

Rhenium-Oxo Catalysts

1,5-Diazadecalin
Copper(II) Catalysts

Pd Catalysts for Carbonylation

NHC-Based Pd Catalysts
and Ligands for C-C Bond
Formation

Hydrogenation Catalysts
and Ligands

2005 Nobel Prize Award
Winning Metathesis
Catalyst Technology

Introduction

Catalysis plays a key role in the industrial production of bulk chemicals. Products of catalytic processes range from essential synthetic building blocks to pharmaceutically active drugs to biodegradable polymers. Our continued quality of life will be enhanced through advances in chemical catalysis. The growth of catalysis in the fine chemicals industry has been fueled by two primary sources: 1) innovative technologies emerging from chemical producers' drive in the last twenty years to fund R&D projects, and 2) the ready accessibility of a wide spectrum of catalysts manufactured and subsequently commercialized, facilitating new discoveries.

Sigma-Aldrich is committed to being your preferred supplier of catalysts and ligands used in the synthesis of your desired target molecules. We offer the broadest range of building blocks to fully integrate your research plans—reagents and catalysts from one common source. For a complete listing of products related to catalysis, please visit sigma-aldrich.com/catalysis. If you cannot find a product related to your specific research efforts, "please bother us" at amaestri@sial.com. We welcome your inquiries and look forward to accelerating your research success.

Sigma-Aldrich's New Web-Based Chemistry Seminars

Cheminars™

- Featuring the latest innovative chemical synthesis technologies and products
- Access directly via your desktop browser
- Convenient navigation
- Highly interactive

To check out Sigma-Aldrich's new Web-based chemistry seminar series, please visit sigma-aldrich.com/cheminars.

About Our Cover

The cover illustration depicts the likely active catalyst structure employed in the carbonylation reaction of benzyl halides under mild conditions. The acyl intermediate shown is generated via the reaction of a palladacycle "pre-catalyst" with carbon monoxide. Presumably the carbonyl group inserts into a Pd-C bond effectively forming a seven-membered palladium complex, which is stabilized by a donating benzyl alcohol ligand. (Note that the Pd center has triphenylphosphine bound to it, represented pictorially as the bronze globe.)

ChemFiles

Vol. 6 No. 1

Aldrich Chemical Co., Inc.
Sigma-Aldrich Corporation
 6000 N. Teutonia Ave.
 Milwaukee, WI 53209, USA

To Place Orders

Telephone 800-325-3010 (USA)
 FAX 800-325-5052 (USA)

Customer & Technical Services

| | |
|----------------------|--|
| Customer Inquiries | 800-325-3010 |
| Technical Service | 800-231-8327 |
| SAFC™ | 800-244-1173 |
| Custom Synthesis | 800-244-1173 |
| Flavors & Fragrances | 800-227-4563 |
| International | 414-438-3850 |
| 24-Hour Emergency | 414-438-3850 |
| Web Site | sigma-aldrich.com |
| Email | aldrich@sial.com |

Subscriptions

To request your **FREE** subscription to *ChemFiles*, please contact us by:

Phone: 800-325-3010 (USA)

Mail: **Attn: Marketing Communications**
Aldrich Chemical Co., Inc.
Sigma-Aldrich Corporation
 P.O. Box 355
 Milwaukee, WI 53201-9358

Email: sams-usa@sial.com

International customers, please contact your local Sigma-Aldrich office. For worldwide contact information, please see back cover.

ChemFiles are also available in pdf format on the Internet at sigma-aldrich.com/chemfiles.

Aldrich brand products are sold through Sigma-Aldrich, Inc. Sigma-Aldrich, Inc. warrants that its products conform to the information contained in this and other Sigma-Aldrich publications. Purchaser must determine the suitability of the product for its particular use. See reverse side of invoice or packing slip for additional terms and conditions of sale.

All prices listed in this publication are subject to change without notice.

ChemFiles is a publication of Aldrich Chemical Co., Inc. Aldrich is a member of the Sigma-Aldrich group.
 © 2006 Sigma-Aldrich Co.

"Open-Flask" Rhenium-Oxo Catalysts

Rhenium(V) forms a large number of stable octahedral complexes with multiple bonds to oxygen with traditional Re systems focusing on formal, stoichiometric oxygen atom transfer to organic reductants such as phosphines, alkenes, and sulfides.¹ Re-catalyzed methodologies remained largely unexplored as a means of converting simple organic compounds to functionalized intermediates well suited for use in total synthesis. Recently, the Toste research group at Berkeley has used high oxidation-state Re complexes in a variety of organic transformations (**Scheme 1**).² Re-oxo complexes offer several powerful advantages in metal-mediated catalysis, including 1) the high oxidation-state of the metal offers inherent stability against moisture deactivating the catalyst, and 2) in most reaction paradigms, the mild conditions allow for the activation of substrates that contain sensitive functional groups. We are pleased to offer two Re-oxo complexes that have been shown to facilitate C–C, C–O, and C–N bond forming reactions under mild conditions, without exclusion of moisture.

[Re(O)Cl₃(SMe₂)(Ph₃PO)] (1)

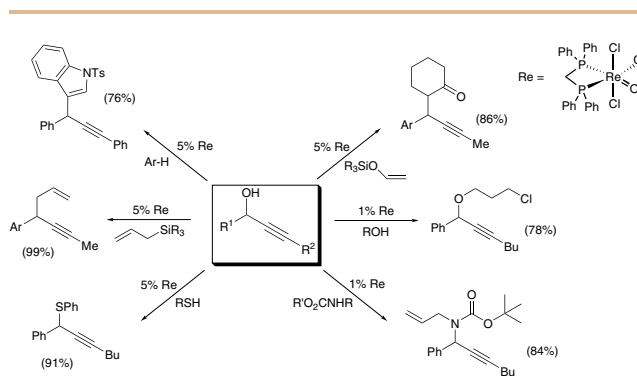
The first Re catalyst performs effortlessly in the metal-mediated addition reaction of nucleophiles to oleosaccharides (**Scheme 2**).³ The O-glycosylation reaction of nucleophiles to glycols proceeded well in a variety of solvents; however, non-polar solvents served as the optimal media. A diverse array of glycosyl donors and acceptors (i.e., olefins) were utilized and the Re(V)-oxo complex tolerated a multitude of protecting groups, including acetals, silyl ethers, acetates, and benzoates. The mild nature of the Re-catalyst system allows an iterative approach to the synthesis of trisaccharides via the successive coupling of two glycols followed by the reaction of the newly formed 2-deoxysaccharide with a thio-glycosyl acceptor. Interestingly, the catalytic addition of simple thiols, such as thiophenol to galactals, resulted in good yields of 2-thioglycosides with no observable catalyst poisoning. It should also be noted that this simple Re(V) complex acts as a convenient precursor to chiral Re-catalysts via ligand metathesis (**Scheme 3**).⁴

[(dppm)Re(O)Cl₃] (2)

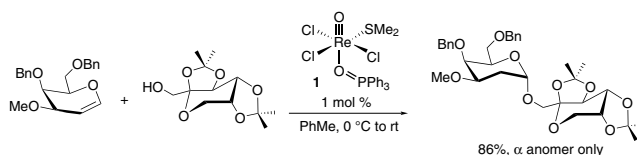
dppm = bis(diphenylphosphino)methane

The second Re complex **2**, based upon a strongly binding bidentate phosphine ligand, catalyzes the coupling of propargylic alcohols and allyl silanes to afford 1,5-enynes (**Scheme 4**).^{2b} Toste and co-workers have prepared a wide variety of 1,5-enynes by the metal-catalyzed formation of propargylic sp³–sp³ carbon–carbon bonds (**Table 1**). This methodology exhibits high yields of enynes at low catalyst loadings (1–5 mol %) and temperatures (rt to 65 °C). Addition of a catalytic (5 mol %) amount of ammonium hexafluorophosphate completely suppresses competing rearrangements to enone byproducts. The reaction proceeds without complications in the presence of electron-rich and electron-poor substrates and sterically demanding *ortho*-disubstituted-phenyl groups present no impediment to enyne formation.

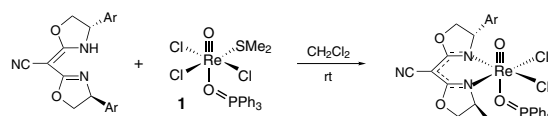
The broad utility of this rhenium catalyst extends through reactions that contain non-benzylic propargyl alcohols, however, silver hexafluoroantimonate must be used as the co-catalyst. It is worth noting that the Re(V) catalyst can be recovered and reused in many cases, without observable decreases in catalyst activity.



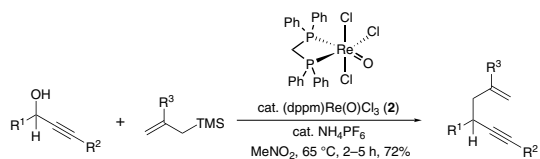
Scheme 1



Scheme 2



Scheme 3



Scheme 4

| Entry | R ¹ | R ² | R ³ | Temp (°C) | Mol% 2 | Yield (%) |
|-------|----------------|--------------------|----------------|-----------|--------|-----------|
| 1 | | Ph | H | 65 | 5 | 79 |
| 2 | | Ph | H | 80 | 1 | 75 |
| 3 | | TMS | H | 65 | 1 | 82 |
| 4 | | <i>n</i> -Bu | H | 65 | 5 | 90 |
| 5 | | Me | H | 65 | 4 | 95 |
| 6 | | Me | H | rt | 4 | 96 |
| 7 | | CO ₂ Et | H | 65 | 5 | 73 |
| 8 | | Me | H | 65 | 5 | 99 |
| 9 | | TMS | H | 65 | 5 | 89 |
| 10 | | Me | H | 65 | 5 | 89 |
| 11 | | Me | H | 65 | 5 | 90 |

Table 1

Ready to scale up? For competitive quotes on larger quantities or custom synthesis, contact SAFC™ at 1-800-244-1173 (USA), or visit www.safcglobal.com.

The Toste group also varied the nature of the allylsilane source to include enantioenriched materials (**Scheme 5**). The Re-catalyzed coupling of crotylsilane **3** consistently yielded the propargyl adduct as a 1.2:1 mixture of diastereomers without erosion of the initial enantiopurity. The propargyl coupling reaction exhibits higher diastereoselectivities if large groups (i.e., Me) are present in the *ortho* position of the allyl silane.

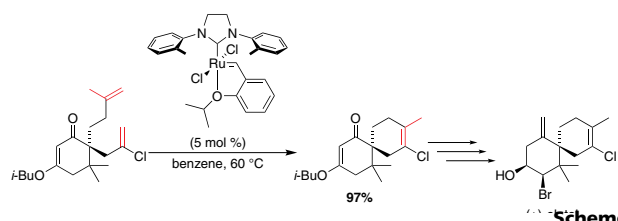
Additional reactivity of rhenium catalyst **2** has been explored in the propargylic etherification reaction of benzylic and non-benzylic propargyl alcohols (**Scheme 6**).^{2a} Primary, secondary, and tertiary alcohols all perform as nucleophiles in the etherification, but with diminished yields of the ether adduct in the case of *tert*-butyl alcohol. In highly polar solvents, the substitution reaction proceeded well with low catalyst loadings under ambient conditions at 65 °C. Most importantly, the etherification process is not accompanied by oxidation and rearrangement reactions, due to the mild nature of the Re catalyst.

Variation in the propargyl alcohol phenyl substitution is well tolerated and notably acid-labile groups, such as ketals, acetals, and *t*-butyl carbamates, were not cleaved under the reaction conditions. Furthermore, the propargylic etherification runs smoothly in the presence of aryl-bromine bonds and pendant alkenyl groups were tolerated.

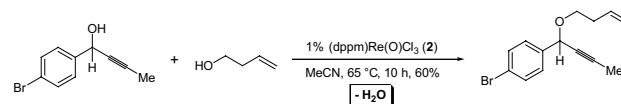
The mild Re(V) catalyst has been applied to reactions of numerous aromatic substrates with propargyl alcohols.^{2c} This methodology offers a practical, direct route for the fabrication of propargylic arenes via aryl and heteroaryl C–H bond activation. 5 mol % of potassium hexafluorophosphate is required to ensure high yields of the coupled product, presumably by abstracting a chloride ligand from the Re complex and accelerating alcohol binding. The propargylation of phenols, which usually results in competitive O-alkylation and benzopyran formation, progresses cleanly to yield complex organic molecules such as mimosifoliol.⁵ It is worth noting that the reaction is completely selective for formation of the propargyl adduct, even when the alkyne is substituted with 1,1-disubstituted olefins that are susceptible to electrophilic attack (**Scheme 7**).

Mild lab-bench conditions for the reactions of propargyl alcohols with sulfonamides and carbamates have also recently been reported by the Toste group.^{2d} The broad scope, ease of reaction handling, and facile construction of C–N bonds in a catalytic fashion make this methodology a valuable tool for synthetic chemists. This reaction is comprised of a broad spectrum of carbamates, alkynyl species, and phenyl/aryl reaction partners including synthetically versatile silyl and halide substituted organic building blocks. The successful development of this chemistry has fueled the expedient synthesis of pentabromopseudilin (**Scheme 8**), which is known as a potent lipoxygenase inhibitor.⁶

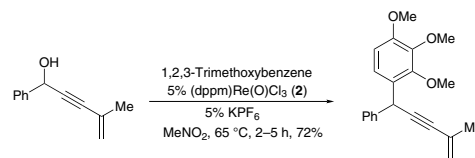
The Re(V) catalysts featured above represent powerful tools for the practical construction of C–C, C–O, and C–N bonds under mild conditions, as exemplified in the vast array of architectures accessed by this methodology.



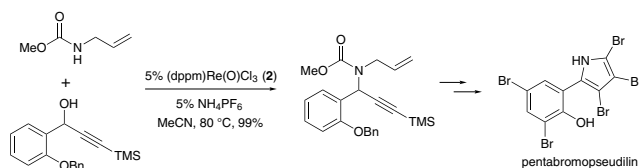
Scheme 5



Scheme 6



Scheme 7

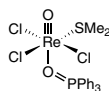


Scheme 8

Oxotrichloro(dimethylsulfoxide)(triphenylphosphineoxide)rhenium(V)

NEW

C₂₀H₂₁Cl₃O₂PreS
FW: 648.98

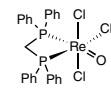


| | | |
|--------------|--------|--------|
| 665096-250MG | 250 mg | 35.00 |
| 665096-1G | 1 g | 120.00 |
| 665096-5G | 5 g | 490.00 |

Oxotrichloro(bis(diphenylphosphino)methane)rhenium(V)

NEW

C₂₅H₂₂Cl₃OP₂Re
FW: 692.95



| | | |
|--------------|--------|--------|
| 665134-250MG | 250 mg | 65.00 |
| 665134-1G | 1 g | 240.00 |

1,5-Diazadecalin Copper(II) Catalysts

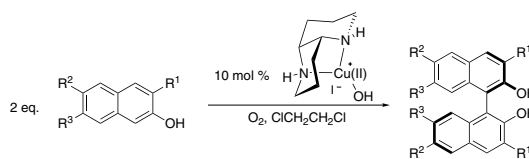
The Kozlowski group at the University of Pennsylvania has developed a practical method for the oxidative biaryl coupling of substituted naphthols, resulting in the expeditious construction of highly functionalized BINOL derivatives in an asymmetric fashion.⁷ BINOL compounds are precursors to a class of natural products generically called the perylenequinones,⁸ and are represented by the protein kinase C inhibitors cercosporin, phleichrome, and the calphostins.⁹

These architecturally complex compounds are promising therapeutic agents for photodynamic cancer treatment.¹⁰

Enantiopure BINOL compounds are also powerful and "privileged" ligands utilized primarily in homogeneous asymmetric catalysis (cf. commercialized BINOLs on following page). Kozlowski and co-workers have applied a 1,5-diaza-*cis*-decalin copper(II) catalyst in the presence of molecular oxygen, in the enantioselective couplings of a diverse array of substituted naphthols from simple achiral starting materials (Scheme 9, Table 2).^{7,11}

The advantages of this catalyst system include 1) the enantioselectivities range from 53 to 94% ee; however, many substrates undergo highly (>89%) selective couplings; 2) enantiomeric enrichment is facilitated by product crystallization; 3) the mild nature of this catalyst system ensures wide functional group fidelity carried forward, produces H₂O as the byproduct, and uses O₂ as the oxidant under bench-top conditions; and 4) reactions have been run on 50 mmol (~35 g) preparative scale to afford material of 93% enantiopurity. It should be noted that competing BINOL formation from achiral starting materials was reported by Nakajima and others,¹² but their system was not as selective as this Cu(II) methodology.

The reaction conditions have been optimized, wherein 10 mol % of catalyst, a high dielectric solvent (CH₃CN), moderate temperatures (usually 40 °C), and reasonable reaction times combine to accelerate biaryl asymmetric induction. High enantioselectivities were seen for phenyl ketone naphthols, whereas moderate enantioselectivities were observed for naphthol substrates containing phenylsulfonyl groups in the 3-position. Most importantly, from an application standpoint, chiral 3,3'-diester BINOL **4** can be prepared on multigram scale from inexpensive starting material. Precipitation afforded > 99% enantiomerically pure BINOL, without subjecting the crude material to column chromatography (Scheme 10). BINOL **4** provides ready access to the chiral carboxamides that, in turn, can be reduced by LiAlH₄ to yield BINOLAM ligands **5-7**. These amino BINOL derivatives facilitate asymmetric transformations such as Michael additions, C-alkylations of alanine Schiff bases, and cyanosilylation reactions.¹³

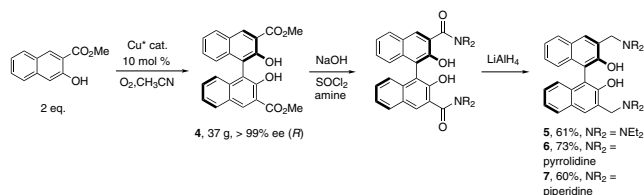


Scheme 9

| Entry ^a | Ligand enantiomer | R ¹ | R ² | R ³ | T (h) | Yield (%) | ee (%) |
|--------------------|-------------------|--|----------------|----------------|-------|-----------|-----------------|
| 1 | (<i>S,S</i>) | CO ₂ Me | H | H | 48 | 85 | 93 (<i>R</i>) |
| 2 | (<i>S,S</i>) | CO ₂ Bn | H | H | 24 | 79 | 90 (<i>R</i>) |
| 3 | (<i>S,S</i>) | CO ₂ Me | Br | H | 48 | 27 | 92 (<i>R</i>) |
| 4 | (<i>S,S</i>) | CON(CH ₂) ₅ | H | H | 48 | 48 | 70 (<i>R</i>) |
| 5 | (<i>S,S</i>) | COC ₆ H ₄ - <i>p</i> -OMe | H | H | 24 | 93 | 90 (<i>R</i>) |
| 6 | (<i>S,S</i>) | COC ₆ H ₄ - <i>p</i> -NMe ₂ | H | H | 24 | 84 | 94 (<i>R</i>) |

^aTrials were run with CuI as the metal source at 10 mol % loading at 40 °C.

Table 2

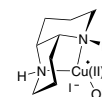


Scheme 10

[(*S,S*)-1,5-Diaza-*cis*-decalin]copper hydroxide iodide hydrate

NEW

C₈H₁₇CuIN₂O · xH₂O
FW: 347.68



591467-500MG

500 mg

117.00

Monthly Chemistry E-Newsletter

Got ChemNews?

sigma-aldrich.com/chemnews

Ready to scale up? For competitive quotes on larger quantities or custom synthesis, contact SAFC™ at 1-800-244-1173 (USA), or visit www.safcglobal.com.

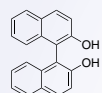
Order: 1.800.325.3010 Technical Service: 1.800.231.8327

ALDRICH

1,5-Diazadecalin
Copper(II) Catalysts

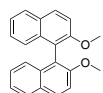
BINOLs

BINOLs are a privileged class of ligands within the field of asymmetric catalysis. These ligands have exhibited high levels of enantiocontrol in many synthetic transformations. Sigma-Aldrich is pleased to offer a comprehensive range of BINOL derivatives for your catalysis research efforts. Most products are available in both enantiomeric forms, with their respective product numbers shown.



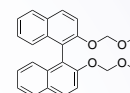
246948
246956

(R)
(S)



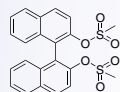
595403
595519

(R)
(S)



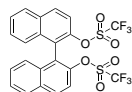
631582
631574

(R)
(S)



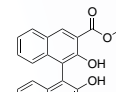
631795
631787

(R)
(S)



440590
431893

(R)
(S)



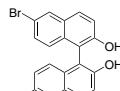
579343
579971

(R)
(S)



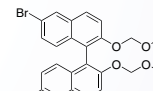
595721
595837

(R)
(S)



482617
482625

(R)
(S)



631604
631590

(R)
(S)



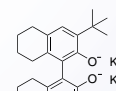
540560
540579

(R)
(S)



540587
540595

(R)
(S)



77939

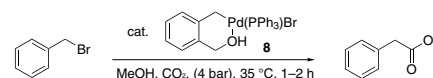
(R)

Additional information covering the chemistry of (R)- and (S)-BINOL can be found in a comprehensive review: Brunel, J. M. *Chem. Rev.* **2005**, *105*, 857.

Palladium Catalysts for Carbonylation

Metal-catalyzed carbonylation functions as one primary and efficient route for introducing carbonyl groups into an organic molecule. The versatility of carbonylation technology has been extended to the formation of a diverse array of organic carbonyl compounds via reactions of aziridines,¹⁴ epoxides,¹⁵ oxazolines,¹⁶ and primary alkyl- or arylmethyl halides.¹⁷ This last class of compounds, following their carbonylation to the corresponding esters, represents important chemical intermediates produced on an industrial scale. The traditional means of synthesizing arylacetic esters is tedious, initially proceeding through a stoichiometric reaction of arylmethyl halides with metal cyanides, followed by hydrolysis and esterification.¹⁸ Preston and co-workers have spearheaded the development of a mild, catalytic system that focuses on Pd as the active metal component.¹⁷ Pd-mediated carbonylation reactions were known prior to the methodology illustrated below; however the original catalysts suffer from the necessity of high pressures and temperatures.¹⁹

Pd catalyst **8** efficiently carbonylates benzyl halides in methanol at pressure ranging from 1 to 4 bar (**Scheme 11**). The carbonylation also proceeds favorably in an aqueous (biphasic) system, but arylmethyl chlorides were shown to be more robust substrates than the corresponding bromides. A side-by-side comparison of catalyst **8** versus PdCl₂(PPh₃)₂ (**9**) at 3.45 bar CO pressure is shown in **Table 3**.



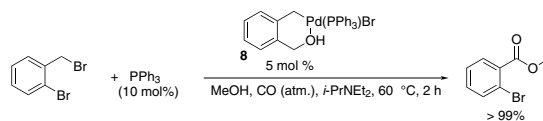
Scheme 11

| Substrate | Catalyst | Temp. (°C) | Products | | SM (%) |
|--|----------|------------|--|---------------------------|--------|
| | | | ArCH ₂ CO ₂ Me (%) | ArCH ₂ OMe (%) | |
| PhCH ₂ Cl | 8 | 48 | 99 | 0 | 0 |
| PhCH ₂ Br | 8 | 24 | 99 | 0 | 0 |
| PhCH ₂ Br | 9 | 48 | 74 | 11 | 15 |
| 4-MeC ₆ H ₄ CH ₂ Br | 8 | 48 | 93 | 7 | 0 |
| 4-MeC ₆ H ₄ CH ₂ Br | 9 | 24 | 59 | 36 | 5 |

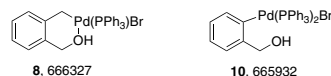
Table 3

TO ORDER: Contact your local Sigma-Aldrich office (see back cover), call 1-800-325-3010 (USA), or visit sigma-aldrich.com/chemicalsynthesis.

High product selectivity is furnished by organopalladium complex **8**, whereas the latter system produces a substantial amount of byproducts. Most importantly, the industrial usefulness of this carbonylation system is found in the experiments conducted at atmospheric CO pressure (**Scheme 12**). Simply bubbling CO through the methanolic solution containing the catalyst and benzyl halide formed a series of aryl halide esters in quantitative yields in 2 h. Reduced Pd species were not observed under these conditions. Sigma-Aldrich has commercialized the innovative Pd catalyst **8** and the related 2-benzyl alcohol complex **10** in collaboration with a Heriot-Watt University research team (**Scheme 13**).²⁰ These catalysts fuel the formal addition of carbon monoxide to benzyl halides affording benzyl esters under low pressure and temperature conditions.



Scheme 12

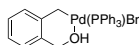


Scheme 13

Bromo[[2-(hydroxy-.k.O)methyl]phenyl]methyl-.k.C] (triphenylphosphine) palladium(II)

NEW

C₂₆H₂₄BrOPd
FW: 569.77
[84941-73-3]

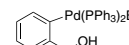


| | | |
|--------------|--------|-------|
| 666327-250MG | 250 mg | 30.00 |
| 666327-1G | 1 g | 95.00 |

2-(Bis(triphenylphosphine)palladium(II)bromide) benzyl alcohol

NEW

C₄₃H₃₇BrOP₂Pd
FW: 555.74



| | | |
|--------------|--------|-------|
| 665932-250MG | 250 mg | 30.00 |
| 665932-1G | 1 g | 95.00 |

MacMillan Imidazolidinone OrganoCatalysts™

Metal-Free Asymmetric Catalysis

Product Highlights

- Superior enantiocontrol in numerous transformations
- High activities at low catalyst loadings
- Extraordinary functional group tolerance
- Asymmetric α -fluorination employed in natural product synthesis

MacMillan and co-workers have created chiral imidazolidinone organo-catalysts that function as the linchpin in a variety of directed enantioselective organic reactions, including the enamine-catalyzed α -chlorination and 1,3-dipolar cycloaddition of aldehydes. Sigma-Aldrich is pleased to offer six imidazolidinone organocatalysts in our collaboration with Materia, Inc. that mediate rapid and enantiocontrolled C-F and C-H bond formation. In the former process, catalyst **1** was utilized in low (5 mol %) loadings in the first example of organocatalytic advanced enantioselective α -fluorination of aldehydes to afford a broad spectrum of highly enantioenriched alcohols.



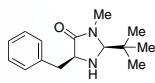
References: (a) MacMillan, D. W. et al. *J. Am. Chem. Soc.* **2000**, 122, 9874. (b) MacMillan, D. W. et al. *J. Am. Chem. Soc.* **2005**, 127, 8826.

(2S,5S)-(-)-2-tert-Butyl-3-methyl-5-benzyl-4-imidazolidinone, 97%

NEW

(2S,5S)-2-tert-Butyl-3-methyl-5-phenylmethyl-4-imidazolidinone

C₁₅H₂₂N₂O
FW: 246.35
[346440-54-8]

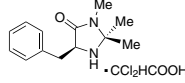


| | | |
|--------------|--------|-------|
| 663107-500MG | 500 mg | 60.00 |
| 663107-1G | 1 g | 95.00 |

(5S)-2,2,3-Trimethyl-5-benzyl-4-imidazolidinone dichloroacetic acid

NEW

C₁₅H₂₀Cl₂N₂O₃
FW: 347.24

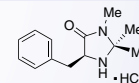


| | | |
|--------------|--------|--------|
| 663085-500MG | 500 mg | 55.00 |
| 663085-2G | 2 g | 150.00 |

(5S)-2,2,3-trimethyl-5-phenylmethyl-4-imidazolidinone monohydrochloride, 97%

NEW

C₁₃H₁₈N₂O · HCl
FW: 254.76
[278173-23-2]

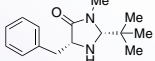


| | | |
|--------------|--------|-------|
| 569763-500MG | 500 mg | 30.00 |
| 569763-2G | 2 g | 80.00 |

(2R,5R)-(-)-2-tert-Butyl-3-methyl-5-benzyl-4-imidazolidinone, 97%

NEW

C₁₅H₂₂N₂O
FW: 246.35
[390766-89-9]

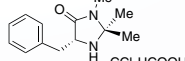


| | | |
|--------------|--------|-------|
| 663093-500MG | 500 mg | 60.00 |
| 663093-1G | 1 g | 95.00 |

(5R)-2,2,3-Trimethyl-5-benzyl-4-imidazolidinone dichloroacetic acid

NEW

C₁₅H₂₀Cl₂N₂O₃
FW: 347.24

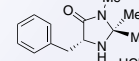


| | | |
|--------------|--------|--------|
| 663077-500MG | 500 mg | 55.00 |
| 663077-2G | 2 g | 150.00 |

(5R)-2,2,3-trimethyl-5-phenylmethyl-4-imidazolidinone monohydrochloride, 97%

NEW

C₁₃H₁₈N₂O · HCl
FW: 254.76
[323196-43-6]



| | | |
|--------------|--------|-------|
| 663069-500MG | 500 mg | 30.00 |
| 663069-2G | 2 g | 80.00 |

For more information, please visit us at sigma-aldrich.com/catalysis.

OrganoCatalysts is a trademark of Materia, Inc.

Ready to scale up? For competitive quotes on larger quantities or custom synthesis, contact SAFC™ at 1-800-244-1173 (USA), or visit www.safcglobal.com.

NHC-Based Pd Catalysts and Ligands for C–C Bond Formation

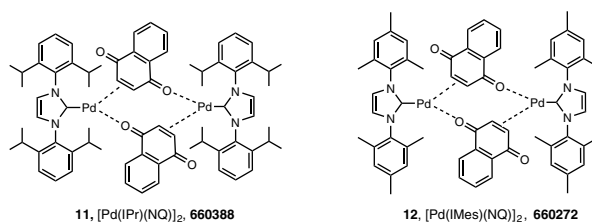
Sigma-Aldrich, in collaboration with Umicore,²¹ is pleased to offer a series of robust Pd(II) and Pd(0) complexes employed as efficient catalysts in C–C bond forming reactions. The high performance Pd catalysts reviewed below can rapidly couple alkyl and aryl chlorides with organoboron compounds on large scale (100 g–100 t/a).²² The high TONs, mild reaction conditions, and economic viability/availability of aryl chlorides, make this methodology attractive to industrial scale applications. Catalysts **11** and **12** (Scheme 14) should exhibit superior activity in C–C coupling reactions, because they are formally Pd(0) and are rare examples of well-characterized monocarbene palladium precursors to 12-electron complexes. Indeed, the Umicore NHC-Pd system performs Suzuki and Kumada couplings as well as α -arylation reactions at mild temperatures.

In the latter case, (NHC)Pd(allyl)Cl (**13**),²² a reactive, formally 16-electron complex, mediates the α -arylation of an array of aryl ketones (Scheme 15).²³ The air-stable catalyst, short reaction times, and high conversions prove the usefulness of this NHC technology over previous Pd systems. This system can be optimized by utilizing excess aryl halides which, in turn, increases the reaction rates and ensures high product yields in as little as 15 min. Reactivity of both alkyl–alkyl and alkyl–aryl ketones was studied in the early NHC-Pd article from Nolan and co-workers.

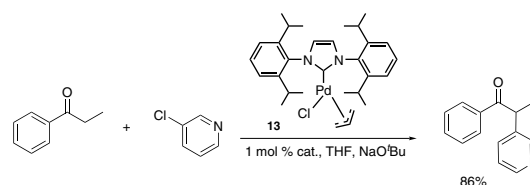
[Pd(IMes)(NQ)]₂ catalyst **12** demonstrated high reactivity and selectivity in sp^3 – sp^2 Kumada couplings.²⁴ The generality of this methodology extends to both electron-rich and electron-poor aryl magnesium reagents. Furthermore, a broad spectrum of functionalized alkyl chlorides was employed to afford complex organic building blocks (Scheme 16). The high product yields at room temperature validates the robustness of this catalytic system versus well-known Pd-phosphine catalysts Pd(PPh₃)₄ and Pd₂(dba)₃ as a function of reaction conditions.

The related [Pd(IPr)(NQ)]₂ catalyst **11** exhibited impressive activity in the Suzuki–Miyaura coupling of aryl chlorides with phenyl boronic acid (Scheme 17). At 50 °C, the high-yielding (88%) reaction was complete in one hour at a catalyst loading of 0.5 mol %.²⁵ Interestingly, Pd(0) catalyst **11** produced lower yields of coupled biaryl product at room temperature, whereas analogous catalyst **12** gave 86% yields of 4-Me-biphenyl at both room temperature and 50 °C under identical loadings conditions. Presumably, catalyst **11** needs additional energy to climb over the activation barrier and enter the catalytic cycle as a naked Pd-NHC species. It should be noted that the reactivity of [Pd(IPr)(NQ)]₂ was also shown to be high in the coupling of sterically encumbered 2,6-diphenyl chloride and 1-naphthalene boronic acid (Scheme 18).

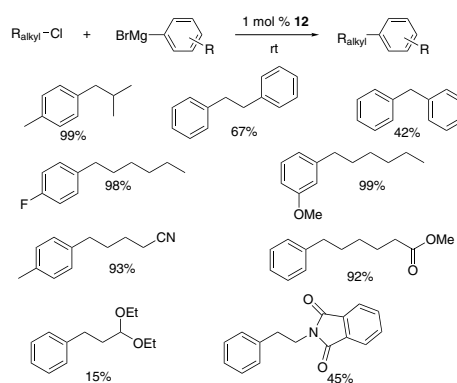
Beller and co-workers succeeded in establishing a reactivity profile for NHC-Pd naphtholquinone catalysts in Heck reactions (Table 4).²⁶ The outstanding capacity of this system is illustrated in Scheme 19, wherein good stillbene yields were obtained at 140 °C in an ionic liquid media. The low catalyst loading (0.5 mol %), cheap aryl chloride reagents, and a stabilized ionic liquid environment all contribute to the potential advancement of this chemistry to the industrial fine chemical arena.



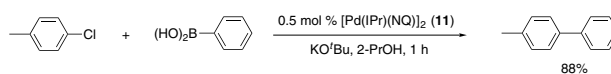
Scheme 14



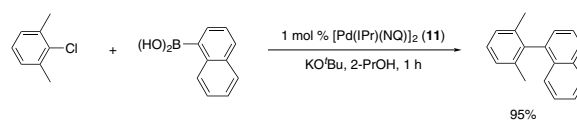
Scheme 15



Scheme 16



Scheme 17



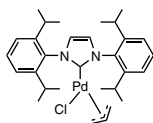
Scheme 18

NHC Ligands

It is well known that the activity of Pd catalysts can be modified by the introduction of sterically encumbered groups approximate to the metal center. Sigma-Aldrich now offers two NHC ligands that contain bulky, dissimilar moieties that will impart greater catalyst design flexibility. These asymmetric ligands expand our commercial line of NHC ligands, granting ready access to a range of highly active catalysts in various important organic transformations when combined with metal precursors. More information related to our NHC ligand technology, including relevant ordering details, can be found at sigma-aldrich.com/carbeneligands.

Allyl[1,3-bis(2,6-diisopropylphenyl)imidazol-2-ylidene]palladium(II) chloride NEW

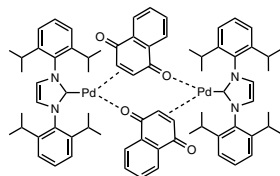
Allylchloro[1,3-bis(2,6-diisopropylphenyl)imidazol-2-ylidene]palladium(II)
 $C_{30}H_{42}ClN_2Pd$
 FW: 572.54
 [478980-03-9]



| | | |
|--------------|--------|--------|
| 660361-250MG | 250 mg | 55.00 |
| 660361-1G | 1 g | 150.00 |

1,3-Bis(2,6-diisopropylphenyl)imidazol-2-ylidene-(1,4-naphthoquinone)palladium(0) dimer NEW

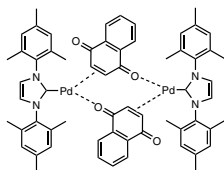
Naphthoquinone-1,3-bis(2,6-diisopropylphenyl)-imidazole-2-ylidene-palladium(0) dimer
 $C_{74}H_{84}N_4O_4Pd_2$
 FW: 1306.32
 [649736-75-4]



| | | |
|--------------|--------|--------|
| 660388-250MG | 250 mg | 50.00 |
| 660388-1G | 1 g | 150.00 |

1,3-Bis(2,4,6-trimethylphenyl)imidazol-2-ylidene-(1,4-naphthoquinone)palladium(0) dimer NEW

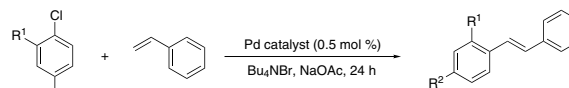
$C_{62}H_{60}N_4O_4Pd_2$
 FW: 1138.00
 [467220-49-1]



| | | |
|--------------|--------|--------|
| 660272-250MG | 250 mg | 50.00 |
| 660272-1G | 1 g | 150.00 |

| Entry | R1 | R2 | Pd Cat. | Temp. (°C) | Conversion (%) | Yield (%) |
|-------|----|-----------------|---------|------------|----------------|-----------|
| 1 | H | H | 2 | 140 | 69 | 62 |
| 2 | H | H | 2 | 140 | 71 | 62 |
| 3 | H | COMe | 2 | 140 | 100 | 96 |
| 4 | H | COMe | 3 | 140 | 100 | 97 |
| 5 | H | CF ₃ | 2 | 140 | 88 | 86 |
| 6 | H | Me | 3 | 160 | 65 | 62 |

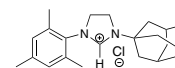
Table 4



Scheme 19

1-(1-Adamantyl)-3-(2,4,6-trimethylphenyl)imidazolium chloride NEW

$C_{22}H_{31}ClN_2$
 FW: 358.95

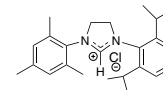


These products are sold in collaboration with Kanata Chemical Technologies, Inc. For questions please contact Aldrich or Kanata.

| | | |
|--------------|--------|--------|
| 665029-100MG | 100 mg | 40.00 |
| 665029-500MG | 500 mg | 142.00 |

1-(2,6-Diisopropylphenyl)-3-(2,4,6-trimethylphenyl)imidazolium chloride NEW

$C_{24}H_{33}ClN_2$
 FW: 384.98



These products are sold in collaboration with Kanata Chemical Technologies, Inc. For questions please contact Aldrich or Kanata.

| | | |
|--------------|--------|-------|
| 665045-100MG | 100 mg | 25.00 |
| 665045-500MG | 500 mg | 75.00 |



Ready to scale up? For competitive quotes on larger quantities or custom synthesis, contact SAFC™ at 1-800-244-1173 (USA), or visit www.safcglobal.com.

Hydrogenation Catalysts and Ligands

Ir and Ru Diamine diphosphine Complexes

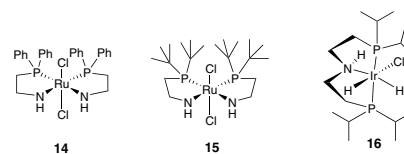
Sigma-Aldrich is proud to offer new catalysts for hydrogenation through our collaboration with Kanata Chemical Technologies.²⁷ The Ir and Ru complexes highlighted herein are especially active in the hydrogenation of sterically congested and electronically deactivated ketones and imines and also exhibit extraordinarily high chemoselectivity in conjugated systems (**Scheme 20**).²⁸ In particular, the Ru complexes have been found to catalyze the hydrogenation of several grams of various ketones in less than 12 h under 1 to 11 atm. of H₂ at ambient temperature. The presence of an amine functionality is crucial for the facile H-atom transfer under the operating hydrogen pressures; therefore, this process is best thought of as a ligand-assisted outer-sphere hydrogenation.

The ruthenium catalysts **14** and **15** are air-stable and exhibit high activities in the hydrogenation of ketones under mild conditions. Importantly, these Ru(II) catalysts are selective enough to discriminate between C=O and C=C bonds under hydrogenation conditions, with the latter functional group remaining unreduced and available for additional functionalization (**Scheme 21**). The iridium(III) catalysts are also air-stable and are extremely active for the transfer hydrogenation of ketones under mild reaction conditions (**Scheme 22**). Hydrogenation reactions with the Ru and Ir catalysts have been performed on multigram scale utilizing bench top handling procedures.

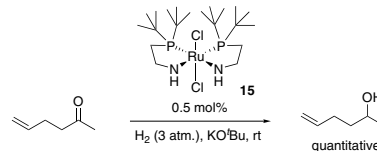
DuPhos and BPE Phospholane Ligands

Asymmetric hydrogenation reactions represent the ideal process for the commercial manufacture of single-enantiomer compounds, because of the ease by which these robust procedures can be scaled up and because of the low levels of byproducts generated in these asymmetric hydrogenations. The most effective hydrogenation systems rely on modifications of the electronic and steric properties of the ligands. Burk and co-workers succeeded in developing a highly-effective chiral phospholane class of ligands called DuPhos and BPE that contain 2,5-disubstituted groups allowing for systematic variation of the steric environment around the metal.²⁹ Sigma-Aldrich is pleased to now offer Me-DuPhos and Me-BPE phospholane ligands in collaboration with Kanata Chemical Technologies that can be ligated to cationic Rh complexes to afford highly active catalysts for asymmetric hydrogenation (**Scheme 23**).³⁰

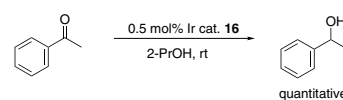
The large-scale capacity of these robust catalysts is observed in the efficiency (substrate-to-catalyst (S/C) ratios up to 50,000) and the high activities (TOF > 5,000 h⁻¹) in a myriad of enamide and ketone reductions. Under optimized conditions, (*R,R*)-Me-BPE-Rh reduced *N*-acetyl α -arylenamides in >95% ee to yield valuable α -1-arylethylamines (**Scheme 24**).³¹ It should be noted that Me-DuPhos-Rh complexes were equally effective in asymmetric reductions of prochiral enamides. The general utility of these phospholane ligands is illustrated in the profound production of a vast array of chiral compounds (**Scheme 25**). Sigma-Aldrich is your dedicated source for a broad spectrum of building blocks that provide essential starting materials in the synthesis of complex organic molecules. Our growing portfolio of catalysis products, supplemented by the DuPhos/BPE family, strongly complements the existing Sigma-Aldrich chemical line and will accelerate your research success.



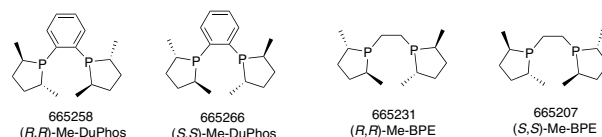
Scheme 20



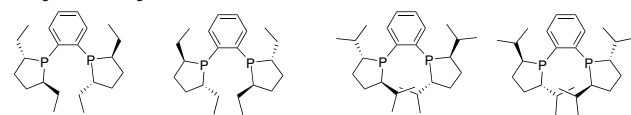
Scheme 21



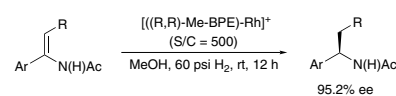
Scheme 22



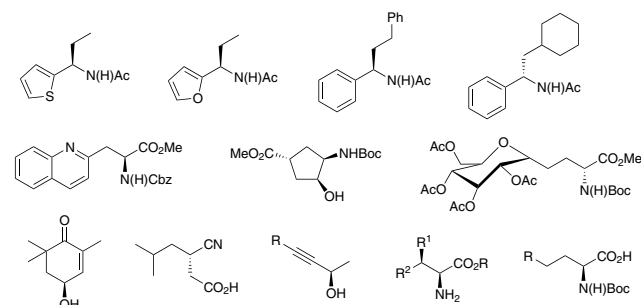
Coming soon from Sigma-Aldrich:



Scheme 23



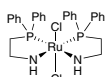
Scheme 24



Scheme 25

Dichlorobis(2-(diphenylphosphino)ethylamine)-ruthenium(II) NEW

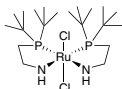
$C_{28}H_{30}Cl_2N_2P_2Ru$
FW: 630.49
[506417-41-0]



| | | |
|--------------|--------|--------|
| 664979-250MG | 250 mg | 70.00 |
| 664979-1G | 1 g | 225.00 |

Dichlorobis[2-(di-tert-butylphosphino)ethylamine]-ruthenium(II) NEW

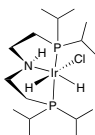
$C_{20}H_{46}Cl_2N_2P_2Ru$
FW: 550.53



| | | |
|--------------|--------|--------|
| 664987-250MG | 250 mg | 82.00 |
| 664987-1G | 1 g | 275.00 |

Chlorodihydrido[bis(2-diisopropylphosphino)ethylamine]iridium(III) NEW

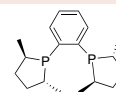
$C_{16}H_{39}ClIrNP_2$
FW: 535.10



| | | |
|--------------|--------|--------|
| 664995-250MG | 250 mg | 95.00 |
| 664995-1G | 1 g | 320.00 |

(-)-1,2-Bis((2R,5R)-2,5-dimethylphospholano)benzene NEW

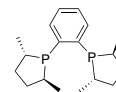
$C_{18}H_{28}P_2$
FW: 332.40
[147253-67-6]



| | | |
|--------------|--------|--------|
| 665258-100MG | 100 mg | 40.00 |
| 665258-500MG | 500 mg | 190.00 |
| 665258-2G | 2 g | 720.00 |

(+)-1,2-Bis((2S,5S)-2,5-dimethylphospholano)benzene NEW

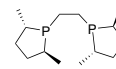
$C_{18}H_{28}P_2$
FW: 332.40
[136735-95-0]



| | | |
|--------------|--------|--------|
| 665266-100MG | 100 mg | 40.00 |
| 665266-500MG | 500 mg | 190.00 |
| 665266-2G | 2 g | 720.00 |

(+)-1,2-Bis((2R,5R)-2,5-dimethylphospholano)ethane NEW

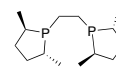
$C_{14}H_{28}P_2$
FW: 258.32
[129648-07-3]



| | | |
|--------------|--------|--------|
| 665231-100MG | 100 mg | 44.00 |
| 665231-500MG | 500 mg | 199.00 |
| 665231-2G | 2 g | 735.00 |

(-)-1,2-Bis((2S,5S)-2,5-dimethylphospholano)ethane NEW

$C_{14}H_{28}P_2$
FW: 258.32
[136779-26-5]



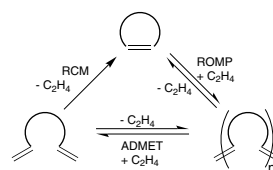
| | | |
|--------------|--------|--------|
| 665207-100MG | 100 mg | 44.00 |
| 665207-500MG | 500 mg | 199.00 |
| 665207-2G | 2 g | 735.00 |

2005 Nobel Prize Award Winning Metathesis Catalyst Technology!

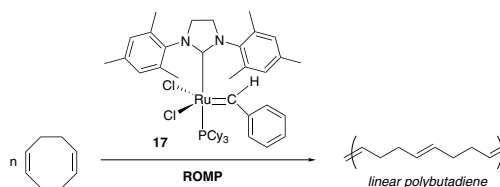
Sigma-Aldrich would like to congratulate Robert Grubbs, Richard Schrock, and Yves Chauvin on their research achievements leading to the 2005 Nobel Prize Award in chemistry! Metathesis catalyst technology has enriched the areas of drug discovery, flavors/fragrances, and polymers while leading scientists to discover new disconnections in synthetic organic chemistry. Through our partnership with Materia, Inc., we are proud to be the exclusive provider of Grubbs' metathesis catalysts for the research market.

Olefin metathesis is an efficient and powerful reaction for the formation of carbon-carbon bonds, via a net exchange of olefin substituents.³² The reaction between substrate and active catalyst proceeds through the reversible formation of a metallacyclobutane intermediate. A significant evolution in the development of olefin metathesis catalysts involves the utilization of ruthenium-based catalysts discovered in the Grubbs' research group at Caltech. Grubbs' first-generation catalyst, $Cl_2(PCy_3)_2Ru=CHPh$, pushed metathesis to the organic synthetic community due to its air and moisture stability and functional group tolerance.³³ The broad synthetic utility of ruthenium-based catalysts is derived from their capacity to orchestrate key metathetical transformations (**Scheme 26**), including Ring-Opening Metathesis Polymerization (ROMP), Ring-Closing Metathesis (RCM), and Acyclic Diene Metathesis Polymerization (ADMET). These transformations enable the production of novel compounds, often of pharmacological importance, and high-performance materials science products.

Recently, Grubbs and co-workers examined the ROMP of 1,5-cyclooctadiene (COD) to afford linear polybutadiene that contains an exclusive 1,4-regioisomeric backbone (**Scheme 27**).³⁴



Scheme 26



Scheme 27

Ready to scale up? For competitive quotes on larger quantities or custom synthesis, contact SAFC™ at 1-800-244-1173 (USA), or visit www.safcglobal.com.

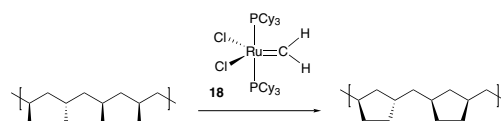
The ROMP reaction readily advances by adding the second generation catalyst **17** into a methylene chloride solution consisting of the monomer at 40 °C. The related 1,5,9-*trans-cis-trans*-cyclododecatriene (CDT) monomer, which is commercially available, also provides 1,4-polybutadiene via ROMP.

Grubbs' utilized Ru alkylidene catalyst (**18**) in a seminal article covering the selective and quantitative Ring Closing Metathesis (RCM) of neighboring vinyl substituents in 1,2-polydienes to generate polycycloolefins (**Scheme 28**).³⁵ Specifically atactic 1,2-polybutadiene undergoes greater than 97% cyclization of the α,ω -dienes. The authors then hydrogenated the polycycloolefin unsaturated backbone to yield atactic poly(methylene-1,3-cyclopentane), whose structure was confirmed by NMR analysis of the known material. It should be noted that this methylene-based ruthenium catalyst would be expected to represent the active species in metathesis processes involving first generation catalyst, $(\text{PCy}_3)_2\text{Cl}_2\text{Ru}=\text{CHPh}$, via transmutation with another terminal olefin.

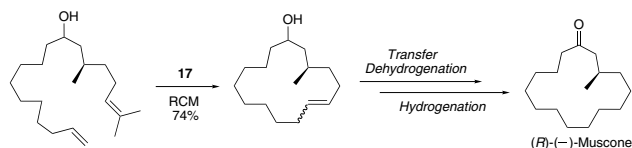
Metathesis catalyst $(\text{IMes})(\text{PCy}_3)\text{Cl}_2\text{Ru}=\text{CHPh}$ (**17**) has been shown to facilitate "one-pot" tandem catalytic metathesis-hydrogenation processes.³⁶ After the RCM reaction is complete by NMR, the reaction container can be pressurized with hydrogen and then heated to 70 °C. The Grubbs research team performed this "one-pot" tandem protocol to obtain (*R*)-(-)-Muscone in an expeditious fashion and in good (56% overall) yield (**Scheme 29**). This methodology has also been extended to include the cross metathesis of vinylketones with aryl olefins, followed by subsequent regiospecific hydrogenation.

RCM has been successively applied to the ring-expansion of bis-vinyl ketones with cycloolefins.³⁷ This novel reaction process utilizes the Grubbs' second generation catalyst **17** and creates a functional-group compatible route for the synthesis of macrocycles of various ring sizes (**Scheme 30**). Interestingly, the same metathesis catalyst reacts with α,β -unsaturated carbonyl compounds under certain conditions to generate active enoic carbene catalysts.³⁸ Grubbs and co-workers have reported the production of enoic carbenes in this manner and their efficient catalytic cross-metathesis reactions (**Scheme 31**). Furthermore, ring-opening of cyclohexene was achieved and applied in the cross metathesis of a vast array of unsaturated ketones. This in situ generated enoic carbene complex, stabilized by electron-deficient groups, effectively catalyzes the cross-coupling of gem-disubstituted olefins and the ROMP of cyclohexene, the latter of which was previously unattainable by standard ROMP conditions.

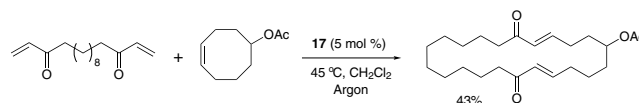
Ruthenium-based olefin metathesis technology has found a privileged status as the driving force behind the manufacture of countless pharmaceutical intermediates and natural products. Perhaps most strikingly, Ring-Closing Metathesis enables the expeditious creation of complex ring architectures from simple acyclic precursors using Grubbs' catalysts. Amos Smith, III and co-workers successfully completed the total synthesis of (-)-Kendomycin,³⁹ a novel polyketide that boasts potent endothelin antagonist activity,⁴⁰ via a decisive RCM reaction to form the macrocycle (**Scheme 32**). Alcohol **19** was exposed to the second generation Grubbs' catalyst **17** to yield macrocycle (+)-**20** as a single isomer,⁴¹ with the configuration of the C(13,14) olefin confirmed unambiguously by X-ray analysis to be *Z*. This article details the first example of a 16-membered ring closure by RCM, in which the substrate bears a sterically encumbered olefin.



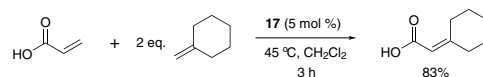
Scheme 28



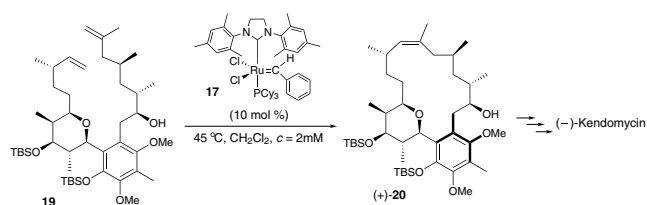
Scheme 29



Scheme 30



Scheme 31



Scheme 32

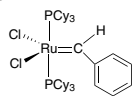
Grubbs Catalyst, 1st Generation

Benzylidene-bis(tricyclohexylphosphine)dichlororuthenium

C₄₃H₇₂Cl₂P₂Ru

FW: 822.96

[172222-30-9]



| | | |
|-----------|-----|--------|
| 579726-1G | 1 g | 77.40 |
| 579726-5G | 5 g | 267.50 |

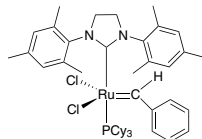
Grubbs Catalyst, 2nd Generation

(1,3-Bis-(2,4,6-trimethylphenyl)-2-imidazolindinylidene)dichloro-(phenylmethylene)(tricyclohexylphosphine)ruthenium

C₄₆H₆₅Cl₂N₂PRu

FW: 848.97

[246047-72-3]



| | | |
|--------------|--------|--------|
| 569747-100MG | 100 mg | 43.30 |
| 569747-500MG | 500 mg | 140.50 |
| 569747-2G | 2 g | 389.50 |

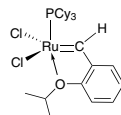
Hoveyda-Grubbs Catalyst 1st Generation

Dichloro(o-isopropoxyphenylmethylene)(tricyclohexylphosphine)ruthenium(II)

C₂₈H₄₅Cl₂OPRu

FW: 600.61

[203714-71-0]



| | | |
|--------------|--------|--------|
| 577944-100MG | 100 mg | 42.00 |
| 577944-500MG | 500 mg | 164.50 |
| 577944-2G | 2 g | 526.00 |

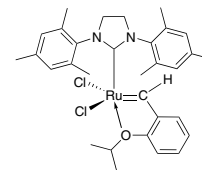
Hoveyda-Grubbs Catalyst 2nd Generation

(1,3-Bis-(2,4,6-trimethylphenyl)-2-imidazolindinylidene)dichloro-(o-isopropoxyphenylmethylene)ruthenium

C₃₁H₃₈Cl₂N₂ORu

FW: 626.62

[301224-40-8]

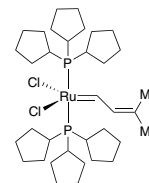


| | | |
|--------------|--------|--------|
| 569755-100MG | 100 mg | 44.90 |
| 569755-500MG | 500 mg | 174.50 |
| 569755-2G | 2 g | 560.00 |

Dichloro(3-methyl-2-butenylidene)bis(tricyclopentylphosphine)ruthenium(II)C₃₅H₆₂Cl₂P₂Ru

FW: 716.79

[220883-08-9]

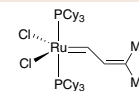


| | | |
|-----------|-----|--------|
| 578703-1G | 1 g | 73.80 |
| 578703-5G | 5 g | 255.50 |

Dichloro(3-methyl-2-butenylidene)bis(tricyclohexylphosphine)ruthenium(II)C₄₁H₇₄Cl₂P₂Ru

FW: 800.95

[194659-03-5]



| | | |
|-----------|-----|--------|
| 578681-1G | 1 g | 73.80 |
| 578681-5G | 5 g | 255.50 |

References

- Rouschias, G. *Chem. Rev.* **1974**, *74*, 531-566.
- (a) Toste, F. D. et al. *J. Am. Chem. Soc.* **2003**, *125*, 6076. (b) Toste, F. D. et al. *J. Am. Chem. Soc.* **2003**, *125*, 15760. (c) Toste, F. D. et al. *Org. Lett.* **2004**, *6*, 1325. (d) Toste, F. D. et al. *Org. Lett.* **2005**, *7*, 2501.
- Toste, F. D. et al. *J. Am. Chem. Soc.* **2004**, *126*, 4510.
- Toste, F. D. et al. *J. Am. Chem. Soc.* **2005**, *127*, 12462 and references therein.
- (a) Wall, M. E. et al. *J. Nat. Prod.* **1996**, *59*, 190. (b) Pettus, T. R. R. *Synlett* **2003**, 2234.
- Holman, T. R. et al. *J. Med. Chem.* **2004**, *47*, 4060.
- Kozłowski, M. C. et al. *J. Org. Chem.* **2003**, *68*, 5500.
- Kozłowski, M. C. et al. *J. Am. Chem. Soc.* **2003**, *68*, 6856.
- (a) Kobayashi, E. et al. *Prog. Chem. Org. Nat. Prod.* **1987**, *52*, 1-71. (b) Tasler, S. et al. *Prog. Chem. Org. Nat. Prod.* **2001**, *82*, 1-249.
- Lown, J. W. *Can. J. Chem.* **1997**, *75*, 99.
- Kozłowski, M. C. et al. *Org. Lett.* **2001**, *3*, 1137.
- Reference 7 *vide supra*: footnote references 9c and 9d contained therein.
- (a) Katsuki, T. et al. *Tetrahedron* **1997**, *53*, 17015. (b) Vega, M. et al. *Tetrahedron: Asymmetry* **2001**, *12*, 699. (c) Saa, J. M. et al. *Org. Lett.* **2002**, *4*, 2589.
- (a) Coates, G. W. et al. *Angew. Chem., Int. Ed. Engl.* **2001**, *41*, 2781. (b) Alper, H. et al. *J. Org. Chem.* **2001**, *166*, 5424 and references therein.
- Coates, W. G. et al. *J. Am. Chem. Soc.* **2005**, *127*, 11426 and references therein.
- Jia, L., Xu, H. *Org. Lett.* **2003**, *5*, 1575.
- (a) Preston, P. N. et al. *Tetrahedron Lett.* **2005**, *46*, 8695. (b) Preston, P. N. et al. *Organometallics*, **2005**, *24*, 1119.
- Beller, M. et al. *J. Mol. Catal. A* **1997**, *116*, 259.
- (a) Geissler, H. Clariant Corporation. US Patent 6653502, 2003; *Chem. Abstr.* **2003**, *136*, 385941. (b) Ziolkowski, J. et al. *J. Mol. Catal. A* **2000**, *154*, 93. (c) Gardano, A. *J. Organomet. Chem.* **1976**, *121*, C55.
- Manufactured by Aldrich under exclusive license from Heriot-Watt University, PCT/GB2005/002738 patent pending.
- These products are sold in collaboration with Umicore. For questions please contact Aldrich or UMICORE.
- Nolan, S. P. et al. *Organometallics* **2002**, *21*, 5470.
- Nolan, S. P. et al. *Org. Lett.* **2002**, 4053.
- Beller, M. et al. *Angew. Chem., Int. Ed. Engl.* **2005**, *44*, 674.
- Nolan, S. P. et al. *J. Organometallic Chem.* **2004**, 3722.
- Beller, M. et al. *Org. Lett.* **2002**, *4*, 3031.
- Ru and Ir catalysts featured above are sold in agreement with Kanata Chemical Technologies for the research market only.
- Abdur-Rashid, K. et al. *Adv. Synth. Catal.* **2005**, *347*, 571.
- Burk, M. J. *Acc. Chem. Res.* **2000**, *33*, 363.
- Sold in collaboration with Kanata Chemical Technologies Inc. for research purposes only. These phospholane compounds were made and sold under license from E.I. du Pont de Nemours and Company, which license does not include the right to use the Compounds in producing products for sale in the pharmaceutical field.
- Burk, M. J. et al. *J. Am. Chem. Soc.* **1996**, *118*, 5142.
- (a) Grubbs, R. H. et al. *Acc. Chem. Res.* **1995**, *28*, 446. (b) Blechert, S. *Angew. Chem., Int. Ed. Engl.* **1997**, *109*, 2124. (c) Grubbs, R. H. et al. *Tetrahedron* **1998**, *54*, 4413. (d) Blechert, S. *Pure Appl. Chem.* **1999**, *71*, 1393. (e) Furstner, A. *Angew. Chem., Int. Ed. Engl.* **2000**, *39*, 3013.
- Zuercher, W. J. et al. *J. Org. Chem.* **1998**, *63*, 4291.
- Grubbs, R. H. et al. *J. Am. Chem. Soc.* **2003**, *125*, 8424.
- Grubbs, R. H. et al. *J. Am. Chem. Soc.* **1996**, *118*, 229.
- Grubbs, R. H. et al. *J. Am. Chem. Soc.* **2001**, *123*, 11312.
- Grubbs, R. H. et al. *J. Am. Chem. Soc.* **2002**, *124*, 3224.
- Grubbs, R. H. et al. *J. Am. Chem. Soc.* **2001**, *123*, 10417.
- Smith, A. B. III et al. *J. Am. Chem. Soc.* **2005**, *127*, 6948.
- Ishimaru, T. et al. Japan Patents 08231551 [A2960910] and 08231552, 1996; *Chem. Abstr.* **1997**, *126*, 6553; *Chem. Abstr.* **1996**, *125*, 326518.
- (a) Grubbs, R. H. et al. *Acc. Chem. Res.* **2001**, *34*, 18. (b) Grubbs, R. H. et al. *J. Org. Chem.* **2001**, *66*, 7155.

Ready to scale up? For competitive quotes on larger quantities or custom synthesis, contact SAFC™ at 1-800-244-1173 (USA), or visit www.safcglobal.com.

NEW SOLVIAS® CHIRAL PHOSPHINE LIGANDS

The Ultimate Toolkit for Asymmetric Catalysis

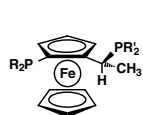


- 80 air-stable, non-hygroscopic ligands and catalysts
- Modular and tunable ligand design
- Industrially proven applications
- CD-ROM including CoA's and MSDS for each product

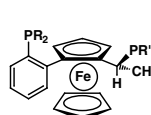
All in one convenient kit!

Sigma-Aldrich, in collaboration with Solvias, is proud to present the Chiral Ligands Kit—the ultimate toolkit for asymmetric catalysis!

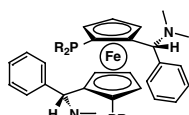
The Solvias Chiral Ligands Kit is designed to allow rapid screening of chiral catalysts and contains sets of the well-known Solvias ligand families below.



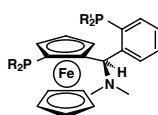
Josiphos



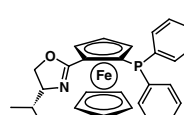
Walphos



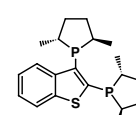
Mandypfos



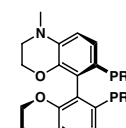
Taniaphos



Naud



Butiphane



Solphos

All products in the kit are 100-mg sample sizes and available in both enantiomeric forms giving you access to a total of 80 products.

Easy Reordering

All 80 ligands are available from Sigma-Aldrich individually in 100-mg, 500-mg, 1-g, and 5-g package sizes for easy reordering.

Solvias® Chiral Ligands Kit

12000-1KT

1 Kit

\$3,750.00

For detailed information about the ligand kit and individual components, please visit sigma-aldrich.com/solviasligands.

More Innovative Products from Sigma-Aldrich

Sigma-Aldrich is pleased to offer the following building blocks and reagents for chemical synthesis, expanding your world of research possibilities.

***N,N*-Bis-[(*R*)-1-phenylethyl]dibenzo[*d,f*][1,3,2]dioxaphosphepin-6-amine, 99%**

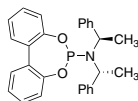
NEW

(*R,R*)-*N*-(5,7-Diox-6-phosphadibenzo[*a,c*]cyclohepten-6-yl)bis(1-phenylethyl)amine

C₂₈H₂₆NO₂P

FW: 439.49

[500103-26-4]



| | | |
|---------------|--------|--------|
| 04907-100MG-F | 100 mg | 109.30 |
| 04907-500MG-F | 500 mg | 432.80 |

***N,N*-Bis-[(*S*)-1-phenylethyl]dibenzo[*d,f*][1,3,2]dioxaphosphepin-6-amine**

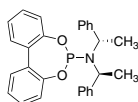
NEW

(*S,S*)-*N*-(5,7-Diox-6-phosphadibenzo[*a,c*]cyclohepten-6-yl)bis(1-phenylethyl)amine

C₂₈H₂₆NO₂P

FW: 439.49

[376355-58-7]



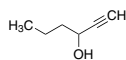
| | | |
|---------------|--------|--------|
| 07033-100MG-F | 100 mg | 109.30 |
| 07033-500MG-F | 500 mg | 432.80 |

1-Hexyn-3-ol, tech. 90%

C₆H₁₀O

FW: 98.14

[105-31-7]



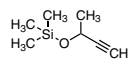
| | | |
|------------|------|--------|
| 537764-5G | 5 g | 33.00 |
| 537764-25G | 25 g | 109.50 |

3-(Trimethylsilyloxy)-1-butyne, 97%

C₇H₁₄OSi

FW: 142.27

[17869-76-0]

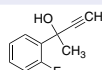


| | | |
|------------|------|-------|
| 632031-5G | 5 g | 25.10 |
| 632031-25G | 25 g | 88.40 |

2-(2-Fluorophenyl)-3-butyne-2-ol, 96%

C₁₀H₉FO

FW: 164.18

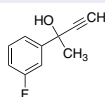


| | | |
|-----------|-----|-------|
| 648949-1G | 1 g | 67.60 |
|-----------|-----|-------|

2-(3-Fluorophenyl)-3-butyne-2-ol, 90%

C₁₀H₉FO

FW: 164.18

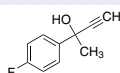


| | | |
|-----------|-----|-------|
| 648930-1G | 1 g | 67.60 |
|-----------|-----|-------|

2-(4-Fluorophenyl)-3-butyne-2-ol, 90%

C₁₀H₉FO

FW: 164.18



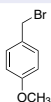
| | | |
|-----------|-----|-------|
| 648922-1G | 1 g | 67.60 |
|-----------|-----|-------|

4-Methoxybenzyl bromide

C₈H₉BrO

FW: 201.06

[2746-25-0]



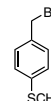
| | | |
|-----------|-----|-------|
| 561282-5G | 5 g | 25.00 |
|-----------|-----|-------|

4-(Methylthio)benzyl bromide

C₈H₉BrS

FW: 217.13

[38185-19-2]



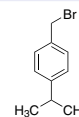
| | | |
|-----------|-----|-------|
| 634816-1G | 1 g | 15.80 |
| 634816-5G | 5 g | 53.50 |

4-Isopropyl benzyl bromide

C₁₀H₁₃Br

FW: 213.11

[73789-86-3]



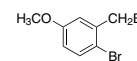
| | | |
|-----------|-----|-------|
| 563285-1G | 1 g | 6.70 |
| 563285-5G | 5 g | 22.00 |

2-Bromo-5-methoxybenzyl bromide

C₈H₈Br₂O

FW: 279.96

[19614-12-1]



| | | |
|------------|------|--------|
| 553387-25G | 25 g | 101.00 |
|------------|------|--------|

2-Iodobenzyl bromide

C₇H₆BrI

FW: 296.93

[40400-13-3]



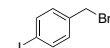
| | | |
|-----------|-----|-------|
| 634603-1G | 1 g | 19.10 |
| 634603-5G | 5 g | 61.70 |

4-Iodobenzyl bromide

C₇H₆BrI

FW: 296.93

[16004-15-2]



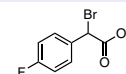
| | | |
|-----------|-----|-------|
| 515604-1G | 1 g | 17.50 |
| 515604-5G | 5 g | 57.20 |

α-Bromo-4-fluorophenylacetic acid

C₈H₆BrFO₂

FW: 233.03

[29270-33-5]



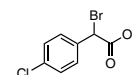
| | | |
|------------|------|--------|
| 638668-5G | 5 g | 92.80 |
| 638668-25G | 25 g | 340.50 |

α-Bromo-4-chlorophenylacetic acid

C₈H₆BrClO₂

FW: 249.49

[3381-73-5]



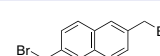
| | | |
|------------|------|--------|
| 638676-5G | 5 g | 97.80 |
| 638676-25G | 25 g | 340.50 |

2,6-Bis(bromomethyl)naphthalene

C₁₂H₁₀Br₂

FW: 314.02

[4542-77-2]



| | | |
|-----------|-----|--------|
| 649546-1G | 1 g | 103.00 |
| 649546-5G | 5 g | 343.00 |

Argentina

SIGMA-ALDRICH DE ARGENTINA, S.A.
Tel: 54 11 4556 1472
Fax: 54 11 4552 1698

Australia

SIGMA-ALDRICH PTY., LIMITED
Free Tel: 1800 800 097
Free Fax: 1800 800 096
Tel: 612 9841 0555
Fax: 612 9841 0500

Austria

SIGMA-ALDRICH HANDELS GmbH
Tel: 43 1 605 81 10
Fax: 43 1 605 81 20

Belgium

SIGMA-ALDRICH NV/SA.
Free Tel: 0800-14747
Free Fax: 0800-14745
Tel: 03 899 13 01
Fax: 03 899 13 11

Brazil

SIGMA-ALDRICH BRASIL LTDA.
Tel: 55 11 3732-3100
Fax: 55 11 3733-5151

Canada

SIGMA-ALDRICH CANADA LTD.
Free Tel: 800-565-1400
Free Fax: 800-265-3858
Tel: 905-829-9500
Fax: 905-829-9292

China

SIGMA-ALDRICH CHINA INC.
Tel: 86-21-6386 2766
Fax: 86-21-6386 3966

Czech Republic

SIGMA-ALDRICH S.R.O.
Tel: +420 246 003 200
Fax: +420 246 003 291

Denmark

SIGMA-ALDRICH DENMARK A/S
Tel: 43 56 59 10
Fax: 43 56 59 05

Finland

SIGMA-ALDRICH FINLAND
Tel: (09) 350 9250
Fax: (09) 350 9255

France

SIGMA-ALDRICH CHIMIE S.à.r.l.
Tel appel gratuit: 0800 211 408
Fax appel gratuit: 0800 031 052

Germany

SIGMA-ALDRICH CHEMIE GmbH
Free Tel: 0800-51 55 000
Free Fax: 0800-649 00 00

Greece

SIGMA-ALDRICH (O.M.) LTD
Tel: 30 210 9948010
Fax: 30 210 9943831

Hungary

SIGMA-ALDRICH Kft
Tel: 06-1-235-9054
Fax: 06-1-269-6470
Ingyenes zöld telefon: 06-80-355-355
Ingyenes zöld fax: 06-80-344-344

India

SIGMA-ALDRICH CHEMICALS
PRIVATE LIMITED
Telephone
Bangalore: 91-80-4112-7272
New Delhi: 91-11-4165-4255
Mumbai: 91-22-2570-2364
Hyderabad: 91-40-5584-5488
Fax
Bangalore: 91-80-4112-7473
New Delhi: 91-11-4165-4266
Mumbai: 91-22-2579-7589
Hyderabad: 91-40-5584-5466

Ireland

SIGMA-ALDRICH IRELAND LTD.
Free Tel: 1800 200 888
Free Fax: 1800 600 222
Tel: 353 1 4041900
Fax: 353 1 4041910

Israel

SIGMA-ALDRICH ISRAEL LTD.
Free Tel: 1-800-70-2222
Tel: 08-948-4100
Fax: 08-948-4200

Italy

SIGMA-ALDRICH S.r.l.
Telefono: 02 33417310
Fax: 02 38010737
Numero Verde: 800-827018

Japan

SIGMA-ALDRICH JAPAN K.K.
Tokyo Tel: 03 5796 7300
Tokyo Fax: 03 5796 7315

Korea

SIGMA-ALDRICH KOREA
Tel: 031-329-9000
Fax: 031-329-9090

Malaysia

SIGMA-ALDRICH (M) SDN. BHD
Tel: 603-56353321
Fax: 603-56354116

Mexico

SIGMA-ALDRICH QUÍMICA, S.A. de C.V.
Free Tel: 01-800-007-5300
Free Fax: 01-800-712-9920

The Netherlands

SIGMA-ALDRICH CHEMIE BV
Tel Gratis: 0800-0229088
Fax Gratis: 0800-0229089
Tel: 078-6205411
Fax: 078-6205421

New Zealand

SIGMA-ALDRICH PTY., LIMITED
Free Tel: 0800 936 666
Free Fax: 0800 937 777
Tel: 61 2 9841 0500
Fax: 61 2 9841 0500

Norway

SIGMA-ALDRICH NORWAY AS
Tel: 23 17 60 60
Fax: 23 17 60 50

Poland

SIGMA-ALDRICH Sp. z o.o.
Tel: 061 829 01 00
Fax: 061 829 01 20

Portugal

SIGMA-ALDRICH QUÍMICA, S.A.
Free Tel: 800 202180
Free Fax: 800 202178
Tel: 21 9242555
Fax: 21 9242610

Russia

SIGMA-ALDRICH RUS, LLC
Tel: +7 (095) 621-5828/6037
Fax: +7 (095) 975-4792

Singapore

SIGMA-ALDRICH PTE. LTD.
Tel: 65-67791200
Fax: 65-67791822

South Africa

SIGMA-ALDRICH
SOUTH AFRICA (PTY) LTD.
Free Tel: 0800 1100 75
Free Fax: 0800 1100 79
Tel: 27 11 979 1188
Fax: 27 11 979 1119

Spain

SIGMA-ALDRICH QUÍMICA S.A.
Free Tel: 900 101376
Free Fax: 900 102028
Tel: 91 661 99 77
Fax: 91 661 96 42

Sweden

SIGMA-ALDRICH SWEDEN AB
Tel: 020-350510
Fax: 020-352522
Outside Sweden Tel: +46 8 7424200
Outside Sweden Fax: +46 8 7424243

Switzerland

SIGMA-ALDRICH CHEMIE GmbH
Swiss Free Call: 0800 80 00 80
Tel: +41 81 755 2828
Fax: +41 81 755 2815

United Kingdom

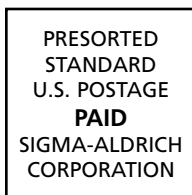
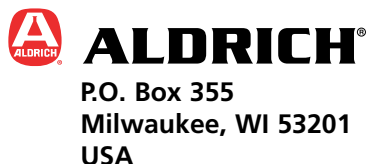
SIGMA-ALDRICH COMPANY LTD.
Free Tel: 0800 717181
Free Fax: 0800 378785
Tel: 01747 833000
Fax: 01747 833313
SAFC (UK): 01202 712305

United States

SIGMA-ALDRICH
P.O. Box 14508
St. Louis, Missouri 63178
Toll-free: 800-325-3010
Call Collect: 314-771-5750
Toll-Free Fax: 800-325-5052
Tel: 314-771-5765
Fax: 314-771-5757

Internet

sigma-aldrich.com

**Return Service Requested**

Order/Customer Service 1-800-325-3010 • Fax 1-800-325-5052
Technical Service 1-800-325-5832 • sigma-aldrich.com/techservice

Development/Bulk Manufacturing Inquiries SAFC 1-800-244-1173

World Headquarters • 3050 Spruce St., St. Louis, MO 63103 • (314) 771-5765

Accelerating Customers' Success through Leadership in Life Science, High Technology and Service

The SIGMA-ALDRICH Group SIGMA ALDRICH Fluka Riedel-de Haën SAFC SUPELCO ISOTEK

©2006 Sigma-Aldrich Co. All rights reserved.
SIGMA, SAFC, SAFC, SIGMA-ALDRICH, ISOTEK, ALDRICH, FLUKA, and SUPELCO are trademarks belonging to Sigma-Aldrich Co. and its affiliate Sigma-Aldrich Biotechnology LP. Riedel-de Haën*: trademark under license from Riedel-de Haën GmbH. Sigma products are sold through Sigma-Aldrich, Inc. Sigma-Aldrich, Inc. warrants that its products conform to the information contained in this and other Sigma-Aldrich publications. Purchaser must determine the suitability of the product(s) for their particular use. Additional terms and conditions may apply. Please see reverse side of the invoice or packing slip. Prices subject to change.



IOF
00342-502800
0016

