THE QUEST FOR ALTERNATIVE ROUTES TO RACEMIC AND NONRACEMIC AZAHELICENE DERIVATIVES

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Dedicated to the memory of Professor Otto Exner.

A series of diverse aromatic azadienetriyne and azatriynes was synthesised. These compounds were subjected to transition metal-mediated [2+2+2] cycloisomerisation to form pentacyclic or hexacyclic helically chiral azahelicene or azahelicene-like structures mostly in moderate yields. Introducing stereogenic centre(s) into selected azatriynes, cyclisation proceeded in a stereoselective fashion providing aza[5]helicenes or aza[6]helicene-like compounds in up to a 100:0 diastereomeric ratio. Gibbs energy differences between corresponding pairs of diastereomers (calculated at the DFT(B3LYP)/TZV+P level) were in good agreement with the experimental data and allowed for the prediction of the stereochemical outcome of the reaction. This study presents for the first time asymmetric synthesis of azahelicene derivatives in high optical purities.

Keywords: Alkynes; Arenes; Chirality; Cross-coupling; Helical structures; Azahelicenes; Pyridines; Helicity; DFT calculation; [2+2+2]cyclotrimerisation; Stereoselective synthesis.

Azahelicenes[1,2] are envisaged to possess attractive chemical and physicochemical properties representing unique helically chiral bases, nucleophiles or ligands for metals. In line with the recent progress in the synthesis and

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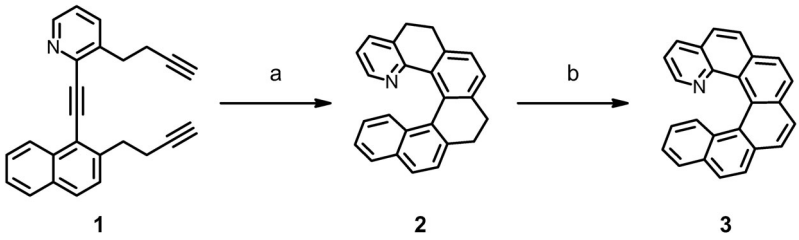
utilisation of carbohelicenes[3,4] and thiaheterohelicenes[5], chemistry of azahelicenes has followed a similar development but with a delay. Now, besides routinely used classical photodehydrocyclisation of pyridostilbene-type precursors[6], a few non-photochemical approaches have already been demonstrated[7]. We have contributed to solving the challenging problem of the azahelicene synthesis by introducing Co^{I}-catalysed [2+2+2] cycloisomerisation of pyridotriynes to create a pyridohelicene backbone (Scheme 1)[8]. As the ring-closing operation provides pyridotetrahydrohelicenes, the reaction sequence is completed by final oxidation to fully aromatic pyridohelicenes.



SCHEME 1[8]
(a) $[CpCo(CO)_2]$ (20 mole %), PPh_3 (40 mole %), decane, halogen lamp, 140 °C, 1 h, 82%; (b) MnO_2 (30 equiv), toluene, microwave oven, 150 °C, 1.3 h, 65%

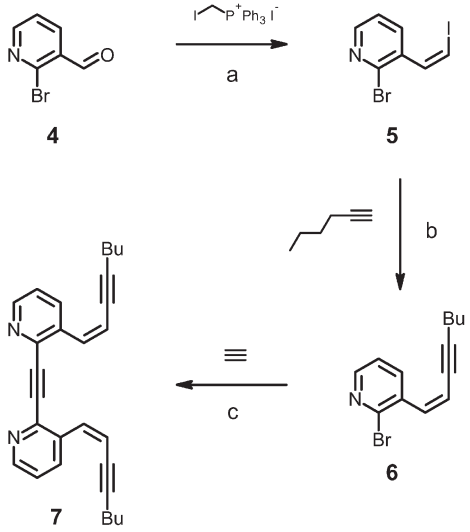
However, properties of azahelicenes have barely been studied. Due to synthetic difficulties, limiting the availability of azahelicenes in the past, there are only a few reports describing X-ray structures[7b,7c,8], basicities[7b,7c,9], proton affinities[10], chiral discrimination in gaseous phase[10], coordination chemistry[8] and self-assembly[6d,11] of certain derivatives. So far, there is only one example of applying nonracemic azahelicenes to enantioselective organocatalysis[12] and none to transition metal catalysis.

As [2+2+2] cycloisomerisation of pyridotriynes has been proved to be an efficient method for building pyridohelicene scaffolds, we decided to continue exploring its potential to prepare diverse azahelicene structures. Herein, we report on the synthesis of a series of nitrogen-containing triynes, which were subjected to transition-metal-catalysed cyclisation. Furthermore, we paid attention to diastereoselective cycloisomerisation of chiral azatriynes to obtain azahelicene derivatives in a nonracemic form. This has extended our ongoing study focused on asymmetric synthesis of helicene-like molecules[13].

RESULTS AND DISCUSSION

Synthesis of Dienetriyne ***7***

Optimising the synthetic scheme, we developed a short and straightforward route to pyridodienetriyne **7** (Scheme 2). The synthesis started from commercially available 2-bromopyridine-3-carbaldehyde (**4**), which underwent the Wittig olefination with iodoylide generated from (iodomethyl)(triphenyl)phosphonium iodide. After the reaction, we could isolate pure *cis*-iodoolefine **5** in 74% yield. The *cis* configuration of the double bond was inferred from ^{1}H NMR spectrum exhibiting an 8.6 Hz coupling constant of vicinal olefinic protons[14]. The following Sonogashira coupling of **5** with commercially available hex-1-yne under Pd(0)/Cu(I) catalysis proceeded smoothly to yield enyne **6** in 58% yield, preserving the olefin configuration. It is worth noting that we could satisfactorily distinguish the reactivity of vinyl iodide from that of 2-pyridyl bromide, which is also prone to the Sonogashira coupling, when conducting the reaction at

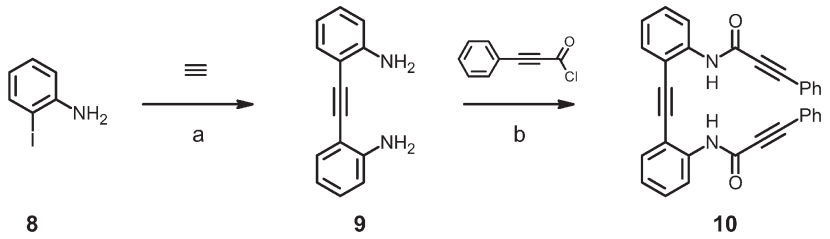


SCHEME 2
(a) $Ph_3P^+CH_2I\ I^-$ (1.2 equiv), $[(CH_3)_3Si]_2NK$ (1.2 equiv), THF, –78 °C, 15 min, then r.t., 30 min, 74%; (b) hex-1-yne (1.1 equiv), $[Pd(PPh_3)_4]$ (5 mole %), CuI (11 mole %), diisopropylamine, 0 °C, 40 min, 58%; (c) gaseous acetylene, $[Pd(PPh_3)_4]$ (5 mole %), CuI (10 mole %), piperidine, r.t., 10 min, then 80 °C, 5 min, 76%

0 °C. Once having enyne **6** in hand, we could attempt the symmetrical Sonogashira coupling with gaseous acetylene under Pd(0)/Cu(I) catalysis, which provided the target pyridodienetriyne **7** in 76% yield. We did not observe a significant participation of the adjacent (1*Z*)-oct-1-en-3-yn-1-yl group in the coupling reaction[15].

*Synthesis of Triyne **10***

Triyne **10** was prepared from commercially available 2-iodoaniline (**8**) in two steps (Scheme 3). Although there is, surprisingly, no record in the literature regarding the direct synthesis of the known 2,2′-ethynediyldianiline (**9**)[16] from 2-iodoaniline (**8**) and gaseous acetylene, we succeeded in performing the Sonogashira coupling under Pd(0)/Cu(I) catalysis to obtain **9** in 90% yield. The attempts at preparing the diamide from aromatic diamine **9** and propynoic or phenylpropynoic acid under treatment with DCC in dichloromethane failed. However, on reaction with 3-phenylpropynoyl chloride (prepared from phenylpropynoic acid and thionyl chloride in dichloromethane under reflux for 3 h)[17], diamine **9** afforded diamide **10** in 64% yield.



8 **9** **10**

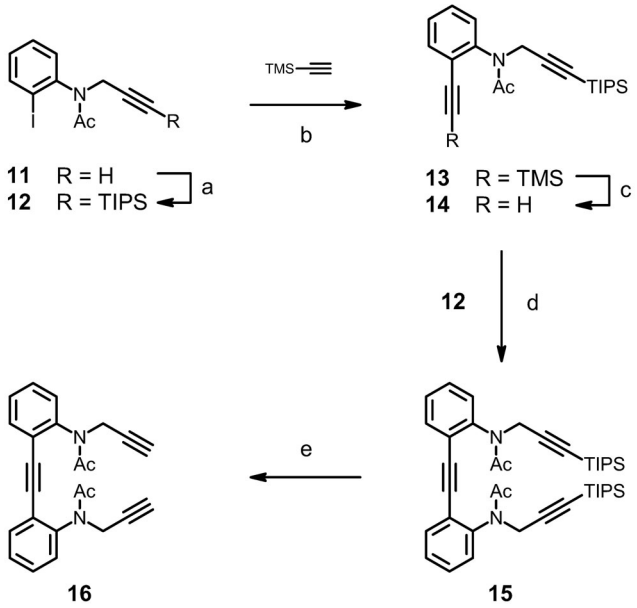
SCHEME 3

(a) Gaseous acetylene, $[Pd(PPh_3)_4]$ (4 mole %), CuI (8 mole %), diisopropylamine, r.t., 30 min, 90%; (b) Ph–C≡C–COCl (3.1 equiv), pyridine (5.1 equiv), dichloromethane, 0 °C, 1.5 h, 64%

*Synthesis of Triyne **16***

The multistep synthesis of triyne **16** started from known functionalised iodoaniline **11** [18], which was easily prepared from 2-iodoaniline (**8**) in two steps by acetylation followed by propargylation[19] (Scheme 4). First, the propargyl group in **11** was protected by triisopropylsilylation after deprotonation with lithium diisopropylamide. The product **12**, obtained in

75% yield, was subjected to the Sonogashira coupling with (trimethylsilyl)-acetylene under Pd(0)/Cu(I) catalysis affording diyne **13** in 56% yield. Due to the different stability of the protecting groups in **13**, we could selectively remove the trimethylsilyl group using sodium methanolate to provide terminal alkyne **14** in 97% yield. Then, we could assemble the triyne backbone by the Sonogashira coupling of iodide **12** and diyne **14** under Pd(0)/Cu(I) catalysis resulting in the formation of silylated triyne **15** in 77% yield. The removal of the triisopropylsilyl groups with tetrabutylammonium fluoride gave rise to the target, unprotected triyne **16** in 48% yield.



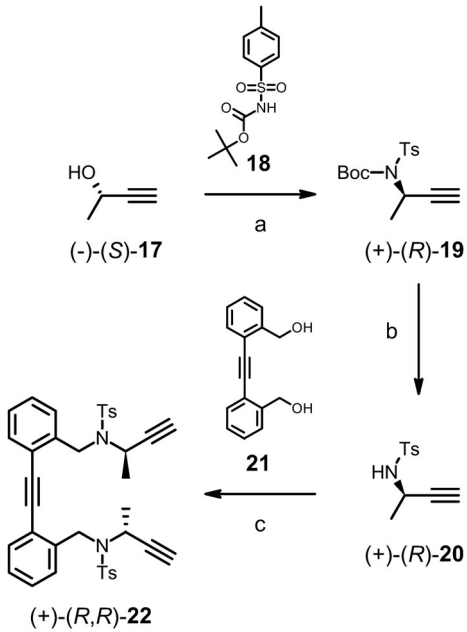
SCHEME 4

(a) LDA (1.0 equiv), THF, –78 °C, 50 min, then TIPSCl (1.4 equiv), r.t., 1 h, 75%; (b) TMS-C≡CH (2.0 equiv), [$Pd(PPh_3)_4$] (5 mole %), CuI (10 mole %), diisopropylamine, 80 °C, 30 min, 56%; (c) CH_3ONa (2.3 equiv), CH_3OH–THF (1:3), r.t., 20 min, 97%; (d) **12** (1.1 equiv), [$Pd(PPh_3)_4$] (5 mole %), CuI (10 mole %), diisopropylamine, 80 °C, 15 min, 77%; (e) Bu_4NF (2.4 equiv), THF, r.t., 15 min, 48%

*Synthesis of Triyne (+)-(R,R)-**22***

The synthesis of optically pure triyne (+)-(*R*,*R*)-**22** took advantage of the fact that both enantiomers of but-3-yn-2-ol (**17**), which served as a key chiral synthon, are commercially available (Scheme 5). The Mitsunobu re-

action of alcohol (–)-(*S*)-**17** with commercially available *N*-(*tert*-butoxycarbonyl)-4-methylbenzene-1-sulfonamide (**18**) afforded alkyne (+)-(*R*)-**19** in 64% yield. It is well known that the Mitsunobu reaction of secondary alcohols proceeds with clean inversion at stereogenic centres[20]. In analogy with other literature examples employing sulfonamide **18** [21], we therefore assumed that alkyne **19** had the *R* configuration at the stereogenic centre. Then, the *tert*-butoxycarbonyl protecting group was easily removed with trifluoroacetic acid to yield chiral tosylamide (+)-(*R*)-**20** in 98% yield. In the final step of the reaction sequence, the known diol **21** [22], which was prepared from commercially available 2-iodobenzyl alcohol, was subjected to the double Mitsunobu reaction we had described earlier[23] employing this time the chiral tosylamide (+)-(*R*)-**20** as a nucleophile to afford the target nonracemic triyne (+)-(*R*,*R*)-**22** in 70% yield.

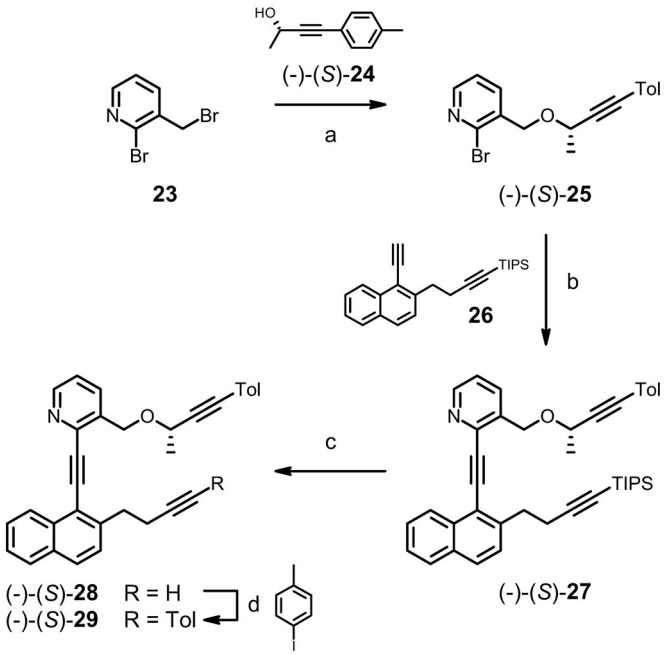


SCHEME 5

(a) BocNHTs **18** (1.8 equiv), ^{i}PrOCO–N=N–COO^{i}Pr (DIAD, 3.2 equiv), PPh_3 (3.7 equiv), THF, 0 °C, overnight, 64%; (b) TFA (15.3 equiv), dichloromethane, r.t., overnight, 98%; (c) **21** (0.5 equiv), DIAD (5.0 equiv), PPh_3 (6.0 equiv), THF, from 0 °C to r.t., overnight, 70%

*Synthesis of Triynes (–)-(S)-**28** and (–)-(S)-**29***

The synthesis of optically pure pyridotriynes (–)-(*S*)-**28** and (–)-(*S*)-**29** followed the procedure we had developed earlier for preparing centrally chiral triynes as precursors for nonracemic helicene-like compounds[24] (Scheme 6). Thus, the known 2-bromo-3-(bromomethyl)pyridine (**23**), readily accessible from commercially available 2-bromo-3-methylpyridine by radical bromination[25], was treated with a sodium salt of chiral alcohol (–)-(*S*)-**24** prepared from (–)-(*S*)-**17** in a single operation[24b]. The substitution reaction provided chiral pyridobromide (–)-(*S*)-**25** in 81% yield. Then, the Sonogashira coupling of this reactive pyridobromide (–)-(*S*)-**25** and known monoprotected naphthyldiyne **26**, the straightforward synthesis of which we had developed earlier[26], led under Pd(0)/Cu(I) catalysis to chiral pyridotriyne (–)-(*S*)-**27** in 88% yield. The following desilylation with tetrabutylam-



SCHEME 6

(a) (–)-(*S*)-**24** (1.1 equiv), NaH (3.0 equiv), THF, 50 °C, 2 h, 81%; (b) **26** (1.0 equiv), $[Pd(PPh_3)_4]$ (5 mole %), CuI (9 mole %), diisopropylamine–toluene (2:1), r.t., 2 h, 88%; (c) Bu_4NF (1.2 equiv), THF, r.t., 2 h, 86%; (d) 4-iodotoluene (1.5 equiv), $[Pd(PPh_3)_4]$ (12 mole %), CuI (32 mole %), diisopropylamine, from r.t. to 80 °C, 2 h, 95%

monium fluoride afforded the optically pure target pyridotriyne (–)-(*S*)-**28** in 86% yield. Finally, the Sonogashira coupling of (–)-(*S*)-**28** with 4-iodotoluene under Pd(0)/Cu(I) catalysis completed the synthesis of the target pyriditriyne (–)-(*S*)-**29** (obtained in 95% yield) having both pendant acetylene units endcapped with the *p*-tolyl groups.

*Study of [2+2+2] Cycloisomerisation of Dienetriyne **7** and Triynes **10**, **16**, (+)-(R,R)-**22**, (–)-(S)-**28** and (–)-(S)-**29***

Having model azatriyne substrates in hand, we could investigate their ability to undergo [2+2+2] cycloisomerisation to form helically chiral products containing nitrogen atoms with different hybridisation in different positions (Table I). Previously, we had found that fully unsaturated aromatic *cis*,*cis*-dienetriynes were appropriate substrates for instantaneous isomerisation to [5]-, [6]- and [7]helicenes[27]. In accord with these observations, *cis*,*cis*-pyridodienetriyne **7** was readily isomerised in the presence of the $[Ni(cod)_2]$ (24 mole %) and PPh_3 (42 mole %) to give diaza[5]helicene **30** (Table I, entry 1). However, the preparative yield was only 9% as competing polymerisation of the pyridine-derived substrate prevailed. Hence, we decided to turn attention to other model azatriynes comprising a 2-alkynylaniline unit. First, the attempts at cyclising the phenylpropynoic amide-type triyne **10** completely failed since the substrate in the presence of $[Ni(cod)_2]$ (24 mole %) and PPh_3 (42 mole %) at room temperature did not react or in the presence of $[CpCo(CO)_2]$ (100 mole %) and PPh_3 (200 mole %) at 140 °C decomposed (Table I, entry 2). Neither other catalysts systems[28] nor microwave irradiation[29] did promote the intended cyclisation. We reasoned the presence of the secondary amide group in **10** might impede the reaction due to a strong complexation of the catalyst or the presence of rigid pendant alkyne units or their unfavourable polarisation. Indeed, the removal of the carbonyl functional groups from the tether in **16** resulted in an increased reactivity of the substrate towards [2+2+2] cycloisomerisation (Table I, entry 3). Thus, triyne **16** was successfully cyclised in the presence of $[CpCo(CO)_2]$ (100 mole %) and PPh_3 (200 mole %) to provide a diaza[5]helicene derivative **32** in 40% yield.

Besides exploring alternative syntheses of diverse azahelicenes, we focused also on obtaining these compounds in a nonracemic form. We had already demonstrated that diastereoselective [2+2+2] cycloisomerisation of chiral triynes was a useful method to control helicity of products[13]. In addition, the stereochemical outcome of cyclisation could be predicted computationally because thermodynamic factors determined diastereo-

TABLE I
Cycloisomerisation of triynes **7**, **10**, **16**, **22**, **28** and **29**

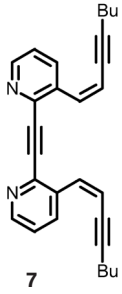
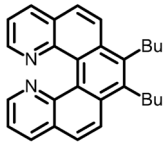
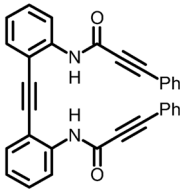
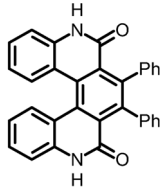
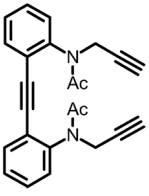
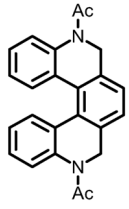
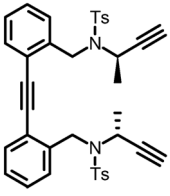
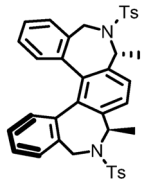
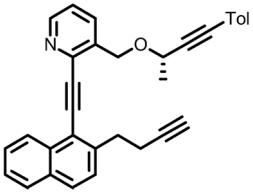
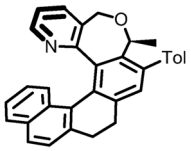
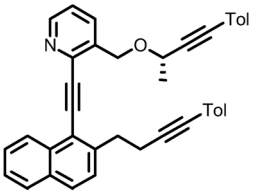
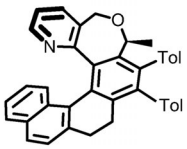
Entry	Triyne	Conditions[a]	Product	Yield, %[b]
1	 **7**	A (r.t., 2 h)	 **30**	9
2	 **10**	A (r.t., 10 h) or B (140 °C, 2 h)	 **31**	0[c]
3	 **16**	B (140 °C, 20 min)	 **32**	40
4	 (+)-(*R*,*R*)-**22**	B (140 °C, 2 h)	 (+)-(*M*,*R*,*R*)-**33**[e]	30 *M*,*R*,*R*:*P*,*R*,*R* 100:0[d]

TABLE I
(*Continued*)

Entry	Triyne	Conditions[a]	Product	Yield, %[b]
5	 (–)-(*S*)-**28**	C (140 °C, 1 h)	 (+)-(*P*,*S*)-**34**[e]	54 *M*,*S*:*P*,*S* 8:92[d]
6	 (–)-(*S*)-**29**	D (120 °C, 42 h)	 (+)-(*P*,*S*)-**35**[e]	38 *M*,*S*:*P*,*S* 0:100[d]

[a] A: [Ni(cod)$_2$] (24 mole %), PPh_3 (42 mole %), THF; B: [$CpCo(CO)_2$] (100 mole %), PPh_3 (200 mole %), decane, halogen lamp; C: [$CpCo(CO)_2$] (22 mole %), PPh_3 (41 mole %), decane, halogen lamp; D: [$CpCo(CO)_2$] (76 mole %), PPh_3 (59 mole %), dioxane. [b] Isolated. [c] Decomposed (Co catalyst) or no reaction (Ni catalyst). [d] Diastereomeric ratio determined by ^{1}H NMR. [e] Helicity assignments based on ^{1}H-^{1}H correlations in ROESY ^{1}H NMR spectra.

selectivity of the reaction. Therefore, we pursued [2+2+2] cycloisomerisation of optically pure azatriyne (+)-(*R*,*R*)-**22** comprising two stereogenic centres in the presence of [$CpCo(CO)_2$] (100 mole %) and PPh_3 (200 mole %) (Table I, entry 4) to obtain the nonracemic diaza[5]helicene-like product (+)-(*M*,*R*,*R*)-**33** in 30% yield[30]. As ^{1}H NMR spectrum of the product did not display a doubled signal of any proton, we concluded that a single diastereomer was formed. Helicity of the product was inferred from ROESY ^{1}H NMR spectrum, which showed an off-diagonal cross-peak belonging to through-space coupling of 3-H with 4-H (Fig. 1). In the case of the *R* configuration retained at the stereogenic centres, the distance between these two hydrogen atoms was only 2.2 Å in (*M*,*R*,*R*)-**33** but 3.7 Å in (*P*,*R*,*R*)-**33**. Accordingly, we could clearly ascribe the *M* helicity to the cyclisation product.

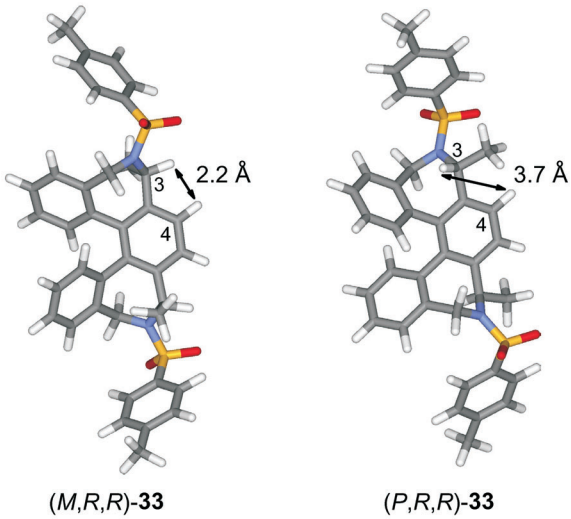


FIG. 1
Molecular models of (*M*,*R*,*R*)-**33** and (*P*,*R*,*R*)-**33** (the structures optimised at the DFT(B3LYP)/TZV+P level)

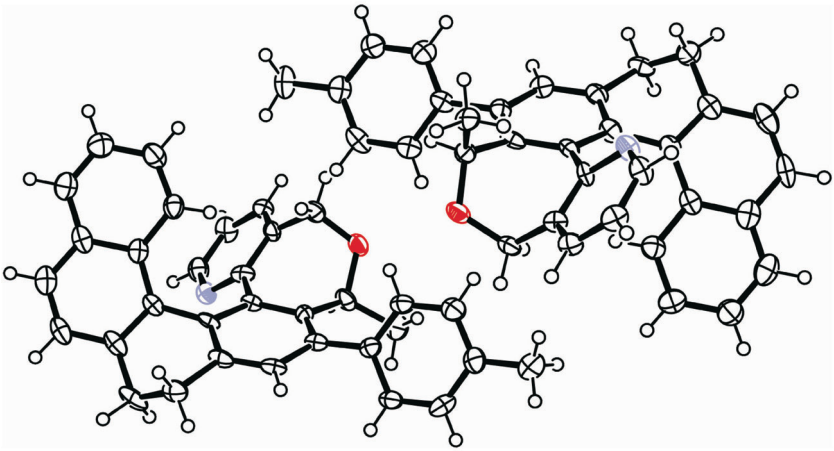


FIG. 2
Single-crystal molecular structure of (*M*,*S*)-**34** and (*P*,*S*)-**34** packed together in a unit cell

A difference in ground-state energies of both possible diastereomers, which we computed (vide infra), also favoured the product with the *M* helicity.

Being encouraged by these results, we returned to pyridohelicenes. We found that the chiral pyridotriyne (–)-(*S*)-**28** underwent [2+2+2] cyclotrimerisation under [$CpCo(CO)_2$] (20 mole %) and PPh_3 (40 mole %) catalysis affording an 8:92 mixture of pyridohelicene (*M*,*S*)-**34** and (+)-(*P*,*S*)-**34** in 54% yield (Table I, entry 5). However, the diastereomers could not be separated by liquid chromatography. We observed even better diastereoselectivity when cyclising chiral pyridotriyne (–)-(*S*)-**29** in the presence of [$CpCo(CO)_2$] (76 mole %) and PPh_3 (59 mole %) to afford pyridohelicene (+)-(*P*,*S*)-**35** in 38% yield and virtually optically pure (Table I, entry 6). In both cases, the *P* helicity of the major or single diastereomer was assigned on the basis of ROESY ^{1}H NMR spectra similarly as we described above and published for close nonracemic carba analogues[13a,13c,31]. Crystallising an 8:92 mixture of pyridohelicene (*M*,*S*)-**34** and (+)-(*P*,*S*)-**34**, we obtained crystals being suitable for X-ray analysis (Fig. 2). However, both diastereomers differing in helicity were packed equally in a unit cell and, therefore, we could confirm only the product structure without assigning helicity to the major diastereomer using this method. We also measured the CD spectrum of an 8:92 mixture of (*M*,*S*)-**34** and (+)-(*P*,*S*)-**34** (Fig. 3).

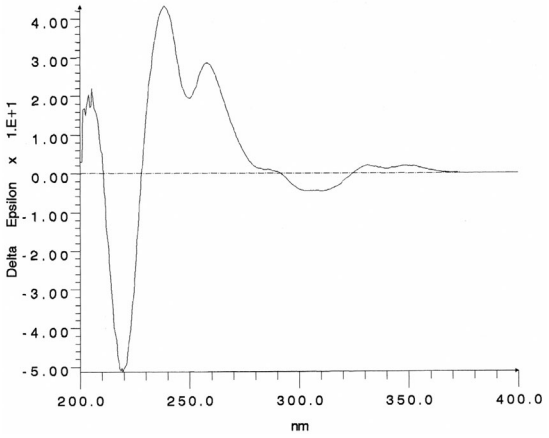


FIG. 3
The CD spectrum of an 8:92 mixture of (*M*,*S*)-**34** and (+)-(*P*,*S*)-**34** (5.51×10^{-4} mol l^{-1} in acetonitrile)

Quantum Chemical Calculations

Recently, we showed that the stereochemical outcome of diastereoselective Co(I)-mediated [2+2+2] cycloisomerisations of related chiral triynes at 140 °C were controlled by thermodynamic factors[13a]. Accordingly, we could predict diastereoselectivity of the reaction on the basis of differences in the Gibbs energies of diastereomers of helicene-like compounds having *M* or *P* helicity using the DFT(B3LYP)/TZV+P method and the polarised continuum model to account for solvation. Following the same procedure, we have studied two pairs of diastereomers: (*M*,*R*,*R*)-**33** versus (*P*,*R*,*R*)-**33** and (*M*,*S*)-**34** versus (*P*,*S*)-**34** (Table II). A remarkable agreement between the experimental and theoretical data was found for these azahelicene-like molecules. This led to the unambiguous identification of the most stable and populated diastereomers.

TABLE II
Calculated differences in Gibbs energies between the *M* and *P* pairs of diastereomers (stereogenic centres unchanged)

Entry	Helicene diastereomers	ΔG_{calc} [a,b] kcal/mol	*M*:*P* calculated[b]	*M*:*P* experimental[c]
1	(*M*,*R*,*R*)-**33** vs (*P*,*R*,*R*)-**33**	–13.52	100:0	100:0
2	(*M*,*S*)-**34** vs (*P*,*S*)-**34**	2.20	6:94	8:92

[a] The negative value indicates the higher stability of diastereomer with *M* helicity. [b] Calculated at the DFT(B3LYP)/TZV+P level. [c] The stereochemical outcome of [$CpCo(CO)_2$]-mediated [2+2+2] cycloisomerisation at 140 °C.

CONCLUSION

Summing up, we synthesised in a straightforward way a series of diverse aromatic azatriynes. These model compounds were subjected to transition-metal-mediated [2+2+2] cycloisomerisation to form pentacyclic or hexacyclic helically chiral pyridohelicene, pyridohelicene-like or azahelicene-like structures mostly in moderate yields. Introducing stereogenic centres to pyrido- or azatriynes, cyclisation proceeded in a stereoselective fashion providing pyrido[6]helicene-like or diaza[5]helicene-like molecules in up to a 100:0 diastereomeric ratio. The Gibbs energy differences between corresponding pairs of diastereomers (calculated at the DFT(B3LYP)/TZV+P level) were in good agreement with the experimental data and allowed for the

prediction of the stereochemical outcome of the reaction. In the case of nonracemic products, helicity assignments were based on ^{1}H-^{1}H correlations in ROESY ^{1}H NMR spectra. Although the alternative route to pyridohelicenes through pyridotetrahydrohelicenes published recently[8] leads to generally higher preparative yields of key pyridotriyne [2+2+2] cycloisomerisation, this study documents versatility of the methodology, provides a synthetic protocol for other azahelicene structures and describes for the first time asymmetric synthesis of azahelicene derivatives in high optical purities.

METHODS

Quantum Chemical Calculations

All the density functional theory (DFT) calculations reported in the study were carried out using Turbomole 5.7 program[32]. The PBE and B3LYP functionals[33,34] have been used throughout. The calculations were performed by expanding the Coulomb integrals in an auxiliary basis set, the resolution-of-identity (RI) approximation[35,36]. All the geometry optimisations were carried out using the RI-PBE method and 6-31G(d) basis set[37], whereas the single-point energies were recomputed in larger basis set TZV+P (triple-ζ valence with one polarisation function on each atom)[38], using the B3LYP method. To account for solvation effects, the conductor-like screening model (COSMO) method[39,40] was used with the dielectric permitivity constant corresponding to acetonitrile (ε_r = 36.6). The Gibbs energy was then calculated as the sum of these contributions (Eq. (*1*))

$$\Delta G = E_{el} + \Delta G_{solv} + E_{ZPE} - RT \ln (q_{trans} q_{rot} q_{vib}) \qquad (1)$$

where E_{el} is the in vacuo energy of the system (at the B3LYP/TZV+P level, using the geometry optimised at the RI-PBE/6-31G(d) level as described above), ΔG_{solv} is the solvation Gibbs energy (at the RI-PBE/6-31G(d) level), E_{ZPE} is the zero-point energy, and $-RT \ln (q_{trans} q_{rot} q_{vib})$ accounts for the entropic terms and the thermal correction to the enthalpy (obtained from a frequency calculation by the same method and software as for the geometry optimisations at the RI-PBE/6-31G(d) level, at 298 K and 1 atm pressure, using an ideal-gas approximation)[41]. The Gibbs energy calculated from Eq. (*1*) is a good approximation to ΔG in dilute solution.

EXPERIMENTAL

General

^{1}H NMR spectra were measured at 500.13 MHz, ^{13}C NMR spectra at 125.7 MHz, in $CDCl_3$ with TMS as an internal standard unless stated otherwise. Chemical shifts are given in δ-scale, coupling constants *J* are given in Hz. gHMBC experiments were set up for J_{C-H} = 5 Hz. For correct assignment of both ^{1}H and ^{13}C NMR spectra of key compounds, the COSY, ROESY, gHMQC and gHMBC experiments were performed. For all the other compounds, general semiempirical equations were applied to the chemical shift assignments. IR spectra (in cm^{-1}) were measured in $CHCl_3$. EI MS spectra were determined at an ionising voltage of 70 eV, *m/z* values are given along with their relative intensities (%). FAB MS spectra were measured using the thioglycerol–glycerol 3:1 matrix; *m/z* values are given. HR MS spectra were obtained by the EI or FAB. Commercially available reagent grade materials such as 2-bromopyridine-3-carbaldehyde (**4**), 2-iodoaniline (**8**), (2*S*)-but-3-yn-2-ol (**17**), *tert*-butyl *N*-(4-methylbenzene-1-sulfonyl)carbamate (**18**), (iodomethyl)triphenylphosphonium iodide, hex-1-yne, gaseous acetylene, phenylpropynoic acid, (trimethylsilyl)acetylene and 4-iodotoluene were used as received. Compounds **11** [18], **21** [22], **23** [25] and **26** [26] were prepared according to the literature procedures. Decane, toluene and diisopropylamine were degassed by three freeze-pump-thaw cycles before use; dioxane and dichloromethane were distilled from calcium hydride under argon; THF was freshly distilled from sodium/benzophenone under nitrogen, methanol was freshly distilled from sodium under argon. TLC was performed on Silica gel 60 F_{254}-coated aluminium sheets (Merck) and spots were detected with a 1% solution of $Ce(SO_4)_2 \cdot 4H_2O$ and 2% $H_3P(Mo_3O_{10})_4$ in 10% sulfuric acid. Flash chromatography was performed on Silica gel 60 (0.040–0.063 mm or <0.063 mm, Merck) or on Biotage KP-Sil® Silica cartridges (0.040–0.063 mm) used in Horizon® or Sp1® HPFC system (Biotage, Inc.).

2-Bromo-3-[(*Z*)-2-iodoethenyl]pyridine (**5**)

A Schlenk flask was charged with (iodomethyl)triphenylphosphonium iodide (713 mg, 1.35 mmol, 1.2 equiv) and flushed with argon. THF (7 ml) and potassium 1,1,1,3,3,3-hexamethyldisilazan-2-ide (0.5 M solution in toluene, 2.7 ml, 1.35 mmol, 1.2 equiv) were added and the mixture was stirred at room temperature for 10 min. The mixture was cooled to –78 °C and aldehyde **4** (204 mg, 1.09 mmol) in THF (8 ml) was added. The mixture was stirred at –78 °C for 15 min and then allowed to reach room temperature over a period of 30 min. The reaction was quenched by adding a saturated aqueous solution of ammonium chloride and the product was extracted with diethyl ether (3×). The combined ethereal extracts were dried over anhydrous Na_2SO_4, the solvents were evaporated in vacuo and the residue was chromatographed on silica gel (petroleum ether–diethyl ether 90:10) to afford *cis*-iodoalkene **5** (247 mg, 74%) as an oil. ^{1}H NMR: 6.88 (1 H, d, *J* = 8.6), 7.32 (1 H, dd, *J* = 8.6, 0.8), 7.32 (1 H, dd, *J* = 7.7, 4.8), 7.97 (1 H, ddd, *J* = 7.7, 2.0, 0.8), 8.34 (1 H, dd, *J* = 4.8, 2.0). ^{13}C NMR: 85.59 (d), 122.20 (d), 134.97 (s), 136.99 (d), 138.27 (d), 142.84 (s), 149.42 (d). IR: 3071 w, 3054 w, 1609 w, 1571 m, 1558 w, 1447 w, 1388 vs, 1305 m, 1184 w, 1121 w, 978 vw, 801 m, 713 s, 692 m, 537 w.

2-Bromo-3-[(1*Z*)-oct-1-en-3-yn-1-yl]pyridine (**6**)

A Schlenk flask was charged with [Pd(PPh_3)$_4$] (50 mg, 0.043 mmol, 5 mole %), CuI (17 mg, 0.089 mmol, 11 mole %) and flushed with argon. Then **5** (250 mg, 0.807 mmol) in diisopropylamine (5 ml) was added at 0 °C and then hex-1-yne (97 µl, 0.844 mmol, 1.1 equiv) and the reaction mixture was stirred at 0 °C for 40 min. The solvent was evaporated at reduced pressure and the residue was chromatographed on silica gel (petroleum ether–diethyl ether 93:7) to afford **6** (124 mg, 58%) as an oil. ^{1}H NMR: 0.92 (3 H, t, *J* = 7.3), 1.42 (2 H, m), 1.53 (2 H, m), 2.39 (2 H, ddt, *J* = 7.0, 7.0, 2.5, 0.8), 5.92 (1 H, dt, *J* = 11.8, 2.4, 2.4), 6.81 (1 H, dq, *J* = 11.8, 0.8, 0.8, 0.8), 7.25 (1 H, ddd, *J* = 7.8, 4.7, 0.7), 8.26 (1 H, dd, *J* = 4.7, 2.0), 8.61 (1 H, ddd, *J* = 7.8, 2.0, 0.5). ^{13}C NMR: 13.55 (q), 19.45 (t), 21.98 (t), 30.42 (t), 77.75 (s), 99.23 (s), 112.69 (d), 122.24 (d), 133.44 (s), 133.80 (d), 137.11 (d), 143.40 (s), 148.74 (d). IR: 3051 w, 2249 w, 2203 m, 1602 w, 1573 s, 1550 s, 1467 m, 1458 m, 1450 m, 1413 s, 1376 vs, 1326 w, 1300 w, 1183 m, 1126 m, 1119 m, 1065 m, 1052 vs, 978 w, 807 s.

2,2′-Ethynediylbis{3-[(1*Z*)-oct-1-en-3-yn-1-yl]pyridine} (**7**)

A Schlenk flask was charged with [Pd(PPh_3)$_4$] (9.4 mg, 0.008 mmol, 5 mole %), CuI (3 mg, 0.016 mmol, 10 mole %) and filled with acetylene. A solution of bromopyridine **6** (40 mg, 0.153 mmol) in piperidine (3 ml) was added and the reaction mixture was stirred at room temperature for 10 min and then at 80 °C for 5 min. The solvent was removed in vacuo and the crude product was chromatographed on silica gel (petroleum ether–acetone 80:20) to provide *cis*,*cis*-dienetriyne **7** (23 mg, 76%) as an amorphous solid. ^{1}H NMR: 0.94 (6 H, t, *J* = 7.3), 1.46 (4 H, m), 1.58 (4 H, m), 2.44 (4 H, ddd, *J* = 7.1, 2.5, 0.7), 5.95 (2 H, dt, *J* = 11.9, 2.5, 2.5), 7.20 (2 H, dt, *J* = 11.9, 0.7, 0.7), 7.28 (2 H, ddd, *J* = 8.1, 4.7, 0.7), 8.54 (2 H, dd, *J* = 4.7, 1.7), 8.85 (2 H, ddd, *J* = 8.1, 1.7, 0.6). ^{13}C NMR: 13.57 (q), 19.56 (t), 22.02 (t), 30.51 (t), 78.53 (s), 90.88 (s), 99.75 (s), 112.47 (d), 122.85 (d), 132.46 (d), 134.45 (d), 134.84 (s), 141.43 (s), 149.05 (d). IR: 3053 w, 2252 vw, 2201 w, 1605 w, 1576 w, 1553 w, 1467 w, 1455 w, 1435 vs, 1408 w, 1326 w, 1310 w, 1176 w, 1121 w, 980 vw, 813 w. EI MS: 392 ($M^{+\bullet}$, 2), 363 (1), 349 (5), 306 (6), 277 (30), 211 (18), 97 (30), 83 (42), 69 (73), 55 (68), 43 (100). HR EI MS: calculated for $C_{28}H_{28}N_2$ 392.2252, found 392.2241.

2,2′-Ethynediyldianiline (**9**)

A Schlenk flask was charged with 2-iodoaniline (**8**) (3.0 g, 13.69 mmol), [Pd(PPh_3)$_4$] (633 mg, 0.55 mmol, 4 mole %), CuI (209 mg, 1.10 mmol, 8 mole %) and flushed with argon. Diisopropylamine (60 ml) was added and gaseous acetylene was slowly bubbled through the reaction mixture at room temperature for 30 min. The solids were removed by filtration and the filtrate was evaporated to dryness under reduced pressure. The residue was chromatographed on silica gel (petroleum ether–ethyl acetate 60:40) to afford diamine **9** (1.28 g, 90%) as an amorphous solid. ^{1}H NMR (200 MHz): 4.27 (4 H, s), 6.72 (4 H, td, *J* = 8.0, 8.0, 1.0), 7.15 (2 H, td, *J* = 7.8, 7.8, 1.8), 7.36 (2 H, dd, *J* = 8.2, 1.6). Analytical data were in agreement with the published ones[16].

N,*N*′-(Ethynediyldibenzene-2,1-diyl)bis(3-phenylprop-2-ynamide) (**10**)

A solution of phenylpropynoic acid (1.085 g, 7.42 mmol, 3.1 equiv) and thionyl chloride (0.8 ml, 10.96 mmol, 4.6 equiv) in dichloromethane (18 ml) was refluxed for 3 h under

nitrogen. The excess of thionyl chloride and dichloromethane were removed in vacuo and the residue was dried in oil pump vacuum for 1 h. The crude acid chloride was immediately used in the next step. A solution of phenylpropynoyl chloride in dichloromethane (3 ml) was added dropwise at 0 °C to a solution of amine **9** (500 mg, 2.4 mmol) and pyridine (1 ml, 12.43 mmol, 5.1 equiv) in dichloromethane (30 ml) and the mixture was stirred for 1.5 h. The reaction mixture was then washed with 5% HCl (1×), brine (1×), water (3×) and dried over anhydrous Na_2SO_4. After filtration and evaporation, flash chromatography on silica gel (petroleum ether–ethyl acetate 100:0 to 60:40) afforded **10** (323 mg, 64%) as an amorphous solid. ^{1}H NMR: 7.10–7.67 (16 H, m), 8.21–8.46 (2 H, m). ^{13}C NMR: 83.24 (s), 86.59 (s), 91.62 (s), 111.73 (s), 119.68 (s), 120.55 (d), 124.38 (d), 128.57 (d), 130.38 (d), 130.52 (d), 131.94 (d), 132.73 (d), 138.41 (s), 150.86 (s). IR: 3387 s, 3302 w, 3066 m, 2272 w (sh), 2236 m, 2209 vs, 2174 w, 1669 vs, 1608 s, 1579 vs, 1515 vs, 1491 vs, 1469 s (sh), 1444 vs, 1307 vs, 1272 s, 1182 s, 1170 vs, 1107 m, 1071 w, 1043 m, 1027 m, 1008 w, 1001 w, 840 w, 689 s, 543 m (sh), 534 m, 511 m, 470 m, 435 m. EI MS: 464 ($M^{+\bullet}$, 43), 463 (60), 445 (13), 436 (10), 427 (15), 387 (22), 362 (10), 335 (19), 318 (14), 290 (12), 256 (19), 236 (18), 205 (16), 178 (10), 129 (57), 111 (16), 97 (29), 83 (35), 69 (63), 55 (81), 43 (100). HR EI MS: calculated for $C_{32}H_{20}N_2O_2$ 464.1525, found 464.1515.

N-(2-Iodophenyl)-*N*-[3-(triisopropylsilyl)prop-2-yn-1-yl]acetamide (**12**)

A solution of **11** [18] (86 mg, 0.28 mmol) in THF (2 ml) was cooled down to –78 °C and a solution of LDA (30 mg, 0.28 mmol, 1.0 equiv) in THF (1 ml) was added dropwise. After stirring for 50 min, TIPSCl (70 μl, 0.39 mmol, 1.4 equiv) was added and the reaction mixture was allowed to warm to room temperature over a period of 1 h. The solvent was removed at reduced pressure, the residue was dissolved in dichloromethane and washed with water (2×). The organic phase was dried over anhydrous Na_2SO_4, filtered and the solvent was evaporated in vacuo. Flash chromatography on silica gel (petroleum ether–ethyl acetate 100:0 to 60:40) afforded **12** (98 mg, 75%) as an amorphous solid. ^{1}H NMR: 0.93–1.01 (21 H, m), 1.81 (3 H, s), 3.98 (1 H, d, J = 17.6), 5.14 (1 H, d, J = 17.6), 7.10 (1 H, ddd, J = 7.9, 6.6, 2.5), 7.40 (1 H, ddd, J = 7.8, 6.6, 1.3), 7.41 (1 H, ddd, J = 7.8, 2.5, 0.8), 7.93 (1 H, ddd, J = 7.9, 1.3, 0.8). ^{13}C NMR: 11.11 (d), 18.51 (q), 22.72 (q), 37.54 (t), 86.11 (s), 100.36 (s), 101.61 (s), 129.35 (d), 130.14 (d), 131.07 (d), 139.93 (d), 143.55 (s), 169.50 (s). IR: 3062 vw, 2866 s, 2177 w, 1660 vs, 1579 w, 1567 vw, 1471 vs, 1463 m (sh), 1439 w, 1388 m, 1362 w, 1118 vw, 1073 w, 1060 w, 998 w, 920 w, 884 m, 679 m, 640 w, 625 w, 598 w, 417 w. EI MS: 455 ($M^{+\bullet}$, 46), 413 (100), 374 (9), 328 (24), 286 (20), 244 (62), 214 (8), 200 (70), 172 (10), 156 (14), 130 (11), 115 (9), 83 (12), 59 (19), 43 (27). HR EI MS: calculated for $C_{20}H_{30}INOSi$ 455.1141, found 455.1149.

N-[3-(Triisopropylsilyl)prop-2-yn-1-yl]-*N*-{2-[(trimethylsilyl)ethynyl]phenyl}-acetamide (**13**)

A sealed tube with a side-arm and PTFE stopcock was charged with [Pd(PPh_3)$_4$] (14 mg, 0.012 mmol, 5 mole %), CuI (4.6 mg, 0.024 mmol, 10 mole %) and flushed with argon. A solution of **12** (110 mg, 0.24 mmol) in diisopropylamine (3 ml) was added. After the addition of (trimethylsilyl)acetylene (70 μl, 0.49 mmol, 2.0 equiv), the tube was tightly closed and the reaction mixture was stirred at 80 °C for 30 min. Volatiles were removed in vacuo and the residue was chromatographed on silica gel (petroleum ether–diethyl ether 100:0 to 80:20) to afford **13** (58 mg, 56%) as an amorphous solid. ^{1}H NMR: 0.22 (9 H, s), 0.92–1.02

(21 H, m), 1.84 (3 H, s), 4.06 (1 H, d, *J* = 17.6), 5.21 (1 H, d, *J* = 17.6), 7.29–7.37 (3 H, m), 7.52 (1 H, ddd, *J* = 7.2, 1.7, 0.9). ^{13}C NMR: 0.31 (q), 11.10 (d), 18.48 (q), 22.17 (q), 37.32 (t), 85.43 (s), 100.49 (s), 100.67 (s), 102.25 (s), 122.88 (s), 128.25 (d), 129.32 (d), 130.04 (d), 133.02 (d), 143.35 (s), 169.65 (s). IR: 3073 w, 3063 w, 3029 w, 2866 s, 2177 w, 2161 m, 1659 vs, 1595 m, 1568 w, 1486 s, 1464 s, 1451, 1389 s, 1361 m, 1252 s, 1111 m, 1074 w, 1041 w, 997 m, 883 s, 863 vs, 846 vs, 679 s, 603 w. EI MS: 425 ($M^{+\bullet}$, 23), 410 (6), 382 (100), 340 (8), 214 (9), 149 (3), 83 (6), 73 (25), 59 (13), 43 (10). HR EI MS: calculated for $C_{25}H_{39}NOSi_2$ 425.2570, found 425.2574.

N-(2-Ethynylphenyl)-*N*-[3-(triisopropylsilyl)prop-2-yn-1-yl]acetamide (**14**)

A solution of sodium (13 mg, 0.57 mmol, 2.3 equiv) in methanol (1 ml) was added to a solution of **13** (109 mg, 0.25 mmol) in THF (3 ml) and the mixture was stirred at room temperature for 20 min. The solvents were then removed in vacuo and the residue was dissolved in dichloromethane and extracted with water (2×). The organic phase was dried over anhydrous Na_2SO_4, filtered and the solvent was evaporated in vacuo to afford **14** (87.8 mg, 97%) as an amorphous solid. ^{1}H NMR: 0.94–1.00 (21 H, m), 1.86 (3 H, s), 2.15 (1 H, s), 4.16 (1 H, dd, *J* = 17.6, 0.3), 5.14 (1 H, d, *J* = 17.6), 7.33–7.42 (3 H, m), 7.57–7.60 (1 H, m). ^{13}C NMR: 11.10 (d), 18.48 (q), 22.26 (q), 37.63 (t), 82.67 (d), 83.18 (s), 85.70 (s), 102.01 (s), 122.03 (s), 128.38 (d), 129.76 (d), 130.06 (d), 133.74 (d), 143.37 (s), 169.79 (s). IR: 3309 m, 3299 m, 3074 vw, 2866 s, 2177 w, 2113 vw, 1657 vs, 1596 w, 1570 w, 1488 m, 1463 m, 1451 m, 1388 s, 1362 m, 1109 w, 1074 w, 1041 w, 997 w, 884 m, 679 m, 629 m, 601 w. EI MS: 353 ($M^{+\bullet}$, 20), 310 (100), 268 (11), 226 (28), 210 (11), 198 (8), 184 (12), 142 (18), 115 (9), 101 (10), 82 (14), 59 (12), 43 (34). HR EI MS: calculated for $C_{22}H_{31}NOSi$ 353.2175, found 353.2181.

N,*N*′-(Ethynediyldibenzene-2,1-diyl)bis{*N*-[3-(triisopropylsilyl)prop-2-yn-1-yl]-acetamide} (**15**)

A Schlenk flask was charged with $[Pd(PPh_3)_4]$ (16 mg, 0.014 mmol, 5 mole %), CuI (5 mg, 0.027 mmol, 10 mole %) and flushed with argon. Then **12** (136 mg, 0.30 mmol, 1.1 equiv) and **14** (96 mg, 0.27 mmol) in diisopropylamine (5 ml) were added and the reaction mixture was stirred at 80 °C for 15 min. The precipitate was filtered off and washed with diisopropylamine. The filtrate was evaporated at reduced pressure and dried in oil pump vacuum. Flash chromatography on silica gel (petroleum ether–ethyl acetate 100:0 to 70:30) afforded **15** (109 mg, 77%) as an amorphous solid. ^{1}H NMR: 0.93–0.99 (42 H, m), 1.87 (6 H, s), 4.11 (2 H, d, *J* = 17.6), 5.23 (2 H, d, *J* = 17.6), 7.35–7.42 (6 H, m), 7.56–7.59 (2 H, m). ^{13}C NMR: 11.11 (d), 18.34 (q), 22.33 (q), 22.36 (q), 37.77 (t), 37.84 (t), 85.79 (s), 85.82 (s), 90.13 (s), 90.17 (s), 102.02 (s), 122.35 (s), 128.57 (d), 128.61 (d), 129.79 (d), 130.07 (d), 133.53 (d), 142.61 (s), 142.64 (s), 169.77 (s), 169.86 (s). IR: 3065 vw, 2866 s, 2177 w, 1660 vs, 1598 w, 1569 w, 1498 m, 1484 w, 1464 s, 1455 m, 1390 s, 1360 m, 1115 w, 1104 w, 1073 w, 1046 w (sh), 997 w, 884 m, 680 m, 601 w. EI MS: 680 ($M^{+\bullet}$, 36), 637 (80), 596 (16), 481 (11), 443 (20), 412 (19), 368 (10), 313 (14), 262 (11), 223 (10), 183 (11), 149 (66), 71 (23), 57 (41), 43 (100), 29 (37). HR EI MS: calculated for $C_{42}H_{60}N_2O_2Si_2$ 680.4193, found 680.4204.

N,*N*′-(Ethynediyldibenzene-2,1-diyl)bis(*N*-prop-2-yn-1-ylacetamide) (**16**)

Bu_4NF (0.964 M solution in THF, 375 µl, 0.36 mmol, 2.4 equiv) was added to a solution of **15** (111 mg, 0.16 mmol) in THF (5 ml) and the mixture was left stirring at room temperature for 15 min. After evaporation of solvent in vacuo, the residue was chromatographed on silica gel (petroleum ether–ethyl acetate 100:0 to 35:65) to afford **16** (28 mg, 48%) as an amorphous solid. ^{1}H NMR: 1.88 (3 H, s), 1.89 (3 H, s), 2.16 (1 H, t, *J* = 2.5), 2.17 (1 H, t, *J* = 2.5), 4.08 (1 H, dd, *J* = 17.4, 2.5), 4.10 (1 H, dd, *J* = 17.4, 2.5), 5.01 (1 H, dd, *J* = 17.4, 2.5), 5.04 (1 H, dd, *J* = 17.4, 2.5), 7.40 (2 H, dd, *J* = 7.6, 1.4), 7.40 (2 H, dt, *J* = 7.5, 7.5, 1.4), 7.45 (2 H, dt, *J* = 7.5, 7.5, 1.6), 7.58–7.62 (2 H, m). ^{13}C NMR: 22.22 (q), 22.23 (q), 37.29 (t), 37.33 (t), 72.31 (d), 72.33 (d), 78.86 (s), 78.88 (s), 90.11 (s), 90.14 (s), 122.32 (s), 122.34 (s), 128.78 (d), 128.79 (d), 129.48 (d), 129.52 (d), 130.11 (d), 133.64 (d), 133.66 (d), 142.89 (s), 142.92 (s), 170.04 (s), 170.06 (s). IR: 3309 m, 3064 w, 2126 vw, 1663 vs, 1599 w, 1569 w, 1498 m, 1483 w, 1454 m, 1390 s, 1363 m, 1292 m, 1115 w, 1020 m, 636 m, 610 w, 530 w. EI MS: 368 ($M^{+\bullet}$, 19), 323 (13), 311 (16), 298 (21), 284 (60), 279 (48), 266 (62), 256 (17), 149 (54), 111 (16), 97 (24), 83 (30), 69 (49), 57 (68), 43 (100). HR EI MS: calculated for $C_{24}H_{20}N_2O_2$ 368.1525, found 368.1512.

(+)-*tert*-Butyl *N*-(4-Methylbenzene-1-sulfonyl) *N*-(1*R*)-1-Methylprop-2-yn-1-yl]-carbamate (**19**)

N,*N*′-Diisopropylcarbodiimide (DIAD, 2.90 ml, 14.84 mmol, 3.2 equiv) was added to a solution of BocNHTs (**18**) (2.322 g, 8.56 mmol, 1.8 equiv), triphenylphosphine (4.510 g, 17.19 mmol, 3.7 equiv) and (-)-(*S*)-**17** (450 µl, 4.70 mmol) in THF (100 ml) at 0 °C. The mixture was allowed to warm to room temperature and left stirring overnight. The solvent was evaporated at reduced pressure and the crude product was flash-chromatographed (petroleum ether–diethyl ether 95:5) to give (+)-(*R*)-**19** (1.18 g, 64%) as an amorphous solid. ^{1}H NMR: 1.36 (9 H, s), 1.75 (3 H, d, *J* = 7.0), 2.38 (1 H, d, *J* = 2.5), 2.44 (3 H, s), 5.48 (1 H, dq, *J* = 7.0, 7.0, 7.0, 2.5), 7.29–7.33 (2 H, m), 7.84–7.88 (2 H, m). $[\alpha]^{22}_D$ +43 (*c* 0.23, dichloromethane). Analytical data were in agreement with the published ones for the racemic product[42].

(+)-4-Methyl-*N*-[(1*R*)-1-methylprop-2-yn-1-yl]benzene-1-sulfonamide (**20**)

TFA (2.1 ml, 27.3 mmol, 15.3 equiv) was added to a solution of (+)-(*R*)-**19** (580 mg, 1.79 mmol) in dichloromethane (30 ml) under argon and left stirring overnight. The reaction mixture was extracted with a $KHCO_3$ solution (3×), water (2×) and dried over anhydrous Na_2SO_4. After filtration and evaporation of the solvent, (+)-(*R*)-**20** (392 mg, 98%) was obtained as a white solid. M.p. 84–86 °C (dichloromethane).^{1}H NMR: 1.42 (3 H, d, *J* = 6.9), 2.09 (1 H, d, *J* = 2.2), 2.43 (3 H, s), 4.18 (1 H, ddq, *J* = 8.8, 6.9, 6.9, 6.9, 2.2), 4.67 (1 H, bd, *J* = 8.8), 7.28–7.33 (2 H, m), 7.76–7.78 (2 H, m). EI MS: 223 ($M^{+\bullet}$, 7), 208 (52), 198 (4), 155 (54), 149 (12), 132 (7), 107 (5), 91 (100), 80 (7), 65 (24), 55 (11), 43 (22). HR EI MS: calculated for $C_{11}H_{13}NO_2S$ 223.0667, found 223.0656. $[\alpha]^{22}_D$ +66 (*c* 0.20, dichloromethane). Analytical data were in agreement with published ones for the racemic product[43].

(+)-*N*,*N*′-[Ethyne-1,2-diylbis(benzene-2,1-diylmethanediyl)]bis{4-methyl-*N*-[(1*R*)-1-methylprop-2-yn-1-yl]benzenesulfonamide} (**22**)

N,*N*′-Diisopropylcarbodiimide (DIAD, 1.2 ml, 6.29 mmol, 5.0 equiv) was added to a solution of triphenylphosphine (1.98 g, 7.55 mmol, 6.0 equiv), tosylamide (+)-(*R*)-**20** (562 mg, 2.52 mmol, 2.0 equiv) and diol **21** (300 mg, 1.26 mmol) in THF (50 ml) at 0 °C. The mixture was allowed to warm to room temperature and left stirring overnight. The solvent was evaporated at reduced pressure and the crude product was chromatographed (petroleum ether–ethyl acetate 98:2 to 75:25) to give (+)-(*R*,*R*)-**22** (528 mg, 70%) as an amorphous solid. ^{1}H NMR: 1.22 (6 H, d, *J* = 7.1), 2.01 (2 H, d, *J* = 2.4), 2.42 (6 H, bs), 4.70 (4 H, s), 4.95 (2 H, dq, *J* = 7.1, 7.1, 7.1, 2.4), 7.21 (2 H, dt, *J* = 7.5, 7.5, 1.4), 7.26–7.30 (4 H, m), 7.36 (2 H, dt, *J* = 7.5, 7.5, 1.3), 7.42 (2 H, dd, *J* = 7.6, 1.4), 7.78–7.79 (6 H, m). ^{13}C NMR: 21.56 (q), 22.34 (q), 46.35 (t), 46.72 (d), 73.56 (d), 81.03 (s), 92.11 (s), 120.99 (s), 126.91 (d), 127.84 (d), 128.47 (d), 128.87 (d), 129.56 (d), 131.82 (d), 135.81 (s), 140.23 (s), 143.65 (s). IR: 3307 m, 3068 w, 3031 m, 2212 vw, 2116 vw, 1599 m, 1571 vw, 1494 m, 1480 w, 1468 w (sh), 1453 m, 1439 w (sh), 1430 w (sh), 1401 w, 1377 m, 1360 s, 1340 vs, 1308 m, 1229 m, 1186 m, 1167 vs, 1154 vs, 1120 m (sh), 1107 s, 1091 s, 1042 w, 1017 m, 952 w, 903 m, 867 w, 814 m, 704 w, 661 vs, 640 m, 619 w, 584 s, 547 m, 533 m, 503 w. FAB MS: 649 $(M + 1)^+$, 630, 493, 270, 256, 218, 154, 137, 91. HR FAB MS: calculated for $C_{38}H_{36}N_2O_4S_2$ 649.2195, found 649.2209. $[\alpha]^{22}_D$ +244 (*c* 0.11, dichloromethane).

(–)-2-Bromo-3-({[(1*S*)-1-methyl-3-(4-methylphenyl)prop-2-yn-1-yl]oxy}-methyl)pyridine (**25**)

A Schlenk flask was charged with NaH (80% suspension in mineral oil, 101 mg, 3.35 mmol, 3.0 equiv) and filled with argon. THF (2 ml) was added and the stirred suspension was cooled to 0 °C. A solution of alcohol (–)-(*S*)-**24** (207 mg, 1.29 mmol, 1.1 equiv) in THF (4 ml) was added dropwise and the mixture was stirred at 0 °C for 1.5 h. Bromide **23** (285 mg, 1.14 mmol) in THF (5 ml) was added at room temperature and the mixture was heated at 50 °C for 2 h. Solvent was removed in vacuo and the residue was chromatographed on silica gel (petroleum ether–diethyl ether 90:10) to provide ether (–)-(*S*)-**25** (304 mg, 81%) as an oil. ^{1}H NMR: 1.61 (3 H, d, *J* = 6.6), 2.35 (3 H, s), 4.56 (1 H, q, *J* = 6.6), 4.62 (1 H, ddt, *J* = 13.7, 1.2, 0.6, 0.6), 4.87 (1 H, dt, *J* = 13.7, 1.1, 1.1), 7.12 (2 H, m), 7.28 (1 H, brdd, *J* = 7.6, 4.7), 7.32 (2 H, m), 7.86 (1 H, ddt, *J* = 7.6, 2.0, 1.0, 1.0), 8.28 (1 H, ddt, *J* = 4.7, 2.0, 0.7, 0.7). ^{13}C NMR: 21.44 (q), 22.20 (q), 66.36 (d), 68.59 (t), 85.99 (s), 87.61 (s), 119.42 (s), 122.81 (d), 129.06 (d), 131.64 (d), 135.44 (s), 137.12 (d), 138.63 (s), 141.89 (s), 148.65 (d). IR: 3078 w, 3055 w, 2992 m, 2937 m, 2926 m, 2868 m, 2227 w, 1608 w, 1581 m, 1564 s, 1510 s, 1446 m, 1415 s, 1408 s, 1376 s, 1328 s, 1259 w, 1189 w, 1117 s, 1106 vs, 1076 m, 1053 vs, 1022 w, 946 w, 819 s, 694 w, 408 w. EI MS: 331 ($M^{+\bullet}$ with ^{81}Br, 1), 329 ($M^{+\bullet}$ with ^{79}Br, 1), 289 (7), 287 (8), 206 (25), 172 (20), 170 (21), 144 (70), 129 (100), 115 (25), 91 (22), 43 (96). HR EI MS: calculated for $C_{17}H_{16}{}^{81}BrNO$ 331.0395, found 331.0408. $[\alpha]^{22}_D$ –109 (*c* 0.24, dichloromethane).

(–)-3-({[(1*S*)-1-Methyl-3-(4-methylphenyl)prop-2-yn-1-yl]oxy}methyl)-2-({2-[4-(triisopropylsilyl)but-3-yn-1-yl]naphthalen-1-yl}ethynyl)pyridine (**27**)

A Schlenk flask was charged with bromide (–)-(*S*)-**25** (1.04 g, 3.16 mmol), diyne **26** (1.14 g, 3.17 mmol, 1.0 equiv), $[Pd(PPh_3)_4]$ (180 mg, 0.156 mmol, 5 mole %) and CuI (55 mg,

0.289 mmol, 9 mole %) and filled with argon. Diisopropylamine (20 ml) and toluene (10 ml) were added and the resulting solution was stirred at room temperature for 2 h. Solvents were removed in vacuo and the crude product was chromatographed on silica gel (petroleum ether–diethyl ether 90:10 to 80:20) to provide triyne (–)-(*S*)-**27** (1.69 g, 88%) as an oil. ^{1}H NMR: 0.87–1.03 (21 H, m), 1.61 (3 H, d, *J* = 6.6), 2.30 (3 H, s), 2.76 (2 H, t, *J* = 7.1), 3.31 (2 H, t, *J* = 7.1), 4.58 (1 H, q, *J* = 6.6), 4.98 (1 H, d, *J* = 13.2), 5.20 (1 H, d, *J* = 13.2), 6.98 (2 H, m), 7.20 (2 H, m), 7.31 (1 H, dd, *J* = 7.8, 4.8), 7.45 (1 H, ddd, *J* = 8.1, 6.8, 1.3), 7.49 (1 H, d, *J* = 8.5), 7.52 (1 H, ddd, *J* = 8.4, 6.8, 1.4), 7.78 (1 H, brd, *J* = 8.5), 7.81 (1 H, ddt, *J* = 8.1, 1.4, 0.7, 0.7), 7.94 (1 H, ddt, *J* = 7.8, 1.7, 0.9, 0.9), 8.52 (1 H, dq, *J* = 8.4, 1.0, 1.0, 1.0), 8.61 (1 H, dd, *J* = 4.8, 1.8). ^{13}C NMR: 11.28 (d), 18.55 (g), 21.15 (t), 21.40 (q), 22.28 (q), 34.47 (t), 66.11 (d), 67.52 (t), 81.53 (s), 85.96 (s), 87.82 (s), 90.25 (s), 95.66 (s), 107.86 (s), 118.33 (s), 119.35 (s), 122.81 (d), 125.87 (d), 126.30 (d), 127.09 (d), 127.57 (d), 127.97 (d), 128.92 (d), 128.98 (d), 131.57 (d), 131.93 (s), 133.77 (s), 135.15 (d), 136.30 (s), 138.40 (s), 141.75 (s), 142.64 (s), 148.92 (d). IR: 3057 w, 2866 vs, 2230 w, 2207 w, 2170 m, 1510 s, 1621 vw, 1595 w, 1582 m, 1569 m, 1464 m, 1437 s, 1430 s, 1390 w, 1367 w, 1328 m, 1184 w, 1114 m, 1094 s, 1071 m, 1062 m, 1026 w, 1022 w, 996 w, 884 m, 868 w, 818 s, 678 m, 663 m, 617 w. EI MS: 609 ($M^{+\bullet}$, <1), 566 (20), 143 (55), 128 (28), 97 (22), 81 (33), 69 (75), 57 (71), 43 (100). HR EI MS: calculated for $C_{42}H_{47}NOSi$ 609.3427, found 609.3408. $[\alpha]^{22}_D$ –122 (*c* 0.21, dichloromethane).

(–)-2-[(2-But-3-yn-1-ylnaphthalen-1-yl)ethynyl]-3-({[(1*S*)-1-methyl-3-(4-methylphenyl)prop-2-yn-1-yl]oxy}methyl)pyridine (**28**)

A Schlenk flask was charged with a solution of triyne (–)-(*S*)-**27** (1.68 g, 2.75 mmol) in THF (20 ml) under argon. A tetrabutylammonium fluoride solution (1.072 M in THF, 30 ml, 3.22 mmol, 1.2 equiv) was added and the reaction mixture was stirred at room temperature for 2 h. Solvent was removed in vacuo and the crude product was chromatographed on silica gel (petroleum ether–diethyl ether–acetone 80:10:10) to provide triyne (–)-(*S*)-**28** (1.08 g, 86%) as an amorphous solid. ^{1}H NMR: 1.62 (3 H, d, *J* = 6.6), 1.96 (1 H, t, *J* = 2.6), 2.30 (3 H, s), 2.67 (2 H, dt, *J* = 7.4, 7.4, 2.6), 3.32 (2 H, t, *J* = 7.4), 4.60 (1 H, q, *J* = 6.6), 4.99 (1 H, dq, *J* = 13.2, 0.6, 0.6, 0.6), 5.20 (1 H, dq, *J* = 13.2, 0.6, 0.6, 0.6), 7.08 (2 H, m), 7.20 (2 H, m), 7.32 (1 H, dd, *J* = 7.9, 4.8), 7.43 (1 H, d, *J* = 8.5), 7.47 (1 H, ddd, *J* = 8.1, 6.8, 1.3), 7.54 (1 H, ddd, *J* = 8.4, 6.8, 1.4), 7.81 (1 H, brd, *J* = 8.5), 7.82 (1 H, ddt, *J* = 8.1, 1.4, 0.6, 0.6), 7.96 (1 H, ddt, *J* = 7.8, 1.7, 0.8, 0.8), 8.53 (1 H, ddt, *J* = 8.4, 1.3, 0.8, 0.8), 8.62 (1 H, ddt, *J* = 4.8, 1.7, 0.6, 0.6). ^{13}C NMR: 19.77 (t), 21.40 (q), 22.29 (q), 34.28 (t), 66.18 (d), 67.51 (t), 69.35 (d), 83.64 (s), 85.96 (s), 87.86 (s), 89.99 (s), 95.70 (s), 118.45 (s), 119.34 (s), 122.90 (d), 126.02 (d), 126.34 (d), 127.17 (d), 127.24 (d), 128.02 (d), 128.92 (d), 129.18 (d), 131.57 (d), 131.93 (s), 133.77 (s), 135.19 (d), 136.41 (s), 138.41 (s), 141.62 (s), 142.18 (s), 148.94 (d). IR: 3309 s, 3057 w, 2225 w, 2207 w, 2119 w, 1621 vw, 1592 w, 1582 m, 1569 m, 1510 s, 1453 m, 1437 vs, 1431 s, 1392 w, 1375 w, 1329 s, 1259 w, 1185 w, 1114 s, 1094 vs, 1027 w, 949 w, 868 w, 819 vs, 640 m, 437 w. EI MS: 453 ($M^{+\bullet}$, 7), 452 (14), 438 (16), 410 (100), 394 (10), 310 (12), 280 (17), 254 (27), 143 (33), 128 (63), 71 (25), 57 (43), 43 (31). HR EI MS: calculated for $C_{33}H_{27}NO$ 453.2093, found 453.2073. $[\alpha]^{22}_D$ –165 (*c* 0.32, dichloromethane).

(–)-3-({[(1*S*)-1-Methyl-3-(4-methylphenyl)prop-2-yn-1-yl]oxy}methyl)-2-({2-[4-(4-methylphenyl)but-3-yn-1-yl]naphthalen-1-yl}ethynyl)pyridine (**29**)

A Schlenk flask was charged with triyne (–)-(*S*)-**28** (57 mg, 0.126 mmol), 4-iodotoluene (40 mg, 0.183 mmol, 1.5 equiv), $[Pd(PPh_3)_4]$ (18 mg, 0.015 mmol, 12 mole %) and CuI (6 mg, 0.040 mmol, 32 mole %) and filled with argon. Diisopropylamine (2 ml) was added and the resulting solution was stirred at 80 °C for 2 h. Solvent was removed in vacuo and the crude product was chromatographed on silica gel (petroleum ether–diethyl ether–acetone 80:10:10) to provide triyne (–)-(*S*)-**29** (65 mg, 95%) as an amorphous solid. ^{1}H NMR: 1.57 (3 H, d, *J* = 6.6), 2.28 (3 H, s), 2.30 (3 H, s), 2.87 (2 H, t, *J* = 7.3), 3.40 (2 H, t, *J* = 7.3), 4.58 (1 H, q, *J* = 6.6), 5.00 (1 H, dq, *J* = 13.2, 0.5, 0.5, 0.5), 5.21 (1 H, brd, *J* = 13.2), 6.98 (2 H, m), 7.04 (2 H, m), 7.20 (2 H, m), 7.23 (2 H, m), 7.31 (1 H, dd, *J* = 7.8, 4.8), 7.47 (1 H, ddd, *J* = 8.1, 6.8, 1.3), 7.49 (1 H, d, *J* = 8.4), 7.54 (1 H, ddd, *J* = 8.4, 6.8, 1.4), 7.81 (1 H, brd, *J* = 8.4), 7.82 (1 H, ddt, *J* = 8.1, 1.4, 0.7, 0.7), 7.95 (1 H, ddt, *J* = 7.8, 1.7, 0.8, 0.8), 8.55 (1 H, ddt, *J* = 8.4, 1.3, 0.8, 0.8), 8.61 (1 H, brdd, *J* = 4.8, 1.7). ^{13}C NMR: 20.92 (t), 21.36 (q), 21.40 (q), 22.24 (q), 34.69 (t), 66.19 (d), 67.52 (t), 81.75 (s), 85.93 (s), 87.90 (s), 88.59 (s), 90.19 (s), 95.61 (s), 118.44 (s), 119.39 (s), 120.80 (s), 122.85 (d), 125.97 (d), 126.36 (d), 127.21 (d), 127.39 (d), 128.01 (d), 128.88 (d), 128.92 (d), 129.11 (d), 131.41 (d), 131.58 (d), 131.93 (s), 133.80 (s), 135.09 (d), 136.46 (s), 137.50 (s), 138.38 (s), 141.63 (s), 142.59 (s), 148.89 (d). IR: 3055 w, 2228 w, 2207 w, 1621 vw, 1592 w, 1582 w, 1569 w, 1510 vs, 1437 s, 1431 m, 1392 w, 1378 w, 1329 m, 1259 w, 1182 w, 1114 m, 1094 m, 1022 w, 948 vw, 867 w, 819 vs. EI MS: 543 ($M^{+\bullet}$, 7), 542 (8), 528 (7), 500 (20), 129 (27), 97 (28), 69 (47), 57 (80), 43 (100). HR EI MS: calculated for $C_{40}H_{33}NO$ 543.2562, found 543.2565. $[\alpha]^{22}_D$ –145 (*c* 0.19, dichloromethane).

3,4-Dibutylbenzo[1,2-*h*:4,3-*h*′]diquinoline (**30**)

A Schlenk flask was charged with triphenylphosphine (5 mg, 0.019 mmol, 42 mole %) and flushed with argon. THF (1 ml) and $[Ni(cod)_2]$ (3 mg, 0.011 mmol, 24 mole %) in THF (200 µl) were added and the mixture was stirred at room temperature for 5 min. *cis*,*cis*-Dienetriyne **7** (18 mg, 0.046 mmol) in THF (2.5 ml) was added and the mixture was stirred at room temperature for 2 h (the addition of another portion of the catalyst had no effect on the reaction conversion and yield according to the TLC analysis). The solvent was evaporated in vacuo and the residue was chromatographed on silica gel (petroleum ether–acetone 80:20) to give diaza[5]helicene **30** (1.7 mg, 9%) as an amorphous solid. ^{1}H NMR: 1.06 (6 H, t, *J* = 7.3), 1.63 (4 H, m), 1.74 (4 H, m), 3.27 (4 H, t, *J* = 8.3), 7.40 (2 H, dd, *J* = 8.0, 4.2), 7.92 (2 H, d, *J* = 9.0), 8.19 (2 H, d, *J* = 9.0), 8.22 (2 H, dd, *J* = 8.0, 1.8), 8.55 (2 H, dd, *J* = 4.2, 1.8). ^{13}C NMR: 14.02 (q), 23.43 (t), 29.18 (t), 33.44 (t), 121.24 (d), 122.56 (d), 125.41 (s), 126.57 (d), 127.21 (s), 133.01 (s), 134.68 (d), 135.90 (s), 146.23 (d), 147.52 (s). EI MS: 393 ($[M + H]^+$, 44), 392 ($M^{+\bullet}$, 100), 349 (51), 319 (28), 307 (87), 305 (33). HR EI MS: calculated for $C_{28}H_{28}N_2$ 392.2252, found 392.2244.

1,6-Diacetyl-1,2,5,6-tetrahydrodibenzo[*a*,*k*][3,8]phenanthroline (**32**)

A Schlenk flask was charged with triyne **16** (20 mg, 0.054 mmol) and triphenylphosphine (28 mg, 0.108 mmol, 2.0 equiv) and flushed with argon. $[CpCo(CO)_2]$ (7 µl, 0.054 mmol, 1.0 equiv) in decane (4 ml) was added. The mixture was heated with a halogen lamp to 140 °C for 20 min. The reaction mixture was allowed to cool down and then was chro-

matographed on silica gel (petroleum ether–ethyl acetate 100:0 to 25:75) to afford **32** (8.0 mg, 40%) as an amorphous solid. ^{1}H NMR: 2.35 (6 H, s), 3.88 (2 H, bs), 5.80 (2 H, bs), 7.22 (2 H, bs), 7.28–7.33 (2 H, m), 7.40–7.50 (2 H, m), 7.53–7.57 (2 H, m), 7.65–7.70 (2 H, m). ^{13}C NMR: 29.69 (q), 45.52 (t), 125.09 (d), 125.30 (d), 128.14 (d), 128.44 (d), 128.54 (d), 130.18 (d), 131.94 (d), 132.06 (d), 132.14 (d). Both ^{1}H and ^{13}C NMR spectra contained very broad signals. In the case of ^{13}C NMR, only CH carbons were assigned due to the character of the spectrum and/or low concentration of the sample. IR: 3063 w, 1654 vs, 1602 m, 1585 w, 1572 w, 1491 s, 1458 m, 1387 vs, 1365 m (sh), 1024 m, 816 w, 695 m, 542 s, 497 w, 418 w. EI MS: 369 ($M^{+\bullet}$, 10), 325 (11), 311 (5), 279 (100), 269 (7), 249 (5), 227 (4), 218 (4), 201 (19), 183 (11), 165 (8), 149 (12), 115 (14), 91 (20), 77 (24), 57 (28). HR EI MS: calculated for $C_{24}H_{20}N_2O_2$ 369.1603, found 369.1591.

(+)-(*M*,3*R*,6*R*)-3,6-Dimethyl-2,7-bis(4-methylbenzene-1-sulfonyl)-1,2,3,6,7,8-hexahydrodibenzo[*e*,*e*′]benzo[1,2-*c*:4,3-*c*′]bisazepine (**33**)

Triyne (+)-(*R*,*R*)-**22** (45 mg, 0.069 mmol) and triphenylphosphine (36 mg, 0.138 mmol, 2.0 equiv) in a Schlenk flask were flushed with argon. [$CpCo(CO)_2$] (9 μl, 0.069 mmol, 1.0 equiv) in decane (4 ml) was added and the mixture was irradiated with a halogen lamp to 140 °C for 2 h. Flash chromatography on silica gel (petroleum ether–ethyl acetate 100:0 to 80:20) afforded (+)-(*M*,*R*,*R*)-**33** (15 mg, 30%) as an amorphous solid (no other diastereomer detected by ^{1}H NMR). ^{1}H NMR: 0.71 (6 H, d, *J* = 7.1), 2.40 (6 H, s), 3.78 (2 H, d, *J* = 11.5), 4.71 (2 H, d, *J* = 11.5), 5.01 (2 H, dq, *J* = 7.1, 7.1, 7.1, 0.6), 6.37 (2 H, dd, *J* = 7.8, 1.3), 6.76 (2 H, s), 6.92 (2 H, dt, *J* = 7.6, 7.6, 1.4), 7.20 (2 H, dt, *J* = 7.5, 7.5, 1.3), 7.25–7.28 (4 H, m), 7.43 (2 H, dd, *J* = 7.6, 1.4), 7.71–7.75 (4 H, m). ^{13}C NMR: 21.51 (q), 22.90 (q), 48.83 (t), 58.87 (d), 127.21 (d), 127.58 (d), 128.22 (d), 129.56 (d), 129.64 (d), 131.59 (d), 133.75 (s), 136.67 (s), 136.94 (s), 138.13 (s), 138.79 (s), 143.25 (s). IR: 2977 w, 2930 m, 2858 w, 1599 w, 1494 w, 1460 w, 1442 w (sh), 1426 w, 1382 w, 1337 s, 1305 m, 1290 w, 1185 w, 1161 vs, 1120 m (sh), 1113 m, 1091 s, 1024 m, 1014 m, 832 w, 814 m, 706 w, 665 s, 583 m, 561 m, 549 s, 509 w. EI MS: 648 ($M^{+\bullet}$, 11), 633 (100), 551 (3), 538 (3), 524 (3), 493 (7), 479 (23), 463 (8), 380 (7), 368 (21), 236 (33), 111 (30), 97 (33), 91 (35), 69 (55), 57 (58), 43 (37). HR EI MS: calculated for $C_{38}H_{36}N_2O_4S_2$ 648.2116, found 648.2100. $[\alpha]^{22}_D$ +225 (*c* 0.20, dichloromethane).

(+)-(*P*,7*S*)-7-Methyl-8-(4-methylphenyl)-5,7,10,11-tetrahydrobenzo[5′,6′]phenanthro-[4′,3′:5,6]oxepino[4,3-*b*]pyridine (**34**)

A Schlenk flask was charged with triyne (–)-(*S*)-**28** (31 mg, 0.069 mmol) and flushed with argon. The substrate was dissolved in decane (2 ml) at 90 °C. Then a solution of triphenylphosphine (7 mg, 0.027 mmol, 41 mole %) in hot decane (1 ml) and [$CpCo(CO)_2$] (2 μl, 0.015 mmol, 22 mole %) in decane (1 ml) were added and the mixture was stirred at 140 °C for 1 h under irradiation with a halogen lamp. The solvent was evaporated in vacuo and the residue was chromatographed on silica gel (petroleum ether–diethyl ether–acetone 90:10:0 to 80:10:10) to obtain the product (17 mg, 54%) as an amorphous solid, which was an 8:92 mixture of inseparable (*M*,*S*)-**34** and (+)-(*P*,*S*)-**34** (according to ^{1}H NMR). ^{1}H NMR of (+)-(*P*,*S*)-**34** (500 MHz, $CDCl_3$): 0.55 (3 H, d, *J* = 7.1), 2.44 (3 H, s), 2.78 (1 H, dddd, *J* = 15.5, 14.5, 4.3, 1.3), 2.88–2.95 (2 H, m), 3.17 (1 H, dt, *J* = 15.0, 15.0, 4.6), 4.77 (1 H, d, *J* = 11.7), 5.09 (1 H, d, *J* = 11.7), 5.35 (1 H, q, *J* = 7.1), 6.71 (1 H, ddd, *J* = 8.4, 6.7, 1.3), 6.76 (1 H, dd, *J* = 7.5, 4.8), 7.04 (1 H, ddd, *J* = 8.0, 6.7, 1.2), 7.21 (1 H, dq, *J* = 8.4, 1.0, 1.0, 1.0), 7.29

(2 H, m), 7.39 (2 H, m), 7.45 (1 H, d, *J* = 7.9), 7.46 (1 H, d, *J* = 1.1), 7.55 (1 H, dd, *J* = 7.5, 1.7), 7.59 (1 H, ddt, *J* = 8.0, 1.3, 0.7, 0.7), 7.66 (1 H, brd, *J* = 7.9), 7.74 (1 H, dd, *J* = 4.8, 1.7). ^{13}C NMR of (+)-(*P*,*S*)-**34**: 21.21 (q), 23.94 (q), 30.59 (t), 30.68 (t), 66.68 (t), 73.04 (d), 121.84 (d), 123.58 (d), 123.97 (d), 124.39 (d), 126.32 (d), 127.32 (d), 127.39 (d), 129.10 (d), 130.14 (d), 131.47 (s), 132.21 (s), 132.95 (s), 133.36 (s), 135.53 (s), 136.05 (d), 136.79 (s), 136.88 (s), 138.42 (s), 138.67 (s), 141.33 (s), 141.72 (s), 148.28 (d), 159.71 (s). IR: 3055 m, 3030 w, 3008 vs, 1621 vw, 1588 m, 1573 m, 1514 s, 1460 m, 1450 m, 1433 s, 1413 w, 1392 w, 1373 s, 1343 w, 1329 w, 1085 s, 1074 s. EI MS: 453 ($M^{+\bullet}$, 1), 84 (67), 59 (24), 49 (100). HR EI MS: calculated for $C_{33}H_{27}NO$ 453.2093, found 453.2074. $[\alpha]^{22}_{D}$ +237 (of an 8:92 mixture of (*M*,*S*)-**34** and (+)-(*P*,*S*)-**34**, *c* 0.27, dichloromethane). X-ray analysis: an 8:92 mixture of (*M*,*S*)-**34** and (+)-(*P*,*S*)-**34** was dissolved in dichloromethane–diethyl ether under reflux, allowed to cool to room temperature and the flask was placed into a refrigerator (4 °C) over a period of a few days. Single crystals containing an equimolar mixture of diastereomeric (*M*,*S*)-**34** and (*P*,*S*)-**34** were separated; $C_{33}H_{27}NO$, M_r = 453.21; space group *P*1 (No. 1), *a* = 9.5430(3) Å, *b* = 11.0450 (2) Å, *c* = 13.3350 (3) Å; *Z* = 2, D_{calc} = 1.280 Mg m^{-3}; dimensions of colourless prism crystal 0.4 × 0.35 × 0.2 mm^3. X-ray data were measured on CCD detector with MoKα radiation, *T* = 150(2) K; θ_{max} = 27.43°; 10370 diffractions collected, 10370 independent, 8938 observed (R_σ = 0.0392); an absorption neglected (μ = 0.08 mm^{-1}). Refinement method: full matrix least squares based on F^2, 627 parameters, goodness of fit 1.159, final *R* indices [$I > 2\sigma(I)$] *R*1 = 0.0784, *wR*2 (all data) = 0.2570, maximal/minimal residual electron density 0.449/–0.330 e Å^{-3}. CCDC 702608 (for (*M*,*S*)-**34** and (*P*,*S*)-**34**) contains the supplementary crystallographic data for this paper. These data can be obtained free of charge via www.ccdc.cam.ac.uk/conts/retrieving.html (or from the Cambridge Crystallographic Data Centre, 12, Union Road, Cambridge, CB2 1EZ, UK; fax: +44 1223 336033; or deposit@ccdc.cam.ac.uk).

(+)-(*P*,7*S*)-7-Methyl-8,9-bis(4-methylphenyl)-5,7,10,11-tetrahydrobenzo[5′,6′]phenanthro-[4′,3′:5,6]oxepino[4,3-*b*]pyridine (**35**)

A Schlenk flask was charged with triyne (–)-(*S*)-**29** (16 mg, 0.029 mmol), triphenylphosphine (4.4 mg, 0.017 mmol, 59 mole %) and flushed with argon. The substrate was dissolved in dioxane (1 ml) and a solution of [$CpCo(CO)_2$] (3 μl, 0.022 mmol, 76 mole %) in dioxane (100 μl) was added. The mixture was stirred at 120 °C for 42 h. The solvent was evaporated in vacuo and the residue was chromatographed on silica gel (petroleum ether–diethyl ether–acetone 80:10:10) to obtain (+)-(*P*,*S*)-**35** (6.1 mg, 38%) as an amorphous solid (no other diastereomer detected by ^{1}H NMR). ^{1}H NMR: 0.65 (3 H, d, *J* = 7.1), 2.27 (3 H, s), 2.28 (3 H, s), 2.32 (1 H, dt, *J* = 15.4, 15.4, 4.4), 2.68–2.75 (2 H, m), 3.0 (1 H, dt, *J* = 15.5, 15.5, 4.5), 4.72 (1 H, d, *J* = 11.8), 5.11 (1 H, d, *J* = 11.8), 5.11 (1 H, q, *J* = 7.1), 6.74 (1 H, dd, *J* = 7.5, 4.9), 6.76 (1 H, ddd, *J* = 8.4, 6.8, 1.3), 6.89–7.01 (8 H, m), 7.04 (1 H, ddd, *J* = 8.1, 6.8, 1.2), 7.37 (1 H, dq, *J* = 8.4, 0.9, 0.9, 0.9), 7.41 (1 H, d, *J* = 8.1), 7.50 (1 H, dd, *J* = 7.5, 1.7), 7.58 (1 H, ddt, *J* = 8.1, 1.4, 0.7, 0.7), 7.65 (1 H, brd, *J* = 8.1), 7.77 (1 H, dd, *J* = 4.9, 1.7). ^{13}C NMR: 21.15 (q), 21.16 (q), 23.98 (q), 28.75 (t), 30.57 (t), 66.55 (t), 73.21 (d), 121.66 (d), 123.56 (d), 124.16 (d), 124.34 (d), 126.06 (d), 127.25 (d), 127.42 (d), 127.83 (d), 128.11 (d), 128.39 (d), 128.62 (d), 129.74 (d), 129.81 (d), 130.12 (d), 130.17 (d), 130.44 (s), 132.04 (s), 132.20 (s), 133.00 (s), 133.66 (s), 135.58 (s), 135.59 (s), 135.72 (s), 135.81 (d), 135.96 (s), 137.07 (s), 137.72 (s), 139.00 (s), 140.52 (s), 140.84 (s), 141.43 (s), 148.24 (d), 159.95 (s). IR: 2964 vs, 2927 vs, 2858 s, 1621 w, 1589 s, 1577 m, 1515 s, 1460 m, 1446 s, 1419 m, 1379 m, 1370 s,

1342 m, 1326 m, 1288 m, 1247 m, 1183 m, 1147 m, 1135 s, 1112 m, 1102 s, 1084 s, 1077 s, 1057 m, 1036 w, 1023 s, 973 m, 863 m, 850 m, 828 m, 812 s, 710 w, 664 m, 635 m, 537 m, 517 m. EI MS: 543 ($M^{+\bullet}$, 100), 528 (13), 500 (20), 400 (5), 206 (7), 91 (12), 69 (17), 57 (31), 43 (36). HR EI MS: calculated for $C_{40}H_{33}NO$ 543.2562, found 543.2552. $[\alpha]^{22}_{D}$ +105 (*c* 0.12, dichloromethane).

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