, as a result, be evaluated and the factors that influence the balance between intramolecular S_N' [path (a)] *vs.* S_N [path (b)] reactions have recently been discussed at length.[11]

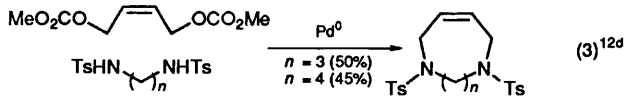
* *Present address:* School of Chemistry, University of Bristol, Bristol BS8 1TS, UK.

† Ag^{I}-Mediated cyclisation of penta-3,4-dienylamine derivatives takes place at the distal trigonal centre or central digonal carbon atom of the allenyl unit to give piperidine or pyrrolidine products respectively, rather than an azetidine.[5] Related cyclisations involving other allenic derivatives have been reported.[3c,e,h]

‡ Kozikowski[8] has achieved a cyclisation of an alkenyl alcohol to give a 7-ring oxepane, but the corresponding *N*-ethoxycarbamate failed to give an azacyclic product. Our attempts to cyclise octa-6,7-dien-1-ol using either Ag^{I} and Pd^{II} electrophiles failed.

Some years ago Trost demonstrated that lactone synthesis *via* addition of stabilised enolates to (π-allyl)palladium electrophiles favours the *larger* of the two possible rings [eqn. (2)][12a–c] and, more recently, Tsuda *et al.* have observed a similar preference for a closely related Pd-mediated process involving nitrogen nucleophiles that leads to 9- and 10-membered diazacycles[12d] [eqn. (3)].

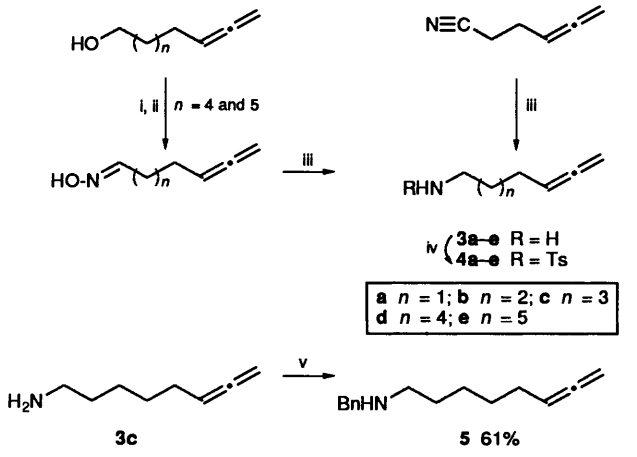




In this paper we describe the results of our studies[13] of the allene-based reaction sequence shown in Scheme 2. The synthesis of medium-ring nitrogen heterocycles has been achieved and, under certain conditions, good selectivity has been observed for the *larger* of the two possible ring sizes, *i.e.* path (b) as shown in Scheme 2. Macrocyclic dimeric products (16- to 22-membered rings), resulting from an initial intermolecular alkylation step may also be isolated, but this pathway can be readily suppressed by appropriate choice of reaction conditions.

Results and Discussion

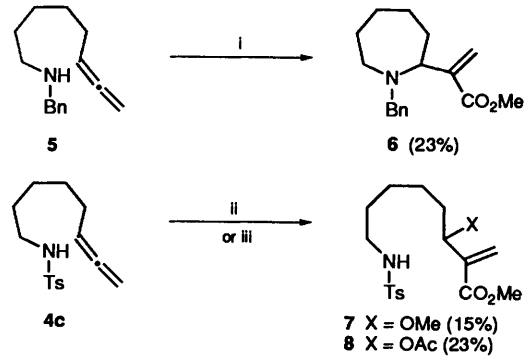
Synthesis of Allenic Substrates.—Using a series of straightforward manipulations, a series of allenic sulfonamides **4a–e** was prepared as shown in Scheme 3. The hepta-5,6-dienyl derivatives **3b** and **4b** and the octa-6,7-dienyl derivatives **3c** and **5** have been described previously.[14b]



Scheme 3 *Reagents:* i, pyridinium chlorochromate; ii, NH_2OH; iii, $LiAlH_4$; iv, py, TsCl (Ts = 4-$MeC_6H_4O_2S$); v, PhCHO then $NaBH_4$

Cyclisation Studies

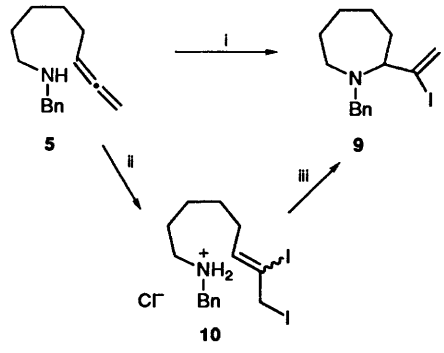
(a) *Use of Metal Ions as Electrophilic Triggers.*—A wide range of allenyl substrates undergo cyclisation to give 5- or 6-membered heterocyclic rings using a range of electrophiles, including a variety of Ag^I or Pd^{II} species.[14] However, the sulfonamide **4c** and the benzylamine **5** both failed to give a 7-membered ring in the presence of $AgOSO_2CF_3$ under a variety of conditions although the more nucleophilic benzylamine **5** was shown to undergo cyclisation in the presence of Pd^{II} (under carbonylating conditions) to give the acrylate **6** (23% yield) (Scheme 4). However, the sulfonamide **4c** gave only the acyclic



Scheme 4 *Reagents:* i, $PdCl_2$, CO, MeOH; ii, **7**: $PdCl_2$, CO, MeOH; iii, **8**: $Pd(OAc)_2$, CO, MeOH (1 equiv.), CH_2Cl_2

adducts **7** or **8** under these conditions, products which result from Pd^{II} activation followed by inter- rather than intramolecular nucleophilic addition.[14b] Given the limited success of this phase of the study, no further Ag^I or Pd^{II}-mediated cyclisations (involving the formation of > 7-membered rings) have been evaluated.

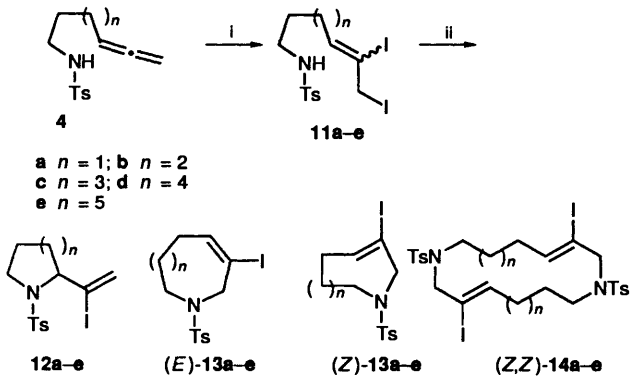
(b) I_2-*Mediated Cyclisations.*—Treatment of the *N*-benzyl allenic amine **5** with I_2 in CH_2Cl_2 gave the hexahydroazepine **9** in 21% isolated yield (Scheme 5). This reaction was slow (2 days



Scheme 5 *Reagents:* i, I_2, CH_2Cl, 2 d (21%); ii, HCl, Et_2O then I_2, $CHCl_2$; iii, Et_3N, CH_2Cl, 1 d (17% from **5**)

at room temp.) and, while no other products could be characterised, there are clearly a number of alternative and potentially unproductive pathways available. As a result, a stepwise sequence has also been evaluated. Addition of I_2 to the hydrochloride salt of **5** gave the isolable allylic iodide **10** as a 1:3 mixture of *E*- and *Z*-isomers which underwent cyclisation to give the 7-membered azacycle **9** (17% overall yield from **5**) on addition of Et_3N. This is an interesting result in terms of the ring size that is formed—path (a) is favoured over path (b) (*cf.* Scheme 2)—(see below), but details of the mechanism of the cyclisation step, including a possible role for an allylic iodide related to **10** in the direct conversion of **5** into the azacycle **9**, have not been established.

Cyclisation of the less nucleophilic sulfonamides **4a–e** was also achieved, but only *via* the two-step procedure shown in Scheme 6. Addition of I_2 occurred across the terminal π-bond



Scheme 6 *Reagents:* i, I_2, THF; ii, NaH, DMPU, THF

Table 1

Entry	Allenic-sulfonamide **4**	Cyclisation conditions	**12** (%)	(*E*/*Z*)-**13** (%)	(*Z*,*Z*)-**14** (%)
1	**4a**	A	**12a** 83	**13a** 10[a]	ND
2	**4b**	A	**12b** 13	**13b** 13[a]	**14b** 23
		B	**12b** 22	**13b** 35[a]	ND
3	**4c**	A	ND	**13c** 38[b]	**14c** 20
		B	ND	**13c** 55[b]	ND
4	**4d**	A	ND	**13d** 15[c]	**14d** 40
		B	ND	**13d** 62[c]	ND
5	**4e**	A	ND	**13e** 10[d]	**14e** 30
		B	ND	**13e** 35[d]	ND

A: concentration of the allylic iodide **11** was 5.5 mmol dm^{-3}; B: Allyl iodide **11** was slowly added (*via* a syringe pump) to a suspension of NaH in THF/DMPU. ND (not detected). [a](*E*)-Isomer only. [b]1:1 Mixture of *E*:*Z* isomers. [c]1:1.5 Mixture of *E*:*Z* isomers. [d]1:3 Mixture of *E*:*Z* isomers.

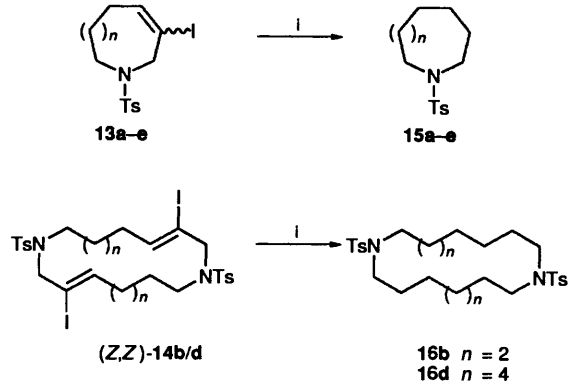
of the allene moiety to give the isolable allylic iodides (**11a–e**).* Cyclisation was then accomplished by use of NaH in the presence of *N*,*N*′-dimethylpropyleneurea [DMPU; 1,3-dimethyl-3,4,5,6-tetrahydropyrimidin-2(1*H*)-one], and the azacycles **12** [path (a), *cf.* Scheme 2] and **13** [path (b), *cf.* Scheme 2], together with the dimers **14** were identified following purification by flash chromatography.

The results of this study, which are displayed in Table 1, showed that both cyclisation modes (as illustrated in Scheme 2) were available but for reactions involving **4c–e**, only the **larger** of the two heterocyclic rings, *i.e.* **13**, was observed. Cyclisation of the hexa-4,5-dienyl derivative **11a** (Table 1, entry 1) gave, as expected, the pyrrolidine **12a** (83%) as the major product but, even in this particularly favourable case, a significant 10% yield of the 7-membered ring (*E*)-**13a** was obtained. Under the same conditions, the hepta-5,6-dienyl derivative **11b** (Table 1, entry 2) gave the piperidine **12b** and (*E*)-**13b** in **equal** amounts. In the other three cases studied (Table 1, entries 3–5), **only the larger** ring products, *i.e.* **13c–e** were observed; in these last mentioned cases both (*E*)- and (*Z*)-azacycloalkenes were produced (see below). In additon, the macrocycles **14b–e** as (*Z*,*Z*)-isomers, resulting from initial intermolecular alkylation of the allylic iodide **11**, were also obtained, but this competing pathway was suppressed effectively by use of pseudo-high dilution conditions for the cyclisation step.

* The allylic iodides **10** and **11a–e** were obtained as approximately 3–10:1 mixtures (as judged by ^{1}H NMR spectroscopy) of *Z*- and *E*-isomers.[15] In the case of **11c**, NOE experiments indicated that the major component had *Z*-geometry (see Experimental section) and, based on comparison of ^{1}H NMR data, the *Z*-isomer appears to be predominant in all cases. Chemical shifts for the alkenyl proton of **10** and **11a–e** are diagnostic: *Z*-isomer δ_H 5.81–5.85; *E*-isomer δ_H 6.09–6.20.

The synthetic utility of the cyclisation sequence shown in Scheme 6 merits recognition in terms of its efficiency and flexibility. While these reactions have not been fully optimised, the 8-, 9-, 10- and 11-membered azacyles **13b–e** are available in 35, 55, 62 and 35% overall yield from **4b–e**, respectively. In addition, incorporation into the cyclic product of the electrophilic mediator (as an alkenyl iodide) provides a valuable means of manipulating the heterocyclic core and aspects of this feature, which is still under study, have been described.[16]

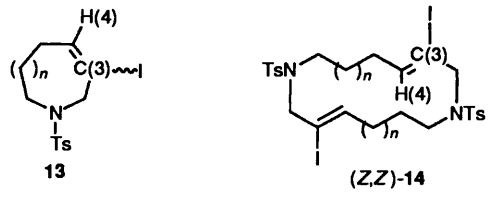
Structural Assignment of Heterocyclic Products.—We are concerned both to verify the structures of the endocyclic alkenes **13** and assign the alkene geometry of the azacycles **13** and **14**. The structures of the azacycles **13a–e** were confirmed by reduction (including concomitant de-iodination) to give the saturated sulfonamides **15a–e** which were then characterised by direct comparison (mixed m.p., IR, ^{1}H NMR) with authentic samples prepared using reported procedures.[17] The bis(sulfonamides) **14b** and **14d** were likewise subjected to this reduction sequence to give the known[18] saturated diaza macrocycles **16b** and **16d**, respectively (Scheme 7).



Scheme 7 *Reagents:* i, H_2, Pd/C, EtOH

The structure of the 16-membered diazacycle **14b** had been established by X-ray crystallographic analysis[19] and this served to assign unambiguously the (*Z*,*Z*)-alkene geometry indicated. An attempt has subsequently been made, using ^{1}H and ^{13}C NMR correlations, to assign the *E*/*Z* geometry of **13a–e** and **14b–e**. Ring strain dictates a *E* geometry for both 7-membered ring **13a** and the 8-membered ring **13b** and only one double-bond isomer was detected in each of these two cases. Using this information, together with the known structure of **14b**, inspection of available spectroscopic data indicates that for **13** and **14** chemical shifts of both C-3 [NCH_2-*C*(I)=CH] and 4-H [$NCH_2C(I)$=C*H*] are both sensitive to alkene geometry and fall into the ranges indicated in Fig. 1; the 18- and 22-ring macrocycles **14c** and **14e**, respectively, were assigned on the basis of ^{1}H NMR analysis alone. It is interesting to note that the proportion of the (*Z*)-alkene isomer increases with ring size (Table 1) and the macrocyclic dimers **14b–e** were only obtained as their *Z*,*Z* isomers. The proton shifts quoted are also consistent with stereochemical assignment of allyl iodides **10** and **11a–e** which were carried out independently.*

In summary, iodine-mediated cyclisation of allenic sulfonamides provides an efficient means of generating medium-ring nitrogen heterocycles. This process complements the recent studies of Tsuda *et al.* [eqn. (3)][12d] who reported a similar preference for the larger of two possible ring sizes for cyclisations leading to medium-ring diazacycles. In addition, we have also considered possible mechanistic explanations for the basis of the selectivity observed between **12** and **13**, and these results of this aspect of the study are described in the accompanying paper.[20]



(*E*)-Isomers	(*Z*)-Isomers
$\delta_{C(3)}$:96.6–87.4	$\delta_{C(3)}$:102.0–99.8
$\delta_{H(4)}$:6.44–6.35	$\delta_{H(4)}$:6.31–5.74

Fig. 1

Experimental

Standard methods were employed for the purification of solvents and reagents. ^{1}H NMR spectra were obtained at 270 or 300 MHz and ^{13}C spectra were obtained at 67.8 MHz, using $CDCl_3$ unless otherwise shown. The preparation of the amines **3b** and **5** and the sulfonamides **4b, c** have been described [14b] and nona-7,8-dien-1-ol and deca-8,9-dien-1-ol were prepared by alkylation of 1-lithioallene using the methods reported by Brandsma.[21]

Hexa-4,5-dienylamine **3a**.—A solution of hexa-4,5-dienenitrile [22] (9.3 g, 100 mmol) in ether (30 cm^3) was added to a stirred suspension of $LiAlH_4$ (3.8 g, 120 mmol) in ether (100 cm^3) at −20 °C. The mixture was allowed to warm to room temperature and was then stirred for 2 h. The reaction was quenched with aq. NaOH (2 mol dm^{-3}) and the mixture filtered. The filtrate was carefully concentrated at reduced pressure to give hexa-4,5-dienylamine **3a** (8.3 g, 85%) as a colourless liquid, b.p. 95–100 °C (760 mmHg) (Found: M^+, 97.091. $C_6H_{11}N$ requires *M*, 97.089); ν_{max}(neat)/cm^{-1} 3320 and 1950; δ_H(270 MHz) 5.12 (1 H, pentet, *J* 7), 4.67 (2 H, m), 2.73 (2 H, t, *J* 7), 2.05 (2 H, qt, *J* 7, 3.5), 1.57 (2 H, pentet, *J* 7) and 1.35 (2 H, s); *m/z* (EI) 97 (M^+).

(E)- *and* (Z)-*Nona-7,8-dienal Oxime*.—Using a similar procedure to that described below for (*E*)- and (*Z*)-deca-8,9-dienal oxime, nona-7,8-dien-1-ol [21] was oxidised and then treated with hydroxylamine, to give a 1:1 mixture of the title (*E*)- and (*Z*)-oximes (130 mg, 93%) as a pale yellow oil (Found: M^+ + H, 154.123. $C_9H_{15}NO$ + H requires *M*, 154.123); ν_{max}(neat)/cm^{-1} 3300, 1950, 1700, 1650 and 840; δ_H(300 MHz) 8.30 (1 H, br s), 7.40/6.71 (1 H, t, *J* 7), 5.08 (1 H, pentet, *J* 7), 4.40–4.49 (2 H, m), 2.38/2.10 (2 H, q, *J* 7), 1.92–2.06 (2 H, m) and 1.30–1.60 (6 H, m); *m/z* (CI) 154 (M^+ + H).

Nona-7,8-dienylamine **3d**.—(*E*)- and (*Z*)-Nona-7,8-dienal oxime (100 mg, 0.66 mmol) in ether (2 cm^3) was added to a stirred suspension of $LiAlH_4$ (50 mg, 1.32 mmol) in ether (5 cm^3) at −78 °C and the mixture was then allowed to warm to room temperature. The reaction mixture was quenched with aqueous NaOH and then filtered and concentrated under reduced pressure to give the *title compound* (80 mg, 88%) as a colourless oil (Found: 140.144. $C_9H_{17}N$ + H requires *M*, 140.144); ν_{max}(neat)/cm^{-1} 3300br, 1950 and 840; δ_H(300 MHz) 5.00 (1 H, pentet, *J* 7), 4.51–4.59 (2 H, m), 2.60 (2 H, t, *J* 7), 1.85–1.96 (2 H, m), 1.55–1.70 (2 H, br s) and 1.20–1.40 (8 H, m); *m/z* (CI) 140 (M^+ + H).

(E)- *and* (Z)-*Deca-8,9-dienal Oxime*.—A solution of deca-8,9-dien-1-ol [21] (14 g, 90 mmol) in CH_2Cl_2 (120 cm^3) was added in a single portion to a rapidly stirred suspension of pyridinium chlorochromate (39 g, 180 mmol), anhydrous sodium acetate (7.4 g) and crushed 4 Å molecular sieves (6.0 g) in CH_2Cl_2 (300 cm^3) at 0 °C. The reaction mixture was allowed to warm to room temperature and then stirred for 3 h. After this it was diluted with ether (500 cm^3), filtered through a Florisil column, and carefully concentrated under reduced pressure to give deca-8,9-dienal which was used without further purification.

The crude aldehyde was dissolved in methanol (60 cm^3) and treated with a solution of sodium acetate (18.4 g) and hydroxylamine hydrochloride (6.3 g, 90 mmol) in water (30 cm^3). The mixture was heated at 60 °C for 1 h and then cooled, diluted with water (150 cm^3) and extracted with CH_2Cl_2 (3 × 100 cm^3). The combined extracts were dried ($MgSO_4$) and concentrated under reduced pressure and the residue was purified by flash chromatography to give, on elution with CH_2Cl_2, a 1:1 mixture of (*E*/*Z*)-deca-8,9-dienal oxime (8.3 g, 55%) as a yellow oil (Found: M^+ + H, 168.140. $C_{10}H_{17}NO$ + H requires *M*, 168.138); ν_{max}(neat)/cm^{-1} 3300, 1955, 1650, 1450 and 1430; δ_H(300 MHz) 7.90 (1 H, br s), 7.41/6.72 (1 H, t, *J* 7), 5.06 (1 H, pentet, *J* 7), 4.60–4.65 (2 H, m), 2.32–2.42/2.13–2.25 (2 H, m), 1.90–2.05 (2 H, m) and 1.22–1.60 (8 H, m); *m/z* (CI) 168 (M^+ + H).

Deca-8,9-dienylamine **3e**.—Using a similar procedure to that described for **3d**, the mixture of (*E*)- and (*Z*)-deca-8,9-dienal oxime was reduced with $LiAlH_4$, to give the *title compound* (4.0 g, 87%) as a yellow oil (Found: M^+ + H, 154.159. $C_{10}H_{19}N$ + H requires *M*, 154.1595); ν_{max}(neat)/cm^{-1} 3300, 1950 and 850; δ_H(270 MHz) 5.05 (1 H, pentet, *J* 7), 4.81–4.85 (2 H, m), 2.68 (2 H, t, *J* 7), 1.95–2.00 (2 H, m), 1.62–1.75 (2 H, m) and 1.20–1.60 (10 H, m); *m/z* (CI) 154 (M^+ + H).

General Procedure for Sulfonamide Preparation.—N-(p-*Tolylsulfonyl*)*hexa-4,5-dienylamine* **4a**. Tosyl chloride (3 g, 16 mmol) was added to hexa-4,5-dienylamine **3a** (3.63 g, 16 mmol) in pyridine (60 cm^3) at 0 °C and the solution was stored at 4 °C for 40 h. After this, the mixture was treated with an excess of hydrochloric acid (2 mol dm^3) and extracted with ether (3 × 100 cm^3). The combined extracts were dried ($MgSO_4$) and concentrated under reduced pressure and the residue was purified by flash chromatography to give, on elution with light petroleum–ether (3:2), the *title compound* **4a** (2.49 g, 62%) as a pale yellow oil (Found: C, 62.2; H, 7.0; N, 5.6. $C_{13}H_{17}NO_2S$ requires C, 62.15; H, 6.8; N, 5.6%); ν_{max}(neat)/cm^{-1} 3300, 1950, 1600, 1310 and 1160; δ_H(300 MHz) 7.73 (2 H, d, *J* 8), 7.30 (2 H, d, *J* 8), 5.00 (1 H, pentet, *J* 7), 4.60–4.68 (2 H, m), 4.50 (1 H, m), 2.95 (2 H, q, *J* 7), 2.42 (3 H, s), 1.94–2.03 (2 H, m) and 1.59 (2 H, q, *J* 7); *m/z* (CI) 252 (M^+ + H).

N-(p-*Tolylsulfonyl*)*nona-7,8-dienylamine* **4d**. Isolated in 65% yield as a yellow oil (Found: M^+ + H, 294.153. $C_{16}H_{23}NO_2S$ + H requires *M*, 294.153); ν_{max}(neat)/cm^{-1} 3280, 1950, 1600, 1320 and 1150; δ_H(300 MHz) 7.75 (2 H, d, *J* 8), 7.30 (2 H, d, *J* 8), 5.04 (1 H, pentet, *J* 7), 4.60–4.68 (2 H, m), 4.45 (1 H, m), 2.90 (2 H, q, *J* 7), 2.41 (3 H, s), 1.88–1.98 (2 H, m), 1.38–1.48 (2 H, m) and 1.20–1.30 (6 H, m); *m/z* (CI) 294 (M^+ + H).

N-(p-*Tolylsulfonyl*)*deca-8,9-dienylamine* **4e**. Isolated in 48% yield as a pale yellow oil (Found: C, 66.0; H, 8.4; N, 4.7. $C_{17}H_{25}NO_2S$ requires C, 66.4; H, 8.1; N, 4.6%); ν_{max}(neat)/cm^{-1} 3300, 1950, 1595, 1320 and 1150; δ_H(300 MHz) 7.75 (2 H, d, *J* 8), 7.30 (2 H, d, *J* 8), 5.06 (1 H, pentet, *J* 7), 4.26–4.69 (2 H, m), 4.40 (1 H, m), 2.88–2.96 (2 H, m), 2.43 (3 H, s), 1.90–2.02 (2 H, m) and 1.51–1.10 (10 H, m); *m/z* (CI) 308 (M^+ + H).

1-*Benzyl*-2-(1-*iodovinyl*)*perhydroazepine* **9**.—(*a*) *By direct cyclisation of benzylocta-6,7-dienylamine* **5**. A solution of iodine (236 mg, 9.3 mmol) in CH_2Cl_2 (5 cm^3) was added dropwise to a stirred solution of the amine **5** (20 mg, 8.3 mmol) in CH_2Cl_2 (40 cm^3). The reaction mixture was stirred at room temperature for 4 d, concentrated under reduced pressure and purified by flash chromatography to give, on elution with hexane, the *title compound* **9** (70 mg, 22%) as a yellow oil (Found: M^+ + H,

342.073. $C_{15}H_{20}IN$ + H requires *M*, 342.072); ν_{max}(neat)/cm^{-1} 1610; δ_H(300 MHz) 7.20–7.40 (5 H, m), 6.39 (1 H, s), 5.80 (1 H, s), 3.81 (1 H, d, *J* 15), 3.62 (1 H, d, *J* 15), 2.95–3.05 (2 H, m), 2.70 (1 H, m), 1.78–1.90 (2 H, m) and 1.40–1.70 (6 H, m); *m/z* (CI) 342 (M^+ + H).

(*b*) Via *the allylic iodide* **10**. Dry HCl gas was bubbled into an ice-cold solution of *N*-benzylocta-6,7-dienylamine **5** (71 mg, 0.33 mmol) in ether (10 cm^3). The resulting hydrochloride salt was filtered off and air dried (Found: C, 71.8; H, 9.0; N, 5.2. $C_{15}H_{22}ClN$ requires C, 71.6; H, 8.75; N, 5.6%); ν_{max}(Nujol)/cm^{-1} 2920, 1950 and 850; δ_H(300 MHz) 9.71–9.95 (2 H, br s), 7.25–7.60 (5 H, m), 4.99 (1 H, pentet, *J* 7), 4.5–4.60 (2 H, m), 3.91–4.00 (2 H, br s), 2.61–2.89 (2 H, m), 1.70–1.95 (4 H, m) and 1.20–1.45 (4 H, m).

A solution of iodine (84 mg, 0.33 mmol) in CH_2Cl_2 (5 cm^3) was added to a solution of the hydrochloride salt prepared above in CH_2Cl_2 (20 cm^3) and the reaction mixture was stirred at room temperature for 1 h to give, after evaporation of the solvents, the allylic iodide **10** as a 1:3 mixture of *E*- and *Z*-isomers; δ_H(300 MHz) 9.30–10.0 (2 H, br s), 7.54–7.61 (2 H, m), 7.34–7.45 (3 H, m), 6.15 (1 H, t, *J* 7, minor isomer), 5.88 (1 H, t, *J* 7, major isomer), 4.38 (2 H, s, major isomer), 4.26 (2 H, s, minor isomer), 4.00 (2 H, s), 2.70–2.81 (2 H, m), 1.94–2.09 (2 H, m), 1.78–1.93 (2 H, m) and 1.28–1.48 (4 H, m). Isolation of **10** was not usually carried prior to the cyclisation step.

To the solution of the allylic iodide **10** (prepared above) was added slowly a solution of triethylamine (0.1 cm^3, 0.66 mmol) in CH_2Cl_2 (5 cm^3) and the mixture was then stirred at room temperature for 24 h. After this it was washed with brine (10 cm^3), dried ($MgSO_4$), concentrated under reduced pressure and the residue was purified to give, on elution with light petroleum–ether (10:1), the title compound **9** (20 mg, 17%).

General Procedures for the Cyclisation of the Sulfonamides **4**

(*a*) *Under Pseudo High Dilution Conditons.*—A solution of iodine (107 mg, 0.42 mmol) in THF (5 cm^3) was added dropwise to a stirred solution of each of the allenic sulfonamides **4a–e** (0.42 mmol) in THF (20 cm^3). The reaction mixture was stirred at room temperature in the dark for 1 h [or until all the allenic sulfonamide had reacted, as monitored by TLC {ether–light petroleum (2:3)}]. **Note:** After this time, the allylic iodides **11** could be isolated following evaporation of solvents and ^{1}H NMR data for **11a–e** are presented below.

The reaction mixture containing the crude allylic iodides **11** was diluted with THF (25 cm^3) and added, at a rate of 2 cm^3 h^{-1} using a syringe pump, to a stirred suspension of sodium hydride (60% dispersion in oil; 17 mg, 0.42 mmol) in THF (20 cm^3) and dry DMPU (5 cm^3) over 25 h in the dark. The reaction mixture was then quenched with wet ether (10 cm^3) and concentrated under reduced pressure. The bulk of the DMPU was removed by bulb-to-bulb distillation (at *ca.* 100 °C, 0.1 mmHg) and the residue was purified by flash chromatography to give, on elution with CH_2Cl_2, the azacycles **12** and **13**.

(*b*) *Under Standard Conditions.*—The crude allylic iodides prepared as described above were treated directly with NaH, DMPU in THF (same proportions as above) and, after 16–25 h the reaction mixtures were quenched and work-up was carried out as described above. Under these conditions the sulfonamides **12** and **13** together with the cyclic dimers **14** were isolated.

All yields are shown in Table 1 and data for (i) the crude allylic iodides (only ^{1}H NMR data was obtained), (ii) the azacycles **12**/**13** and (iii) the cyclic dimers **14** are presented below.

(E)- *and* (Z)-5,6-*Diiodo*-N-(p-*tolylsulfonyl*)*hex*-4-*enylamine* **11a**. Isolated as a 3:1 mixture of *Z*- and *E*-isomers; δ_H(300 MHz) 7.75 (2 H, d, *J* 8), 7.30 (2 H, d, *J* 8), 6.09 (1 H, t, *J* 7, minor), 5.81 (1 H, t, *J* 7, major), 4.70 (1 H, br t), 4.35 (2 H, s, major), 4.22 (2 H, s, minor), 2.90–3.00 (2 H, m), 2.42 (3 H, s), 1.95–2.10 (2 H, m) and 1.52–1.65 (2 H, m).

(E)/(Z)-6,7-*Diiodo*-N-(p-*tolylsulfonyl*)*hept*-5-*enylamine* **11b**. Isolated as a 10:1 mixture of *Z*- and *E*-isomers; δ_H(300 MHz) 7.75 (2 H, d, *J* 8), 7.30 (2 H, d, *J* 8), 6.11 (1 H, t, *J* 7, minor), 5.82 (1 H, t, *J* 7, major), 4.61 (1 H, m), 4.35 (2 H, s, major), 4.23 (2 H, s, minor), 2.91 (2 H, q, *J* 6), 2.41 (3 H, s), 2.02 (2 H, q, *J* 7) and 1.36–1.54 (4 H, m).

(E)/(Z)-7,8-*Diiodo*-N-(p-*tolylsulfonyl*)*oct*-6-*enylamine* **11c**. Isolated as a 9:1 mixture of *Z*- and *E*-isomers; δ_H(300 MHz) 7.75 (2 H, d, *J* 8), 7.30 (2 H, d, *J* 8), 6.15 (1 H, t, *J* 7, minor), 5.85 (1 H, t, *J* 7, major), 4.50 (1 H, br s), 4.38 (2 H, s, major), 4.26 (2 H, s, minor), 2.92 (2 H, q, *J* 7), 2.41 (3 H, s), 2.00 (2 H, q, *J* 8) and 1.22–1.50 (6 H, m). The major isomer has been assigned as (*Z*)-**11c** on the basis of NOE experiments which involved irradiation at: (a) δ 5.85 (t, major isomer) which resulted in enhancement of δ 4.38 (s, major isomer) and δ 2.00 (q, major isomer); (b) δ 4.38 (s, major isomer) which resulted in enhancement of δ 5.85 (t, major isomer); (c) δ 6.15 (t, minor isomer) which resulted in enhancement of δ 2.00 (q, minor isomer); (d) δ 4.26 (t, minor isomer) which resulted in enhancement of δ 2.00 (q, minor isomer).

(E)/(Z)-8,9-*Diiodo*-N-(p-*tolylsulfonyl*)*non*-7-*enylamine* **11d**. Isolated as a 3:1 mixture of *Z*- and *E*-isomer; δ_H(300 MHz) 7.75 (2 H, d, *J* 8), 7.30 (2 H, d, *J* 8), 6.20 (1 H, t, *J* 7, minor), 5.88 (1 H, t, *J* 7, major), 4.39 (2 H, s, major), 4.28 (2 H, s, minor), 4.30 (1 H, br s), 2.94 (2 H, q, *J* 7), 2.42 (3 H, s), 1.91–2.08 (2 H, m) and 1.20–1.50 (8 H, m).

(E)/(Z)-9,10-*Diiodo*-N-(p-*tolylsulfonyl*)*dec*-8-*enylamine* **11e**. Isolated as a 10:1 mixture of *Z*- and *E*-isomers; δ_H(300 MHz) 7.75 (2 H, d, *J* 8), 7.30 (2 H, d, *J* 8), 6.20 (1 H, t, *J* 7, minor), 5.88 (1 H, t, *J* 7, major), 4.40 (2 H, s, major), 4.22 (2 H, s, minor), 4.20 (1 H, m), 2.90 (2 H, t, *J* 7), 2.40 (3 H, s), 1.95–2.05 (2 H, m) and 1.16–1.60 (10 H, m).

2-(1-*Iodovinyl*)-1-(p-*tolylsulfonyl*)*pyrrolidine* **12a**. Isolated as a colourless solid, m.p. 103–104 °C (cyclohexane) (Found: C, 41.5; H, 4.3; N, 3.7. $C_{13}H_{16}INO_2S$ requires C, 41.4; H, 4.2; N, 3.7%); ν_{max}(Nujol)/cm^{-1} 1710, 1610, 1590, 1340 and 1150; δ_H(300 MHz) 7.72 (2 H, d, *J* 8), 7.31 (2 H, d, *J* 8), 5.95 (1 H, t, *J* 1.5), 5.85 (1 H, dd, *J* 1, 2), 4.15 (1 H, m), 3.49 (1 H, m), 3.30 (1 H, m), 2.42 (3 H, s) and 1.55–2.00 (4 H, m); *m/z* (CI) 378 (M^+ + H).

(E)-6-*Iodo*-1-(p-*tolylsulfonyl*)-2,3,4,7-*tetrahydro*-1H-*azepine* **13a**. Isolated as a colourless oil (Found: M^+, 376.993. $C_{13}H_{16}INO_2S$ requires *M*, 376.994); ν_{max}(neat)/cm^{-1} 1710, 1330 and 1160; δ_H(300 MHz) 7.70 (2 H, d, *J* 8), 7.30 (2 H, d, *J* 8), 6.35 (1 H, t, *J* 6), 4.18 (2 H, s), 3.40 (2 H, t, *J* 7), 2.41 (3 H, s), 2.02–2.11 (2 H, m) and 1.78–189 (2 H, m); *m/z* (CI) 378 (M^+ + H).

2-(1-*Iodovinyl*)-1-(p-*tolylsulfonyl*)*piperidine* **12b**. Isolated as a colourless solid, m.p. 60.5–61.5 °C (benzene–light petroleum) (Found: M^+ + H, 392.020. $C_{14}H_{18}INO_2S$ + H requires *M*, 392.018); ν_{max}(neat)/cm^{-1} 1620, 1600, 1340 and 1160; δ_H(270 MHz) 7.65 (2 H, d, *J* 8), 7.31 (2 H, d, *J* 8), 6.29 (1 H, t, *J* 2), 6.02 (1 H, t, *J* 2), 4.74 (1 H, s), 3.71 (1 H, dd, *J* 4, 14), 3.06 (1 H, dt, *J* 3, 12), 2.42 (3 H, s), 2.30 (1 H, m), 1.20–1.60 (5 H, m); δ_C 143.2, 137.9, 129.6, 128.4, 127.05, 110.7, 60.33, 41.7, 27.9, 23.8, 21.5 and 18.5; *m/z* (CI) 392 (M^+ + H).

(E)-7-*Iodo*-1-(p-*tolylsulfonyl*)-1,2,3,4,5,8-*hexahydro*-1H-*azocine* **13b**. Isolated as a colourless solid, m.p. 112.5–113 °C (benzene–light petroleum) (Found: M^+ + H, 392.020. $C_{14}H_{18}INO_2S$ + H, requires *M*, 392.018); ν_{max}(neat)/cm^{-1} 1620, 1600, 1340 and 1160; δ_H(300 MHz) 7.65 (2 H, d, *J* 8), 7.31 (2 H, d, *J* 8), 6.44 (1 H, t, *J* 8.5), 4.02 (2 H, s), 3.28 (2 H, dd, *J* 5, 6), 2.58 (2 H, dt, *J* 7.5, 6), 2.43 (3 H, s) and 1.58–1.78 (4 H, m); δ_C 143.4, 140.6, 135.4, 129.7, 126.9, 96.6, 57.9, 49.0, 28.0, 25.8, 24.2 and 21.4; *m/z* (CI) 392 (M^+ + H).

(E)- *and* (Z)-8-*Iodo*-1-(p-*tolylsulfonyl*)-2,3,4,5,6,9-*hexahydro*-1H-*azonine* **13c**. The Z-isomer was isolated as a colourless solid, m.p. 140–141 °C (cyclohexane) (Found: C, 44.6; H, 5.0; N, 3.5. $C_{15}H_{20}INO_2S$ requires C, 44.4; H, 4.9; N, 3.5%); ν_{max}(neat)/cm^{-1} 1600, 1340 and 1160; δ_H(270 MHz) 7.69 (2 H, d, *J* 8), 7.31 (2 H, d, *J* 8), 5.87 (1 H, dd, *J* 5, 11), 4.33 (1 H, d, *J* 13), 3.80 (1 H, d, *J* 13), 3.28 (1 H, dt, *J* 15, 5), 2.86 (1 H, ddd, *J* 2, 9, 15), 2.40 (3 H, s), 2.20–2.35 (2 H, m), 1.90–2.00 (2 H, m), 1.20–1.65 (4 H, m); δ_C 143.2, 143.1, 136.1, 129.7, 127.2, 99.8, 63.5, 47.3, 34.8, 33.0, 27.9, 23.3 and 21.5; *m/z* (CI) 406 (M^+ + H).

The *E*-isomer was isolated as a colourless solid, m.p. 103–104 °C (cyclohexane) (Found: C, 44.7; H, 5.4; N, 3.5. $C_{15}H_{20}INO_2S$ requires C, 44.4; H, 4.9; N, 3.5%); ν_{max}(neat)/cm^{-1} 1340 and 1160; δ_H(270 MHz) 7.69 (2 H, d, *J* 8), 7.31 (2 H, d, *J* 8), 6.38 (1 H, t, *J* 9.5), 5.68 (2 H, s), 3.00–3.10 (2 H, m), 2.57–2.69 (2 H, m), 2.43 (3 H, s), 1.74–1.84 (2 H, m), 1.58–1.73 (2 H, m) and 1.45–1.57 (2 H, m); δ_C 144.3, 143.5, 135.2, 129.7, 127.2, 94.5, 61.6, 53.1, 30.2, 29.2, 26.9, 25.4 and 21.5; *m/z* (CI) 406 (M^+ + H).

(E)- *and* (Z)-9-*Iodo*-1-(p-*tolylsulfonyl*)-1,2,3,4,5,6,7,10-*octahydro*-1H-*azecine* **13d**. The *Z*-isomer was isolated as a colourless solid, m.p. 90–91 °C (benzene–light petroleum) (Found: M^+ + H, 420.052. $C_{16}H_{22}INO_2S$ + H requires *M*, 420.049); ν_{max}(neat)/cm^{-1} 1710, 1360 and 1150; δ_H(270 MHz) 7.76 (2 H, d, *J* 8), 7.30 (2 H, d, *J* 8), 6.42 (1 H, t, *J* 9), 4.28–4.37 (2 H, m), 3.30–3.40 (2 H, m), 2.42 (3 H, s), 2.25–2.38 (2 H, m) and 1.20–1.70 (8 H, m); δ_C 147.8, 143.0, 137.1, 129.4, 127.5, 94.8, 53.0, 41.5, 28.4, 29.6, 27.9, 25.0, 21.8 and 21.5; *m/z* (CI) 420 (M^+ + H).

The *E*-isomer was isolated as a colourless solid, m.p. 109–110 °C (benzene–light petroleum) (Found: M^+ + H, 420.052. $C_{16}H_{22}INO_2S$ + H requires *M*, 420.049); ν_{max}(Nujol)/cm^{-1} 1630, 1590, 1330 and 1150; δ_H(270 MHz) 7.67 (2 H, d, *J* 8), 7.31 (2 H, d, *J* 8), 6.31 (1 H, t, *J* 8), 3.95–4.08 (2 H, br s), 3.06 (2 H, t, *J* 6), 2.43 (3 H, s), 2.30 (2 H, dt, *J* 7, 6.5), 1.50–1.80 (4 H, m) and 1.30–1.50 (4 H, m); δ_C 143.3, 141.6, 135.7, 129.7, 127.1, 99.8, 62.3, 47.4, 34.9, 27.4, 25.9, 24.6, 24.0 and 21.5; *m/z* (CI) 420 (M^+ + H).

(E)- and (Z)-3-*Iodo*-1-(p-*tolylsulfonyl*)-*azacycloundec*-3-*ene* **13e**. This was isolated as an inseparable mixture of *E*- and *Z*-isomers as a colourless oil (Found: C, 47.4; H, 5.6; N, 3.4. $C_{17}H_{24}INO_2S$ requires C, 47.1; H, 5.5; N, 3.2%); ν_{max}(CHCl_3)/cm^{-1} 1630, 1590, 1330 and 1150; δ_H(270 MHz) (*Z*)-major isomer: 7.76 (2 H, d, *J* 8), 7.30 (2 H, d, *J* 8), 6.10 (1 H, t, *J* 7.5), 3.95 (2 H, s), 3.00 (2 H, t, *J* 6), 2.40 (3 H, s), 2.20–2.30 (2 H, m), 1.42–1.78 (4 H, m) and 1.15–1.40 (6 H, m); (*E*)-minor isomer: 7.76 (2 H, d, *J* 8), 7.30 (2 H, d, *J* 8), 6.35 (1 H, t, *J* 7.5), 4.06 (2 H, s), 3.11 (2 H, t, *J* 6), 2.40 (3 H, s), 2.20–2.30 (2 H, m), 1.42–1.78 (4 H, m) and 1.15–1.40 (6 H, m); δ_C (only C-3 is shown from this mixture) 102.0 (*Z*-isomer), 87.4 (*E*-isomer); *m/z* (CI) 434 (M^+ + H).

(Z,Z)-3,11-*Diiodo*-N,N-*bis*(p-*tolylsulfonyl*)-1,9-*diazacyclohexadeca*-3,11-*diene* **14b**. M.p. 212–213 °C (from benzene) (Found: C, 42.9; H, 4.6; N, 3.5. $C_{28}H_{36}I_2N_2O_4S_2$ requires C, 43.0; H, 4.6; N, 3.6%); ν_{max}(Nujol)/cm^{-1} 1595, 1330 and 1130; δ_H(270 MHz) 7.69 (4 H, d, *J* 8), 7.30 (4 H, d, *J* 8), 5.90 (2 H, t, *J* 7), 3.95 (4 H, s), 2.96–3.05 (4 H, m), 2.43 (6 H, s), 2.38–2.58 (4 H, m) and 1.38–1.63 (8 H, m); δ_C 143.5, 136.9, 136.0, 129.8, 127.2, 104.6, 61.2, 50.2, 34.9, 28.5, 25.7 and 21.5; *m/z* (thermospray) 783 (M^+ + H).

(Z,Z)-3,12-*Diiodo*-N,N-*bis*(p-*tolylsulfonyl*)-1,10-*diazacyclooctadeca*-3,12-*diene* **14c**. Isolated as a colourless solid, m.p. 239–240 °C (benzene) (Found: C, 44.7; H, 5.0; N, 3.45. $C_{30}H_{40}I_2N_2O_4S_2$ requires C, 44.4; H, 4.9; N, 3.5%); ν_{max}(CHCl_3)/cm^{-1} 1600, 1320 and 1160; δ_H(270 MHz) 7.73 (4 H, d, *J* 8), 7.30 (4 H, d, *J* 8), 5.74 (2 H, t, *J* 7), 4.04 (4 H, s), 2.92–3.03 (4 H, m), 2.42 (6 H, s), 2.12–2.36 (4 H, m), 1.42–1.58 (4 H, m), 1.27–1.41 (4 H, m) and 1.02–1.25 (4 H, m); *m/z* (thermospray) 811 (M^+ + H).

(Z,Z)-3,13-*Diiodo*-N,N-*bis*(p-*tolylsulfonyl*)-1,11-*diazacycloeicosa*-3,13-*diene* **14d**. Isolated as a colourless solid, m.p. 205–206 °C (toluene) (Found: C, 46.1; H, 5.4; N, 3.5. $C_{32}H_{44}I_2N_2O_4S_2$ requires C, 45.8; H, 5.25; N, 3.3%); ν_{max}(Nujol)/cm^{-1} 1340 and 1150; δ_H(270 MHz) 7.69 (4 H, d, *J* 8), 7.30 (4 H, d, *J* 8), 5.92 (2 H, t, *J* 7), 3.96 (4 H, s), 2.98 (4 H, t, *J* 8), 2.43 (6 H, s), 2.18 (4 H, q, *J* 6) and 1.12–1.54 (16 H, m); δ_C 143.3, 138.0, 136.3, 129.7, 129.2, 103.4, 60.6, 49.4, 35.5, 29.0, 28.4, 27.9, 27.3 and 21.5; *m/z* (thermospray) 839 (M^+ + H).

(Z,Z)-3,14-*Diiodo*-N,N-*bis*(p-*tolylsulfonyl*)-1,12-*diazacyclodocosa*-3,14-*diene* **14e**. Isolated as a colourless solid, m.p. 199–201 °C (toluene–light petroleum) (Found: C, 47.0; H, 5.5; N, 3.0. $C_{34}H_{48}I_2N_2O_4S_2$ requires C, 47.1; H, 5.5; N, 3.2%); ν_{max}(Nujol)/cm^{-1} 1590 and 1330; δ_H(270 MHz) 7.72 (4 H, d, *J* 8), 7.30 (4 H, d, *J* 8), 5.80 (2 H, t, *J* 7), 4.01 (4 H, br s), 2.95–3.04 (4 H, m), 2.42 (6 H, s), 2.06–2.18 (4 H, m) and 1.05–1.60 (20 H, m); δ_C 143.3, 139.9, 136.8, 129.6, 127.4, 102.8, 59.6, 46.8, 35.9, 29.6, 29.2, 28.25, 28.0, 26.95 and 21.5; *m/z* (thermospray) 867 (M^+ + H).

General Procedure for Reduction of Azacycles (**13a–e**) *and Cyclic Dimers* **14b, d** 1-(p-*Tolylsulfonyl*)*octahydro*-1H-*azonine* **15c**.—A suspension of (*E*)- and (*Z*)- **13c** (12 mg, 0.03 mmol) and 10% palladium-on-charcoal (12 mg) in ethanol (10 cm^3) was stirred under an atmosphere of H_2 for 18 h at room temperature. The mixture was then filtered through a small plug of Celite and the filtrate was concentrated under reduced pressure to give the *title compound* **15c** (7 mg, 81%) as a colourless solid, m.p. 104–105 °C (methanol) (lit.,[17] m.p. 103.5–104.5 °C). Samples of **15a, b, d, e** and **16b, d** were obtained in an analogous fashion and identified by direct comparison with authentic samples which were prepared by literature methods.[17,18]

Acknowledgements

We thank Shell Research Centre for financial support and Drs. D. Lathbury and M. Anderson for helpful discussions.

References

1 K. E. Harding and T. H. Tiner in *Comprehensive Organic Synthesis*, eds. B. M. Trost and I. Fleming, Pergamon, Oxford, 1991, vol. 4, p. 363.

2 For electrophile-mediated cyclisations involving alkynes and nitrogen nucleophiles, see: Y. Fukuda, K. Uchimoto and H. Nozaki, *Heterocycles*, 1987, **25**, 297; M. Kimura, S. Kure, Z. Yoshida, S. Tanaka, K. Fugami and Y. Tamura, *Tetrahedron Lett.*, 1990, **31**, 4887; Y. Fukuda and K. Utimoto, *Synthesis*, 1991, 975; K. Ohe, T. Ishihara, N. Chatani, Y. Kawasaki and S. Murai, *J. Org. Chem.*, 1991, **56**, 2267; Y. Fukuda, S. Matsubara and K. Utimoto, *J. Org. Chem.*, 1991, **56**, 5812.

3 For electrophile-mediated cyclisations involving allenes and nitrogen nucleophiles, see: (*a*) S. Arseniyadis and J. Gore, *Tetrahedron Lett.*, 1983, **24**, 3997; (*b*) S. Arseniyadis and J. Sartoretti, *Tetrahedron Lett.*, 1985, **26**, 729; (*c*) J. Grimaldi and A. Cormons, *Tetrahedron Lett.*, 1985, **26**, 825; (*d*) D. Lathbury and T. Gallagher, *J. Chem. Soc., Chem. Commun.*, 1986, 1017; (*e*) J. Grimaldi and A. Cormons, *Tetrahedron Lett.*, 1986, **27**, 5089; (*f*) R. Kinsman, D. Lathbury, P. Vernon and T. Gallagher, *J. Chem. Soc., Chem. Commun.*, 1987, 243; (*g*) J. S. Prasad and L. S. Liebeskind, *Tetrahedron Lett.*, 1988, **29**, 4253; (*h*) J. Grimaldi and A. Cormons, *Tetrahedron Lett.*, 1988, **29**, 6609; (*i*) D. C. Lathbury, R. W. Shaw, P. A. Bates, M. B. Hursthouse and T. Gallagher, *J. Chem. Soc., Perkin Trans. 1*, 1989, 2415; (*j*) D. N. A. Fox and T. Gallagher, *Tetrahedron*, 1990, **46**, 4697.

4 For an application of this principle see, D. N. A. Fox, D. Lathbury, M. F. Mahon, K. C. Molloy and T. Gallagher, *J. Am. Chem. Soc.*, 1991, **113**, 2652.

5 L.-I. Olsson and A. Claesson, *Synthesis*, 1979, 743; J. Grimaldi,

C.R. Acad. Sci., Ser. C, 1978, **286**, 593; J. Grimaldi, J. Hatem, C. Henriet-Bernard and R. Maurin, *J. Chem. Res.*, 1994 (*S*), 36 and references therein.
6 R. Shaw, D. Lathbury, M. Anderson and T. Gallagher, *J. Chem. Soc., Perkin Trans. 1*, 1991, 659; see also ref. 3*c*.
7 M. J. Kurth, M. J. Rodriguez and M. M. Olmstead, *J. Org. Chem.*, 1990, **55**, 283.
8 L. Xiang and A. P. Kozikowski, *Synlett*, 1990, 279.
9 For studies relevant to the synthesis of azacycles by intramolecular alkylation of amines and sulfonamides by alkyl halides, see: S. Searles, M. Tamres, F. Block and L. A. Quarterman, *J. Am. Chem. Soc.*, 1956, **78**, 4917; W. R. Vaughan, R. S. Klonowski, R. S. McElhinney and B. B. Millward, *J. Org. Chem.*, 1961, **26**, 138; R. Bird, A. C. Knipe and C. J. M. Stirling, *J. Chem. Soc., Perkin Trans. 2*, 1973, 1215; J. H. Coy, A. F. Hegarty, E. J. Flynn and F. L. Scott, *J. Chem. Soc., Perkin Trans. 2*, 1974, 53; A. Di Martino, C. Galli, P. Gargano and L. Mandolini, *J. Chem. Soc., Perkin Trans. 2*, 1985, 1345.
10 For other applications of allylic iodides derived from I_2 addition to allenes,[15] see: R. W. Friesen and A. E. Kolaczewska, *J. Org. Chem.*, 1991, **56**, 4888; R. D. Walkup, L. Guan, S. W. Kim and Y. S. Kim, *Tetrahedron Lett.*, 1992, **33**, 3969; R. W. Friesen and M. Blouin, *J. Org. Chem.*, 1993, **58**, 1653.
11 L. A. Paquette and C. J. M. Stirling, *Tetrahedron*, 1992, **48**, 7383; see also R. M. Magid, *Tetrahedron*, 1980, **36**, 1901.
12 (*a*) B. M. Trost and T. R. Verhoeven, *J. Am. Chem. Soc.*, 1977, **99**, 3867; (*b*) B. M. Trost and T. R. Verhoeven, *J. Am. Chem. Soc.*, 1979, **101**, 1595; (*c*) B. M. Trost, *Angew. Chem., Int. Ed. Engl.*, 1989, **28**, 1173; (*d*) T. Tsuda, T. Kiyoi and T. Saegusa, *J. Org. Chem.*, 1990, **55**, 3388.
13 R. Shaw, M. Anderson and T. Gallagher, *Synlett*, 1990, 584.
14 (*a*) T. Gallagher, S. W. Jones, M. F. Mahon and K. C. Molloy, *J. Chem. Soc., Perkin Trans. 1*, 1991, 2193; (*b*) T. Gallagher, I. W. Davies, S. W. Jones, D. Lathbury, M. F. Mahon, K. C. Molloy, R. W. Shaw and P. Vernon, *J. Chem. Soc., Perkin Trans. 1*, 1992, 433.
15 C. Georgoulis, W. Smadja and J. M. Valery, *Synthesis*, 1981, 572; H. F. Schuster and G. M. Coppola, *Allenes in Organic Synthesis*, Wiley, New York, 1984.
16 I. W. Davies, D. I. C. Scopes and T. Gallagher, *Synlett*, 1993, 85.
17 P. Gargano and L. Mandolini, *Gazz. Chim. Ital.*, 1982, **112**, 31 and references therein.
18 A. Müller, E. Srepel, E. Funder-Fritzsche and F. Dicher, *Monatsh. Chem.*, 1952, **83**, 386.
19 M. Anderson, **T**. Gallagher, M. F. Mahon, K. C. Molloy and R. Shaw, *Acta Crystallogr., Sect. C*, 1992, **48**, 883.
20 I. W. Davies, R. W. Shaw, R. Wisedale and T. Gallagher, *J. Chem. Soc., Perkin Trans. 1*, following paper.
21 L. Brandsma and H. D. Verkruijsse in *Synthesis of Acetylenes, Allenes and Cumulenes*, in *Studies in Organic Chemistry*, Elsevier, Amsterdam, 1981, vol. 8.
22 R. M. Coates, P. D. Senter and W. R. Baker, *J. Org. Chem.*, 1982, **47**, 3597.

Paper 4/04915B
Received 10*th August* 1994
Accepted 6*th September* 1994