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Preparation and Reactions of Allylic Zinc Reagents

and

Transition Metal-Catalyzed Cross-Coupling Reactions

von

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aus

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Erklärung

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Ehrenwörtliche Versicherung

Diese Dissertation wurde selbständig, und ohne unerlaubte Hilfe erarbeitet.

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3. Ren, H.; Dunet, G.; Mayer, P.; Knochel, P. "Highly Diastereoselective synthesis of Homoallylic Alcohols Bearing Adjacent Quaternary Centers Using Substituted Allylic Zinc Reagents" *J. Am. Chem. Soc.* **2007**, *129*, 5376-5377.

4. Dunet, G.; Mayer, P.; Knochel,P. "Highly Diastereoselective Addition of Cinnamylzinc Reagents to α-Chiral Carbonyl Derivatives" *Org. Lett.* In press

Après la pluie, le beau temps...

Table of Contents

Abbreviations

[α]	specific rotaion [expressed without units; the actual units, deg mL/(g dm), are understood	HRMS	high resolution mass spectroscopy
Ac	acetyl	IR	infra-red
Acac	acetylacetone	*J*	coupling constant (NMR)
Ar	aryl	M	molarity
Bn	benzyl	*m*	meta
br	broad	m	multiplet
Bu	butyl	Me	methyl
n-Bu	*n*-butyl	min	minute
calcd.	calculated	mol.	mole
δ	chemical shift in ppm	mp.	melting point
d	doublet	MS	mass spectroscopy
DMAP	4-dimethylaminopyridine	Ms	mesyl ($-SO_2CH_3$)
DME	1,2-dimethoxyehtane	Nf	nonaflate ($-SO_2C_4F_9$)
DMSO	dimethyl sulfoxide	NMR	nuclear magnetic resonance
dppe	$Ph_2P(CH_2)_2PPh_2$	*o*	ortho
dr	diastereomeric ratio	Oct	octyl
ee	enantiomeric excess	*p*	para
equiv.	equivalent	Ph	phenyl
EI	electron-impact	Piv	pivaloyl
Et	ethyl	*i*-Pr	iso-propyl
FAB	fast-atom bombardment	q	quartet
FG	functional group	rt	room temperature
GC	gas chromatography	s	singlet
h	hour	t	triplet
Hex	hexyl	TBAF	Bu_4NF
c-Hex	cyclohexyl	Tf	triflate ($-SO_2CF_3$)
		Ts	4-toluenesulfonyl
		TP	typical procedure

Theoretical Part

1.   Introduction

1.1.   Overview

"Many new synthetic processes have been discovered as a result of a perceived need in connection with specific problems involving novel or complicated structures and a deliberate search for suitable methodology". Those words of *E. J. Corey* point out the issues organic chemists have been facing for the past decades: respond to the need of an ever-growing agrochemical and pharmaceutical industry for new, efficient, and environmentally friendly methodologies to perform chemical transformations. Among these transformations, the creation of a carbon-carbon bond is certainly of the greatest importance, as it constitutes a unique tool for the construction of complex molecules.

The synthesis of diethylzinc by *Frankland* in 1849,[1] and the remarkable work of *Grignard* on organomagnesium reagents[2] have paved the way for the development of modern organometallic chemistry. Nowadays, organometallic species are among the most powerful tools offered to organic chemists as, depending on the very nature of the metal, reactivity and selectivity can be tuned. For instance, organolithium reagents, though highly reactive, are hardly compatible with sensitive functional groups and present a poor selectivity, whereas the use of less reactive species, such as organozinc, -tin, or –boron reagents, increases the tolerance towards functionalities, but often requires transition metal catalysts to perform the reaction efficiently.

1.1.1.   Allylic Zinc reagents

Allylmetals

Allylic organometallic species have been thoroughly studied since the 1960s. At first, efforts were put on the structural determination of allylmetals, e.g. the stereochemistry of the

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[1] (a) Frankland, E. *Liebigs Ann. Chem.* **1848-9**, *71*, 171. (b) Frankland, E. *J. Chem. Soc.* **1848-9**, *2*, 263.
[2] (a) Grignard, V. *Compt. Rend. Acad. Sci. Paris* **1900**, *130*, 1322. (b) Grignard, V. *Ann. Chim.* **1901**, *24*, 433.

double bond or 1,3-transposition of metals on the allylic system.[3] But a few years later, the discoveries of *Gaudemar*,[4] *Heathcock*,[5] *Hoffmann*,[6] and *Yamamoto*[7] showed that the stereocontrol of the C-C bond formation in the reaction of allylmetals with aldehydes or ketones could be achieved. For instance, *Heathcock* noticed that the *Hiyama* (*E*)-crotylchromium reagent[8] undergoes highly *anti*-selective addition to aldehydes. Later, *Hoffmann* found that (*Z*)-crotylboronates were leading to *syn*-homoallylic alcohols in a stereoselective manner, and *Yoshinori Yamamoto* discovered that crotyltins, regardless of the geometry of the double bond, were producing *syn*-homoallylic alcohols under Lewis acid catalysis (Scheme 1).[5,6]

Me⁀⁀⁀Sn(*n*-Bu)₃

PhCHO

$BF_3 \cdot OEt_2$ (2 equiv.)
CH_2Cl_2
- 78 °C to 0 °C

Ph⁀(OH)⁀⁀(Me)

90 %; dr = 99: 1
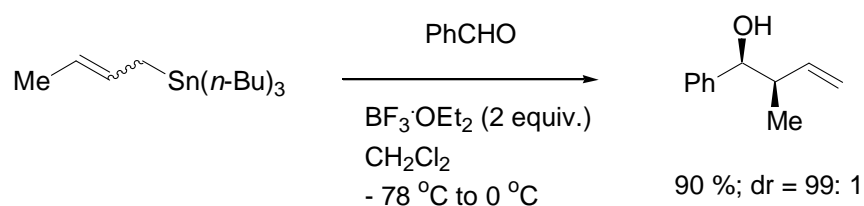
Scheme 1. Stereoselective reaction of crotyltin reagents with aldehydes.

These discoveries paved the way for a dramatic development of the allylmetals chemistry, particularly in the field of stereoregulated synthesis of nonrigid complex molecules, such as macrolides, or polyether antibiotics.[9] Indeed, the reaction of allylic organometallics is synthetically analogous to the aldol addition of metal enolates, since the resulting homoallylic alcohols can be easily converted to aldol products (Scheme 2).[10]

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[3] For reviews, see: (a) Courtois, C.; Miginiac, L. *J. Organomet. Chem.* **1974**, *69*, 1. (b) Benkeser, R. A. *Synthesis* **1971**, 347. (c) Schlosser, M. *Angew. Chem. Int. Ed. Engl.* **1974**, *13*, 701. (d) Mikhailov, B. M. *Organomet. Chem. Rev., Sect. A* **1972**, *8*, 1. (e) Chan, T. H.; Fleming, I. *Synthesis* **1979**, 61. (f) Hill, E. A. *J. Organomet. Chem.* **1975**, *91*, 123. (g) Biellmann, J. F.; Ducep, J. B. *Org. React. (N.Y.)* **1982**, *27*, 1. (h) Miginiac-Groizeleau, L.; Miginiac, P; Prevost, C. *Compt. Rend.* **1965**, *5*, 1442. (i) Andrac, M.; Prevost, C.; *Bull. Soc. Chim. Fr.* **1964**, 2284.
[4] Gaudemar first studied the stereochemical outcome of the addition of propargyl- and allenylboronates to carbonyl derivatives: (a) Favre, E.; Gaudemar, M. *J. Organomet. Chem.* **1974**, *76*, 297. (b) Favre, E.; Gaudemar, M. *J. Organomet. Chem.* **1974**, *76*, 305. (c) Favre, E.; Gaudemar, M. *J. Organomet. Chem.* **1975**, *92*, 17.
[5] Buse, C. T.; Heathcock, C. H. *Tetrahedron Lett.* **1978**, 1685.
[6] Hoffmann, R. W.; Zeiss, H.-J. *Angew. Chem. Int. Ed. Engl.* **1979**, *18*, 306.
[7] Yamamoto, Y.; Yatagai, H.; Naruta, Y.; Maruyama, K. *J. Am. Chem. Soc.* **1980**, *102*, 7107.
[8] Okude, Y.; Hirano, S.; Hiyama, T.; Nozaki, H. *J. Am. Chem. Soc.* **1977**, *99*, 3179.
[9] For recent examples, see: (a) Langkopf, E.; Schinzer, D. *Chem. Rev.* **1995**, *95*, 1375. (b) Weinreb, S. M. *J. Heterocycl. Chem.* **1996**, *33*, 1429. (c) Marshall, J. A. *Chem. Rev.* **1996**, *96*, 31. (d) Marshall, J. A.; Luke, G. P. *J. Org. Chem.* **1991**, *56*, 483.
[10] For reviews, see: (a) Yamamoto, Y.; Maruyama, K. *Hetereocycles* **1982**, *18*, 357. (b) Hoffmann, R. W. *Angew. Chem. Int. Ed. Engl.* **1982**, *21*,555. (c) Yamamoto, Y. *Acc. Chem. Res.* **1987**, *20*, 243. (d) Yamamoto, Y. *Aldrichim. Acta.* **1987**, *20*, 45.

Furthermore, allylmetal additions present other advantages compared to the standard aldol condensation, since the double bond present in the homoallylic alcohols can be readily transformed into an aldehyde *via* ozonolysis,[11] be homologated to δ-lactone *via* hydroformylation,[12] or be selectively epoxidized to introduce another chiral center.[13] Therefore, the reaction of allylic organometallic species with various electrophiles, such as aldehydes, ketones, imines, Michael acceptors, alkynes and alkenes (ene substrates), has become one of the most useful procedure for controlling the stereochemistry in acyclic systems.
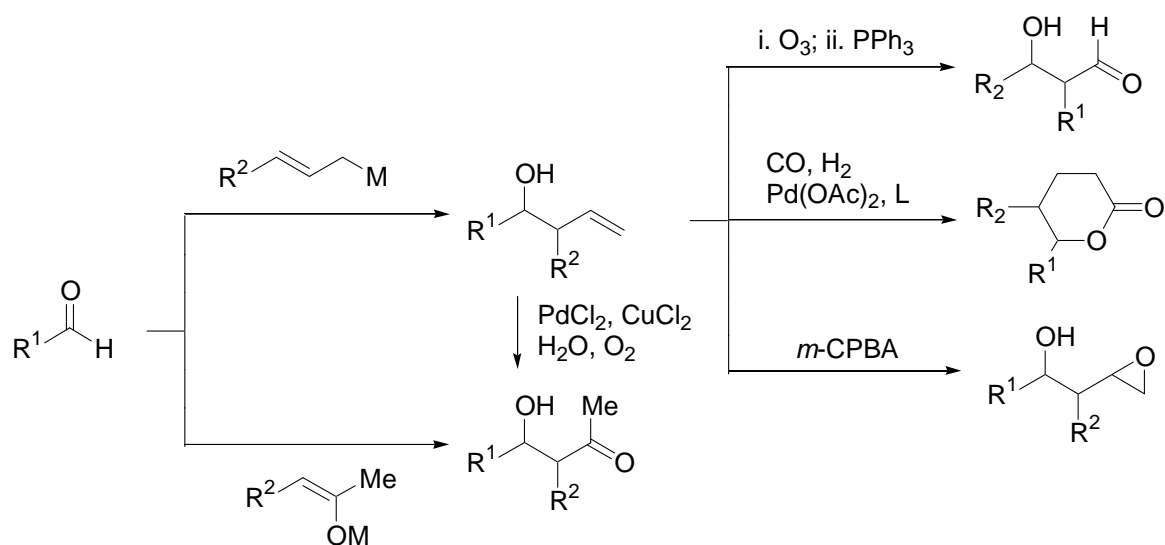
Scheme 2. Comparison between the addition of allylmetals and an aldol reaction.

Various allylmetals have found applications in organic synthesis. Among them, allylic magnesium, -boron, -silicon, -tin and -zinc reagents have proven to be the most commonly used. Allylic Grignard reagents are known to react predominantly at the γ-position with aromatic and aliphatic aldehydes, leading to the corresponding secondary homoallylic

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[11] For a recent review on ozonolysis and its applications in synthesis, see: Van Ornum, S. G.; Champeau, R. M.; Pariza, R. *Chem. Rev.* **2006**, *106*, 2990.

[12] See: (a) Falbe, J. *Carbon monoxide in Organic Synthesis*; SpringerVerlag: New York, 1970; *New Syntheses with Carbon Monoxide*; Springer Verlag: New York, 1980. (b) Agbossou, F.; Carpentier, J-F.; Mortreux, A. *Chem. Rev.* **1995**, *95*, 2485. (c) El Ali, B.; Okuro, K.; Vasapollo, G.; Alper, H. *J. Am. Chem. Soc.* **1996**, *118*, 4264. (d) Granito, C.; Troisi, L.; Ronzini, L. *Heterocycles* **2004**, *63*, 1027.

[13] For recent reviews, see: (a) Xia, Q.-H.; Ge, H.-Q.; Ye, C.-P.; Liu, Z.-M.; Su, K.-X *Chem. Rev.* **2007**, *107*, 1603. (b) McGarrigle, E. M.; Gilheany, D. G. *Chem. Rev.* **2005**, *105*, 1563. (c) Lane, B. S.; Burgess, K. *Chem. Rev.* **2003**, *103*, 2457.

alcohols.[3] They were also found to react with aldimines, affording homoallylamines containing one stereocenter in high yields (Scheme 3).[14]

Scheme 3. Addition of allylic magnesium reagents to imines.

This reaction could be extended to imines containing one stereocenter at the α-position. In this case, the nature of the substituent, e.g. its bulkiness or its chelating hability, played an important role on reaction diastereofacial selectivity. Thus, when imine **1**, bearing a phenyl group in α-position, was treated with allylmagnesium chloride, the Cram product was obtained preferentially.[15] On the contrary, when the substituent was an alkoxy, as in the case of imine **2**, the chelation product was formed predominantly[16] (Scheme 4).

Scheme 4. Addition of allylmagnesium chloride to imines bearing a stereocenter at the α-position.

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[14] (a) For a review, see: Kleinmann, E. F.; Volkmann, R. A. In *Comprehensive Org. Synth.*, Heathcock, C. H., Ed.; Pergamon: Oxford, 1990, Vol. 2, p 975. (b) Hart, D. J.; Kanai, K.; Thomas, D. G.; Yang, T-K. *J. Org. Chem.* **1983**, *48*, 289.

[15] (a) Yamamoto, Y.; Nishii, S.; Maruyama, K.; Komatsu, T.; Ito, W. *J. Am. Chem. Soc.* **1986**, *108*, 7778. (b) Yamamoto, Y.; Komatsu, T.; Maruyama, K. *J. Am. Chem. Soc.* **1984**, *106*, 5031.

[16] Yamamoto, Y.; Ito, W. *J. Chem. Soc., Chem. Commun.* **1985**, 814.

Allylic magnesium reagents were also successfully used in "ene" reactions, providing a new tool for the construction of cyclic molecules. A good example is the *Oppolzer´s* synthesis of $(\pm)$-$\Delta^{9(12)}$-capnellene,[17,18] where two successive intramolecular type-I-"magnesium-ene" reactions were used to build stereoselectively the bicyclic core of the molecule (Scheme 5).
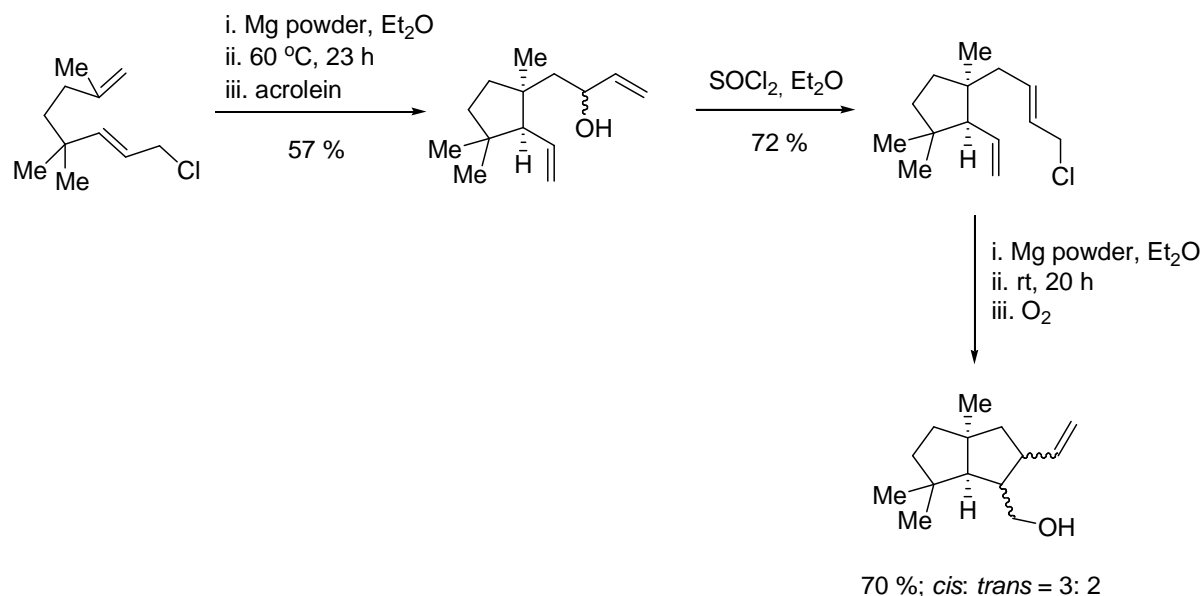

Scheme 5. $(\pm)$-$\Delta^{9(12)}$-capnellene synthesis by Oppolzer *via* a "magnesium-ene" reaction.

Allylic boron reagents have proven to be highly efficient tools in forming new C-C bond since it was found that triallylboron reacts with aldehydes to afford the corresponding homoallylic alcohols upon hydrolysis.[19] Allylboranes or the more configurationally stable allylboronates react with various aldehydes to afford the corresponding homoallylic alcohols in high yields and with good diastereoselectivity. The stereochemistry of the resulting products can be rationalized by considering a six-membered cyclic transition state such as **A** or **B** (Scheme 6).

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[17] Oppolzer, W.; Bättig, K. *Tetrahedron Lett.* **1982**, 4669.

[18] Oppolzer also applied this intramolecular "magnesium-ene" reaction to the synthesis of other natural products, see: (a) Oppolzer, W.; Strauss, H. F.; Simmons, D. P. *Tetrahedron Lett.* **1982**, 4673. (b) Oppolzer, W.; Pitteloud, R. *J. Am. Chem. Soc.* **1982**, *104*, 6478. (c) Oppolzer, W.; Begley, T.; Ashcroft, A. *Tetrahedron Lett.* **1984**, 825. (d) Oppolzer, W.; Jacobsen, E. J. *Tetrahedron Lett.* **1986**, 1141. (e) Oppolzer, W.; Cunningham, A. F. *Tetrahedron Lett.* **1986**, 5467.

[19] Mikhailov, B. M.; Bubnov, Yu. N. *Izv. Akad. Nauk. SSSR, Ser. Khim.* **1964**, 1874.
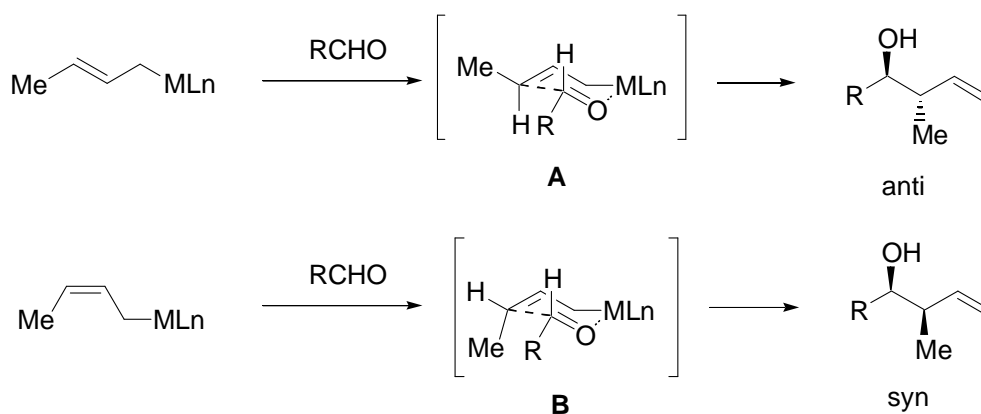
Scheme 6. Cyclic transition state for the addition of allylmetals to aldehydes.

Later, enantiopure allylic boron reagents, bearing chiral auxiliaries as the boron ligands, were prepared and reacted with aldehydes to yield the expected alcohols in both good diastereoselectivities and enantioselectivities. Thus, the 3-amino-2-borneol derived allylic reagent **3** afforded hex-5-en-3-ol in 92 % yield and 92 % *ee* when reacted with propanal (Scheme 7).[20] Similarly, other boron ligands displayed both interesting diastereoselectivities and enantioselectivities. Among them, (+)-α-pinene, (+)-limonene, (-)-β-pinene, (+)-longifolene, and tartrate esters have been extensively used. [21,22]
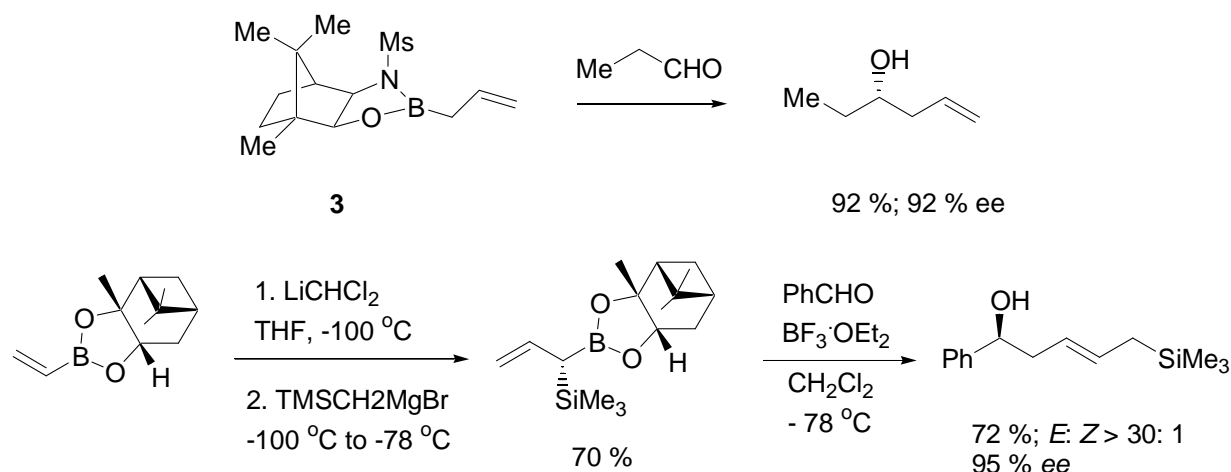
Scheme 7. Enantioselective addition of allylboron reagents to aldehydes.

[20] Reetz, M. T.; Zierke, T. *Chem. Ind.* **1988**, 663.
[21] (a) Brown, H. C.; Jadhav, P. K. *J. Am. Chem. Soc.* **1983**, *105*, 2092. (b) Brown, H. C.; Baht, K. S. *J. Am. Chem. Soc.* **1986**, *108*, 293. (c) Brown, H. C.; Jadhav, P. K.; Baht, K. S. *J. Am. Chem. Soc.* **1988**, *110*, 1535. (d) Brown, H. C.; Jadhav, P. K. *J. Org. Chem.* **1984**, *49*, 4089. (e) Garcia, J.; Masamune, S. *J. Org. Chem.* **1987**, *52*, 4831. (f) Roush, W. R.; Walts, A. E.; Hoong, L. K. *J. Am. Chem. Soc.* **1985**, *107*, 8186. (g) Roush, W. R.; Banfi, L.; Park, J. C.; Hoong, L. K. *Tetrahedron Lett.* **1989**, *30*, 6457.
[22] Peng, F.; Hall, D. G. *J. Am. Chem. Soc.* **2007**, *129*, 3070.

Allylsilanes and allylstannanes have been also extensively used as allyl anion equivalents for the last decades.[23,24] The regioselectivity observed when they are reacted with electrophiles has been rationalised considering the intermediate formation of carbeniums ions, which are hyperconjugatively stabilised by the carbon-silicon or carbon-tin bond in the β-position (Scheme 8).[25]
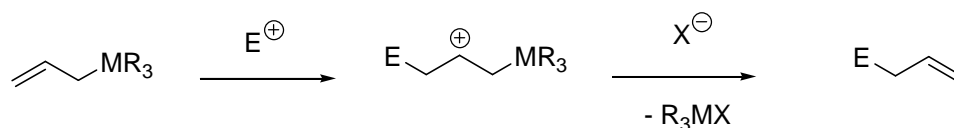
Scheme 8. Formation of a carbenium ion in the case of allylic silicon and tin reagents.
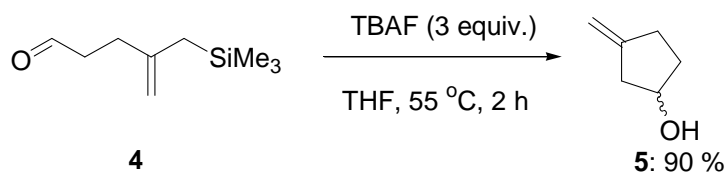
The addition of trialkylallylsilanes to aldehydes and ketones is induced either by stoechiometric amounts of Lewis acids or by catalytic quantities of fluoride ions,[26] and can be performed intermolecularly and intramolecularly.[27] Thus, treating allylsilane **4** with TBAF led to the *exo*-methylene-cyclopentanol **5** (Scheme 9).[28]

Scheme 9. Intramolecular addition of allylsilanes to aldehydes.

[23] (a) Fleming, I.; Dunogues, J.; Smithers, R. *Org. React. (N.Y.)* **1989**, *37*, 57. (b) Eaborn, R.; Boot, W. In *Organometallic compounds of the Group IV Elements*; MacDiarmid, A. G., Ed.; Marcel Dekker, New-York, 1968, Vol. 1, Part 1.

[24] For reviews, see: (a) Giese, B. Radicals in Org. Synth.: Formation of C-C Bonds. In *Org. Chem. Series*; Baldwin, J. E., Ed.; Pergamon Press: Oxford, 1986, pp 98-102. (b) Curran, D. P. *Synthesis* **1988**, 489.

[25] (a) Wierschke, S. G.; Chandrasekhar, J.; Jogensen, W. L. *J. Am. Chem. Soc.* **1985**, *107*, 1496. (b) Ibrahim, M. R.; Jorgensen, W. L. *J. Am. Chem. Soc.* **1989**, *111*, 819. (c) White, J. C.; Cave, R. J.; Davidson, E. R. *J. Am. Chem. Soc.* **1988**, *110*, 6308.

[26] (a) Sakurai, H. *Pure Appl. Chem.* **1982**, *54*, 1. (b) Yamamoto, Y.; Sasaki, N. In *Stereochem. of Organomet. and Inorg. Compds*; Bernal, I., Ed.; Elsevier: Amsterdam, 1989; Vol. 3; p 363. (c) Hosomi, A.; Shirahata, A.; Sakurai, H. *Tetrahedron Lett.* **1978**, *19*, 3043. (d) Colvin, E. W. *Silicon in Organic Synthesis*; Butterwoths: London, 1981. (e) Weber, W. P. *Silicon Reagents for Organic Synthesis*; Springer: Berlin, 1983. (f) Fleming, I. In *Comprehensive Organic Synthesis*; Trost, B. M.; Flemming, I. Eds; Pergamon Press: Oxford, 1991, Vol. 2, p 563.

[27] (a) Májetich, G. In *Organic Synthesis, Theory and applications*; Hudlicky, T., Ed.; JAI Press Inc.: London, 1989, Vol. 1, pp173-240. (b) Schinzer, D. *Synthesis*, **1988**, 263. (c) Schinzer, D.; Allagriannis, C.; Wichmann, S. *Tetrahedron* **1988**, *44*, 3851.

[28] (a) Lee, T. V.; Ronden, F. S. *Tetrahedron Lett.* **1990**, *31*, 2067. (b) Sarkar, T. K.; Andersen, N. H. *Tetrahedron Lett.* **1978**, *19*, 3513.

Hosomi and *Sakurai* also found that allylic silicon reagents react with Michael acceptors in the presence of TiCl$_4$, leading to the 1,4-addition products (Scheme 10).[29]
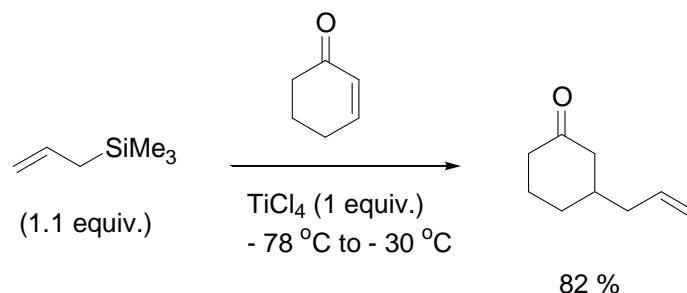
Scheme 10. Michael addition of allylsilanes to α,β-unsaturated ketones.

The reaction of allylstannanes with electrophiles such as aldehydes, ketones, acetals, imines, or iminium ions has proven to be a very mild method for the formation of carbon-carbon bond.[30] One advantageous feature is that the stereochemical outcome of allylic tin-ketone condensation reactions can be tuned by using different additives. *Baba* reported in 2003 that various allylstannanes reacted with a wide range of ketones to afford either the *anti* products or the *syn* products, depending on the additive used (Scheme 11).[31]

additive = SnCl$_2$; 84 %; *anti*: *syn* = 93: 7
additive = BF$_3$·OEt$_2$; 83 %; *anti*: *syn* = 13: 87
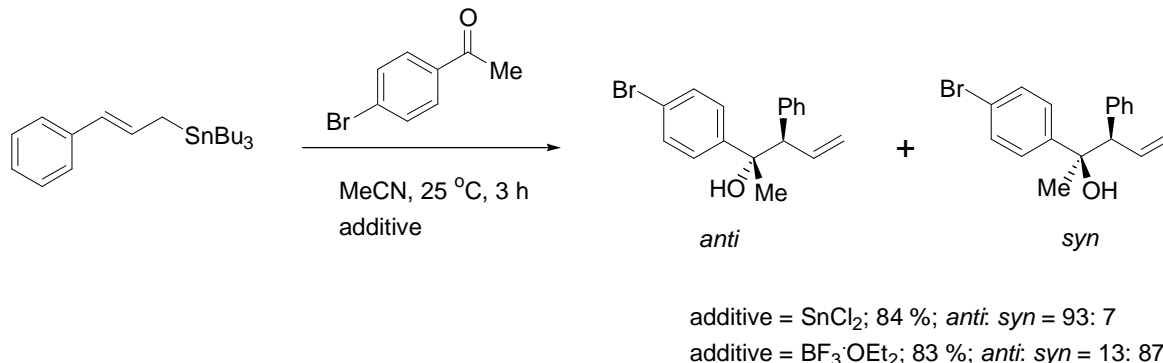
Scheme 11. Effects of additives on the stereoselectivity of the condensation of cinnamylstannanes and ketones.

Allylic zinc reagents

Gaudemar reported in 1962 that the direct insertion of zinc to various allylic bromides afforded the corresponding allylzinc bromides in moderate to good yields.[32] This insertion is

[29] Hosomi, A.; Sakurai, H. *J. Am. Chem. Soc.* **1977**, *99*, 1673.
[30] For recent reviews, see: (a) Gung, B. W. *Org. React. (N.Y.)* **2004**, *64*, 1. (b) Marshall, R. L. *Sci. Synth.* **2003**, *5*, 573.
[31] Yasuda, M.; Hirata, K.; Nishino, M.; Yamamoto, A.; Baba, A. *J. Am. Chem. Soc.* **2002**, *124*, 13442.
[32] Gaudemar, M. *Bull. Soc. Chim. Fr.* **1962**, 974.

very sensitive to the reaction temperature, as depicted in Scheme 12. When cinnamyl bromide was reacted with zinc in THF between – 15 ºC and – 5 ºC, the corresponding allylic zinc reagent was formed in 70 %, but when the reaction was performed at room temperature, only *Wurtz* coupling products were observed.
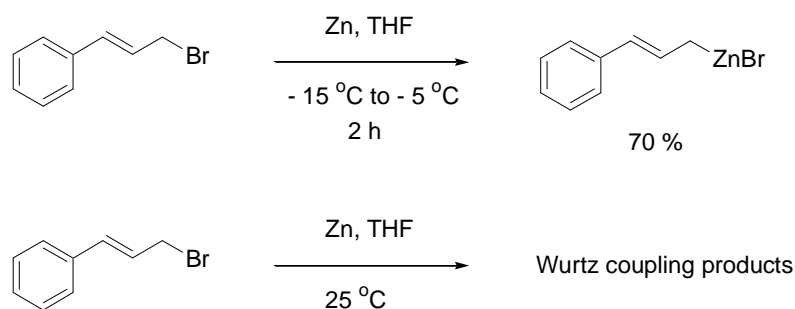
Scheme 12. Preparation of cinnamylzinc bromide by *Gaudemar*.

Later, allylic zinc reagents formed *in situ* were found to react with carbonyls derivatives, leading to the corresponding homoallylic alcohol in high yields. *Luche* especially showed that this reaction could also be performed in aqueous media under Barbier conditions, with THF as cosolvent (Scheme 13).[33,34]
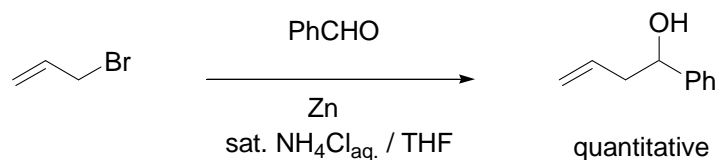
Scheme 13. Addition of allylic zinc reagents to aldehydes in aqueous media.

In 1992, *Knochel* reported that allylic zinc reagents could also be prepared from allylic mesylates or allylic phosphates, with a minimum formation of homocoupling products. Under Barbier conditions in the presence of zinc (ca. 2 equiv.) and a catalytic amount of LiI (20 mol %), the allylic phosphate and benzaldehyde react in DMA or DMPU, leading to the corresponding homoallylic alcohol in high yield (Scheme 14).[35]

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[33] (a) Luche, J. L.; Damiano, J. C. *J. Am. Chem. Soc.* **1980**, *102*, 7926. (b) Sprich, J. D.; Lewandos, G. S. *Inorg. Chim. Acta* **1983**, *76*, L241. (c) For a review of sonochemistry, see: Einhorn, C.; Einhom, J.; Luche, J. L. *Synthesis* **1989**, 787.
[34] (a) Patrier, C.; Luche, J. L. *J. Org. Chem.* **1985**, *50*, 910. (b) Petrier, C.; Einhom, J.; Luche, J.L. *Tetrahedron Lett.* **1985**, *26*,1449. (c) Einhom, C.; Luche, J. L. *J. Organomet. Chem.* **1987**, *322*, 177.
[35] Jubert, C.; Knochel, P. *J. Org. Chem.* **1992**, *57*, 5425.
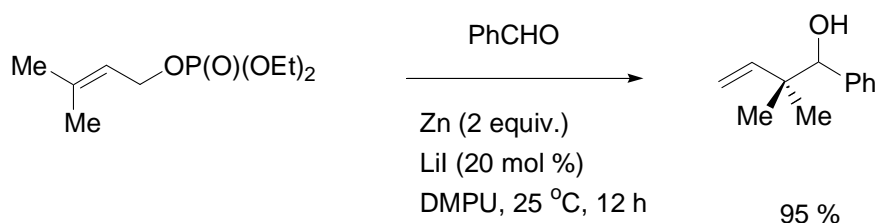
Scheme 14. Formation of allylic zinc species from allyl phosphates and their addition to PhCHO.

Nakamura made a breakthrough in 1998, when he found that the condensation of allylic zinc halides to alkynyl ketones could be performed enantioselectively using a lithiated bisoxazoline as ligand (Scheme 15).[36]
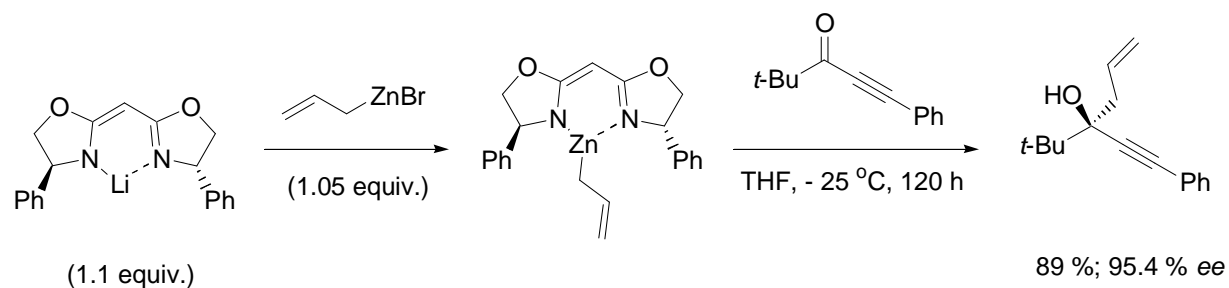
Scheme 15. Enantioselective addition of allylzinc reagents to alkynyl ketones.

Allylic zinc reagents were also found to react with imines. In the case of cyclic aldimines, the addition could be accomplished in an enantioselective manner, as described by *Nakamura* (Scheme 16).[37]
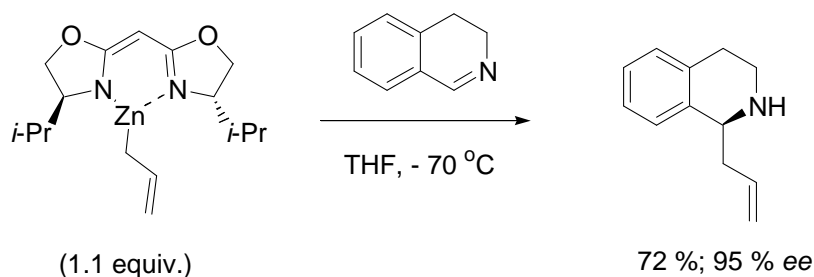
Scheme 16. Enantioselective addition of allylzinc reagents to cyclic aldimines.

[36] Nakamura, M.; Hirai, A.; Sogi, M.; Nakamura, E. *J. Am. Chem. Soc.* **1998**, *120*, 5846.
[37] Nakamura, M.; Hirai, A.; Nakamura, E. *J. Am. Chem. Soc.* **1996**, *118*, 8489.

Allylic zinc species were also successfully used in intramolecular "zinc-ene" reactions. Thus, after transmetalation of an appropriate allylic magnesium derivative with ZnBr$_2$, *Klumpp* synthesized several oxygen- and nitrogen-containing heterocycles (Scheme 17).[38]

Scheme 17. Heterocycles synthesis via an intramolecular "zinc-ene" reaction.

Later, *Oppolzer* reported that allylic zinc reagents could be prepared *in situ* from allyl acetates under palladium catalysis, and subsequently undergo an intramolecular "zinc-ene" reaction, leading to the corresponding carbocycles (Scheme 18).[39]
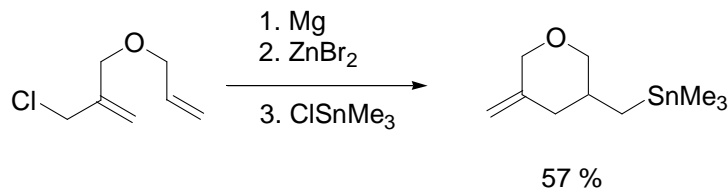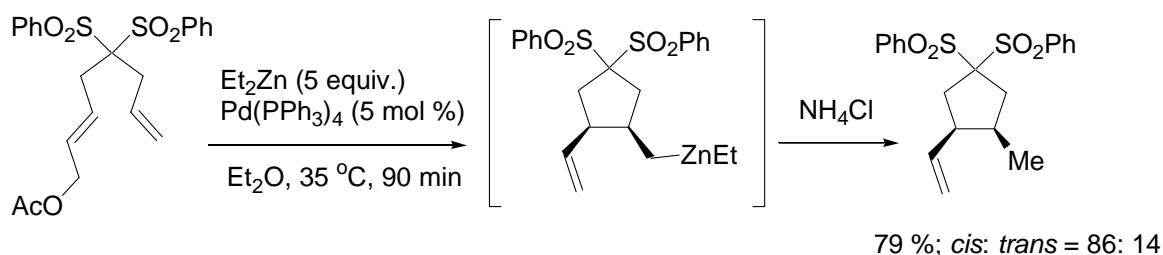

Scheme 18. *Oppolzer*´s palladium-catalysed "zinc-ene" reaction.

Gaudemar showed that allylic zinc halides reacted as well with alkynes.[40] In the case of monosubstituted alkynes or enynes, a metalation occurs prior to the addition, leading to a bismetalated species (Scheme 19).[41] Later, *Miginiac* reported that this addition could also be performed intramolecularly.[42]

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[38] van der Louw, J.; van der Baan, J. L.; Stieltjes, H.; Bickelhaupt, F.; Klumpp, G. W. *Tetrahedron Lett.* **1987**, *28*, 5929.

[39] (a) Oppolzer, W.; Schröder, F. *Tetrahedron Lett.* **1994**, *35*, 7939. (b) Oppolzer, W.; Flachsmann, F. *Tetrahedron Lett.* **1998**, *39*, 5019. (c) Oppolzer, W.; Flachsmann, F. *Helv. Chim. Acta* **2001**, *84*, 416.

[40] (a) Frangin, Y.; Gaudemar, M. *Bull. Soc.Chim. Fr.* **1976**, 1173; *C. R. Acad. Sci. Paris, Sér. C* **1974**, 885. (b) Frangin,Y.; Favre,E.; Gaudemar, M. *C. R. Hebd. Seances Acad. Sci. Ser. C* **1976**, *282*, 277.

[41] Bellaesoued, M.; Frangin, Y.; Gaudemar, M. *J. Organomet. Chem.* **1979**, *166*, 1.

[42] Courtois, G.; Masson, A.; Miginiac, L. *C. R. Acad. Sci. Paris, Sér.C* **1978**, *286*, 265.
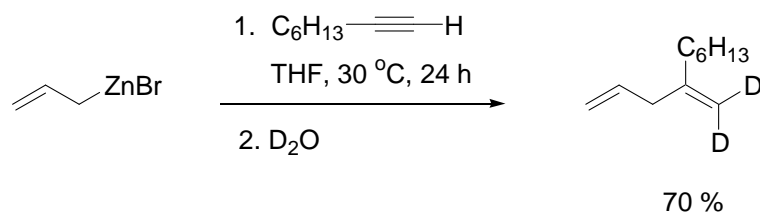
Scheme 19. Addition of allyl zinc bromide to alkynes.

Finally, *Normant* and *Knochel* reported the addition of allylic zinc reagents to alkenylmagnesium species leading, *via* a "metalla Claisen" rearrangement, to bimetallic intermediates that could subsequently be quenched with various electrophiles.[43] Thus, allyl zinc bromide reacted with vinylmagnesium bromide in THF at 0 °C to afford the pure (Z)-**6** upon quenching with (7-acetoxyheptylidene)malonate (Scheme 20).[44]

Scheme 20. Addition of allylzinc bromide to vinylmagnesium bromides.

1.1.2. Cross-coupling reactions

Palladium- and nickel-catalyzed cross-couplings

Transition metal-catalyzed cross-coupling reactions have been playing an important role in organic synthesis for the last 30 years, and have therefore been successfully used in
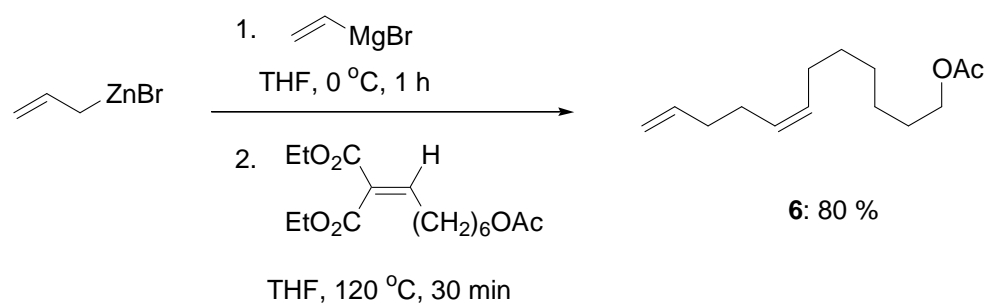
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[43] (a) Knochel, P.; Normant, J. F. *Tetrahedron Lett.* **1986**, *27*, 1039. (b) Knochel, P.; Normant, J. F. *Tetrahedron Lett.* **1986**, *27*, 1043. (c) Knochel, P.; Normant, J. F. *Tetrahedron Lett.* **1986**, *27*, 4427. (d) Knochel, P.; Normant, J. F. *Tetrahedron Lett.* **1986**, *27*, 4431. (e) Knochel, P.; Xiao, C.; Yeh, H. C. P. *Tetrahedron Lett.* **1988**, *29*, 6697. (f) Knochel, P.; Yeh, M. C. P.; Xiao, C. *Organometallics* **1989**, *8*, 2831. (g) Knochel, P.; Normant, J. F. *Tetrahedron Lett.* **1986**, *27*, 5727. (h) Marek, I.; Lefrancois, J. M.; Normant, J. F. *Tetrahedron Lett.* **1991**, *32*, 5969. (i) Marek, I.; Normant, J. F. *Tetrahedron Lett.* **1991**, *32*, 5973.
[44] Tucker, C. E.; Rao, S. A.; Knochel, P. *J. Org. Chem.* **1990**, *55*, 5446.

many natural product syntheses.[45] Among them, the very general and selective palladium-catalysed Stille (involving organotin reagents) and Suzuki-Miyaura (involving boronic acids or esters) couplings have been particularly popular. Other cross-couplings, using different metal species have been developed, offering chemists new methods to achieve C-C bond formations. For instance, the palladium-catalyzed Hiyama- (organosilicon reagents), Negishi- (organozinc reagents), Sonogashira- (alkynylcopper reagents), or the nickel-catalyzed Kumada-Corriu-reaction (organomagnesium reagents) have proven to be highly valuable tools in organic synthesis.[46]

All the palladium- or nickel-catalyzed cross-coupling reactions have the particularity to share a common mechanism pathway (Scheme 21).
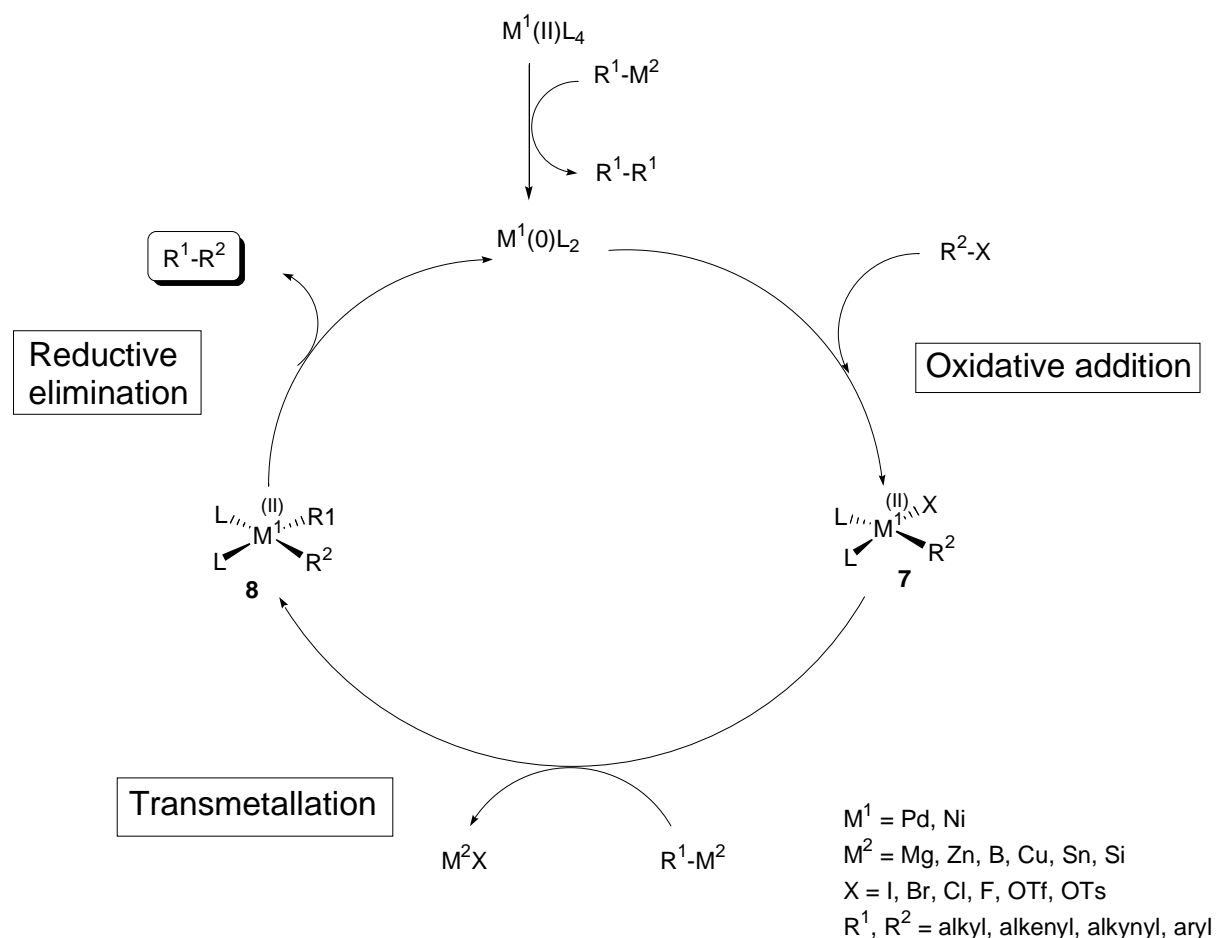
Scheme 21. Catalytic cycle of the palladium- and nickel-catalyzed cross-coupling reactions

[45] For a few examples, see: Nicolaou, K. C.; Sorensen, E. J., *Classics in Total Synthesis*, Verlag Chemie, Weinheim, **1996**.

[46] (a) *Handbook of Functionalysed Organometallics*, (Editor: P. Knochel), Wiley-VCH, Weinheim, **2005**; (b) *Metal Catalyzed Cross-Coupling Reactions*, (Editors: A. de Meijere, F. Diederich), Wiley-VCH, Weinheim, **2004**; (c) *Transition Metals for Organic Synthesis*, 2nd Ed., (Editors: M. Beller, C. Bolm), Wiley-VCH, Weinheim, **2004**; (d) *Handbook of Organopalladium Chemistry for Organic Synthesis*, (Editor: E. Negishi), Wiley-Interscience, New-York, **2002**; (e) Tsuji, J. *Transition Metal Reagents and Catalysts: Innovations in Organic Synthesis*, Wiley, Chichester, **1995**.

The first step usually involves the *in situ* reduction of the catalyst precursor $M^1(II)L_4$ to the reactive species $M^1(0)L_2$. This step is followed by an oxidative addition to the C-X bond of the electrophile R^2X, affording the complex **7**. Subsequent transmetallation leads to complex **8** which, upon a reductive elimination, provides the cross-coupling product R^1-R^2, and regenerates the active catalyst $M^1(0)L_2$.

Alternatively, metal(0) complexes, such as $Pd(PPh_3)_4$ or $Ni(COD)_2$ can also be used. In this case, no preliminary reduction is required.

Among the factors influencing the catalysis efficiency, the nature of the ligand L plays an essential role. For instance, electron-rich ligands facilitate the oxidative addition step, whereas electron-poor ligands enhance both the transmetallation and the reductive elimination steps. Thus, when the determining-rate step is the oxidative addition (aryl chlorides used as electrophiles for example), electron-rich ligands are more advantageous and enhance the reaction rate.

New trends in cross-coupling: iron-and cobalt-catalyzed transformations

Although palladium- and nickel-catalyzed cross-coupling reactions are very efficient and tolerant towards most organic functionalities, drawbacks, such as cost (palladium precursors and ligands) or toxicity (nickel salts) remain.[47] On the opposite, iron salts are cheap and display no specific toxicity. Furthermore, the iron catalysis offers two advantages: it does not require additional ligands, and is even efficient at low temperatures.[48,49]

The pioneering discoveries were achieved in 1971, when *Kochi* found that iron salts could efficiently catalyze the $C(sp^3)$-$C(sp^2)$ cross-coupling reaction between alkenyl bromides and alkylmagnesium bromides (Scheme 22).[50] This reaction proceeded diastereospecifically, but required a huge excess of the electrophile.
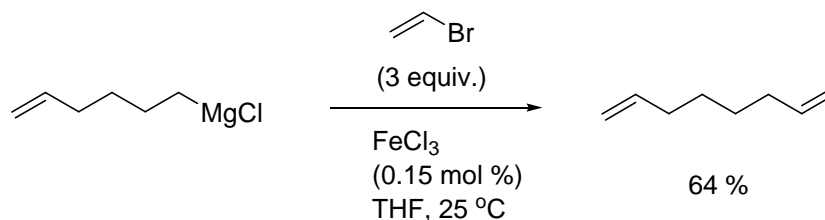
Scheme 22. *Kochi´s* iron-catalyzed $C(sp^3)$-$C(sp^2)$ cross-coupling reaction.

[47] Fürstner, A.; Leitner, A.; Méndez, M.; Krause, H. *J. Am. Chem. Soc.* **2002**, *124*, 13856.
[48] For reviews, see: (a) Bolm, C.; Legros, J.; Le Paih, J.; Zani, L. *Chem. Rev.* **2004**, *104*, 6217. (b) Martin, R.; Fürstner, A. *Chem. Lett.* **2005**, *34*, 624.
[49] Oestreich, M. *Nachr. Chemie* **2004**, *52*, 446.
[50] (a) Tamura, M.; Kochi, J. *Synthesis* **1971**, 303. (b) Tamura, M.; Kochi, J. *J. Am. Chem. Soc.* **1971**, *93*, 1487.

In 1998, *Cahiez* reported that the use of a polar cosolvent like NMP could improve this $C(sp^3)$-$C(sp^2)$ cross-coupling,[51] the scope of which was extended to primary, secondary and even tertiary alkylmagnesium reagents (Scheme 23).
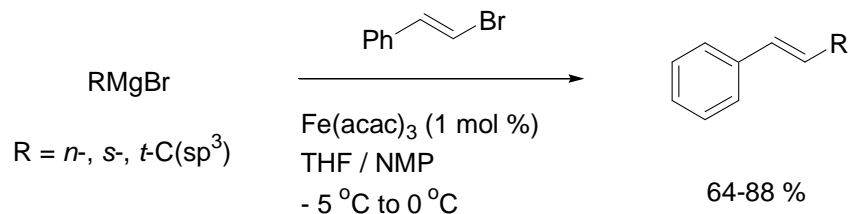
Scheme 23. Effect of NMP of iron-catalyzed cross-couplings.

The iron-catalyzed cross-coupling of arylmagnesium reagents with alkenyl halides proved to be a sluggish reaction,[52] until *Molander* found that $Fe(dbm)_3$ in DME was an effective catalyst for this transformation.[53] Later, *Knochel* could successfully extend this aryl-alkenyl cross-coupling to functionalized arylmagnesium reagents,[54] and was also able to perform the first iron-catalyzed aryl-aryl cross-coupling between aryl iodides and functionalized arylcopper reagents (Scheme 24).[55]
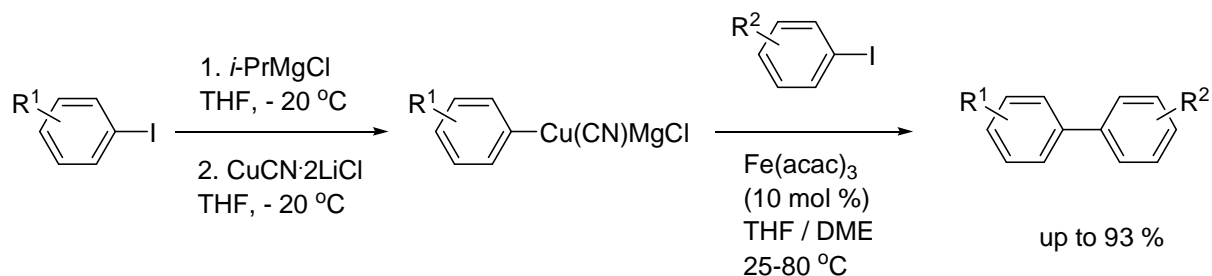
Scheme 24. *Knochel´s* iron-catalyzed aryl-aryl cross-coupling reaction.

In 2002, *Fürstner* made a breakthrough when he found that alkylmagnesium halides could react with aryl chlorides, triflates or tosylates upon iron catalysis, leading to the

[51] Cahiez, G.; Avedissian, H. *Synthesis* **1998**, 1199.

[52] Neumann, S. M.; Kochi, J. K. *J. Org. Chem.* **1975**, *40*, 599.

[53] Molander, G. A.; Rahn, B. J.; Shubert, D. C.; Bonde, S. E. *Tetrahedron Lett.* **1983**, *24*, 5449.

[54] Dohle, W.; Kopp, F.; Cahiez, G.; Knochel, P. *Synlett* **2001**, 1901.

[55] Sapountzis, I.; Lin, W.; Kofink, C. C.; Despotopoulou. C.; Knochel, P. *Angew. Chem.* **2005**, *117*, 1682; *Angew. Chem. Int. Ed.* **2005**, *44*, 1654.

corresponding cross-coupling products in high yields.[46,56] The high chemoselectivity of this reaction made it possible to successively couple the pyridine derivative **9** with two different alkylmagnesium reagents (Scheme 25). The efficiency of this cross-coupling was assessed, as it has been successfully applied to the synthesis of numerous natural products.[57]
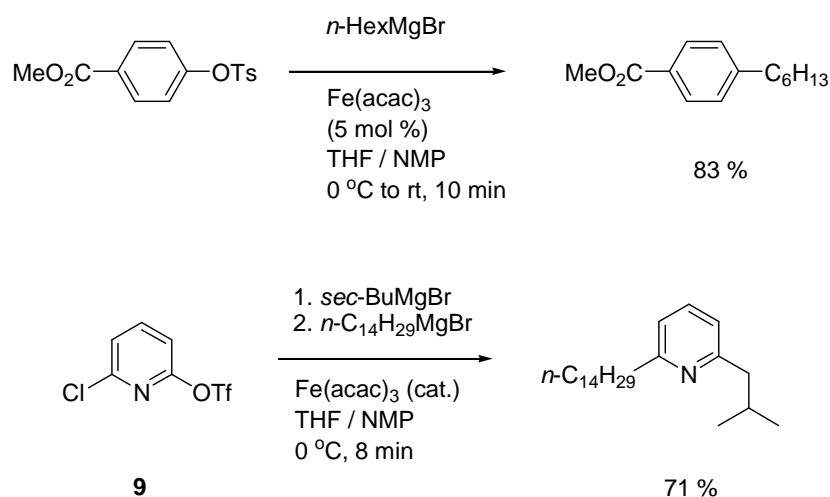
**Scheme 25.** Chemoselective iron-catalyzed cross-coupling.

The cobalt catalysis presents the same advantage as for iron (low cost of the catalysts and ligand-free catalysis), and is therefore an excellent complement to the iron-catalyzed cross-coupling reactions.

Kharasch, who could successfully couple alkyl- and aryl magnesium reagents with various vinyl bromides in the presence of $CoCl_2$ (5 mol %), was the first to report the use of cobalt as a catalyst in 1943 (Scheme 26).[58]

[56] (a) Fürstner, A.; Leitner, A. *Angew. Chem.* **2002**, *114*, 632; *Angew. Chem. Int. Ed.* **2002**, *41*, 609. (b) Scheiper, B.; Bonnekessel, M.; Krause, H.; Fürstner, A. *J. Org. Chem.* **2004**, 69, 3943.
[57] (a) Fürstner, A.; De Souza, D.; Parra-Rapado, L.; Jensen, J. T. *Angew. Chem.* **2003**, *115*, 5516; *Angew. Chem. Int. Ed.* **2003**, *42*, 5358. (b) Fürstner, A.; Leitner, A. *Angew. Chem.* **2003**, *115*, 320; *Angew. Chem. Int. Ed.* **2003**, *42*, 308. (c) Seidel, G.; Laurich, D.; Fürstner, A. *J. Org. Chem.* **2004**, 69, 3950. (d) Scheiper, B.; Glorius, F.; Leitner, A.; Fürstner, A. *Proc. Natl. Acad. Sci. U.S.A* **2004**, *101*, 11960. (e) Lepage, O.; Kattnig, E. Fürstner, A. *J. Am. Chem. Soc.* **2004**, *126*, 15970.
[58] (a) Kharasch, M. S.; Fuchs, C. F. *J. Am. Chem. Soc.* **1943**, *65*, 504. Cobalt was also found to catalyse the homocoupling reaction of arylmagnesium reagents: (b) Kharasch, M. S.; Fields, E. K. *J. Am. Chem. Soc.* **1941**, *63*, 2316.
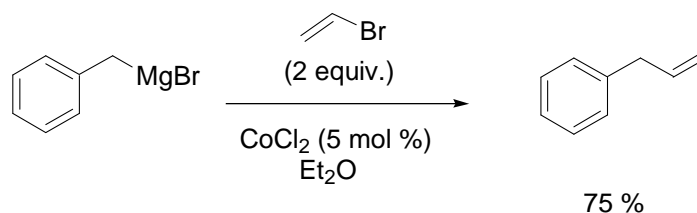
Scheme 26. *Kharasch*´s cobalt-catalyzed cross-coupling.

Nonetheless, the major developments in the field of cobalt-catalyzed coupling reactions occurred in the late 1990s, when *Cahiez* found that the use of NMP as a cosolvent had a dramatic effect, and could therefore couple alkyl-, alkenyl-, and aryl magnesium reagents with alkenyl bromides in high yields.[59] The important role played by NMP was once again illustrated the same year, when *Knochel* reported that CoCl$_2$ could efficiently catalyze the cross-coupling reaction of alkenyl iodides and alkyl zinc halides in a 5: 2 THF: NMP solvent system (Scheme 27).[60]
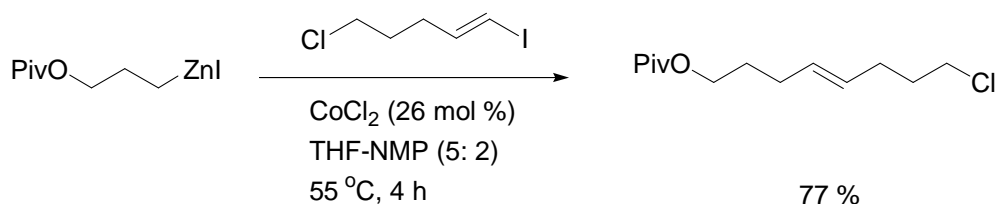
Scheme 27. *Knochel*´s cobalt-catalyzed alkenyl-alkyl cross-coupling.

Another important development occurred in 2002, when *Oshima* extended the scope of the cobalt-catalyzed cross-coupling to the formation of C(sp^3)-C(sp^3) bonds, through the use of reactive allyl- or benzyl magnesium reagents (Scheme 28).[61]
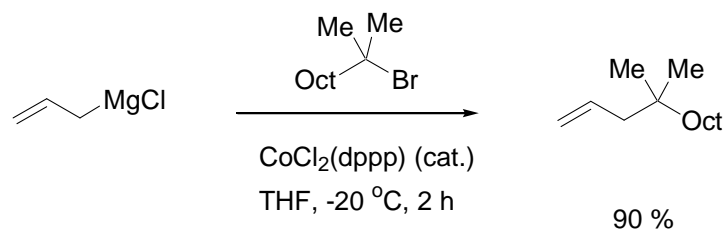
Scheme 28. *Oshima*´s cobalt-catalyzed C(sp3)-C(sp3) cross-coupling.

[59] Cahiez, G.; Avedissian, H. *Tetrahedron Lett.* **1998**, *39*, 6159.
[60] Avedissian, H.; Bérillon, G.; Cahiez, G.; Knochel, P. *Tetrahedron Lett.* **1998**, *39*, 6163.
[61] (a) Tsuji, T.; Yorimitsu, H.; Oshima, K. *Angew. Chem.* **2002**, *114*, 4311; *Angew. Chem. Int. Ed.* **2002**, *41*, 4137. (b) Ohmiya, H.; Tsuji, T.; Yorimitsu, H.; Oshima, K. *Chem. Eur. J.* **2004**, *10*, 5640.

Ultimately, *Knochel* reported a cobalt-catalyzed aryl-aryl cross-coupling, with which aryl bromides, chlorides, fluorides and even tosylates reacted with functionalized aryl copper reagents in a straightforward manner (Scheme 29).[62]
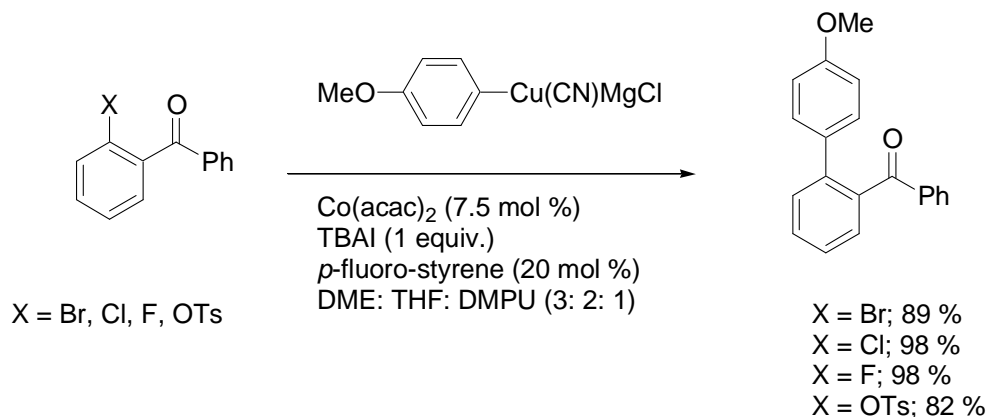
Scheme 29. *Knochel´s* cobalt-catalyzed aryl-aryl cross-coupling.

Similarly, the cobalt catalysis proved to be highly efficient in allylation reactions. Thus, *Knochel* showed in 1996 that dialkylzinc reagents, as well as the less reactive alkylzinc halides reacted stereoselectively with allylic chlorides, -bromides or –phosphates to afford the S_N2-products in high yields (Scheme 30).[63]
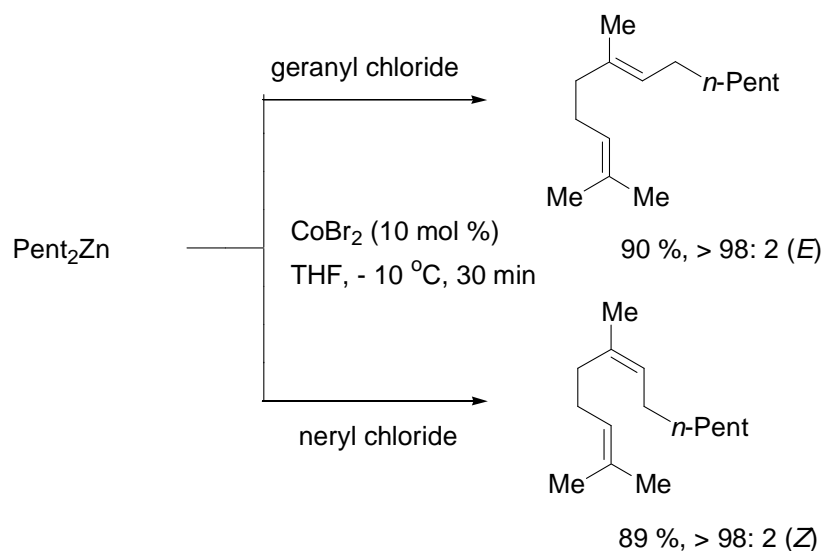
Scheme 30. Stereoselective cobalt-catalyzed allylation of dialkylzinc reagents.

[62] (a) Korn, T. J.; Knochel, P. *Angew. Chem.* **2005**, *117*, 3007; *Angew. Chem. Int. Ed.* **2005**, *44*, 2947. (b) Korn, T. J.; Schade, M. A.; Wirth, S.; Knochel, P. *Org. Lett.* **2006**, *8*, 725. (c) Korn, T. J.; Schade, M. A.; Cheemala, M. N.; Wirth, S.; Guevara, S.; Cahiez, G.; Knochel, P. *Synthesis* **2006**, *21*, 3547.
[63] Reddy, K.; Knochel, P. *Angew. Chem.* **1996**, *108*, 1812; *Angew. Chem. Int. Ed. Engl.* **1996**, *35*, 1700.

A few years later, *Oshima* found that cobalt salts associated with a bidentate phosphine ligand were a good catalytic system for the reaction of allylic ethers with arylmagnesium reagents. Under these conditions, even *α-β* unsaturated aldehyde dialkyl acetals reacted to give either the mono- or the di-substituted coupling products (Scheme 31).[64]

dpph = Ph$_2$P(CH$_2$)$_6$PPh$_2$
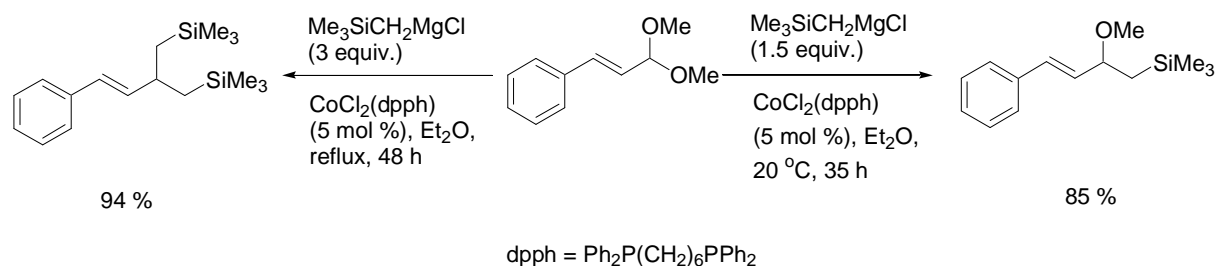
Scheme 31. Cobalt-catalyzed cross-coupling between Grignard reagents and aldehyde dialkyl acetals.

Finally, *Gosmini* described the direct cobalt-catalyzed allylation or aryl bromides or chlorides with allyl acetate (Scheme 32).[65] This reaction could even be extended to the vinylation of aryl halides with vinyl acetate.[66]
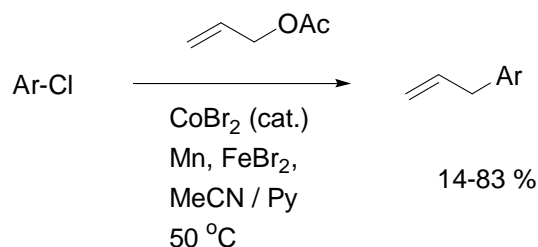
Scheme 32. *Gosmini*´s allylation of aryl chlorides.

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[64] Yasui, H.; Mizutani, K.; Yorimitsu, H.; Oshima, K. *Tetrahedron* **2006**, *62*, 1410.

[65] Gomes, P.; Gosmini, C.; Périchon, J. *Org. Lett.* **2003**, *5*, 1043. (b) Gomes, P.; Gosmini, C.; Périchon, J. *J. Org. Chem.* **2003**, *68*, 1142.

[66] Amatore, M.; Gosmini, C.; Périchon, J. *Eur. J. Org. Chem.* **2005**, 989. (b) Gomes, P.; Gosmini, C.; Périchon, J. *Tetrahedron* **2003**, *59*, 2999.

1.2.   Objectives

As described previously, allylic zinc reagents offer very interesting synthetic possibilities. Nonetheless, their preparation is complicated by the formation of homocoupling products. Thus, in a first project, efforts will be made to find a new and convenient method for the synthesis of these reactive organometallics, and their subsequent reaction with electrophiles will be studied. Especially interesting is to know if the reaction of substituted allylic zinc reagents with aldehydes or ketones can be performed in a diastereoselective manner (Scheme 33).
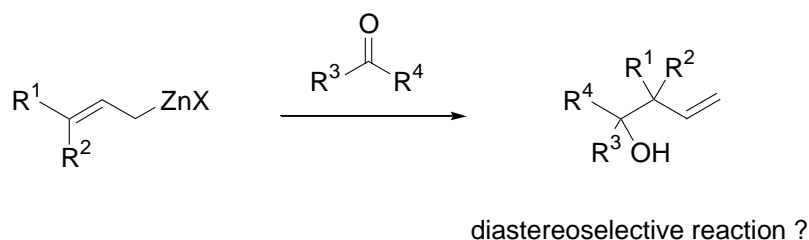
Scheme 33. Reaction of allylic zinc reagents with carbonyl derivatives.

In a second project, new cobalt- and iron-catalyzed transformations will be investigated; for instance the reaction of alkenyl or dienyl sulfonates with arylcopper reagents in the presence of iron salts, and the cobalt-catalyzed allylation of diarylzinc reagents (Scheme 34).
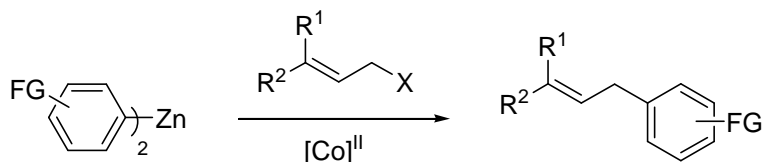
Scheme 34. Cobalt-catalyzed allylation of diarylzinc reagents.

Finally, in a third project, aryl phosphates will be investigated as potential electrophiles in a nickel-catalyzed aryl-aryl cross-coupling with functionalized arylmagnesium reagents (Scheme 35).
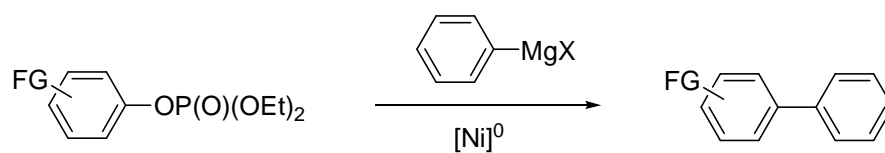
Scheme 35. Nickel-catalyzed aryl-aryl cross-coupling between aryl phosphates and arylmagnesium reagents.

3. LiCl-mediated preparation of allylic zinc reagents and their reaction with electrophiles

3.1. Introduction

The stereoselective generation of quaternary centers is one of the major challenges in asymmetric synthesis.[67] The addition of highly substituted allylic organometallics to carbonyl derivative[68] offers a straightforward synthesis of homoallylic alcohols bearing quaternary centers. To be efficient, this approach requires a convenient preparation of the allylic organometallics.[69] Although allylic lithium and magnesium reagents are highly reactive, they are difficult to prepare and unstable.[70] On the opposite, allylic zinc reagents are much more readily available. Thus, allylzinc bromide is produced in high yield by the direct insertion into allyl bromide.[32] Nonetheless, the zinc insertion to substituted allylic bromides is less satisfactory and increased amounts of homocoupling products are formed. Thus, cyclohexenylzinc bromide can only be prepared in 65 % yield *via* the direct zinc insertion.[71] Recently, *Knochel* reported a LiCl-mediated insertion of zinc dust into alkyl, aryl, and heteroaryl iodides, leading to the corresponding organozincs in good yields.[72] Therefore, it was envisioned that the combination of zinc and LiCl could promote the direct insertion into allylic substrates, and maybe limit the amount of homocoupling products formed.

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[67] (a) Corey, E. J.; Guzman-Perez, A. *Angew. Chem. Int. Ed.* **1998**, *37*, 388. (b) Christoffers, J.; Mann, A. *Angew. Chem., Int. Ed.* **2001**, *40*, 4591. (c) d'Augustin, M.; Palais, L.; Alexakis, A. *Angew. Chem. Int. Ed.* **2005**, *44*, 1376. (d) Sklute, G., Amsallem, D., Shabli, A., Varghese, J. P., Marek, I. *J. Am. Soc. Chem.* **2003**, *125*, 11776. (e) Sklute, G., Marek, I. *J. Am. Soc. Chem.* **2006**, *128*, 4642. (f) Breit, B.; Demel, P.; Studte, C. *Angew. Chem. Int. Ed.* **2004**, *43*, 3785. (g) Li, H.; Walsh, P. J. *J. Am. Soc. Chem.* **2004**, *126*, 6538. (h) Kennedy, J. W. J.; Hall, D. G. *J. Am. Chem. Soc.* **2002**, *124*, 898. (i) Denmark, S. E.; Fu, J. *J. Am. Chem. Soc.* **2001**, *123*, 9488. (j) Denmark, S. E.; Fu, J. *Org. Lett.* **2002**, *4*, 1951. (k) Heo, J.-N.; Micalizio, G. C.; Roush, W. R. *Org. Lett.* **2003**, *5*, 1693.

[68] For allylmetal additions, see : (a) Chemler, S. R.; Roush, W. R. In *Modern Carbonyl Chemistry*; Otera, J., Ed.; Wiley-VCH: Weinheim, 2000; Chapter 10. (b) Denmark, S. E.; Almstead, N. G. In *Modern Carbonyl Chemistry*; Otera, J., Ed.; Wiley-VCH: Weinheim, 2000; Chapter 11. (c) *Stereoselective Synthesis, Methods of Organic Chemistry* (Houben-Weyl), ed. E21; Helmchen, G., Hoffmann, R., Mulzer, J., Schaumann, E., Eds.; Thieme: Stuttgart 1996; Vol. 3. (d) Thadani, A. N.; Batey, R. A. *Org. Lett.* **2002**, *4*, 3827. (e) Li, S. W.; Batey, R. A. *Chem. Commun.* **2004**, 1382.

[69] (a) Czernecki, S.; Georgoulis, C. *Bull. Soc. Chim. Fr.* **1968**, 3713. (b) Yamamoto, Y.; Asao, N. *Chem. Rev.* **1993**, *93*, 2207. (c) Marshall, J. A. *Chem. Rev.* **2000**, *100*, 3163. (d) Denmark, S. E.; Fu, J. *Chem. Rev.* **2003**, *103*, 2763. (e) Chabaud, L.; James, P.; Landais, Y. *Eur. J. Org. Chem.* **2004**, 3173. (f) Lipshutz, B. H.; Hackmann, C. *J. Org. Chem.* **1994**, *59*, 7437. (g) Füstner, A.; Voigtländer, D. *Synthesis*, **2000**, 975. (h) Roush, W. R. in *Comprehensive Organic Synthesis,* Ed. B. M. Trost, I. Fleming and C. H. Heathcock, Pergamon, Oxford, 1991, vol. 2, pp. 1-53. (i) Kim, J. G.; Camp, E. H.; Walsh, P. J. *Org. Lett.* **2006**, *8*, 4413.

[70] Schlosser, M.; Desponds, O.; Lehmann, R.; Moret, E.; Rauchschwalbe, G. *Tetrahedron*, **1993**, *49*, 10175.

[71] Bellassoued, M.; Frangin, Y.; Gaudemar, M. *Synthesis*, **1977**, 205.

[72] Krasovskiy, A.; Malakhov, V.; Gavryushin, A.; Knochel, P. *Angew. Chem., Int. Ed.* **2006**, *45*, 6040.

3.2. LiCl-mediated preparation of allylic zinc reagents

Recently, a LiCl-mediated direct insertion of zinc powder to cyclic allylic chlorides has been developed in our group by *Hongjun Ren*, which led to the corresponding allylic zinc reagents in 55-84 % yield.[73] These organometallics were found to add diastereoselectively to various carbonyl derivatives, leading to the corresponding homoallylic alcohols bearing adjacent quaternary centers (Scheme 36).
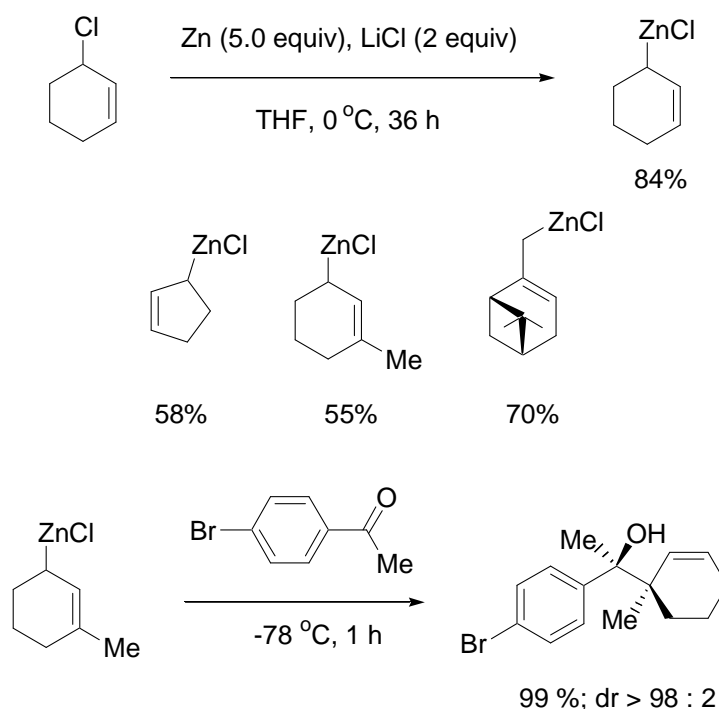
Scheme 36. Diastereoselective addition of cyclic allylzinc chlorides to carbonyl derivatives according to *Ren* and *Knochel*.

Thus, it was envisioned to extend this methodology to linear allylic chorides or phosphates. The study started with the readily available cinnamyl phosphate,[74] which was treated with zinc (3 equiv.) and LiCl (3 equiv.) in THF at 25 °C. After 18 h, the conversion was complete and titration by iodolysis indicated that the corresponding allylic zinc species **10** was formed in 72 % yield (Scheme 37). Importantly, no homocoupling was formed during the process. When the same reaction was carried out in the absence of LiCl, the insertion still

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[73] (a) Ren, H. Ph.D thesis, LMU München. (b) Ren, H.; Dunet, G.; Mayer, P.; Knochel, P. *J. Am. Chem. Soc.* **2007**, *129*, 5376.

[74] Prepared from the corresponding alcohol according to: Nowotny, S.; Tucker, C. E.; Jubert, C. *J. Org. Chem.* **1995**, *60*, 2762.

occurred, but less efficiently (52 % yield by iodolysis), and homocoupling products could be detected by GC (between 5 % and 10 % yield). Similarly, when the amount of zinc and LiCl were diminished to 1.5 equiv. compared to the allyl phosphate, the rate of the insertion dropped and only 60 % conversion were achieved after 24 h at room temperature.
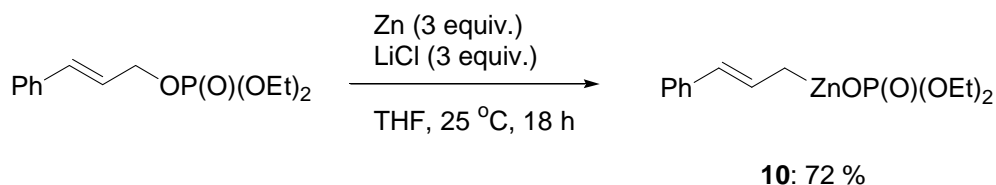
Scheme 37. LiCl-mediated direct zinc insertion to cinnamyl phosphate.

This procedure was then successfully extended to other allylic zinc reagents (Scheme 38). When cinnamyl chloride reacted with zinc (3 equiv.) and LiCl (3 equiv.) in THF at room temperature, the allylzinc reagent **11** was formed within 1 h in 78 % yield. Likewise, starting from diethyl myrtenyl phosphate,[75] the corresponding zinc species **12** was formed in 61 % yield (25 °C, 48 h). Under the same conditions, the zinc reagents **13** and **14** were prepared from (*E*)-1-chloro-4-methylpent-2-ene and ((*E*)-3-chloroprop-1-enyl) cyclohexane in 63 % and 65 % yield respectively. Finally, the substituted allylzinc species **15** and **16** could also be obtained in moderate yield (70 % and 63 % yield respectively) from the corresponding allylic phosphates.
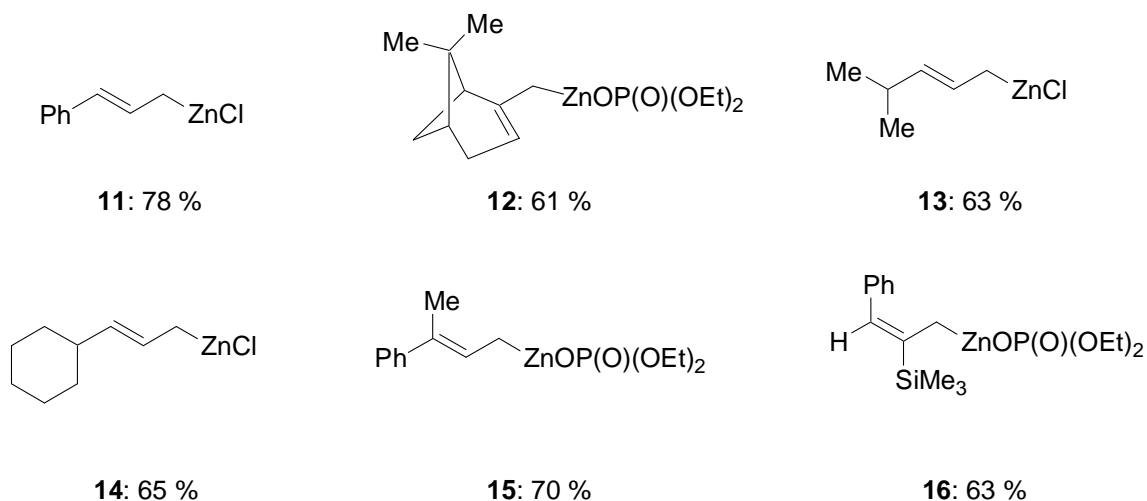

Scheme 38. LiCl-mediated preparation of allylic zinc reagents.

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[75] Araki, S.; Hatano, M.; Butsugan, Y. *J. Org. Chem.* **1986**, *51*, 2126.

3.3.   Diasteroselective reaction of allylic zinc reagents with aldehydes and ketones

With these organozincs in hand, their reaction with carbonyl derivatives was studied (Scheme 39 and Table 1). When cinnamylzinc phosphate (**10**) reacted with benzaldehyde in THF at - 78 °C, the corresponding *anti* homoallylic alcohol **17** was obtained in 96 % yield and with a good diastereoselectivity (dr = 94: 6) within 1 h (Scheme 39). Interestingly, no relevant difference in yield or diastereoselectivity was observed when cinnamylzinc chloride (**11**) was used instead of **10**; in this case, **17** was prepared in 97 % yield and a dr = 96: 4.[31]

17: 95 %; dr = 94: 6; X = OP(O)(OEt)$_2$
97 %; dr = 94: 6; X = Cl
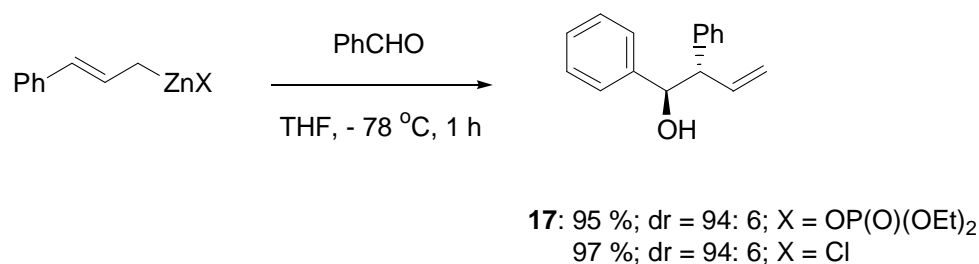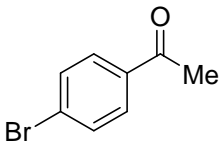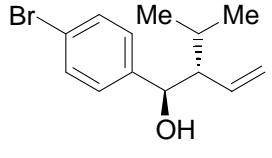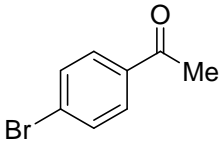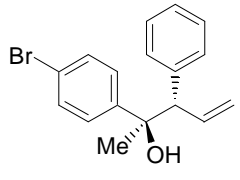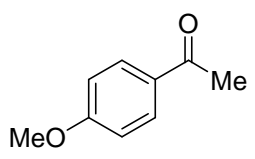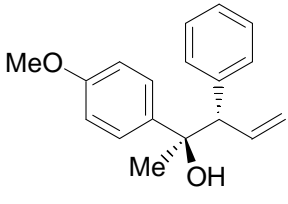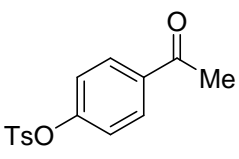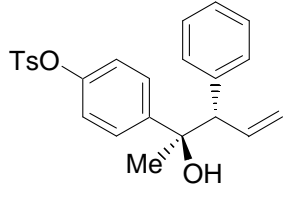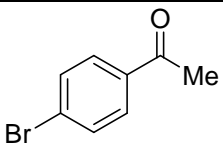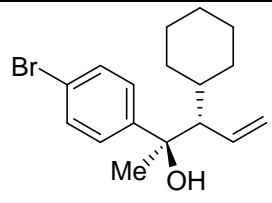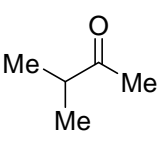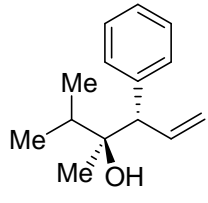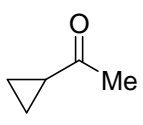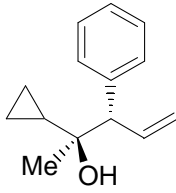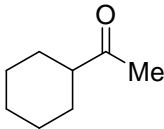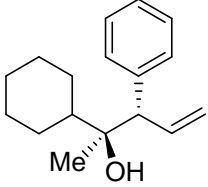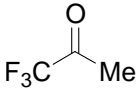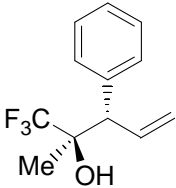
Scheme 39. Reaction of cinnamylzinc reagents **10** and **11** with benzaldehyde.

Similarly, the zinc reagent **12** reacted with 5-iodo-furan-2-carbaldehyde under the same conditions to afford the alcohol **18** in high yield as a single diastereoisomer (95 %; dr > 98: 2; entry 1 of Table 1).[73b] When 4-methyl-pent-2-enylzinc chloride (**13**) reacted with 4-bromobenzaldehyde in THF at - 78 °C, alcohol **19** was obtained quantitatively, but as a mixture of 2 diastereoisomers (99 %; dr = 86: 14, entry 2).

Table 1. Reaction of allylic zinc reagents with carbonyl derivatives.[a]

Entry	Allylic zinc reagent	Electrophile	Product	Yield (%)[b]
1	**12**		**18**; dr = 98: 2	95

Entry	Reagent	Ketone	Product	Yield
2	**13**	4-bromoacetophenone	**19**; dr = 86: 14	99
3	**11**	4-bromoacetophenone	**20**; dr = 99: 1	99
4	**10**	4-methoxyacetophenone	**21**; dr = 98: 2	98
5	**10**	4-(tosyloxy)acetophenone	**22**; dr = 97: 3	92
6	**14**	4-bromoacetophenone	**23**; dr = 97: 3	86
7	**11**	3-methylbutan-2-one	**24**; dr = 99: 1	96
8	**11**	cyclopropyl methyl ketone	**25**; dr = 99: 1	93

9	**11**	O=C(cyclohexyl)Me	**26**; dr = 99: 1	95
10	**11**	F$_3$C–C(=O)–Me	**27**; dr = 99: 1	77

[a] Unless stated otherwise, all reactions were carried out with 1 mmol of ketone and 1.2 mmol of allylic zinc reagent at – 78 ºC for 1 h. [b] Isolated yield of analytically pure compounds.

The reaction of the previously prepared allylic zinc reagents with ketones was then studied (Table 1). Substituted acetophenones reacted with **10** or **11** affording the corresponding homoallylic alcohols **20**-**22** with good diastereoselectivities (yields > 90 %; dr > 98: 2; entries 3-5).[31] Likewise, when 3-cyclohexyl-prop-2-enylzinc chloride (**14**) was added to 4-bromo-acetophenone, the corresponding alcohol bearing a quaternary center (**23**) was obtained as one single diastereoisomer (86 %; dr > 97: 3; entry 6). The reaction of cinnamylzinc chloride (**11**) with various methyl alkyl ketones proceeds diastereoselectively as well. Thus, the addition of 3-methyl-butan-2- one, 1- cyclopropyl -ethanone, 1-cyclohexyl-ethanone or even 1,1,1- trifluoro-propan-2-one to **11** led to the corresponding alcohols with dr > 99:1 (**24**-**27**; 77-99 % yield; entries 7-10). Noteworthy, when cinnamylzinc chloride was reacted with 1- cyclopropyl -ethanone at 0 °C, the reaction proved to be less selective, as the homoallylic alocohol **25** was isolated in 92 % and dr > 92: 8. Finally, when 1-trimethylsilanyl-ethanone was reacted with organozinc **11**, the corresponding tertiary alcohol (**28**) was obtained in good yield (93 %; dr > 97: 3) and no Brook rearrangement[76] was observed (Scheme 40).

---

[76] (a) Brook, A. G. *J. Am. Chem. Soc.* **1958**, *80* 1886. (b) Brook, A. G. *Acc. Chem. Res.* **1974**, *7*, 77. (c) Page, P. C. B.; Klair, S. S.; Rosenthal, S. *Chem. Soc. Rev.* **1990**, *19*, 147.
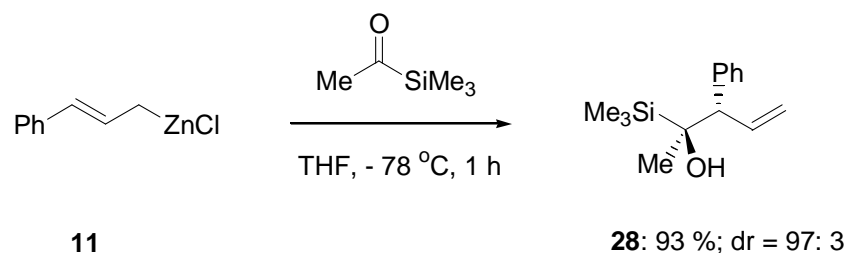
Scheme 40. Reaction of cinnamylzinc phosphate with 1-trimethylsilanyl-ethanone.

When linear methyl alkyl ketones were used as electrophiles, the diastereoselectivity dropped, and only inseparable mixtures of diastereoisomers could be isolated (Scheme 41). Thus, with butan-2-one as electrophile, alcohol **29** was obtained in 95 % yield with a dr = 61: 39. When 2-octanone was used instead, the corresponding alcohol (**30**) was isolated as a 1: 1 mixture of diastereoisisomers.

10

29: 95 %; dr = 61: 39; R = Et
30: 89 %; dr = 50: 50; R = *n*-Hex
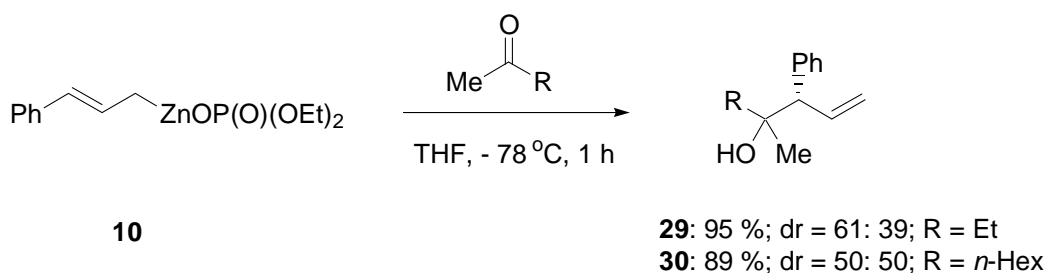
Scheme 41. Unselective reaction of alkyl methyl ketones with cinnamylzinc phosphate **10**.

The determination of the structures of the homoallylic alcohols resulting from the addition to aromatic ketones could be readily established by literature comparison[31]. In the case of the methyl alkyl ketones, no direct assignment could be made, and the alcohols **24** and **27** were converted to the tetrahydrofurans **33** and **34** in a two-step procedure (Scheme 42). First, the homoallylic alcohols were converted to the diols **31** and **32** *via* a hydroboration-oxidation sequence, and subsequent cyclization was achieved with MsCl in the presence of Et$_3$N in CH$_2$Cl$_2$ (the stereochemistry of **33** and **34** was confirmed by NOESY).
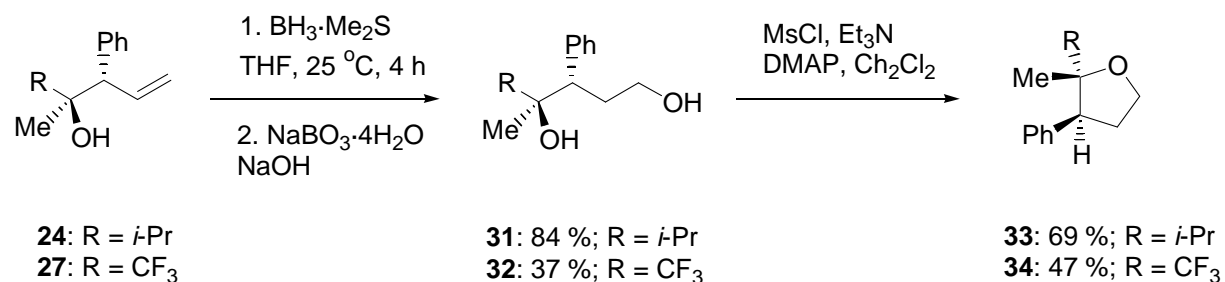
Scheme 42. Synthesis of tetrahydrofurans **33** and **34**.

The structures thus found confirmed that the addition of these allylic zinc reagents to carbonyl derivatives occurs *via* a cyclic chair-like transition state, in which the large group (R_L) is preferentially oriented in the pseudo-equatorial position (Scheme 43).
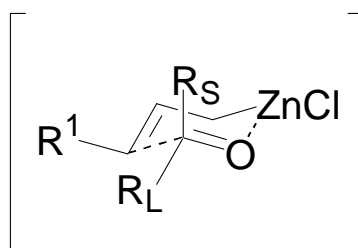
Scheme 43. Postulated cyclic chair-like transition state.

When alkyl vinyl ketones were added to the cinnamylzinc reagent **10** in THF at -78 °C, the diastereoselectivity observed in the corresponding homoallylic alcohols depended of the level of substitution of one of the two moieties (Scheme 44). Thus, when **10** reacted with β-ionone, alcohol **35** was obtained with dr = 66: 34 in 73 % yield. Interestingly, when 2-iodo-cyclohex-2-enone was used as electrophile instead, the alcohol **36** was obtained with good diastereoselectivity (94 %; dr > 99: 1).
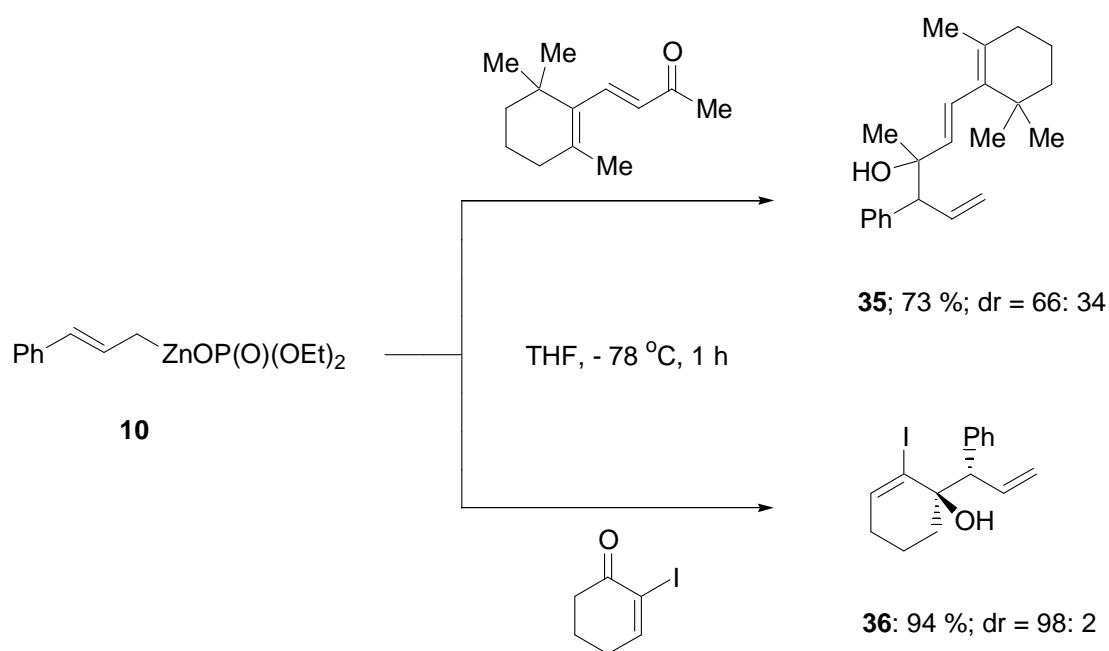
Scheme 44. Reaction of cinnamylzinc phosphate **10** with methyl vinyl ketones.

The trimethylsilyl-substituted allylic zinc reagent **16** was then treated with 4-bromoacetophenone under the same conditions to see if the substitution could affect the high selectivity this addition displayed so far. In this case, the corresponding homoallylic alcohol bearing a vinylsilyl functionality (**37**) was obtained in good yield as a single diastereoisomer (93 %; dr = 98> 2). Unfortunately, in this case, the exact structure of the product could not be assessed with certainty (Scheme 45).[77]
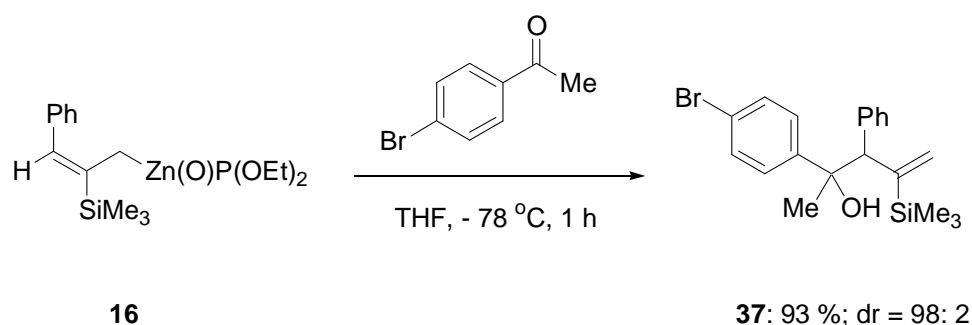
Scheme 45. Diastereoselective reaction of organozinc **16** with 4-bromo-acetophenone.

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[77] All desilylation attempts failed, preventing any comparison with the known desilylated alcohols; see: Sato, F.; Kusakabe, M.; Kobayashi, Y. *J. Chem. Soc., Chem. Commun.* **1984**, 1130.

Finally, the zinc reagent **10** appeared to react with imines as well. Thus, when it was treated with *N*-benzylidene-4-methyl-benzenesulfonamide in THF at -78 °C, the corresponding *syn*-amine **38** was obtained in 74 % within 1 h (98 > 2; Scheme 46).[78]
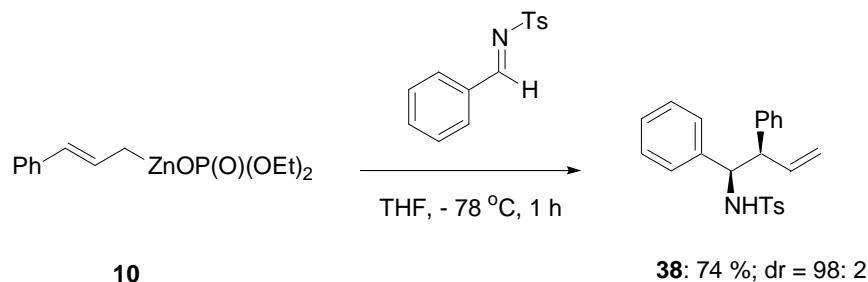
Scheme 46. Addition of cinnamylzinc phosphate **10** to imines.

3.4.   Reaction with α-chiral ketones

3.4.1.   Reaction with α-chiral cyclohexanones

In the previous chapter, it has been shown that allylic zinc reagents, prepared by the LiCl-mediated direct insertion of zinc to allylic chlorides or phosphates, react with carbonyl derivatives in a diastereoselective manner. To investigate the possibility of controlling three adjacent stereocentres *via* this allylmetal addition, it was envisioned to study the condensation of allylzinc reagents with various α-substituted ketones. As cyclic ketones constitute more rigid systems, it was decided to start the study with α-substituted cyclohexanones (Scheme 46 and Table 2). Thus, cinnamylzinc phosphate (**10**) was treated with 2-methyl-cyclohexanone; after 1 h, the reaction was complete and the homoallylic alcohol **39** was isolated in 90 % yield as a single diastereoisomer (dr > 99: 1; Scheme 47).
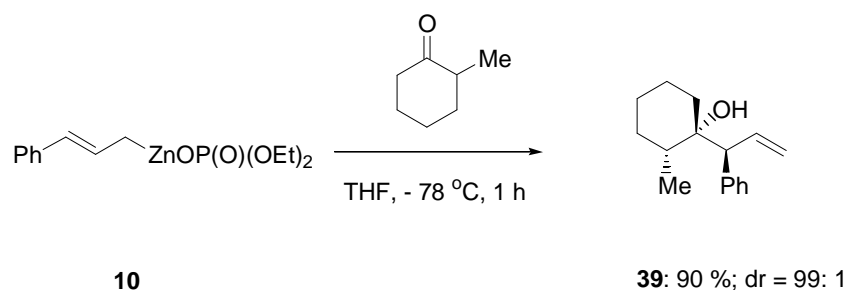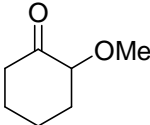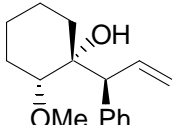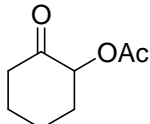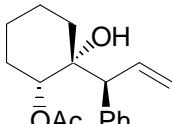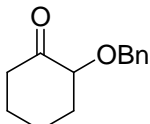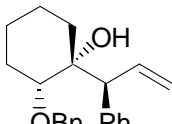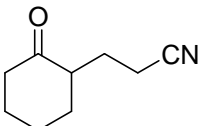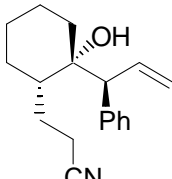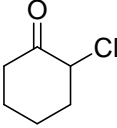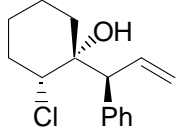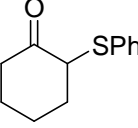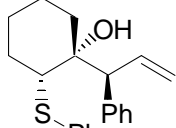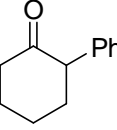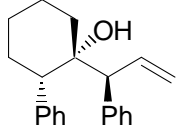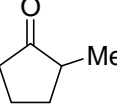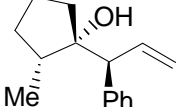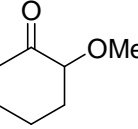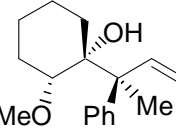
Scheme 47. Diastereoselective addition of allylic reagent **10** to 2-methyl-cyclohexanone

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[78] Stereochemistry determined by literature comparison: Miyabe, H.; Yamaoka, Y.; Naito, T.; Takemoto, Y. *J. Org. Chem.* **2003**, *68*, 6745.

This reaction could then be extended to various α-chiral cyclohexanones, regardless of the substitution pattern in the α-position of the keto function. Thus, α-methoxy cyclohexanone reacted smoothly with **10**, leading to the corresponding homoallylic alcohol (**40**) in 87 % yield and dr > 99: 1 (entry 1 of Table 2) within 1 h at – 78 °C. Likewise, larger substituents like an α-acetoxy or an α-benzyloxy group led to the corresponding homoallylic alcohols **41** and **42** in both good yields and diastereoselectivities (entries 2 and 3). Under the same conditions, 3-(2-oxo-cyclohexyl)-propionitrile reacted with the cinnamylzinc reagent **10** to afford, within 1 h at – 78 °C, compound **43**, whose structure was confirmed by X-ray analysis (92 %; dr > 99: 1; entry 4, see Experimental Part).

Table 2. Reaction of allylic zinc reagents with cyclic α-substituted ketones.[a]

Entry	Allyl zinc reagent	ketone	Product	Yield (%)[b]
1	**10**		**40**; dr = 99: 1	87
2	**10**		**41**; dr = 99: 1	83[c]
3	**10**		**42**; dr = 98: 2	90
4	**10**		**43**; dr = 99: 1	92[c]

5	**10**	ketone with Cl	**44**; dr = 99: 1	73
6	**11**	ketone with SPh	**45**; dr = 99: 1	87
7	**10**	ketone with Ph	**46**; dr = 99: 1	26
8	**10**	cyclopentanone with Me	**47**; dr = 99: 1	75
9	**15**	ketone with OMe	**48**; dr = 86: 14	90

[a] Unless stated otherwise, all reactions were carried out with 1 mmol of ketone and 1.2 mmol of allylic zinc reagent at – 78 ºC for 1 h. [b] Isolated yield of analytically pure compounds. [c] Structure proved by X-ray analysis.

Similarly, other heteroatom-substituted cyclohexanones reacted smoothly with allylic zinc reagents **10** and **11**. Thus, the chloro- and thiophenyl subsituted homoallylic alcohols (**44** and **45**) were both isolated in 73-87 % yield (dr > 98: 2; entries 5 and 6). Interestingly, when 2-phenyl-cyclohexanone reacted with cinnamylzinc phosphate **10** under the same conditions, the corresponding homoallylic alcohol (**46**) could only be isolated in 26 % yield (dr > 98: 2; entry 7). This may be explained by the competitive deprotonation of the benzylic proton α to the keto function. Noteworthy, 2-methyl-cyclopentanone led to the alcohol **47** in 75 % as a single diastereoisomer when reacted with **10** (dr > 99: 1; entry 8). The substitution pattern on the allylic system is important and a decreased diastereoselectivity was observed when the substituted-allylic reagent **15** reacted with 2-methoxy-cyclohexanone, leading to the alcohol **48** in 90 % with dr = 86: 14 (entry 9). Finally, it is interesting to notice that this addition is

only selective with α-substituted ketones; indeed, when cinnamyl zinc chloride **11** was treated with 3-methyl cyclohexanone, only a 1: 1 mixture of diastereoisomers could be isolated.

The selectivity observed in this reaction can be rationalised by considering a cyclic chair-like transition state, where the allylic zinc reagent approaches from the sterically less crowded side (Scheme 48).
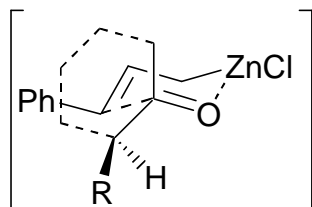
Scheme 48. Postulated cyclic chair-like transition state.

The prepared alcohols proved to be valuable building blocks for the preparation of polycyclic systems. Thus, when 2-allyl-cyclohexanone was added to cinnamylzinc phosphate (**10**), the alcohol **49** was obtained in 83 %, as a single diastereoisomer (dr > 99: 1). Subsequent metathesis[79] with the Grubbs II catalyst (5 mol %)[80] led to the bicyclic alcohol **50** in 93 %, whose structure was confirmed by X-ray analysis (Scheme 49).

10   **49**: 83 %; dr = 99: 1   **50**: 93 %; dr = 99: 1
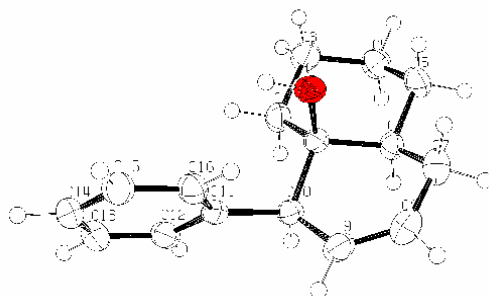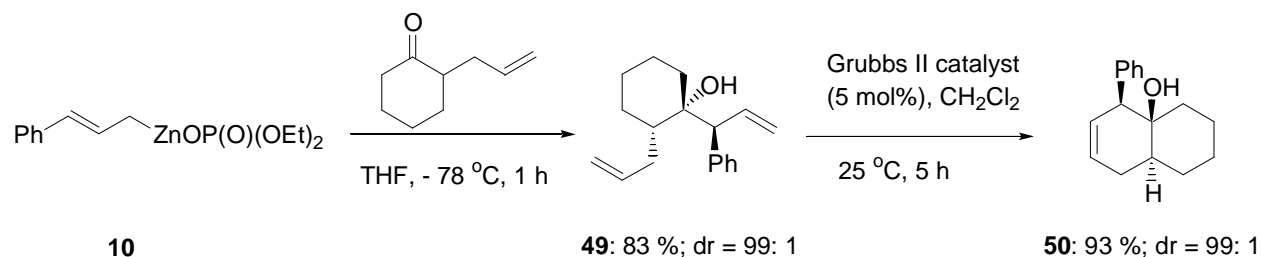
Scheme 49. Preparation of bicyclic alcohol **50** and its ORTEP representation.

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[79] For a review on Ring-Closing Metathesis, see: Grubbs, R. H.; Miller, S. J.; Fu, G. C. *Acc. Chem. Res.* **1995**, *28*, 446.
[80] (a) Trnka, T. M; Grubbs, R. H. *Acc. Chem. Res.* **2001**, *34*, 18. (b) Chatterjee, A. K.; Grubbs, R. H. *Org. Lett.* **1999**, *1*, 1751.

Likewise, it was possible to synthesize spiro-tetrahydrofurans in a two-step procedure starting from the homoallylic alcohols **40** and **42** (Scheme 50). After a hydroboration-oxidation sequence, the corresponding diols **51** and **52** were cyclized by the action of MsCl in the presence of Et$_3$N, leading to the spiro-compounds **53** and **54** in 55-78 % yield (the structure of **54** was confirmed by X-ray analysis).
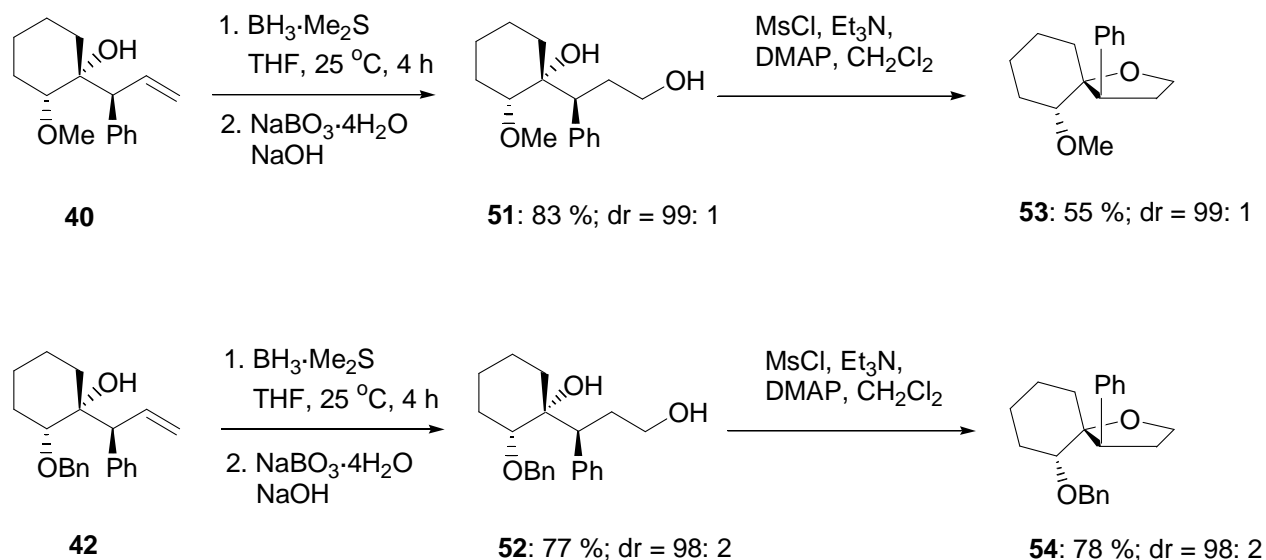
Scheme 50. Preparation of spiro-tetrahydrofurans **53** and **54**.

Finally, the alcohols that were prepared underwent a selective epoxidation directed by the free OH group.[81] Thus, the homoallylic alcohol **39** was treated with *m*-CPBA to yield the corresponding epoxide **55** in 82 %, as a single diastereoisomer. Subsequent LiAlH$_4$-mediated opening of the epoxide led to the diol **56**, bearing four contiguous stereocenters with a defined configuration (Scheme 51).
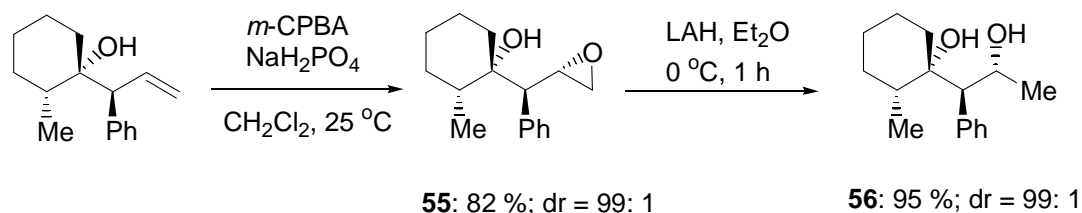
Scheme 51. Selective epoxidation of homoallylic alcohol **39**.

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[81] See: Houk, K. N.; Liu, J.; DeMello, N. C; Condroski, K. R. *J. Am. Chem. Soc.* **1997**, *119*, 10147.

3.4.2. Reaction with acyclic α-chiral ketones

The reaction of allylic zinc reagents with acyclic α-substituted ketones was then studied. Thus, cinnamylzinc chloride **11** was treated with 3-chloro-butan-2-one in THF at – 78 °C. After 1 h, the homoallylic alcohol **57** was isolated in 83 %, as a single diastereoisomer (dr = 98: 2; Scheme 52).
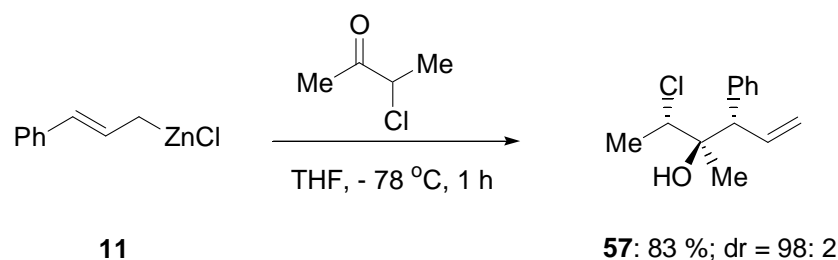
Scheme 52. Reaction of cinnamylzinc chloride 11 with 3-chloro-butan-2-one.

Other 3-halo-butan-2-ones reacted with **11** under the same reaction conditions. Remarkably, the corresponding homoallylic alcohols were not isolated; instead, epoxide **58** was obtained in good yield (Scheme 53). Likewise, 3-tosyloxy-butan-2-one led to epoxide **58**, when reacted with cinnamylzinc chloride **11**. In this case, the observed selectivity can be explained considering the Cornforth model.[82]
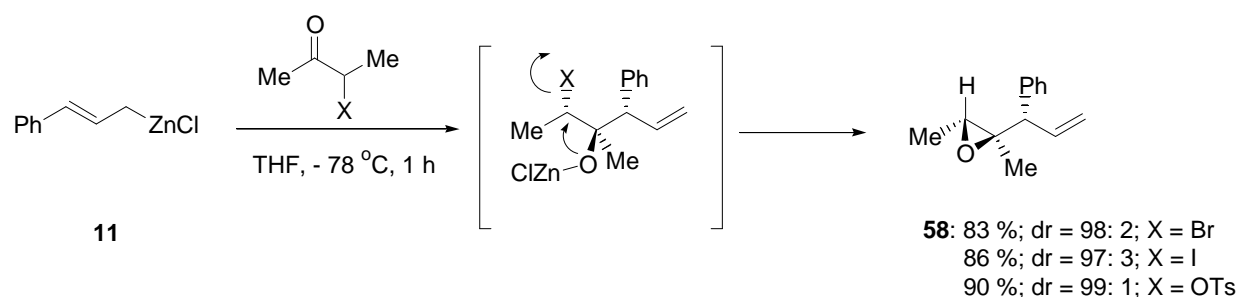
Scheme 53. Diastereoselective formation of epoxide **58**.

[82] (a) Cornforth, J. W.; Cornforth, R. H.; Mathew, K. K. *J. Chem. Soc.* **1959**, 112. (b) Evans, D. A; Siska, S. J.; Cee, V. J. *Angew. Chem. Int. Ed.* **2003**, *42*, 1761. (c) Cee, V. J.; Cramer, C. J.; Evans, D. A. *J. Am. Chem. Soc.* **2006**, *128*, 2920.

When non-halide groups like Ph or SPh were used as substituents, the reaction afforded the corresponding homoallylic alcohols in high yields, but with lower selectivity (Scheme 54). Thus, the alcohol **59** was isolated in 87 % with a dr = 91: 9. Under the same conditions, the thiophenyl-alcohol **60** was obtained in almost quantitive yield, as a mixture of two diastereoisomers (96 %; dr = 81: 19).
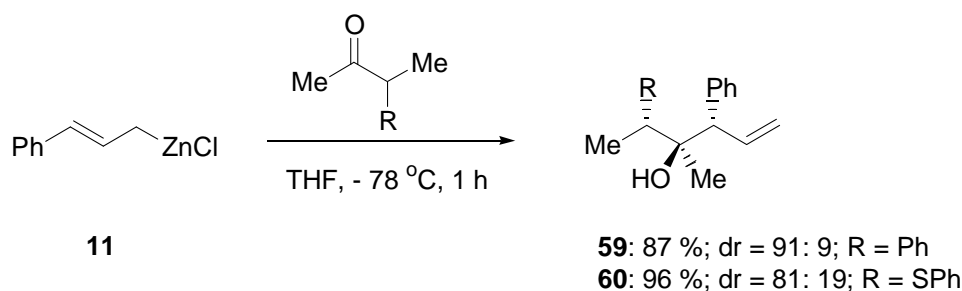
Scheme 54. Reaction of cinnamylzinc chloride **11** with α-substituted butanones.

3.4.3. Application to enantioenriched α-chiral ketones

This diastereoselective allylmetal addition could also be successfully applied to enantioenriched α-chiral ketones, leading to the corresponding homoallylic alcohols without loss of stereoselectivity. Thus, when (2*S*)-2-methoxy cyclohexanone[83] (**(2S)-2b**; 94 % *ee*) was treated with cinnamylzinc phosphate (**10**) at – 78 ºC for 1 h, the corresponding alcohol **(2S,1R,1´S)-40** was obtained in 81 % (dr > 99: 1; 94 % *ee*, Scheme 55). Likewise, the reaction of (3*R*)-3-tosyloxy-butanone[84] with **11** led to the enantioenriched epoxide **58** which, upon treatment with LiAlH$_4$ afforded the homoallylic alcohol **29** in good yield (87 %; dr > 99: 1; 99 % *ee*; Scheme 54). This result contrasts with the direct reaction of butanone with cinnamylzinc chloride (**11**) that displays a poor diastereoselectivity (dr = 61: 39, see Scheme 41.

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[83] Prepared by the PDC oxidation of the commercially available (2*S*)-methoxy-cyclohexan-(1*S*)-ol.
[84] Prepared from the commercially available (2*R*),(3*R*)-butan- 2,3-diol in a two step sequence: monotosylation and PDC oxidation.
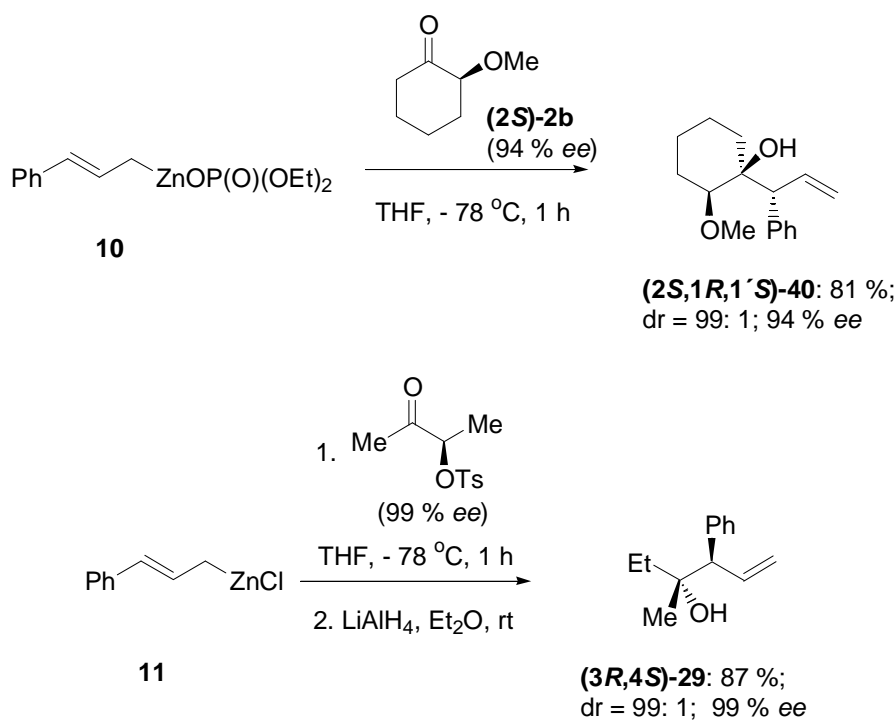
Scheme 55. Enantioselective preparation of homoallylic alcohol **29**.

3.5. Direct "zinc-ene" reaction from allylic chlorides

The stereochemistry control in C-C bond formation is one of the major challenges in organic synthesis. "Metallo-ene" reactions have already shown that they were powerful tools to achieve stereocontrol in cyclic molecules. They have therefore found many applications in the synthesis of naturally occurring substances (Scheme 56).[17,18,38,39,85]

(-)-erythrodiene   (+)-spirojatamol   chokol-A
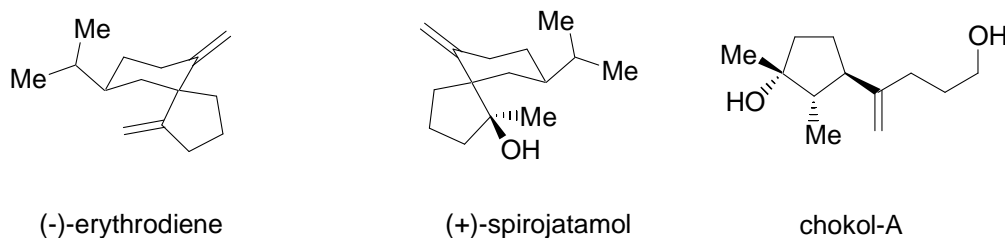
Scheme 56. Natural products prepared *via* a "metallo-ene" reaction according to *Oppolzer*.

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[85] Chalker, J. M.; Yang, A.; Deng, K.; Cohen, T. *Org. Lett.* **2007**, *19*, 3825.

Although "magnesium-ene" reactions could be directly carried out from allylic chlorides, "zinc-ene" cyclisations have been so far achieved by generating *in situ* the adequate allylic zinc species, either *via* transmetallation[38] or *via* a Pd(0) catalysis.[39] Since the LiCl-mediated direct insertion of zinc to allylic chlorides or phosphates proved to be an efficient and convenient tool for preparing allylic zinc species, it was envisioned to perform a direct "zinc-ene" reaction from allylic chlorides that would lead to stereoselectively defined carbo- and heterocycles.

The required starting allylic chlorides were prepared in high yields from the corresponding aldehyde *via* a two-step sequence: addition of vinylmagnesium chloride, followed by a treatment with thionyl chloride (Scheme 57). Noteworthy, these chlorides were generally not obtained as a single compound, but as an inseparable mixture of allylic chlorides. This did not prove to be a problem as the subsequent zinc insertion led to a single zinc species.
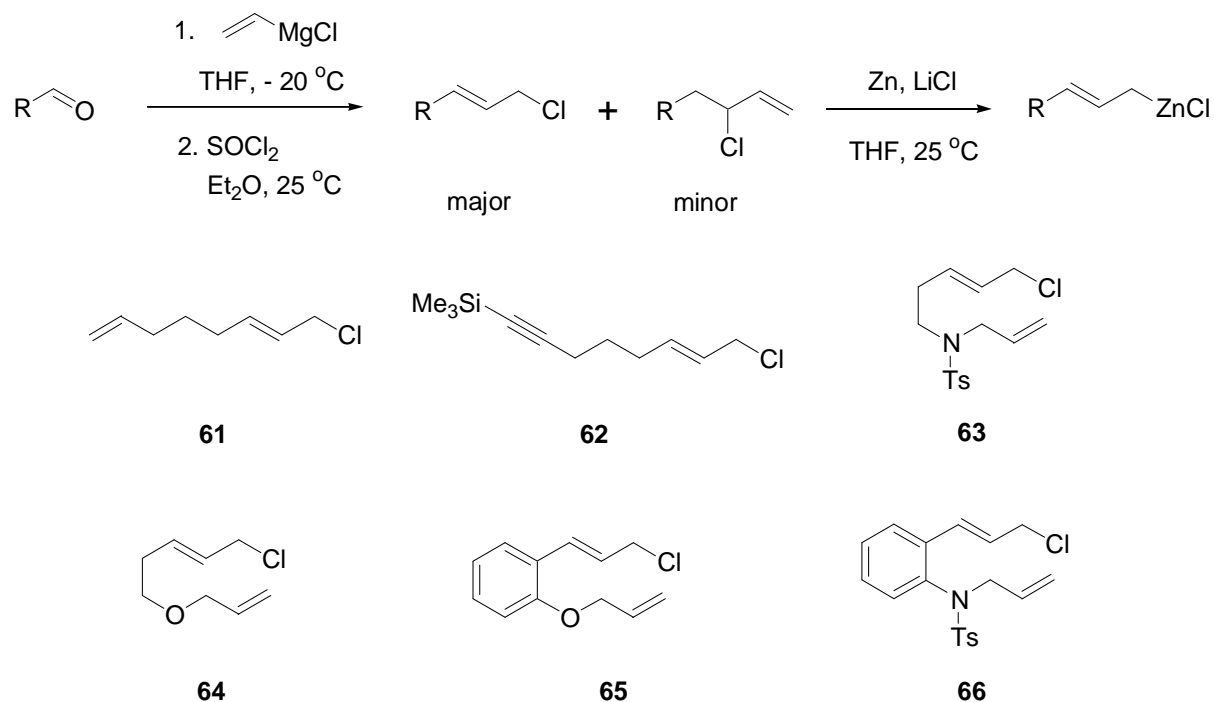
Scheme 57. Synthesis of the starting allylic chlorides.

When allyl chloride **61** was treated with zinc (6 equiv.) and LiCl (3 equiv.) in THF at 25 °C, the reaction was complete within 20 h and subsequent quench with iodine afforded the *cis*-cyclopentane **67** in 71 % yield (dr = 99: 1, Scheme 58).
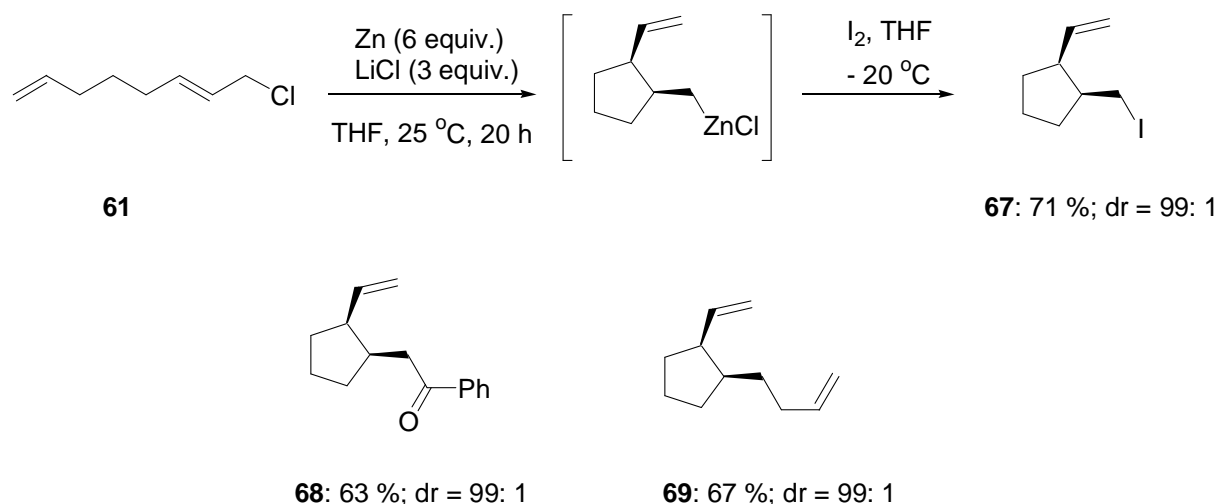
Scheme 58. Diastereoselective "zinc-ene" reactions.

Likewise, the intermediate zinc species could be quenched with benzoyl chloride (after transmetallation with CuCN·2LiCl) or allyl bromide (under copper catalysis), leading to the cyclopentane derivatives **68** and **69** in 63 % and 67 % yield respectively and dr > 99: 1. Interestingly, **69** led to the bicyclic species **70** *via* a metathesis[79] reaction (Scheme 59). Finally, it is important to notice that only the cyclised alkylzinc reagent could be observed during the reaction, which indicates that the cyclisation step was quicker than the zinc insertion itself.
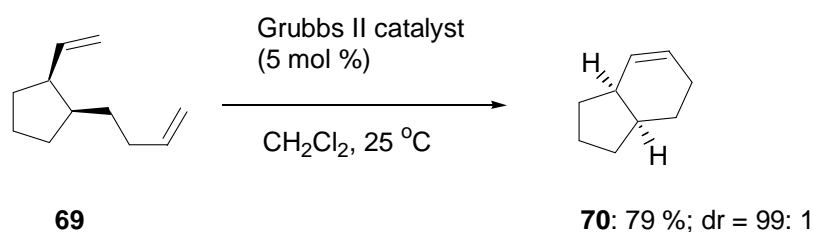
Scheme 59. Synthesis of **70** *via* a metathesis reaction.

The *cis*-selectivity observed can be rationalised by the cyclic chair-type transition state depicted in Scheme 60.[17]
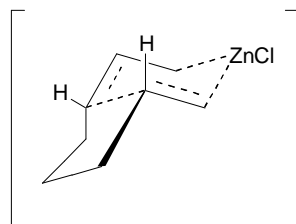
Scheme 60. Tentative cyclic chair-like transition state.

The intramolecular "zinc-ene" reaction with alkynes was then studied. Thus, when the allylic chloride **62** was treated with zinc (6 equiv.) and LiCl (3 equiv.) in THF at 25 ºC, the corresponding cyclic organozinc species formed smoothly within 40 h. This alkenylzinc reagent could then be quenched with various electrophiles, such as iodine or allyl bromide, to afford the cyclic compounds **71** and **72** in 64 % and 61 % yield respectively (Scheme 61). Compound **72** could then be reacted in a metathesis reaction,[79] to yield the bicyclic vinylsilane **73** in 84 % yield.
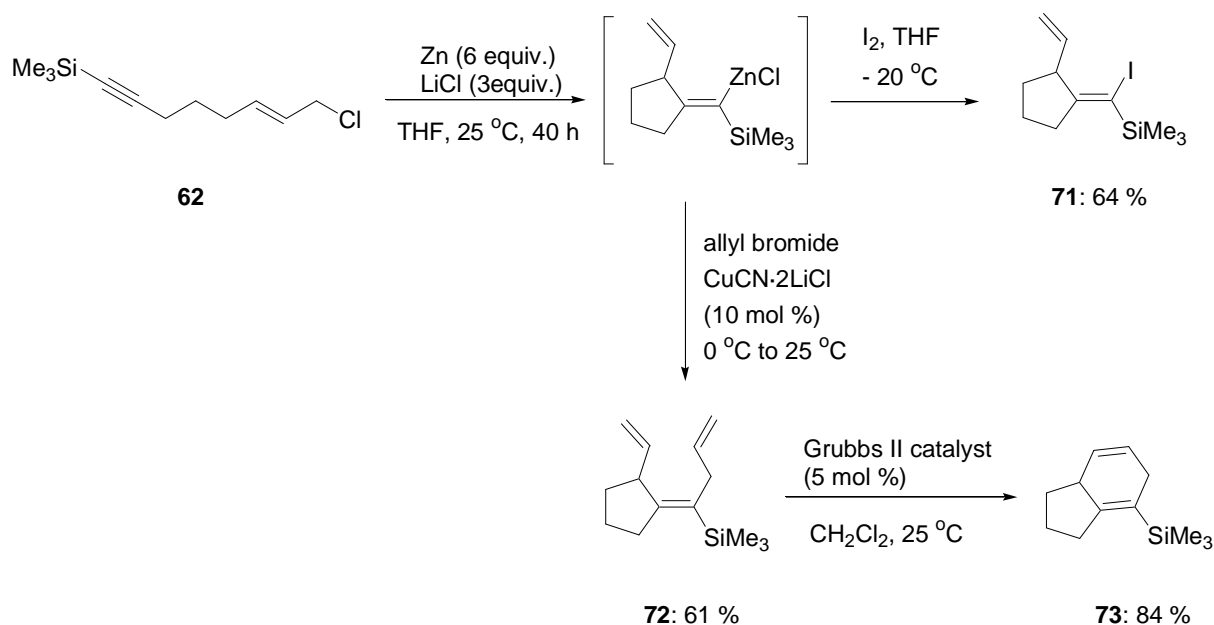
Scheme 61. Cyclisation with alkynes.

This reaction was then used to prepare different heterocycles. Thus, the LiCl-mediated direct zinc insertion to allylic chloride **63** led to the corresponding cyclic organozinc species

within 40 h at 25 ºC. Subsequent quench with iodine or allyl bromide afforded the substituted *cis*-piperidines **74** and **75** in 74 % and 73 % yield respectively (dr = 95: 5; Scheme 62). Likewise, tetrahydro-2*H*-pyran derivative **76** could be synthesised starting from allylic chloride **64** in 65 % (dr = 93: 7). In this case, the zinc insertion was achieved within 15 h at room temperature but the subsequent intramolecular cyclisation required another 55 h to go to completion. Furthermore, treatment of piperidine **75** with Grubbs II catalyst[80] (5 mol %) led smoothly to the tetrahydroiosoquinoline **75a** in almost quantitative yield, extending the scope of the reaction to the formation of bicyclic heteroaromatics.

63: X = NTs
64: X = O

74: 74 %; dr = 95: 5   **75**: 73 %; dr = 95: 5   **76**: 65 %; dr = 93: 7
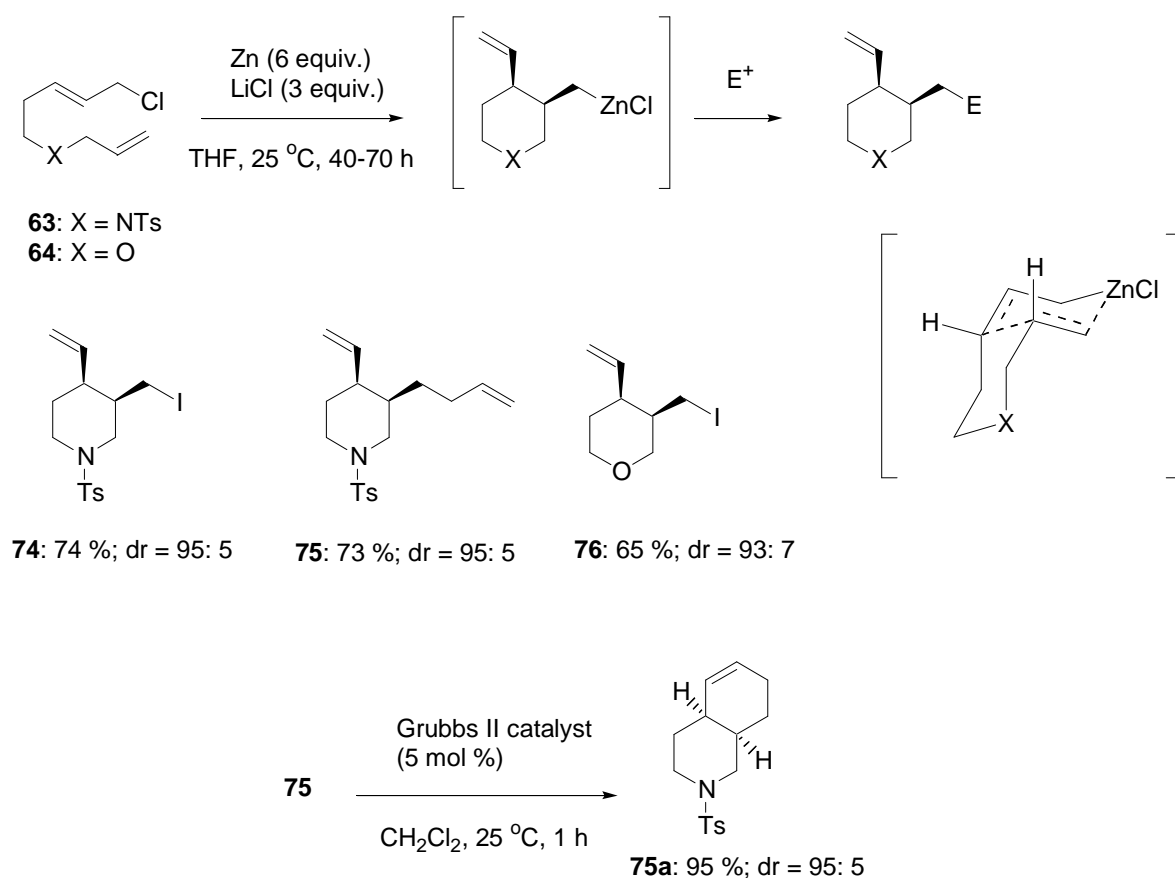
Scheme 62. Preparation of piperidine and tetrahydropyran derivatives.

Finally, this direct intramolecular "zinc-ene" reaction was applied to the synthesis of tetrahydroquinoline derivatives **77** and **78**, and to the preparation of substituted dihydrochromene **79** from the allylic chlorides **65** and **66** (Scheme 63). Interestingly, in this case, the stereochemistry was inversed and the *trans* compounds were obtained. This result

can be rationalised by considering that the cinnamyl-derived zinc reagents exist in the (*E*)-form in the cyclic chair-like transition state depicted in Scheme 63.

77: 70 %; dr = 98: 2   **78**: 68 %; dr = 98: 2   **79**: 64 %; dr = 82: 18
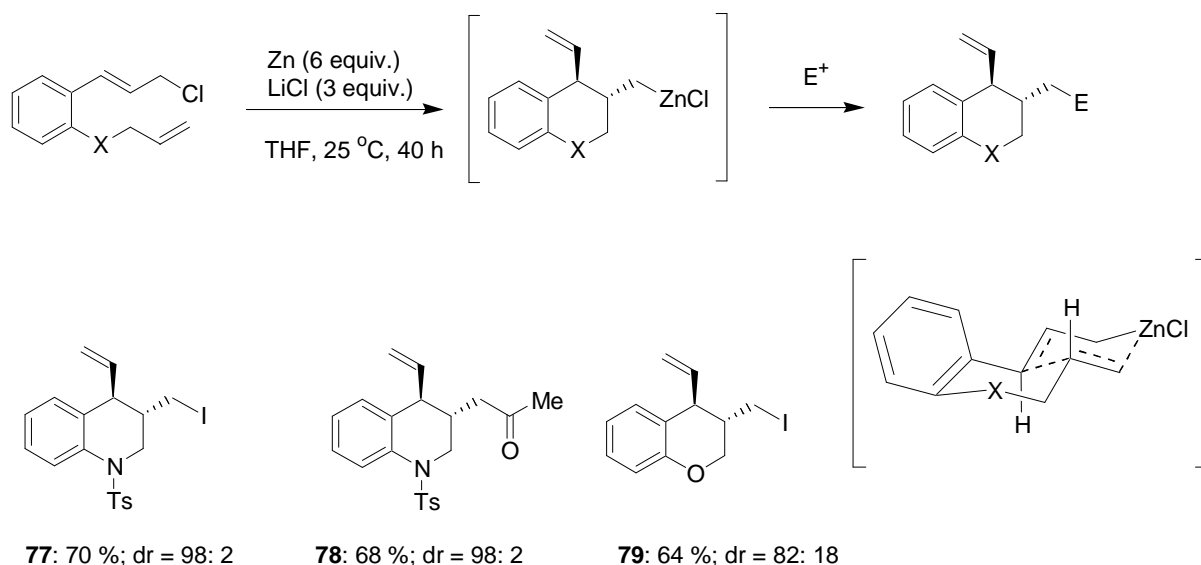
Scheme 63. Preparation of heterocycles **77**-**79** and ORTEP representation of **78**.

3.6.   Conclusion

In this section, it has been shown that allylic zinc reagents could be readily prepared from the corresponding allylic chlorides or phosphates using *via* a direct LiCl-mediated insertion of zinc. These organometallics then reacted with various carbonyl derivatives, under very mild conditions (1 h at – 78 ºC), to yield the corresponding homoallylic alcohols in good yields in a very diastereoselective manner. This allylzinc addition could even be extended to α-chiral ketones, leading to alcohols with three defined stereocentres. Finally, it was possible

to carry out a direct "zinc-ene" reaction from allylic chlorides, leading diastereoselectively to various carbo- and heterocycles in moderate to good yields.

4.   New transition metal-catalyzed cross-coupling reaction

4.1.   Highly stereoselective cobalt-catalyzed allylation of functionalized diarylzinc reagents

Palladium-, nickel- and copper-catalyzed cross-couplings between allylic substrates and organometallic reagents are among the most useful reactions catalyzed by transition metals.[86] Less attention, though, was given to other transition metals, particularly to cobalt.[64,6587] Furthermore, numerous natural products or molecules of pharmaceutical interest present an allyl-aryl core (Scheme 64), which is often synthesized by the addition of an aryl lithium species to an allyl bromide. This method, though efficient, presents a very low tolerance toward functional groups. Thus, it was decided to investigate an allylation reaction with which functional groups could be tolerated.

Surangin B

Schweinfurthin A; R = H
Schweinfurthin B; R = Me
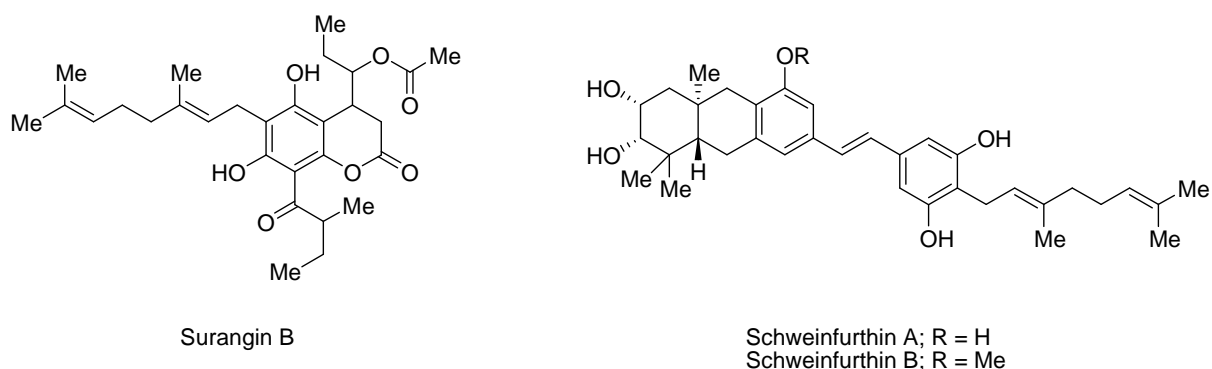
Scheme 64. Molecules of intrests presenting an allyl-aryl core.

Recently, a stereoselective cobalt (II)-catalyzed cross-coupling reaction between alkylzinc halides or dialkylzinc reagents and allylic chlorides or phosphates was described. It

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[86] (a) Tamao, K. In: Trost, B. M., Fleming, I. and Pattenden, G., Editors, *Comprehensive Organic Synthesis* Vol. 3, Pergamon, Oxford (1991) Chapter 2.2.10.4. (b) Tsuji, J. *Palladium Reagents and Catalysts*, Wiley, Chichester (1995). (c) Negishi, E. and Liu, F. In: Negishi, E., Editor, *Handbook of Organopalladium Chemistry for Organic Synthesis*, Wiley, New York (2002) Chapter III.2.9 and Chapter III.2.10. (d) Takahashi, T. and Kanno, K. In: Tamaru, Y., Editor, *Modern Organonickel Chemistry*, Wiley-VCH, Weinheim (2005) Chapter 2.3. (e) Shintani, R. and Hayashi, T. In: Tamaru, Y., Editor, *Modern Organonickel Chemistry*, Wiley-VCH, Weinheim (2005) Chapter 9.2. (f) Magid, R. M. *Tetrahedron* **1980** (36), 1901–1930. (g) Lipshutz, B. H. and Sengupta, S. *Org. React.* **1992**, *41*, 135–631. (h) Karlström, A. S. E. and Bäckvall, J.-E. In: Krause, N., Editor, *Modern Organocopper Chemistry*, Wiley-VCH, Weinheim (2002), 259–288. (i) Yorimitsu, H.; Oshima, K. *Angew. Chem., Int. Ed.* **2005**, *44*, 4435.
[87] Mizutani, K.; Yorimitsu, H.; Oshima, K. *Chem. Lett.* **2004**, *7*, 832.

led exclusively to the S_N2-substitution products with full retention of the double bond configuration.[63] It was therefore envisioned to extend this method to highly functionalized diarylzinc reagents, which can be obtained from the corresponding aryl iodides *via* a direct iodine-zinc exchange[88] (Scheme 65).
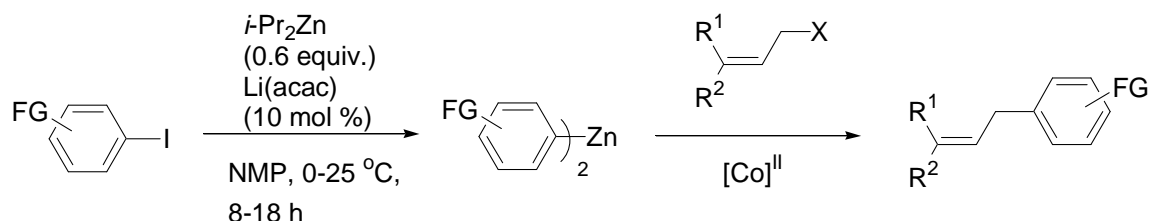
Scheme 65. Cobalt-catalyzed allylation of diaryl zinc reagents.

First, geranyl chloride was treated with diphenylzinc in the presence of a cobalt(II) salt. A systematic study showed that the best results were obtained when geranyl chloride (**80**, 1 equiv.) was treated with diphenylzinc (**85**; 1.3 equiv.) in NMP, in the presence of Co(acac)$_2$ (10 mol % ; Table 3). In this case, the reaction was complete within 1 h, yielding (*E*)-(3,7-dimethyl-octa-2,6-dienyl)-benzene (**95**) in 87 % yield. Interestingly, when the reaction was performed in THF, the amount of homocoupling product increased and the conversion was only 65 % after 1 h at 0 °C.

Table 3. Optimisation of the reaction conditions.

_____
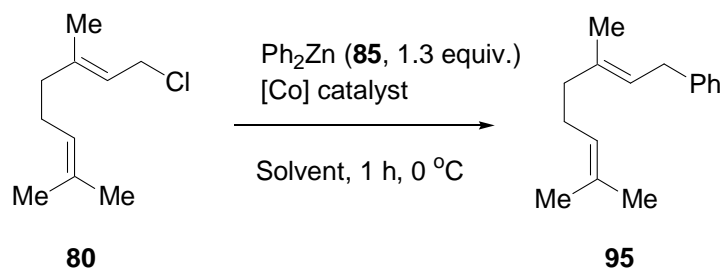
[88] Kneisel, F. F.; Dochnahl, M.; Knochel, P. *Angew. Chem. Int. Ed.* **2004**, *43*, 1017.

Entry	Catalyst	Solvent	Conversion (%)[a]
1	CoBr$_2$ (10 mol %)	NMP	50
2	Co(acac)$_2$ (2.5 mol %)	NMP	24
3	Co(acac)$_2$ (5 mol %)	NMP	75
4	Co(acac)$_2$ (10 mol %)	NMP	100 (52[b], 82[c])
5	Co(acac)$_2$ (10 mol %)	THF	65[d]
6	Ni(acac)$_2$ (1 mol %)	NMP	39

[a] GC conversion after 1h. [b] 0.65 equiv. of Ph$_2$Zn was used. [c] 1 equiv. of Ph$_2$Zn was used. [d] Large amounts of homocoupling product were observed.

The reaction of the functionalized zinc reagent **86** with geranyl chloride was then investigated. Under the same conditions, the benzoate **96** was isolated in 72 % (entry 1 of Table 4). This reaction proceeded similarly when the zinc reagent **86** was formed in a two-step procedure (an iodine-magnesium exchange,[89,90] followed by a transmetallation with 0.5 equiv. of ZnBr$_2$), yielding **96** in 69 % yield. Other functionalities are also tolerated in these cross-couplings. Thus, the diarylzinc reagent **87**, bearing a cyano functionality, reacted smoothly with geranyl chloride affording the benzonitrile **97** in 75 % yield (entry 2). In a similar manner, di(3-trifluoromethyl-phenyl)zinc (**88**), and di(2-bromo-phenyl)zinc (**89**) reacted with geranyl chloride, leading to the (*E*)-dienes **98** and **99** in 87 % and 72 % yield respectively (entries 3 and 4). Even the bulkier zinc reagent dinaphthylzinc (**90**) reacted smoothly under these conditions conditions, leading to the expected diene **100** in 82 % yield. Interestingly, when we performed this allylation with neryl chloride (**81**), only (*Z*)-dienes were obtained, showing that the configuration of the double bond has been preserved throughout the process. Thus, when neryl chloride was reacted with the functionalised diarylzinc reagents **88**, **91** and **92**, the corresponding (*Z*)-dienes **101**-**103** were isolated in 76-78 % yield (entries 6-8).

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[89] Recent review : Knochel, P.; Dohle, W.; Gommermann, N.; Kneisel, F. F.; Kopp, F.; Korn, T.; Sapountzis, I.; Vu, V. A. *Angew. Chem. Int. Ed. Engl.* **2003**, *42*, 4302.
[90] For recent advances in halogen-magnesium exchange, see : a) Krasovskiy, A.; Knochel, P., *Angew. Chem. Int. Ed.* **2004**, *43*, 3333. (b) Liu, C. -Y.; Knochel, P., *Org. Lett.* **2005**, *7*, 2543. (c) Ren, H.; Krasovskiy, A.; Knochel, P., *Chem. Commun.* **2005**, 543. (d) Ren, H.; Krasovskiy, A.; Knochel, P., *Org. Lett.* **2004**, *6*, 4215.

Table 4. Reaction of allylic chlorides and phosphates with functionalized diarylzinc reagents.

$$X = Cl, OP(O)(OEt)_2$$
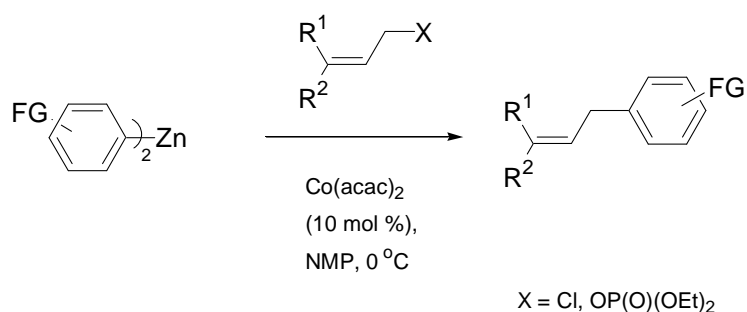
Entry	Allyl chloride or phosphate	Diarylzinc reagent	Product	Yield[a] (%)
1	Geranyl chloride (**80**)	FG = p-CO$_2$Et (**86**)	**96**	72 (69)[b] (> 98 % E)
2	**80**	FG = m-CN (**87**)	**97**	75 (> 98 % E)
3	**80**	FG = m-CF$_3$ (**88**)	**98**	87 (> 98 % E)
4	**80**	FG = o-Br (**89**)	**99**	72 (> 98 % E)
5	**80**	Dinaphthylzinc (**90**)	**100**	82 (> 98 % E)
6	Neryl Chloride (**81**)	**88**	**101**	78 (> 98 % Z)
7	**81**	FG = p-CO$_2$Me (**91**)	**102**	76 (> 98 % Z)

8	**81**	FG = *m*-Br (**92**)	**103**	76 (> 98 % *Z*)
9	Geranyl phosphate (**82**)	**91**	**104**	68 (> 98 % *E*)
10	**82**	FG = *m*-OMe (**93**)	**105**	71 (> 98 % *E*)
11	**82**	FG = *p*-OPiv (**94**)	**106**	64 (> 98 % *E*)
12	Neryl phosphate (**83**)	**88**	**107**	70 (> 98 % *Z*)
13	**83**	**90**	**108**	73 (> 98 % *Z*)
14	**83**	**93**	**109**	77 (> 98 % *Z*)
15	Cinnamyl phosphate (**84**)	**91**	**110**	67 (> 98 % *E*)

[a] Isolated yield of anatically pure compounds. [b] The zinc reagent was prepared through an I-Mg exchange, followed by a transmetallation with $ZnBr_2$ (0.5 equiv.).

This allylic reaction was then extended to the more easily available allylic phosphates. Thus, when di(4-methylcarbetoxy-phenyl)zinc (**91**) reacted with geranyl phosphate (**82**) , the expected (*E*)-diene **104** was obtained in 68 % yield. In a similar manner, the diene **105** and the pivalate **106** were isolated in 64-71 % yield (entries 10 and 11). Under the same conditions, neryl phosphate (**83**) led to the (*Z*)- dienes **107**-**109** in moderate to good yields (entries 12-14). When cinnamyl phosphate (**84**) reacted with **91**, the configuration of the double bond was also retained, leading to the expected product **110** in 67 % yield (entry 15).

Diheteroarylzinc reagents could also be used as substrates. Thus, di(5-iodo-thiophen-2-yl)zinc (**111**) was prepared *via* a direct iodine-zinc exchange[88] and reacted with geranyl chloride (**80**), yielding the expected (*E*)-diene **113** in 77 % (Scheme 66). In a similar manner, the thiophene derivative **114** was formed in 78 %, showing that a keto function was also tolerated.
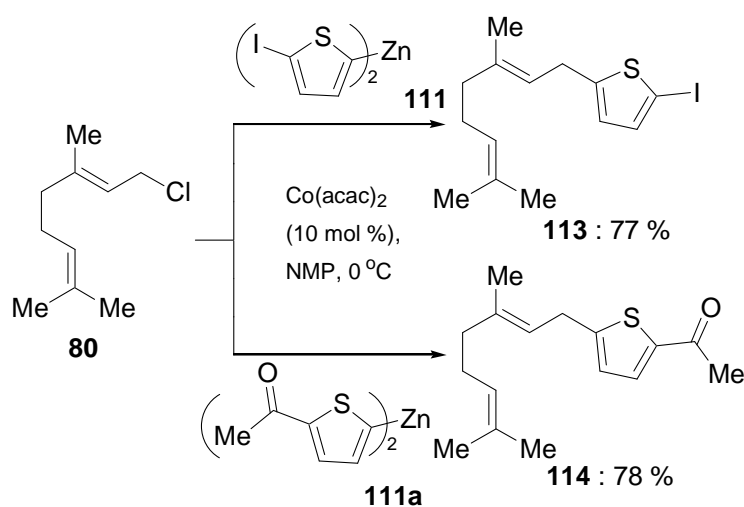
Scheme 66. Reaction of geranyl chloride with diheteroaryl zinc reagents.

This cross-coupling reaction was finally applied to an expedient synthesis of Nocarasin C,[91] a metabolite from the Actinomycete *Nocardia Brasiliensis*, exhibiting some cytotoxic activity (Scheme 67). After a regioselective iodination of 3-hydroxy-benzoic acid (**115**), and subsequent methylation with dimethyl sulfate in acetone, the corresponding methyl-4-iodo-3-methoxy-benzoate (**116**) was obtained in 60 %. A direct I-Zn exchange with *i*-Pr$_2$Zn and Li(acac) in NMP (20 °C, 12 h) afforded the correponding diarylzinc reagent (**117**) which reacted with geranyl chloride in the presence of Co(acac)$_2$, (10 mol %) leading to Nocarasin C (**118**) in 78 % yield.

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[91] Tsuda, M.; Nemoto, A.; Komaki, H.; Tanaka, Y.; Yazawa, K.; Mikami, Y.; Kobayashi, J. *J. Nat. Prod.* **1999**, *62*, 1640.
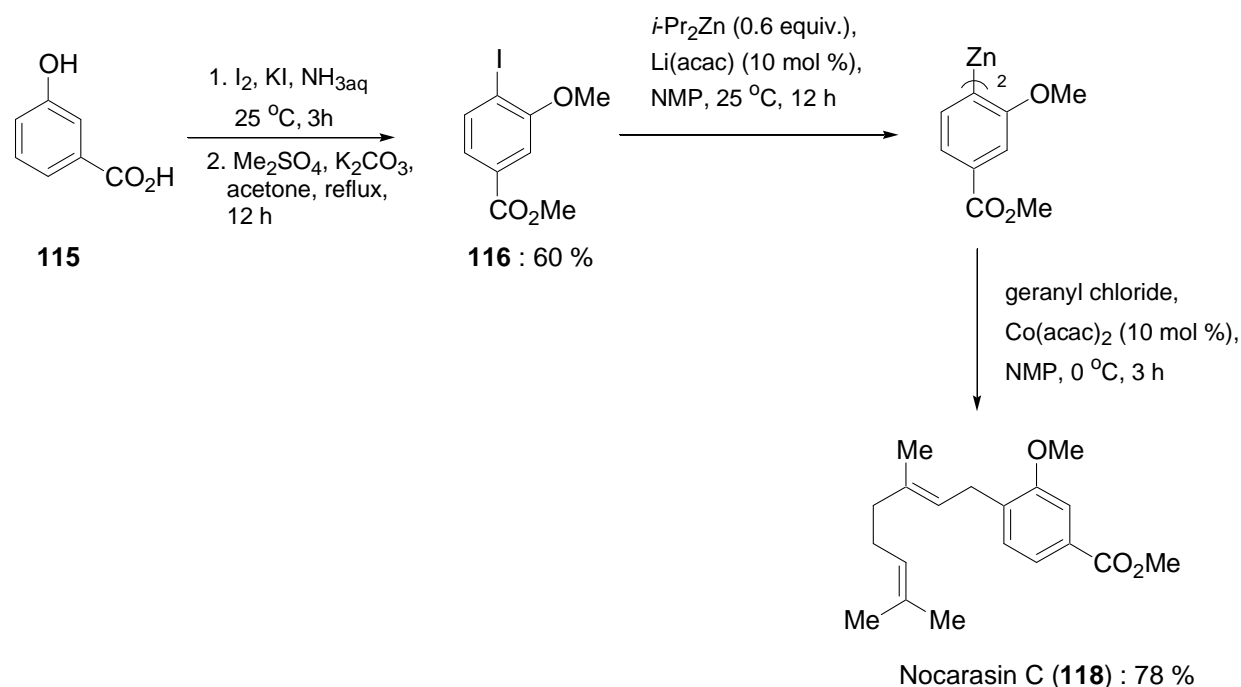
Scheme 67. Synthesis of Nocarasin C.

In summary, a cobalt-catalyzed allylation reaction of diarylzinc reagents was developed. Under the reaction conditions, the cross-couplings were highly stereoselective, and provided the S_N2 products with retention of the double bond configuration. Functionalities like an ester, a ketone, or a nitrile were perfectly tolerated, which makes this cross-coupling particularly attractive for the synthesis of polyfunctional target molecules.

4.2. Iron-catalyzed cross-coupling between alkenyl and dienyl sulfonates and functionalized arylcopper reagents

Palladium- and nickel-catalyzed cross-coupling reactions have been extensively used for forming new carbon-carbon bonds between $C(sp^2)$ centers.[46,92] Recently, iron- and cobalt-catalyzed reactions have also been reported.[47-56,93] Whereas arylmagnesium derivatives react

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[92] (a) *Cross-Coupling Reactions. A Practical Guide* Top. Curr. Chem. **2002**, 219. (b) *Transition Metals for Organic Synthesis* (Eds. Beller, M.; Bolm,C.) Wiley VCH, Weinheim, **1998**.
[93] (a) Tamura, M.; Kochi, J. K., *J. Organomet. Chem.* **1971,** *31,* 289. (b) Tamura, M.; Kochi, J. K., *Bull. Chem. Soc. Jpn.* **1971**, *44*, 3063. (c) Kochi, J. K., *Acc. Chem. Res.* **1974**, *7*, 351. (d) Smith, R. S.; Kochi, J. K., *J. Org. Chem.* **1976**, *41*, 502. (e) Cahiez, G.; Marquais, S., *Pure Appl. Chem.* **1996**, *68*, 669. (f) Fakhfakh, M. A.; Franck, X.; Hocquemiller, R.; Figadère, B., *J. Organomet. Chem.* **2001**, *624*, 131. (g) Hocek, M.; Dvoráková, H., *J. Org. Chem.* **2003**, *68*, 5773. (h) Hölzer, B.; Hoffmann, R. W., *Chem. Comm.* **2003**, 732. (i) Ojo, M.; Murakami, Y.; Aihara, H.; Sakuragi, R.; Baba, Y.; Hosomi, A., *Angew. Chem. Int.Ed.* **2001**, *40*, 621. (j)

with aryl halides to give homocoupling products, it was found that the corresponding arylcopper derivatives give mainly the desired cross-coupling products.[55,62] It was therefore envisioned to investigate an iron(III)-catalyzed cross-coupling between the alkenyl triflates and nonaflates **119-122** and the functionalized arylcopper derivatives **123**-**130** prepared from the corresponding arylmagnesium derivatives.[89,90] As depicted in Scheme 68 and Table 5, the cross-coupling reaction occurs readily in DME at 25 °C leading to products **131**-**142** in 54-90 % yield.

119 : $R^1=CF_3$; $R^2=Ph$; $R^3=H$
120 : $R^1=C_4F_9$; $R^2=Ph$; $R^3=H$
121 : $R^1=C_4F_9$; $R^2=H$; $R^3=H$

56-90%
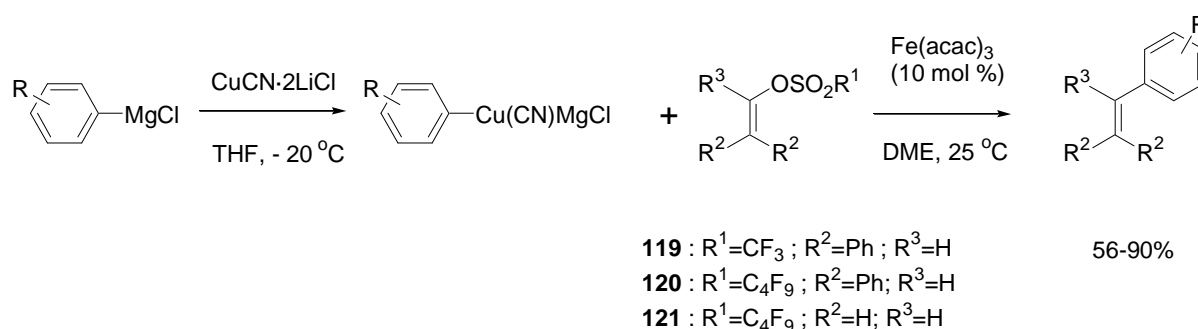
Scheme 68. Iron-catalyzed cross-coupling between alkenyl sulfonates and functionalized arylcopper reagents.

Thus, the alkenyl triflate **119**[94] reacted with phenylcopper (**123**) to afford the corresponding tri-substituted alkene **131** in 86 % yield within 1 h at room temperature (entry 1 of Table 5). Interestingly, alkenyl nonaflate **120**[95] showed a similar reactivity towards arylcopper reagents. Thus, when **120** was treated with phenylcopper (**123**) in the presence of Fe(acac)$_3$ (10 mol %), 2,2-diphenylvinylbenzene (**131**) was isolated in 81 % (entry 2). Remarkably, electron-poor arylcopper derivatives reacted well with the corresponding alkenyl sulfonates to provide the expected products in good yields. Thus, *p*-carbethoxy-phenylcopper (**124**) underwent a smooth cross-coupling reaction with triflate **119** producing ethyl 4-(2,2-diphenylvinyl)-benzoate (**132**) in 77% yield (entry 3). Under these conditions, 3-trifluoromethyl-phenylcopper (**125**) reacted with **119** to afford the expected alkene **133** in 74% yield (entry 4). A cyano functionality was also tolerated as the copper derivative **126**

Nakamura, N.; Hirai, A.; Nakamura, E., *J. Am. Chem. Soc.* **2001**, *122*, 978. (k) Alvarez, E.; Cuvigny, T.; du Penhoat, C. H.; Julia, M., *Tetrahedron* **1998**, *44*, 119. (l) Finandanese, V.; Marchese, G.; Martina, V.; Ronzini, L., *Tetrahedron Lett.* **1984**, *25*, 4805. (m) Nakamura, M; Matsuo, K.; Ito, S.; Nakamura, E., *J. Am. Chem.Soc.* **2004**, *126*, 3686. (n) Nagano, T.; Hayashi, T., *Org. Lett.* **2004**, *6*, 1297. (o)
[94] Prepared by treating 2,2-diphenylacetaldehyde with 1.4 equiv. of t-BuOK in refluxing THF for 4 h and quenching of the resulting enolate with *N*-phenyl-bis-(trifluoromethanesulfonimide) (Ph-NTf$_2$).
[95] Prepared by treating 2,2-diphenylacetaldehyde with 1.4 equiv. of t-BuOK in refluxing THF for 4 h and quenching of the resulting enolate with nonafluorobutanesulfonyl fluoride (Nf-F).
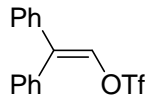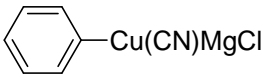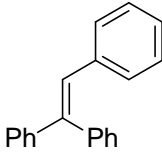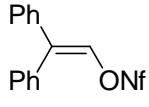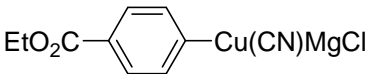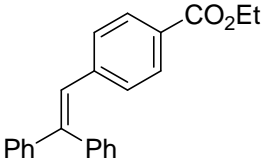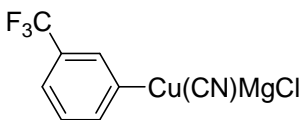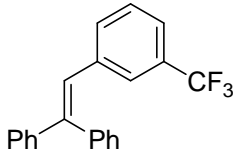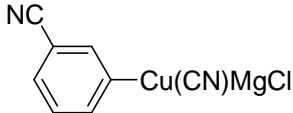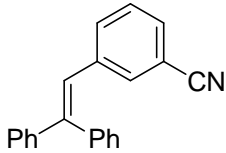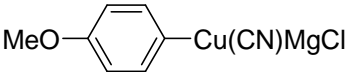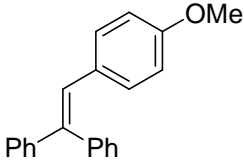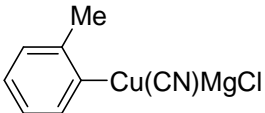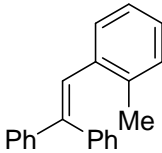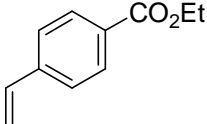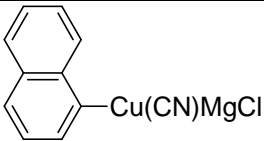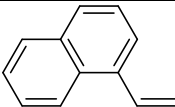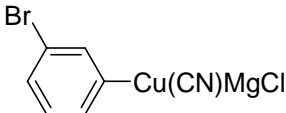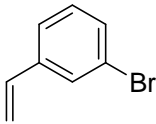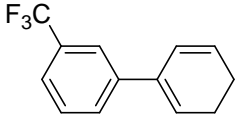
reacted with the alkenyl nonaflate **120** to give the expected cross-coupling product (**134**) in 56% yield (entry 5). Likewise, electron-rich arylcopper reagent, such as 4-methoxy-phenylcopper (**127**) or the bulkier 2-methyl-phenylcopper (**128**) reacted smoothly with alkenyl sulfonate **119** , leading to the corresponding tri-substituted alkenes **135** and **136** in 78 % and 59 % respectively (entries 6 and 7).
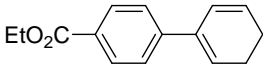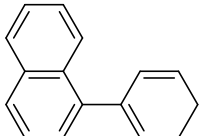
Under the same conditions, the cross-coupling of vinyl nonaflate[96] (**121**) with functionalised arylcopper reagents provided the corresponding functionalized styrene derivatives in 62-71 % yield (entries 8-10). Thus, *p*-carbethoxyphenylcopper (**124)** reacted within 30 min with **121** leading to the desired ethyl 4-vinylbenzoate (**137**) in 64% yield. In contrast, 22 h were required for the reaction of 1-naphthylcopper (**129**) with **121** to complete, providing 1-vinylnaphthalene (**138**) in 71 % yield. It is interesting to notice that although aryl sulfonates showed little reactivity towards arylcopper reagents,[55] here alkenyl sulfonates prove to be much more reactive under these conditions, following the general tendency (alkenyl halides are more reactive than aryl halides in cross-couplings).

Table 5. Reaction of functionalized arylcopper reagents with alkenyl and dienyl sulfonates.[a]

Entry	Alkenyl sulfonate	Aryl copper reagent	Product	Yield (%)[b]
1	Ph Ph OTf **119**	Cu(CN)MgCl **123**	Ph Ph **131**	86[c]
2	Ph Ph ONf **120**	**123**	**131**	81[c]
3	**119**	EtO₂C—Cu(CN)MgCl **124**	CO₂Et Ph Ph **132**	79

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[96] Prepared according to: Lyapkalo, I. M.; Webel, M.; Reißig, H-U. *Eur. J. Org. Chem.* **2001**, 4189.

Entry	Substrate	Reagent	Product	Yield
4	**119**	F$_3$C—C$_6$H$_4$—Cu(CN)MgCl **125**	**133**	74 (41[d], 59[e])
5	**120**	NC—C$_6$H$_4$—Cu(CN)MgCl **126**	**134**	56
6	**119**	MeO—C$_6$H$_4$—Cu(CN)MgCl **127**	**135**	78
7	**119**	Me—C$_6$H$_4$—Cu(CN)MgCl **128**	**136**	59
8	ONf **121**	**124**	CO$_2$Et **137**	64
9	**121**	naphthyl—Cu(CN)MgCl **129**	**138**	71
10	**121**	Br—C$_6$H$_4$—Cu(CN)MgCl **130**	**139**	62
11	ONf **122**	**125**	F$_3$C **140**	90[f]

12	**122**	**124**	EtO$_2$C—⟨structure⟩ **141**	86^f
13	**122**	**129**	⟨structure⟩ **142**	72^f

^{a} Unless stated otherwise, all reactions were carried out on a 1 mmol scale using 2.8 equiv of arylcopper derivative and 10 mol% of Fe(acac)$_3$; ^{b} Isolated yield of analytically pure product; ^{c} Reaction carried out with 2 equiv of arylcopper reagent; ^{d} Isolated yield when 2.8 equiv of arylmagnesium chloride was used instead of arylcopper derivative; ^{e} GC conversion after 4 h in the case where no Fe(acac)$_3$ is used; ^{f} Reaction carried out with 1.4 equiv of arylcopper reagent.

Finally, this cross-coupling reaction could also be performed with dienyl sulfonate **122**[97] yielding the corresponding dienes **140**-**142** in good yields. Thus, when nonaflate **122** was reacted with 3-trifluoromethyl-phenylcopper (**125**), the expected cross-coupling product **140** was isolated in 90% yield (entry 11). Ethyl 4-cyclohexa-1,5-dienyl-benzoate (**141**) was obtained under the same conditions in 86% yield (entry 12), and 1-naphthylcopper (**129**), when treated with **122** , led to the corresponding diene **142** in 72 % yield (entry 13).

In summary, it has been shown that alkenyl sulfonates react with functionalized arylcopper reagents in the presence of Fe(acac)$_3$ under mild conditions (25 °C). This cross-coupling could also be applied to dienyl sulfonates, leading to the corresponding functionalized dienes. Thus, iron salts have proven to be a good alternative to palladium- and nickel-catalyzed cross-coupling reactions, as they appear to be efficient, cheap, and environmentally safe catalyst.

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[97] Obtained from 2-cyclohexenone *via* treatment with LDA and Nf-F.

4.3. Nickel-catalyzed   cross-coupling   between   aryl   phosphates   and arylmagnesium reagents

Transition metal-catalyzed cross-coupling reactions have been widely used for the formation of carbon-carbon and carbon-heteroatom bonds. Thus, palladium and nickel catalysts have been successfully used with a wide range of electrophiles (aryl halides, triflates, tosylates, carbamates) and organometallic reagents (magnesium, zinc, tin or boron).[45,46] In 1981, *Kumada* reported the cross-coupling of various organometallics with aryl phosphates in the presence of Ni(acac)$_2$.[98] Nonetheless, these cross-couplings required long reaction times (6-16 h) and high loadings of both catalyst (5 mol %) and organometallic species (up to 3 equiv.). Therefore, it was envisioned to investigate an improved cross-coupling between aryl phosphates[99] **143**-**147** and various arylmagnesium reagents (**148**-**155**), leading to the corresponding biaryls (Scheme 69).

$$Ar^1-O-\overset{\displaystyle O}{\overset{\displaystyle \|}{P}}(OEt)_2 \quad \xrightarrow[\text{[Ni]}^0]{Ar^2-MgX} \quad Ar^1-Ar^2$$
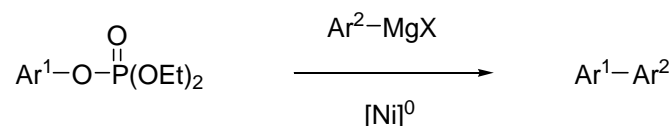
Scheme 69. Nickel-catalyzed cross-coupling between aryl phosphates and arylmagnesium reagents.
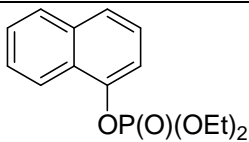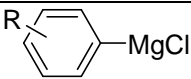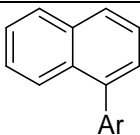
In early experiments, the nickel-catalyzed reaction of 1-naphthyl diethyl phosphate (**143**) with phenylmagnesium chloride (**148**) was studied. Screening of several catalysts, solvents and reaction conditions showed that optimal results were obtained with NiCl$_2$(dppe) (1 mol %) in diethyl ether at 25 °C. Under these conditions using phenylmagnesium chloride (1.2 equiv.), the conversion was complete within 20 min yielding 1-phenylnaphthalene (**156**) in 92 % (entry 1 of Table 1). Importantly, the same reaction could be carried out at -20 °C overnight affording 1-phenyl naphthalene in 87 % yield. This reaction was then extended to other arylmagnesium reagents obtained from the corresponding aryl iodides or bromides *via* a bromine- or iodine-magnesium exchange.[89,90] The first attempts to couple **143** with 3-

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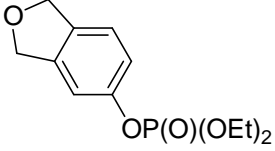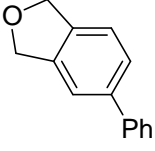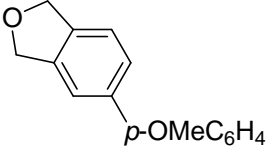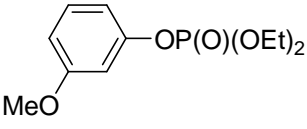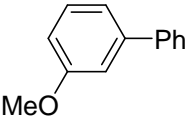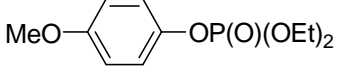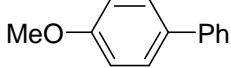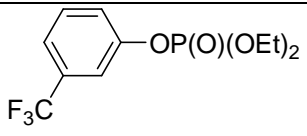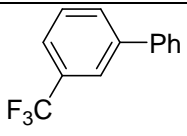
[98] (a) Hayashi, T.; Katsuro, Y.; Okamoto, Y.; Kumada, M. *Tetrahedron Lett.* **1981**, *22*, 4449. For the nickel-catalysed cross-coupling of organic halides with Grignard reagents, see : (b) Tamao, K.; Sumitani, K.; Kumada, M. *J. Am. Chem. Soc.* **1972**, 4374. (c) Tamao, K.; Sumitani, K., Kiso, Y.; Zembayashi, M.; Fujioka, A.; Kodama, S-I.; Nakajima, I.; Minato, A.; Kumada, M. *Bull. Chem. Soc. Jpn* **1976**, 1958. (d) Corriu, R. J. P.; Nasse, J. P. *Chem. Commun.* **1972**, 144.

[99] Aryl phosphates are readily prepared in high yields from the corresponding phenol derivatives *via* treatment with NaH (1.2 equiv.) in THF, followed by diethyl chlorophosphate (1.2 equiv.).

trifluoromethyl-substituted phenylmagnesium reagent (**149**) were unsuccessful though. Thus, instead of the expected 1-(3-trifluoromethyl-phenyl)-naphthalene (**157**), only the homocoupling product could be observed. It was then envisioned that isopropyl iodide (resulting from the exchange reaction) could interfere. This proved to be true, as the desired product **157** could be isolated in 80% yield, when this iodide was removed *in vacuo* prior to coupling reaction (Scheme 70 and entry 2).

Table 6. Nickel-catalyzed reaction of functionalized arylmagnesium reagents with aryl phosphates.[a]

Entry	Aryl phosphate	Aryl magnesium reagent	Product	Yield (%)[b]
1	**143** (OP(O)(OEt)$_2$)	**148**: R = H	**156**: Ar = Ph	92 (87[c,d])
2	**143**	**149**: R = m-CF$_3$	**157**: Ar = m-CF$_3$C$_6$H$_4$	80
3	**143**	**150**: R = 3,5-(CF$_3$)$_2$	**158**: Ar = 3,5-(CF$_3$)$_2$C$_6$H$_3$	72
4	**143**	**151**: R = 3,4-F$_2$	**159**: Ar = 3,4-F$_2$C$_6$H$_3$	64
5	**143**	**152**: R = 3,5-F$_2$	**160**: Ar = 3,5-F$_2$C$_6$H$_3$	54
6	**143**	**153**: R = p-CF$_3$	**161**: Ar = p-CF$_3$C$_6$H$_4$	42
7	**143**	**154**: R = p-F	**162**: Ar = p-FC$_6$H$_4$	35
8	**143**	**155**: R = p-OMe	**163**: Ar = p-OMeC$_6$H$_4$	82[c]

Entry	Substrate	Grignard	Product	Yield
9	![144] OP(O)(OEt)$_2$ **144**	**148**	Ph **164**	64
10	**144**	**155**	p-OMeC$_6$H$_4$ **165**	70[e]
11	MeO / OP(O)(OEt)$_2$ **145**	**148**	MeO / Ph **166**	80[e]
12	MeO—OP(O)(OEt)$_2$ **146**	**148**	MeO—Ph **167**	82[e]
13	F$_3$C / OP(O)(OEt)$_2$ **147**	**148**	F$_3$C / Ph **168**	69[c]

[a] Unless stated otherwise, all reactions were carried out on 1 mmol scale using 2 equiv. of arylmagnesium chloride and 1 mol % of NiCl$_2$(dppe). [b] Isolated yield of anatically pure product. [c] 1.2 equiv. of Grignard reagent were used. [d] The reaction was carried out at -20 °C overnight. [e] 3 mol % of NiCl$_2$(dppe) was used.

Other electron-deficient arylmagnesium reagents reacted well under these conditions. Thus, reaction of 3,5-bis-trifluoromethyl-phenylmagnesium chloride (**150**) with the phosphate **143** led to the expected naphthalene derivative **158** in 72 % yield (entry 3). Likewise, the di-substituted phenylmagnesium reagents **151** and **152** afforded the cross-coupling products **159** and **160** in 64% and 54 % yield respectively when they reacted with the phosphate **143** (entries 4 and 5). Interestingly, the electron-poor *para*-substituted arylmagnesium reagents (**153** and **154**) led to mediocre results. Thus, the reaction of 4-trifluoromethy-phenyl magnesium chloride (**153**) with **143** afforded the expected product **161** in 42 % yield (entry 6). Under the same conditions, the flurophenyl-naphthalene **162** was obtained in 35% yield (entry 7).
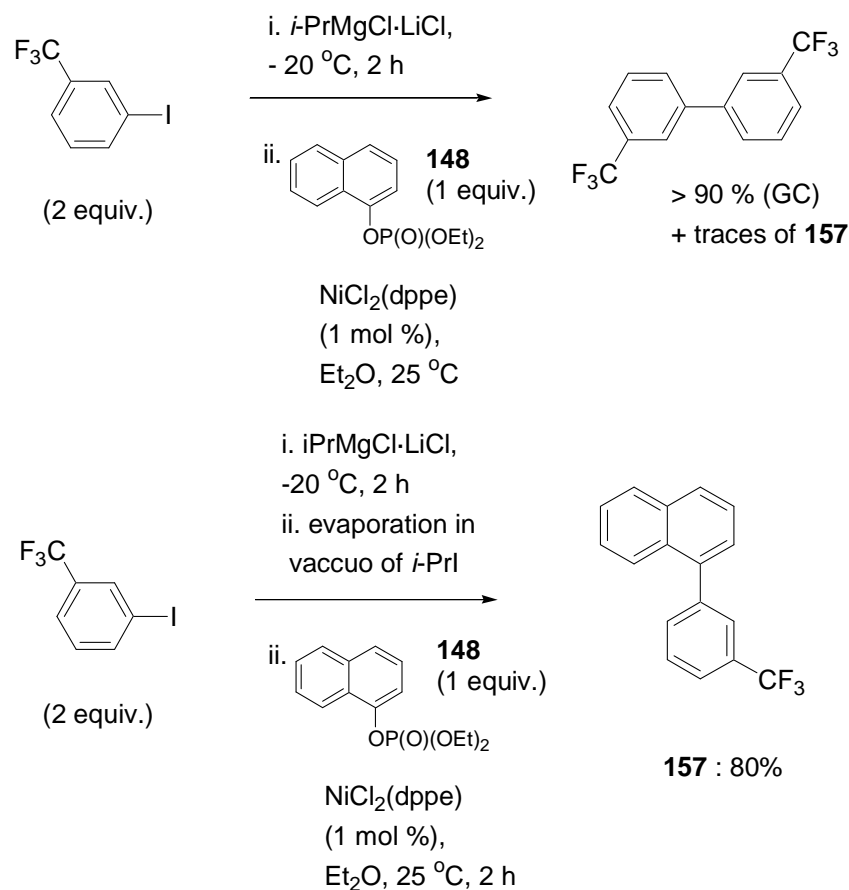
Scheme 70. Influence of the presence of *i*-PrI on the reaction.

Electron-rich magnesium derivatives could also be used. Thus, 4-methoxy-phenylmagnesium bromide (**155**) reacted readily with **143**, leading to the expected methoxyphenyl-naphthalene **163** in 82 % yield (entry 8).

Electron-rich aryl phosphates prove to react less easily under these conditions. Thus, 36 h are required for the reaction of 5-benzo[1-3]dioxolyl diethyl phosphate (**144**) with phenylmagnesium chloride, leading to the expected cross-coupling product **164** in 64% yield (entry 9). The reaction time could nonetheless be shortened using a larger amount of catalyst. Thus, 5-(4-methoxyphenyl)-benzo[1,3]dioxole (**165**) could be obtained in 70% yield within 3 h using 3 mol % of the catalyst (entry 10). Under the same conditions, 3-methoxy-phenyl diethyl phosphate (**145**) and 4-methoxy-phenyl diethyl phosphate (**146**), when reacted with phenylmagnesium chloride **148**, led to the corresponding biaryls **166** and **167** in 80 % and 82 % yield respectively (entries 11 and 12). The electron-deficient aryl phosphate **147** reacted also readily to give the expected cross-coupling product **168** in 69 % yield (entry 13). Interestingly, the reaction of 4-bromophenyl diethyl phosphate (**169**) with 1.2 equiv. of phenylmagnesium chloride (**148**) is chemoselective; thus, when the cross-coupling was

carried out at 0 °C for 1 h in diethyl ether, the bromide reacted preferentially to yield the biphenyl phosphate **170** in 72 % yield (Scheme 71). Nonetheless, when the reaction was performed with 4-chlorophenyl diethyl phosphate, only a mixture was obtained, where the major product was [1,1';4',1"]terphenyl. Finally, it is important to notice that this cross-coupling is very sensitive to steric hindrance. Thus, reaction of mesithylmagnesium bromide (**171**) with phosphate **143** did not proceed, and only traces of cross-coupling product were observed when 2-tolyl diethyl phosphate (**172**) was reacted with phenylmagnesium chloride (**148**).
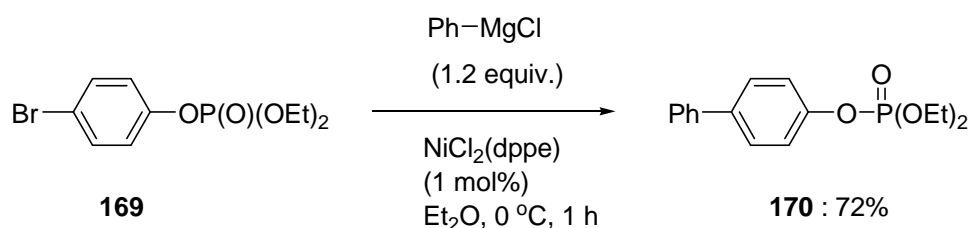
Scheme 71. Chemoselective cross-coupling with phosphate **169**.

In summary, an improved nickel-catalyzed cross-coupling of aryl phosphates with arylmagnesium reagents was developed. Under mild conditions, a few functionalities were tolerated, and the corresponding biaryls were obtained in moderate to good yield.

5.   Summary and outlook

5.1.   LiCl-mediated preparation of allylic zinc reagents and their reaction with electrophiles

In a first part, it has been shown that various allylic zinc reagents could be efficiently and conveniently prepared from the corresponding allylic chlorides or phosphates under very mild conditions. Thus, cinnamylzinc chloride **11** could be obtained in 78 % within 1 h, without the formation of homocoupling products (Scheme 72).

11: 78 %
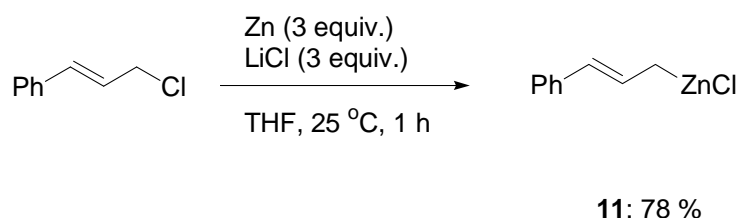
Scheme 72. Preparation of cinnamylzinc chloride **11**.

The reaction of these highly reactive organometallics with various carbonyl derivatives was then found to be highly diastereoselective, affording the corresponding homoallylic alcohols in high yield in a setereocontrolled manner (Scheme 73).
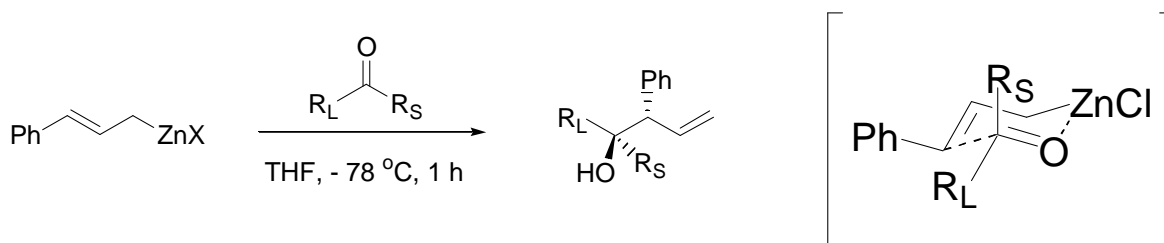
Scheme 73. Addition of allylic zinc reagents to carbonyl derivatives.

This addition could even be extended to cyclic and acyclic α-chiral ketones, leading to the corresponding alcohols with good diastereoselectivities. Thus, α-acetoxy-cyclohexanone reacted smoothly with cinnamylzinc phosphate **10** to yield alcohol **41** as a single compound (Scheme 74).
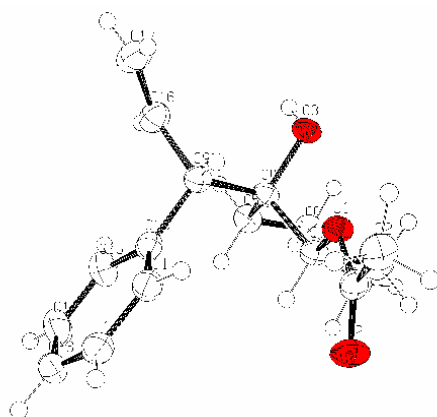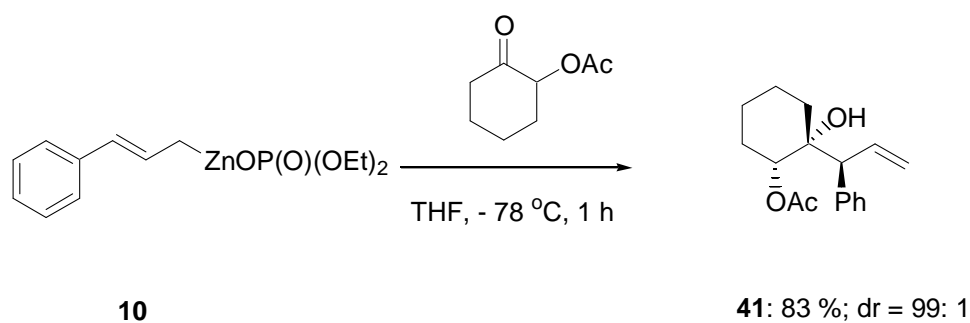
Scheme 74. Preparation of homoallylic alcohol **41**, and its ORTEP representation.

Finally, "zinc-ene" cyclisations could be performed directly from allylic chlorides, leading to the corresponding carbo- and heterocycles (Scheme 75).
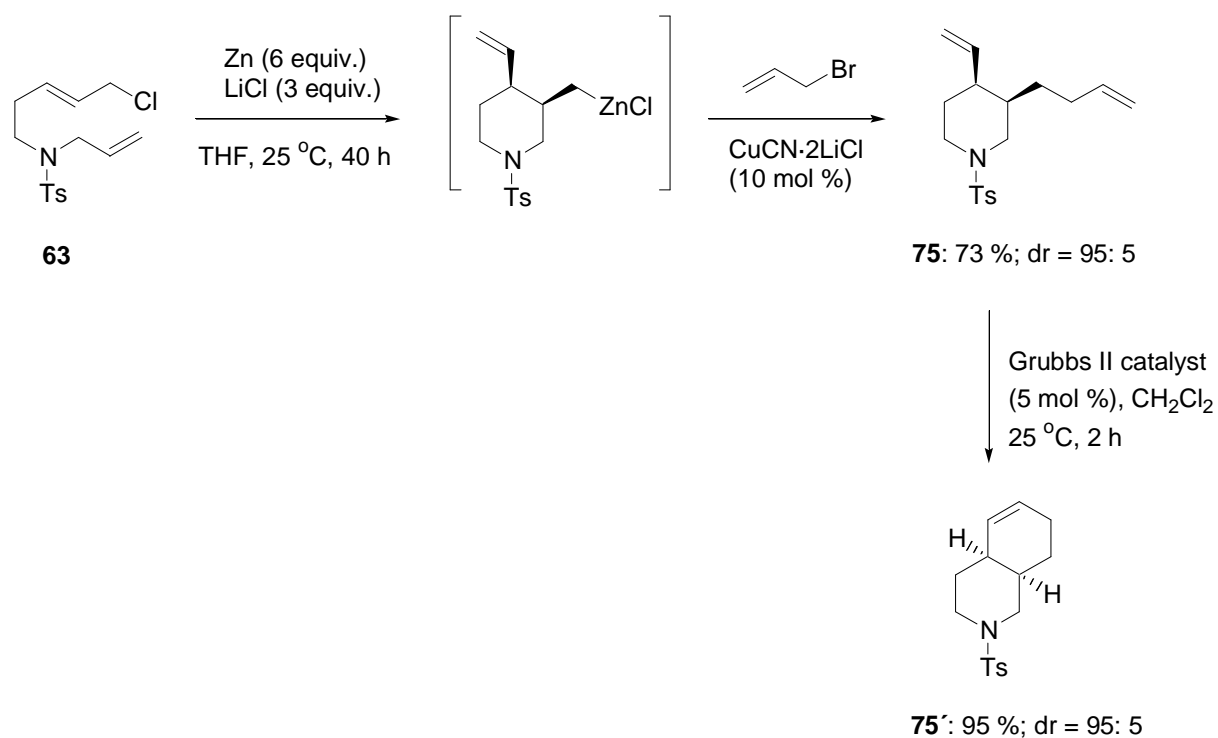
Scheme 75. Formation of heterocycles via a "zinc-ene" cyclisation.

5.2. Highly stereoselective cobalt-catalyzed allylation of functionalized diarylzinc reagents

In a second project, a cobalt-catalysed allylation reaction of diarylzinc reagents was developed. Under the reaction conditions, the cross-couplings were highly stereoselective, and provided the S_N2 products with retention of the double bond configuration. Functionalities like an ester, a ketone, or a nitrile were perfectly tolerated (Scheme 76). This cross-coupling was also applied to the expedient synthesis of Nocarasin C.
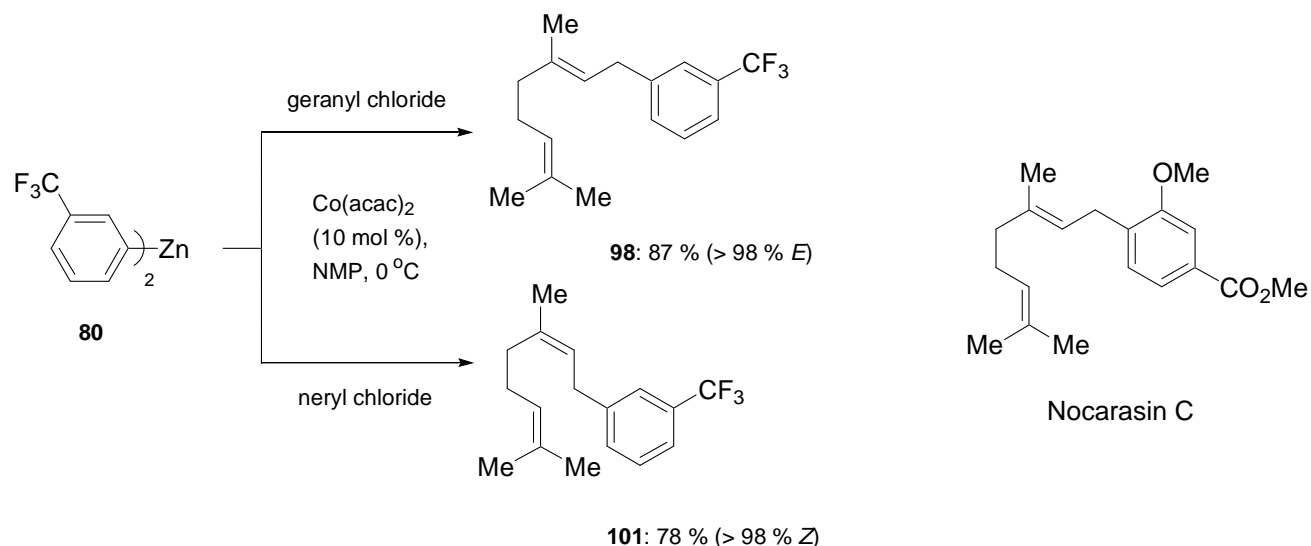
Scheme 76. Stereoselective allylation of diarylzinc reagents.

5.3. Iron-catalyzed cross-coupling between alkenyl and dienyl sulfonates and functionalized arylcopper reagents

In a third project, it has been shown that alkenyl sulfonates react with functionalised arylcopper reagents in the presence of Fe(acac)$_3$ under mild conditions (room temperature). This cross-coupling could also be applied to dienyl sulfonates, leading to the corresponding functionalized dienes (Scheme 77).
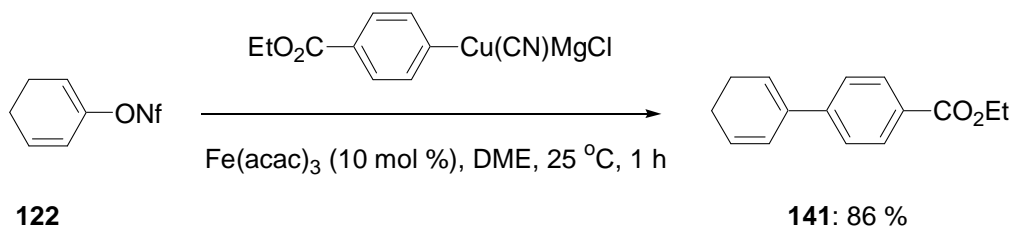
Scheme 77. Preparation of diene **141**.

5.4. Nickel-catalyzed cross-coupling between aryl phosphates and arylmagnesium reagents

Finally, in a fourth project, an improved nickel-catalyzed cross-coupling of aryl phosphates with arylmagnesium reagents was developed. Under mild conditions, a few functionalities were tolerated, leading to the corresponding biaryls (Scheme 78).
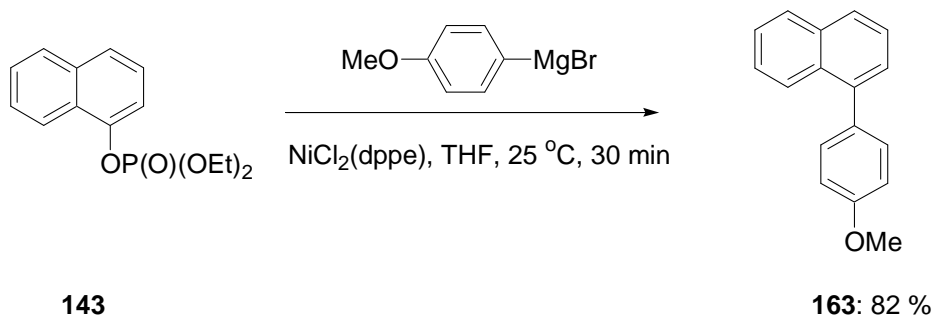
Scheme 78. Preparation of biaryl **163**.

Experimental Part

6. General considerations

Unless otherwise stated, all reactions were carried out with magnetic stirring and, if air or moisture sensitive, in flame-dried glassware and under argon. Syringes used to transfer reagents and solvent were purged with argon prior to use.

Solvents

Solvents were dried according to standard methods by distillation over drying agents as follows: dichloromethane, DMF, NMP and pentane (CaH_2), THF, diethylether and DME (Na/benzophenone), toluene (Na), methanol, ethanol and isopropanol (Mg), pyridine and triethylamine (KOH).

Reagents

Reagents of > 98% purity were used without further purification. The following reagent were prepared according to literature procedures: diethyl cinnamyl phosphate,[74] diethyl myrtenyl phosphate,[75] 1-chloro-4-methyl-pent-2-ene,[100] ((E)-3-chloroprop-1-enyl)cyclohexane,[101] diethyl (3-phenyl-2-trimethylsilanyl-allyl) phosphate,[102] 2-iodo-cyclohex-2-enone,[103] *N*-benzylidene-4-methyl-benzenesulfonamide,[104] 2-benzyloxy-cyclohexanone,[105] 2-phenylsulfanyl-cyclohexanone,[106] 3-iodo-butan-2-one,[107] hex-5-enal,[108] 6-trimethylsilanyl-hex-5-ynal,[109] *N*-allyl-4-methyl-*N*-(3-oxo-propyl)-benzenesulfonamide,[110] 3-allyloxy-

[100] Chan, T. H.; Mychaljlowskij, W.; Ong, B. S.; Harpp, D. N. *J. Org. Chem.* **1978**, *43*, 1526.

[101] Smith, J. G.; Drozda, S. E.; Petraglia, S. P.; Quinn, N. R.; Rice, E. M.; Taylor, B. S.; Viswanathan, M. *J. Org. Chem.* **1984**, *49*, 4112.

[102] Prepared according to refernce 68 starting from the corresponding alcohol: Shipman, M.; Thorpe, H. R.; Clemens, I. R. *Tetrahedron* **1998**, *54*, 14265.

[103] William, A. D.; Kobayashi, Y. *J. Org. Chem.* **2003**, *67*, 8771.

[104] Masquelin, T.; Obrecht, D. *Synthesis* **1995**, *3*, 276.

[105] Demaele, D.; D´Angelo, J; *Tetrahedron Lett.* **1989**, *30*, 345.

[106] Hannaby, M.; Warren, S. *Terahedron Lett.* **1986**, *27*, 765.

[107] Barluenga, J.; Martinez-Gallo, J. M.; Najera, C.; Yus, M. *Synthesis* **1986**, *8*, 678.

[108] Meyer, C.; Marek, I.; Courtemanche, G.; Normant, J.-F. *Tetrahedron* **1994**, *50*, 11665.

[109] Witulski, B.; Bergsträßer, U.; Gößmann, M. *Tetrahedron* **2000**, *56*, 4747.

[110] Parsons, A. F.; Pettifer, R. M. *J. Chem. Soc., Perkin Trans. 1* **1998**, 651.

propionaldehyde,[111]   *N*-allyl-*N*-(2-formyl-phenyl)-4-methyl-benzenesulfonamide,[112]   neryl chloride,[75] geranyl phosphate,[75] neryl phosphate,[75] methyl 4-iodo-3-methoxy-benzoate,[113] and vinyl nonaflate.[114]

CuCN·2LiCl[115] solution (1.0 M) was prepared by drying CuCN (896 mg, 10 mmol) and LiCl (848 mg, 20 mmol) in a Schlenk flask under vacuum for 5 h at 140°C. After cooling to rt, dry THF (10 mL) was added and stirring was continued until the salts were dissolved.

Organolithium reagents:

n-Buthyllithium was used as 1.5 M solution in hexane (Chemetall).

t-Buthyllithium was used as 1.5 M solution in pentane (Chemetall).

Organozinc reagents:

Ph_2Zn was prepared by Mg/Zn exchange from PhMgBr and $ZnBr_2$, as a solution in toluene (1 M).

i-Pr_2Zn[116]   was prepared by Mg/Zn exchange from *i*-PrMgBr and $ZnBr_2$, as a solution in diethyl ether (5-7 M).

Content determination of organometallic reagent:

Organolithium and organomagnesium solutions were titrated according to the Paquette or Krasovskiy procedures.[117,118] The concentration of organozinc solutions were determined by back titration of iodine with an aqueous $Na_2S_2O_3$ solution.

Chromatography

Thin layer chromatography (TLC) was performed using aluminium plates coated with SiO_2 (Merck 60, F-254). The spots were visualized by UV light and by treating the plate with different solutions:

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[111] Farquhar, D.; Cherif, A.; Bakina, E.; Nelson, J. A. *J. Med. Chem.* **1998**, *41*, 965.
[112] Mahmud, H.; Lovely, C. J.; Dias, H. V. R. *Tetrahedron* **2001**, *57*, 4095.
[113] Speicher, A.; Kolz, J.; Sambanje, R. P. *Synthesis* **2002**, *17*, 2503.
[114] Lyapkalo, I. M.; Webel, M.; Reißig, H-U. *Eur. J. Org. Chem.* **2001**, 4189.
[115] P. Knochel, M. C. P. Yeh, S. C. Berk, J. Talbert, *J. Org. Chem.* **1988**, *53*, 2390.
[116] Boudier, A., PhD Thesis, LMU München, **2001**.
[117] Lin, H. S.; Paquette, L. A. *Synth. Commun.* **1994**, *24*, 2503.
[118] Krasovskiy, A.; Knochel, P. *Synthesis* **2006**, *5*, 890.

- KMnO$_4$ (3 g), K$_2$CO$_3$ (20 g), KOH (0.3 g) in water (300 mL)
- Phosphomolybdic acid (10 g) in absolute ethanol (100 mL)
- Cerium molybdate: phosphomolybdic acid (5 g), Ce(SO$_4$)$_2$ (2 g), conc. H$_2$SO$_4$ (12 mL) in water (230 mL).

Flash column chromatography was performed using SiO$_2$ 60 (0.040-0.063 mm; 230-400 mesh ASTM) from Merck and the amount of silicagel was calculated according to the recommendations of W. C. Still.[119]

Analytical data

Melting points were uncorrected and measured on a Büchi B-540 apparatus.

NMR spectra were recorded on a Varian Mercury 200, VXR 400S and on a Bruker ARX 300, AMX 600 instruments. Chemical shifts (δ/ppm) were given relative to CDCl$_3$ (7.26 ppm, for ^{1}H-NMR, 77.0 ppm for ^{13}C-NMR).

For the characterization of the observed signal multiplicities the following abbreviations were applied: s (singlet), d (doublet), dd (doublet doublet), dt (doublet triplet), t (triplet), q (quartet), m (multiplet) and br (broad).

Infrared spectra were recorded from 4000-400 cm^{-1} on a Nicolet 510 FT-IR or a Perkin-Elmer 281 IR spectrometer or BX FT-IR System with a Smith Durasampl IR II, ATR unit in substance. Samples were measured either as neat or as a film between sodium plates for liquids and as potassium tablets for solids. The absorption bands were reported in wave numbers (ν/cm^{-1}).

Optical rotations were measured on a Perkin-Elmer 241 polarimeter.

Mass spectroscopy: mass spectra were recorded on a Finnigan MAT 95Q or a Finnigan 90 instrument for electro impact ionization (EI). High resolution mass spectra (HRMS) were recorded on the same instruments. Fast atom bombardment (FAB) samples were recorded in either a 2-nitrobenzyl alcohol or a glycerine-matrix.

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[119] Still, W. C.; Khan, M.; Mitra, A. *J. Org. Chem.* **1978**, *43*, 2923.

Determination of the enantiomeric excess

Gas chromatography (GC) was performed on the following columns:

- Chiraldex B-PH, Astec, G0112-18 (30.0 m x 250 μm x 0.00 μm),

- Chirasil-L-val, Varian, CP7495 (25.0 m x 250 μm x 0.12 μm),

- Chirasil-Dex CB, Varian, CP7502 (25.0 m x 250 μm x 0.25 μm),
  12.10 psi, 2.8 mL/min, H_2-flux.

- TFA-γ-Cyclodextrin, Astec, G 9105-18 (30.0 m x 250 μm x 0.00 μm)
  10.86 psi, 2.1 mL/min, H_2-flux.

7.   Preparation and reactions of allylic zinc reagents

7.1.   Typical Procedures (TPs)

7.1.1. Typical procedure for the formation of allyl zinc reagents from allylic chlorides or phosphates (TP1):

LiCl (105 mg per mmol of substrate, 2.5 equiv.) was dried at 450 ºC for 3 min under high vacuum in a 25 mL Schlenck tube, before zinc dust (200 mg per mmol of substrate, 3 equiv.) was added. The mixture was heated at 450 ºC for another 3 min under high vacuum, before THF (0.5 mL per mmol of substrate) was added. Zn was then activated with DBE (0.02 mL per mmol of substrate) and TMSCl (0.01 mL per mmol of substrate) successively. A solution of the allylic chloride or phosphate in THF (1 mL per mmol of substrate) was then added to the Zn suspension at 25 ºC, which was further stirred at the determined temperature until the reaction was complete (as determined by GC analysis). The solution was then centrifuged and titrated by iodolysis to determine the yield.

7.1.2. Typical procedure for the reaction of allylic zinc reagents with aldehydes, ketones or imines (TP2):

A solution of the aldehyde or ketone (1 mmol) in THF (1.5 mL) was added dropwise to a solution of the allylic zinc reagent (1.2 mmol) at – 78 ºC. The resulting solution was further stirred at this temperature until the completion of the reaction (determined by TLC and-or GC analysis). The reaction was subsequently quenched with water (1 mL), and extracted several times with diethyl ether. The organic phases were combined, dried over $MgSO_4$, and concentrated to afford a crude product, which was purified by flash chromatography.

7.1.3. Typical procedure for the intramolecular "zinc-ene" reaction (TP3):

To a pre-activated suspension of zinc powder (800 mg, 12.2 mmol) and LiCl (210 mg, 5 mmol) in THF (1 mL), was added a solution of the allylic chloride (or mixture of allylic chlorides) (2 mmol) in THF (2 mL) at 25 ºC. The resulting solution was stirred at this temperature until the reaction was complete (as determined by GC analysis). The solution was subsequently centrifuged, and the clear solution transferred to a flame-dried Schlenk tube.

7.2. Experimental section:

Preparation of cinnamylzinc phosphate (**10**):
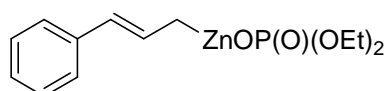
Prepared from cinnamyl phosphate (2.70 g, 10 mmol), zinc dust (2.00 g, 3 equiv.), LiCl (1.10 g, 2.5 equiv.), and THF (15 mL) according to **TP1** (reaction time: 18 h at 25 ºC). Titration by iodolysis indicated a concentration of 0.47 M (72 %).

Preparation of cinnamylzinc chloride (**11**):
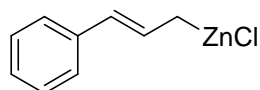
Prepared from cinnamyl chloride (1.53 g, 10 mmol), zinc dust (2.00 g, 3 equiv.), LiCl (1.10 g, 2.5 equiv.), and THF (15 mL) according to **TP1** (reaction time: 1 h at 25 ºC). Titration by iodolysis indicated a concentration of 0.52 M (78 %).

Preparation of (1-*R*)-(-)-myrtenylzinc phosphate (**12**):
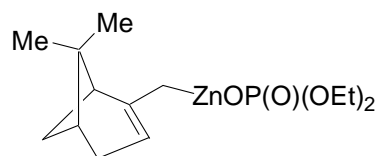
Prepared from phosphoric acid 6,6-dimethyl-bicyclo[3.1.1]hept-2-en-3-ylmethyl ester diethyl ester (2.88 g, 10 mmol), zinc dust (2.00 g, 3 equiv.), LiCl (1.10 g, 2.5 equiv.), and THF (15 mL) according to **TP1** (reaction time: 48 h at 25 ℃). Titration by iodolysis indicated a concentration of 0.41 M (61 %).

Preparation of 4-methyl-pent-2-enylzinc chloride (**13**):
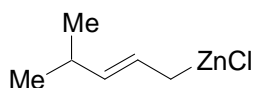
Prepared from 1-chloro-4-methyl-pent-2-ene (1.19 g, 10 mmol), zinc dust (4.00 g, 6 equiv.), LiCl (1.10 g, 2.5 equiv.), and THF (15 mL) according to **TP1** (reaction time: 15 h at 40 °C). Titration by iodolysis indicated a concentration of 0.42 M (63 %).

Preparation of 3-cyclohexylprop-2-en-1-ylzinc chloride (**14**):
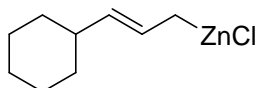
Prepared from ((*E*)-3-chloroprop-1-enyl)cyclohexane (1.59 g, 10 mmol), zinc dust (2.00 g, 3 equiv.), LiCl (1.10 g, 2.5 equiv.), and THF (15 mL) according to **TP1** (reaction time: 20 h at 25 ℃). Titration by iodolysis indicated a concentration of 0.43 M (65 %).

Preparation of 3-phenyl-but-2-enylzinc phosphate (**15**):
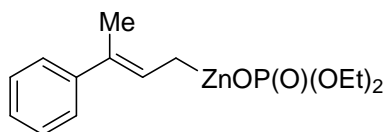
Prepared from phosphoric acid diethyl ester 3-phenyl-but-2-enyl ester (2.85 g, 10 mmol), zinc dust (2.00 g, 3 equiv.), LiCl (1.10 g, 2.5 equiv.), and THF (15 mL) according to **TP1** (reaction time: 15 h at 40 °C). Titration by iodolysis indicated a concentration of 0.46 M (70 %).

Preparation of 3-phenyl-2-trimethylsilanyl-prop-2-enylzinc phosphate (**16**):
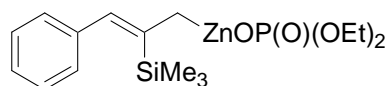
Prepared from phosphoric acid diethyl ester 3-phenyl-2-trimethylsilanyl-allyl ester (3.42 g, 10 mmol), zinc dust (2.00 g, 3 equiv.), LiCl (1.10 g, 2.5 equiv.), and THF (15 mL) according to **TP1** (reaction time: 24 h at 40 °C). Titration by iodolysis indicated a concentration of 0.42 M (63 %).

Preparation of (1R*)-(2S*)-diphenyl-but-3-en-1-ol (**17**):
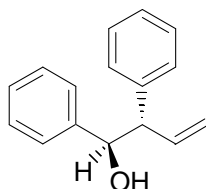
Prepared from benzaldehyde (107 mg, 1.0 mmol) and cinnamylzinc phosphate (**10**, 1.2 mmol) according to **TP2**. Purification by flash chromatography (eluent: pentane: ether = 9: 1) provided the pure compound **17** (214 mg, 96 %) as a colourless oil. dr = 94: 6.

^{1}H-NMR (CDCl$_3$, 300 MHz): δ / ppm = 7.03-7.25 (m, 10 H), 6.19-6.33 (m, 1 H), 5.18-5.30 (m, 2 H), 4.86 (d, J = 7.9 Hz, 1 H), 3.52-3.60 (m, 1 H) 2.10-2.35 (br s, 1 H).

^{13}C-NMR (CDCl$_3$, 75 MHz): δ / ppm = 142.1, 140.9, 138.1, 128.6, 128.6, 128.2, 127.7, 126.9, 126.8, 118.7, 77.5, 59.5.

IR (neat): ν/cm^{-1} = 3417, 3063, 3029, 2907, 1637, 1601, 1493, 1452, 1191, 1027, 917, 848, 760, 696.

MS (EI, 70 ev): m/z (%) = 206 (3), 118 (100), 115 (20), 107 (55), 79 (41), 77 (18).

HRMS (EI): calcd. for [C$_{16}$H$_{16}$O – H$_2$O]$^+$: 206.1096; found: 206.1127.

Preparation of (5-iodo-furan-2-yl)-(3-methylene-bicyclo[3.1.1]hept-2-yl)-methanol (**18**):
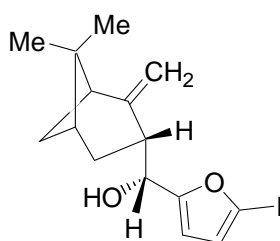
Prepared from 5-iodo-furan-2-carbaldehyde (222 mg, 1.0 mmol) and (1-*R*)-(-)-myrtenylzinc phosphate (**12**, 1.2 mmol) according to **TP2**. Purification by flash chromatography (eluent: pentane: ether = 7: 3) provided the pure compound **18** (340 mg, 95 %) as a yellow oil. dr > 99: 1.

^{1}H-NMR (CDCl$_3$, 300 MHz): δ / ppm = 6.50 (d, *J* = 2.6 Hz, 1 H), 6.24 (d, *J* = 2.8 Hz, 1 H), 4.90 (dt, *J* = 7.1 Hz, *J* = 1.8 Hz, 2 H), 4.47 (d, *J* = 9.7 Hz, 1 H), 2.82-2.97 (m, 2 H), 2.52 (t, *J* = 5.4 Hz, 1 H), 2.25-2.36 (m, 1 H), 1.91-2.02 (m, 1 H), 1.44-1.53 (m, 1 H), 1.29 (s, 3 H), 1.25 (d, *J* = 10.5 Hz, 1 H), 0.78 (s, 3 H).

^{13}C-NMR (CDCl$_3$, 75 MHz): δ / ppm = 160.7, 151.6, 121.1, 112.3, 111.4, 87.4, 72.2, 52.6, 41.6, 40.7, 40.3, 27.8, 26.8, 26.0, 21.8.

IR (neat): ν/cm^{-1} = 3407, 3072, 2976, 2917, 2868, 1632, 1484, 1456, 1383, 1368, 1260, 1195, 1102, 1030, 1009, 911, 881, 784, 753.

MS (EI, 70 ev): m/z (%) = 358 (1), 340 (2), 224 (6), 223 (100), 222 (7), 136 (17), 93 (35), 92 (19).

HRMS (EI): calcd. for [C$_{15}$H$_{19}$IO$_2$]$^+$: 358.0430; found: 358.0411.

[α]$_D$ (c = 0.0099 g.mL^{-1}, CHCl3) = - 19.6

Preparation of (2R*)-(3S*)-2-(4-bromo-phenyl)-3-phenyl-pent-4-en-2-ol (**20**):
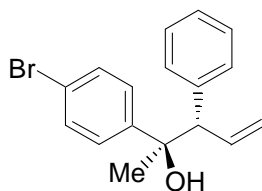
Prepared from 4-bromoacetophenone (199 mg, 1.0 mmol) and cinnamylzinc chloride (**11**, 1.2 mmol) according to **TP2**. Purification by flash chromatography (eluent: pentane: ether = 8: 2 + 1 % Et$_3$N) provided the pure compound **20** (315 mg, 99%) as a colourless oil. dr > 99: 1.

^{1}H-NMR (CDCl$_3$, 300 MHz): δ / ppm = 7.42 (d, J = 8.5 Hz, 2 H), 7.05-7.32 (m, 7 H), 6.07-6.17 (m, 1 H), 5.08 (d, J = 10.3 Hz, 1 H), 4.96 (d, J = 17.1 Hz, 1 H), 3.58 (d, J = 8.8 Hz, 1 H), 2.00 (br s, 1 H), 1.43 (s, 3 H).

^{13}C-NMR (CDCl$_3$, 75 MHz): δ / ppm = 145.4, 139.8, 137.0, 130.8, 129.5, 128.2, 127.5, 127.0, 120.6, 118.4, 76.0, 61.8, 28.4.

IR (neat): ν/cm^{-1} = 3560, 2974, 2924, 1638, 1598, 1486, 1452, 1394, 1084, 1008, 920, 743.

MS (EI, 70 ev): m/z (%) = 319 (2), 317 (2), 301 (77), 299 (79), 223 (16), 221 (16), 201 (60), 199 (61), 143 (100), 119 (29), 105 (22), 91 (14).

HRMS (EI): calcd. for [C$_{17}$H$_{18}$BrO + H]$^+$: 317.0541; found: 317.0555.

Preparation of (2R*)-(3S*)-2-(4-methoxy-phenyl)-3-phenyl-pent-4-en-2-ol (**21**):
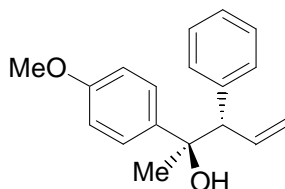
Prepared from 4-methoxy-acetophenone (150 mg, 1.0 mmol) and cinnamylzinc phosphate (**10**, 1.2 mmol) according to **TP2**. Purification by flash chromatography (eluent: pentane: ether = 8: 2 + 1 % Et$_3$N) provided the pure compound **21** (262 mg, 98 %) as a colourless oil. dr > 98: 2.

¹H-NMR (CDCl₃, 300 MHz): δ / ppm = 7.20-7.32 (m, 5 H), 7.10-7.16 (m, 2 H), 8.86 (d, J = 8.8 Hz, 2 H), 6.10-6.23 (m, 1 H), 5.10 (dd, J = 10.6 Hz, J = 1.8 Hz, 1 H), 5.00 (dd, J = 15.9 Hz, J = 1.8 Hz, 1 H), 3.84 (s, 3 H), 3.63 (d, J = 8.8 Hz, 2 H), 2.00 (s, 1 H), 1.47 (s, 3 H).

¹³C-NMR (CDCl₃, 75 MHz): δ / ppm = 158.2, 140.2, 138.5, 137.5, 129.6, 128.0, 126.7, 118.0, 113.0, 76.0, 62.1, 55.2, 28.5.

IR (neat): v/cm⁻¹ = 3496, 3061, 2975, 2932, 1610, 1583, 1511, 1452, 1297, 1246, 1176, 1031, 916, 832, 700.

MS (EI, 70 ev): m/z (%) = 269 (11), 251 (100), 173 (6), 161 (10), 151 (62), 143 (14), 135 (3), 105 (4), 84 (5).

HRMS (EI): calcd. for $[C_{18}H_{20}O_2 - OH]^+$: 251,1436; found: 251.1425.

Preparation of (2*R**)-(3*S**)-toluene-4-sulfonic acid 4-(1-hydroxy-1-methyl-2-phenyl-but-3-enyl)-phenyl ester (**22**):
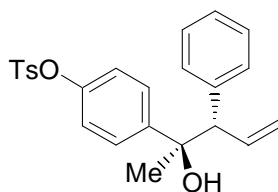
Prepared from toluene-4-sulfonic acid 4-acetyl-phenyl ester (291 mg, 1.0 mmol) and cinnamylzinc phosphate (**10**, 1.2 mmol) according to **TP2**. Purification by flash chromatography (eluent: pentane: ether = 1: 1 + 1 % Et₃N) provided the pure compound **22** (377 mg, 92 %) as a colourless oil. dr > 97: 3.

¹H-NMR (CDCl₃, 300 MHz): δ / ppm = 7.72 (d, J = 8.3 Hz, 2 H), 7.33 (d, J = 8.1 Hz, 2 H), 7.21-7.30 (m, 5 H), 7.05-7.11 (m, 2 H), 6.93 (d, J = 8.8 Hz, 2 H), 6.05-6.19 (m, 1 H), 5.08 (dd, J = 10.2 Hz, J = 1.6 Hz, 1 H), 4.94 (d, J = 17.2 Hz, 1 H), 3.55 (d, J = 9.0 Hz, 1 H), 2.48 (s, 3 H), 2.02-2.05 (m, 1 H), 1.46 (m, 3 H).

¹³C-NMR (CDCl₃, 75 MHz): δ / ppm = 148.5, 145.5, 139.9, 137.2, 132.7, 129.9, 129.7, 128.8, 128.4, 127.2, 127.2, 121.8, 118.6, 76 3, 62.4, 46.5, 28.3, 22.0.

IR (neat): v/cm⁻¹ = 3555, 3063, 2968, 1638, 1597, 1497, 1452, 1360, 1197, 1172, 1148, 1093, 994, 873, 852, 812, 700, 668.

MS (EI, 70 ev): m/z (%) = 355 (2), 290 (26), 207 (13), 155 (82), 92 (11), 91 (100), 65 (15), 43 (5).

HRMS (EI): calcd. for $[C_{24}H_{24}O_4S - OH]^+$: 391.1368; found: 391.1367.

Preparation of (2R*)-(3S*)-2-(4-bromo-phenyl)-3-cyclohexyl-pent-4-en-2-ol (**23**):
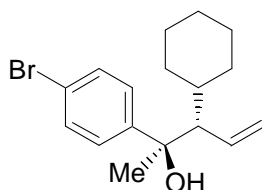
Prepared from 4-bromo-acetophenone (200 mg, 1.0 mmol) and 3-cyclohexylprop-2-en-1-ylzinc chloride (**11**, 1.2 mmol) according to **TP2**. Purification by flash chromatography (eluent: pentane: ether = 8: 2 + 1 % Et$_3$N) provided the pure compound **23** (277 mg, 86 %) as a colourless oil. dr > 97: 3.

¹H-NMR (CDCl₃, 300 MHz): δ / ppm = 7.44 (d, J = 8.6 Hz, 2 H), 7.31 (d, J = 8.6 Hz, 2 H), 5.74 (dt, J = 17.0 Hz, J = 10.3 Hz, 1 H), 5.12 (dd, J = 10.2 Hz, J = 2.3 Hz, 1 H), 4.97 (dd, J = 17.0 Hz, J = 2.3 Hz, 1 H), 2.09 (dd, J = 10.4 Hz, J = 2.2 Hz, 1 H), 1.92 (s, 1 H), 1.41-1.68 (m, 7 H), 0.83-1.33 (m, 9 H).

¹³C-NMR (CDCl₃, 75 MHz): δ / ppm = 146.3, 135.8, 130.8, 127.6, 120.6, 119.3, 75.9, 62.5, 37.3, 34.0, 29.4, 27.4, 26.8, 26.6, 26.3.

IR (neat): v/cm^{-1} = 3564, 2922, 2850, 1484, 1448, 1396, 1076, 1008, 912, 821.

MS (EI, 70 ev): m/z (%) = 202 (7), 201 (100), 199 (92), 125 (10), 123 (8), 97 (22), 95 (16), 81 (17), 43 (79).

HRMS (FAB): calcd. for $[C_{17}H_{23}BrO - OH]^+$: 305.0905; found: 305.0906.

Preparation of (2S*)-(3S*)-2,3-dimethyl-4-phenyl-hex-5-en-3-ol (**24**):
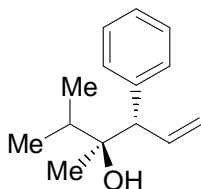
Prepared from 3-methyl-butan-2-one (86 mg, 1.0 mmol) and cinnamylzinc chloride (**11**, 1.2 mmol) according to **TP2**. Purification by flash chromatography (eluent: pentane: ether = 8: 2 + 1 % Et_3N) provided the pure compound **24** (196 mg, 96%) as a colourless oil. dr > 99: 1.

^{1}H-NMR (CDCl$_3$, 300 MHz): δ / ppm = 7.22-7.38 (m, 5 H), 6.39 (dt, J = 17.2 Hz, J = 9.9 Hz, 1 H), 5.19 (dd, J = 10.2 Hz, J = 1.9 Hz, 1 H), 5.13 (ddd, J = 17.2 Hz, J = 1.8 Hz, J = 0.7 Hz, 1 H), 3.46 (d, J = 9.6 Hz, 1 H), 2.00 (hept, J = 6.8 Hz, 1 H), 1.40 (br s, 1 H), 1.02 (d, J = 6.9 Hz, 3 H), 0.96 (*d*, J = 6.8 Hz, 3 H), 0.91 (*s*, 3 H).

^{13}C-NMR (CDCl$_3$, 75 MHz): δ / ppm = 142.1, 138.1, 129.6, 128.5, 126.7, 117.1, 76.3, 57.9, 34.3, 20.4, 17.8, 17.1.

IR (neat): ν/cm^{-1} = 3480, 3074, 3027, 2976, 2962, 2877, 1636, 1601, 1491, 1470, 1452, 1387, 1376, 1156, 1080, 1001, 912, 734.

MS (EI, 70 ev): m/z (%) = 161 (3), 119 (8), 118 (87), 117 (28), 115 (14), 91 (9), 87 (100), 69 (27).

HRMS (EI): calcd. for $[C_{14}H_{20}O - OH]^+$: 187.1487; found: 187.1466.

Preparation of (2*S**)-(3*S**)-2-cyclopropyl-3-phenyl-pent-4-en-2-ol (**25**):
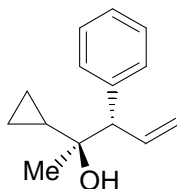
Prepared from 1-cyclopropyl-ethanone (85 mg, 1.0 mmol) and cinnamylzinc chloride (**11**, 1.2 mmol) according to **TP2**. Purification by flash chromatography (eluent: pentane: ether = 8: 2 + 1 % Et_3N) provided the pure compound **25** (188 mg, 93%) as a colourless oil. dr > 99: 1.

^{1}H-NMR (CDCl$_3$, 300 MHz): δ / ppm = 7.23-7.39 (m, 5 H), 6.44 (dt, J = 16.9 Hz, J = 9.9 Hz, 1 H), 5.15-5.26 (m, 2 H), 3.44 (d, J = 9.4 Hz, 1 H), 1.33 (s, 1 H), 1.11 (s, 3 H), 0.84-0.95 (m, 1 H), 0.28-0.47 (m, 4 H).

^{13}C-NMR (CDCl$_3$, 75 MHz): δ / ppm = 140.9, 137.8, 129.4, 128.1, 126.6, 117.7, 72.4, 62.1, 24.3, 19.5, 1.1, 0.8.

IR (neat): ν/cm^{-1} = 3570, 3475, 3082, 3006, 2977, 2932, 1636, 1601, 1493, 1452, 1418, 1372, 1307, 1138, 1020, 915, 734 cm^{-1}.

MS (EI, 70 ev): m/z (%) = 128 (1), 119 (3), 118 (29), 117 (13), 115 (10), 86 (3), 85 (52), 67 (4), 43 (100).

HRMS (EI): calcd. for $[C_{14}H_{18}O - H_2O]^+$: 184.1252; found: 184.1264.

Note: The same reaction carried out at 0 ºC afforded **4c** in 92 % yield and 92: 8 diastereoselectivity.

Preparation of (2*S**)-(3*S**)-2-cyclohexyl-3-phenyl-pent-4-en-2-ol (**26**):
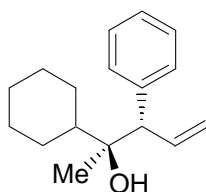
Prepared from 1-cyclohexyl-ethanone (127 mg, 1.0 mmol) and cinnamylzinc chloride (**11**, 1.2 mmol) according to **TP2**. Purification by flash chromatography (eluent: pentane: ether = 8: 2 + 1 % Et$_3$N) provided the pure compound **26** (231 mg, 95%) as a colourless oil. dr > 99: 1.

^{1}H-NMR (CDCl$_3$, 300 MHz): δ / ppm = 7.21-7.37 (m, 5 H), 6.37 (dt, *J* = 17.2 Hz, *J* = 9.9 Hz, 1 H), 5.18 (dd, *J* = 10.2 Hz, *J* = 1.9 Hz, 1 H), 5.10 (dd, *J* = 17.2 Hz, *J* = 1.6 Hz, 1 H), 3.47 (d, *J* = 9.7 Hz, 1 H), 1.58-2.06 (m, 6 H), 0.94-1.58 (m, 6 H), 0.91 (s, 3 H).

^{13}C-NMR (CDCl$_3$, 75 MHz): δ / ppm = 141.9, 137.9, 129.4, 128.2, 126.4, 116.8, 75.6, 57.3, 44.5, 27.8, 26.7, 26.7, 21.5.

IR (neat): ν/cm^{-1} = 3477, 3072, 3027, 2976, 2903, 2852, 1635, 1600, 1490, 1451, 1378, 1062, 909, 746, 701 cm^{-1}.

MS (EI, 70 ev): m/z (%) = 161 (4), 128 (6), 127 (68), 119 (9), 118 (100), 117 (25), 115 (13), 109 (37), 83 (40), 43 (30).

HRMS (EI): calcd. for $[C_{17}H_{24}O - H_2O]^+$: 226.1721; found: 226.1716.

Preparation of (2*S**)-(3*S**)-1,1,1-trifluoro-2-methyl-3-phenyl-pent-4-en-2-ol (**27**):
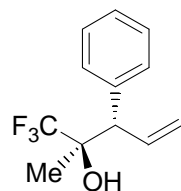
Prepared from 1,1,1-trifluoro-propan-2-one (111 mg, 1.0 mmol) and cinnamylzinc chloride (**11**, 1.2 mmol) according to **TP2**. Purification by flash chromatography (eluent: pentane: ether = 9: 1 + 1 % Et$_3$N) provided the pure compound **27** (177 mg, 77 %) as a colourless oil. dr > 99: 1.

^{1}H-NMR (CDCl$_3$, 300 MHz): δ / ppm = 7.24-7.39 (m, 5 H), 6.29-6.44 (m, 1 H), 5.24 (dd, J = 10.2 Hz, J = 1.3 Hz, 1 H), 5.18 (ddd, J = 17.0 Hz, J = 1.4 Hz, J = 1.1 Hz, 1 H), 3.65 (d, J = 9.0 Hz, 1 H), 2.21 (br s, 1 H), 1.28 (q, J = 1.1 hz, 3 H).

^{13}C-NMR (CDCl$_3$, 75 MHz): δ / ppm = 138.9, 135.6, 129.2, 128.5, 127.3, 126.1 (q, J = 286.9 Hz), 118.6, 76.8 (q, J = 26.6 Hz), 55.1, 20.6 (m).

IR (neat): ν/cm^{-1} = 3452, 3083, 2982, 2936, 1639, 1602, 1492, 1455, 1384, 1251, 1176, 1120, 1091, 996, 924, 751, 706 cm^{-1}.

MS (EI, 70 ev): m/z (%) = 230 (5), 118 (17), 117 (100), 116 (9), 115 (37), 91 (17), 65 (4), 43 (12).

HRMS (EI): calcd. for [C$_{12}$H$_{13}$F$_3$O]$^+$: 230.0918; found: 230.0895.

Preparation of (2S*)-(3S*)-3-phenyl-2-trimethylsilanyl-pent-4-en-2-ol (**28**):
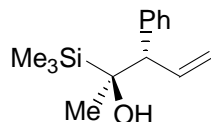
Prepared from 1-trimethylsilanyl-ethanone (117 mg, 1.0 mmol) and cinnamylzinc chloride (**11**, 1.2 mmol) according to **TP2**. Purification by flash chromatography (eluent: pentane: ether = 9: 1 + 1 % Et$_3$N) provided the pure compound **28** (218 mg, 93 %) as a colourless oil. dr > 97: 3.

^{1}H-NMR (CDCl$_3$, 300 MHz): δ / ppm = 7.19-7.38 (m, 5 H), 6.31-6.45 (m, 1 H), 5.10-5.23 (m, 2 H), 3.41 (d, J = 9.7 Hz, 1 H), 1.28 (br s, 1 H), 1.14 (s, 3 H), 0.07 (s, 9 H).

^{13}C-NMR (CDCl$_3$, 75 MHz): δ / ppm = 140.8, 138.6, 129.2, 128.3, 126.6, 117.1, 67.8, 58.7, 22.8, -2.8.

IR (neat): ν/cm^{-1} = 3523, 3075, 2954, 2899, 1634, 1600, 1491, 1452, 1308, 1245, 1079, 887, 834, 700.

MS (EI, 70 ev): m/z (%) = 234 (1), 233 (3), 220 (11), 219 (70), 129 (74), 118 (51), 117 (100), 115 (35), 101 (65), 91 (21), 76 (17), 75 (31), 73 (46), 43 (30).

HRMS (EI): calcd. for [C$_{14}$H$_{22}$OSi + H]$^+$: 235.1518; found: 235.1479.

Preparation of (2*S**)-(3*S**)-2-isopropyl-2-methyl-3-phenyl-tetrahydrofuran (**33**):
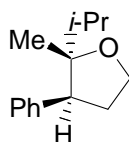
BH$_3$·Me$_2$S (1.8 mL, 19 mmol, 3 equiv.) was added at room temperature to a solution of homoallylic alcohol **24** (1.20 g, 6.0 mmol) in dry THF (20 mL). The resulting solution was stirred at 25 °C under nitrogen for 4 h, then it was quenched with water (7 mL) at 0 °C. Sodium perborate (8.50 g, 55 mmol, 9 equiv) and NaOH (2.2 g, 55 mmol, 9 equiv) were subsequently added, and the reaction mixture was heated to 45 °C for 4 h. The phases were separated and the aqueous phase was extracted with Et$_2$O. The combined organic phases were dried over MgSO$_4$, and concentrated *in vacuo*. Purification by flash chromatography (eluent: ether + 1 % Et$_3$N) provided (4*S**)-(3*S**)-4,5-dimethyl-3-phenyl-hexane-1,4-diol (**31**, 1.101 g, 84 %) as a colourless oil. dr > 99:1.

^{1}H-NMR (CDCl$_3$, 300 MHz): δ / ppm = 7.21-7.36 (m, 5 H), 3.48-3.60 (m , 1 H), 3.29-3.42 (m, 1H), 2.95 (dd, J = 11.1 Hz, J = 3.6 Hz, 1 H), 2.11-2.25 (m, 1 H), 1.89-2.09 (m, 2 H), 1.44 (br s, 2 H), 1.02 (d, J = 6.7 Hz, 3 H), 0.95 (*d*, J = 6.9 Hz, 3 H), 0.91 (s, 3 H).

^{13}C-NMR (CDCl$_3$, 75 MHz): δ / ppm = 141.8, 129.6, 128.2, 126.6, 76.4, 61.5, 49.2, 34.0, 31.8, 20.7, 17.8, 17.0.

IR (neat): ν/cm^{-1} = 3317, 2966, 2912, 2877, 1601, 1451, 1364, 1158, 1054, 1031, 931, 733, 700.

MS (EI, 70 ev): m/z (%) = 189 (2), 161 (32), 136 (16), 118 (100), 117 (31), 105 (18), 91 (16), 87 (58), 69 (11), 43 (26).

HRMS (EI): calcd. for $[C_{14}H_{22}O_2]^+$: 222,1620; found: 222.1607.

Mesyl chloride (0.5 mL, 6.5 mmol, 1.5 equiv) was added at 0 ºC to a solution of the diol **31** (0.90 g, 4.1 mmol), Et$_3$N (1.1 mL, 8 mmol, 2.0 equiv) and DMAP (30 mg) in CH$_2$Cl$_2$ (15 mL). After 90 min, water was added and the aqueous phase extracted with CH$_2$Cl$_2$. The combined organic phases were dried over MgSO$_4$, and concentrated *in vacuo*. Purification by flash chromatography (eluent: pentane: ether = 98: 2) the pure tetrahydrofuran **33** (571 mg, 69 %) as a colourless oil. dr > 99:1.

^{1}H-NMR (CDCl$_3$, 600 MHz): δ / ppm = 7.19-7.32 (m, 5 H), 4.06-4.11 (m, 1 H), 3.87 (q, *J* = 8.1 Hz, 1 H), 2.25-2.40 (m, 2 H), 1.88 (hept, *J* = 6.8 Hz, 1 H), 1.00 (d, *J* = 6.8 Hz, 3 H), 0.95 (d, *J* = 6.9 Hz, 3 H), 0.79 (s, 3 H).

^{13}C-NMR (CDCl$_3$, 75 MHz): δ / ppm = 142.4, 128.6, 128.1, 126.2, 87.3, 65.5, 50.3, 35.5, 33.7, 19.0, 18.3, 17.1.

IR (neat): ν/cm^{-1} = 3029, 2964, 2875, 1603, 1495, 1453, 1386, 1372, 1082, 1052, 852, 767.

MS (EI, 70 ev): m/z (%) = 167 (3), 162 (6), 119 (10), 118 (100), 117 (59), 91 (13), 65 (2), 43 (17).

HRMS (EI): calcd. for **$[C_{14}H_{20}O + H]^+$**: 205.1592; **found**: 205.1584.

Preparation of (2R*)-(3*S*)-2-methyl-3-phenyl-2-trifluoromethyl-tetrahydrofuran (**34**):
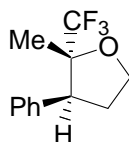
BH$_3$·Me$_2$S (1.8 mL, 19 mmol, 3 equiv.) was added at room temperature to a solution of homoallylic alcohol **27** (1.40 g, 6.0 mmol) in dry THF (20 mL). The resulting solution was stirred at 25 °C under nitrogen for 4 h, then it was quenched with water (7 mL) at 0 ºC. Sodium perborate (8.50 g, 55 mmol, 9 equiv) and NaOH (2.2 g, 55 mmol, 9 equiv) were subsequently added, and the reaction mixture was heated to 45 ºC for 4 h. The phases were separated and the aqueous phase was extracted with Et$_2$O. The combined organic phases were

dried over $MgSO_4$, and concentrated *in vacuo*. Purification by flash chromatography (eluent: pentane: ether = 6: 4 + 1 % Et_3N) provided (4*R**)-(3*S**)**-5,5,5-trifluoro-4-methyl-3-phenyl-pentane-1,4-diol (**32**, 554 mg, 37 %) as a white solid. dr > 99:1.

^{1}H-NMR (CDCl$_3$, 300 MHz): δ / ppm = 7.20-7.34 (m, 5 H), 3.57 (quint , *J* = 5.3 Hz, 1 H), 3.22-3.41 (m, 1 H), 3.18 (dd, *J* = 10.1 Hz, *J* = 3.8 Hz, 1 H), 2.11-2.25 (m, 1 H), 2.16-2.50 (m, 3 H), 2.01-2.13 (m, 1 H), 1.27 (br s, 3 H).

^{13}C-NMR (CDCl$_3$, 75 MHz): δ / ppm = 139.1, 129.5 (br), 128.4, 127.3, 126.5 (q, *J* = 287.2 Hz), 75.9 (q, *J* = 26.4 Hz), 60.6, 47.1, 32.6, 19.8 (m).

IR (neat): v/cm^{-1} = 3335, 3119, 2888, 1604, 1488, 1455, 1297, 1242, 1188, 1168, 1132, 1037, 706, 669.

MS (EI, 70 ev): m/z (%) = 137 (2), 136 (23), 135 (16), 118 (37), 117 (19), 106 (9), 105 (100), 91 (51), 43 (10).

HRMS (EI): calcd. for $[C_{12}H_{15}F_3O_2 - H_2O]^+$: 230.0918; found: 230.0906.

Mesyl chloride (0.16 mL, 1.5 equiv) was added at 0 ºC to a solution of the diol **32** (345 mg, 1.4 mmol), Et_3N (0.4 mL, 2.0 equiv) and DMAP (8 mg) in CH_2Cl_2 (3 mL) and Et_2O (3 mL). After 40 min, water was added and the aqueous phase extracted with Et_2O. The combined organic phases were dried over $MgSO_4$, and concentrated *in vacuo*. Purification by flash chromatography (eluent: pentane: ether = 98: 2) the pure tetrahydrofuran **34** (151 mg, 47 %) as a colourless oil. dr > 99:1.

^{1}H-NMR (CDCl$_3$, 300 MHz): δ / ppm = 7.23-7.40 (m, 5 H), 4.19-4.29 (m, 1 H), 4.04 (q, *J* = 8.0 Hz, 1 H), 3.73 (t, *J* = 8.6 Hz, 1 H), 2.37-2.48 (m, 2H), 0.99 (q, *J* = 1.1 Hz, 3 H).

^{13}C-NMR (CDCl$_3$, 75 MHz): δ / ppm = 138.4, 128.8, 128.4, 127.3, 127.0 (q, *J* = 286.2 Hz), 84.2 (q, *J* = 27.4 Hz), 68.6, 48.3, 32.8, 18.5 (m).

IR (neat): v/cm^{-1} = 3034, 2994, 2952, 2885, 1604, 1495, 1456, 1383, 1286, 1208, 1179, 1117, 1084, 1044, 916, 883, 773, 700.

MS (EI, 70 ev): m/z (%) = 231 (4), 230 (29), 161 (11), 118 (100), 117 (96), 115 (13), 91 (17), 43 (7).

HRMS (EI): calcd. for $[C_{12}H_{13}F_3O]^+$: 230.0918; found: 230.0914.

Preparation of 2-iodo-1-(1-phenyl-allyl)-cyclohex-2-enol (**36**):
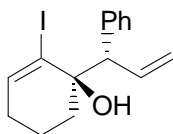
Prepared from 2-iodo-cyclohex-2-enone (222 mg, 1.0 mmol) and cinnamylzinc phosphate (**10**, 1.2 mmol) according to **TP2**. Purification by flash chromatography (eluent: pentane: ether = 8: 2 + 1 % Et$_3$N) provided the pure compound **36** (322 mg, 94 %) as a colourless oil. dr > 98: 2.

^{1}H-NMR (CDCl$_3$, 300 MHz): δ / ppm = 7.43-7.50 (m, 2 H), 7.21-7.35 (m, 3 H), 6.62 (dd, J = 5.3 Hz, J = 3.3 Hz, 1 H), 6.37-6.51 (m, 1 H), 5.36 (dd, J = 10.2 Hz, J = 1.8 Hz, 1 H), 5.30 (ddd, J = 17.1 Hz, J = 1.7 Hz, J = 0.8 Hz, 1 H), 3.95 (d, J = 9.4 Hz, 1 H), 2.24 (s, 1 H), 2.11-2.22 (m, 1 H), 1.86-2.04 (m, 2 H), 1.52 (m, 2 H), 1.27-1.42 (m, 1H).

^{13}C-NMR (CDCl$_3$, 75 MHz): δ / ppm = 143.7, 139.8, 135.9, 128.9, 128.0, 126.8, 119.8, 111.7, 74.7, 59.4, 32.5, 29.4, 18.7.

IR (neat): v/cm^{-1} = 3535, 3060, 3028, 2933, 2867, 1633, 1600, 1495, 1451, 1327, 1165, 1084, 1048, 978, 964, 916, 749, 698.

MS (EI): m/z (%) = 224 (5), 223 (100), 118 (29), 117 (8), 96 (14), 95 (7).

HRMS (EI): calcd. for [C$_{15}$H$_{17}$IO]$^+$: 340,0324; found: 340.0333.

Preparation of 2-(4-bromo-phenyl)-3-phenyl-4-trimethylsilanyl-pent-4-en-2-ol (**37**):
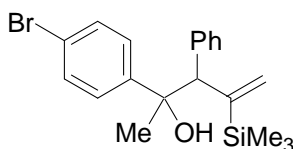
Prepared from 4-bromo-acetophenone (200 mg, 1.0 mmol) and 3-phenyl-2-trimethylsilanyl-prop-2-enylzinc phosphate (**10**, 1.2 mmol) according to **TP2**. Purification by flash chromatography (eluent: pentane: ether = 8: 2 + 1 % Et$_3$N) provided the pure compound **37** (361 mg, 93 %) as a colourless oil. dr > 97: 3.

¹H-NMR (CDCl₃, 300 MHz): δ / ppm = 7.32 (d, *J* = 8.6 Hz, 2 H), 7.07-7.13 (m, 3 H), 7.04 (d, *J* = 8.6 Hz, 2 H), 6.95-7.01 (m, 2 H), 6.47 (dd, *J* = 2.4 Hz, *J* = 0.8 Hz, 1 H), 5.79 (d, *J* = 2.5 Hz, 1 H), 3.91 (s, 1 H), 2.15 (br s, 1 H), 1.65 (s, 3 H), -0.04 (s, 9H).

¹³C-NMR (CDCl₃, 75 MHz): δ / ppm = 151.3, 147.3, 138.8, 130.7, 130.2, 127.9, 127.7, 127.0, 126.5, 120.2, 77.3, 59.0, 29.2, -1.6.

IR (neat): ν/cm⁻¹ = 3561, 3060, 3027, 2955, 2895, 1592, 1487, 1395, 1247, 1080, 1008, 946, 833, 757, 699, 602.

MS (EI): m/z (%) = 202 (9), 201 (96), 199 (100), 175 (51), 159 (14), 135 (14), 111 (18), 109 (12), 81 (16), 73 (66), 43 (76).

HRMS (FAB): calcd. for $[C_{20}H_{25}BrOSi - OH]^+$: 371,0831; found: 371.0829.

Preparation of *N*-(1,2-diphenyl-but-3-enyl)-4-methyl-benzenesulfonamide (**38**):
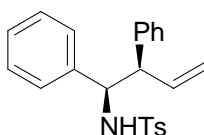
Prepared from *N*-benzylidene-4-methyl-benzenesulfonamide (260 mg, 1.0 mmol) and cinnamylzinc phosphate (**10**, 1.2 mmol) according to **TP2**. Purification by flash chromatography (eluent: pentane: ether = 1: 1 + 1 % Et₃N) provided the pure compound **38** (280 mg, 74 %) as a white solid. dr > 98: 2.

mp (°C) = 147.7-148.6

¹H-NMR (CDCl₃, 300 MHz): δ / ppm = 7.39 (d, *J* = 8.3 Hz, 2 H), 7.23-7.29 (m, 3 H), 7.04-7.18 (m, 5 H), 6.88-7.02 (m, 4 H), 5.74-5.89 (m, 1 H), 5.01-5.05 (m, 1 H), 4.91 (dt, *J* = 17.0 Hz, *J* = 1.3 Hz, 1 H), 4.76 (d, *J* = 6.0 Hz, 1 H), 4.55 (dd, *J* = 7.5 Hz, *J* = 6.2 Hz, 1 H), 3.56 (t, *J* = 8.0 Hz, 1 H), 2.36 (s, 3 H).

¹³C-NMR (CDCl₃, 75 MHz): δ / ppm = 142.9, 138.9, 138.3, 137.1, 136.3, 129.1, 128.8, 128.4, 127.8, 127.8, 127.4, 127.4, 127.1, 118.3, 61.6, 56.5, 21.4.

IR (neat): ν/cm⁻¹ = 3332, 3030, 2927, 1634, 1599, 1494, 1456, 1430, 1320, 1151, 1088, 1058, 960, 910, 807, 759, 697, 668.

MS (EI): m/z (%) = 262 (5), 261 (15), 260 (100), 155 (50), 91 (59), 57 (10).

HRMS (EI): calcd. for $[C_{23}H_{23}NO_2S + H]^+$: 378.1528; found: 378.1531.

Preparation of 2-methyl-1-(1-phenyl-allyl)-cyclohexanol (**39**):
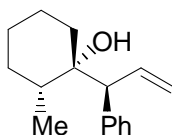
Prepared from 2-methyl-cyclohexanone (450 mg, 4.0 mmol) and cinnamylzinc phosphate (**10**, 5 mmol) according to **TP2**. Purification by flash chromatography (eluent: pentane: ether = 8: 2 + 1 % Et$_3$N) provided the pure compound **39** (824 mg, 90 %) as a colourless oil. dr > 99:1.

^{1}H-NMR (CDCl$_3$, 300 MHz): δ / ppm = 7.28-7.33 (m, 4 H), 7.19-7.27 (m, 1 H), 6.33 (dt, J = 16.9 Hz, J = 9.8 Hz, 1 H), 5.11-5.25 (m, 2 H), 3.69 (d, J = 9.5 Hz, 1 H), 1.61-1.72 (m, 1 H), 1.34-1.60 (m, 9 H), 1.03 (d, J = 6.1 Hz, 3 H).

^{13}C-NMR (CDCl$_3$, 75 MHz): δ / ppm = 140.9, 137.9, 129.1, 128.2, 126.5, 118.2, 74.9, 57.5, 35.5, 32.6, 40.0, 24.6, 21.7, 15.4.

IR (neat): ν/cm^{-1} = 3570, 3077, 2925, 2858, 1633, 1601, 1492, 1450, 1376, 963, 915, 725, 700.

MS (EI, 70 ev): m/z (%) = 213 (100), 172 (2), 102 (3).

HRMS (EI): calcd. for [C$_{16}$H$_{22}$O – OH]$^+$: 213.1643 ; found: 213.1635.

Preparation of 2-methoxy-1-(1-phenyl-allyl)-cyclohexanol (**40**):
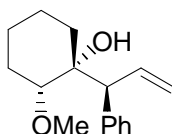
Prepared from 2-methoxy-cyclohexanone (128 mg, 1.0 mmol) and cinnamylzinc phosphate (**10**, 1.2 mmol) according to **TP2**. Purification by flash chromatography (eluent: pentane: ether = 8: 2 + 1 % Et$_3$N) provided the pure compound **40** (214 mg, 87 %) as a colourless oil. dr > 99:1.

^{1}H-NMR (CDCl$_3$, 300 MHz): δ / ppm = 7.30 (d, J = 4.4 Hz, 4 H), 7.16-7.25 (m, 1 H), 6.29-6.43 (m, 1 H), 5.15 (dd, J = 10.1 Hz, J = 1.6 Hz, 1 H), 5.09 (ddd, J = 17.1 Hz, J = 1.6 Hz, J =

0.9 Hz, 1 H), 3.80 (d, J = 9.0 Hz, 1 H), 3.32 (s, 3 H), 2.90 (dd, J = 8.5 Hz, J = 3.9 Hz, 1 H), 2.28 (s, 1 H), 1.29-1.83 (m, 7 H), 1.05-1.12 (m, 1 H).

^{13}C-NMR (CDCl$_3$, 75 MHz): δ / ppm = 141.0, 137.9, 129.6, 128.1, 126.4, 117.1, 79.6, 75.2, 55.9, 55.6, 31.0, 24.6, 22.2, 21.2.

IR (neat): ν/cm^{-1} = 3488, 3079, 2934, 2862, 2824, 1635, 1601, 1492, 1452, 1091, 1065, 994, 976, 911, 747, 702.

MS (EI, 70 ev): m/z (%) = 229 (100), 215 (51), 197 (33), 102 (70).

HRMS (EI): calcd. for [C$_{16}$H$_{22}$O$_2$ – OH]$^+$: 229.1592 ; found: 229.1585.

Note: When the reaction was carried out with (2*S*)-methoxy-cyclohexanone (94 % *ee*), the resulting alcohol **(2*S*,1*R*,1´*S*)-40** was obtained in 81 % as a single diastereoisomer (dr > 99: 1; 94 % ee; [α]$_D$ (c = 0.0198 g.mL^{-1}, CHCl$_3$) = -70.9).

Preparation of 2-hydroxy-2-(1-phenyl-allyl)-cyclohexyl acetate (**41**):
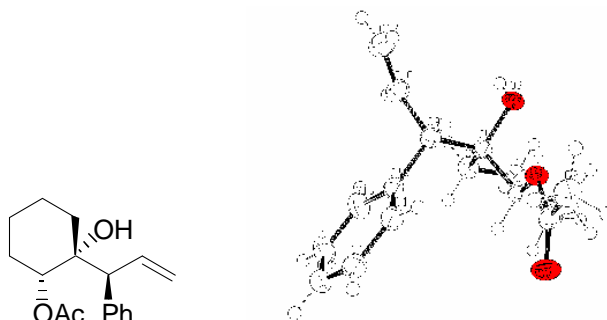
Prepared from 2-oxo-cyclohexyl acetate (156 mg, 1.0 mmol) and cinnamylzinc phosphate (**10**, 1.2 mmol) according to **TP2**. Purification by flash chromatography (eluent: pentane: ether = 1: 1 + 1 % Et$_3$N) provided the pure compound **41** (228 mg, 83 %) as a white solid. dr > 99:1

mp (°C) = 101.3-102.2.

^{1}H-NMR (CDCl$_3$, 300 MHz): δ / ppm = 7.19-7.35 (m, 5 H), 6.31-6.44 (m, 1 H), 5.11-5.23 (m, 2 H), 4.61 (dd, J = 9.5 Hz, J = 4.6 Hz, 1 H), 3.59 (d, J = 9.4 Hz, 1 H), 2.12 (s, 3 H), 2.00 (s, 1 H), 1.37-1.88 (m, 7 H), 1.14-1.21 (m, 1 H).

^{13}C-NMR (CDCl$_3$, 75 MHz): δ / ppm = 170.1, 140.1, 137.1, 129.1, 128.4, 126.8, 117.5, 75.1, 74.5, 57.5, 32.5, 27.2, 22.4, 21.5, 20.7.

IR (neat): ν/cm^{-1} = 3406, 3072, 3032, 2936, 2856, 1708, 1604, 1492, 1380, 1272, 1251, 1144, 977, 708.

MS (EI, 70 ev): m/z (%) = 275 (100), 257 (6).

HRMS (EI): calcd. for $[C_{17}H_{22}O_3 + H]^+$: 275.1647 ; found: 275.1642.

Preparation of 2-benzyloxy-1-(1-phenyl-allyl)-cyclohexanol (**42**):
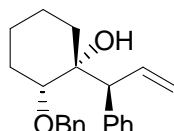
Prepared from 2-benzyloxy-cyclohexanone (205 mg, 1.0 mmol) and cinnamylzinc chloride (**11**, 1.2 mmol) according to **TP2**. Purification by flash chromatography (eluent: pentane: ether = 8: 2 + 1 % Et$_3$N) provided the pure compound **42** (290 mg, 90 %) as a colourless oil. dr > 99:1.

^{1}H-NMR (CDCl$_3$, 300 MHz): δ / ppm = 7.17-7.44 (m, 10 H), 6.31-6.46 (m, 1 H), 5.15 (ddd, J = 10.2 Hz, J = 1.9 Hz, J = 0.7 Hz, 1 H), 5.06 (ddd, J = 17.1 Hz, J = 1.9 Hz, J = 1.1 Hz, 1 H), 4.64 (d, J = 11.3 Hz, 1 H), 4.35 (d, J = 11.3 Hz, 1 H), 3.82 (d, J = 8.7 Hz, 1 H), 3.28 (dd, J = 8.1 Hz, J = 3.9 Hz, 1 H), 2.44 (br s, 1 H), 1.08-1.92 (m, 8 H).

^{13}C-NMR (CDCl$_3$, 75 MHz): δ / ppm = 141.0, 138.7, 138.8, 129.6, 128.4, 128.1, 127.5, 127.5, 126.4, 116.7, 78.6, 75.3, 70.0, 55.8, 31.2, 25.5, 22.0, 21.3.

IR (neat): ν/cm^{-1} = 3559, 3064, 3029, 2934, 2861, 1635, 1601, 1494, 1452, 1385, 1160, 1073, 1028, 912, 735, 697.

MS (EI, 70 ev): m/z (%) = 305 (58), 277 (2), 207 (4).

HRMS (EI): calcd. for $[C_{22}H_{26}O_2 - OH]^+$: 305.1905 ; found: 305.1903.

Preparation of 3-[2-hydroxy-2-(1-phenyl-allyl)-cyclohexyl]-propionitrile (**43**):
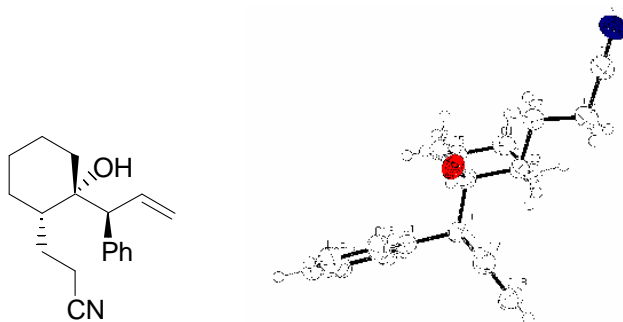
Prepared from 3-(2-oxo-cyclohexyl)-propionitrile (152 mg, 1.0 mmol) and cinnamylzinc phosphate (**10**, 1.2 mmol) according to **TP2**. Purification by flash chromatography (eluent: pentane: ether = 6: 4 + 1 % Et₃N) provided the pure compound **43** (247 mg, 92 %) as a white solid. dr > 99:1.

mp (°C) = 70.9-72.9.

¹H-NMR (CDCl₃, 300 MHz): δ / ppm = 7.30-7.34 (m , 2 H), 7.22-7.29 (m, 3 H), 6.29 (dt, J = 16.9 Hz, J = 9.8 Hz, 1 H), 5.23 (dd, J = 10.1 Hz, J = 1.5 Hz, 1 H), 5.18 (d, J = 17.0 Hz, 1 H), 3.73 (d, J = 9.6 Hz, 1Hz), 2.38-2.45 (m, 1 H), 2.19-2.29 (m, 2 H), 1.63-1.72 (m, 1 H), 1.36-1.60 (m, 9 H), 1.14-1.23 (m, 1 H).

¹³C-NMR (CDCl₃, 75 MHz): δ / ppm = 140.3, 137.2, 128.9, 128.6, 126.8, 120.2, 118.5, 74.9, 56.6, 39.5, 32.7, 26.5, 25.4, 23.0, 21.7, 15.4.

IR (neat): ν/cm⁻¹ = 3491, 3085, 2950, 2922, 2865, 2256, 1636, 1603, 1492, 1452, 1170, 1068, 920, 704.

MS (EI, 70 ev): m/z (%) = 270 (74), 252 (100), 239 (17), 102 (6).

HRMS (EI): calcd. for [C₁₈H₂₃NO + H]⁺: 270,1858 ; found: 270.1857.

Preparation of 2-chloro-1-(1-phenyl-allyl)-cyclohexanol (**44**):
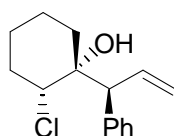
Prepared from 2-chloro-cyclohexanone (133 mg, 1.0 mmol) and cinnamylzinc phosphate (**10**, 1.2 mmol) according to **TP2**. Purification by flash chromatography (eluent: pentane: ether = 85: 15 + 1 % Et₃N) provided the pure compound **44** (182 mg, 73 %) as a colourless oil. dr > 99:1.

¹H-NMR (CDCl₃, 300 MHz): δ / ppm = 7.22-7.43 (m, 5 H), 6.30-6.45 (m, 1 H), 5.26 (dd, J = 10.1 Hz, J = 1.5 Hz, 1 H), 5.17 (dt, J = 17.0 Hz, J = 1.3 Hz, 1 H), 3.91 (d, J = 8.8 Hz, 1 H), 3.80-3.89 (m, 1 H), 1.88-2.13 (m, 4 H), 1.40-1.74 (m, 5 H).

¹³C-NMR (CDCl₃, 75 MHz): δ / ppm = 139.8, 136.6, 129.5, 128.3, 126.9, 118.5, 74.8, 67.1, 57.0, 32.6, 31.3, 24.7, 20.5.

IR (neat): ν/cm^{-1} = 3559, 3080, 3031, 2939, 2863, 1636, 1601, 1492, 1448, 1368, 1065, 980, 917, 849.

MS (EI, 70 ev): m/z (%) = 214 (1), 135 (8), 133 (27), 118 (100), 97 (12).

HRMS (EI): calcd. for [C15H$_{19}$ClO – OH]$^{+}$: 250,1124 ; found: 250,1136.

Preparation of 1-(1-phenyl-allyl)-2-phenylsulfanyl-cyclohexanol (**45**):
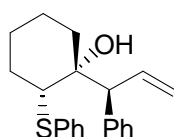
Prepared from 2-phenylsulfanyl-cyclohexanone (206 mg, 1.0 mmol) and cinnamylzinc chloride (**11**, 1.2 mmol) according to **TP2**. Purification by flash chromatography (eluent: pentane: ether = 8: 2 + 1 % Et$_3$N) provided the pure compound **45** (281 mg, 87 %) as a colourless oil. dr > 99:1.

^{1}H-NMR (CDCl$_3$, 300 MHz): δ / ppm = 7.48-7.84 (m, 2 H), 7.39-7.46 (m, 2 H), 7.22-7.39 (m, 6 H), 6.37-6.51 (m, 1 H), 5.22-5.32 (m, 2 H), 4.12 (d, *J* = 9.5 Hz, 1 H), 3.35 (br s, 1 H), 2.42 (s, 1 H), 1.85-2.08 (m, 2 H), 1.51-1.74 (m, 5 H), 1.26-1.39 (m, 1 H).

^{13}C-NMR (CDCl$_3$, 75 MHz): δ / ppm = 140.5, 137.3, 135.9, 130.9, 129.4, 128.9, 128.2, 126.7, 126.4, 118.3, 74.7, 56.0, 55.3, 33.4, 30.3, 23.4, 21.6.

IR (neat): ν/cm^{-1} = 3553, 3060, 3028, 2931, 2858, 1634, 1600, 1583, 1492, 1480, 1448, 1440, 1364, 1088, 916, 732, 689.

MS (EI, 70 ev): m/z (%) = 324 (2), 208 (12), 207 (100), 189 (11), 117 (18), 115 (12), 110 (10), 97 (32), 69 (20).

HRMS (EI): calcd. for [C$_{21}$H$_{24}$OS]$^{+}$: 324,1548; found: 324.1561.

Preparation of 2-phenyl-1-(1-phenyl-allyl)-cyclohexanol (**46**):
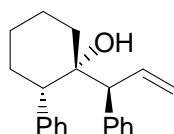
Prepared from 2-phenyl-cyclohexanone (174 mg, 1.0 mmol) and cinnamylzinc phosphate (**10**, 1.2 mmol) according to **TP2**. Purification by flash chromatography (eluent: pentane: ether = 8: 2 + 1 % Et$_3$N) provided the pure compound **46** (76 mg, 26 %) as a colourless oil. dr > 99:1.

^{1}H-NMR (CDCl$_3$, 300 MHz): δ / ppm = 7.19-7.50 (m, 8 H), 7.02-7.06 (m, 2 H), 6.22 (dt, *J* = 16.9 Hz, *J* = 9.9 Hz, 1 H), 5.17 (dd, *J* = 10.1 Hz, *J* = 1.7 Hz, 1 H), 5.04 (dd, *J* = 16.9 Hz, *J* = 0.9 Hz, 1 H), 3.40 (d, *J* = 9.7 Hz, 1 H), 1.95 (qd, *J* = 13.5 Hz, *J* = 3.8 Hz, 1 H), 1.87 (s, 1 H), 1.48-1.85 (m, 6 H), 1.16-1.25 (m, 1 H).

^{13}C-NMR (CDCl$_3$, 75 MHz): δ / ppm = 144.2, 140.2, 137.8, 130.0, 129.7, 127.9, 127.9, 126.5, 126.1, 118.8, 75.4, 59.2, 50.1, 34.3, 32.6, 26.2, 21.4.

IR (neat): ν/cm^{-1} = 3556, 3080, 2943, 2859, 1631, 1600, 1499, 1445, 1240, 1136, 916, 760, 704.

MS (EI, 70 ev): m/z (%) = 176 (6), 175 (100), 118 (35), 117 (16), 115 (11), 91 (40).

HRMS (EI): calcd. for [C$_{21}$H$_{24}$O]$^+$: 292,1827; found: 292.1818.

Preparation of 2-methyl-1-(1-phenyl-allyl)-cyclopentanol (**47**):
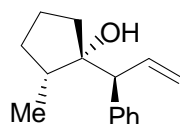
Prepared from 2-methyl-cyclopentanone (98 mg, 1.0 mmol) and cinnamylzinc phosphate (**10**, 1.2 mmol) according to **TP2**. Purification by flash chromatography (eluent: pentane: ether = 8: 2 + 1 % Et$_3$N) provided the pure compound **47** (172 mg, 75 %) as a colourless oil. dr > 99:1.

^{1}H-NMR (CDCl$_3$, 300 MHz): δ / ppm = 7.20-7.39 (m, 5 H), 6.30-6.48 (m, 1 H), 5.17-5.29 (m, 2 H), 3.47 (d, *J* = 9.6 Hz, 1 H), 1.82-1.98 (m, 1 H), 1.36-1.80 (m, 7 H), 1.02 (d, *J* = 6.0 Hz, 3 H).

^{13}C-NMR (CDCl$_3$, 75 MHz): δ / ppm = 141.3, 138.1, 128.8, 128.2, 126.5, 117.8, 83.0, 58.5, 40.0, 36.6, 32.1, 20.9, 13.5.

IR (neat): ν/cm^{-1} = 3567, 3076, 2945, 2862, 1636, 1601, 1492, 1451, 1377, 960, 913, 731, 700.

MS (EI, 70 ev): m/z (%) = 199 (100), 117 (1), 102 (3).

HRMS (EI): calcd. for [C$_{15}$H$_{20}$O – OH]$^+$: 199.1487 ; found: 199.1481.

Preparation of 2-methoxy-1-(1-methyl-1-phenyl-allyl)-cyclohexanol (**48**):
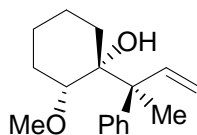
Prepared from 2-methoxy-cyclohexanone (130 mg, 1.0 mmol) and 3-phenyl-but-2-en-1-ylzinc phosphate (**15**, 1.2 mmol) according to**TP2**. Purification by flash chromatography (eluent: pentane: ether = 8: 2 + 1 % Et$_3$N) provided compound **48** (234 mg, 90 %) as a colourless oil. dr = 86:14.

^{1}H-NMR (CDCl$_3$, 300 MHz): δ / ppm = 7.42-7.56 (m, 2 H), 7.14-7.33 (m, 3 H), 6.85 (dd, J = 17.5 Hz, J = 11.0 Hz, 1 H), 6.70 (dd, J = 17.5 Hz, J = 11.0 Hz, 1 H, *minor isomer*), 5.17-5.30 (m, 2H, *minor isomer*), 5.08 (dd, J = 11.0 Hz, J = 0.8 Hz, 1 H), 4.93 (dd, J = 17.5 Hz, J = 0.8 Hz, 1 H), 3.25 (dd, J = 11.0 Hz, J = 4.8 Hz, 1 H, *minor isomer*), 3.23 (s, 3 H, *minor isomer*), 3.18 (s, 3 H), 3.16 (dd, J = 10.9 Hz, J = 4.7 Hz, 1 H), 2.50-2.55 (m, 1 H, *minor isomer*), 2.43-2.48 (m, 1 H), 1.84-1.96 (m, 1 H), 1.62-1.71 (m, 1 H), 1.62 (s, 3 H, *minor isomer*), 1.58 (s, 3 H), 0.87-1.55 (m, 5 H).

^{13}C-NMR (CDCl$_3$, 75 MHz): δ / ppm = 147.1 (*minor isomer*), 145.8, 145.2, 144.1 (*minor isomer*), 128.4, 127.8 (*minor isomer*), 127.4 (*minor isomer*), 127.2, 125.6, 113.4 (*minor isomer*), 112.0, 81.6 (*minor isomer*), 81.2, 77.8, 55.1, 55.0 (*minor isomer*), 52.1 (*minor isomer*), 51.9, 32.3 (*minor isomer*), 32.2, 26.5, 26.4 (*minor isomer*), 23.8, 21.9, 21.4 (*minor isomer*), 21.2.

IR (neat): ν/cm^{-1} = 3516, 2936, 2860, 2824, 1631, 1600, 1444, 1371, 1193, 1096, 981, 965, 913, 750, 700.

MS (EI, 70 ev): m/z (%) = 133 (23), 129 (100), 91 (46).

HRMS (EI): calcd. for [C$_{17}$H$_{24}$O$_2$]$^+$: 260.1776 ; found: 260.1801.

Preparation of 2-allyl-1-(1-phenyl-allyl)-cyclohexanol (**49**):
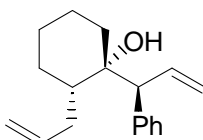
Prepared from 2-allyl-cyclohexanone (415 mg, 3.0 mmol) and cinnamylzinc phosphate (**10**, 3.8 mmol) according to **TP2**. Purification by flash chromatography (eluent: pentane: ether = 85: 15 + 1 % Et$_3$N) provided the pure compound **49** (622 mg, 83 %) as a colourless oil. dr > 99:1.

^{1}H-NMR (CDCl$_3$, 300 MHz): δ / ppm = 7.22-7.40 (m, 5 H), 6.30-6.46 (m, 1 H), 5.68-5.85 (m, 1 H), 4.99-5.31 (m, 4 H), 3.85 (d, J = 9.4 Hz, 1 H), 2.65-2.78 (m, 1 H), 1.97-2.12 (m, 1 H), 1.28-1.71 (m, 9 H), 1.04-1.21 (m, 1 H).

^{13}C-NMR (CDCl$_3$, 75 MHz): δ / ppm = 140.7, 138.1, 137.7, 129.2, 128.2, 126.5, 118.2, 115.6, 75.2, 56.9, 40.1, 33.5, 32.7, 26.8, 23.7, 21.8.

IR (neat): v/cm^{-1} = 3568, 3075, 2929, 2860, 1638, 1600, 1492, 1451, 1137, 996, 952, 908, 736, 703.

MS (EI, 70 ev): m/z (%) = 239 (57), 102 (4).

HRMS (EI): calcd. for [C$_{18}$H$_{24}$O – OH]$^+$: 239.1800 ; found: 239.1795.

Preparation of 5-phenyl-1,3,4,5,8,8a-hexahydro-2H-naphthalen-4a-ol (**50**):
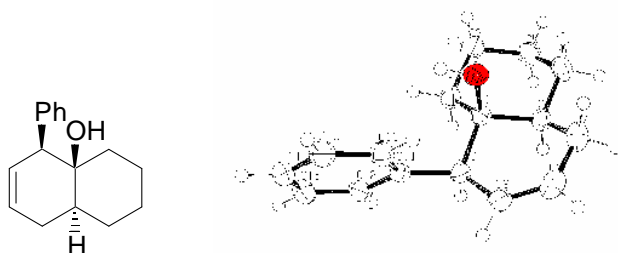
Homoallylic alcohol **49** (256 mg, 1 mmol) in CH$_2$Cl$_2$ (5 mL) was added to a solution of Grubbs II catalyst (43 mg, 5 mol %) in CH$_2$Cl$_2$ at 25 °C. The reaction mixture was stirred at this temperature for 5 h. Water (5 mL) was added, and the reaction was extracted with CH$_2$Cl$_2$. Concentration, followed by flash chromatography purification (eluent: pentane: ether = 85: 15 + 1 % Et$_3$N), yielded the alcohol **50** as a white solid (213 mg, 93 %). dr > 99:1.

mp (°C) = 58.9-60.8.

^{1}H-NMR (CDCl$_3$, 300 MHz): δ / ppm = 7.19-7.38 (m, 5 H), 5.87-5.95 (m, 1 H), 5.52-5.59 (m, 1 H), 3.36-3.41 (m, 1 H), 2.01-2.09 (m, 2 H), 1.67-1.84 (m, 1 H), 1.20-1.59 (m, 8 H), 1.02 (br s, 1 H).

^{13}C-NMR (CDCl$_3$, 75 MHz): δ / ppm = 140.5, 130.1, 128.9, 128.0, 127.6, 126.7, 69.8, 53.6, 40.3, 37.1, 29.5, 29.1, 26.0, 21.7.

IR (neat): ν/cm^{-1} = 3561, 3020, 2917, 2851, 1443, 983, 950, 831, 756, 703.

MS (EI, 70 ev): m/z (%) = 228 (3), 131 (11), 130 (67), 128 (16), 116 (18), 115 (100), 98 (20), 91 (24), 83 (13), 77 (23), 70 (23), 65 (12), 39 (30).

HRMS (EI): calcd. for $[C_{16}H_{20}O]^+$: 228.1514 ; found: 228.1504.

Preparation of 6-methoxy-4-phenyl-1-oxa-spiro[4.5]decane (**53**):
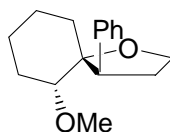
BH$_3$·Me$_2$S (0.90 mL, 9.5 mmol) was added at 25 °C to a solution of homoallylic alcohol **40** (643 mg, 2.6 mmol) in dry THF (10 mL). The resulting solution was stirred at 25 °C under nitrogen for 4 h, then it was quenched with water (5 mL) at 0 ºC. NaBO$_3$·4H$_2$O (4.20 g, 27 mmol) and NaOH (1.10 g, 27 mmol) were subsequently added, and the reaction mixture was heated to 45 ºC for 3 h. The phases were separated and the aqueous phase was extracted with Et$_2$O. The combined organic phases were dried over MgSO$_4$, and concentrated *in vacuo*. Purification by flash chromatography (eluent: ether + 1 % Et$_3$N) provided 1-(3-hydroxy-1-phenyl-propyl)-2-methoxy-cyclohexanol **51** (575 mg, 83 %) as a colourless oil. dr > 99:1.

^{1}H NMR (CDCl$_3$, 300 MHz): δ / ppm = 7.19-7.34 (m, 5 H), 3.37-3.62 (m, 2H), 3.31 (dd, *J* = 10.4 Hz, *J* = 4.4 Hz, 1 H), 3.28 (s, 3 H), 2.68 (dd, *J* = 10.4 Hz, *J* = 4.4 Hz, 1 H), 2.40 (d, *J* = 1.7 Hz, 1 H), 2.23-2.36 (m, 1 H), 2.17 (br s, 1 H), 1.77-2.01 (m, 3 H), 1.25-1.69 (m, 5 H), 0.80-1.01 (m, 1 H)

^{13}C NMR (CDCl$_3$, 75 MHz): δ / ppm = 141.7, 129.5, 128.0, 126.4, 79.4, 75.7, 62.2, 54.9, 49.4, 32.2, 29.2, 24.8, 23.0, 20.8.

IR (neat): ν/cm^{-1} = 3400, 3029, 3935, 2862, 2824, 1600, 1494, 1451, 1096, 1034, 982, 952, 768, 704.

MS (EI, 70 ev): m/z (%) = 173 (1), 129 (100), 118 (18), 105 (11), 97 (25), 91 (8), 69 (14).

HRMS (EI): calcd. for $[C_{16}H_{24}O_3 + H]^+$: 265.1804; found: 265.1800.

Mesyl chloride (0.25 mL, 3.2 mmol) was added at 0 ºC to a solution of the diol **51** (500 mg, 1.9 mmol), Et$_3$N (0.6 mL, 4 mmol) and DMAP (12 mg) in CH$_2$Cl$_2$ (10 mL). After 90 min, water was added and the aqueous phase extracted with CH$_2$Cl$_2$. The combined organic phases

were dried over $MgSO_4$, and concentrated *in vacuo*. Purification by flash chromatography (eluent: pentane: ether = 7: 3) afforded the pure spiro-compound **53** (258 mg, 55 %) as a colourless oil. dr > 99:1.


^{1}H NMR (CDCl$_3$, 300 MHz): δ / ppm = 7.19-7.38 (m, 5 H), 3.93-4.11 (m, 2 H), 3.87 (dd, *J* = 11.5 Hz, *J* = 7.7 Hz, 1 H), 3.51 (s, 3 H), 2.99 (dd, *J* = 11.3 Hz, *J* = 4.4 Hz, 1 H), 2.33-2.49 (m, 1 H), 2.18-2.32 (m, 1 H), 1.97-2.09 (m, 1 H), 1.27-1.76 (m, 5 H), 0.92-1.11 (m, 1 H), 0.45-0.61 (m, 1 H).

^{13}C NMR (CDCl$_3$, 75 MHz): δ / ppm = 139.8, 128.7, 128.1, 126.5, 85.2, 80.6, 66.2, 56.6, 46.8, 31.8, 30.7, 26.4, 24.0, 21.1.

IR (neat): v/cm^{-1} = 3028, 2934, 2861, 2819, 1603, 1496, 1452, 1370, 1192, 1100, 1060, 1040, 978, 768, 700.

MS (EI, 70 ev): m/z (%) = 247 (5), 246 (26), 173 (26), 118 (100), 117 (37), 91 (13), 57 (13), 39 (12).

HRMS (EI): calcd. for $[C_{16}H_{22}O_2]^+$: 246,1620; found: 246.1614.

Preparation of 6-benzyloxy-4-phenyl-1-oxa-spiro[4.5]decane (**54**):
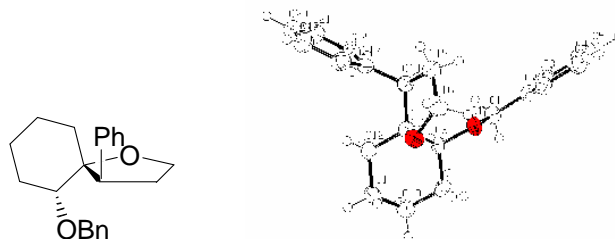
BH$_3$·Me$_2$S (0.90 mL, 9.5 mmol, 3 equiv.) was added at 25 °C to a solution of homoallylic alcohol **42** (1.04 g, 3.2 mmol) in dry THF (15 mL). The resulting solution was stirred at 25 °C under nitrogen for 4 h, then it was quenched with water (5 mL) at 0 °C. NaBO$_3$·4H$_2$O (4.20 g, 27 mmol, 9 equiv.) and NaOH (1.10 g, 27 mmol, 9 equiv.) were subsequently added, and the reaction mixture was heated to 45 °C for 4 h. The phases were separated and the aqueous phase was extracted with Et$_2$O. The combined organic phases were dried over MgSO$_4$, and concentrated *in vacuo*. Purification by flash chromatography (eluent: ether + 1 % Et$_3$N) provided 2-benzyloxy-1-(3-hydroxy-1-phenyl-propyl)-cyclohexanol **52** (840 mg, 77 %) as a colourless oil. dr > 99:1.

¹H NMR (CDCl₃, 300 MHz): δ / ppm = 7.43 (d, J = 4.4 Hz, 4 H), 7.20-7.41 (m, 6 H), 4.64 (d, J = 11.2 Hz, 1 H), 4.31 (d, J = 11.2 Hz, 1 H), 3.39-3.62 (m, 2 H), 3.36 (dd, J = 10.5 Hz, J = 4.4 Hz, 1 H), 3.05 (dd, J = 10.1 Hz, J = 4.3 Hz, 1 H), 2.48 (d, J = 1.5 Hz, 1 H), 2.25-2.41 (m, 1 H), 1.84-2.06 (m, 4 H), 1.32-1.77 (m, 5 H), 0.88-1.18 (m, 1 H).

¹³C NMR (CDCl₃, 75 MHz): δ / ppm = 141.6, 138.7, 129.5, 128.4, 128.1, 127.6, 127.5, 126.5, 78.5, 75.8, 69.4, 62.2, 49.5, 32.4, 29.5, 25.8, 23.0, 20.8.

IR (neat): ν/cm⁻¹ = 3388, 3029, 2935, 2862, 1601, 1495, 1452, 1072, 1028, 975, 871, 731, 698.

MS (EI, 70 ev): m/z (%) = 323 (1), 322 (2), 206 (3), 205 (24), 105 (13), 91 (100), 65 (3).

HRMS (EI): calcd. for $[C_{22}H_{28}O_3]^+$: 340.2038; **found**: 340.2041.

Mesyl chloride (0.25 mL, 3.2 mmol, 1.5 equiv.) was added at 0 ºC to a solution of the diol **52** (782 mg, 2.3 mmol), Et₃N (0.60 mL, 4 mmol, 2.0 equiv.) and DMAP (12 mg) in CH₂Cl₂ (10 mL). After 90 min, water was added and the aqueous phase extracted with CH₂Cl₂. The combined organic phases were dried over MgSO₄, and concentrated *in vacuo*. Purification by flash chromatography (eluent: pentane: ether = 9: 1) afforded the pure spiro-compound **54** (578 mg, 78 %) as a white solid. dr > 99:1.

mp (°C) = 72.2-73.5.

¹H NMR (CDCl₃, 300 MHz): δ / ppm = 7.28-7.49 (m, 5 H), 7.14-7.27 (m, 3 H), 6.92-7.01 (m, 2 H), 4.82 (d, J = 12.0 Hz, 1 H), 4.53 (d, J = 12.0 Hz, 1 H), 3.95-4.12 (m, 2 H), 3.84 (dd, J = 11.0 Hz, J = 7.7 Hz, 1 H), 3.24 (dd, J = 11.0 Hz, J = 4.5 Hz, 1 H), 2.17-2.44 (m, 2 H), 2.02-2.14 (m, 1 H), 1.25-1.82 (m, 5 H), 0.84-1.14 (m, 1 H), 0.40-0.57 (m, 1 H).

¹³C NMR (CDCl₃, 75 MHz): δ / ppm = 140.1, 138.9, 128.6, 128.4, 128.1, 128.0, 127.5, 126.4, 85.2, 78.8, 70.3, 66.7, 47.0, 32.8, 31.3, 27.1, 24.1, 21.2.

IR (neat): ν/cm⁻¹ = 3492, 3028, 2940, 2888, 2856, 1495, 1454, 1147, 1097, 1047, 729, 704.

MS (EI, 70 ev): m/z (%) = 323 (16), 322 (68), 231 (21), 173 (18), 118 (100), 117 (43), 98 (17), 91 (93), 67 (12).

HRMS (EI): calcd. for $[C_{22}H_{26}O_2]^+$: 322,1933; found: 322.1930.

Preparation of 2-methyl-1-(oxiranyl-phenyl-methyl)-cyclohexanol (**55**):
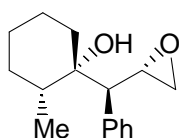
To a stirred solution of **39** (460 mg, 2 mmol) and NaH_2PO_4 (780 mg), in CH_2Cl_2, was added *m*-CPBA (630 mg of 70-75 % pure) at 25 °C. The resulting mixture was stirred at this temperature overnight. Addition of water, followed by extraction with CH_2Cl_2, gave a crude, which afforded the pure epoxide **55** (405 mg, 82 %) after purification by flash chromatography (eluent: pentane: ether = 7: 3). dr > 99: 1

¹H NMR (CDCl₃, 300 MHz): δ / ppm = 7.24-7.36 (m, 5 H), 3.50-3.55 (m, 1 H). 2.74 (dd, *J* = 4.8 Hz, *J* = 4.1 Hz, 1 H), 2.65 (d, *J* = 9.1 Hz, 1 H), 2.46 (br s, 1 H), 2.43 (dd, *J* = 4.8 Hz, *J* = 2.8 Hz, 1 H), 1.94-2.06 (m, 1 H), 1.23-1.76 (m, 7 H), 1.00-1.16 (m, 1 H), 0.96 (d, *J* = 6.4 Hz, 3 H).

¹³C NMR (CDCl₃, 75 MHz): δ / ppm = 138.5, 129.2, 128.3, 127.0, 76.2, 55.8, 53.2, 46.7, 36.2, 33.1, 30.6, 24.8, 21.6, 15.2.

IR (neat): v/cm⁻¹ = 3520, 3030, 2934, 2858, 1601, 1492, 1450, 1389, 1260, 967, 851, 700.

MS (EI, 70 ev): m/z (%) = 247 (24), 229 (12).

HRMS (EI): calcd. for $[C_{12}H_{22}O_2 + H]^+$: 247.1698; found: 247.1694.

Preparation of 1-(2-hydroxy-1-phenyl-propyl)-2-methyl-cyclohexanol (**56**):
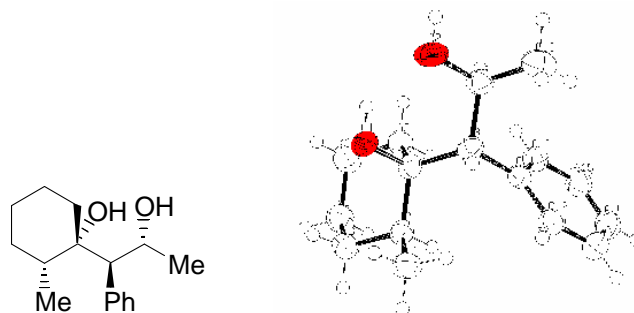
To a stirred solution of epoxide **55** (335 mg, 1.4 mmol) in diethylether (6 mL), was added $LiAlH_4$ (160 mg, 4.2 mmol) at 0 °C. After 90 min at room temperature, the reaction was carefully quenched with water (5 mL) and extracted with diethyl ether. The organic phase was dried over $MgSO_4$, concentrated and purified *via* flash chromatography (eluent: pentane: ether = 1: 1) to yield the diol **56** (321 mg, 95 %) as a white solid. dr > 99: 1

mp (°C) = 140.5-141.8.

¹H NMR (CDCl₃, 300 MHz): δ / ppm = 7.19-7.38 (m, 5 H), 4.45-4.58 (m, 1 H), 3.19-3.41 (m, 2 H), 2.95 (d, J = 10.3 Hz, 1 H), 2.17-2.27 (m, 1 H), 1.72-1.88 (m, 1 H), 1.51-1.70 (m, 3 H), 1.25-1.38 (m, 2 H), 0.94-1.18 (m, 5 H), 0.92 (d, J = 6.0 Hz, 3 H).

¹³C NMR (CDCl₃, 75 MHz): δ / ppm = 139.9, 128.2, 128.2, 126.7, 77.8, 69.4, 59.6, 37.0, 31.8, 30.8, 25.6, 23.7, 21.5, 15.3.

IR (neat): ν/cm⁻¹ = 3216, 2979, 2925, 2851, 1492, 1447, 1377, 1114, 1032, 960, 768, 704.

MS (EI, 70 ev): m/z (%) = 186 (6), 119 (10), 118 (100), 117 (24), 95 (8), 91 (8).

HRMS (EI): calcd. for $[C_{16}H_{24}O_2 - H_2O]^+$: 230.1671; found: 230.1665.

Preparation of 2-chloro-3-methyl-4-phenyl-hex-5-en-3-ol (**57**):
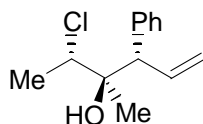
Prepared from 3-chloro-butan-2-one (107 mg, 1.0 mmol) and cinnamylzinc phosphate (**10**, 1.2 mmol) according to **TP2**. Purification by flash chromatography (eluent: pentane: ether = 7: 3 + 1 % Et₃N) provided the pure compound **57** (186 mg, 83 %) as a colourless oil. dr > 98: 2.

¹H-NMR (CDCl₃, 300 MHz): δ / ppm = 7.21-7.38 (m, 5 H), 6.21-6.36 (m, 1 H), 5.20-5.27 (m, 2 H), 4.16 (q, J = 6.7 Hz, 1 H), 3.78 (d, J = 9.5 Hz, 1 H), 1.56 (br s, 1 H), 1.54 (d, J = 6.7 Hz, 3 H), 1.09 (s, 3 H).

¹³C-NMR (CDCl₃, 75 MHz): δ / ppm = 140.6, 136.5, 129.3, 128.5, 126.8, 118.3, 76.5, 61.1, 56.4, 20.1, 19.9.

IR (neat): ν/cm⁻¹ = 3610, 3472, 3079, 2985, 2941, 1636, 1600, 1492, 1452, 1379, 1238, 1135, 1092, 1075, 1027, 985, 918, 747, 700.

MS (EI, 70 ev): m/z (%) = 118 (100), 117 (30), 107 (7), 43 (12).

HRMS (EI): calcd. for $[C_{13}H_{17}O^{35}Cl]^+$: 224.0968 ; found: 224.0972.

Preparation of 2,3-dimethyl-2-(1-phenyl-allyl)-oxirane (**58**):
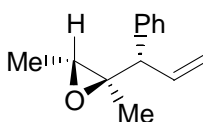
From **57**:

NaOH (0.5 mL of a 2 M solution in water) was added at 25 °C to a solution of 2-chloro-3-methyl-4-phenyl-hex-5-en-3-ol (**57**, 224 mg, 1 mmol) in *i*-PrOH (5 mL). The reaction mixture mixture was stirred at room temperature for 1 h, then diluted with water and extracted with diethyl ether. The organic extracts were combined, dried over MgSO$_4$ and concentrated *in vacuo* to yield **58** as colourless oil (181 mg, 96 %).

From 3-bromo-butan-2-one:

Prepared from 3-bromo-butan-2-one (152 mg, 1.0 mmol) and cinnamylzinc chloride (**11**, 1.2 mmol) according to **TP2**. Purification by flash chromatography (eluent: pentane: ether = 95: 5 + 1 % Et$_3$N) provided the pure compound **58** (156 mg, 83 %) as a colourless oil. dr > 98: 2.

From 3-iodo-butan-2-one:

Prepared from 3-iodo-butan-2-one (1.40 g, 7.1 mmol) and cinnamylzinc chloride (**11**, 8.5 mmol) according to **TP2**. Purification by flash chromatography (eluent: pentane: ether = 95: 5 + 1 % Et$_3$N) provided the pure compound **58** (1.15 g, 86 %) as a colourless oil. dr > 97: 3.

From toluene-4-sulfonic acid 1-methyl-2-oxo-propyl ester:

Prepared from toluene-4-sulfonic acid 1-methyl-2-oxo-propyl ester (245 mg, 1 mmol) and cinnamylzinc chloride (**11**, 1.2 mmol) according to **TP2** (**REVERSE ADDITION**). Purification by flash chromatography (eluent: pentane: ether = 95: 5 + 1 % Et$_3$N) provided the pure compound **58** (170 mg, 90 %) as a colourless oil. dr > 99: 1.

^{1}H-NMR (CDCl$_3$, 300 MHz): δ / ppm = 7.22-7.39 (m, 5 H), 6.01-6.16 (m, 1 H), 5.16-5.26 (m, 2 H), 3.36 (d, *J* = 8.5 Hz, 1 H), 3.07 (q, *J* = 5.5 Hz, 1 H), 1.33 (d, *J* = 5.5 Hz, 3 H), 1.22 (s, 3 H).

^{13}C-NMR (CDCl$_3$, 75 MHz): δ / ppm = 140.8, 136.9, 128.4, 128.4, 126.7, 117.6, 62.4, 57.0, 56.6, 15.2, 13.9.

IR (neat): ν/cm^{-1} = 3064, 3001, 2929, 1638, 1602, 1492, 1452, 1384, 996, 918, 870, 754, 700.

MS (EI, 70 ev): m/z (%) = 146 (2), 145 (11), 128 (13), 118 (10), 117 (100), 115 (26), 91 (11).

HRMS (EI): calcd. for [C$_{13}$H$_{16}$O]$^+$: 188,1201; found: 188.1183.

Preparation of 3-methyl-2,4-diphenyl-hex-5-en-3-ol (**59**):
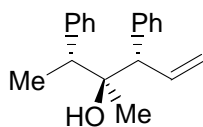
Prepared from 3-phenyl-butan-2-one (149 mg, 1.0 mmol) and cinnamylzinc chloride (**11**, 1.2 mmol) according to **TP2**. Purification by flash chromatography (eluent: pentane: ether = 9: 1 + 1 % Et_3N) provided compound **59** (232 mg, 87 %) as a colourless oil. dr = 91: 9.

^{1}H-NMR (CDCl$_3$, 300 MHz): δ / ppm = 7.12-7.35 (m, 10 H), 6.38-6.46 (m, 1 H), 5.27 (d, J= 10.2 Hz, 1 H), 5.12 (d, J = 17.2 Hz, 1 H), 3.47 (d, J = 8.3 Hz, 1 H), 2.88 (q, J = 7.1 Hz, 1 H), 1.62 (d, J = 1.3 Hz, 1 H), 1.40 (d, J = 7.1 Hz, 3 H), 0.94 (s, 3 H).

^{13}C-NMR (CDCl$_3$, 75 MHz): δ / ppm = 144.0, 141.6, 138.2, 129.1, 129.1, 128.3, 127.9, 126.5, 126.3, 118.4, 76.1, 57.4, 46.0, 23.0, 15.9.

IR (neat): v/cm^{-1} = 3576, 3551, 3501, 3074, 3025, 2974, 2911, 2879, 1635, 1600, 1581, 1491, 1452, 1374, 1139, 1076, 916, 907, 740, 703.

MS (EI, 70 ev): m/z (%) = 234 (2), 161 (13), 149 (69), 118 (55), 105 (44), 91 (29), 57 (23), 43 (100).

HRMS (EI): calcd. for [C$_{19}$H$_{22}$O - OH]$^+$: 249.1643 ; found: 249.1649.

Preparation of 3-methyl-4-phenyl-2-phenylsulfanyl-hex-5-en-3-ol (**60**):
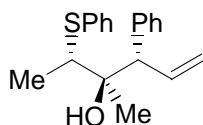
Prepared from 3-thiophenyl-butan-2-one (180 mg, 1.0 mmol) and cinnamylzinc chloride (**11**, 1.2 mmol) according to **TP2**. Purification by flash chromatography (eluent: pentane: ether = 8: 2 + 1 % Et_3N) provided compound **60** (286 mg, 96 %) as a colourless oil. dr = 81: 19.

^{1}H-NMR (CDCl$_3$, 300 MHz): δ / ppm = *major isomer*: 7.20-7.47 (m, 10 H), 6.30-6.44 (m, 1 H), 5.15-5.25 (m, 2 H), 3.98 (d, J = 9.6 Hz, 1 H), 3.51 (q, J = 6.9 Hz, 1 H), 1.76 (br s, 1 H), 1.41 (d, J = 6.9 Hz, 3 H), 1.08 (s, 3 H). *minor isomer*: 7.17-7.57 (m, 10 H), 6.36-6.53 (m, 1

H), 5.10-5.23 (m, 2 H), 3.51-3.62 (m, 2 H), 2.73 (s, 1 H), 1.45 (d, J = 7.0 Hz, 3 H), 1.08 (s, 3 H)

^{13}C-NMR (CDCl$_3$, 75 MHz): δ / ppm = *major isomer*: 141.3, 137.2, 135.8, 131.6, 129.3, 128.9, 128.4, 126.8, 126.7, 118.1, 76.2, 57.0, 51.7, 22.1, 16.8. *minor isomer*: 141.3, 137.6, 136.0, 131.3, 129.5, 120.0, 128.1, 126.8, 126.6, 117.2, 75.8, 57.2, 55.7, 22.1, 18.1.

IR (neat): ν/cm^{-1} = 3580, 3472, 3074, 3060, 3026, 2976, 2934, 2872, 1635, 1600, 1584, 1492, 1478, 1452, 1440, 1379, 1137, 1085, 1070, 1023, 986, 916, 746, 700, 690.

MS (EI, 70 ev): m/z (%) = 298 (0), 181 (62), 180 (9), 163 (16), 138 (57), 117 (26), 115 (22), 91 (17), 71 (24), 57 (22), 43 (100).

HRMS (EI): calcd. for [C$_{19}$H$_{22}$OS]$^+$: 298,1391; found: 298.1404.

Preparation of 3-methyl-4-phenyl-hex-5-en-3-ol (**29**):
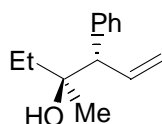
LiAlH$_4$ (55 mg, 1.5 mmol) was added at once to a solution of 2,3-dimethyl-2-(1-phenyl-allyl)-oxirane (**58**, 100 mg, 0.5 mmol) in diethyl ether (3 mL). The reaction mixture was stirred at 25 °C overnight, then carefully quenched by addition of water (3 mL) at 0 ºC. Subsequent extraction with diethyl ether, and purification *via* flash chromatography (eluent: pentane: ether = 8: 2 + 1 % Et$_3$N) provided the pure compound **29** (84 mg, 88 %) as a colourless oil. dr > 99: 1.

^{1}H-NMR (CDCl$_3$, 300 MHz): δ / ppm = 7.19-7.34 (m, 5 H), 6.28-6.40 (m, 1 H), 5.09-5.22 (m, 2 H), 3.31 (d, J = 9.6 Hz, 1 H), 1.53 (q, J = 7.5 Hz, 2 H), 1.45 (s, 1 H), 1.06 (s, 3 H), 0.93 (t, J = 7.5 Hz, 3 H).

^{13}C-NMR (CDCl$_3$, 75 MHz): δ / ppm = 141.3, 137.8, 129.2, 128.3, 126.6, 117.5, 74.1, 60.0, 32.5, 24.3, 8.0.

IR (neat): ν/cm^{-1} = 3467, 3076, 3028, 2970, 2938, 2881, 1636, 1600, 1492, 1452, 1377, 1155, 995, 910, 740, 700.

MS (EI, 70 ev): m/z (%) = 174 (13), 173 (100), 131 (3).

HRMS (EI): calcd. for [C$_{13}$H$_{18}$O – OH]$^+$: 173.1330; found: 173.1324.

Note 1: When butan-2-one (1 mmol) and cinnamylzinc chloride (**11**, 1.2 mmol) were reacted together according to **TP2**, compound **29** was obtained in 93 % yield as a mixture of 2 diastereoisomers (dr = 61: 39).

Note 2: When (3*R*)-toyloxy-butanone (99 % *ee*) was reacted with cinnamyzinc chloride (**11**), and the resulting epoxide was opened with LiAlH$_4$, the alcohol **(3R,4S)-29** was obtained in 87 % as a single diastereoisomer (dr > 99: 1; 99 % ee; [α]$_D$ (c = 0.0182 g.mL^{-1}, CHCl$_3$) = - 101.2).

Preparation of 8-chloro-octa-1,6-diene (**61**):
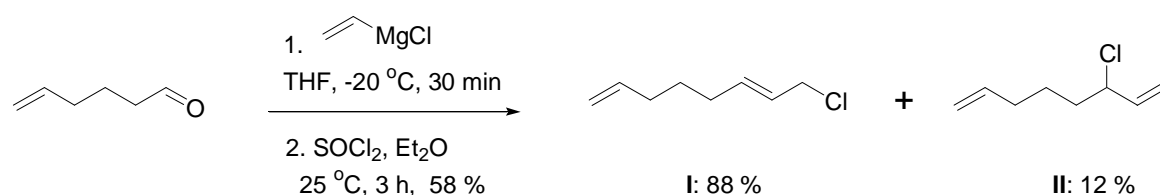
A solution of hex-5-enal (1.97 g, 20 mmol) in THF (15 mL) was added dropwise to a solution of vinylmagnesium chloride (17.0 mL of a 1.7 M solution in THF, 29 mmol) in THF (20 mL) at – 20 °C. After 30 min, the reaction was quenched with a saturated NH$_4$Cl solution (10 mL). Aqueous HCl was then added until the magnesium salts were dissolved, and the phases were separated. The organic phase was then extracted with diethyl ether before the combined organic phases were dried over MgSO$_4$ and concentrated to afford an oil, which was passed through a short pad of silica gel (eluent: diethyl ether).

The crude allylic alcohol was then diluted in dry diethyl ether (50 mL), before thionyl chloride (30 mmol) was added dropwise at 25 °C. After 3 h at this temperature, water (5 mL) was carefully added and the resulting solution was extracted with diethyl ether. The combined organic phases were dried over MgSO$_4$, and concentrated. Purification via flash chromatography (eluent: pentane) afforded **61** as a mixture of two allylic chlorides (1.68 g, 58 %, **I**: **II** = 88: 12).

^{1}H-NMR (CDCl$_3$, 300 MHz): δ / ppm = 5.56-5.95 (m, 3 H), 4.93-5.09 (m, 2 H), 4.05 (d, *J* = 6.8 Hz, 2 H), 2.03-2.15 (m, 4 H), 1.44-1.57 (m, 2 H).
^{13}C-NMR (CDCl$_3$, 75 MHz): δ / ppm = 138.4, 135.7, 126.2, 114.7, 45.4, 33.1, 31.4, 28.0.

IR (neat): ν/cm^{-1} = 3078, 2977, 2930, 2858, 1667, 1640, 1440, 1249, 991, 964, 911, 677.

MS (EI, 70 ev): m/z (%) = 144 (2), 109 (21), 108 (30), 93 (68), 81 (23), 80 (27), 79 (100), 78 (15), 77 (13), 67 (53), 55 (12), 54 (17), 53 (14), 40 (24).

HRMS (EI): calcd. for $[C_8H_{13}Cl]^+$: 144.0706; found: 144.0713.

Preparation of (8-chloro-oct-6-en-1-ynyl)-trimethyl-silane (**62**):

I: 92 %   II: 8 %
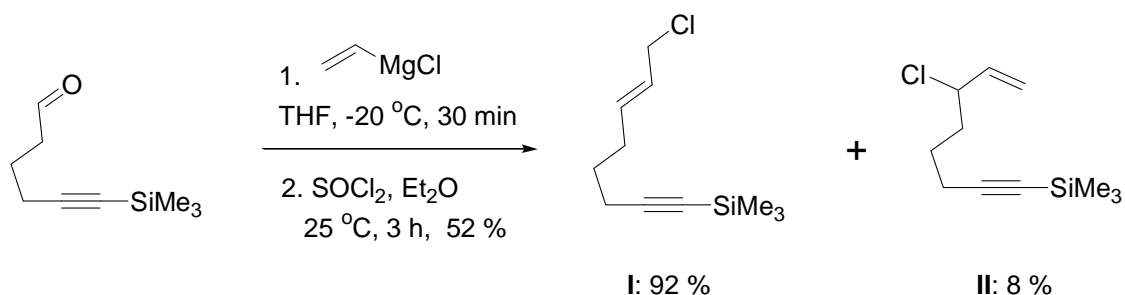
A solution of 6-trimethylsilanyl-hex-5-ynal (3.37 g, 20 mmol) in THF (15 mL) was added dropwise to a solution of vinylmagnesium chloride (17.0 mL of a 1.7 M solution in THF, 29 mmol) in THF (20 mL) at – 20 °C. After 30 min, the reaction was quenched with a saturated NH_4Cl solution (10 mL). Aqueous HCl was then added until the magnesium salts were dissolved, and the phases were separated. The organic phase was then extracted with diethyl ether before the combined organic phases were dried over $MgSO_4$ and concentrated to afford an oil, which was passed through a short pad of silica gel (eluent: diethyl ether).

The crude allylic alcohol was then diluted in dry diethyl ether (50 mL), before thionyl chloride (30 mmol) was added dropwise at 25 °C. After 3 h at this temperature, water (5 mL) was carefully added and the resulting solution was extracted with diethyl ether. The combined organic phases were dried over $MgSO_4$, and concentrated. Purification via flash chromatography (eluent: pentane) afforded **62** as a mixture of two allylic chlorides (2.23 g, 52 %, **I**: **II** = 92: 8).

^{1}H-NMR (CDCl$_3$, 300 MHz): δ / ppm = 5.60-5.86 (m, 2 H), 4.05 (dd, J = 6.8 Hz, J = 0.7 Hz, 2 H), 2.14-2.30 (m, 4 H), 1.57-1.69 (m, 2 H), 0.17 (s, 9 H).

^{13}C-NMR (CDCl$_3$, 75 MHz): δ / ppm = 134.9, 126.7, 106.8, 85.0, 45.2, 31.0, 27.7, 19.2, 0.1.

IR (neat): ν/cm^{-1} = 2957, 2902, 2864, 2175, 1167, 1442, 1327, 1248, 966, 837, 759, 638.

MS (EI, 70 ev): m/z (%) = 214 (0), 199 (2), 179 (13), 163 (9), 109 (11), 106 (20), 105 (30), 95 (35), 93 (100), 91 (14), 73 (51), 67 (11).

HRMS (EI): calcd. for $[C_{11}H_{19}ClSi]^+$: 214.0945; found: 214.0920.

Preparation of *N*-allyl-*N*-(5-chloro-pent-3-enyl)-4-methyl-benzenesulfonamide (**63**):
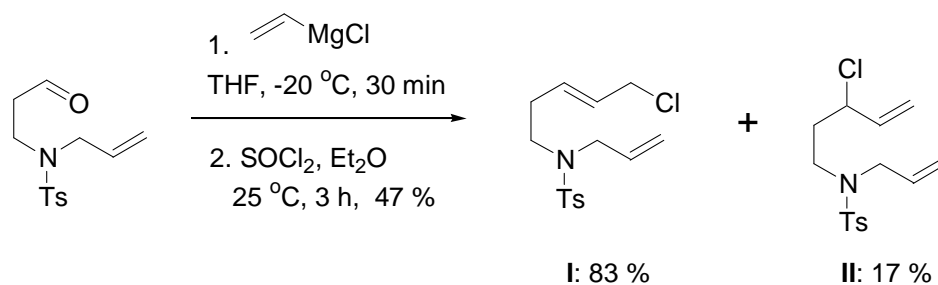
A solution of *N*-allyl-4-methyl-*N*-(3-oxo-propyl)-benzenesulfonamide (5.36 g, 20 mmol) in THF (15 mL) was added dropwise to a solution of vinylmagnesium chloride (17.0 mL of a 1.7 M solution in THF, 29 mmol) in THF (20 mL) at − 20 °C. After 30 min, the reaction was quenched with a saturated NH$_4$Cl solution (10 mL). Aqueous HCl was then added until the magnesium salts were dissolved, and the phases were separated. The organic phase was then extracted with diethyl ether before the combined organic phases were dried over MgSO$_4$ and concentrated to afford an oil, which was passed through a short pad of silica gel (eluent: diethyl ether).

The crude allylic alcohol was then diluted in dry diethyl ether (50 mL), before thionyl chloride (30 mmol) was added dropwise at 25 °C. After 3 h at this temperature, water (5 mL) was carefully added and the resulting solution was extracted with diethyl ether. The combined organic phases were dried over MgSO$_4$, and concentrated. Purification via flash chromatography (eluent: pentane: diethyl ether = 8: 2) afforded **63** as a mixture of two allylic chlorides (2.95 g, 47 %, **I**: **II** = 83: 17).

^{1}H-NMR (CDCl$_3$, 300 MHz): δ / ppm = 7.69 (d, *J*= 8.3 Hz, 2 H), 7.30 (d, *J* = 8.5 Hz, 2 H), 5.55-5.72 (m, 3 H), 5.11-5.23 (m, 2 H), 3.98 (br d, *J* = 5.3 Hz, 2 H), 3.80 (br d, *J* = 6.4 Hz, 2 H), 3.14-3.23 (m, 2 H), 2.42 (br s, 3 H), 2.25-2.34 (m, 2 H).

^{13}C-NMR (CDCl$_3$, 75 MHz): δ / ppm = 143.3, 137.0, 133.1, 131.5, 129.7, 128.3, 127.1, 118.9, 50.8, 46.5, 44.8, 31.3, 21.5.

IR (neat): ν/cm^{-1} = 2925, 2868, 1644, 1598, 1495, 1445, 1420, 1338, 1304, 1252, 1153, 1090, 972, 923, 815, 741, 659.

MS (EI, 70 ev): m/z (%) = 314 (0), 313 (0), 278 (5), 226 (8), 225 (19), 224 (49), 155 (46), 92 (11), 91 (100), 68 (25), 65 (15).

HRMS (EI): calcd. for $[C_{15}H_{20}ClNO_2S]^+$: 313,0903; found: 313.0913.

Preparation of 5-allyloxy-1-chloro-pent-2-ene (**64**):
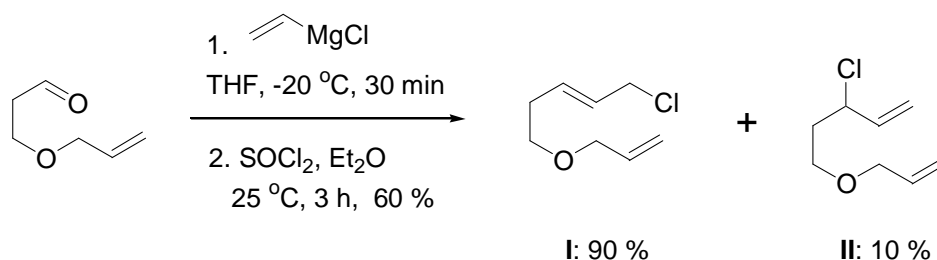
A solution of 3-allyloxy-propionaldehyde (2.28 g, 20 mmol) in THF (15 mL) was added dropwise to a solution of vinylmagnesium chloride (17.0 mL of a 1.7 M solution in THF, 29 mmol) in THF (20 mL) at – 20 °C. After 30 min, the reaction was quenched with a saturated NH$_4$Cl solution (10 mL). Aqueous HCl was then added until the magnesium salts were dissolved, and the phases were separated. The organic phase was then extracted with diethyl ether before the combined organic phases were dried over MgSO$_4$ and concentrated to afford an oil, which was passed through a short pad of silica gel (eluent: diethyl ether).

The crude allylic alcohol was then diluted in dry diethyl ether (50 mL), before thionyl chloride (30 mmol) was added dropwise at 25 ºC. After 3 h at this temperature, water (5 mL) was carefully added and the resulting solution was extracted with diethyl ether. The combined organic phases were dried over MgSO$_4$, and concentrated. Purification via flash chromatography (eluent: pentane: diethyl ether = 95: 5) afforded **64** as a mixture of two allylic chlorides (1.93 g, 60 %, **I**: **II** = 90: 10).

^{1}H-NMR (CDCl$_3$, 300 MHz): δ / ppm = 5.63-6.00 (m, 3 H), 5.29 (dq, J = 17.2 Hz, J = 1.6 Hz, 1 H), 5.19 (dq, J = 10.6 Hz, J = 1.5 Hz, 1 H), 4.05 (dd, J = 6.7 Hz, J = 0.7 Hz, 2 H), 3.99 (dt, J = 5.6 Hz, J = 1.4 Hz, 2 H), 3.50 (t, J = 6.7 Hz, 2 H), 2.34-2.42 (m, 2 H).

^{13}C-NMR (CDCl$_3$, 75 MHz): δ / ppm = 134.7, 132.2, 127.7, 116.9, 71.8, 69.2, 45.2, 32.5.

IR (neat): v/cm^{-1} = 3081, 2856, 1168, 1647, 1479, 1443, 1421, 1347, 1252, 1103, 992, 966, 924, 677.

MS (EI, 70 ev): m/z (%) = 160 (0), 125 (2), 89 (1), 71 (1), 53 (2), 41 (100).

HRMS (EI): calcd. for $[C_8H_{13}ClO]^+$: 160.0655; found: 160.0645.

Preparation of 1-allyloxy-2-(3-chloro-propenyl)-benzene (**65**):
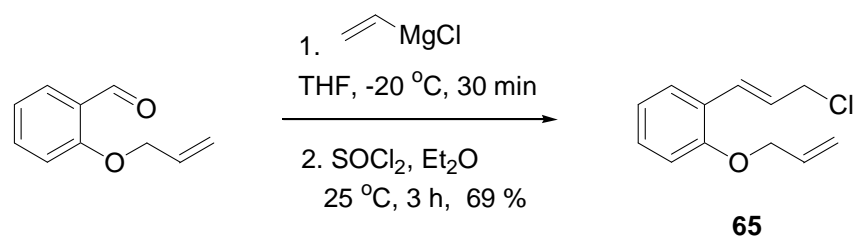
A solution of 2-allyloxy-benzaldehyde (3.24 g, 20 mmol) in THF (15 mL) was added dropwise to a solution of vinylmagnesium chloride (17.0 mL of a 1.7 M solution in THF, 29 mmol) in THF (20 mL) at – 20 °C. After 30 min, the reaction was quenched with a saturated NH_4Cl solution (10 mL). Aqueous HCl was then added until the magnesium salts were dissolved, and the phases were separated. The organic phase was then extracted with diethyl ether before the combined organic phases were dried over $MgSO_4$ and concentrated to afford an oil, which was passed through a short pad of silica gel (eluent: diethyl ether).

The crude allylic alcohol was then diluted in dry diethyl ether (50 mL), before thionyl chloride (30 mmol) was added dropwise at 25 °C. After 3 h at this temperature, water (5 mL) was carefully added and the resulting solution was extracted with diethyl ether. The combined organic phases were washed with a saturated $NaHCO_3$ solution, brine and water, dried over $MgSO_4$, and concentrated to afford **65,** which was not further purified (2.88 g, 69 %).

^{1}H-NMR (CDCl$_3$, 300 MHz): δ / ppm = 7.45 (dd, *J* = 7.7 Hz, *J* = 1.7 Hz, 1 H), 7.19-7.26 (m, 1 H), 6.84-7.07 (m, 3 H), 6.37 (dt, *J* = 15.7 Hz, *J* = 7.3 Hz, 1 H), 6.01-6.15 (m, 1 H), 5.43 (dq, *J* = 17.3 Hz, *J* = 1.6 Hz, 1 H), 5.31 (dq, *J* = 10.5 Hz, *J* = 1.4 Hz, 1 H), 4.55-4.61 (m, 2 H), 4.27 (dd, *J* = 7.3 Hz, *J* = 1.1 Hz, 2 H).

^{13}C-NMR (CDCl$_3$, 75 MHz): δ / ppm = 155.9, 133.2, 129.2, 129.1, 127.3, 125.5, 125.2, 120.9, 117.5, 112.3, 69.2, 46.1.

IR (neat): ν/cm^{-1} = 3076, 3033, 2953, 2866, 1648, 1597, 1580, 1487, 1452, 1440, 1423, 1330, 1294, 1240, 1223, 1108, 1017, 996, 967, 924, 747, 670.

MS (EI, 70 ev): m/z (%) = 210 (26), 208 (85), 173 (95), 169 (19), 167 (65), 145 (38), 133 (17), 132 (100), 131 (28), 104 (23), 103 (89), 91 (13), 77 (41), 41 (30).

HRMS (EI): calcd. for $[C_{12}H_{13}ClO]^+$: 208.0655; found: 208.0649.

Preparation of *N*-allyl-*N*-[2-(3-chloro-propenyl)-phenyl]-4-methyl-benzenesulfonamide (**66**):
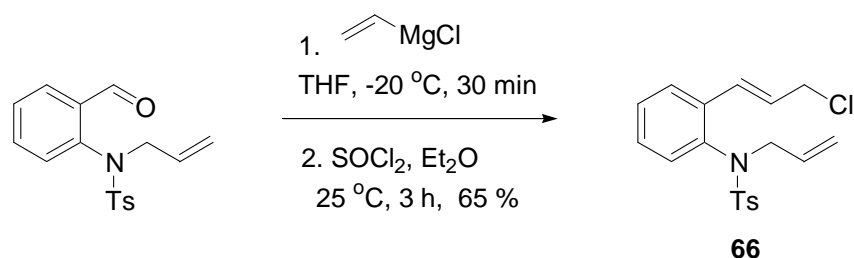
A solution of *N*-allyl-*N*-(2-formyl-phenyl)-4-methyl-benzenesulfonamide (6.31 g, 20 mmol) in THF (15 mL) was added dropwise to a solution of vinylmagnesium chloride (17.0 mL of a 1.7 M solution in THF, 29 mmol) in THF (20 mL) at – 20 °C. After 30 min, the reaction was quenched with a saturated NH$_4$Cl solution (10 mL). Aqueous HCl was then added until the magnesium salts were dissolved, and the phases were separated. The organic phase was then extracted with diethyl ether before the combined organic phases were dried over MgSO$_4$ and concentrated to afford an oil, which was passed through a short pad of silica gel (eluent: diethyl ether).

The crude allylic alcohol was then diluted in dry diethyl ether (50 mL), before thionyl chloride (30 mmol) was added dropwise at 25 ºC. After 3 h at this temperature, water (5 mL) was carefully added and the resulting solution was extracted with diethyl ether. The combined organic phases were dried over MgSO$_4$, and concentrated. Purification via flash chromatography (eluent: pentane: diethyl ether = 8: 2) afforded **66** as colourless oil (4.70 g, 65 %).

^{1}H-NMR (CDCl$_3$, 300 MHz): δ / ppm = 7.50-7.64 (m, 3 H), 7.24-7.33 (m, 3 H), 7.16 (td, *J* = 7.8 Hz, *J* = 1.4 Hz, 1 H), 6.88 (d, *J* = 15.7 Hz, 1 H), 6.72 (d, *J* = 7.9 Hz, 1 H), 6.19-6.31 (m, 1 H), 5.63-5.81 (m, 1 H), 4.92-5.06 (m, 2 H), 3.82-4.49 (m, 4 H), 2.45 (s, 3 H).

13C-NMR (CDCl3, 75 MHz): δ / ppm = 143.7, 137.0, 136.0, 132.2, 129.8, 129.5, 129.4, 128.6, 128.4, 127.9, 127.9, 126.8, 126.6, 119.5, 54.8, 45.4, 21.6.

IR (neat): v/cm^{-1} = 3086, 3068, 2962, 2923, 2865, 1644, 1598, 1484, 1448, 1348, 1248, 1158, 1091, 1055, 972, 944, 861, 727, 660, 571.

MS (EI, 70 ev): m/z (%) = 326 (3), 208 (100), 207 (360), 206 (17), 171 (37), 170 (21), 156 (44), 130 (23), 115 (25), 91 (54).

HRMS (EI): calcd. for $[C_{19}H_{20}ClNO_2S - Cl]^+$: 326,1215; found: 326.1213.

Preparation of 1-iodomethyl-2-vinyl-cyclopentane (**67**):
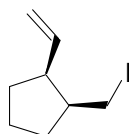
Prepared from 8-chloro-octa-1,6-diene (**61**, 290 mg, 2.0 mmol), zinc (800 mg, 12.2 mmol) and LiCl (210 mg, 5 mmol) according to **TP3** (reaction time: 20 h at 25 ºC). The resulting zinc reagent was treated with iodine (506 mg, 2 mmol) in THF (2 mL) at – 30 ºC. After 30 min, the reaction was quenched with water (2 mL), and extracted several times with diethyl ether. The combined organic phases were dried over $MgSO_4$ and concentrated to yield the crude product. Purification by flash chromatography (eluent: pentane) provided the pure compound **67** (335 mg, 71 %) as a colourless oil. dr > 98: 2.

1H-NMR (CDCl3, 300 MHz): δ / ppm = 5.62-5.77 (m, 1 h), 5.02-5.17 (m, 2 H), 3.02-3.17 (m, 2 H), 2.63-2.75 (m, 1 H), 2.28-2.43 (m, 1 H), 1.56-2.00 (m, 5 H), 1.30-1.46 (, m, 1 H).

13C-NMR (CDCl3, 75 MHz): δ / ppm = 137.6, 115.7, 47.3, 47.0, 31.6, 31.1, 23.0, 9.8.

IR (neat): v/cm^{-1} = 3076, 2954, 2869, 1637, 1452, 1423, 1300, 1176, 996, 912.

MS (EI, 70 ev): m/z (%) = 236 (7), 110 (8), 109 (97), 81 (14), 67 (100), 55 (21), 40 (12).

HRMS (EI): calcd. for $[C_8H_{13}I]^+$: 236,0062; found: 236.0060.

Preparation of 1-phenyl-2-(2-vinyl-cyclopentyl)-ethanone (**68**):
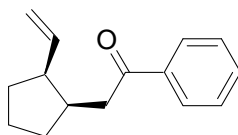
Prepared from 8-chloro-octa-1,6-diene (**61**, 290 mg, 2.0 mmol), zinc (800 mg, 12.2 mmol) and LiCl (210 mg, 5 mmol) according to **TP3** (reaction time: 20 h at 25 ºC). The resulting zinc reagent was treated with CuCN·2LiCl (1.5 mL of a 1 M in THF) at – 30 ºC. After 30 min, benzoyl chloride (282 mg, 2 mmol) in THF (1 mL) was added and the reaction was warmed up to 25 ºC over 2 h, then quenched with water (2 mL), and extracted several times with diethyl ether. The combined organic phases were dried over $MgSO_4$ and concentrated to yield the crude product. Purification by flash chromatography (eluent: pentane: ether = 95: 5) provided the pure compound **68** (269 mg, 63 %) as a colourless oil. dr > 98: 2.

^{1}H-NMR (CDCl$_3$, 300 MHz): δ / ppm = 7.90-7.97 (m, 2 H), 7.50-7.57 (m, 1 H), 7.41-7.48 (m, 2 H), 5.70-5.82 (m, 1 H), 4.93-5.02 (m, 2 H), 3.05 (dd, J = 16.7 Hz, J = 6.2 Hz, 1 H), 2.69-2.83 (m, 2 H), 2.51-2.63 (m, 1 H), 1.51-1.94 (m, 5 H), 1.27-1.40 (m, 1 H).

^{13}C-NMR (CDCl$_3$, 75 MHz): δ / ppm = 200.3, 139.6, 137.4, 132.7, 128.5, 128.0, 114.8, 46.6, 40.2, 39.3, 30.8, 30.8, 23.0.

IR (neat): v/cm^{-1} = 3069, 2951, 2871, 1683, 1637, 1599, 1448, 1209, 993, 911, 751, 688.

MS (EI, 70 ev): m/z (%) = 215 (2), 214 (11), 171 (7), 120 (32), 105 (100), 77 (15).

HRMS (EI): calcd. for $[C_{15}H_{18}O]^+$: 214,1358; found: 214.1360.

Preparation of 1-but-3-enyl-2-vinyl-cyclopentane (**69**):
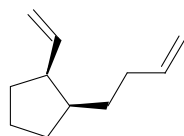
Prepared from 8-chloro-octa-1,6-diene (**61**, 290 mg, 2.0 mmol), zinc (800 mg, 12.2 mmol) and LiCl (210 mg, 5 mmol) according to **TP3** (reaction time: 20 h at 25 ºC). The resulting zinc reagent was treated with allyl bromide (242 mg, 2 mmol) in THF (1.5 mL) and CuCN·2LiCl (0.2 mL of a 1 M in THF) at – 30 ºC. The reaction was subsequently warmed up

to 25 ºC within 1 h, quenched with water (2 mL), and extracted several times with diethyl ether. The combined organic phases were dried over MgSO$_4$ and concentrated to yield the crude product. Purification by flash chromatography (eluent: pentane) provided the pure compound **69** (201 mg, 67 %) as a colourless oil. dr > 98: 2.

^{1}H-NMR (CDCl$_3$, 300 MHz): δ / ppm = 5.67-5.92 (m, 2 H), 4.86-4.99 (m, 4 H), 3.30-3.39 (m, 1 H), 1.16-1.19 (m, 11 H).

^{13}C-NMR (CDCl$_3$, 75 MHz): δ / ppm = 140.1, 139.3, 114.0, 113.8, 47.0, 43.3, 32.8, 31.4, 30.4, 30.4, 23.0.

IR (neat): v/cm^{-1} = 2953, 2921, 2852, 1743, 1462, 1376, 721.

MS (EI, 70 ev): m/z (%) = 153 (7), 152 (6), 151 (8), 125 (21), 111 (40), 71 (59), 69 (67), 57 (100).

HRMS (EI): calcd. for [C$_{11}$H$_{18}$ + H]$^+$: 151.1487 ; found: 151.1479.

Preparation of 2,3,3a,4,5,7a-hexahydro-1H-indene (**70**):
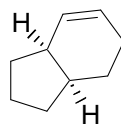
To a solution of Grubbs II catalyst (43 mg, 5 mol %) in CH$_2$Cl$_2$ (5 mL), was added **69** (150 mg, 1 mmol) in CH$_2$Cl$_2$ (10 mL) at 25 ºC. The reaction mixture was stirred at this temperature for 2 h. Water (5 mL) was added and the reaction was extracted with CH$_2$Cl$_2$. The organic phases were combined, dried over MgSO$_4$, concentrated. Purification *via* flash chromatography (eluent: pentane) afforded **70** as a colourless oil (96 mg, 79 %). dr > 98: 2

^{1}H-NMR (CDCl$_3$, 300 MHz): δ / ppm = 5.61-5.71 (m, 2 H), 2.28-2.41 (m, 1 H), 1.18-2.14 (m, 11 H).

^{13}C-NMR (CDCl$_3$, 75 MHz): δ / ppm = 131.2, 126.2, 39.4, 36.7, 32.3, 30.8, 25.9, 24.1, 23.3.

IR (neat): v/cm^{-1} = 2953, 2935, 2832, 1459, 1371, 721.

MS (EI, 70 ev): m/z (%) = 123 (4), 122 (39), 107 (12), 94 (44), 93 (56), 91 (17), 81 (62), 80 (71), 79 (100), 77 (28), 67 (20), 53 (13), 41 (20).

HRMS (EI): calcd. for [C$_9$H$_{14}$]$^+$: 122,1096; found: 122.1092.

Preparation of [iodo-(2-vinyl-cyclopentylidene)-methyl]-trimethyl-silane (**71**):
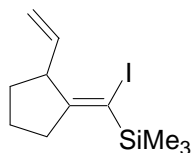
Prepared from (8-chloro-oct-6-en-1-ynyl)-trimethyl-silane (**62**, 430 mg, 2.0 mmol), zinc (800 mg, 12.2 mmol) and LiCl (210 mg, 5 mmol) according to **TP3** (reaction time: 40 h at 25 ℃). The resulting zinc reagent was treated with iodine (506 mg, 2 mmol) in THF (2 mL) at – 30 ℃. After 30 min, the reaction was quenched with water (2 mL), and extracted several times with diethyl ether. The combined organic phases were dried over $MgSO_4$ and concentrated to yield the crude product. Purification by flash chromatography (eluent: pentane) provided the pure compound **71** (392 mg, 64 %) as a colourless oil. dr > 98: 2.

^{1}H-NMR (CDCl$_3$, 300 MHz): δ / ppm = 5.66-5.81 (m, 1 H), 5.01-5.15 (m, 2 H), 3.45-3.54 (m, 1 H), 2.26-2.50 (m, 2 H), 1.65-1.97 (m, 4 H), 0.26 (s, 9 H).

^{13}C-NMR (CDCl$_3$, 75 MHz): δ / ppm = 163.8, 137.3, 114.7, 102.1, 57.8, 33.5, 31.4, 26.0, 1.1.

IR (neat): ν/cm^{-1} = 3080, 2954, 2871, 1707, 1635, 1594, 1449, 1430, 1404, 1248, 912, 876, 835, 756, 693, 622.

MS (EI, 70 ev): m/z (%) = 306 (8), 185 (33), 179 (34), 73 (32), 71 (27), 70 (20), 69 (47), 67 (12), 57 (100), 56 (18), 55 (44), 43 (19).

HRMS (EI): calcd. for $[C_{11}H_{19}ISi]^+$: 306,0301; found: 306.0289.

Preparation of trimethyl-[1-(2-vinyl-cyclopentylidene)-but-3-enyl]-silane (**72**):
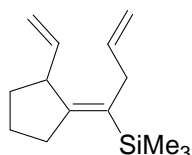
Prepared from (8-chloro-oct-6-en-1-ynyl)-trimethyl-silane (**62**, 430 mg, 2.0 mmol), zinc (800 mg, 12.2 mmol) and LiCl (210 mg, 5 mmol) according to **TP3** (reaction time: 40 h at 25 ℃). The resulting zinc reagent was treated with allyl bromide (242 mg, 2 mmol) in THF (1.5 mL)

and CuCN·2LiCl (0.2 mL of a 1 M in THF) at – 30 ºC. The reaction was subsequently warmed up to 25 ºC within 1 h, quenched with water (2 mL), and extracted several times with diethyl ether. The combined organic phases were dried over $MgSO_4$ and concentrated to yield the crude product. Purification by flash chromatography (eluent: pentane) provided the pure compound **72** (269 mg, 61 %) as a colourless oil. dr > 98: 2.

**^{1}H-NMR (CDCl$_3$, 300 MHz)**: δ / ppm = 5.66-5.84 (m, 2 H), 4.86-4.99 (m, 4H H), 3.30-3.39 (m, 1 H), 2.99 (dd, *J* = 15.8 Hz, *J* = 6.4 Hz, 1 H), 2.77 (dd, *J* = 15.7 Hz, *J* = 5.7 Hz, 1 H), 2.30-2.45 (m, 2 H), 1.52-1.88 (m, 4 H), 0.12 (s, 9 H).

^{13}C-NMR (CDCl$_3$, 75 MHz): δ / ppm = 156.5, 140.9, 138.0, 129.0, 114.0, 113.1, 46.7, 36.6, 32.9, 32.8, 24.1, 0.0.

IR (neat): ν/cm^{-1} = 2954, 2831, 1707, 1633, 1598, 1403, 1246, 912, 876, 835.

MS (EI, 70 ev): m/z (%) = 220 (10), 192 (14), 177 (19), 147 (22), 146 (100), 118 (43), 117 (52), 105 (24), 91 (30), 74 (41), 73 (60), 45 (35)..

HRMS (EI): calcd. for $[C_{14}H_{24}Si]^+$: 220.1647 ; found: 220.1632.

Preparation of trimethyl-(2,3,5,7a-tetrahydro-1H-inden-4-yl)-silane (**73**):
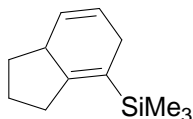
To a solution of Grubbs II catalyst (34 mg, 5 mol %) in CH_2Cl_2 (5 mL), was added **72** (170 mg, 0.8 mmol) in CH_2Cl_2 (10 mL) at 25 ºC. The reaction mixture was stirred at this temperature for 2 h. Water (5 mL) was added and the reaction was extracted with CH_2Cl_2. The organic phases were combined, dried over MgSO4, concentrated. Purification *via* flash chromatography (eluent: pentane) afforded **73** as a colourless oil (125 mg, 84 %). dr > 98: 2

^{1}H-NMR (CDCl$_3$, 300 MHz): δ / ppm = 5.74-5.91 (m, 2 H), 2.24-2.83 (m, 5 H), 1.96-2.09 (m, 1 H), 1.56-1.88 (m, 2 H), 1.13-1.31 (m, 1 H), 0.12 (s, 9 H).

^{13}C-NMR (CDCl$_3$, 75 MHz): δ / ppm = 152.7, 128.7, 125.8, 123.6, 42.1, 32.3, 30.6, 30.3, 23.8, -0.7.

IR (neat): ν/cm^{-1} = 3024, 2952, 2895, 2867, 1661, 1621, 1415, 1247, 1040, 875, 829, 749.

MS (EI, 70 ev): m/z (%) = 194 (1), 193 (3), 192 (21), 177 (8), 119 (17), 118 (100), 117 (28), 73 (38).

HRMS (EI): calcd. for $[C_{12}H_{20}Si]^+$: 192,1334; found: 192.1335.

Preparation of 3-iodomethyl-1-(toluene-4-sulfonyl)-4-vinyl-piperidine (**74**):
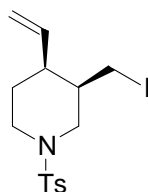
Prepared from *N*-allyl-*N*-(5-chloro-pent-3-enyl)-4-methyl-benzenesulfonamide (**63**, 630 mg, 2.0 mmol), zinc (800 mg, 12.2 mmol) and LiCl (210 mg, 5 mmol) according to **TP3** (reaction time: 40 h at 25 ºC). The resulting zinc reagent was treated with iodine (506 mg, 2 mmol) in THF (2 mL) at – 30 ºC. After 30 min, the reaction was quenched with water (2 mL), and extracted several times with diethyl ether. The combined organic phases were dried over $MgSO_4$ and concentrated to yield the crude product. Purification by flash chromatography (eluent: pentane: ether = 8: 2) provided compound **74** (601 mg, 74 %) as a pale yellow solid. dr = 95: 5.

mp (°C) = 102.3-103.9.

^{1}H-NMR (CDCl$_3$, 300 MHz): δ / ppm = 7.67 (d, *J* = 8.2 Hz, 2 H), 7.33 (d, *J* = 8.4 Hz, 2 H), 5.63-5.78 (m, 1 H), 5.04-5.17 (m, 2 H), 3.29-3.44 (m, 2 H), 3.21 (t, *J* = 9.7 Hz, 1 H), 3.10 (ddd, *J* = 9.8 Hz, *J* = 4.8 Hz, *J* = 0.8 Hz, 1 H), 2.90 (dd, *J* = 11.7 Hz, *J* = 2.9 Hz, 1 H), 2.72-2.83 (m, 1 H), 2.46 (s, 3 H), 2.31-2.34 (m, 1 H), 2.09-2.22 (m, 1 H), 1.64-1.77 (m, 2 H).

^{13}C-NMR (CDCl$_3$, 75 MHz): δ / ppm = 143.6, 138.6, 133.3, 129.7, 127.7, 117.0, 48.6, 44.7, 42.0, 41.5, 26.7, 21.5, 4.6.

IR (neat): ν/cm^{-1} = 3069, 2976, 2923, 2845, 1637, 1597, 1468, 1440, 1344, 1334, 1289, 1157, 1089, 914, 752, 659.

MS (EI, 70 ev): m/z (%) = 405 (8), 279 (16), 278 (89), 199 (11), 198 (84), 155 (87), 95 (15), 91 (100), 67 (15), 65 (15), 42 (17).

HRMS (EI): calcd. for $[C_{15}H_{20}INO_2S]^+$: 405,0259; found: 405.0243.

Preparation of 3-but-3-enyl-1-(toluene-4-sulfonyl)-4-vinyl-piperidine (**75**):

Prepared from *N*-allyl-*N*-(5-chloro-pent-3-enyl)-4-methyl-benzenesulfonamide (**63**, 630 mg, 2.0 mmol), zinc (800 mg, 12.2 mmol) and LiCl (210 mg, 5 mmol) according to **TP3** (reaction time: 40 h at 25 ºC). The resulting zinc reagent was treated with allyl bromide (242 mg, 2 mmol) in THF (1.5 mL) and CuCN·2LiCl (0.2 mL of a 1 M in THF) at – 30 ºC. The reaction was subsequently warmed up to 25 ºC within 1 h, quenched with water (2 mL), and extracted several times with diethyl ether. The combined organic phases were dried over MgSO$_4$ and concentrated to yield the crude product. Purification by flash chromatography (eluent: pentane: ether = 9: 1) provided compound **75** (469 mg, 73 %) as a colourless oil. dr = 95: 5.

^{1}H-NMR (CDCl$_3$, 300 MHz): δ / ppm = 7.64 (d, *J* = 8.3 Hz, 2 H), 7.32 (d, *J* = 8.4 Hz, 2 H), 5.66-5.82 (m, 2 H), 4.92-5.06 (m, 4 H), 3.21-3.29 (m, 1 H), 3.21 (dd, *J* = 11.5 Hz, *J* = 6.4 Hz, 1 H), 2.74-2.84 (m, 2 H), 2.43 (s, 3 H), 2.09-2.28 (m, 2 H), 1.94-2.07 (m, 1 H), 1.67-1.81 (m, 3 H), 1.41-1.52 (m, 1 H), 1.21-1.34 (m, 1 H).

^{13}C-NMR (CDCl$_3$, 75 MHz): δ / ppm = 143.3, 138.3, 138.2, 133.3, 129.6, 127.6, 115.7, 114.8, 48.1, 44.5, 41.0, 37.4, 31.1, 27.4, 26.3, 21.5.

IR (neat): ν/cm^{-1} = 3076, 2977, 2927, 2845, 1640, 1598, 1467, 1352, 1336, 1159, 1092, 996, 911, 816, 733.

MS (EI, 70 ev): m/z (%) = 320 (3), 319 (14), 278 (11), 277 (21), 276 (100), 262 (36), 164 (54), 155 (41), 91 (38).

HRMS (EI): calcd. for [C$_{18}$H$_{25}$NO$_2$S]$^+$: 319.1606 ; found: 319.1612.

Preparation of 2-(toluene-4-sulfonyl)-1,2,3,4,4a,7,8,8a-octahydro-isoquinoline (**75´**):
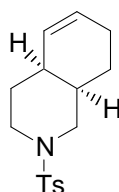
To a solution of Grubbs II catalyst (43 mg, 5 mol %) in CH_2Cl_2 (5 mL), was added **75** (310 mg, 0.97 mmol) in CH_2Cl_2 (10 mL) at 25 °C. The reaction mixture was stirred at this temperature for 2 h. Water (5 mL) was added and the reaction was extracted with CH_2Cl_2. The organic phases were combined, dried over $MgSO_4$, concentrated. Purification *via* flash chromatography (eluent: pentane) afforded **75´** as a colourless oil (268 mg, 95 %). dr = 95: 5

^{1}H-NMR (CDCl$_3$, 300 MHz): δ / ppm = 7.63 (d, *J* = 8.3 Hz, 2 H), 7.30 (d, *J* = 8.5 Hz, 2 H), 5.59-5.67 (m, 1 H), 5.41-5.50 (m, 1 H), 3.08-3.23 (m, 2 H), 2.82 (dd, *J* = 11.5 Hz, *J* = 3.8 Hz, 1 H), 2.61-2.72 (m, 1 H), 2.43 (s, 3 H), 1.52-2.18 (m, 8 H).

^{13}C-NMR (CDCl$_3$, 75 MHz): δ / ppm = 143.2, 133.5, 129.6, 129.5, 127.6, 127.5, 49.4, 45.0, 33.3, 32.8, 29.3, 24.0, 23.2, 21.5.

IR (neat): ν/cm^{-1} = 3016, 2924, 2882, 2853, 1649, 1599, 1494, 1460, 1348, 1337, 1158, 1089, 901, 740, 659.

MS (EI, 70 ev): m/z (%) = 293 (6), 292 (13), 291 (70), 223 (12), 198 (12), 155 (34), 136 (100), 109 (27), 105 (24), 91 (37), 79 (14).

HRMS (EI): calcd. for $[C_{16}H_{21}NO_2S]^+$: 291,1293; found: 291.1294.

Preparation of 3-iodomethyl-4-vinyl-tetrahydropyran (**76**):
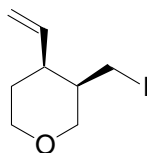
Prepared from 5-allyloxy-1-chloro-pent-2-ene (**64**, 320 mg, 2.0 mmol), zinc (800 mg, 12.2 mmol) and LiCl (210 mg, 5 mmol) according to **TP3** (reaction time: 70 h at 25 °C). The resulting zinc reagent was treated with iodine (506 mg, 2 mmol) in THF (2 mL) at – 30 °C. After 30 min, the reaction was quenched with water (2 mL), and extracted several times with diethyl ether. The combined organic phases were dried over $MgSO_4$ and concentrated to yield the crude product. Purification by flash chromatography (eluent: pentane: ether = 98: 2) provided compound **76** (328 mg, 65 %) as a colourless oil. dr > 93: 7.

¹H-NMR (CDCl₃, 300 MHz): δ / ppm = 5.82-5.97 (m, 1 h), 5.07-5.21 (m, 2 H), 3.86-3.98 (m, 2 H), 3.48-3.67 (m, 2 H), 3.28 (t, J = 10.0 Hz, 1 H), 3.15 (ddd, J = 9.8 Hz, J = 4.7 Hz, J = 1.2 Hz, 1 H), 2.54-2.67 (m, 1 H), 2.00-2.13 (m, 1 H), 1.58-1.69 (m, 2 H).

¹³C-NMR (CDCl₃, 75 MHz): δ / ppm = 138.2, 116.1, 69.8, 66.9, 42.4, 41.4, 27.4, 5.4.

IR (neat): v/cm⁻¹ = 2956, 2847, 1636, 1452, 1422, 912.

MS (EI, 70 ev): m/z (%) = 252 (10), 209 (13), 111 (20), 109 (17), 107 (17), 97 (26), 95 (49), 85 (23), 83 (28), 81 (53), 79 (28), 71 (41), 69 (38), 67 (61).

HRMS (EI): calcd. for $[C_8H_{13}IO]^+$: 252.0011 ; found: 252.0014.

Preparation of 3-iodomethyl-1-(toluene-4-sulfonyl)-4-vinyl-1,2,3,4-tetrahydro-quinoline (**77**):
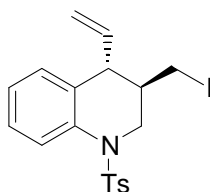
Prepared from *N*-allyl-*N*-[2-(3-chloro-propenyl)-phenyl]-4-methyl-benzenesulfonamide (**66**, 722 mg, 2.0 mmol), zinc (800 mg, 12.2 mmol) and LiCl (210 mg, 5 mmol) according to **TP3** (reaction time: 40 h at 25 °C). The resulting zinc reagent was treated with iodine (506 mg, 2 mmol) in THF (2 mL) at – 30 °C. After 30 min, the reaction was quenched with water (2 mL), and extracted several times with diethyl ether. The combined organic phases were dried over MgSO₄ and concentrated to yield the crude product. Purification by flash chromatography (eluent: pentane: ether = 9: 1) provided compound **77** (632 mg, 70 %) as a pale yellow solid. dr > 97: 3.
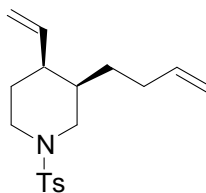
mp (°C) = 72.7-73.9.

¹H-NMR (CDCl₃, 300 MHz): δ / ppm = 7.82 (d, J = 8.1 Hz, 1 H), 7.50 (d, J = 8.4 Hz, 2 H), 7.19-7.24 (m, 3 H), 7.09-7.12 (m, 2 H), 4.97-5.17 (m, 3 H), 4.35 (dd, J = 13.8 Hz, J = 3.8 Hz, 1 H), 3.21-3.28 (m, 2 H), 3.00-3.04 (m, 1 H), 2.95 (dd, J = 10.3 Hz, J = 7.0 Hz, 1 H), 2.39 (s, 3 H), 1.20-1.27 (m, 1 H).

¹³C-NMR (CDCl₃, 75 MHz): δ / ppm = 143.9, 138.5, 136.4, 136.1, 129.9, 129.7, 129.6, 127.3, 127.1, 125.2, 124.7, 118.9, 50.8, 47.9, 36.5, 21.5, 8.3.

IR (neat): v/cm^{-1} = 3065, 3029, 3000, 2925, 2856, 1636, 1597, 1577, 1484, 1448, 1345, 1192, 1163, 1089, 1064, 992, 813, 763, 658.

MS (EI, 70 ev): m/z (%) = 454 (20), 453 (100), 172 (73), 171 (51), 170 (96), 156 (25), 144 (20), 143 (20), 130 (58), 115 (15), 104 (45), 91 (29), 57 (10).

HRMS (EI): calcd. for $[C_{19}H_{20}INO_2S]^+$: 453,0259; found: 453.0256.

Preparation of 1-[1-(toluene-4-sulfonyl)-4-vinyl-1,2,3,4-tetrahydro-quinolin-3-yl]-propan-2-one (**78**):
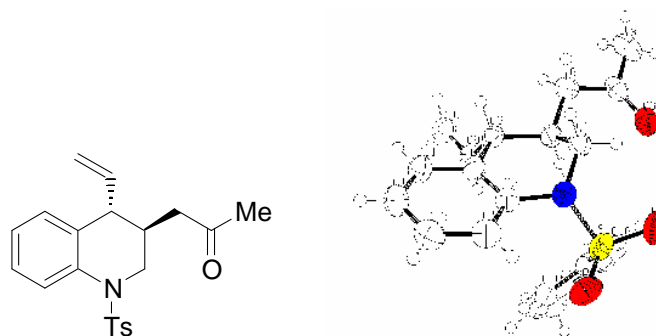
Prepared from *N*-allyl-*N*-[2-(3-chloro-propenyl)-phenyl]-4-methyl-benzenesulfonamide (**66**, 724 mg, 2.0 mmol), zinc (800 mg, 12.2 mmol) and LiCl (210 mg, 5 mmol) according to **TP3** (reaction time: 40 h at 25 ºC). The resulting zinc reagent was treated with CuCN·2LiCl (1.5 mL of a 1 M in THF) at – 30 ºC. After 30 min, acetyl chloride (158 mg, 2 mmol) in THF (1 mL) was added and the reaction was warmed up to 25 ºC over 12 h, then quenched with water (2 mL), and extracted several times with diethyl ether. The combined organic phases were dried over MgSO$_4$ and concentrated to yield the crude product. Purification by flash chromatography (eluent: pentane: ether = 1: 1) provided compound **78** (510 mg, 69 %) as a white solid. dr > 97: 3.

mp (°**C**) = 111.4-112.8.

^{1}H-NMR (CDCl$_3$, 300 MHz): δ / ppm = 7.82 (d, *J* = 8.2 Hz, 1 H), 7.59 (d, *J* = 8.3 Hz, 2 H), 7.14-7.25 (m, 3 H), 7.03-7.08 (m, 2 H), 4.84-5.22 (m, 3 H), 4.16 (dd, *J* = 13.5 Hz, *J* = 3.8 Hz, 1 H), 3.28 (dd, *J* = 13.5 Hz, *J* = 9.6 Hz, 1 H), 2.90 (t, *J* = 8.3 Hz, 1 H), 2.48 (dd, *J* = 17.9 Hz, *J* = 4.2 Hz, 1 H), 2.37 (s, 3 H), 2.28 (dd, *J* = 17.9 Hz, *J* = 8.6 Hz, 1 H), 2.11 (s, 3 H), 1.91-2.05 (m, 1 H).

^{13}C-NMR (CDCl$_3$, 75 MHz): δ / ppm = 206.5, 143.6, 139.7, 136.7, 136.3, 130.0, 129.5, 129.4, 127.4, 127.0, 124.7, 123.8, 117.9, 48.9, 47.5, 45.3, 31.4, 30.4, 21.5.

IR (neat): ν/cm^{-1} = 2928, 1712, 1485, 1347, 1160, 1060, 932, 763, 666.

MS (EI, 70 ev): m/z (%) = 369 (1), 326 (6), 301 (18), 215 (17), 214 (100), 196 (14), 172 (36), 171 (44), 170 (94), 157 (21), 156 (98), 155 (20), 130 (43), 91 (27).

HRMS (EI): calcd. for [C$_{21}$H$_{23}$NO$_3$S]$^+$: 369,1399; found: 369.1403.

Preparation of 3-iodomethyl-4-vinyl-chroman (**79**):
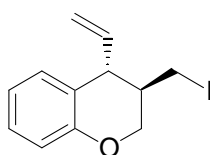
Prepared from 1-allyloxy-2-(3-chloro-propenyl)-benzene (**65**, 420 mg, 2.0 mmol), zinc (800 mg, 12.2 mmol) and LiCl (210 mg, 5 mmol) according to **TP3** (reaction time: 40 h at 25 ºC). The resulting zinc reagent was treated with iodine (506 mg, 2 mmol) in THF (2 mL) at – 30 ºC. After 30 min, the reaction was quenched with water (2 mL), and extracted several times with diethyl ether. The combined organic phases were dried over MgSO$_4$ and concentrated to yield the crude product. Purification by flash chromatography (eluent: pentane: ether = 95: 5) provided compound **79** (384 mg, 64 %) as a colourless oil. dr = 82: 18.

^{1}H-NMR (CDCl$_3$, 300 MHz): δ / ppm = 7.02-7.18 (m, 2 H), 6.79-6.94 (m, 2 H), 5.75-5.89 (m, 1 H, *minor isomer*), 5.65-5.79 (m, 1 H), 5.14-5.34 (m, 2 H), 4.30 (dd, *J* = 11.1 Hz, *J* = 2.9 Hz, 1 H), 4.25 (ddd, *J* = 10.9 Hz, *J* = 3.2 Hz, *J* = 1.3 Hz, 1 H, *minor isomer*), 3.95-4.06 (m, 1 H), 3.67-3.74 (m, 1 H, *minor isomer*), 3.08-3.44 (m, 3 H), 2.41-2.55 (m, 1 H, *minor isomer*), 1.84-1.98 (m, 1 H).

^{13}C-NMR (CDCl$_3$, 75 MHz): δ / ppm = 153.9, 153.8 (*minor isomer*), 139.7, 136.2 (*minor isomer*), 130.3, 128.1 (*minor isomer*), 128.0, 127.7, 122.7 (*minor isomer*), 120.7, 120.6 (*minor isomer*), 119.1 (*minor isomer*), 118.5, 116.7, 116.6 (*minor isomer*), 68.2, 66.4 (*minor isomer*), 45.3, 43.8 (*minor isomer*), 39.3 (*minor isomer*), 38.4, 7.0, 3.7 (*minor isomer*).

IR (neat): ν/cm^{-1} = 3076, 2974, 2918, 2875, 1638, 1607, 1582, 1486, 1451, 1221, 1184, 1051, 920, 752.

MS (EI, 70 ev): m/z (%) = 300 (68), 174 (9), 173 (30), 157 (16), 145 (27), 132 (14), 131 (100), 128 (28), 115 (25), 77 (27), 41 (42).

HRMS (EI): calcd. for $[C_{12}H_{13}IO]^+$: 300,0011; found: 300.0029.

8.   Cross-coupling reaction

8.1. Typical Procedures (TPs)

8.1.2. Typical procedure for the formation of diarylzinc reagents via an I/Zn-exchange (TP4):

In a dry nitrogen-flushed Schlenk tube equipped with a septum and a magnetic stirring bar, the iodoaryl derivative (2.60 mmol) and dry Li(acac) (35 mg) were dissolved in dry NMP (3.0 mL) and cooled to 0 °C. Then, i-Pr$_2$Zn (0.27 mL, 5.9 M solution in Et$_2$O, 1.59 mmol, 0.6 equiv.) was added dropwise. The reaction mixture was kept stirring at 25 ºC until the exchange reaction was complete (GC monitoring).

8.1.3. Typical procedure for the cobalt-catalyzed reaction of allylic chlorides or phosphates with diarylzinc reagents (TP5):

In a dry nitrogen-flushed Schlenk tube equipped with a septum and a magnetic stirring bar, the allylic chloride or phosphate (1 mmol) and Co(acac)$_2$ (27 mg, 10 mol %) were dissolved in dry NMP (0.5 mL) and cooled to 0 °C. Then, the freshly prepared diarylzinc reagent (1.3 mmol) was added dropwise. The reaction mixture was kept stirring at 0 °C, until the reaction was complete (GC monitoring). Saturated aqueous NH$_4$Cl was added, and the mixture was extracted several times with Et$_2$O. The organic layer was dried (MgSO$_4$) and the volatiles removed *in vacuo* (CAUTION: it may be necessary to heat (50 °C) while evaporating under high vacuum). The product was purified by flash column chromatography.

8.1.4. Typical procedure for the iron-catalyzed cross-coupling between alkenyl sulfonates and arylcopper reagents (TP6):

Version A

A 25 mL flame-dried Schlenk tube flushed with argon was charged with the arylmagnesium reagent (2.9 mmol) and cooled to –20 °C. Subsequently, a solution of CuCN·2LiCl (2.8 mmol, 2.8 mL of a 1 M solution in THF) was added and the reaction mixture was stirred for 20 min. A solution of the alkenyl triflate or nonaflate (1 mmol) and Fe(acac)$_3$ (38 mg, 0.1 mmol) in DME (3 mL) was added at once at -20 °C and the reaction mixture was stirred at 25 ºC for 1h. The reaction was quenched with a saturated aqueous NH$_4$Cl solution, and extracted several times with diethyl ether. The combined organic phases were successively washed with a NH$_4$OH: NH$_4$Cl (2: 1) solution and brine, then dried over MgSO$_4$ and concentrated under reduced pressure. Purification was accomplished *via* flash chromatography.

Version B

A 25 mL flame-dried Schlenk tube flushed with argon was charged with the aryl iodide (2.9 mmol), DME (5 mL) and cooled to –20 °C. Isopropylmagnesium chloride (2.9 mmol, 1.33 mL of a 2.1 M solution in THF) was then slowly added and the reaction mixture was stirred at –20 °C until GC analysis of reaction aliquots indicated complete exchange. Subsequently, a solution of CuCN·2LiCl (2.8 mmol, 2.8 mL of a 1 M solution in THF) was added and the reaction mixture was stirred for 20 min. A solution of the alkenyl triflate or nonaflate (1 mmol) and Fe(acac)$_3$ (38 mg, 0.1 mmol) in DME (3 mL) was added at once at -20 °C and the reaction mixture was stirred at 25 ºC for 1h. The reaction was quenched with a saturated aqueous NH$_4$Cl solution, and extracted several times with diethyl ether. The combined organic phases were successively washed with a NH$_4$OH: NH$_4$Cl (2: 1) solution and brine, then dried over MgSO$_4$ and concentrated under reduced pressure. Purification was accomplished *via* flash chromatography.

8.1.5. Typical procedure for the iron-catalyzed cross-coupling between dienyl nonaflates and arylcopper reagents (TP7):

A 25 mL flame-dried Schlenk tube flushed with nitrogen was charged with the aryl iodide (1.5 mmol), DME (5 mL) and cooled to –20 °C. Isopropylmagnesium chloride (1.5 mmol, 0.71 mL of a 2.1 M solution in THF) was then slowly added and the reaction mixture was stirred at –20 °C until GC analysis of reaction aliquots indicated complete exchange. Subsequently, a solution of CuCN·2LiCl (1.4 mmol, 1.4 mL of a 1 M solution in THF) was added and the reaction mixture was stirred for 20 min. A solution of the dienyl nonaflate (1 mmol) and Fe(acac)$_3$ (38 mg, 0.1 mmol) in DME (3 mL) was added at once at -20 °C and the reaction mixture was stirred at 25 ℃ for 1h. The reaction was quenched with a saturated aqueous NH$_4$Cl solution, and extracted several times with diethyl ether. The combined organic phases were successively washed with a NH$_4$OH: NH$_4$Cl (2: 1) solution and brine, then dried over MgSO$_4$ and concentrated under reduced pressure. Purification was accomplished *via* flash chromatography.

8.1.6. Typical procedure for the preparation of aryl phosphates from the corresponding phenol derivatives (TP8):

In a dry nitrogen-flushed flask equipped with a septum and a magnetic stirring bar, the phenol derivative (1 equiv.) was added dropwise to a suspension of NaH (60 % in oil, 1.2 equiv.) in dry THF (2mL / mmol) at 0 ℃. After the evolution of gas ended (about 30 min), diethyl chlorophosphate (1.2 equiv.) was slowly added, and the reaction mixture was stirred at 25 ℃ overnight. The resulting solution was diluted with water and diethyl ether, extracted two times. The organic phases were combined, dried over MgSO4, and concentrated *in vacuo*. The pure aryl phosphates were obtained via flash column chromatography.

8.1.7. Typical procedure for the nickel-catalyzed cross-coupling between aryl phosphates and arylmagnesium reagents (TP9):

Version A

A 10 mL flame-dried Schlenk tube flushed with nitrogen was charged with the arylmagnesium reagent (2 mmol). The solution was evaporated under high vacuum until dryness (typically 2 h or 3 h), and the residue was dissolved in diethyl ether. The resulting solution was then added dropwise to a solution of the aryl phosphate (1 mmol) and $NiCl_2$(dppe) (1 mol %, 5 mg) in diethyl ether (2 mL) at 25 ºC. The reaction mixture was stirred at this temperature until GC analysis of reaction aliquots indicated completion of the reaction. The reaction was quenched with a saturated aqueous NH_4Cl solution, and extracted several times with diethyl ether. The combined organic phases were washed with brine, dried over $MgSO_4$ and concentrated. Purification was achieved *via* flash chromatography.

Version B

A 10 mL flame-dried Schlenk tube flushed with nitrogen was charged with the aryl iodide or bromide (2 mmol) and cooled to –10 °C. Subsequently, *i*-PrMgCl·LiCl (2.1 mmol, 1.35 mL of a 1.6 M solution in THF) was slowly added and the reaction mixture was stirred at -10 °C until GC analysis of reaction aliquots indicated complete exchange. The resulting mixture was then evaporated under high vacuum until dryness (typically 2 h or 3 h), and the residue was dissolved in diethyl ether. The resulting solution was then added dropwise to a solution of the aryl phosphate (1 mmol) and $NiCl_2$(dppe) (1 mol %, 5 mg) in diethyl ether (2 mL) at 25 ºC. The reaction mixture was stirred at this temperature until GC analysis of reaction aliquots indicated completion of the reaction. The reaction was quenched with a saturated aqueous NH_4Cl solution, and extracted several times with diethyl ether. The combined organic phases were washed with brine, dried over $MgSO_4$ and concentrated. Purification was achieved *via* flash chromatography.

8.2. Experimental section

Preparation of (*E*)-ethyl-4-(3,7-dimethyl-octa-2,6-dienyl)-benzoate (**96**):
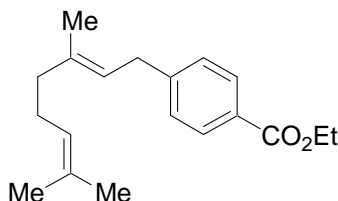
Prepared according to **TP5** from geranyl chloride **80** (172 mg, 1 mmol), Co(acac)$_2$ (27 mg, 10 mol %) and di(4-ethylcarbetoxyphenyl)zinc **86** (1.3 mmol, prepared according to **TP4**: reaction time = 8 h at 25 ºC). Purification by flash chromatography (eluent: pentane: ether = 98: 2) yielded **96** as a colourless oil (205 mg, 72 %).

^{1}H-NMR (CDCl$_3$, 400 MHz): δ / ppm = 7.88 (d, *J* = 8.2 Hz, 2 H), 7.16 (d, *J* = 8.6 Hz, 2 H), 5.22-5.27 (m, 1 H), 5.00-5.04 (m, 1 H), 4.28 (q, *J* = 7.0 Hz, 2 H), 3.33 (d, *J* = 7.4 Hz, 2 H), 1.96-2.07 (m, 4 H), 1.63 (d, *J* = 1.2 Hz, 3 H), 1.61 (d, *J* = 1.2 Hz, 3 H), 1.53 (s, 3 H), 1.31 (t, *J* = 7.0 Hz, 3 H).

^{13}C-NMR (CDCl$_3$, 75 MHz): δ / ppm = 165.7, 146.2, 136.1, 130.5, 128.6, 127.2, 127.0, 123.1, 121.0, 59.7, 38.6, 33.2, 25.5, 24.7, 16.7, 15.1, 13.3.

IR (neat): v/cm^{-1} = 2968, 2913, 1711, 1605, 1442, 1366, 1252, 1174, 1101, 1029, 769.

MS (EI): m/z (%) = 286 (8), 243 (16), 241 (24), 218 (22), 189 (22), 145 (61), 143 (31), 123 (81), 69 (100).

HRMS (EI): calcd. for $[C_{19}H_{26}O_2]^+$: 286.1933; found: 286.1922.

Preparation of (*E*)-3-(3,7-dimethyl-octa-2,6-dienyl)-benzonitrile (**97**):
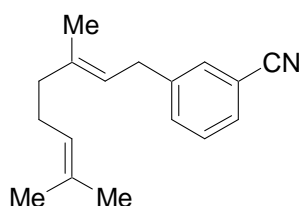
Prepared according to **TP5** from geranyl chloride **80** (172 mg, 1 mmol), Co(acac)$_2$ (27 mg, 10 mol %) and di(3-cyanophenyl)zinc **87** (1.3 mmol, prepared according to **TP4**: reaction time = 8 h at 25 ºC). Purification by flash chromatography (eluent: pentane: ether = 98: 2) yielded **97** as a colourless oil (180 mg, 75 %).

^{1}H-NMR (CDCl$_3$, 300 MHz): δ / ppm = 7.24-7.42 (m, 4 H), 5.17-5.26 (m, 1 H), 4.96-5.05 (m, 1 H), 3.30 (d, J = 7.1 Hz, 2 H), 1.94- 2.12 (m, 4 H), 1.62 (s, 3 H), 1.61 (s, 3 H), 1.53 (s, 3 H).

^{13}C-NMR (CDCl$_3$, 75 MHz): δ / ppm = 142.2, 136.8, 131.9, 130.8, 130.7, 128.5, 128.0, 123.0, 120.3, 118.1, 111.3, 38.6, 32.7, 25.4, 24.7, 16.7, 15.2.

IR (neat): v/cm^{-1} = 3379, 2968, 2924, 2230, 1600, 1582, 1482, 1434, 1379, 1096, 792.

MS (EI): m/z (%) = 239 (1), 196 (4), 171 (6), 156 (7), 123 (24), 69 (100).

HRMS (EI): calcd. for [C$_{17}$H$_{21}$N]$^+$: 239.1674; found: 239.1661.

Preparation of (*E*)-1-(3,7-dimethyl-octa-2,6-dienyl)-3-trifluoromethyl-benzene (**98**):
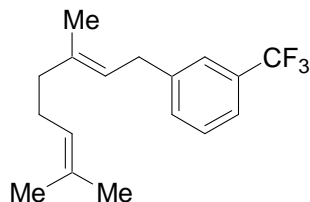
Prepared according to **TP5** from geranyl chloride **80** (172 mg, 1 mmol), Co(acac)$_2$ (27 mg, 10 mol %) and di(3-trifluoromethyl phenyl)zinc **88** (1.3 mmol, prepared according to **TP4**: reaction time = 8 h at 25 ºC). Purification by flash chromatography (eluent: pentane) yielded **98** as a colourless oil (246 mg, 87 %).

^{1}H-NMR (CDCl$_3$, 600 MHz): δ / ppm = 7.38-7.43 (m, 2 H), 7.31-7.37 (m, 2 H), 5.28-5.33 (m, 1 H), 5.06-5.11 (m 1 H), 3.41 (d, J = 7.6 Hz, 2H), 2.05-2.18 (m, 4 H), 1.72 (d, J = 1.0 Hz, 3 H), 1.68 (s, 3 H), 1.60 (s, 3 H).

^{13}C-NMR (CDCl$_3$, 75 MHz): δ / ppm = 142.9, 137.5, 131.9, 131.8, 130.8 (q, J = 32.5 Hz), 128.9, 125.5 (q, J = 272.6 Hz), 125.2 (m), 124.2, 122.8 (m), 122.2, 39.9, 34.2, 26.7, 25.8, 17.9, 16.5.

IR (neat): v/cm^{-1} = 2968, 2913, 1442, 1366, 1328, 1156, 1115, 824, 631.

MS (EI): m/z (%) = 282 (2), 239 (5), 159 (6), 123 (25), 69 (100).

HRMS (EI): calcd. for $[C_{17}H_{21}F_3]^+$: 282.1595; found: 282.1608.

Preparation of (*E*)-1-bromo-2-(3,7-dimethyl-octa-2,6-dienyl)-benzene (**99**):
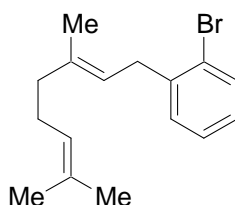
Prepared according to **TP5** from geranyl chloride **80** (172 mg, 1 mmol), Co(acac)$_2$ (27 mg, 10 mol %) and di(2-bromophenyl)zinc **89** (1.3 mmol, prepared according to **TP4**: reaction time = 8 h at 25 ºC). Purification by flash chromatography (eluent: pentane) yielded **99** as a colourless oil (211 mg, 72 %).

^{1}H-NMR (CDCl$_3$, 400 MHz): δ / ppm = 7.53 (d, *J* = 7.4 Hz, 1 H), 7.21-7.24 (m, 2 H), 7.02-7.08 (m, 1 H), 5.27-5.33 (m, 1 H), 5.08-5.14 (m, 1 H), 3.45 (d, *J* = 7.4 Hz, 2 H), 2.04-2.17 (m, 4 H), 1.71 (d, *J* = 0.8 Hz, 3 H), 1.69 (d, *J* = 1.2 Hz, 3 H), 1.61 (s, 3 H).

^{13}C-NMR (CDCl$_3$, 75 MHz): δ / ppm = 141.1, 137.5, 132.8, 131.8, 130.2, 127.6, 127.6, 124.9, 124.4, 121.5, 40.0, 34.8, 26.8, 26.0, 18.0, 16.5.

IR (neat): v/cm^{-1} = 2968, 2913, 1604, 1500, 1442, 1366, 1101, 769.

MS (EI): m/z (%) = 294 (2), 292 (2), 251 (9), 249 (9), 145 (17), 144 (87), 143 (23), 129 (47), 128 (19), 123 (100), 69 (78).

HRMS (EI): calcd. for $[C_{16}H_{21}Br]^+$: 292.0827; found: 292.0831.

Preparation of (*E*)-1-(3,7-dimethyl-octa-2,6-dienyl)-naphthalene (**100**):
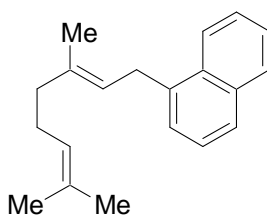
Prepared according to **TP5** from geranyl chloride **80** (172 mg, 1 mmol), Co(acac)$_2$ (27 mg, 10 mol %) and dinaphthylzinc **90** (1.3 mmol, prepared according to **TP4**: reaction time = 8 h at 25 °C). Purification by flash chromatography (eluent: pentane) yielded **100** as a colourless oil (218 mg, 82 %).

^{1}H-NMR (CDCl$_3$, 300 MHz): δ / ppm = 7.92-7.98 (m, 1 H), 7.73-7.80 (m, 1 H), 7.63 (d, J = 7.4 Hz, 1 H), 7.38-7.47 (m, 2 H), 7.23-7.36 (m, 2 H), 5.30-5.38 (m, 1 H), 4.98-5.07 (m, 1 H), 3.71 (d, J = 6.7 Hz, 2 H), 1.95-2.11 (m, 4 H), 1.71 (d, J = 1.5 Hz, 3 H), 1.58 (s, 3 H), 1.51 (s, 3 H).

^{13}C-NMR (CDCl$_3$, 75 MHz): δ / ppm = 138.0, 136.6, 134.1, 132.4, 131.7, 128.9, 126.8, 125.9, 125.9, 125.8, 125.7, 124.5, 124.3, 123.1, 40.0, 31.9, 26.9, 25.9, 18.0, 16.5.

IR (neat): ν/cm^{-1} = 3045, 2966, 2913, 2853, 1597, 1510, 1440, 1396, 1376, 790.

MS (EI): m/z (%) = 264 (37), 196 (18), 195 (98), 193 (33), 181 (24), 167 (45), 166 (42), 165 (99), 153 (100), 141 (59), 123 (85), 69 (51).

HRMS (EI): calcd. for [C$_{20}$H$_{24}$]$^+$: 264.1878; found: 264.1886.

Preparation of (Z)-1-(3,7-dimethyl-octa-2,6-dienyl)-3-trifluoromethyl-benzene (**101**):
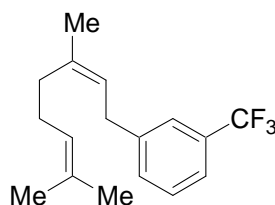
Prepared according to **TP5** using neryl chloride **81** (174 mg, 1 mmol), Co(acac)$_2$ (28 mg, 10 mol %) and di(3-trifluoromethylphenyl)zinc **88** (1.3 mmol, prepared according to **TP4**: reaction time = 8 h at 25 °C). Purification by flash chromatography (eluent: pentane) yielded **101** as a colourless oil (219 mg, 78 %).

^{1}H-NMR (CDCl$_3$, 400 MHz): δ / ppm = 7.41-7.44 (m, 2 H), 7.33-7.39 (m, 2 H), 5.28-5.32 (m, 1 H), 5.10-5.15 (m 1 H), 3.40 (d, J = 7.6 Hz, 2 H), 2.07-2.17 (m, 4 H), 1.76 (d, J = 1.0 Hz, 3 H), 1.67 (s, 3H), 1.60 (s, 3H).

13C-NMR (CDCl₃, 75 MHz): δ / ppm = 143.0, 137.5, 132.1, 131.9, 130.8 (q, J = 31.4 Hz), 128.9, 125.2 (m), 124.5 (q, J = 272.6 Hz), 124.1 122.9, 122.8 (m), 34.1, 32.2, 26.7, 25.9, 23.6, 17.8.

IR (neat): v/cm^{-1} = 2968, 2913, 1442, 1366, 1328, 1156, 1115, 824, 631.

MS (EI): m/z (%) = 282 (3), 239 (7), 212 (7), 197 (6), 159 (7), 69 (100).

HRMS (EI): calcd. for $[C_{17}H_{21}F_3]^+$: 282.1595; found: 282.1586.

Preparation of (*Z*)-methyl-4-(3,7-dimethyl-octa-2,6-dienyl)-benzoate (**102**):
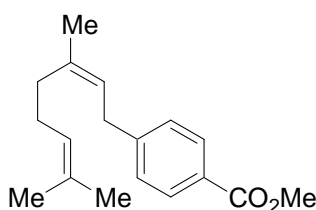
Prepared according to **TP5** using neryl chloride **81** (174 mg, 1 mmol), Co(acac)₂ (29 mg, 10 mol %) and di(4-methylcarbetoxyphenyl)zinc **91** (1.3 mmol, prepared according to **TP4**: reaction time = 8 h at 25 ºC). Purification by flash chromatography (eluent: pentane: ether = 98: 2) yielded **102** as a colourless oil (207 mg, 76 %).

1H-NMR (CDCl₃, 400 MHz): δ / ppm = 7.87 (d, J = 8.2 Hz, 2 H), 7.17 (d, J = 8.2 Hz, 2 H), 5.20-5.34 (m, 1 H), 5.02-5.13 (m, 1 H), 3.82 (s, 3 H), 3.32 (d, J = 7.5 Hz, 2 H), 1.97-2.14 (m, 4 H), 1.68 (s, 3 H), 1.61 (s, 3 H), 1.54 (s, 3 H).

13C-NMR (CDCl₃, 75 MHz): δ / ppm = 166.1, 146.4, 136.1, 130.8, 128.7, 127.3, 126.7, 123.0, 121.7, 50.9, 33.1, 31.0, 25.5, 24.7, 22.4, 16.6.

IR (neat): v/cm^{-1} = 2968, 2914, 1711, 1605, 1442, 1292, 1174, 1101, 769.

MS (EI): m/z (%) = 272 (32), 241 (32), 229 (57), 201 (36), 189 (34), 145 (41), 143 (84), 123 (42), 69 (100).

HRMS (EI): calcd. for $[C_{18}H_{24}O_2]^+$: 272.1776; found: 272.1788.

Preparation of (*Z*)-1-bromo-3-(3,7-dimethyl-octa-2,6-dienyl)-benzene (**103**):
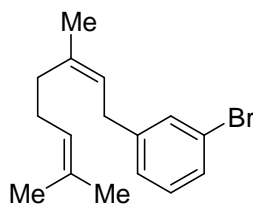
Prepared according to **TP5** using neryl chloride **81** (172 mg, 1 mmol), Co(acac)$_2$ (27 mg, 10 mol %) and di(3-bromophenyl)zinc **92** (1.3 mmol, prepared according to **TP4**: reaction time = 8 h at 25 ºC). Purification by flash chromatography (eluent: pentane) yielded **103** as a colourless oil (222 mg, 76 %).

^{1}H-NMR (CDCl$_3$, 400 MHz): δ / ppm = 7.20-7.27 (m, 2 H), 6.98-7.10 (m, 2 H), 5.18-5.26 (m, 1 H), 5.02-5.09 (m, 1 H), 3.24 (d, *J* = 7.2 Hz, 2 H), 1.98-2.11 (m, 4 H), 1.68 (t, *J* = 1.4 Hz, 3 H), 1.61 (s, 3 H), 1.54 (s, 3 H).

^{13}C-NMR (CDCl$_3$, 75 MHz): δ / ppm = 144.4, 137.3, 132.1, 131.6, 130.1, 129.0, 127.2, 124.2, 123.1, 122.7, 34.0, 32.2, 26.8, 26.0, 23.7, 17.9.

IR (neat): ν/cm^{-1} = 2968, 2914, 1596, 1576, 1500, 1442, 1366, 1100, 824.

MS (EI): m/z (%) = 294 (11), 292 (12), 251 (7), 249 (8), 145 (7), 144 (20), 143 (33), 129 (322), 128 (21), 123 (30), 69 (100).

HRMS (EI): calcd. for [C$_{16}$H$_{21}$Br]$^+$: 292.0827; found: 292.0832.

Preparation of (*E*)-methyl-4-(3,7-dimethyl-octa-2,6-dienyl)-benzoate (**104**):
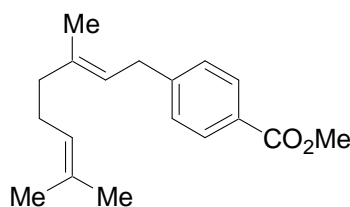
Prepared according to **TP5** using geranyl phosphate **82** (290 mg, 1 mmol), Co(acac)$_2$ (29 mg, 10 mol %) and di(4-methylcarbetoxyphenyl)zinc **91** (1.3 mmol, prepared according to **TP4**: reaction time = 8 h at 25 ºC). Purification by flash chromatography (eluent: pentane: ether = 98: 2) yielded **104** as a colourless oil (185 mg, 68 %).

^{1}H-NMR (CDCl$_3$, 400 MHz): δ / ppm = 7.94 (d, J = 8.0 Hz, 2 H), 7.24 (d, J = 8.5 Hz, 2 H), 5.29-5.35 (m, 1 H), 5.06-5.13 (m, 1 H), 3.90 (s, 3 H), 3.40 (d, J = 7.0 Hz, 2 H), 2.03-2.16 (m, 4 H). 1.70 (s, 3 H), 1.68 (d, J = 1.0 Hz, 3 H), 1.60 (s, 3 H).

^{13}C-NMR (CDCl$_3$, 75 MHz): δ / ppm = 167.4, 147.6, 137.4, 131.8, 129.9, 128.5, 127.9, 124.3, 122.2, 52.2, 39.9, 34.5, 26.7, 26.0, 17.9, 16.4.

IR (neat): ν/cm^{-1} = 2968, 2913, 1711, 1605, 1500, 1442, 1366, 1292, 1174, 1101, 769.

MS (EI): m/z (%) = 272 (20), 241 (29), 229 (42), 204 (37), 203 (17), 202 (16), 201 (14), 189 (28), 171 (20), 149 (12), 145 (39), 143 (41), 129 (41), 123 (100), 69 (79).

HRMS (EI): calcd. for [C$_{18}$H$_{24}$O$_2$]$^+$: 272.1776; found: 272.1778.

Preparation of (*E*)-1-(3,7-dimethyl-octa-2,6-dienyl)-3-methoxy-benzene (**105**):
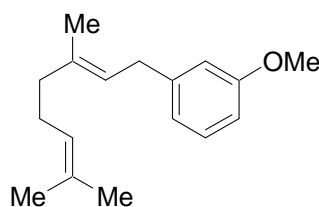
Prepared according to **TP5** using geranyl phosphate **82** (291 mg, 1 mmol), Co(acac)$_2$ (27 mg, 10 mol %) and di(3-methoxyphenyl)zinc **93** (1.3 mmol, prepared according to **TP4**: reaction time = 12 h at 25 ºC). Purification by flash chromatography (eluent: pentane: ether = 99: 1) yielded **105** as a colourless oil (175 mg, 71 %).

^{1}H-NMR (CDCl$_3$, 400 MHz): δ / ppm = 7.17-7.23 (m, 1 H), 6.78 (d, J = 7.6 Hz, 1 H), 6.71-6.76 (m, 2 H), 5.32-5.38 (m, 1 H), 5.08-5.15 (m, 1 H), 3.80 (s, 3 H), 3.34 (d, J = 7.1 Hz, 2 H), 2.02-2.17 (m, 4 H), 1.71 (s, 3 H), 1.69 (d, J = 0.9 Hz, 3 H), 1.61 (s, 3 H).

^{13}C-NMR (CDCl$_3$, 75 MHz): δ / ppm = 159.9, 143.7, 136.6, 131.7, 129.5, 124.5, 123.0, 121.0, 114.4, 111.1, 55.4, 39.9, 34.4, 26.9, 26.0, 17.9, 16.4.

IR (neat): ν/cm^{-1} = 2968, 2913, 1605, 1500, 1442, 1292, 1230, 1101, 824.

MS (EI): m/z (%) = 244 (29), 201 (24), 176 (17), 175 (100), 174 (14), 173 (26), 161 (18), 160 (25), 159 (17), 123 (85), 122 (18), 121 (31), 69 (53), 41 (30).

HRMS (EI): calcd. for [C$_{17}$H$_{24}$O]$^+$: 244.1827; found: 244.1822.

Preparation of (*E*)-2,2-dimethyl-propionic acid 4-(3,7-dimethyl-octa-2,6-dienyl)-phenyl ester (**106**):
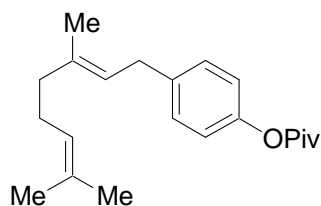
Prepared according to **TP5** using geranyl phosphate **82** (290 mg, 1 mmol), Co(acac)$_2$ (26 mg, 10 mol %) and di(4-pivaloxyphenyl)zinc **94** (1.3 mmol, prepared according to **TP4**: reaction time = 8 h at 25 ºC). Purification by flash chromatography (eluent: pentane: ether = 98: 2) yielded **106** as a colourless oil (201 mg, 64 %).

^{1}H-NMR (CDCl$_3$, 400 MHz): δ / ppm = 7.16 (d, *J* = 8.3 Hz, 2 H), 6.95 (d, *J* = 8.6 Hz, 2 H), 5.29-5.36 (m, 1 H), 5.07-5.14 (m, 1 H), 3.34 (d, *J* = 7.3 Hz, 2 H), 2.02-2.16 (m, 4 H), 1.67-1.70 (m, 6 H), 1.60 (s, 3 H), 1.35 (s, 9 H).

^{13}C-NMR (CDCl$_3$, 75 MHz): δ / ppm = 177.5, 149.3, 139.3, 136.7, 131.7, 129.3, 124.4, 123.0, 121.4, 39.9, 39.3, 33.7, 27.4, 26.8, 26.0, 17.9, 16.3.

IR (neat): ν/cm^{-1} = 2968, 2913, 1726, 1605, 1500, 1442, 1366, 1292, 1174, 1101, 769.

MS (EI): m/z (%) = 314 (36), 271 (14), 230 (13), 187 (15), 162 (19), 161 (100), 160 (11), 147 (11), 123 (81), 122 (13), 107 (22), 85 (13), 69 (24), 57 (57).

HRMS (EI): calcd. for [C$_{21}$H$_{30}$O$_2$]$^+$: 314.2246; found: 314.2238.

Preparation of (*Z*)-3-(3,7-dimethyl-octa-2,6-dienyl)-benzonitrile (**107**):
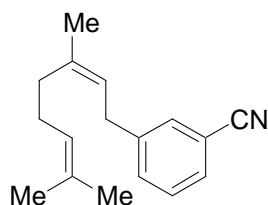
Prepared according to **TP5** using neryl phosphate **83** (291 mg, 1 mmol), Co(acac)$_2$ (28 mg, 10 mol %) and di(3-cyanophenyl)zinc **88** (1.3 mmol, prepared according to **TP4**: reaction time = 8 h at 25 ºC). Purification by flash chromatography (eluent: pentane: ether = 98: 2) yielded **107** as a colourless oil (169 mg, 70 %).

¹H-NMR (CDCl₃, 600 MHz): δ / ppm = 7.37-7.41 (m, 2 H), 7.27-7.35 (m, 2 H), 5.19-5.23 (m, 1 H), 5.01-5.06 (m, 1 H), 3.30 (d, J = 7.6 Hz, 2 H), 2.01-2.08 (m, 4 H), 1.70 (s, 3 H), 1.60 (s, 3 H), 1.54 (s, 3 H).

¹³C-NMR (CDCl₃, 75 MHz): δ / ppm = 142.2, 136.9, 131.9, 131.0, 130.9, 128.5, 128.0, 122.8, 121.0, 118.1, 111.3, 32.5, 31.0, 25.4, 24.7, 22.4, 16.6.

IR (neat): ν/cm⁻¹ = 3379, 2968, 2913, 2230, 1500, 1442, 1366, 908, 824.

MS (EI): m/z (%) = 239 (19), 196 (11), 171 (11), 156 (12), 123 (20), 69 (100).

HRMS (EI): calcd. for $[C_{17}H_{21}N]^+$: 239.1674; found: 239.1681.

Preparation of (Z)-1-(3,7-dimethyl-octa-2,6-dienyl)-naphthalene (**108**):
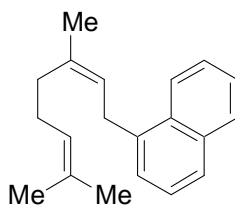
Prepared according to **TP5** using neryl phosphate **83** (289 mg, 1 mmol), Co(acac)₂ (26 mg, 10 mol%) and dinaphthylzinc **90** (1.3 mmol, prepared according to **TP4**: reaction time = 8 h at 25 °C). Purification by flash chromatography (eluent: pentane) yielded **108** as a colourless oil (181 mg, 68 %).

¹H-NMR (CDCl₃, 600 MHz): δ / ppm = 7.95 (d, J = 8.2 Hz, 1 H), 7.76 (d, J = 7.8 Hz, 1 H), 7.62 (d, J = 8.2 Hz, 1 H), 7.36-7.44 (m, 2 H), 7.31 (t, J = 7.8 Hz, 1 H), 7.25 (d, J = 7.1 Hz, 1 H), 5.32-5.36 (m, 1 H), 5.09-5.13 (m, 1 H), 3.71 (d, J = 7.1 Hz, 2 H), 2.15-2.19 (m, 2 H), 2.06-2.11 (m, 2 H), 1.68 (d, J = 1.1 Hz, 3 H), 1.62 (s, 3 H), 1.56 (s, 3 H).

¹³C-NMR (CDCl₃, 75 MHz): δ / ppm = 138.1, 136.7, 134.1, 132.3, 132.0, 128.9, 126.8, 125.9, 125.9, 125.8, 125.6, 124.4, 124.2, 123.7, 32.4, 31.7, 26.7, 26.0, 23.6, 17.9.

IR (neat): ν/cm⁻¹ = 2968, 2913, 1605, 1500, 1442, 1366, 1328, 1292, 769.

MS (EI): m/z (%) = 265 (26), 264 (100), 195 (57), 194 (38), 193 (96), 181 (28), 179 (91), 166 (29), 165 (78), 153 (70), 141 (50), 123 (21), 69 (34).

HRMS (EI): calcd. for $[C_{20}H_{24}]^+$: 264.1878; found: 264.1893.

Preparation of (Z)-1-(3,7-dimethyl-octa-2,6-dienyl)-3-methoxy-benzene (**109**):
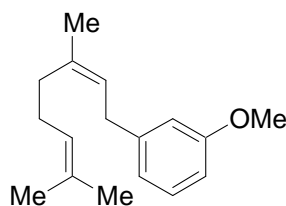
Prepared according to **TP5** using neryl phosphate **83** (290 mg, 1 mmol), Co(acac)$_2$ (27 mg, 10 mol %) and di(3-methoxyphenyl)zinc **93** (1.3 mmol, prepared according to **TP4**: reaction time = 12 h at 25 ºC). Purification by flash chromatography (eluent: pentane: ether = 99: 1) yielded **109** as a colourless oil (188 mg, 77 %).

^{1}H-NMR (CDCl$_3$, 400 MHz): δ / ppm = 7.20 (t, J = 7.6 Hz, 1 H), 6.79 (d, J = 7.5 Hz, 1 H), 6.71-6.76 (m, 2 H), 5.30-5.36 (m, 1 H), 5.11-5.18 (m, 1 H), 3.80 (s, 3 H), 3.33 (d, J = 7.2 Hz, 2 H), 2.06-2.17 (m, 4 H), 1.75 (s, 3 H), 1.69 (s, 3 H), 1.62 (s, 3 H).

^{13}C-NMR (CDCl$_3$, 75 MHz): δ / ppm = 159.9, 143.7, 136.6, 132.0, 129.5, 124.4, 123.8, 121.0, 114.4, 111.1, 55.4, 34.3, 32.2, 26.8, 26.0, 23.7, 17.9.

IR (neat): ν/cm^{-1} = 2968, 2913, 1604, 1596, 1499, 1442, 1328, 1292, 1230, 1101, 824.

MS (EI): m/z (%) = 244 (76), 201 (39), 187 (15), 176 (17), 175 (94), 174 (44), 173 (100), 161 (33), 160 (37), 159 (50), 123 (42), 122 (28), 121 (44), 69 (94).

HRMS (EI): calcd. for [C$_{17}$H$_{24}$O]$^+$: 244.1827; found: 244.1841.

Preparation of (Z)-4-methyl-(3-phenyl-allyl)-benzoate (**110**):
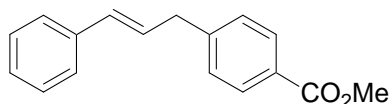
Prepared according to **TP5** using cinnamyl phosphate **84** (270 mg, 1 mmol), Co(acac)$_2$ (28 mg, 10 mol %) and di(4-methylcarbetoxyphenyl)zinc **91** (1.3 mmol, prepared according to **TP4**: reaction time = 8 h at 25 ºC). Purification by flash chromatography (eluent: gradient ranging from pentane: ether = 99: 1 to ether) yielded **110** as a colourless oil (168 mg, 67 %).

^{1}H-NMR (CDCl$_3$, 400 MHz): δ / ppm = 7.99 (d, J = 7.9 Hz, 2 H), 7.28-7.39 (m, 6 H), 7.19-7.25 (m, 1 H), 6.47 (d, J = 15.9 Hz, 1 H), 6.34 (dt, J = 15.9 Hz, J = 6.7 Hz, 1 H), 3.91 (s, 3 H), 3.60 (d, J = 7.0 Hz, 2 H).

^{13}C-NMR (CDCl$_3$, 75 MHz): δ / ppm = 167.3, 145.8, 137.4, 132.0, 130.1, 128.9, 128.8, 128.4, 128.3, 127.6, 126.4, 52.3, 39.5.

IR (neat): ν/cm^{-1} = 2968, 2914, 1711, 1605, 1500, 1442, 1366, 1328, 1292, 1252, 1174, 1101, 1029, 769.

MS (EI): m/z (%) = 253 (14), 252 (80), 237 (12), 221 (18), 194 (18), 193 (100), 192 (12), 191 (13), 178 (26), 115 (35).

HRMS (EI): calcd. for [C$_{17}$H$_{16}$O$_2$]$^+$: 252.1150; found: 252.1149.

Preparation of (*E*)-2-(3,7-Dimethyl-octa-2,6-dienyl)-5-iodo-thiophene (**113**):
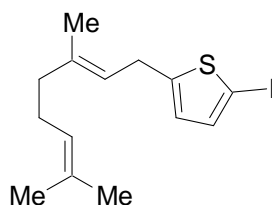
Prepared according to **TP5** using geranyl chloride **80** (173 mg, 1 mmol), Co(acac)$_2$ (28 mg, 10 mol %) and di(5-iodo-thiophen-2-yl)zinc **111** (1.3 mmol, prepared according to **TP4**: reaction time = 8 h at 0 ºC). Purification by flash chromatography (eluent: pentane) yielded **113** as a colourless oil (268 mg, 77 %).

^{1}H-NMR (CDCl$_3$, 300 MHz): δ / ppm = 7.06 (d, J = 3.9 Hz, 1 H), 6.47-6.51 (m, 1 H), 5.33-5.41 (m, 1 H), 5.09-5.17 (m, 1 H), 3.52 (d, J = 7.2 Hz, 2 H), 2.02-2.20 (m, 4 H), 1.72 (d, J = 1.1 Hz, 3 H), 1.71 (s, 3 H), 1.63 (s, 3 H).

^{13}C-NMR (CDCl$_3$, 75 MHz): δ / ppm = 151.6, 138.0, 136.9, 131.9, 125.8, 124.3, 121.7, 70.1, 39.8, 28.9, 26.7, 26.0, 18.0, 16.3.

IR (neat): ν/cm^{-1} = 3480, 2968, 2913, 1711, 1499, 1442, 1366, 1328, 1101, 908, 824, 769.

MS (EI): m/z (%) = 346 (24), 303 (28), 277 (13), 251 (25), 223 (21), 150 (39), 135 (56), 123 (78), 69 (100).

HRMS (EI): calcd. for [C$_{14}$H$_{19}$IS]$^+$: 346.0252; found: 346.0264.

Preparation of (*E*)-1-[5-(3,7-Dimethyl-octa-2,6-dienyl)-thiophen-2-yl]-ethanone (**114**):
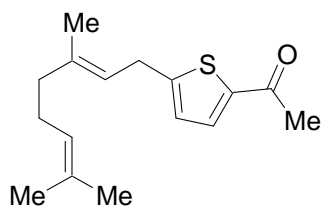
Prepared according to **TP5** using geranyl chloride **80** (172 mg, 1 mmol), Co(acac)$_2$ (27 mg, 10 mol %) and di(5-ethanone-thiophen-2-yl)zinc **112** (1.3 mmol, prepared according to **TP4**: reaction time = 5 h at 0 °C). Purification by flash chromatography (eluent: pentane: ether = 98: 2) yielded **114** as a colourless oil (198 mg, 76 %).

^{1}H-NMR (CDCl$_3$, 400 MHz): δ / ppm = 7.55 (d, *J* = 3.6 Hz, 1 H), 6.81-6.84 (m, 1 H), 5.35-5.43 (m, 1 H), 5.07-5.16 (m, 1 H), 3.55 (d, *J* = 7.7 Hz, 2 H), 2.52 (s, 3 H), 2.02-2.20 (m, 4 H), 1.71 (br s, 6 H), 1.62 (s, 3 H).

^{13}C-NMR (CDCl$_3$, 75 MHz): δ / ppm = 190.7, 155.6, 142.4, 138.7, 133.1, 131.9, 125.5, 124.2, 121.1, 39.8, 29.4, 26.7, 26.7, 25.9, 17.9, 16.4.

IR (neat): ν/cm^{-1} = 2968, 2913, 1664, 1499, 1442, 1366, 1328, 1292 1101, 908, 824, 769, 631.

MS (EI): m/z (%) = 262 (18), 219 (16), 194 (51), 179 (26), 151 (29), 140 (20), 123 (36), 69 (100), 43 (63), 41 (47).

HRMS (EI): calcd. for [C$_{16}$H$_{22}$OS]$^+$: 262.1391; found: 262.1377.

Preparation of Nocarasin C (**118**):
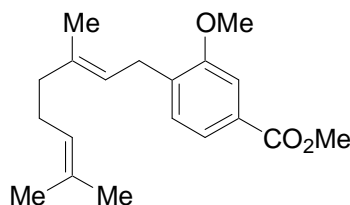
Prepared according to **TP5** using geranyl chloride **80** (172 mg, 1 mmol), Co(acac)$_2$ (27 mg, 10 mol %) and di(2-methoxy-4-methylcarbetoxyphenyl)zinc **117** (1.3 mmol, prepared

according to **TP4**: reaction time = 8 h at 25 ºC). Purification by flash chromatography (eluent: pentane: ether = 98: 2) yielded **118** as a colourless oil (230 mg, 76 %).

^{1}H-NMR (CDCl$_3$, 400 MHz): δ / ppm = 7.60 (dd, J = 7.7 Hz, J = 2.1 Hz, 1 H), 7.52 (d, J = 1.4 Hz, 1 H), 7.21 (d, J = 7.7 Hz, 1 H), 5.26-5.36 (m, 1 H), 5.03-5.16 (m, 1 H), 3.92 (s, 3 H), 3.91 (s, 3 H), 3.38 (d, J = 7.7 Hz, 2 H), 2.03-2.19 (m, 4 H), 1.70 (br s, 6 H), 1.62 (s, 3 H).

^{13}C-NMR (CDCl$_3$, 75 MHz): δ / ppm = 167.5, 157.4, 137.2, 136.0, 131.7, 129.2, 129.0, 124.5, 122.3, 121.6, 111.0, 55.7, 52.2, 40.0, 28.6, 26.8, 25.9, 17.9, 16.3.

IR (neat): ν/cm^{-1} = 2968, 2913, 1711, 1605, 1500, 1442, 1328, 1292 1252, 1174, 1120, 1101, 1029, 824, 769, 631.

MS (EI): m/z (%) = 302 (13), 271 (19), 259 (15), 201 (50), 179 (20), 174 (26), 173 (36), 159 (30), 124 (12), 123 (100), 122 (17), 69 (45), 41 (24).

HRMS (EI): calcd. for [C$_{19}$H$_{26}$O$_3$]$^+$: 302.1882; found: 302.1854.

Preparation of trifluoro-methanesulfonic acid 2,2-diphenyl-vinyl ester (**119**):
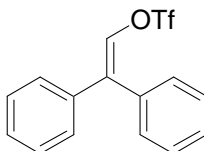
A solution of diphenyl acetaldehyde (2.00 g, 10.2 mmol) and *t*-BuOK (1.49 g, 13.3 mmol) in dry THF (30 mL) was refluxed for 2 h. *N*-phenyl-bis(trifluoromethanesulfonimide) (6.2 g, 17.4 mmol) was subsequently added at 0 ºC. The reaction mixture was stirred at this temperature for 1 h, and another hour at 25 °C. After addition of water, extraction with diethyl ether, and concentration *in vacuo*, the crude compound was filtered off and washed with pentane. The filtrate was concentrated under reduced pressure and purified via flash chromatography (eluent: pentane) to yield **119** as a colourless liquid (2.47 g, 74 %).

^{1}H-NMR (CDCl$_3$, 300 MHz): δ / ppm = 7.35-7.47 (m, 6 H), 7.23-7.33 (m, 4 H), 7.06 (s, 1 H).

^{13}C-NMR (CDCl$_3$, 75 MHz): δ / ppm = 137.4, 135.0, 132.7, 131.8 (m), 130.5, 129.8, 129.6, 129.5, 129.3, 129.2, 119.4 (q, J = 321.0 Hz).

^{19}F NMR (CDCl$_3$, 75 MHz): δ / ppm = - 72.66.

IR (neat): ν/cm^{-1} = 1650, 1215, 1145, 952.

MS (EI): m/z (%) = 330 (2), 329 (4), 328 (23), 196 (13), 195 (75), 168 (13), 167 (100), 166 (20), 165 (64), 152 (25), 64 (5).

HRMS (EI): calcd. for $[C_{15}H_{11}F_3O_3S]^+$: 328,0381; found: 328.0390.

Preparation of nonafluoro-butane-1-sulfonic acid 2,2-diphenyl-vinyl ester (**120**):
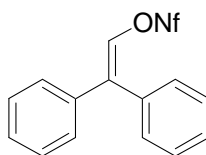
A solution of diphenyl acetaldehyde (2.00 g, 10.2 mmol) and *t*-BuOK (1.49 g, 13.3 mmol) in dry THF (30 mL) was refluxed for 2 h. Nonafluorobutane-1-sulfonyl fluoride (3.1 mL, 17.3 mmol) was subsequently added at 0 ^{o}C over 10 min. The reaction mixture was stirred at this temperature for 2 h, then refluxed for 18h. After addition of water at 0 ^{o}C, extraction with diethyl ether, and concentration *in vacuo*, the crude compound was purified via flash chromatography (eluent : gradient ranging from pentane to pentane: ether = 8: 2) to yield **120** as a colourless liquid (2.43 g, 50 %).

^{1}H-NMR (CDCl$_3$, 300 MHz): δ / ppm = 7.25-7.46 (m, 10 H), 7.11 (s, 1 H).

^{13}C-NMR (CDCl$_3$, 75 MHz): δ / ppm = 135.4, 133.8, 132.6, 131.1, 128.5, 127.8, 127.6, 127.3 (carbons bearing fluorides are eluded and two carbons are missing due to overlap).

^{19}F NMR (CDCl$_3$, 75 MHz): δ / ppm = -79.6, -108.7, -120.0, -124.8.

IR (neat): ν/cm^{-1} = 3103, 3061, 3031, 1640, 1496, 1427, 1352, 1236, 1224, 11989, 1142, 1125, 1016, 950, 760, 696.

MS (EI): m/z (%) = 478 (4), 385 (5), 196 (14), 195 (75), 168 (19), 167 (100), 166 (21), 165 (61), 152 (28), 69 (8).

HRMS (EI): calcd. for $[C_{18}H_{11}F_9O_3S]^+$: 478,0285; found: 478.0294.

Preparation of cyclohexa-1,5-dienyl nonafluorobutane-1-sulfonate (**122**):
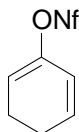
A solution of cyclohex-2-enone (1.30 mL, 13 mmol) in dry THF (15 mL) was added dropwise to a solution of LDA (prepared *in situ*, 14.4 mmol) in THF (20 mL) at - 78 $^{\circ}$C. After 30 min at this temperature, nonafluorobutane-1-sulfonyl fluoride (3.60 mL, 20 mmol) was added carefully, and the reaction mixture was further stirred at 0 $^{\circ}$C for 3 h, and at 25 $^{\circ}$C overnight. The solvent was removed under reduced pressure, and the residue was dissolved in diethyl ether. The resulting organic phase was washed twice with water, dried over MgSO$_4$, and concentrated *in vacuo*. Purification via flash chromatography (eluent : 100 % pentane) afforded **122** as a colourless oil (3.70 g, 75 %).

^{1}H-NMR (CDCl$_3$, 300 MHz): δ / ppm = 5.93 (dt, *J* = 10.4 Hz, *J* = 4.0 Hz, 1 H), 5.76 (dd, *J* = 10.4 Hz, *J* = 2.0 Hz, 1 H), 5.62 (td, *J* = 4.4 Hz, *J* = 2.0 Hz, 1 H), 2.28-2.38 (m, 2 H), 2.12-2.22 (m, 2 H).

^{13}C-NMR (CDCl$_3$, 75 MHz): δ / ppm = 147.0, 132.3, 121.8, 115.5, 22.4, 22.2 (carbons bearing fluorides are eluded).

^{19}F NMR (CDCl$_3$, 75 MHz): δ / ppm = -79.7, -108.7, -119.9, -124.8.

IR (neat): v/cm^{-1} = 2928, 1422, 1356, 1240, 1203, 1144, 892.

MS (EI): m/z (%) = 378 (3), 131 (2), 95 (16), 69 (18), 67 (46), 65 (11), 41 (100).

HRMS (EI): calcd. for [C$_{10}$H$_7$F$_9$O$_3$S]$^+$: 377,9972; found: 377.9963.

Preparation of 1,1,2-triphenylethene (**131**):
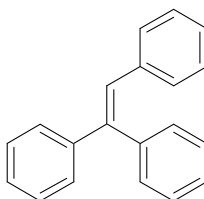
Prepared using **119** (331 mg, 1 mmol), PhMgCl (1.4 mL of a 1.5 M solution in THF, 2.2 mmol), CuCN·2LiCl (2.2 mL of a 1 M solution in THF), Fe(acac)$_3$ (38 mg, 10 mol %) according to **TP6** *Version A* (reaction time: 1 h at room temperature). Purification by flash chromatography (eluent: pentane) yielded **131** as a colourless oil (221 mg, 86 %).

Alternatively prepared using **120** (478 mg, 1 mmol), PhMgCl (1.4 mL of a 1.5 M solution in THF, 2.2 mmol), CuCN·2LiCl (2.1 mL of a 1 M solution in THF), Fe(acac)$_3$ (38 mg, 10 mol %) according to **TP6** *Version A* (reaction time: 1 h at 25 °C). Purification by flash chromatography (eluent: pentane) yielded **131** as a colourless oil (208 mg, 81 %).

^{1}H-NMR (CDCl$_3$, 300 MHz): δ / ppm = 7.20-7.28 (m, 8 H), 7.11-7.16 (m, 2 H), 7.01-7.09 (m, 3 H), 6.93-6.97 (m, 2 H), 6.89 (s, 1 H).

^{13}C-NMR (CDCl$_3$, 75 MHz): δ / ppm = 143.9, 143.0, 140.8, 137.8, 130.8, 130.0, 129.0, 128.6, 128.6, 128.4 , 128.0 , 127.9, 127.8, 127.2.

IR (film): v/cm^{-1} = 3055, 3022, 1949, 1598, 1492, 1445, 1222, 777, 762, 695, 588.

MS (EI, 70 ev): m/z (%) = 256 (100), 255 (24), 241 (14), 178 (25).

HRMS (EI): calcd. for [C$_{20}$H$_{16}$]$^+$: 256.1252; found: 256.1256.

Preparation of ethyl 4-(2,2-diphenylvinyl)benzoate (**132**):
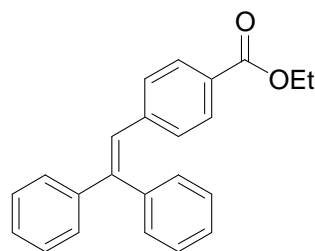
Prepared using **119** (331 mg, 1 mmol), ethyl 4-iodo-benzoate (800 mg, 2.9 mmol), *i*-PrMgCl (2.0 mL of a 1.5 M solution in THF, 3 mmol), CuCN·2LiCl (2.9 mL of a 1 M solution in THF), Fe(acac)$_3$ (38 mg, 10 mol %) according to **TP6** *Version B* (reaction time: 90 min at 25 °C). Purification by flash chromatography (eluent: pentane: diethyl ether = 96: 4) yielded **132** as a colourless oil (278 mg, 77 %).

¹H-NMR (CDCl₃, 300 MHz): δ / ppm = 7.72 (d, *J* = 8.4 Hz, 2 H), 7.21-7.28 (m, 8 H), 7.08-7.13 (m, 2 H), 6.99 (d, *J* = 8.6, 2 H), 6.91 (s, 1 H), 4.25 (q, *J* = 7.1 Hz, 2 H), 1.27 (t, *J* = 7.1 Hz, 3 H).

¹³C-NMR (CDCl₃, 75 MHz): δ / ppm = 166.4, 144.9, 142.9, 142.0, 139.8, 130.3, 129.3, 129.2, 128.7, 128.3, 128.3, 127.9, 127.8, 127.7, 127.1, 60.8, 14.3.

IR (film): ν/cm⁻¹ = 2980, 1715, 1604, 14445, 1367, 1276, 1180, 1103, 882, 762, 700.

MS (EI, 70 ev): m/z (%) = 328 (100), 283 (18), 255 (48), 239 (14).

HRMS (EI): calcd. for $[C_{23}H_{20}O_2]^+$: 328.1463; found: 328.1455.

Preparation of 1-(2-(3-(trifluoromethyl)phenyl)-1-phenylvinyl)benzene (**133**):
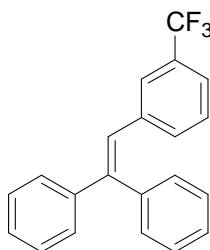
Prepared using **119** (331 mg, 1 mmol), 1-iodo-3-trifluoromethyl-benzene (790 mg, 2.9 mmol), *i*-PrMgCl (2.0 mL of a 1.5 M solution in THF, 3 mmol), CuCN·2LiCl (2.9 mL of a 1 M solution in THF), Fe(acac)₃ (38 mg, 10 mol %) according to **TP6** *Version B* (reaction time: 90 min at 25 °C). Purification by flash chromatography (eluent: pentane) yielded **133** as a colourless oil (241 mg, 74 %).

¹H-NMR (CDCl₃, 300 MHz): δ / ppm = 7.21-730 (m, 9 H), 7.16-7.19 (m, 2 H), 7.08-7.13 (m, 3 H), 6.90 (s, 1 H).

¹³C-NMR (CDCl₃, 75 MHz): δ / ppm = 145.0, 143.1, 140.0, 138.5, 132.9 (q, *J* = 1.2 Hz), 13.7 (q, *J* = 32.3 Hz), 130.5, 129.2, 129.1 (q, *J* = 36.4 Hz), 128.7, 128.3, 128.2, 128.0, 126.8, 126.7 (q, *J* = 4.1 Hz), 126.6 (q, *J* = 272.3 Hz), 123.5 (q, *J* = 4.1 Hz).

IR (film): ν/cm⁻¹ = 3059, 3028, 1600, 1493, 1446, 1331, 1166, 1126, 1074, 880, 697.

MS (EI, 70 ev): m/z (%) = 324 (100), 283 (10), 255 (13), 178 (11).

HRMS (EI): calcd. for $[C_{21}H_{15}F_3]^+$: 324.1126; found: 324.1118.

Preparation of 3-(2,2-diphenyl-vinyl)-benzonitrile (**134**):
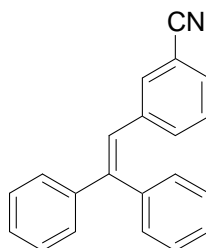
Prepared using **120** (478 mg, 1 mmol), 3-iodo-benzonitrile (664 mg, 2.9 mmol), *i*-PrMgCl (2.0 mL of a 1.5 M solution in THF, 3 mmol), CuCN·2LiCl (2.9 mL of a 1 M solution in THF), Fe(acac)$_3$ (38 mg, 10 mol %) according to **TP6** *Version B* (reaction time: 6 h at 25 °C). Purification by flash chromatography (eluent: pentane: diethyl ether = 99: 1) yielded **134** as a colourless oil (157 mg, 56 %).

^{1}H-NMR (CDCl$_3$, 300 MHz): δ / ppm = 7.22-7.32 (*m*, 9H), 7.19-7.21 (*m*, 1H), 7.11-7.16 (*m*, 2H), 7.05-7.11 (*m*, 2H), 6.83 (*s*, 1H).

^{13}C-NMR (CDCl$_3$, 75 MHz): δ / ppm = 145.8, 142.9, 139.7, 139.1, 134.0, 133.3, 130.5, 130.3, 129.5, 129.3, 129.1, 128.7, 128.6, 128.5, 128.1, 125.8, 112.6.

IR (neat): ν/cm^{-1} = 3435, 3056, 2228, 1616, 1491, 1444, 796, 765, 701.

MS (EI, 70 ev): m/z (%) = 283 (2), 282 (21), 281 (100), 280 (35), 266 (19), 253 (11), 204 (13), 203 (19).

HRMS (EI): calcd. for [C$_{21}$H$_{15}$N]$^+$: 281.1204; found: 281.1186.

Preparation of 1-(2-(4-methoxyphenyl)-1-phenylvinyl)benzene (**135**):
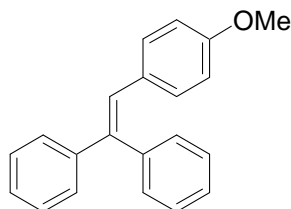
Prepared using **119** (331 mg, 1 mmol), *p*-OMe-C$_6$H$_4$MgBr (1.8 mL of a 1.5 M solution in THF, 2.8 mmol), CuCN·2LiCl (2.8 mL of a 1 M solution in THF), Fe(acac)$_3$ (38 mg, 10 mol %) according to **TP6** *Version A* (reaction time: 1 h at 25 °C). Purification by flash

chromatography (eluent: pentane: diethyl ether = 9: 1) yielded **135** as a colourless oil (224 mg, 78 %).

^{1}H-NMR (CDCl$_3$, 300 MHz): δ / ppm = 7.21-7.29 (m, 7 H), 7.18-7.20 (m, 1 H), 7.12-7.16 (m, 2 H), 6.88 (d, *J* = 8.6 Hz, 2 H), 6.84 (s, 1 H), 6.59 (d, *J* = 8.6 Hz, 2 H), 3.67 (s, 3 H).

^{13}C-NMR (CDCl$_3$, 75 MHz): δ / ppm = 158.8, 144.0, 141.0, 141.0, 131.2, 130.8, 130.5, 129.1, 128.5, 128.0, 127.8, 127.7, 127.6, 113.8, 55.5.

IR (film): v/cm^{-1} = 3436, 2993, 2837, 1602, 1509, 1493, 1442, 1301, 1255, 1178, 1036, 878, 702, 692.

MS (EI, 70 ev): m/z (%) = 286 (100), 165 (15).

HRMS (EI): calcd. for [C$_{21}$H$_{18}$O]$^+$: 286.1358; found: 286.1341.

Preparation of 1-methyl-2-(2,2-diphenylvinyl)benzene (**136**):
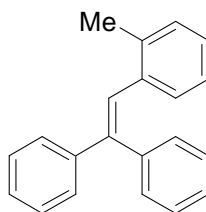
Prepared using **119** (331 mg, 1 mmol), 2-iodo-toluene (632 mg, 2.9 mmol), *i*-PrMgCl (2.0 mL of a 1.5 M solution in THF, 3 mmol), CuCN·2LiCl (2.9 mL of a 1 M solution in THF), Fe(acac)$_3$ (38 mg, 10 mol %) according to **TP6** *Version B* (reaction time: 3 h at 25 °C). Purification by flash chromatography (eluent: pentane) yielded **136** as a colourless oil (241 mg, 79 %).

^{1}H-NMR (CDCl$_3$, 300 MHz): δ / ppm = 7.19-7.30 (m, 6 H), 7.09-7.14 (m, 3 H), 6.98-7.03 (m, 2 H), 6.90-6.97 (m, 1 H), 6.89 (s, 1 H), 6.71-6.80 (m, 2 H), 2.23 (s, 3 H).

^{13}C-NMR (CDCl$_3$, 75 MHz): δ / ppm = 144.0, 143.8, 140.7, 137.4, 137.3, 131.1, 130.2, 130.1, 128.6, 128.5, 128.5, 127.9, 127.7, 127.6, 127.2, 125.6, 20.7.

IR (film): v/cm^{-1} = 3058, 3019, 1949, 1598, 1492, 1445, 1222, 777, 762, 695.

MS (EI, 70 ev): m/z (%) = 271 (23), 270 (100), 269 (9), 256 (12), 255 (43), 254 (14), 253 (16), 252 (14), 239 (12), 193 (10), 192 (19), 191 (12), 179 (33), 178 (29), 126 (14), 91 (6).

HRMS (EI): calcd. for [C$_{21}$H$_{18}$]$^+$: 270.1409; found: 270.1411.

Preparation of ethyl 4-vinylbenzoate (**137**):
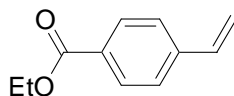
Prepared using **121** (655 mg, 2 mmol), ethyl 4-iodo-benzoate (1.60 g, 5.9 mmol), *i*-PrMgCl (2.9 mL of a 2.1 M solution in THF, 6.1 mmol), CuCN·2LiCl (5.8 mL of a 1 M solution in THF), Fe(acac)$_3$ (76 mg, 10 mol %) according to **TP6** *Version B* (reaction time: 45 min at 25 °C). Purification by flash chromatography (eluent: pentane: diethyl ether = 99: 1) yielded **137** as a colourless oil (226 mg, 64 %).

^{1}H-NMR (CDCl$_3$, 300 MHz): δ / ppm = 7.93 (d, *J* = 8.4 Hz, 2 H), 7.38 (d, *J* = 8.6 Hz, 2 H), 6.68 (dd, *J* = 17.7 Hz, *J* = 10.8 Hz, 1 H), 5.79 (d, *J* = 17.7 Hz, 1 H), 5.31 (d, *J* = 10.8 Hz, 1 H), 4.30 (q, *J* = 7.1 Hz, 2 H), 1.32 (t, *J* = 7.1 Hz, 3 H).

^{13}C-NMR (CDCl$_3$, 75 MHz): δ / ppm = 194.3, 166.4, 141.8, 136.1, 129.8, 126.0, 116.4, 60.9, 14.3.

IR (film): ν/cm^{-1} = 3418, 2982, 2918, 1715,1608,1275, 1105.

MS (EI, 70 ev): m/z (%) = 176 (33), 148 (27), 131 (100), 103 (27), 77 (24)

HRMS (EI): calcd. for [C$_{11}$H$_{12}$O$_2$]$^+$: 176.0837; found: 176.0849.

Preparation of 1-vinylnaphthalene (**138**):
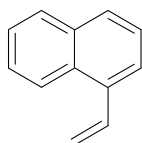
Prepared using **121** (330 mg, 1 mmol), 1-iodo-naphthalene (765 mg, 3 mmol), *i*-PrMgCl (1.5 mL of a 2.1 M solution in THF, 6.1 mmol), CuCN·2LiCl (2.8 mL of a 1 M solution in THF), Fe(acac)$_3$ (38 mg, 10 mol %) according to **TP6** *Version B* (reaction time: 22 h at 25 °C). Purification by flash chromatography (eluent: pentane) yielded **138** as a colourless oil (109 mg, 71 %).

¹H-NMR (CDCl₃, 300 MHz): δ / ppm = 8.04 (d, *J* = 7.9 Hz, 1 H), 7.75-7.79 (m, 1 H), 7.71 (d, *J* = 8.4 Hz, 1 H), 7.55 (d, *J* = 7.1 Hz, 1 H), 7.36-7.46 (m, 4 H), 5.72 (dd, *J* = 17.3 Hz, *J* = 1.5 Hz, 1 H), 5.40 (dd, *J* = 10.9 Hz, *J* = 1.6 Hz, 1 H).

¹³C-NMR (CDCl₃, 75 MHz): δ / ppm = 136.0, 134.8, 134.0, 131.5, 128.9, 128.5, 126.4, 126.1, 126.0, 124.1, 124.0, 117.5.

IR (film): ν/cm⁻¹ = 3048, 2922, 2852, 799, 776.

MS (EI, 70 ev): m/z (%) = 154 (88), 153 (100), 152 (61), 151 (13).

HRMS (EI): calcd. for [C₁₂H₁₀]⁺: 154.0783; found: 154.0774.

Preparation of 1-bromo-3-vinylbenzene (**139**):
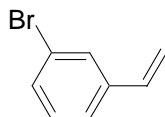
Prepared using **121** (655 mg, 2 mmol), 1-bromo-3-iodo-benzene (1.67 g, 5.9 mmol), *i*-PrMgCl (2.9 mL of a 2.1 M solution in THF, 6.1 mmol), CuCN·2LiCl (5.8 mL of a 1 M solution in THF), Fe(acac)₃ (76 mg, 10 mol %) according to **TP6** *Version B* (reaction time: 4 h at 25 °C). Purification by flash chromatography (eluent: pentane) yielded **139** as a colourless oil (226 mg, 62 %).

¹H-NMR (CDCl₃, 300 MHz): δ / ppm = 7.48 (t, *J* = 1.6 Hz, 1 H), 7.30 (d, *J* = 7.9 Hz, 1 H), 7.24 (d, *J* = 7.7 Hz, 1 H), 7.11 (t, *J* = 7.7 Hz, 1 H), 6.57 (dd, *J* = 17.7 Hz, *J* = 10.8 Hz, 1 H), 5.68 (d, *J* = 17.7 Hz, 1 H), 5.22 (d, *J* = 10.8 Hz, 1 H).

¹³C-NMR (CDCl₃, 75 MHz): δ / ppm = 138.7, 134.5, 129.6, 128.0, 128.1, 123.9, 121.7, 114.4.

IR (film): ν/cm⁻¹ = 3088, 3060, 3010, 2988, 2922, 1592, 1560, 1474, 1412, 1199, 1073, 987, 913, 786.

MS (EI, 70 ev): m/z (%) = 184 (89), 182 (90), 103 (100), 97 (44), 85 (49), 83 (43), 77 (73), 71 (62), 55 (51)

HRMS (EI): calcd. for [C₈H₇Br]⁺: 181.9731; found: 181.9726.

Preparatin of 1-(cyclohexa-1,5-dienyl)-3-(trifluoromethyl)benzene (**140**):
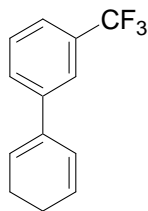
Prepared using **122** (378 mg, 1 mmol), 1-iodo-3-trifluoromethyl-benzene (410 mg, 1.5 mmol), *i*-PrMgCl (1.0 mL of a 1.5 M solution in THF, 1.5 mmol), CuCN·2LiCl (1.4 mL of a 1 M solution in THF), Fe(acac)$_3$ (38 mg, 10 mol %) according to **TP7** (reaction time: 5 h at 25 °C). Purification by flash chromatography (eluent: pentane) yielded **140** as a colourless oil (203 mg, 90 %).

^{1}H-NMR (CDCl$_3$, 300 MHz): δ / ppm = 7.54 (s, 1 H), 7.30-7.52 (m, 3 H), 6.22 (dq, *J* = 9.7 Hz, *J* = 1.8 Hz, 1 H), 6.06 (tt, *J* = 4.6 Hz, *J* = 1.3 Hz, 1 H), 5.98 (dtd, *J* = 9.7 Hz, *J* = 4.3 Hz, *J* = 0.9 Hz, 1 H), 2.23-2.33 (m, 2 H), 2.09-2.19 (m, 2 H).

^{13}C-NMR (CDCl$_3$, 75 MHz): δ / ppm = 141.8, 135.3, 131.5 (q, *J* = 32.2 Hz), 129.2, 129.0, 128.8, 125.4, 124.8, 124.6 (q, *J* = 272.3 Hz), 123.8 (q, *J* = 4.1 Hz), 122.5 (q, *J* = 4.1 Hz), 23.2, 22.2.

IR (film, cm^{-1}) : 3065, 3033, 1600, 1493, 1446, 1331, 1127, 1071, 885, 701.

MS (EI, 70 ev): m/z (%) = 224 (82), 223 (32), 209 (58), 183 (87), 155 (100).

HRMS (EI): calcd. for [C$_{13}$H$_{11}$F$_3$]$^+$: 224.0813; found: 224.0839.

Preparation ofethyl 4-(cyclohexa-1,5-dienyl)benzoate (**141**):
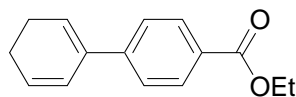
Prepared using **122** (378 mg, 1 mmol), ethyl 4-iodo-benzoate (415 mg, 1.5 mmol), *i*-PrMgCl (1.0 mL of a 1.5 M solution in THF, 1.5 mmol), CuCN·2LiCl (1.4 mL of a 1 M solution in THF), Fe(acac)$_3$ (38 mg, 10 mol %) according to **TP7** (reaction time: 30 min at 25 °C). Purification by flash chromatography (eluent: pentane: diethyl ether = 99: 1) yielded **141** as a colourless oil (193 mg, 84 %).

¹H-NMR (CDCl₃, 300 MHz): δ / ppm = 7.92 (d, *J* = 8.4 Hz, 2 H), 7.36 (d, *J* = 8.4 Hz, 2 H), 6.26 (dq, *J* = 9.7 Hz, *J* = 1.8 Hz, 1 H), 6.09-6.11 (m, 1 H), 5.93-6.01 (m, 1 H), 4.30 (q, *J* = 7.1 Hz, 2 H), 2.23-2.33 (m, 2 H), 2.09-2.19 (m, 2 H), 1.32 (t, *J* = 7.1 Hz, 3 H).

¹³C-NMR (CDCl₃, 75 MHz): δ / ppm = 166.9, 145.3, 135.6, 130.1, 129.2, 128.6, 125.5, 125.4, 125.3, 61.2, 23.3, 22.2; 14.7.

IR (neat): v/cm⁻¹ = 3430, 3040, 2982, 2937, 1714, 1607, 1282, 1189, 1108, 1023, 771.

MS (EI, 70 ev): m/z (%) = 228 (100), 200 (10), 183 (32), 155 (87), 153 (19), 128 (10).

HRMS (EI): calcd. for $[C_{15}H_{16}O_2]^+$: 228.1150; found: 228.1135.

Preparation of 1-(cyclohexa-1,5-dienyl)naphthalene (**142**):
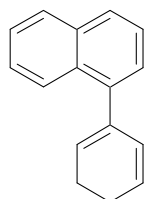
Prepared using **122** (378 mg, 1 mmol), 1-iodo-naphthalene (380 mg, 1.5 mmol), *i*-PrMgCl (1.0 mL of a 1.5 M solution in THF, 1.5 mmol), CuCN·2LiCl (1.4 mL of a 1 M solution in THF), Fe(acac)₃ (38 mg, 10 mol %) according to **TP7** (reaction time: 12 h at 25 °C). Purification by flash chromatography (eluent: pentane) yielded **142** as a colourless oil (150 mg, 73 %).


¹H-NMR (CDCl₃, 300 MHz): δ / ppm = 7.91-7.97 (m, 1 H), 7.72-7.79 (m, 1 H), 7.68 (d, *J* = 8.0 Hz, 1 H), 7.33-7.42 (m, 3 H), 7.24 (dd, *J* = 7.0 Hz, *J* = 1.3 Hz, 1 H), 6.05 (dq, *J* = 9.7 Hz, *J* = 1.3 Hz, 1 H), 5.82-5.92 (m, 2 H), 2.29-2.39 (m, 2 H), 2.18-2.28 (m, 2 H).

¹³C-NMR (CDCl₃, 75 MHz): δ / ppm = 140.8, 136.7, 134.1, 131.8, 128.8, 128.6, 127.7, 126.4, 126.4, 126.1, 126.0, 126.0, 125.9, 125.8, 23.2, 22.4.

IR (film): v/cm⁻¹ = 3486, 3037, 2933, 2870, 2822, 799, 776.

MS (EI, 70 ev): m/z (%) = 207 (15), 206 (100), 205 (90), 178 (53), 165 (49).

HRMS (EI): calcd. for $[C_{16}H_{14}]^+$: 206.1096; found: 206.1078.

Preparation of diethyl naphthalen-1-yl phosphate (**143**):
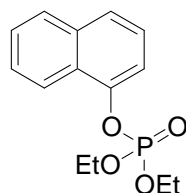
Prepared according to **TP8**, using 1-naphthol (2.90 g, 20 mmol), NaH (890 mg of a 60 % suspension in oil, 22 mmol), and diethyl chlorophosphate (3.20 mL, 22 mmol). Purification by flash chromatography (eluent: pentane: diethyl ether = 2: 8) yielded **143** as a red oil (4.50 g, 81 %).

^{1}H-NMR (CDCl$_3$, 300 MHz): δ / ppm = 8.06-8.13 (m, 1 H), 7.72-7.79 (m, 1 H), 7.57 (dd, J = 8.0 Hz, J = 0.9 Hz, 1 H), 7.37-7.49 (m, 3 H), 7.32 (t, J = 8.0 Hz, 1 H), 4.10-4.25 (m, 4 H), 1.25 (dt, J = 7.1 Hz, J = 1.1 Hz, 6 H).

^{13}C-NMR (CDCl$_3$, 75 MHz): δ / ppm = 147.1 (d, J = 7.0 Hz), 135.1, 128.1, 127.0, 126.8 (d, J = 7.0 Hz), 126.7, 125.9 (d, J = 1.8 Hz), 125.2 (d, J = 1.2 Hz), 122.0 (d, J = 1.2 Hz), 115.2 (d, J = 2.9 Hz), 65.1 (d, J = 6.5 Hz), 16.5 (d, J = 6.5 Hz).

IR (neat): ν/cm^{-1} = 2958, 2872, 1671, 1445, 1376, 1242, 1156, 10223, 1012, 923.

MS (EI, 70 ev): m/z (%) = 281 (13), 280 (100), 252 (19), 224 (28), 154 (10), 144 (52), 115 (30).

HRMS (EI): calcd. for [C$_{14}$H$_{17}$O$_4$P]$^+$: 280.0864; found: 280.0857.

Preparation of phosphoric acid benzo[1,3]dioxol-5-yl ester diethyl ester (**144**):
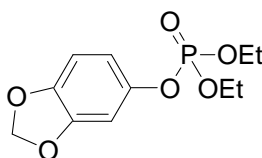
Prepared according to **TP8**, using benzo[1,3]dioxol-5-ol (2.80 g, 20 mmol), NaH (880 mg of a 60 % suspension in oil, 22 mmol), and diethyl chlorophosphate (3.20 mL, 22 mmol). Purification by flash chromatography (eluent: diethyl ether) yielded **144** as a colourless oil (5.01 g, 91 %).

^{1}H-NMR (CDCl$_3$, 300 MHz): δ / ppm = 6.66-6.69 (m, 1 H), 6.63 (s, 1 H), 6.57-6.61 (m, 1 H), 5.88 (s, 2 H), 4.07-4.19 (m, 4 H), 1.28 (dt, J = 7.1 Hz, J = 1.1 Hz, 6 H).

^{13}C-NMR (CDCl$_3$, 75 MHz): δ / ppm = 148.5, 145.5 (d, J = 7.0 Hz), 145.1 (d, J = 1.8 Hz), 112.7 (d, J = 5.3 Hz), 108.3 (d, J = 1.8 Hz), 102.9 (d, J = 4.7 Hz), 102.1, 65.0 (d, J = 5.9 Hz), 16.4 (d, J = 7.0 Hz).

IR (neat): ν/cm^{-1} = 2985, 2909, 2782, 1634, 1613, 1503, 1483, 1445, 1394, 1273, 1245, 1174, 1127, 1021, 885, 802.

MS (EI, 70 ev): m/z (%) = 275 (7), 274 (64), 218 (73), 200 (18), 138 (100), 137 (34).

HRMS (EI): calcd. for $[C_{11}H_{15}O_6P]^+$: 274.0606; found: 274.0609.

Preparation of phosphoric acid diethyl ester 3-methoxy-phenyl ester (**145**):
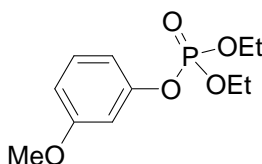
Prepared according to **TP8**, using 3-methoxy-phenol (2.50 g, 20 mmol), NaH (890 mg of a 60 % suspension in oil, 22 mmol), and diethyl chlorophosphate (3.20 mL, 22 mmol). Purification by flash chromatography (eluent: diethyl ether) yielded **145** as a colourless oil (4.70 g, 90 %).

^{1}H-NMR (CDCl$_3$, 300 MHz): δ / ppm = 7.17-7.24 (m, 1 H), 6.64-6.84 (m, 3 H), 4.14-4.26 (m, 4 H), 3.77 (s, 3 H), 1.34 (dt, J = 7.1 Hz, J = 1.0 Hz, 6 H).

^{13}C-NMR (CDCl$_3$, 75 MHz): δ / ppm = 161.0, 152.0 (d, J = 6.5 Hz), 130.4 (d, J = 1.2 Hz), 112.4 (d, J = 4.7 Hz), 111.1 (d, J = 1.2 Hz), 106.5 (d, J = 5.3 Hz), 64.9 (d, J = 5.9 Hz), 55.8, 16.4 (d, J = 6.5 Hz).

IR (neat): ν/cm^{-1} = 2984, 2940, 2911, 2839, 1606, 1590, 1491, 1452, 1394, 1370, 1268, 1192, 1143, 1023, 1000, 980, 851, 770, 685.

MS (EI, 70 ev): m/z (%) = 261 (10), 260 (100), 245 (12), 232 (15), 231 (15), 217 (25), 204 (20), 203 (11), 134 (85), 124 (52), 119 (17), 94 (10).

HRMS (EI): calcd. for $[C_{11}H_{17}O_5P]^+$: 260.0814; found: 260.0802.

Preparation of phosphoric acid diethyl ester 4-methoxy-phenyl ester (**146**):
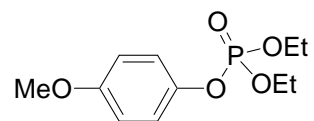
Prepared according to **TP8**, using 4-methoxy-phenol (2.50 g, 20 mmol), NaH (890 mg of a 60 % suspension in oil, 22 mmol), and diethyl chlorophosphate (3.20 mL, 22 mmol). Purification by flash chromatography (eluent: diethyl ether) yielded **146** as a colourless oil (4.32 g, 83 %).

^{1}H-NMR (CDCl$_3$, 300 MHz): δ / ppm = 7.12 (d, J = 8.4 Hz, 2 H), 6.40 (d, J = 9.3 Hz, 2 H), 4.12-4.25 (m, 4 H), 3.75 (s, 3 H), 1.32 (br t, J = 7.1, 6 H).

^{13}C-NMR (CDCl$_3$, 75 MHz): δ / ppm = 157.3 (d, J = 1.2 Hz), 144.7 (d, J = 7.0 Hz), 122.2 (d, J = 4.1), 115.0, 64.8 (d, J = 5.9 Hz), 55.9, 16.4 (d, J = 6.5 Hz).

IR (neat): v/cm^{-1} = 3496, 2985, 2936, 2910, 2839, 1596, 1503, 1444, 1394, 1272, 1250, 1203, 1101, 1022, 953, 935, 834, 758, 693.

MS (EI, 70 ev): m/z (%) = 261 (9), 260 (100), 245 (2), 232 (23), 231 (2), 217 (6), 204 (40), 134 (7), 124 (50), 123 (18), 109 (16).

HRMS (EI): calcd. for [C$_{11}$H$_{17}$O$_5$P]$^+$: 260.0814; found: 260.0803.

Preparation of phosphoric acid diethyl ester 3-trifluoromethyl-phenyl ester (**147**):

Prepared according to **TP8**, using 3-trifluoromethyl-phenol (1.62 g, 10 mmol), NaH (440 mg of a 60 % suspension in oil, 11 mmol), and diethyl chlorophosphate (1.6 mL, 11 mmol). Purification by flash chromatography (eluent: pentane: diethyl ether = 2: 8) yielded **147** as a colourless oil (2.51 g, 85 %).
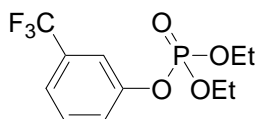
^{1}H-NMR (CDCl$_3$, 300 MHz): δ / ppm = 7.34-7.45 (m, 4 H), 4.10-4.23 (m, 4 H), 1.29 (*dt*, J = 7.1 Hz, J = 1.1 Hz, 6 H).

13C-NMR (CDCl3, 75 MHz): δ / ppm = 151.3 (d, J = 6.5 Hz), 132.6 (q, J = 32.9 Hz), 130.7, 123.9 (dt, J = 4.7 Hz, J = 1.2 Hz), 123.8 (q, J = 272.3 Hz), 122.1 (m), 117.6 (m), 65.2 (d, J = 5.9 Hz), 16.4 (d, J = 6.5 Hz).

IR (neat): ν/cm^{-1} = 3498, 2988, 2936, 2914, 1596, 1493, 1448, 1395, 1326, 1277, 1212, 1166, 1126, 1024, 887, 797, 697.

MS (EI, 70 ev): m/z (%) = 298 (29), 255 (18), 172 (72), 162 (100), 99 (28).

HRMS (EI): calcd. for $[C_{11}H_{14}F_3O_4P]^+$: 298.0582; found: 298.0557.

Preparation of 1-phenyl-naphthalene (**156**):
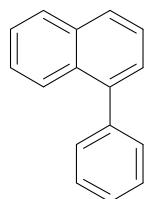
Prepared according to **TP9** *Version A*, using **143** (285 mg, 1 mmol), PhMgCl (0.8 mL of a 1.5 M solution in THF, 1.2 mmol), and NiCl$_2$(dppe) (5 mg, 1 mol %). Purification by flash chromatography (eluent: pentane) yielded **156** as a colourless oil (177 mg, 87 %).

1H-NMR (CDCl3, 300 MHz): δ / ppm = 7.81 (d, J = 8.0 Hz, 2 H), 7.76 (d, J = 8.0 Hz, 1 H), 7.28-7.46 (m, 9 H).

13C-NMR (CDCl3, 75 MHz): δ / ppm = 141.2, 140.7, 134.2, 132.1 130.5, 128.7 128.6 128.1 127.7 127.4 126.5 126.4, 126.2 125.8.

IR (neat): ν/cm^{-1} = 3055, 2923, 1948, 1591, 1507, 1493, 1394, 800, 777, 759, 701, 615.

MS (EI, 70 ev): m/z (%) = 205 (15), 204 (100), 202 (56), 101 (25).

HRMS (EI): calcd. for $[C_{16}H_{12}]^+$: 204.0939; found: 204.0933.

Preparation of 1-(3-trifluoromethyl-phenyl)-naphthalene (**157**):
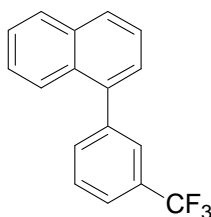
Prepared according to **TP9** *Version B* using **143** (284 mg, 1 mmol), 3-trifluoromethyl-iodobenzene (546 mg, 2 mmol), *i*-PrMgCl·LiCl (1.3 mL of a 1.5 M solution in THF, 2 mmol), and NiCl$_2$(dppe) (5 mg, 1 mol %). Purification by flash chromatography (eluent: pentane) yielded **157** as a colourless oil (218 mg, 80 %).

^{1}H-NMR (CDCl$_3$, 300 MHz): δ / ppm = 8.82 (t, *J* = 8.4 Hz, 2 H), 7.66-7.73 (m, 2 H), 7.56-7.63 (m, 2 H), 7.26-7.55 (m, 5 H).

^{13}C-NMR (CDCl$_3$, 75 MHz): δ / ppm = 141.9, 139.0, 134.2, 133.8 (q, *J* = 1.2 Hz), 131.7, 131.2 (q, *J* = 32.3 Hz), 129.1, 128.8, 128.8, 127.5, 127.2 (dd, *J* = 7.6 Hz, *J* = 4.1 Hz), 126.9, 126.4, 125.8, 125.7, 124.6 (q, *J* = 272.3 Hz), 124.5 (dd, *J* = 7.6 Hz, *J* = 3.5 Hz).

IR (neat): ν/cm^{-1} = 3061, 2926, 2855, 1932, 1592, 1509, 1396, 1330, 1268, 1162, 1111, 1092, 1072, 1020, 798, 772, 702, 620.

MS (EI, 70 ev): m/z (%) = 273 (13), 272 (100), 251 (12), 203 (46), 202 (36).

HRMS (EI): calcd. for [C$_{17}$H$_{11}$F$_3$]$^+$: 272.0813; found: 272.0821.

Preparation of 1-(3,5-bis-trifluoromethyl-phenyl)-naphthalene (**158**):
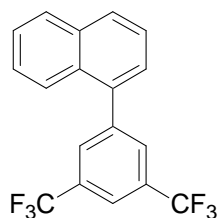
Prepared according to **TP9** *Version B* using **143** (286 mg, 1 mmol), 1-bromo-3,5-bis-trifluoromethyl-benzene (586 mg, 2mmol), *i*-PrMgCl·LiCl (1.3 mL of a 1.5 M solution in THF, 2 mmol), and NiCl$_2$(dppe) (5 mg, 1 mol %). Purification by flash chromatography (eluent: pentane) yielded **158** as a white solid (242 mg, 71 %).

mp (ºC) = 53.6-55.9.

^{1}H-NMR (CDCl$_3$, 300 MHz): δ / ppm = 7.82-7.96 (m, 5 H), 7.62 (dd, *J* = 8.0 Hz, *J* = 0.9 Hz, 1 H), 7.32-7.52 (m, 4 H).

^{13}C-NMR (CDCl$_3$, 75 MHz): δ / ppm = 143.3, 137.3, 134.2, 132.1 (q, *J* = 33.5 Hz), 131.4, 130.6 (m), 129.5, 129.0, 127.8, 127.4, 126.7, 125.7, 125.2, 123.9 (q, *J* = 272.3 Hz), 121.6 (m).

IR (neat): ν/cm^{-1} = 3063, 2922, 1814, 1620, 1510, 1469, 1406, 1364, 1262, 1178, 1121, 1105, 1064, 900, 803, 774, 684.

MS (EI, 70 ev): m/z (%) = 341 (18), 340 (100), 271 (24), 202 (16).

HRMS (EI): calcd. for $[C_{18}H_{10}F_6]^+$: 340.0687; found: 340.0683.

Preparation of 1-(3,4-difluoro-phenyl)-naphthalene (**159**):
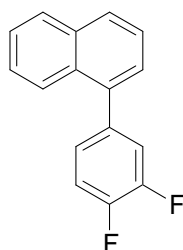
Prepared according to **TP9** *Version B* using **143** (280 mg, 1 mmol), 4-bromo-1,2-difluorobenzene (387 mg, 2mmol), *i*-PrMgCl·LiCl (1.3 mL of a 1.5 M solution in THF, 2 mmol), and NiCl$_2$(dppe) (5 mg, 1 mol %). Purification by flash chromatography (eluent: pentane) yielded **159** as a colourless oil (153 mg, 64 %).

^{1}H-NMR (CDCl$_3$, 300 MHz): δ / ppm = 7.82-7.98 (m, 3 H), 7.18-7.59 (m, 7 H).

^{13}C-NMR (CDCl$_3$, 75 MHz): δ / ppm = 150.5 (d, J = 248.8 Hz), 150.3 (d, J = 247.1 Hz), 138.4, 138.0 (m), 134.2, 131.7, 128.8, 128.7, 128.4, 126.8, 126.5 (m), 126.4, 125.8, 125.7, 119.4 (d, J = 16.4 Hz), 117.5 (dd, J = 17.0 Hz, J = 1.2 Hz).

IR (neat): ν/cm^{-1} = 3050, 2926, 1932, 1618, 1603, 1517, 1503, 1643, 1417, 1392, 1308, 1266, 1200, 1118, 800, 776, 766, 654.

MS (EI, 70 ev): m/z (%) = 240 (100), 239 (52), 238 (40), 220 (13), 119 (11).

HRMS (EI): calcd. for $[C_{16}H_{10}F_2]^+$: 240.0751; found: 240.0745.

Preparation of 1-(3,5-difluoro-phenyl)-naphthalene (**160**):
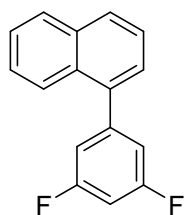
Prepared according to **TP9** *Version B* using **143** (282 mg, 1 mmol), 4-bromo-1,3-difluorobenzene (387 mg, 2mmol), *i*-PrMgCl·LiCl (1.3 mL of a 1.5 M solution in THF, 2 mmol), and NiCl$_2$(dppe) (5 mg, 1 mol %). Purification by Flash Chromatography (100 % n-pentane) yielded **160** as a white solid (130 mg, 54 %).

mp (ºC) = 82.3-83.8

^{1}H-NMR (CDCl$_3$, 300 MHz): δ / ppm = 7.85-7.98 (m, 3 H), 7.46-7.59 (m, 3 H), 7.39-7.45 (m, 1 H), 7.01, 7.12 (m, 2 H), 6.86-6.97 (m, 1 H).

^{13}C-NMR (CDCl$_3$, 75 MHz): δ / ppm = 163.3 (d, *J* = 248.8 Hz), 163.1 (d, *J* = 248.8 Hz), 144.4 (m), 138.3, 134.2, 131.4, 129.0, 128.8, 127.2, 126.9, 126.5, 125.7, 125.6, 113.6 (d, *J* = 8.2 Hz), 113.3 (d, *J* = 8.2 Hz), 103,1 (t, *J* = 25.2 Hz).

IR (neat): v/cm^{-1} = 3086, 3059, 2854, 1622, 1591, 1508, 1448, 1424, 1396, 1332, 1225, 1112, 1024, 985, 887, 859, 800, 774, 692, 641.

MS (EI, 70 ev): m/z (%) = 241 (15), 240 (100), 239 (80), 238 (42), 220 (10), 119 (11).

HRMS (EI): calcd. for $[C_{16}H_{10}F_2]^+$: 240.0751; found: 240.0757.

Preparation of 1-(4-trifluoromethyl-phenyl)-naphthalene (**161**):
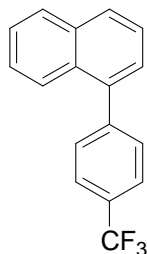
Prepared according to **TP9** *Version B* using **143** (285 mg, 1 mmol), 4-trifluoromethyl-bromobenzene (450 mg, 2mmol), *i*-PrMgCl·LiCl (1.3 mL of a 1.5 M solution in THF, 2 mmol), and NiCl$_2$(dppe) (5 mg, 1 mol %). Purification by flash chromatography (eluent: pentane) yielded **161** as a colourless oil (113 mg, 42 %).

^{1}H-NMR (CDCl$_3$, 300 MHz): δ / ppm = 7.81 (t, *J* = 8.0 Hz, 2 H), 7.58-7.75 (m, 3 H), 7.27-7.55 (m, 6 H).

^{13}C-NMR (CDCl$_3$, 75 MHz): δ / ppm = 144.9 (m), 139.1, 134.2, 131.7, 130.8, 129.9 (q, *J* = 32.3Hz), 128.8, 128.8, 127.4, 126.8, 126.4, 125.90, 125.7, 125.6 (m), 124.8 (q, *J* = 272.3 Hz).

IR (neat): ν/cm^{-1} = 3061, 2926, 2855, 1932, 1396, 1330, 1268, 1246, 1162, 1110, 1092, 1072, 798, 772, 702.

MS (EI, 70 ev): m/z (%) = 273 (14), 272 (100), 203 (32), 202 (33).

HRMS (EI): calcd. for [C$_{17}$H$_{11}$F$_3$]$^+$: 272.0813; found: 272.0822.

Preparation of 1-(4-fluoro-phenyl)-naphthalene (**162**):
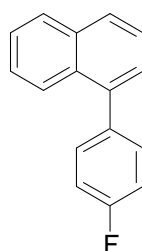
Prepared according to **TP9** *Version B* using **143** (280 mg, 1 mmol), 4-fluoro-bromobenzene (350 mg, 2mmol), *i*-PrMgCl·LiCl (1.3 mL of a 1.5 M solution in THF, 2 mmol), and NiCl$_2$(dppe) (5 mg, 1 mol %). Purification by flash chromatography (eluent: pentane) yielded **162** as a white solid (78 mg, 35 %).

mp (ºC) = 71.7-73.3.

^{1}H-NMR (CDCl$_3$, 300 MHz): δ / ppm = 7.73-7.86 (m, 3 H), 7.28-7.47 (m, 6 H), 7.05-7.15 (m, 2 H).

^{13}C-NMR (CDCl$_3$, 75 MHz): δ / ppm = 162.7 (d, *J* = 245.9 Hz), 139.6, 137.1, 134.2, 132.0 (d, *J* = 8.2 Hz), 128.7, 128.2, 127.4, 127.4, 126.5, 126.2, 126.2, 125.7, 115.6 (d, *J* = 21.1 Hz).

IR (neat): ν/cm^{-1} = 3067, 3045, 2958, 2921, 2851, 1934, 1604, 1588, 1511, 1502, 1395, 1215, 1156, 1094, 1014, 836, 799, 778, 658.

MS (EI, 70 ev): m/z (%) = 223 (12), 222 (100), 221 (60), 220 (37), 218 (5), 202 (3).

HRMS (EI): calcd. for [C$_{16}$H$_{11}$F]$^+$: 222.0845; found: 222.0839.

Preparation of 1-(4-methoxy-phenyl)-naphthalene (**163**):
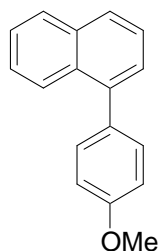
Prepared according to **TP9** *Version A* using **143** (281 mg, 1 mmol), 4-methoxyphenylmagnesium choride (1.5 mL of a 0.8 M solution in THF, 1.2 mmol), and NiCl$_2$(dppe) (6 mg, 1 mol %). Purification by flash chromatography (eluent: pentane: diethyl ether = 98: 2) yielded **163** as a white solid (192 mg, 82 %).

mp ($^{\circ}$C) = 114.6-116.2.

^{1}H-NMR (CDCl$_3$, 300 MHz): δ / ppm = 7.78-7.86 (m, 2 H), 7.74 (d, J = 8.4 Hz, 1 H), 7.29-7.45 (m, 6 H), 6.95 (d, J = 8.4 Hz, 2 H), 3.80 (s, 3 H).

^{13}C-NMR (CDCl$_3$, 75 MHz): δ / ppm = 159.4, 140.3, 134.3, 133.6, 132.3, 131.5, 128.7, 127.73, 127.3, 126.5, 126.3, 126.1, 125.8, 114.1, 55.8.

IR (neat): v/cm^{-1} = 3044, 2992, 2952, 2832, 1894, 1832, 1608, 1572, 1504, 1438, 1284, 1240, 1174, 1106, 962, 802, 780, 586, 436.

MS (EI, 70 ev): m/z (%) = 235 (15), 234 (100), 219 (23), 189 (17).

HRMS (EI): calcd. for [C$_{17}$H$_{14}$O]$^+$: 234.1045; found: 234.1033.

Preparation of 5-phenyl-benzo[1,3]dioxole (**164**):
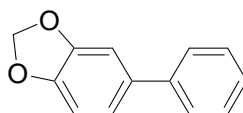
Prepared according to **TP9** *Version A* using **144** (272 mg, 1 mmol), PhMgCl (1.35 mL of a 1.5 M solution in THF, 2 mmol), and NiCl$_2$(dppe) (15 mg, 3 mol %). Purification by flash chromatography (eluent: pentane: diethyl ether = 99: 1) yielded **164** as a pale yellow oil (125 mg, 64 %).

¹H-NMR (CDCl₃, 300 MHz): δ / ppm = 7.40-7.46 (m, 2 H), 7.28-7.36 (m, 2 H), 7.19-7.26 (m, 1 H), 6.95-7.00 (m, 2 H), 6.79 (dd, *J* = 7.5 Hz, *J* = 1.3 Hz, 1 H), 5.91 (s, 2 H).

¹³C-NMR (CDCl₃, 75 MHz): δ / ppm = 148.5, 147.5, 141.3, 136.0, 129.1, 127.3, 127.3, 121.0, 109.0, 108.1, 101.5.

IR (neat): v/cm⁻¹ = 3006, 2957, 2907, 2839, 1606, 1578, 1526, 1465, 1445, 11413, 1345, 1280, 1186, 1032, 930, 887, 818.

MS (EI, 70 ev): m/z (%) = 199 (12), 198 (100), 197 (30), 139 (31).

HRMS (EI): calcd. for $[C_{13}H_{10}O_2]^+$: 198.0681; found: 198.0678.

Preparation of 5-(4-methoxy-phenyl)-benzo[1,3]dioxole (**165**):
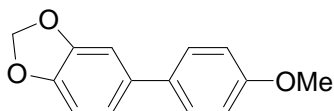
Prepared according to **TP9** *Version A* using **144** (272 mg, 1 mmol), 4-methoxyphenylmagnesium chloride (2.6 mL of a 0.8 M solution in THF, 2.1 mmol), and NiCl₂(dppe) (15 mg, 3 mol %). Purification by flash chromatography (eluent: pentane: diethyl ether = 99: 1) yielded **165** as a pale yellow oil (159 mg, 70 %).

¹H-NMR (CDCl₃, 300 MHz): δ / ppm = 7.33-7.40 (m, 2 H), 6.84-6.96 (m, 4 H), 6.78 (d, *J* = 8.4 Hz, 1 H), 5.90 (s, 2 H), 3.76 (s, 3 H).

¹³C-NMR (CDCl₃, 75 MHz): δ / ppm = 159.3, 148.4, 147.0, 135.7, 134.0, 128.3, 120.5, 114.6, 108.9, 107.8, 101.4, 55.7.

IR (neat): v/cm⁻¹ = 3074, 3038, 3005, 2905, 2840, 2535, 2039, 1605, 1465, 1444, 1345, 1276, 1250, 1222, 1184, 1032, 1012, 930, 887, 823, 801, 694.

MS (EI, 70 ev): m/z (%) = 229 (15), 228 (100), 213 (61), 185 (14), 155 (7), 114 (5).

HRMS (EI): calcd. for $[C_{14}H_{12}O_3]^+$: 228.0786; found: 228.0797.

Preparation of 3-methoxy-biphenyl (**166**):
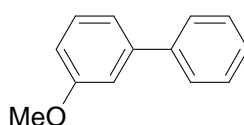
Prepared according to **TP9** *Version A* using **145** (260 mg, 1 mmol), PhMgCl (1.4 mL of a 1.5 M solution in THF, 2.1 mmol), and NiCl$_2$(dppe) (16 mg, 3 mol %). Purification by flash chromatography (eluent: pentane: diethyl ether = 98: 2) yielded **166** as a colourless oil (148 mg, 80 %).

^{1}H-NMR (CDCl$_3$, 300 MHz): δ / ppm = 7.47-7.53 (m, 2 H), 7.31-7.38 (m, 2 H), 7.22-7.30 (m, 2 H), 7.07-7.12 (m, 1 H), 7.03-7.06 (m, 1 H), 6.79-6.84 (m, 1 H), 3.77 (s, 3 H).

^{13}C-NMR (CDCl$_3$, 75 MHz): δ / ppm = 160.4, 143.2, 141.5, 130.2, 129.1, 127.8, 127.8, 127.6, 120.1, 113.3, 113.1, 55.7.

IR (neat): ν/cm^{-1} = 3059, 2956, 2937, 1598, 1572, 1477, 1420, 1294, 1211, 1177, 1169, 1053, 1037, 1019, 862, 850, 787, 694.

MS (EI, 70 ev): m/z (%) = 184 (100), 169 (37), 141 (65), 139 (22), 115 (18).

HRMS (EI): calcd. for [C$_{13}$H$_{12}$O]$^+$: 184.0888; found: 184.0885.

Preparation of 4-methoxy-biphenyl (**167**):
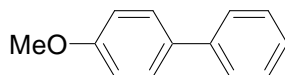
Prepared according to **TP9** *Version A* using **146** (260 mg, 1 mmol), PhMgCl (1.4 mL of a 1.5 M solution in THF, 2.1 mmol), and NiCl$_2$(dppe) (16 mg, 3 mol %). Purification by flash chromatography (eluent: pentane: diethyl ether = 98: 2) yielded **167** as a white solid (151 mg, 82 %).

mp (°C) = 86.3-89.1

^{1}H-NMR (CDCl$_3$, 300 MHz): δ / ppm = 7.42-7.51 (m, 4 H), 7.30-7.38 (m, 2 H), 7.19-7.26 (m, 1 H), 6.90 (d, J = 8.8 Hz, 2 H), 3.78 (s, 3 H).

^{13}C-NMR (CDCl$_3$, 75 MHz): δ / ppm = 158.1, 139.8, 132.8, 127.7, 127.1, 125.7, 125.6, 113.2, 54.3.

IR (neat): ν/cm^{-1} = 3066, 3034, 2908, 1607, 1523, 1489, 1270, 1252, 1202, 1036, 834, 761, 689, 550.

MS (EI, 70 ev): m/z (%) = 184 (100), 169 (52), 141 (52), 139 (12), 115 (35).

HRMS (EI): calcd. for [C$_{13}$H$_{12}$O]$^+$: 184.0888; found: 184.0883.

Preparation of 3-trifluoromethyl-biphenyl (**168**):
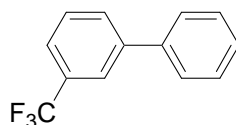
Prepared according to **TP9** *Version A* using **147** (298 mg, 1 mmol), PhMgCl (0.8 mL of a 1.5 M solution in THF, 1.2 mmol), and NiCl$_2$(dppe) (6 mg, 1 mol%). Purification by flash chromatography (eluent: pentane) yielded **168** as a colourless oil (153 mg, 69 %).

^{1}H-NMR (CDCl$_3$, 300 MHz): δ / ppm = 7.85-7.89 (m, 1 H), 7.77-7.82 (m, 1 H), 7.55-7.67 (m, 4 H), 7.38-7.54 (m, 3 H).

^{13}C-NMR (CDCl$_3$, 75 MHz): δ / ppm = 142.4, 140.2, 131.6 (q, J = 32.2 Hz), 130.8 (q, J = 1.2 Hz), 129.6, 129.4, 128.4, 127.6, 124.6 (q, J = 272.3 Hz), 124.4 (q, J = 1.2 Hz), 124.3 (m).

IR (neat): ν/cm^{-1} = 3061, 2926, 1330, 1268, 1246, 1162, 1110, 1092, 1072, 798, 772, 702.

MS (EI, 70 ev): m/z (%) = 223 (15), 222 (100), 201 (8), 153 (11), 152 (12).

HRMS (EI): calcd. for [C$_{13}$H$_9$F$_3$]$^+$: 222.0656; found: 222.0654.

Preparation of phosphoric acid 4-bromo-phenyl ester diethyl ester (**169**):
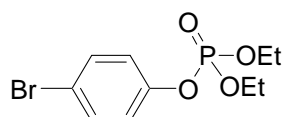
Prepared according to **TP8**, using 4-bromophenol (3.50 g, 20 mmol), NaH (880 mg of a 60 % suspension in oil, 22 mmol), and diethyl chlorophosphate (3.20 mL, 11 mmol). Purification by flash chromatography (eluent: pentane: ether = 3: 7) yielded **169** as a colourless oil (5.13 g, 81 %).

^{1}H-NMR (CDCl$_3$, 300 MHz): δ / ppm = 7.37 (d, J = 8.4 Hz, 2 H), 7.01-7.07 (m, 2 H), 4.07-4.20 (m, 4 H), 1.28 (dt, J = 7.1 Hz, J = 1.1 Hz, 6 H).

^{13}C-NMR (CDCl$_3$, 75 MHz): δ / ppm = 150.2 (d, J = 6.5 Hz), 133.1, 122.2 (d, J = 4.7 Hz), 118.2, 65.1 (d, J = 5.9 Hz), 16.4 (d, J = 6.5 Hz).

IR (neat): ν/cm^{-1} = 3094, 2984, 2933, 2910, 1583, 1484, 1444, 1394, 1370, 1273, 1215, 1164, 1097, 1011, 951, 923, 831, 778, 745, 632.

MS (EI, 70 ev): m/z (%) = 310 (73), 308 (71), 282 (31), 280 (29), 184 (50), 182 (49), 174 (95), 172 (100).

HRMS (EI): calcd. for [C$_{10}$H$_{14}$BrO$_4$P]$^+$: 307.9813; found: 307.9807.

Preparation of diethyl biphenyl-4-yl phosphate (**170**):
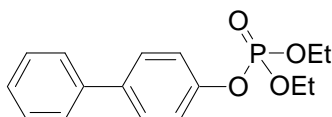
Prepared according to **TP9** *Version A* using **169** (310 mg, 1 mmol), PhMgCl (0.8 mL of a 1.5 M solution in THF, 1.2 mmol), and NiCl$_2$(dppe) (5 mg, 1 mol %). Purification by flash chromatography (eluent: pentane: diethyl ether = 3: 7) yielded **170** as a colourless oil (220 mg, 72 %).

^{1}H-NMR (CDCl$_3$, 300 MHz): δ / ppm = 751-7.59 (m, 4 H), 7.24-7.48 (m, 5 H), 4.17-4.33 (m, 4 H), 1.37 (dt, *J* = 7.1 Hz, *J* = 1.0 Hz, 6 H).

^{13}C-NMR (CDCl$_3$, 75 MHz): δ / ppm = 150.2 (d, *J* = 6.8 Hz), 138.1, 132.6, 128.8, 128.3, 127.3, 127.0, 120.2 (d, *J* = 4.9 Hz), 64.6 (d, *J* = 6.1 Hz), 16.1 (d, *J* = 6.6 Hz).

IR (neat): ν/cm^{-1} = 3495, 3033, 2984, 2910, 1606, 1516, 1484, 1271, 1217, 11165, 1052, 1009, 952, 928, 763.

MS (EI, 70 ev): m/z (%) = 307 (12), 306 (100), 278 (20), 250 (33), 180 (21), 170 (67), 141 (13).

HRMS (EI): calcd. for [C$_{16}$H$_{19}$O$_4$P]$^+$: 306,1021; found: 306.0999.

9.   Appendix

9.1. X-ray Data

2-Hydroxy-2-(1-phenyl-allyl)-cyclohexyl acetate (41):
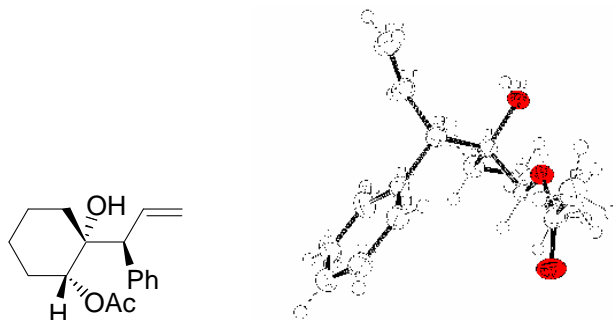
Crystal Data

Formula	$C_{17}H_{22}O_3$
Formula weight	274.36
Crystal system	Monoclinic
Space group	P21/n (No. 14)
[a, b, c] (Å)	[7.5516(2), 11.5133(3), 17.1622(5)]
[α, β, γ] (deg)	[90, 98.1398(15), 90]
V (Å^3)	1477.11(7)
Z	4
D_{calc} (g.cm^{-3})	1.234
M (Mo$_{K\alpha}$) (mm^{-1})	0.083
F (000)	592
Crystal size [mm]	0.10 x 0.16 x 0.25

Data Collection

Temperature (K)	200
Radiation (Mo$_{K\alpha}$) (Å)	0.71073
θ_{min}, θ_{max} (deg)	3.3, 27.5
Dataset	-9: 9; -14: 14; -22: 22
Tot., Uniq. Data, R_{int}	6439, 3366, 0.020
Observed data [I > 2.0 σ(I)]	2598

Refinement

N_{ref}, N_{par}	3366, 186
R, wR^2, S	0.0442, 0.1244, 1.04
Max. and av. shift/error	0.00, 0.00
Min. and max. resd. dens. (e. Å^{-3})	-0.27, 0.27

CCDC 664517 contains the supplementary crystallographic data for this paper and is available free of charge from the Cambridge Crystallographic Data Centre.

3-[2-Hydroxy-2-(1-phenyl-allyl)-cyclohexyl]-propionitrile (43):

<div align="center">
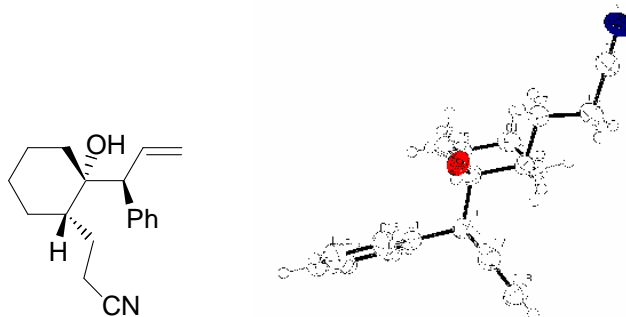
Crystal Data

</div>

Formula	$C_{18}H_{23}NO$
Formula weight	269.38
Crystal system	Orthorhombic
Space group	Pna21 (No. 33)
[a, b, c] (Å)	[12.8059(4), 8.5365(3), 14.3248(6)]
V (Å^3)	1565.95(10)
Z	4
D_{calc} (g.cm^{-3})	1.143
M (Mo$_{K\alpha}$) (mm^{-1})	0.070
F (000)	584
Crystal size [mm]	0.16 x 0.20 x 0.25

<div align="center">

Data Collection

</div>

Temperature (K)	200
Radiation (Mo$_{K\alpha}$) (Å)	0.71073
θ_{min}, θ_{max} (deg)	3.2, 25.0
Dataset	-15: 15; -10: 10; -17: 16
Tot., Uniq. Data, R_{int}	2598, 2598, 0.000
Observed data [I > 2.0 σ(I)]	2285

<div align="center">

Refinement

</div>

N_{ref}, N_{par}	2598, 274
R, wR^2, S	0.0352, 0.0839, 1.03
Max. and av. shift/error	0.00, 0.00
Flack x	1.80(16)
Min. and max. resd. dens. (e. Å^{-3})	-0.12, 0.11

CCDC 664518 contains the supplementary crystallographic data for this paper and is available free of charge from the Cambridge Crystallographic Data Centre.

5-Phenyl-1,3,4,5,8,8a-hexahydro-2H-naphthalen-4a-ol (50):
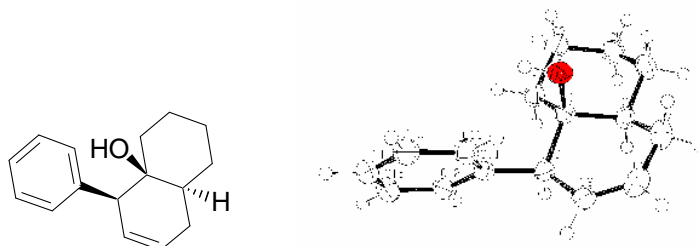
Crystal Data

Formula	$C_{16}H_{20}O$
Formula weight	228.33
Crystal system	Triclinic
Space group	P-1 (No. 2)
[a, b, c] (Å)	[6.2381(2), 10.5891(3), 11.1078(3)]
[α, β, γ] (deg)	[114.8952(16), 103.5047(16), 96.4693(18)]
V (Å^3)	628.37(3)
Z	2
D_{calc} (g.cm^{-3})	1.207
M (Mo$_{K\alpha}$) (mm^{-1})	0.073
F (000)	248
Crystal size [mm]	0.09 x 0.13 x 0.21

Data Collection

Temperature (K)	200
Radiation (Mo$_{K\alpha}$) (Å)	0.71073
θ_{min}, θ_{max} (deg)	3.5, 27.5
Dataset	-8: 8; -13: 13; -14: 13
Tot., Uniq. Data, R_{int}	5439, 2866, 0.017
Observed data [I > 2.0 σ(I)]	2300

Refinement

N_{ref}, N_{par}	2866, 234
R, wR^2, S	0.0420, 0.1159, 1.05
Max. and av. shift/error	0.00, 0.00
Min. and max. resd. dens. (e. Å^{-3})	-0.17, 0.22

CCDC 664519 contains the supplementary crystallographic data for this paper and is available free of charge from the Cambridge Crystallographic Data Centre.

6-Benzyloxy-4-phenyl-1-oxa-spiro[4.5]decane (54):
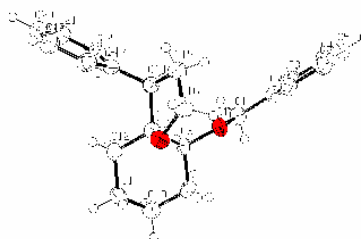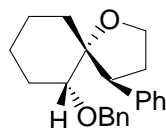
Crystal Data

Formula	$C_{22}H_{26}O_2$
Formula weight	322.44
Crystal system	Monoclinic
Space group	P21/n (No. 14)
[a, b, c] (Å)	[11.1290(3), 5.8900(2), 27.1429(7)]
[α, β, γ] (deg)	[90, 97.6503(17), 90]
V (Å^3)	1763.38(9)
Z	4
D_{calc} (g.cm^{-3})	1.214
M (Mo$_{K\alpha}$) (mm^{-1})	0.076
F (000)	696
Crystal size [mm]	0.13 x 0.18 x 0.25

Data Collection

Temperature (K)	200
Radiation (Mo$_{K\alpha}$) (Å)	0.71073
θ_{min}, θ_{max} (deg)	3.5, 26
Dataset	-13: 13; -7: 6; -33: 33
Tot., Uniq. Data, R_{int}	6222, 3449, 0.022
Observed data [I > 2.0 σ(I)]	2598

Refinement

N_{ref}, N_{par}	3449, 321
R, wR^2, S	0.0404, 0.1052, 1.04
Max. and av. shift/error	0.00, 0.00
Min. and max. resd. dens. (e. Å^{-3})	-0.18, 0.16

CCDC 664520 contains the supplementary crystallographic data for this paper and is available free of charge from the Cambridge Crystallographic Data Centre.

1-(2-Hydroxy-1-phenyl-propyl)-2-methyl-cyclohexanol (56):
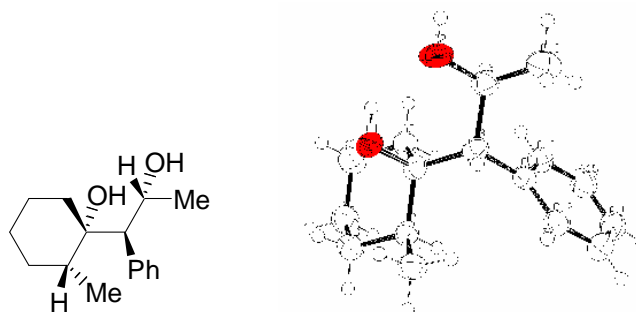
Crystal Data

Formula	$C_{16}H_{24}O_2$
Formula weight	248.36
Crystal system	Tetragonal
Space group	P-421c (No. 114)
[a, b, c] (Å)	[19.0785(3), 19.0785(3), 8.4534(2)]
V (Å^3)	3076.95(10)
Z	8
D_{calc} (g.cm^{-3})	1.072
M (Mo$_{K\alpha}$) (mm^{-1})	0.069
F (000)	1088
Crystal size [mm]	0.15 x 0.20 x 0.23

Data Collection

Temperature (K)	200
Radiation (Mo$_{K\alpha}$) (Å)	0.71073
θ_{min}, θ_{max} (deg)	3.2, 25
Dataset	-22: 22; -22: 22; -10: 10
Tot., Uniq. Data, R_{int}	20071, 2695, 0.044
Observed data [I > 2.0 σ(I)]	2404

Refinement

N_{ref}, N_{par}	2695, 166
R, wR^2, S	0.0645, 0.2046, 1.08
Max. and av. shift/error	0.00, 0.00
Flack x	-1.00(2)
Min. and max. resd. dens. (e. Å^{-3})	-0.46, 0.47

CCDC 664521 contains the supplementary crystallographic data for this paper and is available free of charge from the Cambridge Crystallographic Data Centre.

1-[1-(Toluene-4-sulfonyl)-4-vinyl-1,2,3,4-tetrahydro-quinolin-3-yl]-propan-2-one:
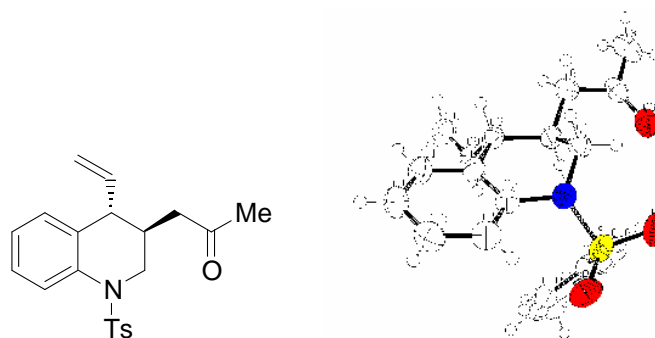
Crystal Data

Formula	$C_{21}H_{23}NO_3S$
Formula weight	369.48
Crystal system	Monoclinic
Space group	P21/c (No. 14)
[a, b, c] (Å)	[8.4209(2), 16.3335(4), 14.0636(4)]
[α, β, γ] (deg)	[90, 101.5655(16), 90]
V (Å^3)	1895.07(8)
Z	4
D_{calc} (g.cm^{-3})	1.295
M (Mo$_{K\alpha}$) (mm^{-1})	0.191
F (000)	784
Crystal size [mm]	0.13 x 0.20 x 0.22

Data Collection

Temperature (K)	200
Radiation (Mo$_{K\alpha}$) (Å)	0.71073
θ_{min}, θ_{max} (deg)	3.2, 27.5
Dataset	-10: 10; -19: 21; -18: 18
Tot., Uniq. Data, R_{int}	8296, 4328, 0.035
Observed data [I > 2.0 σ(I)]	2838

Refinement

N_{ref}, N_{par}	4328, 327
R, wR^2, S	0.0447, 0.1201, 1.03
Max. and av. shift/error	0.00, 0.00
Min. and max. resd. dens. (e. Å^{-3})	-0.33, 0.19

9.2. Resume

Guillaume Dunet

Nationality: French	French: mother tongue
Date of birth: 18.04.1980	English: fluent
Single	German: fluent

Education

2004-2007   *Ph.D. thesis* at the Ludwig-Maximilians Universität in Munich, Germany, under the supervision of Prof. Dr. Paul Knochel.
"Preparation and reactions of allylic zinc reagents and cross-coupling reactions"

2004   *Diplôme d´Etudes Approfondies* (Master equivalent), majoring in Organic Chemistry and Macromolecular Syntheses (Rank : 1st / 25).
Université de Haute-Alsace in Mulhouse, France.

2004   *Diplôme d´Ingenieur Chimiste* (Master equivalent), majoring in Organic and Bioorganic Chemistry.
Ecole Nationale Supérieure de Chimie de Mulhouse, France.

2002   *Maîtrise de Chimie Physique* specialyzing in physical chemistry
Université de Haute-Alsace in Mulhouse, France.

2001   *Licence de Chimie Physique* (BSc equivalent) specializing in Physical Chemistry
Université de Haute-Alsace in Mulhouse, France.

1998   *Baccalauréat S* (equivalent to A-levels), majoring in Maths, Physics and Chemistry, with distinction.
Lycée Benjamin Franklin in Orléans, France.

Work Experience

2004   **Actelion Pharmaceuticals**

6 months   Medicinal Chemistry Department, Alschwil, Switzerland.

                            "Inhibitors of Plasmepsine II : Potential Antimalarial Agents"

                            Key words : cross-coupling reactions, parallel syntheses, SARs.

2002-2003   **GlaxoSmithKline**

12 months   Medicinal Chemistry 2 Department, Stevenage, UK

                            "New Glucocorticoids Agonists for Inhaled Treatment of Asthma"

                            Key words : parallel synthesis, SARs.

Publications

1) <u>Dunet, G.</u>; Knochel, P. *Synlett*, **2006**, *3*, 407-410.

   "Iron-Catalyzed Cross-Coupling between Alkenyl and Dienyl Sulfonates and Functionalized Arylcopper Reagents"

2) Corminboeuf, O.; <u>Dunet, G.</u>; Hafsi, M.; Grimont, J.; Grisostomi, C. ; Meyer, S. ; Binkert, C. ; Bur, D.; Jones, A.; Prade, L.; Brun, R.; Boss, C. *Bioorg. Med. Chem. Lett.* **2006**, *16*, 6194-6199.

   "Inhibitors of Plasmepsine II: Potential Antimalarial Agents"

3) <u>Dunet, G.</u>; Knochel, P. *Synlett* **2007**, *9*, 1383.

   "Highly Stereoselective Cobalt-Catalyzed Allylation of Functionalized Diarylzinc Reagents"

4) Ren, H.; <u>Dunet, G.</u>; Mayer, P.; Knochel, P. *J. Am. Chem. Soc.* **2007**, *129*, 5376-5377.

   "Highly Diastereoselective synthesis of Homoallylic Alcohols Bearing Adjacent Quaternary Centers Using Substituted Allylic Zinc Reagents"

5) <u>Dunet, G.</u>; Mayer, P.; Knochel, P. *Org. Lett.* In press.

   "Highly Diastereoselective Addition of Cinnamylzinc Derivatives to α-Chiral Carbonyl Compounds"

Posters and presentations

1) <u>Dunet, G.</u>; Knochel, P. "Iron-Catalyzed Cross-Coupling between Alkenyl and Dienyl Sulfonates and Functionalized Arylcopper Reagents" (Poster)
   OMCOS 13, 17th-21st July 2005, Geneva, Switzerland.

2) <u>Dunet, G.</u>; Knochel, P. "Highly Stereoselective Cobalt-Catalyzed Allylation of Functionalyzed Diarylzinc Reagents" (Poster)
   Münchner Industrie Tag, 05th October 2006, München, Germany.