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Preparation Of 1-Substituted-3,4-dihydronaphthalene-2-carboxaldehyde *N,N*-Dimethylhydrazones By Palladium(0) Coupling, And Their Electrocyclic Ring Closure[1]

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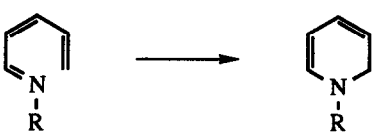
Abstract 1-Bromo-3,4-dihydronaphthalene-2-carboxaldehyde **2** has been converted by three methods, each involving halogen–metal exchange and palladium(0) catalysed cross coupling, into *N,N*-dimethylhydrazones of 1-aryl- and 1-vinyl-3,4-dihydronaphthalene-2-carboxaldehydes The *N,N*-dimethylhydrazone **10** of the aldehyde **2** undergoes efficient bromine–lithium exchange with butyllithium, as does 2-bromobenzaldehyde *N,N*-dimethylhydrazone **17** The dimethylhydrazones of 1-vinyl-3,4-dihydronaphthalene-2-carboxaldehydes were not isolated but underwent electrocyclic ring closure followed by loss of dimethylamine in solution to give 5,6-dihydrobenz[*f*]isoquinolines 1-Aryl-3,4-dihydronaphthalene-2-carboxaldehyde *N,N*-dimethylhydrazones also cyclised in the same way when subjected to vapour phase pyrolysis

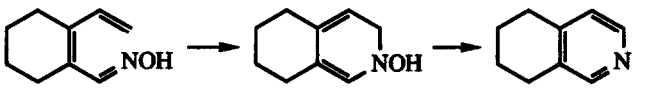
Introduction

Examples of the formation of 1,2-dihydropyridines from 1-azatrienes (Scheme 1) have been known since the early part of this century [2] From the 1970's Kametani and his co-workers investigated reactions of this type as a step in the synthesis of isoquinoline alkaloids[3] and a pyrolytic route to simple 1-acyl-1,2-dihydropyridines from transient *N*-acyl-1-azatrienes was discovered by Wyle and Fowler [4] More recently Okamura and colleagues have described the formation of dihydropyridines by cyclisation of imines derived from polyenic aldehydes [5,6]



Scheme 1

The cyclisation shown in Scheme 1 can proceed further to give fully aromatic pyridines if there is a leaving group attached either to C-2 or to nitrogen Several reactions have been described in which oximes or oxime ethers have been cyclised to pyridines The first detailed study of such a process was carried out by Schiess and co-workers.[7] They showed that the oxime **1** cyclised readily in solution to give tetrahydroisoquinoline (Scheme 2) and they established by deuterium labelling experiments that cyclisation was the rate determining step. An analogous reaction was used by Oppolzer and co-workers as a route to isoquinolines from *o*-quinodimethanes [8] There have been several more recent examples of the use of the electrocyclic ring closure of oximes and oxime ethers as a method of synthesis of isoquinolines and other fused pyridines [9] A related process has been used by Büchi and Galindo to synthesise alkylpyrazines.[10]



1

Scheme 2

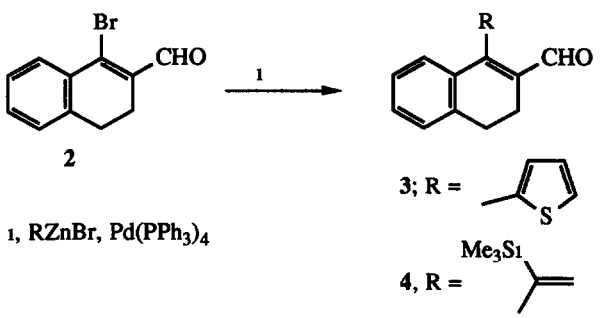
We have explored the use of the electrocyclic ring closure of conjugated trienes as a method of synthesis of phenanthrene derivatives, including some compounds related to estrone [11] We were interested in applying the same methodology to the synthesis of aromatic azasteroids [12] Preliminary experiments were based on the use of azatrienes derived from 1-bromo-3,4-dihydronaphthalene-2-carboxaldehyde **2** since this is readily available from α-tetralone and it had been succesfully used in the earlier work to delineate the scope of the reaction

The cyclisations we have explored have all been based on the use of aldehyde *N,N*-dimethylhydrazones rather than oximes. It is well established that the dimethylhydrazono group is much less electrophilic at carbon than the carbonyl group, indeed dimethylhydrazones sometimes react as if the polarity were reversed It therefore seemed possible to us that dimethylhydrazones might closely resemble their all carbon counterparts in the electrocyclisation reactions In the earlier work palladium-catalysed cross coupling reactions were used to construct the precursors Another reason for using the dimethylhydrazono group in the present work was that, owing to its reduced polarity, it offered greater potential for constructing the precursors by metallation reactions

Results

Palladium(0) catalysed coupling reactions of the bromoaldehyde **2** The first approach to the preparation of azatrienes suitable for cyclisation was based on the replacement of the bromine in the bromoaldehyde **2** by a vinyl or an aryl group Compound **2** was used as the electrophile in palladium(0) catalysed cross-coupling reactions with vinyl- or aryl-zinc halides

Reaction of 2-thienylzinc bromide with the bromoaldehyde **2**, in the presence of 4 mol% *tetrakis*(triphenylphosphine)palladium(0), gave the coupled product **3** in 67% yield after flash chromatography (Scheme 3) The palladium(0) coupling reaction of 1-(trimethylsilylethenyl)zinc bromide with the bromoaldehyde **2** also proceeded smoothly, the coupled product **4** being obtained in 62% yield after flash chromatography together with some unreacted bromoaldehyde (18%).



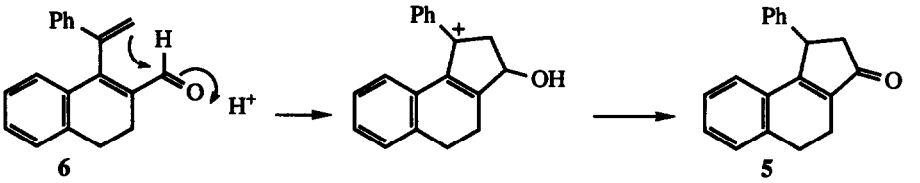
2

1, RZnBr, $Pd(PPh_3)_4$

Scheme 3

The coupling reaction of 1-(phenylethenyl)zinc bromide with the bromoaldehyde **2** was not so successful Following the method of Overman *et al* ,[13] 1-phenylethenyllithium was generated by the reaction of α-bromostyrene with tert-butyllithium in THF at –78 °C for 40 minutes Zinc bromide was added at –20 °C to effect transmetallation to the organozinc derivative and the bromoaldehyde **2** and palladium catalyst were then added. The mixture was heated under reflux in THF and the progress of the reaction was monitored by tlc After 3 hours the bromoaldehyde remained as the major component The reaction was continued for a further 39 hours, unreacted bromoaldehyde was isolated by flash chromatography in 44% yield together with a polar

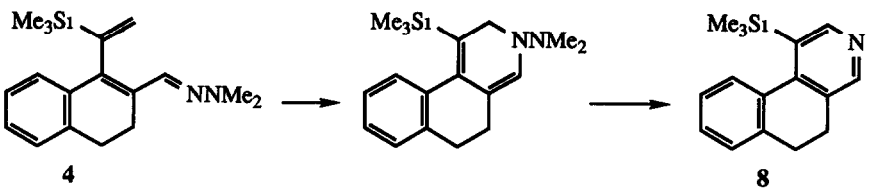
component (29%) which was identified as compound **5** on the basis of its spectra. A possible explanation for the formation of the ketone **5** is that the expected coupled product **6** is formed but then undergoes a cyclisation reaction (Scheme 4)



6 5

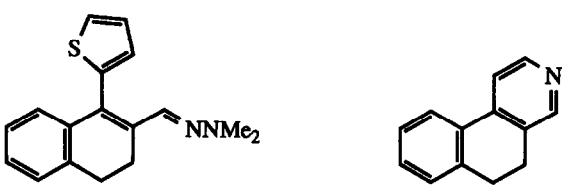
Scheme 4

Reaction of aldehydes **3** *and* **4** *with N,N-dimethylhydrazine* The method used by Potts and Walsh for the preparation of furan-2-carboxaldehyde *N,N*-dimethylhydrazones[14] was employed to prepare the *N,N*-dimethylhydrazone of the thienyl aldehyde **3**. An equimolar mixture of the aldehyde **3** and 1,1-dimethylhydrazine was heated in toluene under reflux for 12 hours in the presence of an acid catalyst. This gave the desired product **7** in 90% yield as a yellow solid. Under the same conditions the reaction of the aldehyde **4** with 1,1-dimethylhydrazine yielded a yellow waxy solid (55%) which was identified as the dihydrobenzisoquinoline **8** on the basis of its ^{1}H nmr spectrum This shows two singlets at δ 8.46 and δ 8 70 characteristic of protons attached to a pyridine ring It appears, therefore, that in boiling toluene the *N,N*-dimethylhydrazone of the aldehyde **4** undergoes electrocyclic ring closure and elimination of dimethylamine to afford the fused pyridine **8** (Scheme 5)



4 8

Scheme 5



7 9

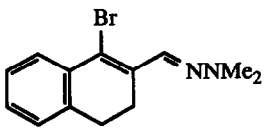
The dihydrobenzisoquinoline **9** became the major product when the reaction mixture was heated under reflux for longer periods (greater than 16 hours). This compound was also isolated as the major product (45%) after only 45 minutes when the reaction of the aldehyde **4** with dimethylhydrazine was carried out in boiling ethanol, the protic solvent obviously promoting the desilylation step.

An attempt was also made to prepare the oxime of the aldehyde **4** When the aldehyde was treated in ethanol with hydroxylamine at room temperature a new product appeared (by tlc) after 5 minutes. After 2 hours the reaction had gone to completion and the dihydrobenzisoquinoline **8** was isolated in 68% yield. It appears that the oxime cyclises at least as readily as the dimethylhydrazone.

The question arises as to whether the ease of the cyclisations of the *N,N*-dimethylhydrazone and the oxime derived from the aldehyde **4** are influenced by the presence of the trimethylsilyl group. If the cyclisation reaction is represented as a nucleophilic attack by the imine nitrogen on the carbon–carbon double bond the ability of silicon to stabilise α-carbanions will favour the process. However, subsequent examples of the cyclisation, described below, have led us to conclude that this substituent does not have a significant effect on the rate of cyclisation

Palladium(0) catalysed coupling reactions using the dimethylhydrazone **10** *of 1-bromo-3,4-dihydronaphthalene-2-carboxaldehyde as the electrophilic component* The bromoaldehyde **2** was converted into its *N,N*-dimethylhydrazone **10** in high yield by reaction with 1,1-dimethylhydrazine in dichloromethane at room temperature (It was found that if the reaction was carried out in toluene under reflux for 16 hours the product was instead naphthalene-2-carboxaldehyde dimethylhydrazone, which is presumably formed by dehydrobromination of compound **10**)

2-Thienylzinc chloride was generated *in situ* from treatment of 2-thienyllithium with zinc chloride at –20 °C, and this was coupled successfully with the bromohydrazone **10** in the presence of $Pd(PPh_3)_4$ It was necessary to heat the reaction mixture in THF under reflux for 16 hours to effect total conversion. The coupled product **7** was isolated in 85% yield after flash chromatography. 2-Furylzinc chloride and phenylzinc chloride, prepared from 2-furyllithium and phenyllithium respectively, similarly gave the coupled products **11** (68%) and **12** (41%) The coupling reaction of 1-(phenylethenyl)zinc chloride and the bromohydrazone **10** produced the dihydrobenzisoquinoline **13** (27%) which obviously results from cyclisation of the intermediate dimethylhydrazone and aromatisation under the reaction conditions



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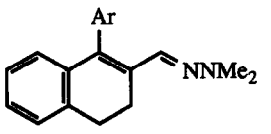
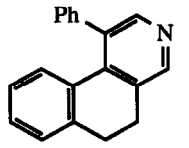
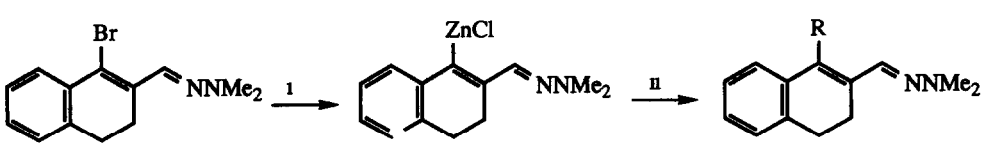


11, Ar = 2-furyl
12, Ar = Ph



13

Palladium(0) catalysed coupling reactions using the dimethylhydrazone **10** *of 1-bromo-3,4-dihydronaphthalene-2-carboxaldehyde as the nucleophilic component* We attributed the low yields obtained in some of the above palladium(0) coupling reactions to the incomplete formation or instability of the organozinc species involved This prompted us to investigate the possibility of using the bromohydrazone **10** as the nucleophilic component in coupling reactions with vinyl, aryl and heteroaryl halides We thus required a means of converting the bromohydrazone **10** into a suitable organometallic reagent. An obvious solution was to attempt the bromine–lithium exchange reaction of the bromohydrazone **10** and to then effect transmetallation to the chlorozinc species by treatment with zinc chloride (Scheme 6)



10

i, t-BuLi or BuLi, $ZnCl_2$; ii, RX, $Pd(PPh_3)_4$.

Scheme 6

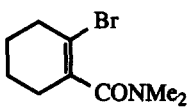
To our knowledge no bromine–lithium exchange reactions of β-bromo-α,β-unsaturated aldehyde *N,N*-dimethylhydrazones, nor of aromatic *o*-bromoaldehyde dimethylhydrazones, have been reported. It seemed likely that such reactions would be much more favourable than for the analogous bromoaldehydes, however Nucleophilic attack by an alkyllithium reagent is less likely to occur at the C=N bond and the product of bromine–lithium exchange could be stabilised by coordination of the lithium with the lone pair on the imine nitrogen atom. In an analogous reaction Baker and Coates showed that 2-bromocyclohexene 1-*N,N*-dimethylcarboxamide **14** underwent efficient bromine–lithium exchange when reacted with tert-butyllithium at –75 °C [15] We therefore applied these conditions to the bromohydrazone **10** and found that the exchange did occur, 3,4-dihydronaphthalene-2-carboxaldehyde *N,N*-dimethylhydrazone **15** being formed as the only product (by ^{1}H nmr) after an aqueous workup. The bromine–lithium exchange reaction worked equally well when butyllithium was used, in contrast to the work of Baker and Coates who obtained products in lower yields [15]

Having generated the organolithium intermediate, we carried out a metal exchange reaction by adding a solution of zinc chloride. Palladium coupling reactions were then investigated with a range of organic halides With iodobenzene as the electrophilic component the three-step sequence from the bromohydrazone **10** to the hydrazone **12** went in 79% yield

As expected from previous approaches, vinylic halides gave fused pyridines directly from the coupling reaction. The dihydrobenzisoquinoline **13** was obtained (35%) by reaction with α-bromostyrene When (*E*)-2-(bromoethenyl)trimethylsilane was employed as the electrophile the dihydrobenzisoquinoline **9** was obtained in 82% yield; this indicates that the position of the trimethylsilyl substituent has little influence on the rate of cyclisation of the intermediate hydrazones. Because the trimethylsilyl group is absent from the final product **9** the trimethylsilyl group must be lost in the aromatisation step in preference to a proton

5,6-Dihydrobenz[*f*]isoquinoline **9** is a known compound,[16] Vander Donckt and co-workers have also reported the ^{1}H nmr spectrum of benz[*f*]isoquinoline in a study of the spectra of aza-aromatic compounds [17] They observe that in such compounds the nitrogen atom has a deshielding effect on *ortho*, *para*, *peri* and angular protons and a shielding effect on *meta* protons The ^{1}H nmr spectrum of the cyclised product **9** is consistent with the literature data for the fully aromatic compound, the two hydrogens *ortho* to the pyridine nitrogen resonating as a broad singlet at δ 8.48 and the *meta* hydrogen appearing as a doublet at δ 7 54

Although this coupling procedure proved to be more efficient than the previous approaches a disappointing result was that obtained with 3-bromo-2-methylcyclopent-2-enone as the electrophile The major product (57%) in this case was 3,4-dihydronaphthalene-2-carboxaldehyde *N,N*-dimethylhydrazone **15**, the hydrolysis product of the lithio intermediate. The coupled product **16** was isolated only in low yield (12%), it was identified by mass spectrometry and from its ^{1}H nmr spectrum A possible explanation is that for steric reasons the coupling step is inhibited or is very slow



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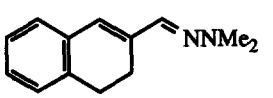

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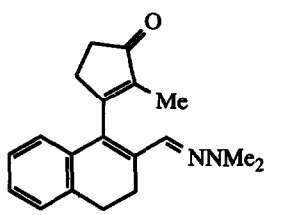

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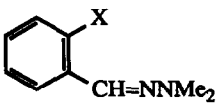
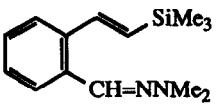
A brief investigation of an analogous reaction sequence starting from 2-bromobenzaldehyde *N,N*-dimethylhydrazone **17** was also carried out, in order to extend the scope of the metallation and coupling reactions. The dimethylhydrazone was converted into the chlorozinc species **18** by reaction with butyllithium followed by zinc chloride and this was coupled with two bromoalkenes, (*E*)-2-(bromoethenyl)trimethylsilane and 3-bromo-2-methylcyclopent-2-en-1-one, to give the dimethylhydrazones **19** and **20** in good yield.



17; X = Br
18; X = ZnCl



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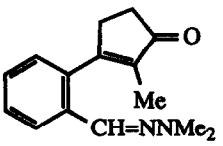
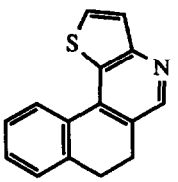


20

Cyclisation of the dimethylhydrazones **7**, **11** *and* **12** The experiments have shown that the dimethylhydrazones bearing a vinyl substituent at position 1 undergo the 6π-electrocyclic ring closure under remarkably mild conditions We therefore set out to investigate whether, and under what conditions, the hydrazones bearing a phenyl, 2-thienyl and 2-furyl group at the 1-position could be induced to cyclise In these compounds the terminal carbon–carbon double bond of the 1-azatriene system is part of an aromatic ring and thus it was envisaged that cyclisation would be much more difficult to achieve The 1-(2-thienyl)hydrazone **7** was investigated first. We discovered that when the compound was subjected to flash vacuum pyrolysis at 650 °C and 10^{-2} mmHg, a new polar product appeared The pyrolysis product was identified as one of the isomeric thienoisoquinolines **21** or **22** on the basis of its ^{1}H nmr spectrum and other data. The characteristic resonances are an AB system with a coupling constant of 5 6 Hz, which is assignable to the two adjacent hydrogens on the fused thiophene ring, and a singlet at δ 8.61 typical of an α-proton of a pyridine ring

If the reaction were concerted, with electrocyclic ring closure being followed by aromatisation and spontaneous elimination of dimethylamine, the product should be the thienoisoquinoline **21** The possibility of either or both of the isomers **21** and **22** being formed emerges only if the reaction proceeds *via* an initial attack at the 2-position of the thiophene ring to give a spiro intermediate, followed by rearrangement. If this second reaction pathway were operating it seems most likely that a mixture of the two isomers would result. From the ^{1}H nmr spectrum of the pyrolysis product it was clear that there was only one thienoisoquinoline present and thus it seemed more likely that the concerted pathway was operating. A literature search for related compounds for which ^{1}H nmr spectral data were available revealed 6-ethylthieno[3,2-*b*]pyridine **23** and 5-ethylthieno[2,3-*b*]pyridine **24** as the closest analogues [18] The chemical shifts of the thienyl hydrogens (δ 7 60 and δ 7 72) and of the hydrogen attached to the pyridine ring (δ 8 61) of the pyrolysis product were compared with the values for compounds **23** and **24**



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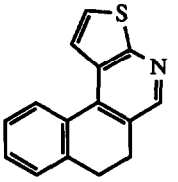

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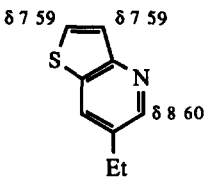

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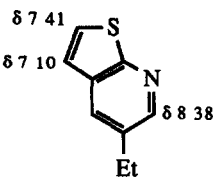


24

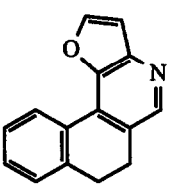
There is a closer analogy with the literature values for the [3,2-*b*] isomer **23** than for those of the [2,3-*b*] isomer **24** in the spectrum of compound **24** the signal for the pyridyl hydrogen is shifted upfield, as is that for H-3 Thus we conclude that the thienoisoquinoline **21** is formed exclusively in the pyrolysis, and probably by a concerted mechanism. Attempts were made to effect the conversion under milder conditions but these met with limited success When the dimethylhydrazone was subjected to flash vacuum pyrolysis at a lower temperaure (500 °C) and 10^{-4} mmHg a 1.5 mixture (by ^{1}H nmr) of starting dimethylhydrazone and thienoisoquinoline **21** was isolated. Solution pyrolysis either in bromobenzene or in xylene containing a catalytic quantity of 4-toluenesulfonic acid resulted in little conversion A minor peak was observed at δ 8 61 in the nmr spectrum of

the crude product, indicating the presence of about 5% of the product **21**, but there was also evidence of much decomposition

In the pyrolysis of the thienylhydrazone **7** it is perhaps surprising that the 6π-electrocyclic ring closure proceeds in preference to elimination of dimethylamine to give the corresponding nitrile There are examples of elimination of dimethylamine from dimethylhydrazones during attempted cycloadditions in boiling xylene,[19] possibly the steric crowding in compound **7** strongly favours the (*E*)-isomer in which this elimination would be less accessible

Pyrolysis of the 2-furylhydrazone **11** was much less successful than for the thienyl analogue because the compound did not sublime very well A mass spectrum of the pyrolysis product was obtained which revealed a molecular ion at *m/z* 221, characteristic of loss of dimethylamine from the hydrazone **11** This of course could be assigned either to the cyclised product **25** or to the nitrile which would result from 1,2-elimination of dimethylamine from the dimethylhydrazone The ^{1}H nmr spectrum obtained for the crude pyrolysate was more consistent with the cyclised structure **25** An AB double doublet with a coupling constant of 2 2 Hz was clearly distinguishable and was attributed to the two furyl protons, this coupling constant being typical for adjacent protons on side *b* of a furan ring A singlet at δ 8 35 was also observed and was assigned to the α–proton attached to the pyridine ring, analogous to that of the thienoisoquinoline **21**

Flash vacuum pyrolysis of the 1-phenyl-*N,N*-dimethylhydrazone **12** gave the benzophenanthridine **26** in 62% yield after purification by column chromatography The picrate of compound **26** has been prepared previously;[20] the melting point of this derivative correlated well with that obtained for the picrate of the pyrolysis product



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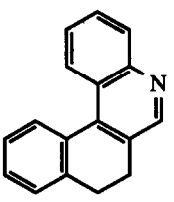

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Conclusions

The results establish that *N,N*-dimethylhydrazones can be used as C=N components in electrocyclic ring closure reactions of 1-azatrienes, these complement the reactions described in the literature in which oximes or oxime ethers are used Even terminal phenyl, thienyl and furyl groups can participate in this 6π-electron electrocyclisation process at elevated temperatures The dimethylhydrazono group has also been shown to allow bromine–lithium exchange at an adjacent carbon atom, and this may be useful in expanding the scope of the reaction

EXPERIMENTAL

General

^{1}H nmr spectra were recorded either on a Bruker AC 200 (200 MHz) or on a Bruker AMX 400 (400 MHz) spectrometer Multiplicities are recorded as broad peaks (br), singlets(s), doublets(d), triplets(t), quartets(q) and multiplets(m) Infrared spectra were recorded either on a Perkin-Elmer 298 or on a Perkin-Elmer 1720-X FTIR spectrometer Solid samples were run as KBr discs or nujol mulls as indicated, and liquids as thin films Mass spectra were recorded on a VG micromass 7070E as electron impact or chemical ionisation spectra. Microanalyses were performed in the University of Liverpool Microanalysis Laboratory Melting points (m.p) were determined on a Kofler block Flash column chromatography was carried out using Mackerey Nagel MN-Kieselgel 60 and hand bellows or an air line to supply the pressure to the column Thin layer chromatography (tlc) was carried out on Merck 10 x 2 cm aluminium-backed plates with a 0 2 mm layer of Kieselgel 60 F_{254}.

1-Bromo-3,4-dihydronaphthalene-2-carboxaldehyde **2**. Dry DMF (1 50 g, 20.5 mmol) in dry dichloromethane (30 ml) was cooled to 0 °C, and phosphorus tribromide (1 65 ml, 17 5 mmol) was then added dropwise. The mixture was stirred at 0 °C for 1 h and a pale yellow suspension was formed. A solution of 3,4-dihydronaphthalene-1(2*H*)-one (0.90 ml, 6.77 mmol) in dry dichloromethane (25 ml) was then added and the mixture was heated under reflux for 1 h After cooling to 0 °C, aqueous sodium hydrogen carbonate was added slowly until the effervescence had subsided Extraction into dichloromethane followed by drying ($MgSO_4$) and evaporation of the solvent gave a yellow oil Flash column chromatography eluting with diethyl ether–light petroleum (1.9) gave *1-bromo-3,4-dihydronaphthalene-2-carboxaldehyde* **1** (1.24 g, 77%) as a yellow solid, m p 42–43 °C (from ethanol) (lit.,[11] 42–44 °C), δ (400 MHz, $CDCl_3$), 2 62 (2 H, t, *J* 8 0 Hz) and 2.83 (2 H, t, *J* 8.0 Hz) (3-H and 4-H), 7.19 (1 H, dd, *J* 8 1 and 1 4 Hz, 5-H), 7 26–7 38 (2 H, m, 6-H and 7-H), 7 89 (1 H, dd, *J* 8.6 and 1 9 Hz, 8-H) and 10 25 (1 H, s, C<u>H</u>O), ν_{max} (nujol) /cm^{-1} 1670 (C=O), *m/z* 237.981 (M^+, 25% $C_{11}H_9{}^{81}BrO$ requires 237 982), 236 (26), 157 (13), 129 (76), 128 (100) and 127 (27).

3,4-Dihydro-1-(2-thienyl)naphthalene-2-carboxaldehyde **3**. Thiophene (0.40 ml, 5.0 mmol) was treated with butyllithium (1 35 <u>M</u>, 4 10 ml, 5.54 mmol) and TMEDA (0 75 ml, 4 97 mmol) in THF (15 ml) at 20 °C for 0 5 h.[11] A THF solution of zinc bromide (8.40 mmol) was then added to the organolithium intermediate at –20 °C After stirring the mixture at –20 °C for 1 h, a solution of $Pd(PPh_3)_4$ (0.23 g, 4 mol%) and 1-bromo-3,4-dihydronaphthalene-2-carboxaldehyde **1** (1 18 g, 4 98 mmol) in THF (25 ml) was added. The reaction mixture was allowed to warm up to room temperature and it was then heated under reflux for 3 h Ammonium chloride was then added and the mixture was extracted with ethyl acetate, dried ($MgSO_4$) and the solvent removed *in vacuo* to afford the crude product as a yellow oil Purification by flash column chromatography eluting with diethyl ether–light petroleum (1 4) afforded *3,4-dihydro-1-(2-thienyl)naphthalene-2-carboxaldehyde* **3** (0 80 g, 67%) as a yellow solid, m p 90–91 °C (from dichloromethane–light petroleum) (Found· C, 75.0, H, 5 0. $C_{15}H_{12}OS$ requires C, 75 0, H, 5 0%), δ (400 MHz, $CDCl_3$) 2.67–2 71 (2 H, m) and 2 87–2 91 (2 H, m) (3-H and 4-H), 7 10–7 20 (4 H, m, thiophene 3-H and 4-H, 5-H and 6-H), 7 23-7 26 (1 H, m, 8-H), 7 31 (1 H, ddd, *J* 7 5, 7 2 and 1 2 Hz, 7-H), 7 52 (1 H, dd, *J* 5 1 and 1 1 Hz, thiophene 5-H) and 9 79 (1 H, s, C<u>H</u>O), ν_{max} (nujol) /cm^{-1} 1655 (C=O), *m/z* 240 061 (M^+, 100% $C_{15}H_{12}O^{32}S$ requires 240 061), 211 (35) and 178 (38)

3,4-Dihydro-1-[(1'-trimethylsilyl)ethenyl]naphthalene-2-carboxaldehyde **4**. Butyllithium (1 46 <u>M</u>, 1 50 ml, 2 19 mmol) was added dropwise to 1-(trimethylsilyl)bromoethene (0 30 ml, 1 95 mmol) in dry THF at –78 °C[21] The mixture was stirred at –78 °C for 1 h to form the yellow organolithium species and zinc chloride (1 0 <u>M</u>, 3.0 ml, 3 0 mmol) was then added The resulting solution was stirred at –20 °C for 1 h and a solution containing $Pd(PPh_3)_4$ (0 09 g, 4 mol%) and 1-bromo-3,4-dihydronaphthalene-2-carboxaldehyde **2** (0.45 g, 1 90 mmol) in THF (20 ml) was then added. The reaction mixture was allowed to warm up to room temperature and it was then heated under reflux for 16 h Aqueous ammonium chloride was added and the mixture was extracted with ethyl acetate, dried ($MgSO_4$) and the solvent removed *in vacuo* to give a brown oil Purification by flash column chromatography eluting with ethyl acetate–cyclohexane (1 19) gave *3,4-dihydro-1-[1'-(trimethylsilyl)ethenyl]naphthalene-2-carboxaldehyde* **4** (0 31 g, 62%) as a yellow oil (Found· C, 74 95, H, 7 9 $C_{16}H_{20}OSi$ requires C, 74 9, H, 7 9%), δ (200 MHz; $CDCl_3$) 0.32 (9 H, s, vinyl-Si<u>Me</u>$_3$), 2 95–3 25 (4 H, m, 3-H and 4-H), 6 14 (1 H, d, *J* 3.2 Hz, vinyl-C<u>H</u>), 6 35 (1 H, d, *J* 3 2 Hz, vinyl-C<u>H</u>), 7 52–7 66 (4 H, m, aryl-C<u>H</u>) and 10.21 (1 H, s, C<u>H</u>O), ν_{max} (film) /cm^{-1} 1665 (C=O), 1605 and 1565, *m/z* 256 127 (M^+, 50% $C_{16}H_{20}O^{28}Si$ requires 256 128), 183 (16) and 73 (100)

1,2,4,5-Tetrahydro-1-phenylcyclopenta[a]naphthalen-3-one **5** To a solution of α-bromostyrene (90% pure, 0 61 ml, 4 20 mmol) in dry THF (20 ml) at –78 °C was added tert-butyllithium (1 70 <u>M</u>, 2 50 ml, 4 25 mmol) dropwise over 20 min [13] The deep red solution was stirred for an additional 20 min at –78 °C and a freshly prepared solution of zinc bromide (6 48 mmol) was then added The reaction mixture was warmed to –20

°C and stirred for 1 h in the cold bath to provide a yellow solution. 1-Bromo-3,4-dihydronaphthalene-2-carboxaldehyde **2** (1.0 g, 4.22 mmol) and $Pd(PPh_3)_4$ (0 20 g, 4 mol%) in THF (15 ml) were added and the mixture was heated under reflux for 42 h Workup followed by flash column chromatography eluting with diethyl ether-light petroleum (1:9) gave the bromoaldehyde **2** (0 44 g, 44%) as the major component

The ketone **5** (0.32 g, 29%) was also isolated as an orange oil, δ (200 MHz, $CDCl_3$) 1 72–2 53 (6 H, m, 2-H, 4-H and 5-H), 3.76–3.82 (1 H, m, 1-H) and 6.25–6 81 (9 H, m), ν_{max} (film) /cm^{-1} 1690 (C=O). It was further characterised as its *2,4-dinitrophenylhydrazone*, m.p. 261–264 °C (from light petroleum-ethyl acetate), *m/z* 440.148 (M^+, 100% $C_{25}H_{20}N_4O_4$ requires 440 148), 258 (18), 242 (24), 217 (14) and 154 (13)

3,4-Dihydro-1-(2-thienyl)naphthalene-2-carboxaldehyde N,N-dimethylhydrazone **7**. *(a) Preparation from 3,4-dihydro-1-(2-thienyl)naphthalene-2-carboxaldehyde* **3** A stirred solution of 3,4-dihydro-1-(2-thienyl)naphthalene-2-carboxaldehyde **3** (0 36 g, 1.50 mmol) in toluene (40 ml) containing a catalytic amount of 4-toluenesulfonic acid was treated with 1,1-dimethylhydrazine (0.12 ml, 1.58 mmol) The solution was then heated under reflux for 12 h and the water formed during the reaction was removed in a Dean-Stark trap Evaporation of the solvent and flash column chromatography gave [with diethyl ether-cyclohexane (1·9)] *3,4-dihydro-1-(2-thienyl)naphthalene-2-carboxaldehyde N,N-dimethylhydrazone* **7** (0 38 g, 90%) as a yellow solid, m.p 112–114 °C (Found: C, 72 3, H, 6 4, N, 9 9 $C_{17}H_{18}N_2S$ requires C, 72 3, H, 6 4, N, 9.9%), δ (400 MHz; $CDCl_3$) 2 77–2 88 (4 H, m, 3-H and 4-H), 2 83 (6 H, s, NMe_2), 6 88 (1 H, d with additional splitting, *J* 7 0 Hz), 6.93 (1 H, d with additional splitting, *J* 3.4 Hz, thiophene 3-H), 7 05–7.11 (5 H, m), 7 10 (1 H, s, CH=N), 7 16 (1 H, br d, *J* 7 0 Hz, 8-H) and 7 39 (1 H, dd, *J* 5 0 and 0.8 Hz, thiophene 5-H), ν_{max} (nujol) /cm^{-1} 1587, 1538 and 1258 cm^{-1}, *m/z* 282 119 (M^+, 98% $C_{17}H_{18}N_2S$ requires 282 119) and 236 (100%)

(b) From 1-bromo-3,4-dihydronaphthalene-2-carboxaldehyde N,N-dimethylhydrazone **10**. Thiophene (0 20 ml, 2 50 mmol) was converted into 2-thienyllithium by reaction with butyllithium (1.55 M, 1.80 ml, 2 79 mmol) and TMEDA (0.40 ml, 2 65 mmol) in THF (10 ml) at 20 °C for 0 5 h A solution of zinc chloride (1 0 M, 3.20 ml, 3 20 mmol) was added and the reaction mixture was stirred at –20 °C for 1 h. A solution of $Pd(PPh_3)_4$ (0 11 g, 4 mol%) and 1-bromo-3,4-dihydronaphthalene-2-carboxaldehyde *N,N*-dimethylhydrazone **10** (0 70 g, 2 51 mmol) in THF (10 ml) was then added The reaction mixture was allowed to warm up to room temperature and it was then heated under reflux for 16 h Workup followed by flash chromatography eluting with diethyl ether–cyclohexane (1 9) gave *the N,N-dimethylhydrazone* **7** (0 60 g, 85%)

5,6-Dihydro-1-(trimethylsilyl)benz[f]isoquinoline **8** *(a) From reaction of* **4** *with N,N-dimethylhydrazine* To a stirred solution of 3,4-dihydro-1-[1'(-trimethylsilyl)ethenyl]naphthalene-2-carboxaldehyde **4** (0 10 g, 0 39 mmol) in dry toluene (10 ml) containing a catalytic quantity of 4-toluenesulfonic acid was added 1,1-dimethylhydrazine (0 03 g, 0 50 mmol) The solution was then heated under reflux in an argon atmosphere for 3 h using a Dean-Stark apparatus Removal of the solvent *in vacuo* and flash column chromatography eluting with ethyl acetate–cyclohexane (1 9) gave *5,6-dihydro-1-(trimethylsilyl)benz[f]isoquinoline* **8** (0.054 g, 55 %) as a pale yellow solid, m p 94–96 °C (Found C, 75 6, H, 7 7, N, 5 1 $C_{16}H_{19}NSi$ requires C, 75 8, H, 7 6, N, 5 5%), δ (200 MHz, $CDCl_3$), 0 32 (9 H, s, $SiMe_3$), 2.71–2 87 (4 H, m, 5-H and 6-H), 7 26–7 36 (3 H, m), 7 63–7.68 (1 H, m, H-10) and 8 46 (1 H, s) and 8 70 (1 H, s) (2-H and 4-H), *m/z* 253 129 (M^+, 29% $C_{16}H_{19}NSi$ requires 253 129), 238 (100), 222 (51), 208 (7) and 73 (6)

Prolonged heating of 1,1-dimethylhydrazine with the aldehyde **4** (16 h) in toluene resulted in the formation of *5,6-dihydrobenz[f]isoquinoline* **9** as the major reaction product. The product was identified from its mass spectrum which was identical to that of a sample prepared via palladium(0) coupling (see below), *m/z* 181 (M^+, 100%), 166 (9) and 152 (28).

(b) From treatment of **4** *with hydroxylamine hydrochloride* Hydroxylamine hydrochloride (0 055 g, 0 79 mmol) and barium carbonate (0.65 g, 3 29 mmol) were added to a stirred solution of 3,4-dihydro-1-[(1'-trimethylsilyl)ethenyl]naphthalene-2-carboxaldehyde **4** (0 17 g, 0 66 mmol) in dry ethanol (15 ml) The resulting mixture was allowed to stir at room temperature under an argon atmosphere for 2 h. The barium

carbonate was then filtered off and the solvent was removed *in vacuo*. The crude product was purified by flash column chromatography eluting with ethyl acetate–cyclohexane (1 9) to afford *the benzisoquinoline* **8** (0 113 g, 68%) as a yellow solid.

1-Bromo-3,4-dihydronaphthalene-2-carboxaldehyde N,N-dimethylhydrazone **10** 1-Bromo-3,4-dihydronaphthalene-2-carboxaldehyde **2** (1.37 g, 5 76 mmol) was dissolved in dry diethyl ether (30 ml) containing a catalytic amount of 4-toluenesulfonic acid. 1,1-Dimethylhydrazine (0.53 ml, 6.91 mmol) was added and the resulting solution was stirred at room temperature under argon until all of the aldehyde had disappeared by tlc analysis of the reaction mixture (3 h). Removal of the solvent *in vacuo* followed by flash column chromatography eluting with ethyl acetate-light petroleum (1.9) gave *1-bromo-3,4-dihydronaphthalene-2-carboxaldehyde N,N-dimethylhydrazone* **10** (1.59 g, 99%) as a yellow oil (Found: C, 55 9, H, 5 4; N, 10 05 $C_{13}H_{15}BrN_2$ requires C, 55 9; H, 5 4; N, 10 0%); δ (200 MHz; $CDCl_3$) 2 67 (4 H, s, 3-H and 4-H), 2 87 (6 H, s, NMe_2), 6.93–7.05 (2 H, m, 5-H and 6-H), 7 10 (1 H, ddd, *J* 7.5, 6.8 and 2.2 Hz, 7-H), 7 33 (1 H, s, CH=N) and 7.57 (1 H, d with additional splitting, *J* 7 5 Hz, 8-H); ν_{max} (CH_2Cl_2) /cm^{-1} 1583, 1538 and 1477 cm^{-1}; *m/z* 278 041 (M^+, 68% $C_{13}H_{15}{}^{79}BrN_2$ requires 278.042), 280 (M^+, 68%), 199 (100) and 128 (64)

Naphthalene-2-carboxaldehyde N,N-dimethylhydrazone from 1-bromo-3,4-dihydronaphthalene-2-carboxaldehyde **2** 1-Bromo-3,4-dihydronaphthalene-2-carboxaldehyde **2** (1.84 g, 7.76 mmol) was dissolved in dry toluene (40 ml) containing a catalytic quantity of 4-toluenesulfonic acid 1,1-Dimethylhydrazine (0 70 ml, 9.21 mmol) was then added and the resulting solution was heated under reflux using a Dean–Stark trap for 16 h The solvent was removed *in vacuo* and the crude product was purified by flash column chromatography eluting with diethyl ether-light petroleum (1·9) to give *naphthalene-2-carboxaldehyde N,N-dimethylhydrazone* (1 09 g, 71%) as a yellow solid, m p 71–72 °C (from methanol) (lit.,[22] 70–71 °C) (Found· C, 78 6, H, 7.1; N, 14 1 Calc for $C_{13}H_{14}N_2$ C, 78 8, H, 7 1; N, 14 1%), δ (200 MHz; $CDCl_3$) 3 01 (6 H, s, NMe_2), 7 36–7 47 (3 H, m), 7 74–7 81 (4 H, m) and 7.91 (1 H, dd, *J* 8 8 and 1 6 Hz), *m/z* 198 116 (M^+, 100%. Calc for $C_{13}H_{14}N_2$ 198.116), 183 (12), 168 (20) and 128 (25) The substance was identical to a sample prepared (89%) from naphthalene-2-carboxaldehyde and 1,1-dimethylhydrazine.

3,4-Dihydro-1-(2-furyl)naphthalene-2-carboxaldehyde N,N-dimethylhydrazone **11**. Furan (0 15 ml, 2 06 mmol) was converted into 2-furyllithium by reaction with butyllithium (1 55 M, 1 50 ml, 2 32 mmol) and TMEDA (0.30 ml, 1.99 mmol) in THF (10 ml) at 20 °C for 0 5 h Zinc chloride (1 0 M, 2 56 ml, 2 65 mmol) was added and the reaction mixture was stirred at –20 °C for 1 h. A solution of $Pd(PPh_3)_4$ (0 10 g, 4 mol%) and 1-bromo-3,4-dihydronaphthalene-2-carboxaldehyde *N,N*-dimethylhydrazone **10** (0 57 g, 2 04 mmol) in THF (10 ml) was then added. The mixture was allowed to warm to room temperature and was then heated under reflux for 16 h Workup followed by flash column chromatography eluting with diethyl ether–light petroleum (1.19) gave *3,4-dihydro-1-(2-furyl)naphthalene-2-carboxaldehyde N,N-dimethylhydrazone* **11** (0.37 g, 68%) as an orange solid, m p 89–91 °C (Found C, 76 6, H, 6 8, N, 10 45 $C_{17}H_{18}N_2O$ requires C, 76 7, H, 6 8, N, 10 5%), δ (400 MHz; $CDCl_3$) 2 83 (4 H, s, 3-H and 4-H), 2 89 (6 H, s, NMe_2), 6 39 (1 H, d, *J* 3.1 Hz, furan 3-H), 6 51 (1 H, dd, *J* 3 1 and 1 9 Hz, furan 4-H), 6 84–6 87 (1 H, m), 7 08–7 17 (3 H, m), 7 25 (1 H, s, CH=N) and 7 52 (1 H, d, *J* 1 5 Hz, furan 5-H), ν_{max} (CH_2Cl_2) /cm^{-1} 1541, 1484 and 1472; *m/z* 266 142 (M^+, 100% $C_{17}H_{18}N_2O$ requires 266 142), 237 (29), 220 (43), 192 (38) and 165 (47)

3,4-Dihydro-1-phenylnaphthalene-2-carboxaldehyde N,N-dimethylhydrazone **12** A solution of bromobenzene (0 14 ml, 1 33 mmol) and butyllithium (1 46 M, 1.85 ml, 2 70 mmol) in diethyl ether (10 ml) was heated under reflux for 45 min The yellow solution was then cooled to –20 °C, zinc chloride (1 0 M, 2 0 ml, 2 0 mmol) was added and the colourless solution was allowed to stir in the cold bath for 1 h A solution of 1-bromo-3,4-dihydronaphthalene-2-carboxaldehyde *N,N*-dimethylhydrazone **10** (0 33 g, 1 18 mmol) and $Pd(PPh_3)_4$ (0.05 g, 4 mol%) in THF (10 ml) was then added and the resulting solution was heated under reflux for 16 h. Workup followed by flash column chromatography eluting with ethyl acetate-light petroleum (1 19)

gave *3,4-dihydro-1-phenylnaphthalene-2-carboxaldehyde N,N-dimethylhydrazone* **12** (0.13 g, 41 %) as a yellow solid, m.p. 70–72 °C (Found: C, 82.8; H, 7.3; N, 10.1. $C_{19}H_{20}N_2$ requires C, 82 6; H, 7 3; N, 10 1%); δ (200 MHz; $CDCl_3$) 2.76 (6 H, s, NMe_2), 2.80–2 97 (4 H, m, 3-H and 4-H), 6.66 (1 H, dd, *J* 7.4 and 1 6 Hz), 6.91 (1 H, s, CH=N), 6.97–7.24 (5 H, m) and 7 34–7 46 (3H, m); ν_{max} (nujol) /cm^{-1} 1541, 1481, 1466 and 1455, *m/z* 276 163 (M^+, 100% $C_{19}H_{20}N_2$ requires 276 163), 230 (90), 215 (20) and 202 (22)

5,6-Dihydro-1-phenylbenz[f]isoquinoline **13**. tert-Butyllithium (1 70 M, 1.25 ml, 2.13 mmol) was added dropwise to a solution of freshly distilled α-bromostyrene (0 25 ml, 90% pure, 1 93 mmol), in THF (10 ml) at –78 °C. The deep red solution was stirred at –78 °C for 40 min and zinc chloride (1 0 M, 2.90 ml, 2 90 mmol) was then added The resulting pale yellow solution was stirred at –20 °C for 1 h, after which time a solution of 1-bromo-3,4-dihydronaphthalene-2-carboxaldehyde *N,N*-dimethylhydrazone **10** (0 47 g, 1 68 mmol) and $Pd(PPh_3)_4$ (0 08 g, 4 mol%) in THF (15 ml) was added The mixture was then heated under reflux for 16 h Workup followed by column chromatography eluting with diethyl ether–cyclohexane (1 19) gave *5,6-dihydro-1-phenylbenz[f]isoquinoline* **13** (0 12 g, 27%) as a yellow solid, m p 141–143 °C, δ (200 MHz, $CDCl_3$) 2 78–2 95 (4 H, m, 5-H and 6-H), 6.85–6.89 (2 H, m), 7 11–7 42 (5 H, m), 7 59–7.70 (2 H, m), 8 43 (1 H, s) and 8 48 (1 H, s) (2-H and 4-H), *m/z* 257 121 (M^+, 100% $C_{19}H_{15}N$ requires 257 120), 242 (9), 183 (10), 149 (11) and 69 (18) The substance was further characterised as its *picrate*, a bright yellow solid m.p 178–180 °C (Found: C, 61 4; H, 3 7; N, 11 4 $C_{25}H_{18}N_4O_7$ requires C, 61 7, H, 3 7, N, 11.5%)

Unreacted 1-bromo-3,4-dihydronaphthalene-2-carboxaldehyde *N,N*-dimethylhydrazone **10** (0 27 g, 58%) was also isolated from the coupling reaction

3,4-Dihydronaphthalene-2-carboxaldehyde N,N-dimethylhydrazone **15** tert-Butyllithium (1.70 M, 0.80 ml, 1 36 mmol) was added dropwise to a solution of 1-bromo-3,4-dihydronaphthalene-2-carboxaldehyde *N,N*-dimethylhydrazone **10** (0 17 g, 0 61 mmol) in dry THF (10 ml) at –78 °C The deep orange solution was stirred in the cold bath for 20 min , and the anion was then quenched with distilled water (1 0 ml). The solution was stirred at –78 °C for 5 min. and was then allowed to warm up to room temperature. After 16 h, ammonium chloride was added and the mixture was extracted with ethyl acetate, dried ($MgSO_4$) and the solvent removed *in vacuo* Flash column chromatography eluting with ethyl acetate-light petroleum (1:9) provided *3,4-dihydronaphthalene-2-carboxaldehyde N,N-dimethylhydrazone* **15** (0 11 g, 90%) as a yellow oil, δ (200 MHz, $CDCl_3$) 2 61–2 70 (2 H, m) and 2 78–2 87 (2 H, m) (3-H and 4-H), 2 91 (6 H, s, NMe_2), 6 46 (1 H, s, vinyl-H) and 7 02–7 15 (5 H, m)

The reaction worked equally well when butyllithium (1 55 M, 0 43 ml, 0 67 mmol) was used instead of tert-butyllithium in the bromine–lithium exchange step

Palladium(0) catalysed coupling reactions of the chlorozinc intermediate derived from **10** *with organic halides General procedure*

1-Bromo-3,4-dihydronaphthalene-2-carboxaldehyde *N,N*-dimethylhydrazone **10** (0 29 g, 1.04 mmol) was converted into its 1-lithio derivative by reaction with tert-butyllithium (1 70 M, 1 35 ml, 2 30 mmol) in THF (10 ml) at –78 °C for 20 min Zinc chloride (1 0 M, 1 56 ml, 1 56 mmol) was then added and the mixture was stirred at –20 °C for 1 h in order to effect the formation of the chlorozinc intermediate. $Pd(PPh_3)_4$ (0.05 g, 4 mol%) and the appropriate electrophile (1 04 mmol) were then added together in THF (10 ml) The reaction mixture was then allowed to warm up to room temperature and it was heated under reflux for 16 h Workup was followed by purification of the crude product by flash column chromatography

3,4-Dihydro-1-phenylnaphthalene-2-carboxaldehyde N,N-dimethylhydrazone **12** Reaction with iodobenzene as the electrophile gave 3,4-dihydro-1-phenyl-naphthalene-2-carboxaldehyde *N,N*-dimethylhydrazone **12** (0 23 g, 79%) after purification by flash column chromatography [ethyl acetate-light petroleum (1 19)]

5,6-Dihydro-1-phenylbenz[f]isoquinoline **13** Reaction with α-bromostyrene as the electrophile gave 3,4-dihydro-1-phenylbenz[*f*]isoquinoline **13** (0.09 g, 35%) after purification by flash column chromatography [ethyl acetate-cyclohexane (3:2)] 3,4-Dihydronaphthalene-2-carboxaldehyde *N,N*-dimethylhydrazone **15** (0 08 g, 40%) was also isolated from the reaction mixture

5,6-Dihydrobenz[f]isoquinoline **9**. Reaction with *(E)*-2-(bromoethenyl)trimethylsilane as the electrophile gave *5,6-dihydrobenz[f]isoquinoline* **9** (0 15 g, 82%) as a yellow oil after purification by flash column chromatography [ethyl acetate–cyclohexane (1·4)], δ (200 MHz, $CDCl_3$) 2.73–3 17 (4 H, m, 5-H and 6-H), 7 14–7 30 (3 H, m, 7-H, 8-H and 9-H), 7 50 (1 H, d, *J* 5.4 Hz, 1-H), 7.67 (1 H, d with additional splitting, *J* 7 2 Hz, 10-H) and 8 37 (2 H, br s, 2-H and 4-H); *m/z* 181.089 (M^+, 100% $C_{13}H_{11}N$ requires 181 089), 166 (10), 152 (28) and 76 (11) *The picrate* of **9** was obtained as a yellow solid, m.p 211–213 °C (lit.,[16] 210–211 °C) when the fused pyridine **9** was treated with picric acid in ethanol

3,4-Dihydro-1-(2-methyl-1-oxocyclopent-2-en-3-yl)naphthalene-2-carboxaldehyde N,N-dimethylhydrazone **16** Reaction with 3-bromo-2-methylcyclopent-2-en-1-one as the electrophile produced *3,4-dihydro-1-(2-methyl-1-oxocyclopent-2-en-3-yl)naphthalene-2-carboxaldehyde N,N-dimethylhydrazone* **16** (0 04 g, 12%) as a yellow oil after purification by flash column chromatography [ethyl acetate–cyclohexane (1:19)], δ (200 MHz; $CDCl_3$) 1 65 (3 H, s with small splitting, Me), 2.44-2 66 (4 H, m), 2 75–2 95 (4 H, m), 2 92 (6 H, s, NMe_2), 6.72-6.83 (2 H, m) and 7 10-7 25 (3 H, m), ν_{max} (film) /cm^{-1} 1700 (C=O) and 1640 (C=C); *m/z* 294 173 (M^+, 43% $C_{19}H_{22}N_2O$ requires 294 173), 265 (100), 222 (25), 165 (16) and 59 (32).

Flash vacuum pyrolysis of 1-aryl- and 1-heteroaryl-N,N-dimethylhydrazones General procedure

The hydrazone was subjected to flash vacuum pyrolysis (650 °C, 10^{-2} mmHg) over a period of approximately 4 h. The solid was allowed to sublime under vacuum through a heated silica tube (20 cm) onto a glass finger cooled with liquid nitrogen The pyrolysate was then extracted off the cold finger with dichloromethane, the solvent was removed *in vacuo*, and the product was purified by flash column chromatography

Thieno[2,3-a]benz[f]isoquinoline **21**. Pyrolysis of 3,4-dihydro-1-(2-thienyl)naphthalene-2-carboxaldehyde *N,N*-dimethylhydrazone **7** (0 15 g, 0 53 mmol) gave *thieno[2,3-a]benz[f]isoquinoline* **21** (0 085 g, 68%) as a brown oil after flash column chromatography [ethyl acetate–cyclohexane (1·1)], δ (400 MHz, $CDCl_3$) 2 89–2 93 (2 H, m) and 2 96–3 00 (2 H, m) (6-H and 7-H), 7 35 (1 H, dd, *J* 7 5 and 2 0 Hz, 8-H), 7 37 (1 H, ddd, *J* 7 5, 7 0 and 1 0 Hz, 9-H), 7 45 (1 H, ddd, *J* 7 5, 7 0 and 2 0 Hz, 10-H), 7 60 (1 H, d, *J* 5 6 Hz, 2-H), 7.72 (1 H, d, *J* 5 6 Hz, 3-H), 8 27 (1 H, dd, *J* 7 5 and 1 0 Hz, 11-H), and 8 61 (1 H, s, 5-H), ν_{max} (CH_2Cl_2) /cm^{-1} 1658, 1605, 1572, 1559, 1537, 1501 and 1486; *m/z* 237.060 (M^+, 100% $C_{15}H_{11}NS$ requires 237.061), 222 (7), 208 (9), 165 (6), 118 (7), and 104 (6) The *picrate* of **21**, m.p 234–236 °C (from 2-methoxyethanol) was prepared by its reaction with picric acid in ethanol (Found. C, 53 9, H, 3 0; N, 12 0 $C_{21}H_{14}N_4O_7S$ requires C, 54 1, H, 3 0, N, 12 0%)

When the hydrazone **7** was subjected to flash vacuum pyrolysis at 500 °C and 10^{-4} mmHg , a 1 5 mixture of hydrazone **7** and cyclised product **21** (by ^1H nmr) resulted

Furo[2,3-a]benz[f]isoquinoline **25** The pyrolysis of 3,4-dihydro-1-(2-furyl)naphthalene-2-carboxaldehyde *N,N*-dimethylhydrazone **11** (0.025 g, 0 09 mmol) was less successful than that of the thienyl analogue **7** as the compound did not sublime very well The crude product (0 04 g), which appeared to contain furo[2,3-*a*]benz[*f*]isoquinoline **25**, was obtained as a green oil, δ (200 MHz, $CDCl_3$) 3 05-3 16 (2 H, m) and 3 21–3 30 (2 H, m) (6-H and 7-H), 7.21–7 27 (2 H, m), 7 37–7 44 (2 H, m), 7 61–7 66 (1 H, dd, J 6 2 and 3 0 Hz), 7 97 (1 H, d, J 2 2 Hz) and 8 35 (1 H, s, 5-H); m/z 221 084 (M^+, 100% $C_{15}H_{11}NO$ requires 221 084), 192 (72), 181 (11), 165 (37) and 95 (21)

7,8-Dihydrobenzo[k]phenanthridine **26**. Pyrolysis of 3,4-dihydro-1-phenylnaphthalene-2-carboxaldehyde *N,N*-dimethylhydrazone **12** (0 15 g, 0.54 mmol) gave *7,8-dihydrobenzo[k]phenanthridine* **26** (0 09 g, 62%) as a yellow oil after flash column chromatography [ethyl acetate-cyclohexane (1.4)], δ (200 MHz; $CDCl_3$) 2 81–2 94 (4 H, m, 7-H and 8-H), 7 34–7 40 (3 H, m), 7 53 (1 H, 2 overlapping dd, J 6.8 and 1 5 Hz), 7 66 (1 H, 2 overlapping dd, *J* 6 8 and 1.5 Hz), 7 93–7 98 (1 H, m), 8 14 (1 H, dd, *J* 8 5 and 1 4 Hz), 8 47 (1 H, dd, *J* 8 5 and 1.4 Hz) and 8 80 (1 H, s, 6-H), ν_{max} (CH_2Cl_2) /cm^{-1} 1569, 1558, 1504 and 1487, m/z 231 105 (M^+, 100% $C_{17}H_{13}N$ requires 231 105), 216 (10), 202 (25) and 101 (15) The *picrate* of **26**, m p 268–270 °C (lit.,[20] 270 °C) was obtained as a yellow solid when compound **26** was treated with picric acid in ethanol (Found. C, 59.9, H, 3.5; N, 12.2 Calc. for $C_{23}H_{16}N_4O_7$· C, 60 0, H, 3 5, N, 12 2%)

2-Bromobenzaldehyde N,N-dimethylhydrazone **17** A solution of 2-bromobenzaldehyde (3 15 g, 17 0 mmol) and 1,1-dimethylhydrazine (1.40 ml, 18 4 mmol) in dry toluene (25 ml) containing a few crystals of toluene-4-sulfonic acid was heated under reflux for 16 h, using a Dean and Stark trap to remove water This gave the *dimethylhydrazone* **17** (3.14 g, 81%) as a colourless oil (Found C, 47.6, H, 4 9, N, 12 4. $C_9H_{11}BrN_2$ requires C, 47.6, H, 4 9; N, 12.3%), δ (200 MHz, $CDCl_3$) 3 02 (6 H, s, N<u>Me</u>$_2$), 7.05 (1 H, ddd, *J* 7.9, 7 2 and 1 6 Hz, 5-H), 7.24 (1 H, ddd, *J* 7 9, 7 2 and 1 1 Hz, 4-H), 7 45 (1 H, s, C<u>H</u>=N), 7.50 (1 H, dd, *J* 7 9 and 1.1 Hz, 6-H) and 7 90 (1 H, dd, *J* 7 9 and 1 6 Hz, 3-H); ν_{max} (film) /cm^{-1} 1572, 1548 and 1462, m/z 228 009 (M^+, 68% $C_9H_{11}{}^{81}BrN_2$ requires 228 009), 226 (69), 147 (88 and 132 (100)

Palladium(0) catalysed coupling reactions of the chlorozinc intermediate **18** *with vinyl bromides General procedure*

2-Bromobenzaldehyde *N,N*-dimethylhydrazone **17** (0 26 g, 1 15 mmol) was converted into its 2-lithio derivative by reaction with butyllithium (1 46 <u>M</u>, 0 90 ml, 1 31 mmol) in THF (15 ml) at –78 °C for 20 min Zinc chloride (1 0 <u>M</u>, 1.75 ml, 1.75 mmol) was then added and the mixture was stirred at –20 °C for 1 h, in order to effect the formation of the chlorozinc intermediate **18** $Pd(PPh_3)_4$ (0 05 g, 4 mol%) and the appropriate electrophile (1 15 mmol) were then added together in THF (15 ml) The reaction mixture was allowed to warm up to room temperature and it was then heated under reflux for 16 h Workup was followed by purification of the crude product by flash column chromatography

2-[(E)-2-(Trimethylsilyl)ethenyl]benzaldehyde N,N-dimethylhydrazone **19** Reaction with *(E)*-2-(bromovinyl)trimethylsilane as the electrophile gave *2-[(E)-2-(trimethylsilyl)ethenyl]benzaldehyde N,N-dimethylhydrazone* **19** (0 22 g, 79%) as a yellow oil after purification by flash column chromatography [ethyl acetate-cyclohexane (1 19)], (Found C, 68 2, H, 9 0, N, 11 5. $C_{14}H_{22}N_2Si$ requires C, 68 2, H, 9 0, N, 11 4%), δ [200 MHz, $(CD_3)_2CO$] 0 16 (9 H, s, Si<u>Me</u>$_3$), 2 95 (6 H, s, N<u>Me</u>$_2$), 6.37 (1 H, d, *J* 19 0 Hz, AB), 7 14–7 25 (2 H, m), 7 50 (1 H, d, *J* 19 0 Hz, AB), 7 45–7 54 (2 H, m) and 7 68–7 73 (1 H, m), ν_{max} (film) /cm^{-1} 1574, 1551, 1467 and 1443, *m/z* 246 156 (M^+, 2 5% $C_{14}H_{22}N_2{}^{28}Si$ requires 246 155), 173 (100), 130 (21) and 73 (51)

2-(2-Methyl-1-oxocyclopent-2-en-3-yl)benzaldehyde N,N-dimethylhydrazone **20** Reaction with 3-bromo-2-methylcyclopent-2-en-1-one as the electrophile gave *2-(2-methyl-1-oxocyclopent-2-en-3-yl)benzaldehyde N,N-dimethylhydrazone* **20** (0 16 g, 59%) as a red-brown oil after purification by flash column chromatography [ethyl acetate–cyclohexane (1 4)], δ (200 MHz, $CDCl_3$) 1 61 (3 H, s with small coupling *J* < 1 0 Hz, Me), 2 54–2 59 (2 H, m), 2 81–2 87 (2 H, m), 2 92 (6 H, s, N<u>Me</u>$_2$), 6 96 (1 H, s, C<u>H</u>=N), 7 10 (1 H, dd, *J* 7 1 and 2 0 Hz), 7 23–7 39 (2 H, m) and 7 92 (1 H, dd, *J* 7 7 and 1 6 Hz), ν_{max} /cm^{-1} 1701 (C=0), 1638, 1573 and 1551, *m/z* 242 142 (M^+, 13% $C_{15}H_{18}N_2O$ requires 242 142), 171 (67), 156 (43), 141 (20), 115 (21) and 59 (100)

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