Boronic Acids

Properties and Applications

ALSO INCLUDES:
Boronic Esters
Oxazaborolidine Reagents
Coupling and Hydroboration Catalysts
Phosphine Ligands
Borylation Reagents

Alfa Aesar®
A Johnson Matthey Company

www.alfa.com

Also Available from Alfa Aesar

2008-09 RESEARCH CHEMICALS, METALS AND MATERIALS CATALOG

The 2008-09 Research Chemicals, Metals and Materials catalog offers more than 30,000 products. The complete range of organics, inorganics, metals and materials includes over 3,000 new products. Order it today! Contact your local sales office or send an email to info@alfa.com. The CD-ROM version of the Catalog features a structure/substructure search and MSDS database.

FINE CHEMICALS & CATALYSTS BROCHURE

The 14-page brochure outlines Alfa Aesar's key capabilities as a supplier of fine chemicals, including organics, high purity inorganics and precious metal catalysts. It focuses on manufacturing, custom synthesis, inventory, customer service and quality control, and new product development.

HIGH PURITY INORGANICS CATALOG

This catalog lists over 1,300 high purity inorganic materials, including base metal compounds, rare earth compounds and ultra dry materials for air and moisture sensitive applications.

PRECIOUS METAL COMPOUNDS AND CATALYSTS CATALOG

This 80-page publication lists a full range of precious metal (platinum, palladium, rhodium, iridium, ruthenium, gold, silver and osmium) chemicals and catalysts, including FibreCat™ anchored homogeneous catalysts and HiSPEC™ fuel cell catalysts.

PLATINUM LABWARE CATALOG

The Platinum Labware Catalog includes a large selection of crucibles, molds, dishes, micro chemical apparatus and utensils. In addition, you will find information about physical properties, care and use and analytical techniques.

SPECTROFLUX® ANALYTICAL FLUXES BROCHURE

Our 10-page color Spectroflux Information Package illustrates the wide range of alkali metal borate fusion fluxes available for use in AA/ICP analytical techniques.

HIGH PURITY METALS & MATERIALS CATALOG

The High Purity Metals and Materials Catalog highlights Alfa Aesar's entire range of metals and alloys from aluminum to zirconium, featuring purities up to 99.9999%. Products are offered in a broad variety of forms, including wires, foils, shots, targets, powders, thermocouple wires, and many more. Ceramics, platinum labware, carbon/graphite, equipment, fuel cell components and other products are also included.

The catalog also contains reference data, such as metals physical properties, mesh size conversion tables, periodic table, table of atomic weights and more. Most items are also available in quantities and sizes beyond those listed in the catalog.

FUEL CELL CATALYSTS & COMPONENTS BROCHURE

This brochure describes Alfa Aesar's offering of high quality Johnson Matthey fuel cell products, including HiSPEC™ brand precious metal fuel cell catalysts, HiFUEL™ brand base metal fuel cell catalysts, plus a range of electrodes and assemblies.

SPECIALTY SILVER COMPOUNDS BROCHURE

The four-page brochure describes Alfa Aesar's expertise in producing silver compounds up to 99.999% (metals basis) purity and in batches as large as 200kg. Seventy-five standard products are listed and Alfa Aesar can also manufacture to meet custom specifications.

Go to www.alfa.com for a full selection of catalogs, brochures, technical flyers and reviews available in downloadable PDF format.

Boronic Acids

Eric Cuthbertson, Alfa Aesar, a Johnson Matthey Company, Heysham, UK

A major role in modern chemistry is played by organoboron compounds, among which boronic acids have emerged in a leading position. With the discovery of a wealth of new chemistry, in particular the Suzuki-Miyaura cross-coupling reaction, together with their accessibility and ease of handling, boronic acids and boronates are now established as intermediates of great value and versatility. Applications abound in synthesis, catalysis, analytical chemistry and biological systems. Since the commercial introduction of a small range of boronic acids by the former Lancaster Synthesis Ltd., more than thirty years have elapsed during which the astonishing growth of interest in this area of chemistry has been paralleled by an enormous increase in the diversity of examples available from commercial sources, including Alfa Aesar. With a recently expanded range of well over 500 boronic acids, esters and organotrifluoroborates, we can provide outstanding synthetic and analytical expertise in these products. This publication outlines the chemical properties and highlights the main synthetic uses of these versatile molecules.

1. Introduction

Elemental boron is rather difficult to isolate in a pure state, in which it is usually obtained as an extremely hard, dark brown or black powder, mp 2075˚C. Its properties, such as electronegativity (Table 1), are those of a non-metal or metalloid, although organoboron compounds are often classed as organometallics, since they have certain similarities to compounds of some metallic elements.

Table 1: Electronegativities (Pauling) of representative elements[1]

H	2.20	Li	0.98
Be	1.57	Mg	1.31
B	2.04	Al	1.61
C	2.55	Si	1.90
N	3.04	P	2.19
O	3.44	S	2.58
F	3.98	Cl	3.16
Zn	1.65	Pd	2.20
Cu	1.90	Sn	1.96

Table 2 shows a representative selection of bond strengths involving boron, along with data for related elements for comparison.

Table 2: Typical covalent bond energies[1,2]

Bond	Bond energy	
	kJ mol^{-1}	kcal mol^{-1}
B-H	375	90
B-C	323	77
B-O	544	130
B-F	659	158
B-Cl	456	109
B-B	286	68
C-C	358	85
Li-C	126	30
Si-C	301	72
Sn-C	225	54

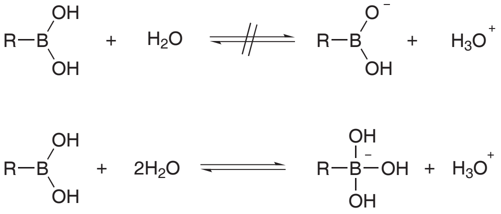
Since trivalent boron has a vacant *p*-orbital, organoboron compounds[3] are Lewis acidic in character. They also tend to be air-sensitive, and in some cases pyrophoric. In 1859, before Mendeleev's periodic classification of the elements, Frankland[4] reported the reaction of pyrophoric diethylzinc with triethyl borate to form a new pyrophoric product, triethylborane, readily oxidized by air to diethylborinic acid Et_2BOH. A second, slow oxidation step gave a more stable, crystalline product, identified as ethylboronic acid $EtB(OH)_2$. This sequence, the first known synthesis of a boronic acid, is inconvenient and of limited scope, but even so, half a century elapsed before the publication of Khotonsky and Melamed's preparation of benzeneboronic acid from phenylmagnesium bromide and trimethyl borate,[5] which was to become the basis of the most generally useful route to boronic acids. The procedure was improved in the 1930s by Johnson,[6] and in the 1950s by Washburn.[7] Further details can be found in Section 4.

Although organoboron chemistry became a focus of attention in the second half of the 20th century, largely due to the work of H. C. Brown, boronic acid chemistry continued to be a relative backwater over 100 years after Frankland's initial disclosure, but from the 1970s onwards, the level of interest has increased dramatically, as new applications have come to light. Whereas the chemistry of boronic acids could be covered by a 47-page review in 1964,[8] a recent comprehensive monograph on the subject runs to well over 500 pages.[9]

Most boronic acids are crystalline solids, easily handled in the presence of air and moisture. They are usually stable to long-term storage, but may undergo dehydration (see below) or, in some cases, are prone to air oxidation or gradual degradation. Where these may present a problem, either the corresponding boronate ester (Section 2) or trifluoroborate salt (Section 3) usually offers a satisfactory alternative which can undergo many of the reactions of the boronic acid itself. Such evidence as exists indicates that the boronic acid moiety is of relatively low intrinsic toxicity.[10] Recent applications in medicine support this view.[11] From an environmental perspective, boronic acids will degrade ultimately to the relatively benign boric acid, although the fate of the rest of the molecule will obviously depend on the nature of any substituents.

Chemical character

Since the electron-deficient boron atom has a vacant *p*-orbital, boronic acids behave as mild Lewis acids, which can coordinate to Lewis bases. Hence, in water they tend to coordinate an OH group to form the tetrahedral anionic species, rather than acting as Brønsted acids by losing a proton (Scheme 1).[12] The measured acidity of arylboronic acids is comparable to phenols (benzeneboronic acid: pK_a 8.9 in water); alkylboronic acids are weaker. Electron-withdrawing substituents on the aryl group increase acidity, and electron-releasing groups decrease it.[13]



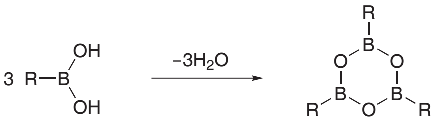
Scheme 1

In this review, the reactions of boronic acids are divided into two broad categories, according to whether they involve retention or cleavage of the boron-carbon bond, which are discussed in Sections 2 and 3 respectively. Section 4 outlines some of the preparative methods used for boronic acids and boronates.

2. Reactions in which the B–C bond is retained

Boroxine formation

Most boronic acids readily undergo dehydration (Scheme 2) to form the cyclic trimeric anhydride (boroxine; 1,3,5,2,4,6-trioxatriborinane). This often tends to occur spontaneously at room temperature, or in the course of drying, so that it may be difficult to obtain the acid free from the anhydride. Apart from difficulties in characterization (variable analyses and unreproducible melting points), this is rarely a serious problem, since in many applications, the acid and the anhydride are essentially indistinguishable.



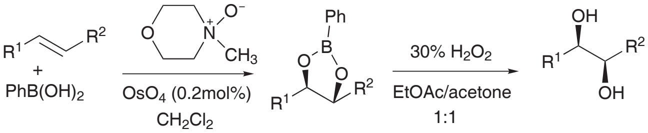
Scheme 2

However, if required, conversion of the boronic acid to a boronate ester with a suitable diol (see below) will prevent the dehydration reaction.

Boronate formation: protection of diols

Boronic acids react with alcohols, with loss of water, to form boronic esters (boronates). With simple alcohols, the products are very susceptible to hydrolysis, but with 1,2- and 1,3-diols, the resulting cyclic boronates (1,3,2-dioxaborolanes and 1,3,2-dioxaborinanes) are stable enough to be isolated.

The main early application was for protection and derivatization of 1,2- and 1,3-diols, particularly in carbohydrate chemistry.[14] These boronates have been widely used as volatile derivatives for GC and GC-MS purposes. They may be formed simply by stirring the boronic acid and diol together at ambient temperature, or by warming, or, if necessary, with azeotropic removal of water. A detailed examination of boronic acid-diol complexation has been published.[15] Usually cleavage occurs readily under hydrolytic conditions, by exchange with a glycol,[16] or by treatment with hydrogen peroxide.[17] Hindered boronic esters, such as those of pinacol (2,3-dimethyl-2,3-butanediol), may be relatively stable to hydrolysis, and can often be purified by chromatography. A useful application of boronate protection is in the osmium(VIII) oxide catalyzed *cis*-dihydroxylation of alkenes under anhydrous conditions in the presence of a boronic acid (Scheme 3).[17b,18]



Scheme 3

Further information on the applications of boronic acids as derivatizing and protecting agents can be found in various reviews[19-21] and monographs.[22-24]

Other applications of diol boronates

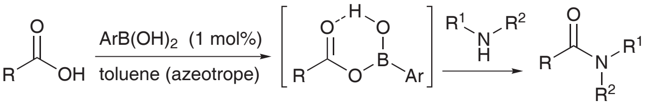
The formation of boronic esters with polymer-bound diols has been utilized as a linker system for solid phase synthesis, enabling modification of the polymer-bound boronic acid, followed by mild deprotection with methanol.[25]

Many other uses of boronates formed with carbohydrate molecules have been developed, including the selective transport of sugars in lipophilic environments,[26,27] and the design of artificial receptors, as discussed in several reviews.[28-32]

Boronic derivatives as activating and directing groups

The mild Lewis acidity of boronic acids, along with the ease of exchange around oxygen or nitrogen atoms attached to boron, has led to the application of the acids and their derivatives as catalysts or temporary scaffolds in a variety of regio-, stereo- and enantioselective syntheses.

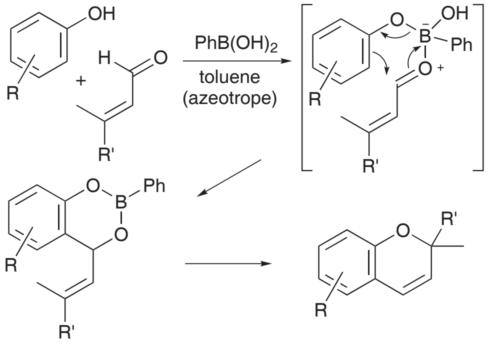
Arylboronic acids can behave as water-, acid-, and base-tolerant, thermally stable Lewis acids. Yamamoto has found that a boronic acid with electron withdrawing substituents, in particular 3,4,5-trifluorobenzeneboronic acid can be an effective catalyst for amidation and esterification of carboxylic acids.[33] The reaction is thought to involve a 6-membered cyclic intermediate (Scheme 4).



Scheme 4

The amidation reaction has been extended to ureas.[34] 3,4,5-Trifluorobenzeneboronic acid also catalyzes the one-pot synthesis of acyl azides from carboxylic acids and sodium azide,[35] and the one-pot reduction of carboxylic acids to alcohols with sodium borohydride.[36] In some reactions, 3-nitrobenzeneboronic acid may be an effective catalyst, as in the transesterification of β-keto esters.[37] The use of arylboron compounds as acid catalysts was reviewed by Ishihara and Yamamoto.[38]

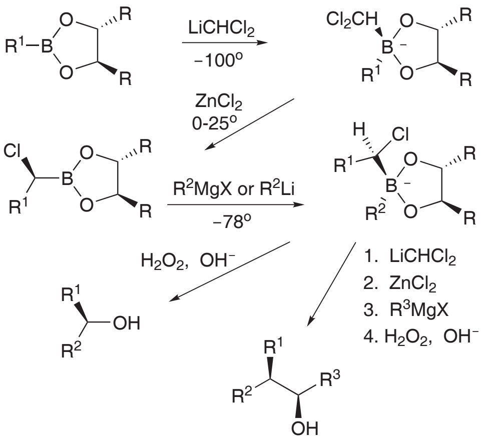
Benzeneboronic acid mediates the *ortho*-specific α-hydroxyalkylation of phenols by aldehydes.[39] The key intermediate is a cyclic boronate, formed via a [3,3] sigmatropic rearrangement. This process was utilized in the mild syntheses of benzo-fused heterocycles, including tetrahydrocannabinoids,[39b] and 2*H*-chromenes (Scheme 5).[40]



Scheme 5

Chiral boronates

Matteson has carried out extensive work on cyclic boronates,[41,42] formed from chiral diols, which undergo carbon insertion with $LiCHCl_2$ in the presence of zinc chloride in up to 99% diastereomeric excess (de). Treatment of the resulting α-chloro boronic esters with various nucleophiles leads to α-substituted boronic esters which can be oxidatively cleaved with hydrogen peroxide, or the sequence can be repeated to introduce a second chiral carbon atom, as illustrated in Scheme 6.

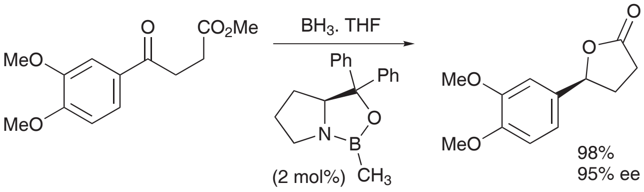


Scheme 6

Further aspects of this area of boronic ester chemistry have since been reviewed by Matteson.[43]

Oxazaborolidines

The reaction of a boronic acid with a chiral 2-amino alcohol gives an oxazaborolidine. These derivatives were introduced by Corey, Bakshi and Shibata[44] ("CBS" reagents) as excellent catalysts for enantioselective borane reduction of prochiral ketones (Scheme 7) with very high yield and enantiomeric excess (ee).

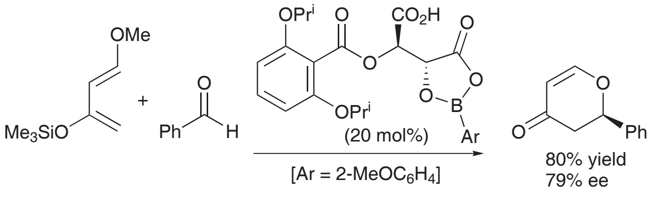


Scheme 7

The reagents derived from (R)- and (S)-α,α-diphenylprolinol, usually with methylboronic acid: (R)- and (S)-2-methyl-CBS-oxazaborolidine have received the most attention, although the use of other amino alcohols has been reported.[45,46] Reviews on the use of oxazaborolidines as enantioselective catalysts,[47,48,49] and the asymmetric reduction of ketones[50,51] are available.

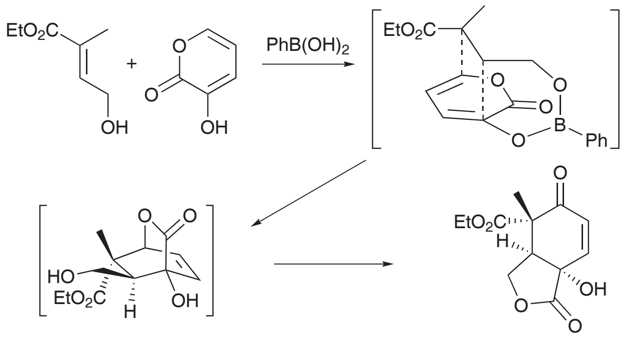
Diels-Alder reactions

Boronic acids can form stable chiral acyloxyborane (CAB) catalysts with tartaric acid derivatives. These compounds have been developed by Yamamoto as catalysts for asymmetric Diels-Alder[52] and hetero Diels-Alder[53] reactions, for example between aldehydes and Danishefsky's diene [1-methoxy-3-(trimethylsiloxy)-1,3-butadiene] to give, enantioselectively, dihydro-4-pyrone derivatives (Scheme 8).[54]



Scheme 8

Benzeneboronic acid itself can be used as a template for Diels-Alder reactions by forming boronate linkages with a hydroxy diene and a hydroxy dieneophile,[55] an approach which was applied successfully by Nicolaou to synthesize the fully functionalized CD ring system of Taxol (Scheme 9).[56]



Scheme 9

The use of boron acids as protective agents and catalysts in synthesis has been reviewed by Duggan and Tyndall.[21]

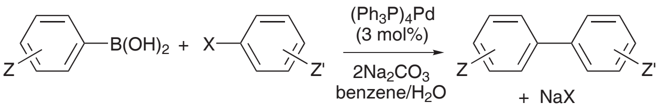
3. Reactions involving B–C bond cleavage

In the reactions described in the following sections, displacement of boron takes place with formation of a new carbon-carbon or carbon-heteroatom bond.

C–C bond-formation

The Suzuki-Miyaura cross-coupling reaction

In comparison with typical organometallic compounds of lithium, magnesium or the transition metals, the difference in electronegativity between boron and carbon is relatively small, and the boron-carbon bond strong (see Tables 1,2). Organoboron compounds, therefore, in the absence of a catalyst, normally exhibit very low reactivity towards electrophiles such as organic halides. In 1979, Suzuki and Miyaura reported the successful coupling of alkenylboranes and catecholyl boronates, in the presence of a Pd(0) catalyst and a base,[57] with alkenyl and alkynyl,[58] aryl[59] allyl and benzyl[60] halides. However, it was their discovery, published in 1981,[61] that stable, easily-handled arylboronic acids undergo palladium-catalyzed cross-coupling with aryl bromides and iodides in the presence of a base (Scheme 10), which stimulated the greatest interest in the this reaction. As a result, a plethora of applications and variants have subsequently been developed leading to the synthesis of unsymmetrical biaryls and many other types of coupled products.



Scheme 10

Early methods for biaryl synthesis generally involved high temperatures (Ullmann coupling), or were low-yielding and unselective (Gomberg-Bachmann). Direct couplings of highly-reactive, moisture- and air-sensitive organometallic reagents (Grignard, organolithium, organozinc, etc.) with aryl halides, generally in the presence of a transition metal catalyst, normally require strictly anhydrous conditions and an inert atmosphere, and are of limited scope, since the presence of many functional groups interferes. In contrast, Suzuki and Miyaura carried out the cross-coupling of boronic acids under aqueous conditions, and the reaction tolerates a wide variety of functional groups. The widely-used Stille cross-coupling reaction,[62] by comparison,[63] is also extremely versatile, and in some ways complementary to the boronic coupling, but involves toxic, environmentally hazardous organotin species.

Since its first disclosure, the cross-coupling reaction of boronic acids (usually known as the Suzuki or Suzuki-Miyaura reaction) has been developed in methodology and scope to become a cornerstone of modern synthetic organic chemistry, from high-throughput screening to full-scale production. Because of its versatility and the mild reaction conditions, it has been widely adopted for solid-phase synthesis on polymer supports.[64,65]

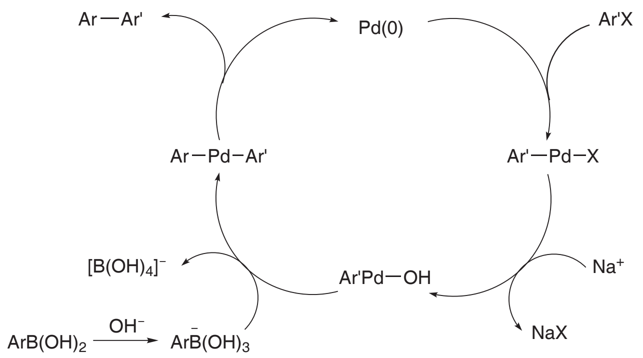
Under the standard coupling conditions, aryl bromides are the most frequently used electrophilic coupling partners, but iodides, if available, are often preferred since they are more reactive, as shown by the respective bond energies (Table 3).

Table 3: Bond dissociation energies of halobenzenes)

Bond	Bond energy	
	kJ mol^{-1}	kcal mol^{-1}
Ph-Cl	402	96
Ph-Br	339	81
Ph-I	272	65

The coupling of unactivated aryl chlorides, which tend to be more readily available and cheaper, but are significantly less reactive, than the corresponding bromides or iodides, has been achieved under modified conditions, using a wide variety of palladium catalysts,[66-77] including systems developed by Johnson Matthey chemists.[78] In some cases nickel-based catalysts have been successfully used.[79,80]

A proposed catalytic cycle for the reaction[81,82] is shown in Scheme 11. A detailed mechanistic study has also been published.[83]



Scheme 11

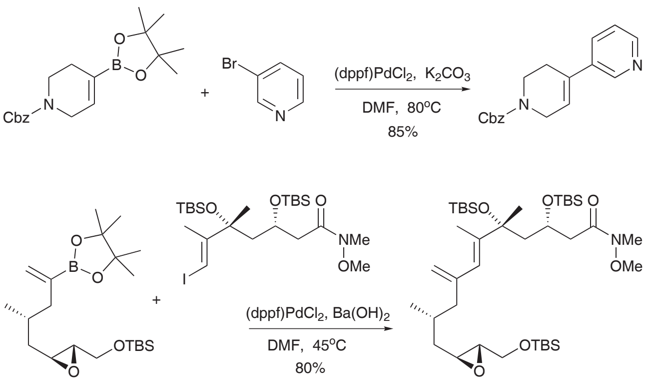
Suzuki and Miyaura's initial publication was followed by a series of papers by Gronowitz *et al*,[84] who showed that the deborylation found as a side reaction, particularly with electron-rich boronic acids, could be minimized by using dimethoxyethane (DME) as solvent in conjunction with aqueous Na_2CO_3. This system was found to be applicable to a variety of aryl and heteroaryl substrates, and has been widely adopted by other workers. Alternative illustrative experimental procedures are described in *Organic Syntheses*.[85] Many reviews of the Suzuki-Miyaura and related reactions have been published, including those by Suzuki and Miyaura,[86,87] by Martin and Yang,[82] with particular emphasis on heteroaryl systems, and by Stanforth[88] on biaryl synthesis via cross-coupling reactions. Nicolaou's review[89] features the use of palladium-catalyzed cross-couplings, including the Suzuki reaction, in selected total syntheses of natural products. More recent developments in the Suzuki cross-coupling have been reviewed by Kotha,[90] and by Rossi.[91] A review of palladium-catalyzed coupling reactions of aryl chlorides is also available,[92] as is a general review of aryl-aryl bond formation.[93]

Related coupling reactions

In early extensions of the biaryl coupling reaction, aryl- and heterorarylboronic acids were coupled with a variety of heterocyclic halides, including thiophenes,[94] furans, thiazoles,[95] oxazoles,[96] isoxazoles,[97] pyridines,[67,98-100] quinolines,[98] pyrimidines,[95,99,101] and pyrazines.[99,100] Many further examples have subsequently been published.

Aryl[102,103] or vinyl[104] triflates also undergo boronic acid coupling, which usefully extends the scope of the reaction to phenols or enols. The relative reactivity of leaving groups is normally in the order $I^- > OTf^- > Br^- >> Cl$ (compare Table 3 above). Cross-coupling of boronate derivatives with aryl mesylates,[105] and tosylates,[106] catalyzed by nickel complexes, has also been described, as has palladium-catalyzed coupling with sulfonium salts[107] or sulfonyl chlorides.[108] Coupling of arylboronic acids with heteroaryl thioethers has been brought about with a palladium catalyst, mediated by a Cu(I) carboxylate,[109] while nickel-catalyzed coupling with aryl quaternary ammonium salts has also been reported.[110] Other substrates (Pd-catalyzed) for arylboronic acid cross-coupling include: benzyl bromides,[111] α-bromo esters,[112] vinyl halides,[113-115] allylic bromides[116] or acetates,[117] allenic alcohols,[118] propargylic alcohols,[119] and allylic alcohols (Pd-catalyzed[120] or Rh-catalyzed[121]).

As already stated, Suzuki and Miyaura's earliest papers on the cross-coupling reaction related to alkenylboranes and boronic esters of catechol,[58,59] and, although the use of free boronic acids now predominates, aryl and enol boronates, especially with pinacol (2,3-dimethyl-2,3-butanediol), still find use in the reaction, particularly in examples where they are more accessible via coupling or hydroboration methods (see Section 4), or more stable, than the corresponding free boronic acids. This is frequently an advantage in complex, multi-step syntheses, where the boronate substituent can be introduced under mild conditions, and may then be utilized to form a C–C bond with a preformed electrophilic fragment. Scheme 12 illustrates examples of boronate coupling.[122,123]



Scheme 12

There are relatively few accounts of boronic acids coupling with unactivated alkyl halides, although these have begun to appear, mainly due to the work of Fu, who has described conditions for Pd-catalyzed coupling of aryl-, alkenyl- or alkylboronic acids with primary alkyl halides, in the presence of hindered phosphines, such as tricyclohexylphosphine or particularly $(t\text{-Bu})_2MeP$,[124] and also of the Ni-catalyzed coupling of aryl- and alkenylboronic acids with secondary alkyl bromides and iodides, in the presence of a phenathroline ligand.[125]

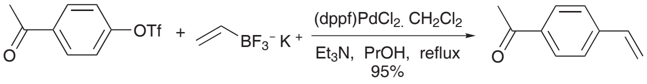
Improved syntheses and availability from commercial sources, including Alfa Aesar, of boronic acids derived from electron-deficient hetereroaryl systems (e.g. pyridines) make their use more attractive. There are several reviews on the chemistry of these molecules.[126-129]

Coupling reactions of organotrifluoroborate salts

Darses and Genêt showed that the cross-coupling of arylboronic acids with arenediazonium tetrafluoroborates, catalyzed by $Pd(OAc)_2$ in dioxane or methanol, needed neither added base nor phosphine ligand.[130] They applied similar conditions to the coupling of diazonium tetrafluoroborates with potassium aryl trifluoroborates,[131] which are air-stable crystalline solids readily prepared from arylboronic acids and KHF_2, and potassium vinyl trifluoroborates,[132] which are also readily isolable crystalline solids, more stable than the corresponding vinylboronic acids. The cross-coupling of potassium aryl and heteroaryl trifluoroborates with aryl and heteroaryl halides was subsequently described by Molander.[133] For aryl and electron-rich heteroaryl (e.g. thiophene) trifluoroborates, these reactions proceed in the presence of $Pd(OAc)_2$ under ligandless conditions. However he found that for electron-deficient heteroaryl (e.g. pyridine) trifluoroborates, the use of a catalyst with a bulky liagnd, [1,1'-bis(diphenylphosphino)ferrocene]palladium(II) chloride, was necessary to give satisfactory yields.[133b] Conditions for coupling potassium aryl and heteroaryl trifluoroborates with aryl and heteroaryl triflates have also been reported.[134] In general, trifluoroborate salts are more nucleophilic than the equivalent boronic acids.[131,135] Furthermore, they are often more crystalline and more stable to long-term storage.

Molander has reported that cross-coupling of aryltrifluoroborates with benzylic halides is superior to that of the corresponding arylboronic acids.[136]

Molander has also demonstrated the coupling of potassium alkenyl trifluoroborates with aryl halides and triflates (Scheme 13).[137] With potassium vinyltrifluoroborate, which, unlike vinylboronic acid, is stable to polymerization, high yields of Suzuki coupling products are obtained free from the products of Heck coupling previously observed with vinylboronic esters.[138]



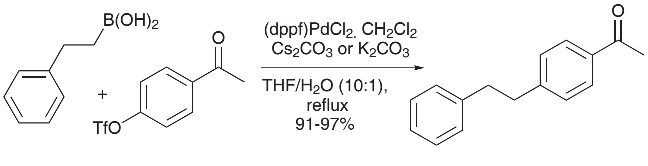
Scheme 13

Microwave-promoted rapid coupling with alkenyl and alkynyl trifluoroborates and aryl iodides has been reported.[139] Potassium alkenyltrifluoroborates also couple with alkenyl bromides, affording, 1,3-dienes with retention of double-bond geometry.[140]

The chemistry of organotrifluoroborates has been reviewed by Molander,[141] Stefani,[142] and by Darses and Genêt.[143]

Alkylboron couplings

Suzuki-Miyaura coupling of alkylboronic acids was described in a 2001 review as difficult to accomplish and limited in scope.[144] However, Molander subsequently reported conditions under which primary alkylboronic acids can be coupled efficiently with aryl halides and triflates (Scheme 14).[145]

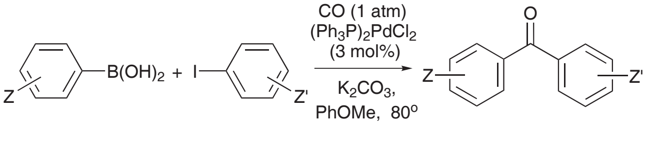


Scheme 14

This has been extended to the coupling of potassium alkyl trifluoroborates with aryl halides and triflates, catalyzed by $(dppf)PdCl_2$.[146] Doucet has reviewed Suzuki-Miyaura cross-coupling reactions of alkylboronic acid derivatives and alkyltrifluoroborates.[147]

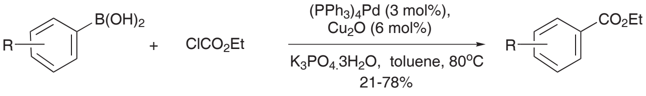
Formation of carbonyl compounds

Suzuki and Miyaura reported a variation of the biaryl coupling reaction, shown in Scheme 15, in which carbonylative cross-coupling of arylboronic acids with aryl iodides occurs in the presence of carbon monoxide at atmospheric pressure, to give unsymmetrical substituted benzophenones.[148]



Scheme 15

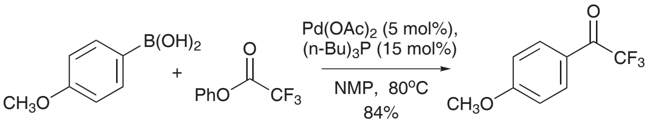
In contrast, Uemura found that, in the absence of an aryl halide, carbonylation of an aryl- or alkenylboronic acid, with a Pd(0) catalyst in THF, leads to the corresponding symmetrical ketone. In methanol without added base, a mixture of the ketone and the methyl aryl or alkenyl carboxylic ester is formed, whereas in the presence of sodium acetate, the methyl ester is the major product.[149] Unsymmetrical ketones were subsequently prepared by reaction of arylboronic acids with acyl chlorides, catalyzed either by $(Ph_3P)_4Pd$,[150,151] $(Ph_3P)_2PdCl_2$,[152] or $Pd(OAc)_2$ with no added ligand,[153,154] and also with anhydrides, catalyzed by $Pd(OAc)_2$[154] or rhodium complexes.[155] A route to esters and amides is available via the coupling of arylboronic acids with chloroformates (Scheme 16).[156]



Scheme 16

Similarly, tertiary amides have been prepared by reaction of arylboronic acids[156] or arylboronates[157] with N,N-dialkylcarbamoyl chlorides.

Coupling reactions of arylboronic acids with S-phenyl trifluorothioacetate, with $Pd_2(dba)_3$ and a Cu(I) co-catalyst,[158] or with phenyl trifluoroacetate, or the phenyl ester of another perfluoroalkanoic acid, catalyzed by $Pd(OAc)_2$[159] (Scheme 17), have been used to prepare the corresponding aryl perfluoroalkyl ketones.

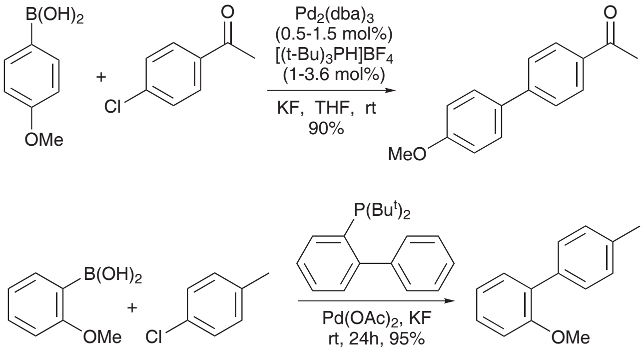


Scheme 17

Catalyst systems

In the original biaryl coupling work,[61] Suzuki and Miyaura employed the readily-available complex tetrakis(triphenylphosphine)palladium(0), which continues to be the preferred catalyst in most routine syntheses. An extremely wide variety of alternative catalyst and ligand systems have been reported, with advantages in cost, efficiency or selectivity for particular applications. Examples include: $(Ph_3P)_2PdCl_2$,[97,148] (dppb)$PdCl_2$,[99,160] $Pd(dba)_n$[130,161] $Pd(OAc)_2$,[130,162,163] $Pd(OAc)_2/(o\text{-tol})_3P$,[100,164] $Pd(OAc)_2$/ dppf,[100] $PdCl_2$/pyridine,[166] $PdCl_2$/PEG,[73] Pd(dppf)$PdCl_2$,[112,115,122,123,145,146] $(PhCN)_2\text{-}PdCl_2/Ph_3As$,[114] $(CH_3CN)_2PdCl_2$,[148] $[Pd(allyl)Cl]_2$,[120] palladium on carbon[68,98,167-169] (review[170]), palladium on a polymer support,[67,74,171] (also the Johnson Matthey FibreCat® range[172,173]), palladium nanoparticles,[75] palladacycle complexes,[174] as well as $(Ph_3P)_2NiCl_2$,[79] $NiCl_2.6H_2O$.[80,175] Low-cost trialkyl phosphites have also been successfully used as ligands in palladium-[176,177] and nickel-[176] catalyzed couplings.

$Pd_2(dba)_3/(t\text{-Bu})_3P$,[70] and the air-stable equivalent $Pd_2(dba)_3/[(t\text{-Bu})_3PH]BF_4$,[71] developed by Fu's group, as well as Buchwald's biphenylphosphine systems, e.g. $Pd(OAc)_2$/2-(di-*tert*-butylphosphino)biphenyl[72] are good for coupling difficult substrates, including aryl chlorides, under mild conditions (Scheme 18).



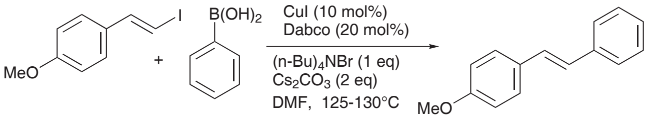
Scheme 18

Hindered ferrocene phosphines, such as 1,1'-bis(di-*tert*-butylphosphino)ferrocene palladium dichloride, have also been found to be effective for challenging coupling reactions, including unactivated and hindered aryl chlorides.[78]

As an alternative to phosphorus(III) derivatives, inexpensive 1,4-diazabicyclo[2.2.2]octane (Dabco), in the presence of $Pd(OAc)_2$ has been found to be an effective ligand.[178,179] Otherwise difficult couplings have also been successfully carried out with N-heterocyclic carbene (NHC) ligands, usually generated in situ from 1,3-diaryl imidazolium salts.[76,77,180-182]

The use of tetrakis(triphenylphosphine)platinum(0) instead of the palladium(0) complex permits selective coupling with an aryl iodide in the presence of an aryl bromide.[183]

Attempts to minimize, or eliminate altogether, the use of palladium in the catalyst system have been reported by Rothenburg, who successfully utilized copper-based nanoclusters,[184] and by Li and co-workers who have developed a palladium-free system consisting of CuI, Dabco and TBAB, by means of which arylboronic acids couple with vinyl bromides and iodides, mostly in good yields, and with several aryl iodides in moderate to good yields (Scheme 19).[185]



Scheme 19

A comprehensive range of coupling catalyst systems, including most of those mentioned above and some more specialized systems, is available from Johnson Matthey Catalysts. These products are offered in research quantities through Alfa Aesar, and a selection is listed in the Product section of this publication. Further technical information on the uses of these catalysts is available on request.

Bases

In contrast to the coupling reactions of organotin or organozinc reagents, Suzuki and Miyaura found that the arylboronic acid coupling requires 2 equivalents of a base, originally aqueous sodium carbonate.[57,61] They also reported that the stronger bases ethoxide or hydroxide gave poorer yields than carbonate, and that sodium acetate was ineffective, although its use under modified conditions has since been reported.[186] Many alternative bases have been introduced for these reactions, some of which offer advantages for particular substrates; examples include: $NaHCO_3$,[97,187] K_2CO_3,[103,122] Cs_2CO_3,[66b] K_3PO_4,[105] Et_3N/DMF,[100] Ag_2O,[114] KO-*t*-Bu,[124] $Ba(OH)_2$,[123,188] good for sterically-hindered biaryls, and CsF,[189] compatible with readily-hydrolyzed functionality, such as esters. The use of TlOH, Tl_2CO_3 or TlOEt has also been found to give superior results with sensitive substrates, particularly in multi-step total syntheses.[89,190]

Other reaction conditions

Many Suzuki-Miyaura biaryl coupling reactions described in the literature use an aqueous mixed solvent with a water-miscible component such as DME or 1,4-dioxane. Examples have appeared of the use of poly(ethylene glycol)[75,154,179,191,192] or poly(ethylene oxide)[193] as co-solvent, potentially replacing volatile organic solvents, and facilitating recycling of the catalyst system.

The coupling reaction of arylboronic acids with aryl bromides is dramatically accelerated by using the ionic liquid, 1-*n*-butyl-3-methylimidazolium tetrafluoroborate $[bmim][BF_4]$ as the reaction medium; improved yields with reduced catalyst loading of $(Ph_3P)_4Pd$ are claimed.[194] 4-Iodophenol immobilized on Wang resin undergoes accelerated coupling with the same catalyst in $[bmim][BF_4]$.[65] The application of ultrasound, also in $[bmim][BF_4]$, with ligand-free $Pd(OAc)_2$ as catalyst and NaOAc as base, has been found to promote rapid coupling at ambient temperature under extremely mild conditions.[186] Water dramatically accelerates the $Pd(OAc)_2$-catalyzed coupling of aryl halides in [bmim][BF_4] and [bmim][PF_6], enabling multiple recycling of the catalyst system.[195] A short review article on palladium-catalyzed C-C coupling reactions in ionic liquids is available.[196]

Arylboronic acids also undergo *rhodium*-catalyzed, copper-mediated coupling with allylic alcohols in [bmim][PF_6].[121] At elevated temperatures, the simple phase-transfer catalyst tetra-*n*-butylammonium bromide (TBAB) behaves as an ionic liquid; mixtures with water have been utilized by Bedford for the ligand-free $Pd(OAc)_2$-catalyzed cross-coupling of aryl chlorides.[69]

Leadbeater studied the accelerating effect of microwaves on ligand-free $Pd(OAc)_2$-catalyzed Suzuki-type couplings in water, with or without TBAB.[197] He also demonstrated Suzuki coupling of aryl chlorides using palladium on carbon catalyst in water with microwave heating and simultaneous cooling.[198] Yu has reported improved yields with aryl chlorides using a Pd-phosphine complex in aqueous media.[199] Leadbeater's claim[200] to have achieved microwave-promoted, transition metal-free coupling was later retracted, with the detection of traces of palladium in the sodium carbonate base.[201] The use of microwave heating in conjunction with FibreCat® supported palladium catalysts has also been recommended in high throughput synthesis techniques.[173] Microwave irradiation enables cross-coupling of organotrifluoroborates with ultra-low (ppm) catalyst loadings.[202] It has also been recommended for the preparation of diaryl ketones from Arylboronic acids and benzoyl chlorides.[151] "Environmentally friendly" Suzuki reactions have been reviewed.[203]

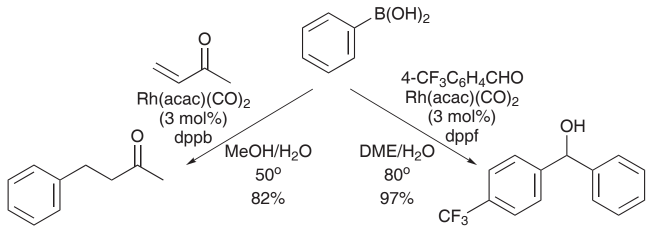
Additions to carbonyl compounds

Palladium-catalyzed reactions

Uemura reported palladium-catalyzed 1,4-addition of arylboronic acids to enones,[204] but yields were generally poor. Ohta later demonstrated 1,2-addition of arylboronic acids to aldehydes, catalyzed by Pd(0), but useful yields of secondary alcohols were only obtained in the presence of chloroform.[205] Organoboronic acids also undergo 1,4-addition to α,β-unsaturated ketones with a Pd phosphine complex and chloroform.[206] More recently, Wu and Cheng demonstrated a dramatic increase in yield for the $PdCl_2$-catalyzed, chloroform-free 1,2-addition of aryl and heteroarylboronic acids to aldehydes, by adding tri(1-naphthyl)phosphine;[207] other phosphine ligands were much less effective. $Pd(OAc)_2$-catalyzed 1,2-addition to nitriles, in the presence of 2,2'-bipyridine, gives ketones in moderate to good yields.[208]

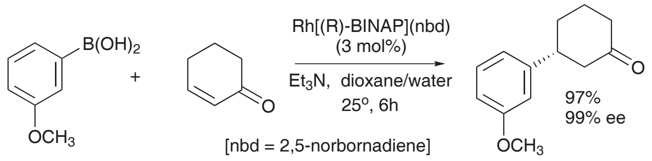
Rhodium-catalyzed reactions

Miyaura and Hayashi described the conjugate addition of arylboronic acids to enones, catalyzed by a rhodium(I) complex and a chelating phosphine, to give good yields of saturated ketones.[209] Under similar conditions, both aryl- and alkenylboronic acids can add to aldehydes to give secondary alcohols in high yield (Scheme 20).[210]



Scheme 20

An extension of these reactions to the addition of potassium alkenyl- and aryltrifluoroborates to aldehydes and enones has been described.[211,212] Miyaura and Hayashi utilized the Rh(I)-catalyzed 1,4-addition reaction of boronic acids to α,β-unsaturated ketones,[213] esters[214] or amides,[215] in the presence of a chiral BINAP ligand, in enantioselective syntheses of the corresponding saturated ketones and esters. This area was reviewed by Hayashi.[216] Further investigations of the 1,4-addition reactions have led to improved results under milder conditions (Scheme 21).[217] New results in this field continue to appear on a regular basis.[218]

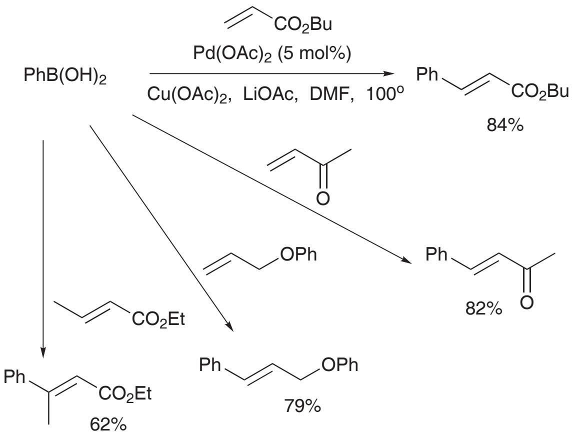


Scheme 21

Rh(I)-catalyzed addition of aryl- and alkenylboronic acids to isocyanates affords secondary amides.[219] Rhodium-catalyzed C-C bond-forming reactions of organometallic compounds have been reviewed.[220]

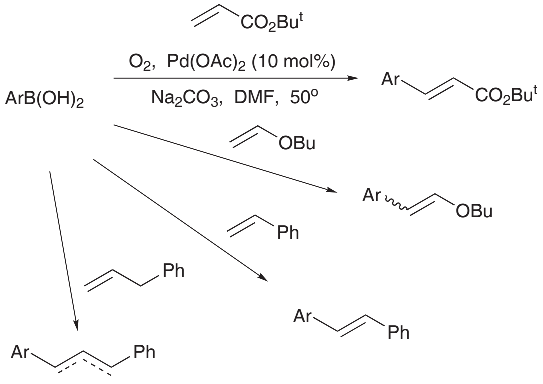
Mizoroki-Heck and other transition metal-catalyzed reactions with alkenes and alkynes

Uemura reported the $Pd(OAc)_2$-catalyzed cross-coupling of arylboronic and alkenylboronic acids with alkenes in acetic acid to give aryl-substituted alkenes and conjugated dienes respectively, by oxidative addition of the B-C bond to an *in situ* formed Pd(0) species.[221] Subsequently, Mori described a Pd(II)-catalyzed pathway, employing catalytic $Pd(OAc)_2$ with $Cu(OAc)_2$ as stoichiometric co-oxidant.[222] Treatment of a variety of alkenes with arylboronic acids thus affords β-arylated products in good yield (Scheme 22). The reaction conditions were also adapted to permit the coupling of sodium tetraphenylborate or alkenylboronates.



Scheme 22

Jung has demonstrated the palladium-catalyzed oxygen-promoted coupling of a number of aryl and heteroaryl boronic acids and boronates with a variety of olefins in good yields under mild conditions (Scheme 23).[223]

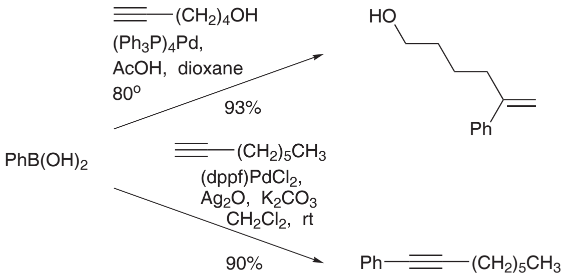


Scheme 23

In contrast, with electron-rich olefins (vinyl ethers and N-vinylamides), the use of a phenanthroline ligand promotes Pd-catalyzed Heck arylation at the internal (heteroatom-substituted) position.[224] Arylboronic acids also undergo aerobic Pd-catalyzed Heck-type coupling with phenyl vinyl sulfones[225] and vinylphosphonates.[226]

Conditions for Heck-type reactions of arylboronic acids with acrylate esters to give cinnamic esters have been described by Brown, with a ruthenium catalyst in the presence of a Cu(II) oxidant,[227] and by Zou, with a rhodium catalyst.[228] Xiao has reported an oxygen and base-free Heck reaction of both electron-rich and electron-deficient olefins, catalyzed by $Pd(OAc)_2$ in the presence of dppp and acetone, which acts as a hydrogen acceptor.[229]

Lautens has investigated the rhodium catalyzed coupling of boronic acids with alkenes and alkynes in aqueous systems. In the presence of $[Rh(COD)Cl]_2$ and a water-soluble phosphine ligand, arylboronic acids undergo a Heck-type reaction with styrenes to give *trans*-stilbenes, whereas, with vinyl-substituted pyridines, quinolines or pyrazine, hydroarylation of the olefinic bond gives the saturated 2-arylethyl heterocycle.[230] Alkynyl heteroaromatic compounds under analogous conditions also undergo hydroarylation to 2-arylvinyl derivatives.[231] Stereoselective rhodium-catalyzed hydroarylation of internal alkynes had previously been demonstrated by Hayashi.[232] Terminal alkynes with a palladium catalyst can undergo either hydroarylation by arylboronic acids, reported by Oh,[233] or Heck-type coupling under oxidative conditions, by Zou (see Scheme 24).[234] The regioselectivity of palladium-catalyzed hydroarylation of unsymmetrical internal alkynes has been studied by Oh.[235]

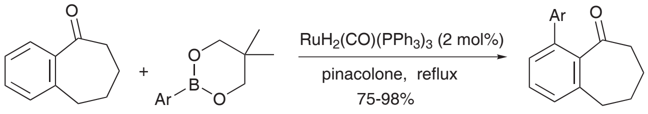


Scheme 24

Internal alkynes undergo addition with arylboronic acids, providing tetrasubstituted olefins.[236]

ortho-Substitution of aromatic ketones

A variety of aryl alkyl ketones react with boronic esters in the presence of a catalytic amount of $RuH_2(CO)(PPh_3)_3$, with *ortho*-specific C–H bond cleavage to give the *ortho*-aryl ketone (Scheme 25).[237]

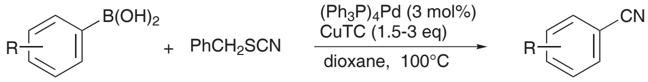


Scheme 25

Neopentyl glycol esters were found to give the best results. Pinacol and other boronic esters gave lower yields but free boronic acids were recovered essentially unchanged. The reaction has been extended to the *ortho*-alkenylation using alkenylboronic esters.[238]

Cyanation and Carboxylation

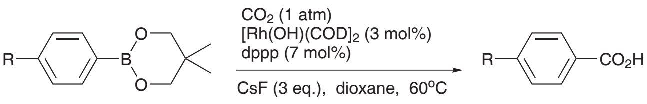
Preparation of aryl nitriles by classical routes (Sandmeyer or Rosenmund-von Braun) involves highly toxic inorganic cyanides (Cu or Zn). Arylboronic acids undergo a copper(I)-mediated, Pd(0) catalyzed coupling reaction with an organic thiocyanate to give high yields of benzonitriles (Scheme 26).[239] The reaction can also be applied to heteroaryl and alkenyl systems.



CuTC = Cu(I) thiophene-2-carboxylate

Scheme 26

Arylboronic and alkenylboronic esters can be converted to benzoic acids by Rh(I)-catalyzed reaction with CO_2 at atmospheric pressure (Scheme 27).[240]

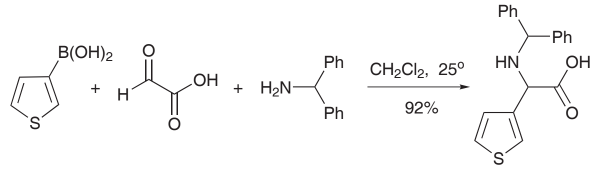


Scheme 27

Transition metal-free C–C condensations

The Boron-Mannich (Petasis) reaction

Petasis initially described the Mannich-type reaction of alkenylboronic acids with paraformaldehyde and secondary amines,[241] affording allylamines in good yield with retention of double-bond geometry. Subsequently, he developed the three-component Mannich reaction of an alkenylboronic acid with glyoxylic acid and an amine to give β,γ-unsaturated α-amino acid derivatives,[242] which was extended to the synthesis α-aryl and α-heteroaryl glycines from the corresponding boronic acids,[243] as shown in Scheme 28.



Scheme 28

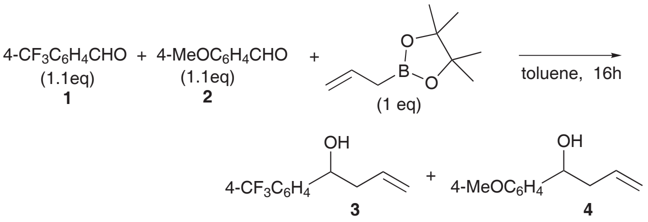
Harwood and co-workers demonstrated the use of a chiral secondary amine as a template in a diastereo-controlled Mannich reaction with furan-2-boronic acid, to give substituted furfurylamines with high de.[244] The Petasis reaction has been investigated with one of the three components anchored to a polymer support, and found to give satisfactory results in most cases.[245] The reaction has also been successfully extended to pinacolyl boronic esters,[246] with chiral induction achievable via a homochiral boronic ester.[247]

Petasis has reported an analogous stereocontrolled three-component condensation, involving a boronic acid, an amine and an α-hydroxy aldehyde, to yield the *anti*-β-amino alcohol.[248] This route has been adapted to give the product enantioselectively with high ee.[249]

The Petasis reaction has been extended to the more reactive potassium organotrifluoroborates (aryl, vinyl and allyl), which condense with an aldehyde and an amine, in the presence of a Lewis acid.[250] Alkenyl, aryl and heteroaryl pinacol boronates react slowly or not at all in the Petasis reaction in aprotic solvents. In alcohols such as methanol or hexafluoroisopropanol, the reaction proceeds well to give amino acid derivatives, mostly in high yield.[251]

Allylation reactions

Allylboronic esters can add stereoselectively to aldehydes, in the absence of a catalyst, to give homoallylic alcohols.[41b] Ishiyama and Miyaura have shown that the reaction of pinacolyl allylboronates is dramatically accelerated, and the chemoselectivity increased, by a catalytic amount of a Lewis acid (Scheme 29).[252] The potential for modest enantioselectivity was demonstrated in the presence of a BINOL co-catalyst.



Catalyst	Temp	Yield%	3:4
none	r.t.	89	81:19
none	-78°	0	
$AlCl_3$ (10 mol%)	-78°	57	99:1
$Sc(OTf)_3$ (10 mol%)	-78°	72	99:1

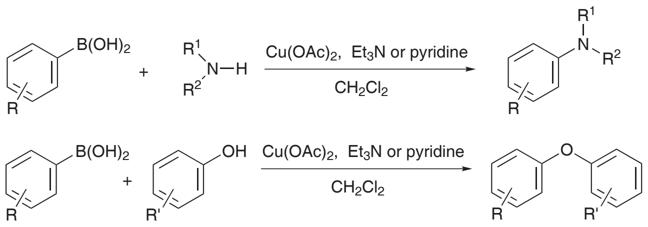
Scheme 29

Kobayashi has described allylation of ketones, catalyzed by In(I) salts.[253] Hall has published a review of Lewis and Brønsted acid catalyzed allylboration of carbonyl compounds.[254]

C–O, C–N and C–S bond forming reactions

Oxidative cleavage of organoboron compounds to give alcohols or phenols is well known. In the case of boronic acids and esters, conditions utilizing hydrogen peroxide[17,255] or Oxone®[256] have been described.

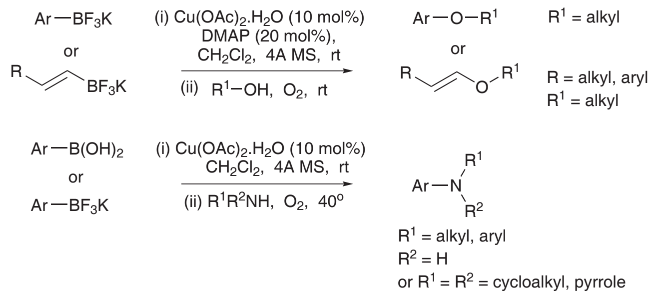
Of much greater synthetic interest was Chan's publication in 1998,[257] describing the ambient temperature arylation with arylboronic acids of N-H groups in amines, amides, imides, ureas, sulfonamides and carbamates, and of O-H groups in phenols, promoted by Cu(II) acetate and triethylamine or pyridine (Scheme 30).



Scheme 30

This methodology provides a mild alternative to classical Ullmann-type chemistry, normally carried out at elevated temperatures. The next two papers in the same issue are by Evans,[258] describing more detailed studies of the phenol arylation reaction, and by Chan and Lam,[259] on the N-arylation of imidazoles, triazoles, tetrazoles and similar heteroaromatics. Subsequent publications have provided many more examples of what is sometimes referred to as the Chan-Lam coupling reaction, including arylation of N-hydroxyphthalimide,[260] amines,[261,262] amides and imides.[262] The C-N coupling reaction has been applied to solid-phase synthesis of N-heterocycles.[263] The formation of unsymmetrical thioethers from arylboronic acids and thiols, mediated by $Cu(OAc)_2$ has been reported.[264] Alkyl and aryl sulfinic acid salts also react with arylboronic acids, in the presence of $Cu(OAc)_2$, to give good yields of aryl sulfones.[265,266] Copper-promoted C-heteroatom bond cross-coupling reactions have been reviewed by Chan and Lam,[267] giving a first-hand insight into the development of this type of reaction. Ley and Thomas have also published a review of Copper mediated aryl C-O, C-N and C-S bond formation,[268].

As originally described, these reactions required stoichiometric amounts of Cu(II). Buchwald reported a catalytic procedure for amination utilizing molecular oxygen as reoxidant for copper,[269] and Batey has since developed improved oxygen-mediated catalytic procedures for the formation of ethers from trifluoroborate salts (or, in reduced yield, boronic acids) and aliphatic alcohols,[270] and also for amination of both boronic acids and trifluoroborates (Scheme 31).[271]



Scheme 31

Arylboronic acids undergo reductive amination with arylnitroso compounds, mediated by Cu(I), providing a route to unsymmetrical diarylamines.[272]

Unsymmetrical diaryl or aryl heteroaryl sulfones have been prepared via a ligand-free, palladium chloride-catalyzed coupling of arylboronic acids with arenesulfonyl chlorides.[273] Sulfones are also available by cross-coupling of aryl- or alkenylboronic acids with aryl or alkyl sulfinate salts, promoted by stoichiometric $Cu(OAc)_2$,[274] or catalytic $Cu(OAc)_2$/1,10-phenathroline.[275]

Miscellaneous displacement reactions of boronic acids

Many other examples can be found of boronic acid chemistry involving displacement of boron:

Reaction of arylboronic acids with copper(II) chloride or bromide to give the corresponding aryl halide with loss of boron has long been known.[276] More recently, *ipso*-bromination or -iodination of arylboronic acids with NBS or NIS in acetonitrile has been described.[277] The reaction has been further developed utilizing 1,3-dibromo-5,5-dimethylhydantoin and the dichloro analogue, providing convenient access to “abnormally” substituted bromo and chloro aromatics.[278] A catalytic amount of sodium methoxide was found to minimize side reactions, affording high yields of the required products. Potassium aryltrifluoroborates salts undergo *ipso*-iodinations using a combination of sodium iodide and Chloramine-T.[279] Arylboronic acids have been converted, via the N-methyldiethanolamine cyclic esters, to aryl fluorides using cesium fluoroxysulfate.[280] Widdowson and co-workers[281] have demonstrated the facile conversion of arylboronic acids to diaryliodonium triflates in the presence of $PhI(OAc)_2$/TfOH. Diaryl and heteroaryl (phenyl)iodonium tosylates can also be readily prepared from the corresponding boronic acid and Koser’s reagent [PhI(OH)OTs]. This approach is preferable to the previous route via toxic stannanes. The displacement reaction of iodonium salts with fluoride ion provides a mild synthesis of aryl fluorides, including ^{18}F labelled derivatives, which can be employed in positron emission tomography.

Vinylboronic acids can be converted to vinyl halides, with retention of double-bond configuration, using NCS, NBS or NIS.[282] Vinyl and alkynyl trifluoroborates can be iodinated with sodium iodide/ Chloramine-T.[283] Fluorination of vinylboronic acids occurs with 1-chloromethyl-4-fluoro-1,4-diazoniabicyclo[2.2.2]octane bis(tetrafluoroborate) [Selectfluor®], but better results have been obtained starting from the corresponding potassium alkenyl trifluoroborates.[284]

Arylboronic acids undergo *ipso*-nitration with ammonium nitrate/ trifluoroacetic anhydride[285] (Crivello’s reagent: *in situ* trifluoroacetyl nitrate), or, more selectively, with a nitrate salt and TMS chloride,[286] to give the boron-free aryl nitro compound, in contrast to conventional nitration which tends to give mainly the *m*-nitro benzeneboronic acid.

With lead(IV) acetate, catalyzed by mercury(II) acetate, arylboronic acids are transmetallated to the aryllead triacetates, used *in situ* for electrophilic arylation, for example of active methylene compounds,[287] or with sodium azide in DMSO for the preparation of aryl azides, providing a useful two-step route for the preparation of these from aryl halides.[288]

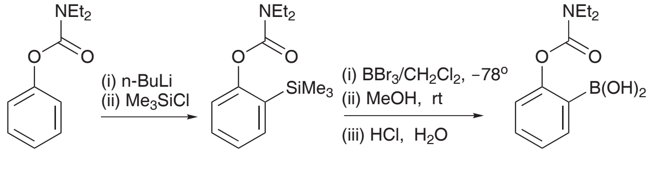
Transmetallation of an arylboronic acid to an arylzinc species *in situ* has been achieved with diethylzinc.[289]

4. Preparative routes to boronic acids and esters

Borylation of organometallics

Boronic acids are still most often prepared from the corresponding organomagnesium or organolithium reagent and a trialkyl borate, followed by acidic hydrolysis of the resulting dialkyl boronate. The original conditions of Kotinsky and Melamed,[5] addition of trimethyl borate to an ether solution of phenylmagnesium bromide, were repeated by Gilman,[290] who claimed yields of benzeneboronic acid as high as 86%. However, most other workers were unable to reproduce this, and often obtained only very low yields, mainly due to the formation of large amounts of diphenylborinic acid. Johnson subsequently used a reverse-addition technique, adding the ethereal phenyl Grignard to trimethyl borate at -12˚C (ca 30% yield),[6a] or to tributyl borate at -70 to -75˚C, (50-60% yield).[6b] Washburn later undertook a more detailed study of the synthesis of benzeneboronic acid from phenylmagnesium bromide and trimethyl borate,[7] confirming that the yield of boronic acid is much improved by carrying out the borylation of the Grignard at low temperatures (generally below -50°C). As the reaction temperature approaches ambient, increasing amounts of the ester of diphenylborinic acid are formed by further attack of the Grignard on the intermediate dimethyl benzeneboronate. He also demonstrated that simultaneous addition of the borate and Grignard to a vessel containing ether stirred at low temperature tended to minimize formation of diphenylborinic acid. In a second key paper,[291] Washburn discussed further experimental and mechanistic aspects of the reaction of phenyl- and substituted phenylmagnesium halides with trialkyl borates. His optimal procedure for benzeneboronic acid is detailed in *Organic Syntheses*.[292] The results of other workers indicate that the use of triisopropyl borate[293] or isopropyl pinacol borate (2-isopropoxy-4,4,5,5-tetramethyl-1,3,2-dioxaborolane)[294] instead of trimethyl borate may have advantages in particular cases.

Snieckus has developed directed metallation[295] routes to boronic acids. His initial publication[296] described *ortho*-lithiation of N,N-dialkyl benzamides, followed by borylation with trimethyl borate. In a subsequent paper,[297] better results for a range of substrates were claimed by an *ortho*-lithiation-silylation-*ipso*-boro-desilylation[298] sequence with boron tribromide (Scheme 32).

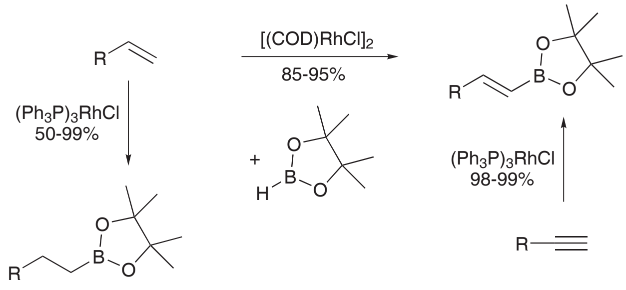


Scheme 32

Other workers[299] have utilized *ipso*-borodesilylation with either BBr$_3$ or BCl$_3$ in the formation of boronic acids and esters. Neopentyl esters have been *ortho*-lithiated with LDA and reacted with triisopropyl borate *in situ* to give good yields of arylboronic acids, isolated via the diethanolamine esters.[300]

Hydroboration methods

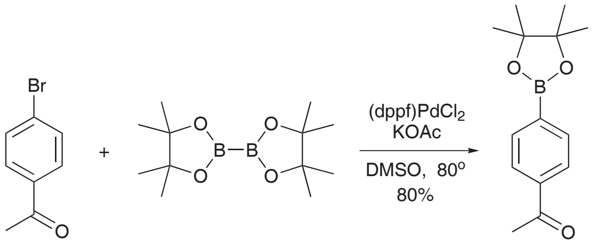
Hydroboration of alkenes with catecholborane to give alkylboronic esters[301] usually requires forcing conditions. Improved results can be obtained by catalysis with LiBH$_4$,[302] or with Rh(I)[303,304] or Ir(I)[304] complexes. Hydroboration of alkynes with catecholborane occurs somewhat more readily, affording alkenylboronic esters, often regio- and stereoselectively.[301] Nevertheless, catalysis with, for example Rh(I),[303] Ni(II)[305] or Pd(II)[306] complexes, may permit reaction under milder conditions, with greater selectivity. Alkenes can undergo Rh(I)-catalyzed hydroboration with pinacolborane, to give the alkylboronate,[307] or, with a phosphine-free Rh(I) complex, the alkenylboronate[308] by dehydrogenative borylation. Vinylboronates are also formed from alkynes and pinacolborane (2 eq.) under mild conditions.[309] High yields are obtained with 1 eq. of the reagent in the presence of Rh or Ni catalysts[307] (Scheme 33).



Scheme 33

Transition metal catalyzed B–C coupling

As well as the need for low temperatures, the use of reactive organometallics, RMgX or RLi, as boronic acid precursors is generally limited to substrates lacking functional groups which could react with the organometallic species. A major advance in the synthesis of arylboronic esters came with the publication by Miyaura[310] of the palladium-catalyzed coupling of aryl halides with diboron esters, especially bis(pinacolato)diboron, by cleavage of the B-B bond, enabling access to boronic acid derivatives without protection of functionalities such as ester, ketone, cyano or nitro groups (Scheme 34).



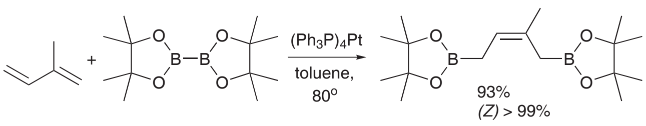
Scheme 34

Aryl triflates are also converted to pinacol arylboronates under similar conditions,[311] as are arenediazonium salts.[312] The reaction has been adapted to borylation of polymer-supported aryl iodides, allowing *in situ* coupling to give unsymmetrical biaryls.[313] Microwave irradiation has been found to offer dramatic rate enhancements and improved yields in the formation of otherwise difficult electron-rich boronates.[314] In a further detailed examination of the borylation reaction, Zhang has shown that ligandless Pd(OAc)$_2$ is a highly effective catalyst with advantages of lower cost, ease of work-up, and the ability to couple the boronate *in situ* with a suitable electrophile.[2315] Buchwald has demonstrated the high-yield borylation of aryl chlorides using the hindered ligand 2-dicyclohexylphosphino-2’,4’,6’-triisopropylbiphenyl.[316]

The preparation of pinacolyl arylboronates by palladium-catalyzed coupling of aryl iodides, triflates or, less readily, bromides with pinacolborane has been described by Masuda.[317] In this reaction, the arene, formed by reduction of the aryl halide, was often found as a significant by-product. This method has been adapted to a one-pot conversion of aryl bromides to unsymmmetrical biaryls via the pinacol boronates.[318] Aryl iodides can also be converted to the pinacol boronates in acceptable yield in a Pd-free, CuI catalyzed reaction, along with a strong base, preferably NaH.[319] Masuda has reported the Pt(0)-catalyzed regio- and stereoselective synthesis of allylboronates from allyl halides and pinacolborane.[320]

Borylation with bis(pinacolato)diboron, catalyzed by Pd complexes, has been extended to alkenyl halides and triflates,[321,322] benzyl halides[323,324] and allyl acetates.[325] Miyaura has also reported coupling with allyl halides, mediated by copper(I) chloride.[326]

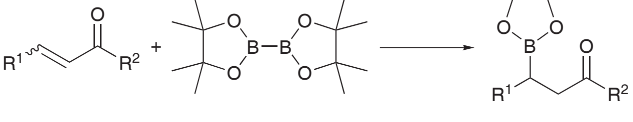
The reaction with alkynes, catalyzed by Pt(0) affords *cis*-bis-boryl alkenes.[327,328] Cu(I)-mediated 1,2-addition to terminal alkynes has also been described.[326] Stereoselective Pt(0)-catalyzed addition to 1,3-dienes gives 1,4-bis-boryl 2-alkenes,[329] (Scheme 35).



Scheme 35

A detailed discussion of diboration reactions with diboron derivatives has been published by Marder and Norman.[330]

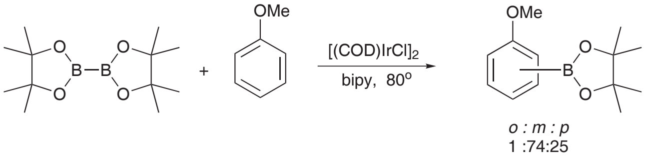
Marder and Norman first reported 1,4-addition of bis(pinacolato)diboron to enones, catalyzed by a Pt(0) complex.[331] Other authors have described a variety conditions for this type of reaction, promoted by Pt(0),[284] Cu(I)[326,333] or Rh(I)[334] systems (Scheme 36).



Scheme 36

Alkylbenzenes can be borylated on the side-chain with either bis(pinacolato)diboron or pinacolborane, in the presence of Pd/C catalyst, providing a direct route to benzylboronates.[335]

A development of considerable interest is the direct borylation of aromatic rings, which has been achieved by Smith using pinacolborane in the presence of a rhodium complex,[336] or by Ishiyama, Miyaura and Hartwig using bis(pinacolato)diboron with an iridium(I) complex (Scheme 37).[337]

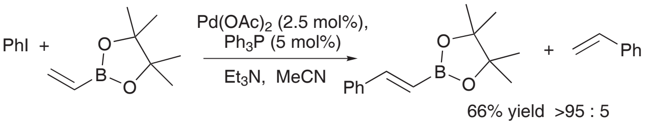


Scheme 37

The Ir-catalyzed reaction has been extended to the regio-selective borylation of heteroaromatics,[338] to selective *ortho*-borylation of aromatic nitriles,[339] and to ferrocenes.[340] Further reactions of arylboronates obtained by this method have provided access to "abnormally" substituted aromatics, including anilines, aryl ethers[341] and aryl bromides.[342]

Vinylboronate reactions

Vinylboronic acid polymerizes too readily for convenient isolation. The pinacol ester, on the other hand, is stable enough to be stored for limited periods,[343] and can undergo a variety of useful reactions. Whiting has shown that palladium-catalyzed cross-coupling with halides can take place in either Suzuki (loss of boron) or Heck (retention of boron) modes.[138] However, use of the more nucleophilic vinyltrifluoroborate salt in the Suzuki coupling may be preferable (see Section 3).[137] With the pinacol ester, Whiting has developed reaction conditions which facilitate the Heck coupling, providing a route to styryl and other 2-substituted vinylboronates (Scheme 38).[344,345]



Scheme 38

Homologated alkenylboronates are available via Grubbs ruthenium-catalyzed cross-metathesis with terminal alkenes.[346] The olefinic double bond of a vinylboronate can also undergo cycloaddition reactions with 1,3-dipoles, such as isoxazolines from nitrile oxides,[347.348] and various free-radical reactions,[349-351] leading to substituted boronates.

References and notes

1 J. Emsley, *The Elements*, 3rd ed., Oxford University Press, Oxford, 1998.
2 M. Sana, G. Leroy, C. Wilante, *Organometallics*, 1991, **10**, 264.
3 See, for example: A. Pelter, K. Smith, H. C. Brown, *Borane Reagents*, Academic Press, London, 1988; K. Smith, 'Organoboron Chemistry', in *Organometallics in Synthesis* 2nd Edition, M. Schlosser, Ed., Wiley, Chichester, 2002.
4 E. Frankland, B. F. Duppa, *Proc. Roy. Soc.*, 1859, **10**, 568; *Liebigs Ann. Chem.*, 1860, **115**, 319; E. Frankland, *J. Chem. Soc.*, 1862, **15**, 363.
5 E. Kotinsky, M. Melamed, *Ber.*, 1909, **42**, 3090
6a W. Seaman, J. R. Johnson, *J. Am. Chem. Soc.*, 1931, **53**, 711.
6b F. R. Bean, J. R. Johnson, *J. Am. Chem. Soc.*, 1932, **54**, 4415.
7 R. M. Washburn, E. Levens, C. F. Albright, F. A. Billig, E. S. Cernak, *Adv. Chem. Ser.*, 1959, **23**, 102.
8 K. Torsell in *Progress in Boron Chemistry*, H. Steinberg, A. L. McCloskey, Eds., Pergamon, New York, 1964.
9 *Boronic Acids*, D. G. Hall, Ed., Wiley-VCH, Weinheim, 2005.
10 Data for benzeneboronic acid: LD_{50} orl-rat 740 mg/kg in *Boron, Metallo-Boron Compounds and Boranes*, R. M. Adams,Ed. Wiley, New York, 1964, p. 693; for 4-carboxybenzeneboronic acid: LD_{50} orl-rat >3 g/kg, *Acta Physiologica Polonica*, 1961, **12**, 173, both quoted in *Registry of Toxic Effects of Chemical Substances*, NIOSH, 2008.
11 See, for example W. Yang, X. Gao, B. Wang, 'Biological and medicinal applications of boronic acids,' chapter 13 in reference 9.
12 J. P. Lorand, J. O Edwards, *J. Org. Chem.*, 1959, **24**, 769.
13 P. R. Westmark, S. J. Gardiner, B. D. Smith, *J. Am. Chem. Soc.*, 1996, **118**, 11093.
14 J. M. Sugihara, C. M. Bowen, *J. Am. Chem. Soc.*, 1958, **80**, 2443.
15 G. Springsteen, B. Wang, *Tetrahedron*, 2002, **58**, 5291.
16 A. M. Yurkevich, I. I. Kolodkina, L. S. Varshavskaya, V. I. Borodulina-Shvetz, I. P. Rudakova, N. A. Preobrazhenski, *Tetrahedron*, 1969, **25**, 477.
17a T. J. Perun, J. R. Martin, R. S. Egan, *J. Org. Chem.*, 1974, **39**, 1490.
17b A. Gypser, D. Michel, D. S. Nirschl, K. B. Sharpless, *J. Org. Chem.*, 1998, **63**, 7322.
18 N. Iwasawa, T. Kato, K. Narasaka, *Chem. Lett.*, 1988, 1721; H. Sakurai, N. Iwasawa, K. Narasaka, *Bull. Chem. Soc. Jpn.*, 1996, **69**, 2585.
19 R. J. Ferrier, 'Carbohydrate boronates', *Adv. Cabohydr. Chem. Biochem.*, 1978, **35**, 31.
20 C. J. W. Brooks, C. G. Edmonds, S. J. Gaskell, 'Cyclic boronates in the characterisation of bifunctional compounds by mass spectrometry', *Adv. Mass Spectrom.*, 1978, **7B**, 1578.
21 P. J. Duggan, E. M. Tyndall, 'Boron acids as protective agents and catalysts in synthesis', *J. Chem. Soc., Perkin 1*, 2002, 1325.
22 D. R. Knapp, *Handbook of Analytical Derivatisation Reactions*, Wiley, New York, 1979.
23 *Handbook of Derivatives for Chromatography*, 2nd ed., K. Blau, J. M. Halket, Ed., Wiley, Chichester, 1993.
24 T. W. Greene, P. G. M. Wuts, *Protective Groups in Organic Synthesis*, 3rd ed., Wiley, New York, 1999.
25 B. Carboni, C. Pourbaix, F. Carreaux, H. Deleuze, B. Maillard, *Tetrahedron Lett.*, 1999, **40**, 7979.
26 T. Shinbo, K. Nishimura, T. Yamaguchi, M. Sugira, *J. Chem. Soc., Chem. Commun.*, 1986, 349.
27 P. R. Westmark, B. D. Smith, *J. Am. Chem. Soc.*, 1994, **116**, 9343.
28 A. W. Czarnik, 'Chemical communication in water using fluorescent chemosensors', *Acc. Chem. Res.*, 1994, **27**, 302.
29 T. D. James, P. Linnane, S. Shinkai, 'Fluorescent saccharide receptors: a sweet solution to the design, assembly and evaluation of boronic acid derived photoinduced electron transfer sensors', *Chem. Commun.*, 1996, 281; J. H. Hartley, T. D. James, C. J. Ward, 'Synthetic receptors', *J. Chem. Soc., Perkin 1*, 2000, 3155.
30 T. D. James, K. R. A. Samankumara Sandanayake, S. Shinkai, 'Saccharide sensing with molecular receptors based on boronic acid', *Angew. Chem. Int. Ed.*, 1996, **35**, 1911.
31 T. D. James, S. Shinkai, 'Artificial receptors as chemosensors for carbohydrates', *Topics Curr. Chem.*, 2002, **218**, 159
32 T. D. James, 'Boronic acid-based receptors and sensors for saccharides', chapter 12 in reference 9.
33 K. Ishihara, S. Ohara, H. Yamamoto, *J. Org. Chem.*, 1996, **61**, 4196; K. Ishihara, S. Ohara, H. Yamamoto, *Macromolecules*, 2000, **33**, 3511.
34 T. Maki, K. Ishihara, H. Yamamoto, *Synlett*, 2004, 1355.
35 R. H. Tale, K. M. Patil, *Tetrahedron Lett.*, 2002, **43**, 9715.
36 R. H. Tale, K. M. Patil, S. E. Dapurkar, *Tetrahedron Lett.*, 2003, **44**, 3427.
37 R. H. Tale, A. D. Sagar, H. D Santan, R. N. Adude, *Synlett*, 2006, 415.
38 K. Ishihara, H. Yamamoto, *Eur. J. Org. Chem.*, 1999, 527.
39a T. Aoki, W. Nagata, K. Okada, *Synthesis*, 1979, 365
39b W. S. Murphy, S. M. Tuladhar, B. Duffy, *J. Chem. Soc.*, Perkin 1, 1992, 605.
40 B. A. Chauder, C. C. Lopes, R. S. C. Lopes, A. J. M. da Silva, V. Snieckus, *Synthesis*, 1998, 279, and references therein.
41a D. S. Matteson, 'Asymmetric synthesis with boronic esters', *Acc. Chem. Res.*, 1988, **21**, 294; 'Boronic esters in stereodirected synthesis', *Tetrahedron*, 1989, **45**, 1859.
41b D. S. Matteson, *Stereodirected Synthesis with Organoboranes*, Springer-Verlag, Berlin, 1995, pp. 187-189.
42 M. M. Midland, *J. Org. Chem.*, 1998, **63**, 914, and references therein.
43 D. S. Matteson, 'α-Halo boronic esters in asymmetric synthesis', *Tetrahedron*, 1998, **54**, 10555; 'Functional group compatibilities in boronic ester chemistry', *J. Organomet. Chem.*, 1999, **581**, 51; '(α-Haloalkyl)boronic esters in asymmetric synthesis', chapter 8 in reference 9.
44 E. J. Corey, R. K. Bakshi, S. Shibata, *J. Am. Chem. Soc.*, 1987, **109**, 5551.
45 Y. H. Kim, D. H. Park, I. S. Byun, *J. Org. Chem.*, 1993, **58**, 4511.
46 J. G. H. Willems, F. J. Dommerholt, J. B. Hammink, A. M. Vaarhorst, L. Thijs, B. Zwanenburg, *Tetrahedron Lett.*, 1995, **36**, 603.
47 B. B. Lohray, V. Bhusan, 'Oxazaborolidines and dioxaborolidines in enantioselective catalysis', *Angew. Chem. Int. Ed.*, 1992, **31**, 729.
48 S. Wallbaum, J. Martens, 'Asymmetric syntheses with chiral oxazaborolidines,' *Tetrahedron: Asym.*, 1992, **3**, 1475.
49 B. T. Chao, 'Recent advances in the synthetic applications of the oxazaborolidine-mediated asymmetric reduction', *Tetrahedron*, 2006, **62**, 7621.
50 V. K. Singh, 'Practical and useful methods for the enantioselective reduction of ketones,' *Synthesis*, 1992, 605.
51 M. Wills, J. R. Studley, 'The asymmetric reduction of ketones,' *Chem. Ind. (London)*, 1994, 552.
52 K. Furuta, S. Shimizu, Y. Miwa, H. Yamamoto, *J. Org. Chem.*, 1989, **54**, 1481.
53 Q. Gao, T. Maruyama, M. Mouri, H. Yamamoto, *J. Org. Chem.*, 1992, **57**, 1951.
54 Q. Gao, K. Ishihara, T. Maruyama, M. Mouri, H. Yamamoto, *Tetrahedron*, 1994, **50**, 979.
55 K. Narasaka , S. Shimada, K. Osoda, N. Iwasawa, *Synthesis*, 1991, 1171.
56 K. C. Nicolaou, J. J. Liu, C.-K. Hwang, W.-M. Dai, R. K. Guy, J. *Chem. Soc., Chem. Commun.*, 1992, 1118; K. C. Nicolaou, J.-J. Liu, Z. Yang, H. Ueno, E. J. Sorensen, C. F. Claiborne, R. K. Guy, C.-K. Hwang, M. Nakada, P. G. Nantermet, *J. Am. Chem. Soc.*, 1995, **117**, 634; K. C. Nicolaou, R. K. Guy, 'The conquest of Taxol', *Angew. Chem. Int. Ed.*, 1995, **34**, 2079.
57 In the absence of base, essentially no coupling was observed: S. Baba, E. Negishi, *J. Am. Chem Soc.*, 1976, **98**, 6729.
58 N. Miyaura, K. Yamada, A. Suzuki, *Tetrahedron Lett.*, 1979, 3437.
59 N. Miyaura, A. Suzuki, *J. Chem. Soc., Chem. Commun.*, 1979, 866.
60 N. Miyaura, T. Yano, A. Suzuki, *Tetrahedron Lett.*, 1980, **21**, 2865.
61 N. Miyaura, T. Yanagi, A. Suzuki, *Synth. Commun.*, 1981, **11**, 513.
62 W. J. Scott, G. T. Crisp, J. K. Stille, *J. Am. Chem. Soc.*, 1984, **106**, 4630; J. K. Stille, 'The palladium-catalyzed cross-coupling reactions of organotin reagents with organic electrophiles', *Angew. Chem. Int. Ed.*, 1986, **25**, 508.
63 For a comparative study of the Suzuki and Stille reactions in the arylation of bromo imidazoles: D. Wang, J. Haseltine, *J. Heterocycl. Chem.*, 1994, **31**, 1637.
64 See, for example: R. Frenette, R. W. Friesen, *Tetrahedron Lett.*, 1994, **35**, 9177; M. Larhed, G. Lindberg, A. Hallberg, *Tetrahedron Lett.*, 1996, **37**, 8219; M. E. Fraley, R. S. Rubino, *Tetrahedron Lett.*, 1997, **38**, 3365; B. Ruhland, A. Bombrun, M. A. Gallop, *J. Org. Chem.*, 1997, **62**, 7820; S. Chamoin, S. Houldsworth, V. Snieckus, C. G. Kruse, W. I. Baker, *Tetrahedron Lett.*, 1998, **39**, 4175.
65 J. D. Revell, A. Ganesan, *Org. Lett.*, 2002, **4**, 3071.
66 W. Shen, *Tetrahedron Lett.*, 1997, **38**, 5575; A. F. Littke, G. C. Fu, *Angew. Chem. Int. Ed.*, 1998, **37**, 3387.

67 K. Inada, N. Miyaura, *Tetrahedron*, 2000, **56**, 8661.

68 C. R. LeBlond, A. T. Andrews, Y. Sun, J. R. Sowa, *Org. Lett.*, 2001, **3**, 1555.

69 R. B. Bedford, M. E. Blake, C. P Butts, D. Holder, *Chem. Commun.*, 2003, 466.

70 A. F. Littke, G. C. Fu, *Angew. Chem. Int. Ed.*, 1998, **37**, 3387; A. F. Littke, C. Dai, G. C. Fu, *J. Am. Chem. Soc.*, 2000, **122**, 4020.

71 M. R. Netherton, G. C. Fu, *Org. Lett.*, 2001, **3**, 4295.

72 J. P. Wolfe, S. L. Buchwald, *Angew Chem. Int. Ed.*, 1999, **38**, 2413; J. P. Wolfe, R. A. Singer, B. H. Yang, S. L. Buchwald, *J. Am. Chem. Soc.*, 199, **121**, 9550.

73 L. Yin, Z. Zhang, Y. Wang, *Tetrahedron*, 2006, **62**, 9359.

74 S. Schweizer, J.-M. Becht, C. Le Drian, *Org. Lett.*, 2007, **9**, 3777.

75 W. Han, C. Liu, Z.-L. Jin, *Org. Lett.*, 2007, **9**, 4005.

76 C. Zhang, J. Huang, M. L. Trudell, S. P. Nolan, *J. Org. Chem.*, 1999, **64**, 3804.

77 V. P. W. Böhm, C. W. K. Gstöttmayr, T. Weskamp, W. A. Herrmann, *J. Organomet. Chem.*, 2000, **595**, 186.

78 T. J. Colacot, H. E. Shea, *Org. Lett.*, 2004, **6**, 3731.

79 A. F. Indolese, *Tetrahedron Lett.*, 1997, **38**, 3513; S. Saito, S. Ohtani, N. Miyaura, *J. Org. Chem.*, 1997, **62**, 8024; K. Inada, N. Miyaura, *Tetrahedron*, 2000, **56**, 8657.

80 L. Zhou, Q. Miao, R. He, X. Feng, M. Bao, *Tetrahedron Lett.*, 2007, **48**, 7899.

81 N. Miyaura, K. Yamada, H. Suginome, A. Suzuki, *J. Am. Chem.* Soc., 1985, **107**, 972.

82 A. R. Martin, Y. Yang, ‘Palladium-catalyzed cross-coupling reactions of organoboronic acids’, *Acta Chem. Scand.*, 1993, **47**, 221.

83 G. B. Smith, G. C. Dezeny, D. L. Hughes, A. O. King, T. R. Verhoeven, *J. Org. Chem.*, 1994, **59**, 8151; see also: M. Moreno-Mañas, M. Pérez, R. Pleixats, *J. Org. Chem.*, 1996, **61**, 2346.

84 S. Gronowitz, K. Lawitz, *Chem. Scr.*, 1983, **22**, 265; 1984, **23**, 5; S. Gronowitz, V. Bobosik, K. Lawitz, *Chem. Scr.*, 1984, **23**, 120.

85 B. E. Huff, T. M. Koenig, D. Mitchell, D. M. Staszak, *Org. Synth.*, 1997, **75**, 53; F. E. Goodson, T. I. Wallow, B. M. Novak, *Org. Synth.*, 1997, **75**, 61.

86 A. Suzuki, ‘Synthetic studies via the cross-coupling reaction of organoboron derivatives with organic halides’, *Pure Appl. Chem.*, 1991, **63**, 419; ‘New synthetic transformations via organoboron compounds’, *Pure Appl. Chem.*, 1994, **66**, 213; N. Miyaura, A. Suzuki, ‘Palladium-catalyzed cross-coupling reactions of organoboron compounds’, *Chem. Rev.*, 1995, **95**, 2457; A. Suzuki, ‘Recent advances in the cross-coupling reaction between organoboron derivatives with organic electrophiles, 1995-1998’, *J. Organomet. Chem.*, 1999, **576**, 147; ‘Cross-coupling reactions via organoboranes’, *J. Organomet. Chem.*, 2002, **653**, 83.

87 N. Miyaura, ‘Metal-catalyzed cross-coupling reactions of organoboron compounds with organic halides’, in *Metal-Catalyzed Cross-Coupling Reactions, 2nd ed.*, A. de Meijere, F. Diederich, Ed., Wiley-VCH, Weiheim, 2004.

88 S. P. Stanforth, ‘Catalytic cross-coupling reactions in biaryl synthesis’, *Tetrahedron*, 1998, **54**, 263.

89 K. C. Nicolaou, P. G. Bulger, D. Sarlah, ‘Palladium-catalyzed cross-coupling reactions in total synthesis’, *Angew. Chem. Int. Ed.*, 2005, **44**, 4442.

90 S. Kotha, K. Lahiri, D. Kashinath, ‘Recent applications of the Suzuki-Miyaura cross-coupling reactions in organic synthesis’, *Tetrahedron*, 2002, **58**, 9633.

91 F. Bellina, A. Carpita, R. Rossi, ‘Palladium catalysts for the Suzuki cross-coupling reaction: An overview of recent advances’, *Synthesis*, 2004, 2419.

92 A. F. Littke, G. C. Fu, ‘Palladium-catalyzed coupling reactions of aryl chlorides’, *Angew. Chem. Int. Ed.*, 2002, **41**, 4176.

93 J. Hassan, M. Sevignon, C. Gozzi, E. Schulz, M. Lamaire, ‘Aryl-aryl bond formation one century after the discovery of the Ullmann reaction’, *Chem. Rev.*, 2002, **102**, 1359.

94 S. Gronowitz, A.-B. Hörnfeld, V. Kristjansson, T. Musil, *Chem. Scr.*, 1986, **26**, 305.

95 Y. Yang, A. R. Martin, *Heterocycles*, 1992, **34**, 1395.

96 E. F. Flegeau, M. E. Popkin, M. Greaney, *Org. Lett.*, 2006, **8**, 2495.

97 S. S. Labadie, *Synth. Commun.*, 1994, **24**, 709.

98 T. Tagata, M. Nishida, *J. Org. Chem.*, 2003, **68**, 9412.

99 N. M. Ali, A. McKillop, M. B. Mitchell, R. A. Rebelo, P. J. Wallbank, *Tetrahedron*, 1992, **48**, 8117.

100 W. J. Thompson, J. H. Jones, P. A. Lyle, J. E. Thies, *J. Org. Chem.*, 1988, **53**, 2052.

101 T. J. Delia; J. M. Schomaker; A. S. Kalinda, *J. Heterocycl. Chem.*, 2006, **43**, 127.

102 A. Huth, I. Beetz, I. Schumann, *Tetrahedron*, 1989, **45**, 6679; J. M. Fu, V. Snieckus, *Tetrahedron Lett.*, 1990, **31**, 1665.

103 W.-C. Shieh, J. A. Carlson, *J. Org. Chem.*, 1992, **57**, 379.

104 N. Yasuda, L. Xavier, D. L. Rieger, Y. Li, A. E. DeCamp, U.-H. Dolling, *Tetrahedron Lett.*, 1993, **34**, 3211.

105 V. Percec, J.-Y. Bae, D. H. Hill, *J. Org. Chem.*, 1995, **60**, 1060.

106 B. M. Savall, N. A. Powell, W. R. Roush, *Org. Lett.*, 2001, **3**, 3049.

107 S. Sogl, G. D. Allred, L. S. Liebeskind, *J. Am. Chem. Soc.*, 1997, **119**, 12376.

108 S. R. Dubbaka, P. Vogel, *Org. Lett.*, 2003, **6**, 95.

109 L. S. Liebeskind, J. Srogl, *Org. Lett.*, 2002, **4**, 979.

110 S. B. Blakey, D. W. C. MacMillan, *J. Am. Chem. Soc.*, 2003, **125**, 6046.

111 S. Chowdhury, P. E. Georghiou, *Tetrahedron Lett.*, 1999, **40**, 7599.

112 L. J. Goossen, *Chem. Commun.*, 2001, 669.

113 S. C. Suri, V. Nair, *Synthesis*, 1990, 695.

114 C. R. Johnson, J .P. Adams, M. P. Braun, C. B. W. Senanayake, *Tetrahedron Lett.*, 1992, **33**, 919; F. S. Ruel, M. P. Braun, C. R. Johnson, *Org. Synth.*, 1997, **75**, 69.

115 B. Shi, R. W. Boyle, *J. Chem. Soc., Perkin 1*, 2002, 1397.

116 M. Moreno-Mañas, F. Pajuelo, R. Pleixats, *J. Org. Chem.*, 1995, **60**, 2396.

117 Y.-G. Chung, Y. Miyake, S. Uemara, *J. Chem. Soc., Perkin 1*, 2000, 15.

118 M. Yoshida, T. Gotou, M. Ihara, *Chem. Commun.*, 2004, 1124.

119 M. Yoshida, T. Gotou, M. Ihara, *Tetrahedron. Lett.*, 2004, **45**, 5573.

120 M. Manabe, K. Nakada, N. Aoyama, S. Kobayashi, *Adv. Synth. Catal.*, 2005, **347**, 1499.

121 G. W. Kabalka, G. Dong, B. Venkataiah, *Org. Lett.*, 2003, **5**, 893.

122 P. R. Eastwood, *Tetrahedron Lett.*, 2000, **41**, 3705.

123 A. Gopalarathnam, S. G. Nelson, *Org. Lett.*, 2006, **8**, 7.

124 J. H. Kirchhoff, M. R. Netherton, I. D. Hills, G. C. Fu, *J. Am. Chem. Soc.*, 2002, **124**, 13662.

125 J. Zhou, G. C. Fu, *J. Am. Chem. Soc.*, 2004, **126**, 1340.

126 E. Tyrrell, P. Brookes, ‘The synthesis and reactivity of heterocyclic boronic acids’ *Synthesis*, 2003, 469.

127 P. R. Parry, C. Wang, A. S. Batsanov, M. R. Bryce, B. Tarbit, *J. Org. Chem.*, 2002, **67**, 7541; P. R. Parry, M. R. Bryce, B. Tarbit, *Synthesis*, 2003, 1035.

128 A. Bouillon, J.-C. Lancelot, V. Collot, P. R. Bovy, S. Rault, *Tetrahedron*, 2002, **58**, 2885, 3323.

129 A. Sutherland, T. Gallagher, *J. Org. Chem.*, 2003, **68**, 3352; ‘The synthesis and reactivity of halopyridyl boronic acids’, 2003; copies of this article available on request from Alfa Aesar.

130 S. Darses, T. Jeffery, J.-L. Brayer, J.-P. Demoute, J.-P. Genêt, *Bull. Soc. Chim. Fr.*, 1996, **133**, 1095; S. Darses, T. Jeffery, J.-P. Genêt, J.-L. Brayer, J.-P. Demoute, *Tetrahedron Lett.*, 1996, **37**, 3857; S. Sengupta, S. Bhattacharyya, *J. Org. Chem.*, 1997, **62**, 3405.

131 S. Darses, J. L. Brayer, J.-P. Demoute, J.-P. Genêt, *Tetrahedron Lett.*, 1997, **38**, 4393. For a review, see ‘Organotrifluoroborates: new persoectives in organic chemistry’, S. Darses, J.-P. Genêt, *Eur. J. Org. Chem.*, 2003, 4313.

132 S. Darses, G. Michaud, J.-P. Genêt, *Tetrahedron Lett.*, 1998, **39**, 5045; *Eur. J. Org. Chem.*, 1999, 1875.

133a G. A. Molander, B. Biolatto, *Org. Lett.*, 2002, **4**, 1867.

133b G. A. Molander, B. Biolatto, *J. Org. Chem.*, 2003, **68**, 4302.

134 G. A. Molander, D. E. Petrillo, N. R. Landzberg, J. C. Rohanna, B. Biolatto, *Synlett*, 2005, 1763.

135 R. A. Batey, T. D. Quach, M. Shen, A. N. Thadani, D. V. Smil, S.-W. Li, D. B. MacKay, *Pure Appl. Chem.*, 2002, **74**, 43.

136 G. A. Molander, M. D. Elia, *J. Org. Chem.*, 2006, **71**, 9198.

137 G. A. Molander, M. R. Rivero, *Org. Lett.*, 2002, **4**, 107; G. A. Molander, C. R. Bernardi, *J. Org. Chem.*, 2002, **67**, 8424.

138 A. R. Hunt, S. K. Stewart, A. Whiting, *Tetrahedron Lett.*, 1993, **34**, 3599.

139 G. W. Kabalka, M. Al-Masum, A. R. Mereddy, E. Dadush, *Tetrahedron Lett.*, 2006, **47**, 1133.

140 G. A. Molander, L. A. Felix, *J. Org. Chem.*, 2005, **70**, 3980.

141 G. A. Molander, N. Ellis, ‘Organotrifluoroborates: protected boronic acids that expand the versatility of the Suzuki coupling reaction’, *Acc. Chem. Res.*, 2007, **40**, 275.

142 H. A. Stefani, R. Cella, ‘Recent advances in organotrifluoroborate chemistry’, A. S. Vieira, *Tetrahedron*, 2007, **63**, 3623.

143 S. Darses, J.-P. Genêt, ‘Potassium organotrifluoroborates: new perspectives in organic synthesis’, *Chem. Rev.*, 2008, **108**, 288.

144 S. R. Chemler, D. Trauner, S. J. Danishefsky, 'The B-alkyl Suzuki-Miyaura cross-coupling reaction: development, mechanistic study and applications in natural product synthesis', *Angew Chem. Int. Ed.*, 2001, **40**, 4545.

145 G. A. Molander, C.-S. Yun, *Tetrahedron*, 2002, **58**, 1465

146 G. A. Molander, C.-S. Yun, M. Ribagorda, B. Biolatto, *J. Org. Chem.*, 2003, **68**, 5534.

147 H. Doucet, 'Suzuki–Miyaura cross-coupling reactions of alkylboronic acid derivatives or alkyltrifluoroborates with aryl, alkenyl or alkyl halides and triflates', Eur. *J. Org. Chem.*, 2008, 2013.

148 T. Ishiyama, H. Kizaki. N. Miyaura, A. Suzuki, *Tetrahedron Lett.*, 1993, **34**, 7595; T. Ishiyama, H. Kizaki, T. Hayashi, A. Suzuki, N. Miyaura, *J. Org. Chem.*, 1998, **63**, 4726.

149 C. S. Cho, T. Ohe, S. Uemara, *J. Organomet. Chem.*, 1995, **496**, 221.

150 M. Haddach, J. R. McCarthy, *Tetrahedron Lett.*, 1999, **40**, 3109.

151 V. Polackova, S. Toma, I. Augustinova, *Tetrahedron*, 2006, **62**, 11675.

152 Y. Urawa, K. Nishiura, S. Souda, K. Ogura, *Synthesis*, 2003, 2882.

153 N. A. Bumagin, D. N. Korolev, *Tetrahedron Lett.*, 1999, **40**, 3057.

154 B. Xin, Y. Zhang, K. Cheng, *J. Org. Chem.*, 2006, **71**, 5725.

155 C. G. Frost, K. J. Wadsworth, *Chem. Commun.*, 2001, 2316.

156 Y.-Z. Duan, M.-Z. Deng, *Synlett*, 2005, 355.

157 M. Lysén, S. Kelleher, M. Begtrup, J. L. Kristensen, *J. Org. Chem.*, 2005, **70**, 5342.

158 L. S. Liebeskind, J. Srogl, *J. Am. Chem. Soc.*, 2000, **122**, 11260.

159 R. Kakino, I. Shimizu, A. Yamamoto, *Bull. Chem. Soc. Jpn.*, 2001, **74**, 371.

160 M. B. Mitchell, P. J. Wallbank, *Tetrahedron Lett.*, 1991, **32**, 2273.

161 R. S. Varma, A. K. Chatterjee, M. Varma, *Tetrahedron Lett.*, 1993, **34**, 3207.

162 N. A. Bugamin, V. V. Bykov, I. P. Beletskaya, *Bull. Acad. Sci. USSR*, 1989, **38**, 2206; T. I. Wallow, B. M. Novak, *J. Org. Chem.*, 1994, **59**, 5034; D. Badone, M. Barone, R. Cardamone, A. Ielmini, U. Guzzi, *J. Org. Chem.*, 1997, **62**, 7170.

163 L. Liu, Y. Zhang, B. Xin, *J. Org. Chem.*, 2006, 71, 3994.

164 W. Müller, D. A. Lowe, H. Neijt, S. Urwyler, P. L. Herrling, *Helv. Chim. Acta*, 1992, **75**, 855.

165 X. Tao, Y. Zhao, D. Shen, *Synlett*, 2004, 359.

166 N. Jiang, A. J. Ragauskas, *Tetrahedron Lett.*, 2006, **47**, 197.

167 G. Marck, A. Villger, R. Buchecker, *Tetrahedron Lett.*, 1994, **35**, 3277; D. Gala, A. Stamford, J. Jenkins, M. Kugelman, *Org. Process Res. Dev.*, 1997, **1**, 163; D. S. Ennis, J. McManus, W. Wood-Kaczmar, J. Richardson, G. E. Smith, A. Carstairs, *Org. Process Res. Dev.*, 1999, **3**, 248.

168 M. Lysen, K. Köhler, *Synlett*, 2005, 1671.

169 D. A. Conlon, B. Pipik, S. Ferdinand, C. R. LeBlond, J. R. Sowa, B. Izzo, P. Collins, G.-J. Ho, J. M. Williams, Y.-J. Shi, Y. Sun, *Adv. Synth. Catal.*, 2003, **345**, 931.

170 F.-X. Felpin, T. Ayad, S. Mitra, 'Pd/C: an old catalyst for new applications – its use for the Suzuki–Miyaura reaction', *Eur. J. Org. Chem.*, 2006, 2679.

171 T. Y. Zhang, M. J. Allen, *Tetrahedron Lett.*, 1999, **40**, 5813.

172 T. J. Colacot, E. S. Gore, A. Kuber, *Organometallics*, 2002, **21**, 3301.

173 Y. Wang, D. R. Sauer, *Org. Lett.*, 2004, **6**, 2793.

174 M. Beller, H. Fischer, W. A. Herrmann, K. Öfele, *Angew. Chem. Int. Ed.*, 1995, **34**, 1848; EP 690,046 (Hoechst A.-G.).

175 D. Zim, A. L. Monteiro, *Tetrahedron Lett.*, 2002, **43**, 4009.

176 C. Griffiths, N. E. Leadbeater, *Tetrahedron Lett.*, 2000, **41**, 2487.

177 A. Zapf, M. Beller, *Chem. Eur. J.*, 2000, **6**, 1830.

178 J.-H. Li, W.-J. Liu, *Org. Lett.*, 2004, **6**, 2809.

179 J.-H. Li, W.-J. Liu, Y.-X. Xie, *J. Org. Chem.*, 2005, **70**, 5409; J.-H. Li, X.-C. Hu, Y. Liang, Y.-X. Xie, *Tetrahedron*, 2006, **62**, 31.

180 A. Fürstener, A. Leitner, *Synlett*, 2001, 290.

181 K. Arentsen, S. Caddick, F. G. N. Cloke, A. P. Herring, P. B. Hitchcock, *Tetrahedron Lett.*, 2004, **45**, 3511.

182 I. J. S. Fairlamb, A. R. Kapdi, A. F. Lee, *Org. Lett.*, 2004, **6**, 4435.

183 C. H. Oh, Y. M. Lim, C. H. You, *Tetrahedron Lett.*, 2002, **43**, 4645.

184 M. B. Thathagar, J. Beckers, G. Rothenburg, *J. Am. Chem. Soc.*, 2002, **124**, 11858; *Adv. Synth. Catal.*, 2003, **345**, 979.

185 J.-H. Li, D.-P. Wang, *Eur. J. Org. Chem.*, 2006, 2063; J.-H. Li, J.-L. Li. Li, D.-P. Wang, S.-F. Pi, Y.-X.-Zie, M.-B. Zhang, X.-C. Hu, *J. Org. Chem.*, 2007, **72**, 2053.

186 R. R. Dilip, V. Jarikote, K. V. Srinivasan, *Chem. Commun.*, 2002, 616.

187 Y. Yang, A.-B. Hörnfeldt, S. Gronowitz, *J. Heterocycl. Chem.*, 1989, **26**, 865.

188 T. Watanabe, N. Miyaura, A. Suzuki, *Synlett*, 1992, 207.

189 S. W. Wright, D. L. Hageman, L. D. McClure, *J. Org. Chem.*, 1994, **59**, 6095.

190 S.A. Frank, H. Chen, R. K. Kunz, M. J. Schnaderbeck, W. R. Roush, *Org. Lett.*, 2000, **2**, 2691.

191 N. Jiang, A. R. Ragauskas, *Tetrahedron Lett.*, 2006, **47**, 197.

192 L. Liu, Y. Ziang, Y. Wang, *J. Org. Chem.*, 2005, **70**, 6122.

193 S. M. Nobre, S. I Wolke, R. G. da Rosa, A. L. Monteiro, *Tetrahedron Lett.*, 2004, **45**, 6527.

194 C. J. Mathews, P. J. Smith, T. Welton, *Chem. Commun.*, 2000, 1249.

195 B. Xin, Y. Zhang, L. Liu, Y. Wang, *Synlett*, 2005, 3083.

196 C. M. Gordon, 'Palladium catalysed C-C-coupling reactions in ionic liquids', *Lancaster Reactivity*, 2003, xi; copies of this article available on request from Alfa Aesar.

197 N. E. Leadbeater, M. E. Marco, *Org. Lett.*, 2002, **4**, 2973.

198 R. K. Arvela, N. E. Leadbeater, *Org. Lett.*, 2005, **7**, 2101.

199 G. Miao, P. Ye, L. Yu, C. M. Baldino, *J. Org. Chem.*, 2005, **70**, 2332.

200 N. E. Leadbeater, M. E. Marco, *J. Org. Chem.*, 2003, **68**, 5660.

201 R. K. Arvela, N. E. Leadbeater, M. S. Sangi, V. A. Williams, P. Granados, R. D. Singer, *J. Org. Chem.*, 2005, **70**, 161.

202 R. K. Arvela, N. E. Leadbeater, T. L. Mack, C. M. Kormos, *Tetrahedron Lett.*, 2006, **47**, 217.

203 L. Bai, J. X. Wang, 'Environmentally friendly aryl-aryl cross-coupling reactions', *Current Org. Chem.*, 2005, **9**, 535.

204 C. S. Cho, S. Motofusa, K. Ohe, S. Uemura, S. C. Shim, *J. Org. Chem.*, 1995, **60**, 883.

205 T. Yamamoto, T. Ohta, Y. Ito, *Org. Lett.*, 2005, **7**, 4153.

206 T. Yamamoto, M. Iizuka, T. Ohta, Y. Ito, *Chem. Lett.*, 2006, 198.

207 C. Qin, H. Wu, J. Cheng; X. Chen, M. Liu, W. Zhang, W. Su, J. Ding, *J. Org. Chem.*, 2007, **72**, 4102.

208 B. Zhao, X. Lu, *Tetrahedron Lett.*, 2006, **47**, 6765.

209 M. Sakai, H. Hayashi, N. Miyaura, *Organometallics*, 1997, **16**, 4229.

210 M. Sakai, M. Ueda, N. Miyaura, *Angew. Chem. Int. Ed.*, 1998, **37**, 3279.

211 R. Batey, A. N. Thadani, D. V. Smil, *Org. Lett.*, 1999, **1**, 1683.

212 M. Pucheault, S. Darses, J.-P. Genêt, *Chem. Commun.*, 2005, 4714.

213 Y. Takaya, M. Ogasawara, T. Hayashi, M. Sakai, N. Miyaura, *J. Am. Chem. Soc.*, 1998, **120**, 5579; Y. Takaya, M. Ogasawara, T. Hayashi, *Tetrahedron Lett.*, 1999, **40**, 6957.

214 S. Sakuma, M. Sakai, R. Itooka, N. Miyaura, *J. Org. Chem.*, 2000, **65**, 5951.

215 S. Sakuma, N. Miyaura, *J. Org. Chem.*, 2001, **66**, 8944.

216 T. Hayashi, 'Rhodium-catalyzed asymmetric 1,4-additions of organoboronic acids and their derivatives to electron deficient olefins', *Synlett*, 2001, 879.

217 R. Itooka, Y. Iguchi, N. Miyaura, *Chem. Lett.*, 2001, 722; *J. Org. Chem.*, 2003, **68**, 6000, and references therein.

218 See for example J.-F. Paquin, C. Defiebier, C. R. J. Stephenson, E. M. Carreira, *J. Am. Chem. Soc.*, 2005, **127**, 10850.

219 T. Miura; Y. Takahashi; M. Murakami, *Chem. Commun.*, 2007, 3577.

220 K. Fagnou, M. Lautens, 'Rhodium-catalyzed carbon-carbon bond-forming reactions of organometallic compounds', *Chem. Rev.*, 2003, **103**, 169.

221 C. S. Cho, S. Uemura, *J. Organomet. Chem.*, 1994, **465**, 85.

222 X. Du, M. Suguro, K. Hirabayashi, A. Mori, *Org. Lett.*, 2001, **3**, 3313.

223 Y. C. Yung, R. K. Mishra, C. W. Yoon, K. W. Jung, *Org. Lett.*, 2003, **5**, 2231.

224 M. S. A. Murugaiah, P. Nilsson, H. von Schenck, M. Larhed, *J. Org. Chem.*, 2004, **69**, 5212.

225 G. W. Kabalka, S. K. Guchhait, *Tetrahedron Lett.*, 2004, **45**, 4021.

226 G. W. Kabalka, S. K. Guchhait, A. Naravane, *Tetrahedron Lett.*, 2004, **45**, 4685.

227 E. J. Farrington, J. M. Brown, C. F. J. Barnard, E. Rowsell, *Angew. Chem. Int. Ed.*, 2002, **41**, 169.

228 G. Zou, Z. Wang, J. Zhu, J. Tang, *Chem. Commun.*, 2003, 2438.

229 J. Ruan, X. Li, O. Saidi, J. Xiao, *J. Am. Chem. Soc.*, 2008, **130**, 2424.

230 M. Lautens, A. Roy, K. Fukuoka, K. Fagnou, B. Martín-Matute, *J. Am. Chem. Soc.*, 2001, **123**, 5358.

231 M. Lautens, M.Yoshida, *Org. Lett.*, 2002, **4**, 123.

232 T. Hayashi, K. Inoue, N. Taniguchi, M. Ogasawara, *J. Am. Chem. Soc.*, 2001, **123**, 9918.

233 C. H. Oh, H. H. Jung, K. S. Kim, N. Kim, *Angew. Chem. Int. Ed.*, 2003, **42**, 805.

234 G. Zou, J. Zhu, J. Tang, *Tetrahedron Lett.*, 2003, **44**, 8709.

235 N. Kim, K. S. Kim, A. K. Gupta, C. H. Oh, *Chem. Commun.*, 2004, 618.

236 C. Zhou, R. C. Larock, *Org. Lett.*, 2005, **7**, 259.

237 F. Kakiuchi, S. Kan, K. Igi, N. Chatani, S. Murai, *J. Am. Chem. Soc.*, 2003, **125**, 1698; F. Kakiuchi, Y. Matsuura, S. Kan, N. Chatani, *J. Am. Chem. Soc.*, 2005, **127**, 5936.

238 S. Ueno, N. Chatani, F. Kakiuchi, *J. Org. Chem.*, 2007, **72**, 3600.

239 Z. Zhang; L. S. Liebeskind, *Org. Lett.*, 2006, **8**, 4331.

240 K. Ukai; M. Aoki; J. Takaya; N. Iwasawa, *J. Am. Chem. Soc.*, 2006, **128**, 8706.

241 N. A. Petasis, I. Akritopoulou, *Tetrahedron Lett.*, 1993, **34**, 583.

242 N. A. Petasis, I. A. Zavialov, *J. Am. Chem. Soc.*, 1997, **119**, 445.

243 N. A. Petasis, , A. Goodman, I. A. Zavialov, *Tetrahedron*, 1997, **53**, 16463.

244 L. M. Harwood, G. S. Currie, M. G. B. Drew, R. W. A. Luke, *Chem. Commun.*, 1996, 1953; G. S. Currie, M. G. B. Drew, L. M. Harwood, D. J. Hughes, R. W. A. Luke, R. J. Vickers, *J. Chem. Soc., Perkin 1*, 2000, 2982.

245 N. Schlienger, M. R. Bryce, T. K. Hansen, *Tetrahedron*, 2000, **56**, 10023.

246 T. Koolmeister, M. Södergren, M. Scobie, *Tetrahedron Lett.*, 2002, **43**, 5965.

247 T. Koolmeister, M. Södergren, M. Scobie, *Tetrahedron Lett.*, 2002, **43**, 5969.

248 N. A. Petasis, I. A. Zavialov, *J. Am. Chem. Soc.*, 1998, **120**, 11798.

249 G. K. S. Prakash, M. Mandal, S. Schweizer. N. A. Petasis, G. A. Olah, *Org. Lett.*, 2000, **2**, 3173.

250 J.-P. Tremblay-Morin, S. Raeppel, F. Gaudette, *Tetrahedron Lett.*, 2004, **45**, 3471.

251 H. Jourdan, G. Gouhier, L. Van Hijfte, P. Angbaud, S. R. Piettre, *Tetrahedron Lett.*, 2005, **46**, 8027.

252 T. Ishiyama, T. Ahiko, N. Miyaura, *J. Am. Chem. Soc.*, 2002, **124**, 12414.

253 U. Schneider, S. Kobayashi, *Angew. Chem. Int. Ed.*, 2007, **46**, 5909.

254 D. G. Hall, ‘Lewis and Brønsted acid catalyzed allylboration of carbonyl compounds: from discovery to mechanism and applications’, *Synlett*, 2007, 1644.

255 H. Kuivilla, *J. Am. Chem. Soc.*, 1954, **76**, 870.

256 K. S. Webb, D. Levy, *Tetrahedron Lett.*, 1995, **36**, 5117.

257 D. A. Evans, J. L. Katz, T. R. West, *Tetrahedron Lett.*, 1998, **39**, 2937.

258 D. M. T. Chan, K. L. Monaco, R.-P. Wang, M. P. Winters, *Tetrahedron Lett.*, 1998, **39**, 2933.

259 H. M. Petrassi, K. B. Sharpless, J. W. Kelly, *Org. Lett.*, 2001, **3**, 139.

260 J. C. Antilla, S. L. Buchwald, *Org. Lett.*, 2001, **3**, 2077.

261 D. J. Cundy, S. A. Forsyth, *Tetrahedron Lett.*, 1998, **39**, 7979.

262 P. Y. S. Lam, C. G. Clark, S. Saubern, J. Adams, M. P. Winters, D. M. T. Chan, A. Combs, *Tetrahedron Lett.*, 1998, **39**, 2941.

263 A. P. Combs, S. Saubern, M. Rafalski, P. Y. S. Lam, *Tetrahedron Lett.*, 1999, **40**, 1623.

264 P. S. Herradura, K. A. Pendola, R. K. Guy, *Org. Lett.*, 2000, **2**, 2019.

265 C. Beaulieu, D. Guay, Z. Wang, D. A. Evans, *Tetrahedron Lett.*, 2004, **45**, 3233.

266 M. L. Kantam, B. Neelima, B. Sreedhar, R. Chakravarti, *Synlett*, 2008, 1455.

267 M. T. Chan, P. Y. S. Lam, ‘Recent advances in copper-promoted C-heteroatom bond cross-coupling reactions with boronic acids and derivatives’, chapter 5 in ref. 9.

268 S. V. Ley, A. W. Thomas, ‘Modern Synthetic Methods for Copper-mediated C(Aryl)-O,C (Aryl)-N and C(Aryl)-S bond formation’, *Angew Chem. Int. Ed.*, 2003, **42**, 5400.

269 J. C. Antilla, S. L. Buchwald, *Org. Lett.*, 2001, **3**, 2077.

270 T. D. Quach, R. A. Batey, *Org. Lett.*, 2003, **5**, 1381.

271 T. D. Quach, R. A. Batey, *Org. Lett.*, 2003, **5**, 4397.

272 Y. Yu, J. Srogl, L. S. Liebeskind, *Org. Lett.*, 2004, **6**, 2631.

273 P. B. Bandgar, S. V. Bettigeri, J. Phopase, *Org. Lett.*, 2004, **6**, 2105.

274 C. Beaulieu, D. Guay, Z. Wang, D. A. Evans, *Tetrahedron Lett.*, 2004, **45**, 3223.

275 F. Huang, R. A. Batey, *Tetrahedron*, 2007, **63**, 7667.

276 A. D. Ainley, F. Challenger, *J. Chem. Soc.*, 1930, 2171.

277 C. Thiebes, G. K. S. Prakash, N. A. Petasis, G. A. Olah, *Synlett*, 1998, 141.

278 R. H. Szumigala, P. N. Devine, D. R. Gauthier, R. P. Volante, *J. Org. Chem.*, 2004, **69**, 566.

279 G. W. Kabalka, A. R. Mereddy, *Tetrahedron Lett.*, 2004, **45**, 343.

280 J. M. Clough, L. J. Diorazio, D. A. Widdowson, *Synlett*, 1990, 761.

281 M. A. Carroll, V. W. Pike, D. A. Widdowson, *Tetrahedron Lett.*, 2000, **41**, 5393, and references therein.

282 N. A. Petasis, I. A. Zavialov, *Tetrahedron. Lett.*, 1996, **37**, 567.

283 G. W. Kabalka, A. R. Mereddy, *Tetrahedron Lett.*, 2004, **45**, 1417.

284 N. A. Petasis, A. K. Yudin, I. A. Zavialov, G. K. S. Prakash, G. A. Olah, *Synlett*, 1997, 606.

285 S. Salzbrunn, J. Simon, G. K. S. Prakash, N. A. Petasis, G. A. Olah, *Synlett*, 2000, 1485.

286 G. K. S. Prakash, C. Panja, T. Mathew, V. Surampudi, N. Petasis, G. A. Olah, *Org. Lett.*, 2004, **6**, 2205.

287 J. Morgan, J. T. Pinhey, *J. Chem. Soc., Perkin 1*, 1990, 715.

288 M.-L. Huber, J. T. Pinhey, *J. Chem. Soc., Perkin 1*, 1990, 721.

289 L. Dong, Y.-J. Xu, L.-Z. Gong, A.-Q. Mi, Y.-Z. Jiang, *Synthesis*, 2004, 1057.

290 H. Gilman, C. C. Vernon, *J. Am. Chem. Soc.*, 1926, **48**, 1063.

291 R. M. Washburn, F. A. Billig, M. Bloom, C. F. Albright, E. Levens, *Adv. Chem. Ser.*, 1961, **32**, 208.

292 R. M. Washburn, E. Levens, C. F. Albright, F. A. Billig, *Org. Synth. Coll.*, 1963, **4**, 68.

293 H. C. Brown, T. E. Cole, *Organometallics*, 1983, **2**, 1316.

294 R. W. Hoffmann, R. Metternich, J. W. Lanz, *Liebigs Ann. Chem.*, 1987, 881; M. W. Andersen, B. Hildebrandt, G. Köstner, R. W. Hoffmann, *Chem. Ber.*, 1989, **122**, 1777; R. W. Wallace, K. K. Zong, *Tetrahedron Lett.*, 1992, **33**, 6941.

295 For reviews: V. Snieckus, ‘Directed ortho metalation. Tertiary amide and O-carbamate directors in synthetic strategies’, *Chem. Rev.*, 1990, **90**, 879; E. J.-G. Anctil, V, Snieckus, ‘The directed ortho-metallation (DoM) cross-coupling Nexus. Synthetic methodology for the formation of aryl-aryl and aryl-heteroatom-aryl bonds’ in *Metal-Catalyzed Cross-Coupling Reactions, 2nd ed.*, A. de Meijere, F. Diederich, Ed., Wiley-VCH, Weiheim, 2004.

296 M. J. Sharp, V. Snieckus, *Tetrahedron Lett.*, 1985, **26**, 5997.

297 M. J. Sharp, M. J. Cheng, V. Snieckus, *Tetrahedron Lett.*, 1987, **28**, 5093, 5097.

298 W. Haubold, J. Herdtle, W. Gollinger, W. Einholz, *J. Organomet. Chem.*, 1986, **315**, 1.

299 D. Kaufmann, *Chem. Ber.*, 1987, **120**, 853, 901; Z. Z. Song, Z. Y. Zhou, T. C. W. Mak, H. N. C. Wong, *Angew. Chem. Int. Ed.*, 1993, **32**, 432; G. M. Farinola, V. Fiandanese, L. Mazzone, F. Naso, *J. Chem. Soc., Chem. Commun.*, 1995, 2523; D. A. Singleton, S.-W. Leung, *J. Organomet. Chem.*, 1997, **544**, 157.

300 S. Caron, J. M. Hawkins, *J. Org. Chem.*, 1998, **63**, 2054.

301 H. C. Brown, S. Gupta, *J. Am. Chem. Soc.*, 1971, **93**, 1816; 1972, **94**, 4370; 1975, **97**, 5249; C. F. Lane, G. W. Kabalka, *Tetrahedron*, 1976, **32**, 981.

302 A. Arase, Y. Nunokawa, Y. Masuda, M. Hoshi, *J. Chem. Soc, Chem. Commun.*, 1991, 205.

303 D. Männig, H. Nöth, *Angew. Chem. Int. Ed.*, 1985, **24**, 878.

304 D. A. Evans, G. C. Fu, A. Hoveyda, *J. Am. Chem. Soc.*, 1992, **114**, 6671; D. A. Evans, G. C. Fu, B. A. Anderson, *J. Am. Chem. Soc.*, 1992, **114**, 6674.

305 I. D. Gridnev, N. Miyaura, A. Suzuki, *Organometallics*, 1993, **12**, 589.

306 I. D. Gridnev, N. Miyaura, A. Suzuki, *J. Org. Chem.*, 1993, **58**, 5351.

307 S. Pereira, M. Srebnik, *Tetrahedron Lett.*, 1996, **37**, 3283.

308 M. Murata, S. Watanabe, Y. Masuda, *Tetrahedron Lett.*, 1999, **40**, 2585; M. Murata, K. Kawakita, T. Asana, S. Watanabe, Y. Masuda, *Bull. Chem. Soc. Jpn.*, 2002, **75**, 825.

309 C. E. Tucker, J. Davidson, P. Knochel, *J. Org. Chem.*, 1992, **57**, 3482.

310 T. Ishiyama, M. Murata, N. Miyaura, *J. Org. Chem.*, 1995, **60**, 7508.

311 T. Ishiyama, Y. Itoh, T. Kitano, N. Miyaura, *Tetrahedron Lett.*, 1997, **38**, 3447.

312 D. M. Willis, R. M. Strongin, *Tetrahedron Lett.*, 2000, **41**, 8683.

313 S. R. Piettre, S. Balzer, *Tetrahedron Lett.*, 1997, **38**, 1197.

314 P. Appukkuttan, E. Van der Eycken, W. Dehaen, *Synlett*, 2003, 1204.

315 L. Zhu, J. Duquette, M. Zhang, *J. Org. Chem.*, 2003, **68**, 3729.

316 K. L. Billingsley, T. E. Barder, S. L. Buchwald, *Angew. Chem. Int. Ed.*, 2007, **46**, 5359.

317 M. Murata, S. Watanabe, Y. Masuda, *J. Org. Chem.*, 1997, **62**, 6458; M. Murata, T. Oyama, S. Watanabe, Y. Masuda, *J. Org. Chem.*, 2000, **65**, 164.

318 P.-E. Brontin, I. Cerna, M. Campaniello, F. Leroux, F. Colobert, *Org. Lett.*, 2004, **6**, 4419.

319 W. Zhu, D. Ma, *Org. Lett.*, 2006, **8**, 261.

320 M. Murata, S. Watanabe, Y. Masuda, *Tetrahedron Lett.*, 2000, **41**, 5877.

321 K. Takahashi, J. Takagi, T. Ishiyama, N. Miyaura, *Chem. Lett.*, 2000, 126.

322 J. Tagaki, A. Kamon, T. Ishiyama, N. Miyaura, *Synlett*, 2002, 1880.

323 T. Ishiyama, Z. Oohashi, T. Ahiko, N. Miyaura, *Chem. Lett.*, 2002, 780.

324 A. Giroux, *Tetrahedron Lett.*, 2003, **44**, 233.

325 T. Ishiyama, T. Ahiko, N. Miyaura, *Tetrahedron Lett.*, 1996, **37**, 6889.

326 K. Takahashi, T. Ishiyama, N. Miyaura, *Chem. Lett.*, 2000, 982; *J. Organomet. Chem.*, 2001, **625**, 47.

327 T. Ishiyama, N. Matsuda, N. Miyaura A. Suzuki, *J. Am. Chem. Soc.*, 1993, **115**, 11018; T. Ishiyama, N. Matsuda, M. Murata, F. Ozawa, A. Suzuki, N. Miyaura, *Organometallics*, 1996, **15**, 713.

328 G. Lesley, P. Nguyen, N. J. Taylor, T. B. Marder, A. J. Scott, W. Clegg, N. C. Norman, *Organometallics*, 1996, **15**, 5137; R. L. Thomas, F. E. S. Souza, T. B. Marder, *J. Chem. Soc. Dalton*, 2001, 1650.

329 T. Ishiyama, M. Yamamoto, N. Miyaura, *Chem. Commun.*, 1996, 2073.

330 T. B. Marder, N. C. Norman, ‘Transition metal catalyzed diboration’, *Topics Catal.*, 1998, **5**, 63.

331 Y. G. Lawson, M. J. G. Lesley, T. B. Marder, N. C. Norman, C. R. Rice, *Chem. Commun.*, 1997, 2051

332 H. A. Ali, I. Goldberg, M. Srebnik, *Organometallics*, 2001, **20**, 3962.

333 H. Ito, H. Yamanaka, J. Tateiwa, A. Hosomi, *Tetrahedron Lett.*, 2000, **41**, 6821.

334 G. W. Kabalka, B. C. Das, S. Das, *Tetrahedron Lett.*, 2002, **43**, 2323.

335 T.Ishiyama, K. Ishida, J. Takagi, N. Miyaura, *Chem. Lett.*, 2001, 1082.

336 M. K. Tse, J.-Y. Cho, M. R. Smith, *Org. Lett.*, 2001, **3**, 2831.

337 T. Ishiyama, J. Tagaki, K. Ishida, N. Miyaura, N. R. Anastasi, J. F. Hartwig, *J. Am. Chem. Soc.*, 2002, **124**, 390.

338 J. Tagaki, K. Sato, J. F. Hartwig, T. Ishiyama, N. Miyaura, *Tetrahedron Lett.*, 2002, **43**, 5649.

339 G. A. Chotana, M. A. Rak, M. R. Smith, *J. Am. Chem. Soc.*, 2005, **127**, 10539.

340 A. Datta, A. Köllhofer, H. Plenio, *Chem. Commun.*, 2004, 1508.

341 C. C. Tzschucke, J. M. Murphy, J. F. Hartwig, *Org. Lett.*, 2006, **9**, 761.

342 J. M. Murphy, X. Liao, J. F. Hartwig, *J. Am. Chem. Soc.*, 2007, **129**, 15434.

343 The ester with 2-methyl-2,4-pentanediol [4,4,6-trimethyl-2-vinyl-1,3,2-dioxaborinane] is claimed to be more stable: A. P. Lightfoot, S. J. R. Twiddle, A, Whiting, *Synlett*, 2005, 529.

344 S. K. Stewart. A. Whiting, *J. Organomet. Chem.*, 1994, **482**, 293; *Tetrahedron Lett.*, 1995, **36**, 3925; N. Henaff, A. Whiting, *Tetrahedron*, 2000, **56**, 5193.

345 K. Tonogaki, K. Soga, K. Itami, J. Yoshida, *Synlett*, 2005, 1802.

346 H. E. Blackwell, D. J. O’Leary, A. K. Chatterjee, R. A. Washenfelder, D. A. Bussmann, R. H. Grubbs, *J. Am. Chem. Soc.*, 2000, **122**, 58.

347 R. H. Wallace, K. K. Zong, *Tetrahedron Lett.*, 1992, **33**, 6941.

348 M. Jazouli, S. Baba, B. Carboni, R. Carrie, M. Soufiaoui, *J. Organomet. Chem.*, 1995, **498**, 229; *Tetrahedron Lett.*, 1997, **38**, 6665.

349 N. Guennouni, F. Lhermitte, S. Cochard, B. Carboni, *Tetrahedron*, 1995, **51**, 6999.

350 A. McCarroll, J. C. Walton, R. Nziengui, B. Carboni, *Chem. Commun.*, 1997, 2075; J. C. Walton, A. J. McCarroll, Q. Chen, B. Carboni, R. Nziengui, *J. Am. Chem. Soc.*, 2000, **122**, 5255.

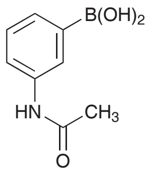
351 H. Lopez-Ruiz, S. Z. Zard, *Chem. Commun.*, 2001, 2618.

The Alfa Aesar Range of Boronics

Arylboronic acids

3-Acetamidobenzeneboronic acid, 98%

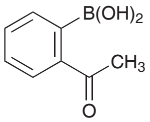
B23833
[78887-39-5]



1g
5g
25g

2-Acetylbenzeneboronic acid, 97%

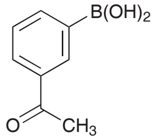
H27327
[308103-40-4]



5g
25g

3-Acetylbenzeneboronic acid, 97%

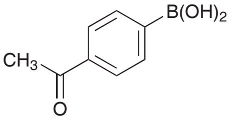
B23478
[204841-19-0]



1g
5g
25g

4-Acetylbenzeneboronic acid, 98%

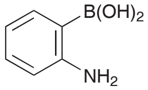
B23234
[149104-90-5]



1g
5g
25g

2-Aminobenzeneboronic acid, 96%

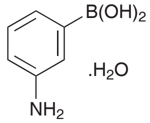
L18069
[5570-18-3]



100mg
1g
5g

3-Aminobenzeneboronic acid monohydrate, 97%

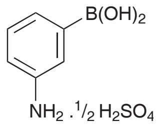
A18189
[206658-89-1]



1g
5g
25g

3-Aminobenzeneboronic acid hemisulfate, 98+%

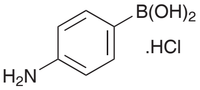
A17240
[66472-86-4]



1g
5g
25g

4-Aminobenzeneboronic acid hydrochloride, 97%

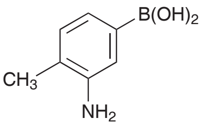
H27479
[80460-73-7]



100mg
500mg

3-Amino-4-methylbenzeneboronic acid, 98%

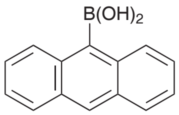
L17695
[22237-12-3]



1g
5g

9-Anthraceneboronic acid, 99%

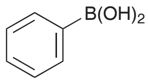
L19630
[100622-34-2]



100mg
500mg

Benzeneboronic acid, 98+%

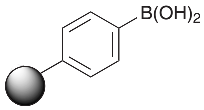
A14257
[98-80-6]



10g
50g
250g

Benzeneboronic acid, polymer-supported, 2.6-3.2 mmol/g

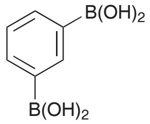
L19459



1g
5g
25g

1,3-Benzenediboronic acid, 97%

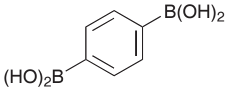
B24903
[4612-28-6]



1g
5g
25g

1,4-Benzenediboronic acid, 96%

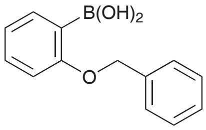
B24064
[4612-26-4]



1g
5g
25g

2-Benzyloxybenzeneboronic acid, 96%

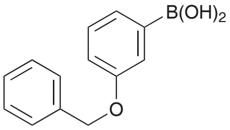
L20100
[190661-29-1]



1g
5g

3-Benzyloxybenzeneboronic acid, 98+%

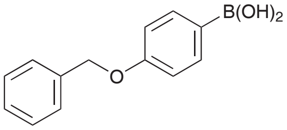
L17474
[156682-54-1]



1g
5g

4-Benzyloxybenzeneboronic acid, 97%

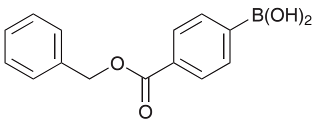
B24351
[146631-00-7]



250mg
1g
5g

4-(Benzyloxycarbonyl)benzeneboronic acid, 95%

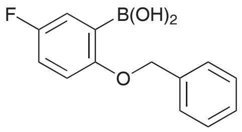
H27675
[184000-11-1]



100mg
500mg

2-Benzyloxy-5-fluorobenzeneboronic acid, 98%

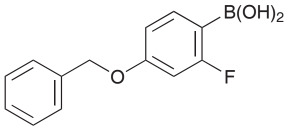
H25880
[779331-47-4]



250mg
1g
5g

4-Benzyloxy-2-fluorobenzeneboronic acid, 98%

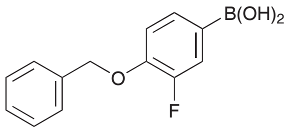
L18521
[166744-78-1]



250mg
1g
5g

4-Benzyloxy-3-fluorobenzeneboronic acid, 98%

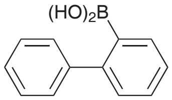
L18520
[133057-83-7]



250mg
1g

2-Biphenylboronic acid, 95%

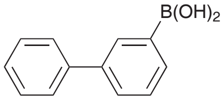
L17547
[4688-76-0]



1g

3-Biphenylboronic acid, 98%

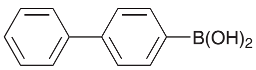
L17552
[5122-95-2]



1g
5g

4-Biphenylboronic acid, 98+%

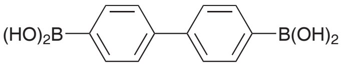
B23703
[156682-54-1]



1g
5g
25g

4,4'-Biphenyldiboronic acid, 97%

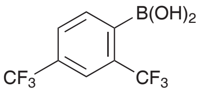
L13328
[4151-80-8]



1g
5g

2,4-Bis(trifluoromethyl)benzeneboronic acid, 97%

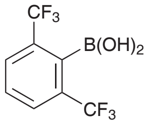
L18161
[153254-09-2]



1g
5g

2,6-Bis(trifluoromethyl)benzeneboronic acid, 97%

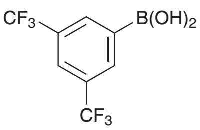
L19952
[681812-07-7]



250mg
1g
5g

3,5-Bis(trifluoromethyl)benzeneboronic acid, 97+%

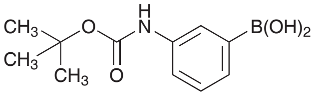
A11373
[73852-19-4]



1g
5g
25g

3-(Boc-amino)benzeneboronic acid, 95%

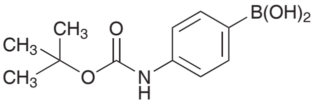
H27258
[380430-68-2]



1g
5g

4-(Boc-amino)benzeneboronic acid, 97%

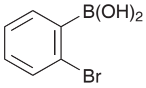
H28799
[380430-49-9]



1g
5g

2-Bromobenzeneboronic acid, 98%

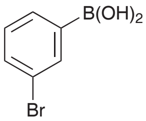
L18581
[244205-40-1]



1g
5g

3-Bromobenzeneboronic acid, 98+%

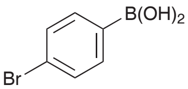
L16354
[89598-96-9]



1g
5g
25g

4-Bromobenzeneboronic acid, 98+%

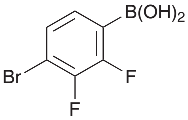
L01565
[5467-74-3]



1g
5g
25g

4-Bromo-2,3-difluorobenzeneboronic acid

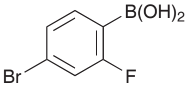
L18516
[374790-99-5]



250mg
1g

4-Bromo-2-fluorobenzeneboronic acid, 95%

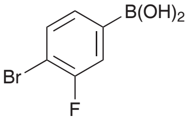
L17468
[216393-64-5]



250mg
1g

4-Bromo-3-fluorobenzeneboronic acid, 98+%

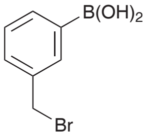
L18514
[374790-97-3]



1g
5g

3-(Bromomethyl)benzeneboronic acid, 95%

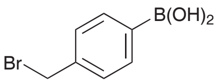
L20102
[51323-43-4]



1g
5g
25g

4-(Bromomethyl)benzeneboronic acid, tech. 85%

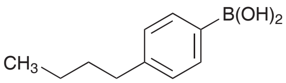
L19953
[68162-47-04]



1g
5g

4-n-Butylbenzeneboronic acid, 98%

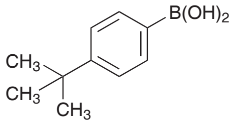
L15584
[145240-28-4]



1g
5g

4-*tert*-Butylbenzeneboronic acid, 97%

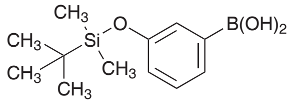
B24408
[123324-71-0]



1g
5g

3-(tert-Butyldimethylsiloxy)benzeneboronic acid, tech. 90%

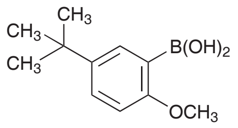
H28378
[261621-12-9]



1g
5g

5-*tert*-Butyl-2-methoxybenzeneboronic acid

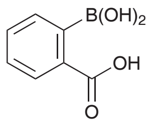
L20415
[128733-85-7]



250mg
1g

2-Carboxybenzeneboronic acid, 95%

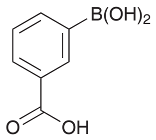
L16301
[149105-19-1]



250mg
1g
5g

3-Carboxybenzeneboronic acid, 98%

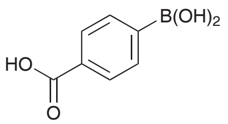
B25315
[25487-66-5]



1g
5g

4-Carboxybenzeneboronic acid, 95%

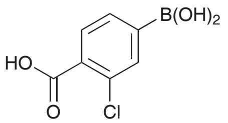
B20954
[14047-29-1]



1g
5g
25g

4-Carboxy-3-chlorobenzeneboronic acid, 97%

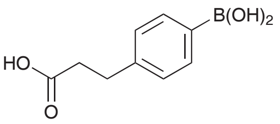
H28999
[136496-72-51]



1g
5g

4-(2-Carboxyethyl)benzeneboronic acid, 97%

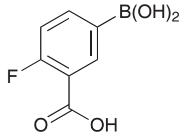
L17485
[166316-48-9]



1g
5g

3-Carboxy-4-fluorobenzeneboronic acid, 97%

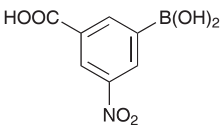
H28313
[872460-12-3]



1g
5g

5-Carboxy-3-nitrobenzeneboronic acid, 97%

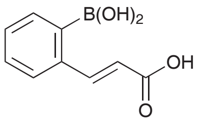
H29348
[101084-81-5]



1g
5g

2-(2-Carboxyvinyl)benzeneboronic acid, 98%

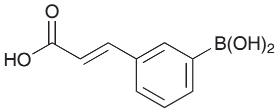
L16368
[374105-86-9]



50mg
250mg

3-(2-Carboxyvinyl)benzeneboronic acid, 97%

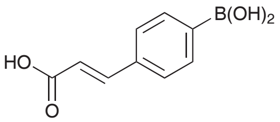
L16369
[216144-91-1]



250mg
1g

4-(2-Carboxyvinyl)benzeneboronic acid, 95%

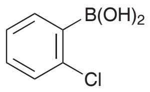
L15586
[151169-68-5]



250mg
1g
5g

2-Chlorobenzeneboronic acid, 97%

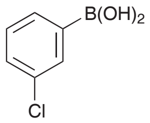
B23324
[3900-89-8]



1g
5g
25g

3-Chlorobenzeneboronic acid, 97%

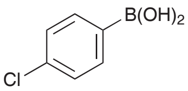
B24444
[63503-60-6]



1g
5g
25g

4-Chlorobenzeneboronic acid, 98+%

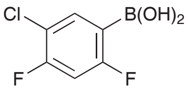
A15657
[1679-18-1]



1g
5g
25g

5-Chloro-2,4-difluorobenzeneboronic acid, 97%

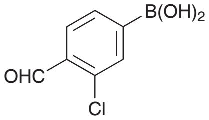
H25923
[911645-24-4]



250mg
1g

3-Chloro-4-formylbenzeneboronic acid, 95%

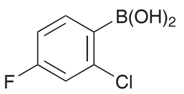
H27725



250mg
1g

2-Chloro-4-fluorobenzeneboronic acid, 98%

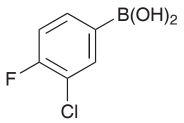
H27591
[313545-72-1]



1g
5g
25g

3-Chloro-4-fluorobenzeneboronic acid, 98%

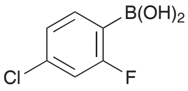
B22755
[144432-85-9]



1g
5g
25g

4-Chloro-2-fluorobenzeneboronic acid, 97%

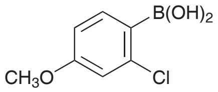
H28872
[160591-91-3]



1g
10g

2-Chloro-4-methoxybenzeneboronic acid, 95%

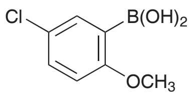
H26917
[219735-99-6]



1g
5g

5-Chloro-2-methoxybenzeneboronic acid, 97%

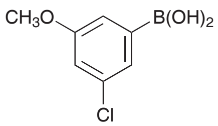
H27127
[89694-48-4]



5g
25g

3-Chloro-5-methoxybenzeneboronic acid, 94%

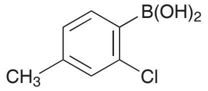
H27442
[915201-07-9]



250mg
1g

2-Chloro-4-methylbenzeneboronic acid, 97%

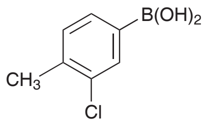
H28604
[145349-62-8]



1g
5g
25g

3-Chloro-4-methylbenzeneboronic acid, 97%

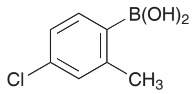
H28288
[175883-63-3]



1g
5g

4-Chloro-2-methylbenzeneboronic acid, 98%

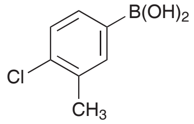
B23688
[209919-30-2]



1g
5g

4-Chloro-3-methylbenzeneboronic acid, 98%

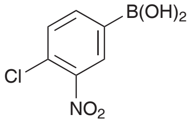
B23179
[161950-10-3]



1g
5g

4-Chloro-3-nitrobenzeneboronic acid, 97%

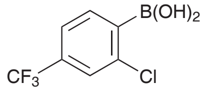
H27093
[151169-67-4]



100mg
500mg

2-Chloro-4-(trifluoromethyl)benzeneboronic acid, 96%

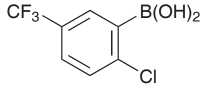
L20103
[254993-59-4]



1g
5g

2-Chloro-5-(trifluoromethyl)benzeneboronic acid, 96%

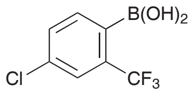
L20104
[182344-18-9]



1g
5g

4-Chloro-2-(trifluoromethyl)benzeneboronic acid, 97%

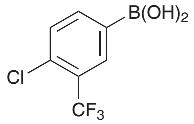
H28351
[313545-41-4]



1g
5g

4-Chloro-3-(trifluoromethyl)benzeneboronic acid, 96%

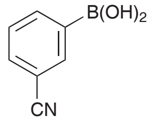
L20105
[176976-42-4]



1g
5g

3-Cyanobenzeneboronic acid, 98+%

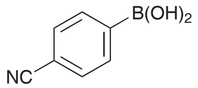
L19635
[150255-96-2]



250mg
1g
5g

4-Cyanobenzeneboronic acid, 98%

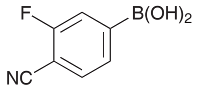
L18007
[126747-14-6]



1g
5g

4-Cyano-3-fluorobenzeneboronic acid, 97%

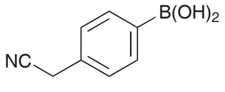
H27710
[843663-18-3]



1g
5g
25g

4-(Cyanomethyl)benzeneboronic acid, 98%

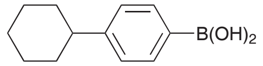
L19955
[91983-26-5]



1g
5g

4-Cyclohexylbenzeneboronic acid, 98%

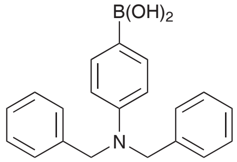
L18076
[374538-04-2]



250mg
1g
5g

4-(Dibenzylamino)benzeneboronic acid, 95%

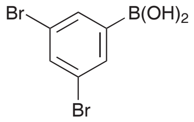
H27550
[159191-44-3]



250mg
1g

3,5-Dibromobenzeneboronic acid, 97%

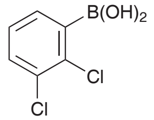
B23863
[117695-55-3]



1g
5g
25g

2,3-Dichlorobenzeneboronic acid, 98+%

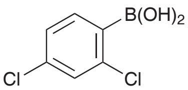
B22781
[151169-74-3]



1g
5g
25g

2,4-Dichlorobenzeneboronic acid, 98+%

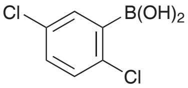
L01563
[68716-47-2]



1g
5g

2,5-Dichlorobenzeneboronic acid, 98+%

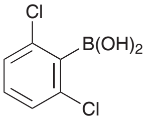
B22984
[135145-90-3]



1g
5g

2,6-Dichlorobenzeneboronic acid, 95%

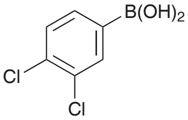
L19816
[73852-17-2]



250mg
1g

3,4-Dichlorobenzeneboronic acid, 97%

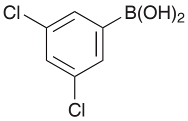
B24292
[151169-75-4]



1g
5g
25g

3,5-Dichlorobenzeneboronic acid, 98+%

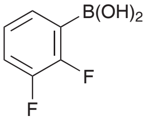
B22765
[67492-50-6]



1g
5g
25g

2,3-Difluorobenzeneboronic acid, 98%

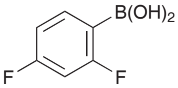
L18012
[121219-16-7]



1g
5g
25g

2,4-Difluorobenzeneboronic acid, 97%

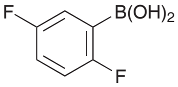
B23821
[144025-03-6]



1g
5g
25g

2,5-Difluorobenzeneboronic acid, 96%

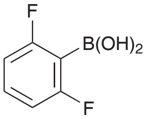
B24113
[193353-34-3]



1g
5g
25g

2,6-Difluorobenzeneboronic acid, 98%

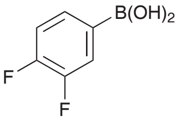
B22805
[162101-25-9]



1g
5g
25g

3,4-Difluorobenzeneboronic acid, 98%

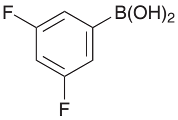
B22799
[168267-41-2]



1g
5g
25g

3,5-Difluorobenzeneboronic acid, 98+%

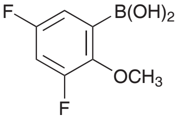
L17425
[156545-07-2]



1g
5g

3,5-Difluoro-2-methoxybenzeneboronic acid, 97%

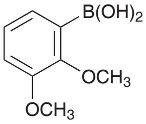
L19773



250mg
1g
5g

2,3-Dimethoxybenzeneboronic acid, 98%

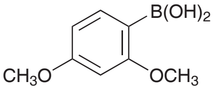
B24125
[40972-86-9]



1g
5g
25g

2,4-Dimethoxybenzeneboronic acid, 98%

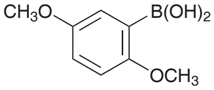
B24374
[133730-34-4]



1g
5g
25g

2,5-Dimethoxybenzeneboronic acid, 98%

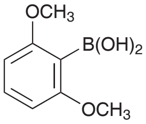
B24571
[107099-99-0]



1g
5g
25g

2,6-Dimethoxybenzeneboronic acid, 98%

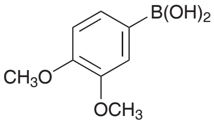
B24305
[23112-96-1]



1g
5g
25g

3,4-Dimethoxybenzeneboronic acid, 98%

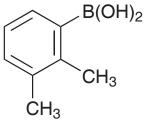
B24240
[122775-35-3]



1g
5g
25g

2,3-Dimethylbenzeneboronic acid, 98%

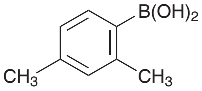
B23942
[183158-34-1]



1g
5g
25g

2,4-Dimethylbenzeneboronic acid, 97%

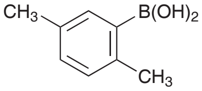
B23076
[55499-44-0]



1g
5g
25g

2,5-Dimethylbenzeneboronic acid, 95%

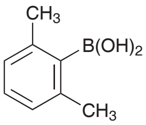
B23740
[85199-06-0]



1g
5g
25g

2,6-Dimethylbenzeneboronic acid, 97%

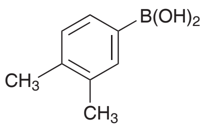
B24613
[100379-00-8]



1g
5g
25g

3,4-Dimethylbenzeneboronic acid, 98+%

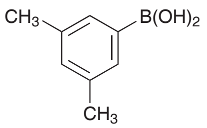
L17461
[55499-43-9]



1g
5g

3,5-Dimethylbenzeneboronic acid, 98%

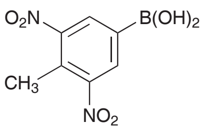
B23434
[172975-69-8]



1g
5g
25g

3,5-Dinitro-4-methylbenzeneboronic acid, 97%

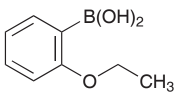
H25773
[28249-49-2]



1g
5g
25g

2-Ethoxybenzeneboronic acid, 98%

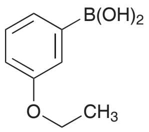
B23644
[213211-69-9]



1g
5g
25g

3-Ethoxybenzeneboronic acid

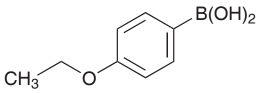
B24485
[90555-66-1]



1g
5g
25g

4-Ethoxybenzeneboronic acid, 98%

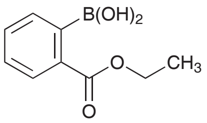
B23683
[22237-13-4]



1g
5g
25g

2-(Ethoxycarbonyl)benzeneboronic acid, 98%

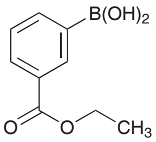
H25867
[380430-53-5]



1g
5g

3-(Ethoxycarbonyl)benzeneboronic acid, 97%

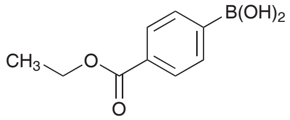
H26615
[4334-87-6]



1g
5g

4-(Ethoxycarbonyl)benzeneboronic acid, 94%

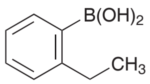
H26356
[4334-88-7]



1g
5g

2-Ethylbenzeneboronic acid, 98+%

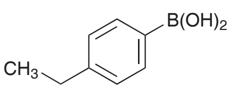
L17719
[90002-36-1]



1g
5g

4-Ethylbenzeneboronic acid, 97%

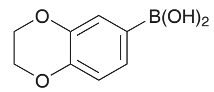
B24656
[63139-21-9]



1g
5g
25g

3,4-(Ethylenedioxy)benzeneboronic acid, 97%

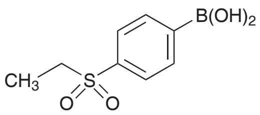
L20296
[164014-95-3]



1g
5g

4-(Ethylsulfonyl)benzeneboronic acid, 98+%

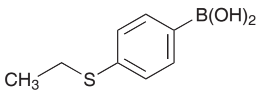
L17814
[352530-24-6]



250mg
1g

4-(Ethylthio)benzeneboronic acid, 98%

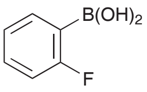
L17623
[145349-76-4]



1g
5g

2-Fluorobenzeneboronic acid, 98%

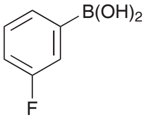
B23103
[1993-03-9]



1g
5g
25g

3-Fluorobenzeneboronic acid, 97%

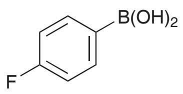
B21247
[768-35-4]



1g
5g
25g

4-Fluorobenzeneboronic acid, 97%

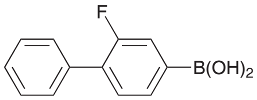
A15991
[1765-93-1]



1g
5g
25g

2-Fluorobiphenyl-4-boronic acid, 97%

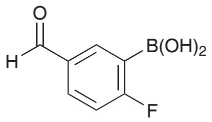
L15634
[178305-99-2]



1g
5g

2-Fluoro-5-formylbenzeneboronic acid, 97%

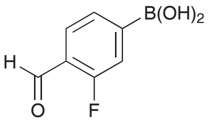
H28857
[352534-79-3]



1g
5g

3-Fluoro-4-formylbenzeneboronic acid, 98%

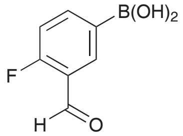
L17851
[248270-25-9]



1g

4-Fluoro-3-formylbenzeneboronic acid, 98+%

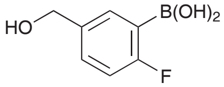
L17808
[374538-01-9]



250mg
1g

2-Fluoro-5-(hydroxymethyl)benzeneboronic acid, 98%

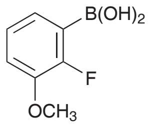
H29251



1g
10g

2-Fluoro-3-methoxybenzeneboronic acid, 97%

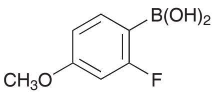
L19655
[352303-67-4]



1g
5g

2-Fluoro-4-methoxybenzeneboronic acid, 97%

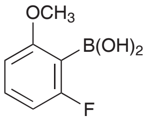
L19960
[162101-31-7]



1g
5g

2-Fluoro-6-methoxybenzeneboronic acid, 98%

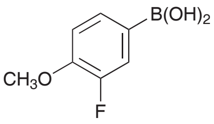
H26064
[78495-63-3]



1g
5g

3-Fluoro-4-methoxybenzeneboronic acid, 98+%

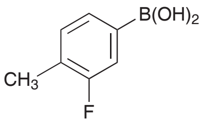
L19818
[149507-26-6]



1g
5g

3-Fluoro-4-methylbenzeneboronic acid, 98%

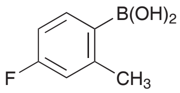
B24512
[168267-99-0]



1g
5g
25g

4-Fluoro-2-methylbenzeneboronic acid, 98%

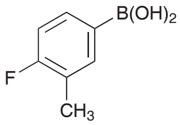
B24117
[139911-29-8]



1g
5g
25g

4-Fluoro-3-methylbenzeneboronic acid, 98%

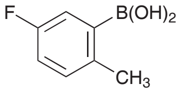
L18753
[139911-27-6]



1g
5g

5-Fluoro-2-methylbenzeneboronic acid, 99%

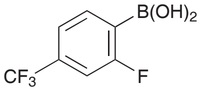
L19819
[163517-62-2]



1g
5g

2-Fluoro-4-(trifluoromethyl)benzeneboronic acid, 98%

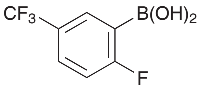
H28788
[503309-11-3]



1g
5g

2-Fluoro-5-(trifluoromethyl)benzeneboronic acid, 98%

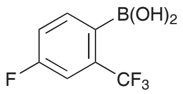
H28144
[352535-96-7]



1g
5g

4-Fluoro-2-(trifluoromethyl)benzeneboronic acid, 98%

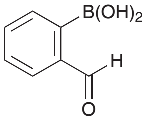
H26144
[182344-16-7]



250mg
1g

2-Formylbenzeneboronic acid, 97%

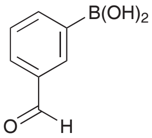
B25434
[40138-16-7]



1g
5g

3-Formylbenzeneboronic acid, 98%

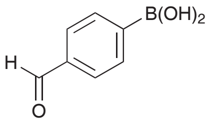
B25437
[87199-16-4]



1g
5g
25g

4-Formylbenzeneboronic acid, 97%

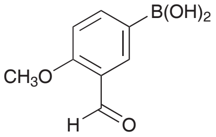
B25199
[87199-17-5]



1g
5g
25g

3-Formyl-4-methoxybenzeneboronic acid, 98%

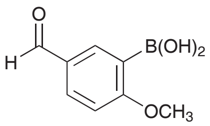
L17850
[121124-97-8]



1g
5g

5-Formyl-2-methoxybenzeneboronic acid, 98%

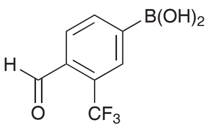
L19059
[127972-02-5]



250mg
1g
5g

4-Formyl-3-(trifluoromethyl)benzeneboronic acid, 95%

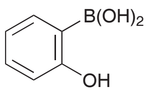
H26988



250mg
1g

2-Hydroxybenzeneboronic acid, 97%

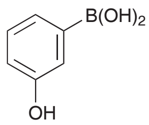
L19400
[89466-08-0]



1g
5g

3-Hydroxybenzeneboronic acid, 97%

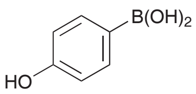
L19061
[87199-18-6]



1g
5g

4-Hydroxybenzeneboronic acid, 97%

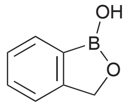
L15594
[71597-85-8]



1g
5g

2-(Hydroxymethyl)benzeneboronic acid hemiester, 98+%

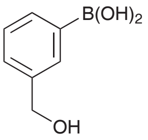
L15192
[5735-41-1]



250mg
1g

3-(Hydroxymethyl)benzeneboronic acid, 94%

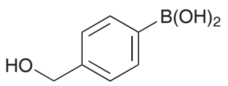
L15193
[87199-15-3]



1g
5g

4-(Hydroxymethyl)benzeneboronic acid, 98%

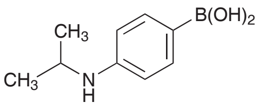
L15194
[59016-93-2]



1g
5g
25g

4-(Isopropylamino)benzeneboronic acid, 95%

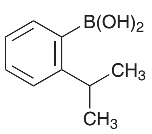
H27800
[219945-56-9]



250mg
1g

2-Isopropylbenzeneboronic acid, 97%

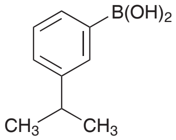
L20110
[89787-12-2]



250mg
1g
5g

3-Isopropylbenzeneboronic acid, 99%

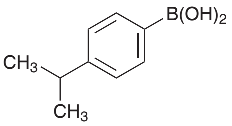
L15530
[216019-28-2]



250mg
1g
5g

4-Isopropylbenzeneboronic acid, 98+%

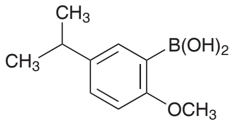
L17459
[16152-51-5]



1g
5g

5-Isopropyl-2-methoxybenzeneboronic acid, 98+%

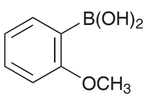
L17460
[216393-63-4]



1g
5g

2-Methoxybenzeneboronic acid, 97%

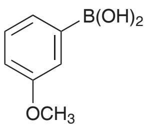
B21071
[5720-06-9]



1g
5g
25g

3-Methoxybenzeneboronic acid, 97%

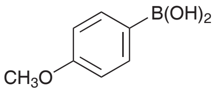
B24412
[10365-98-7]



1g
5g
25g

4-Methoxybenzeneboronic acid, 98%

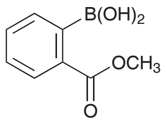
A14462
[5720-07-0]



1g
5g
25g

2-(Methoxycarbonyl)benzeneboronic acid, 97%

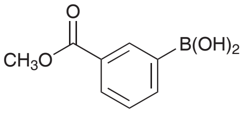
L17958
[374538-03-1]



250mg
1g
5g

3-(Methoxycarbonyl)benzeneboronic acid, 97%

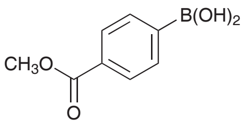
H27444
[99769-19-4]



1g
5g

4-(Methoxycarbonyl)benzeneboronic acid, 97%

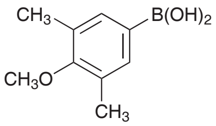
H27627
[99768-12-4]



1g
5g

4-Methoxy-3,5-dimethylbenzeneboronic acid, 99%

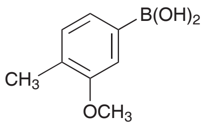
L19820
[301699-39-8]



1g
5g

3-Methoxy-4-methylbenzeneboronic acid, 97%

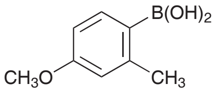
H28753
[917757-15-4]



1g
5g

4-Methoxy-2-methylbenzeneboronic acid, 98%

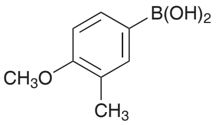
L20112
[208399-66-0]



1g
5g

4-Methoxy-3-methylbenzeneboronic acid, 98+%

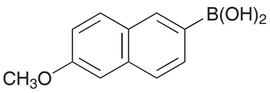
L19821
[175883-62-2]



1g
5g

6-Methoxy-2-naphthaleneboronic acid, 95%

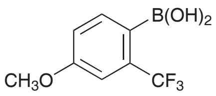
L19060
[156641-98-4]



1g
5g

4-Methoxy-2-(trifluoromethyl)benzeneboronic acid

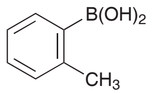
H27062
[313546-16-6]



1g
5g

2-Methylbenzeneboronic acid, 98%

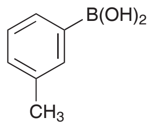
B23154
[16419-60-6]



1g
5g
25g

3-Methylbenzeneboronic acid, 97%

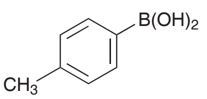
B23025
[17933-03-8]



1g
5g
25g

4-Methylbenzeneboronic acid, 99%

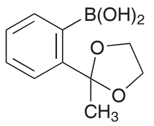
A13347
[5720-05-8]



1g
5g
25g

2-(2-Methyl-1,3-dioxolan-2-yl)benzeneboronic acid, 95%

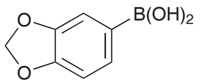
H26923
[243140-14-9]



250mg
1g

3,4-(Methylenedioxy)benzeneboronic acid, 98%

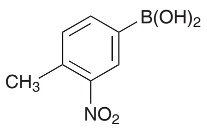
B24217
[94839-07-3]



1g
5g

4-Methyl-3-nitrobenzeneboronic acid, 98%

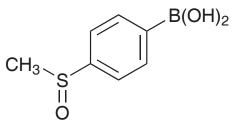
L17052
[80500-27-2]



1g
5g

4-(Methylsulfinyl)benzeneboronic acid, 98%

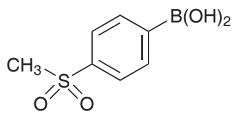
L17865
[166386-48-7]



100mg
1g

4-(Methylsulfonyl)benzeneboronic acid, 98%

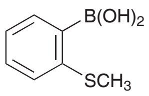
L17720
[149104-88-1]



250mg
1g
5g

2-(Methylthio)benzeneboronic acid, 98+%

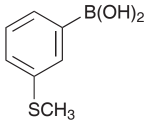
L17456
[168618-42-6]



1g
5g

3-(Methylthio)benzeneboronic acid, 97%

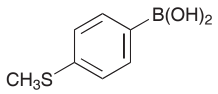
L20250
[128312-11-8]



250mg
1g
5g

4-(Methylthio)benzeneboronic acid, 97%

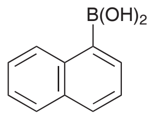
B23454
[98546-51-1]



1g
5g
25g

1-Naphthaleneboronic acid, 96%

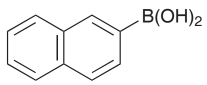
B21219
[13922-41-3]



1g
5g
25g

2-Naphthaleneboronic acid, 97%

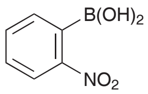
B24157
[32316-92-0]



1g
5g
25g

2-Nitrobenzeneboronic acid, 96%

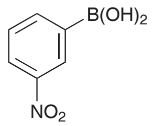
L17988
[5570-19-4]



1g
5g

3-Nitrobenzeneboronic acid, 98%

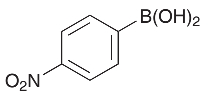
A13336
[13331-27-6]



1g
5g
25g

4-Nitrobenzeneboronic acid, 95%

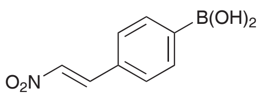
H27767
[24067-17-2]



1g
5g

trans-4-(β-Nitrovinyl)benzeneboronic acid, 97%

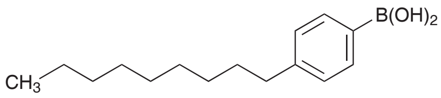
L17004
[216394-04-6]



250mg
1g

4-*n*-Nonylbenzeneboronic acid, 98+%

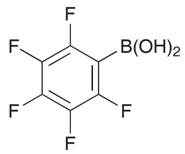
L17753
[256383-45-6]



1g
5g

2,3,4,5,6-Pentafluorobenzeneboronic acid, 97%

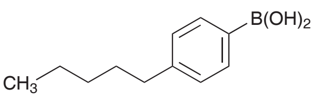
B22922
[1582-24-7]



5g
25g

4-*n*-Pentylbenzeneboronic acid, 97%

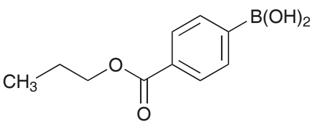
L18011
[121219-12-3]



250mg
1g
5g

(4-*n*-Propoxycarbonyl)benzeneboronic acid, 97%

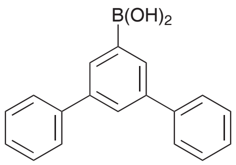
H27938
[91062-38-3]



1g
10g

1,1':3',1''-Terphenyl-5'-boronic acid, 95%

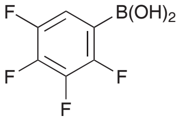
H27640
[128388-54-5]



250mg
1g
5g

2,3,4,5-Tetrafluorobenzeneboronic acid, 98%

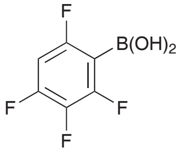
L19824
[179923-32-1]



250mg
1g

2,3,4,6-Tetrafluorobenzeneboronic acid

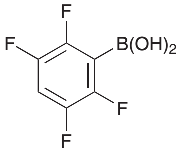
L19825
[511295-00-4]



250mg
1g

2,3,5,6-Tetrafluorobenzeneboronic acid, 99%

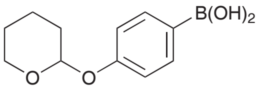
L19826
[511295-01-5]



1g

4-(Tetrahydro-2*H*-pyran-2-yloxy)benzeneboronic acid

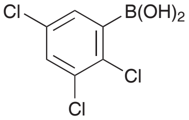
H50445
[182281-01-2]



250mg
1g

2,3,5-Trichlorobenzeneboronic acid, 98%

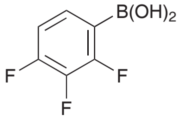
L17511
[212779-19-6]



1g
5g

2,3,4-Trifluorobenzeneboronic acid

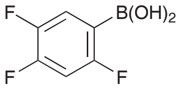
L19827
[226396-32-3]



250mg
1g

2,4,5-Trifluorobenzeneboronic acid

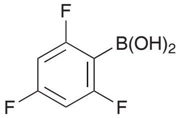
H27858
[247564-72-3]



5g
25g

2,4,6-Trifluorobenzeneboronic acid, 97%

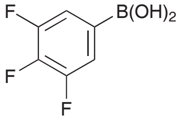
L19402
[182482-25-3]



1g
5g

3,4,5-Trifluorobenzeneboronic acid, 97%

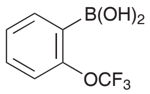
L18519
[143418-49-9]



250mg
1g

2-(Trifluoromethoxy)benzeneboronic acid, 98%

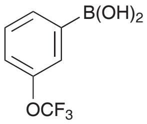
L19774
[175676-65-0]



250mg
1g

3-(Trifluoromethoxy)benzeneboronic acid, 98%

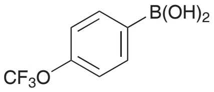
L19775
[179113-90-7]



1g
5g

4-(Trifluoromethoxy)benzeneboronic acid, 98%

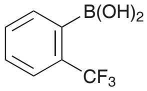
B23233
[139301-27-2]



1g
5g
25g

2-(Trifluoromethyl)benzeneboronic acid, 97%

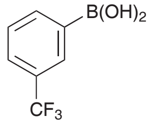
B24343
[1423-27-4]



1g
5g
25g

3-(Trifluoromethyl)benzeneboronic acid, 98%

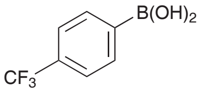
B21661
[1423-26-3]



1g
5g
25g

4-(Trifluoromethyl)benzeneboronic acid, 98%

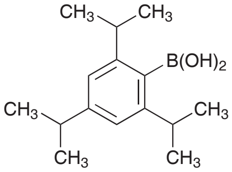
B22374
[128796-39-4]



1g
5g
25g

2,4,6-Triisopropylbenzeneboronic acid, 98%

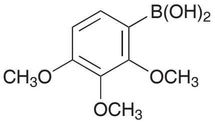
B22891
[154549-38-9]



1g
5g
25g

2,3,4-Trimethoxybenzeneboronic acid, 98%

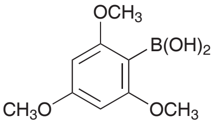
L19838
[118062-05-8]



1g
5g

2,4,6-Trimethoxybenzeneboronic acid, 98%

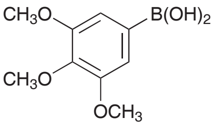
L19837
[135159-25-0]



1g
5g

3,4,5-Trimethoxybenzeneboronic acid, 98+%

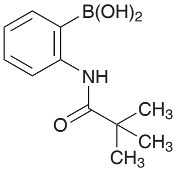
L15191
[182163-96-8]



1g
5g

2-(2,2,2-Trimethylacetamido)benzeneboronic acid, 95%

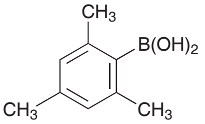
H27004
[146140-95-6]



250mg
1g

2,4,6-Trimethylbenzeneboronic acid, 97%

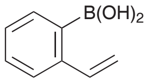
B24060
[5980-97-2]



1g
5g

2-Vinylbenzeneboronic acid, 98%

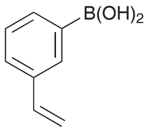
L19828
[15016-42-9]



250mg
1g

3-Vinylbenzeneboronic acid, 98%

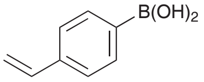
L19829
[15016-43-0]



250mg
1g

4-Vinylbenzeneboronic acid, 98%

B23709
[2156-04-9]

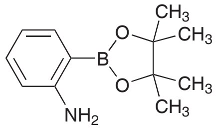


1g
5g

Arylboronic esters

2-Aminobenzeneboronic acid pinacol ester, 97%

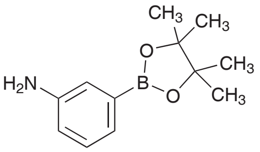
L19951
[191171-55-8]



1g
5g

3-Aminobenzeneboronic acid pinacol ester, 97%

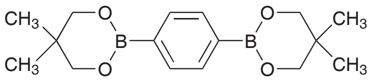
H28448
[210907-84-9]



1g
5g

1,4-Benzenediboronic acid bis(neopentyl glycol) ester, 99%

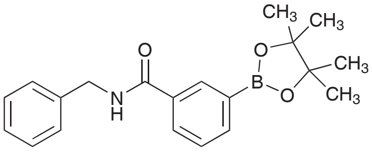
L16187
[5565-36-6]



250mg
1g
5g

3-(Benzylaminocarbonyl)benzeneboronic acid pinacol ester, 97%

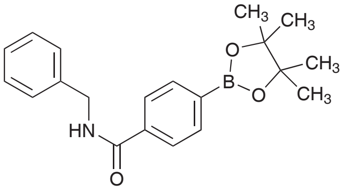
H28205



1g
5g

4-(Benzylaminocarbonyl)benzeneboronic acid pinacol ester, 97%

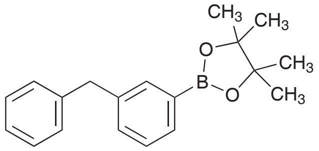
H29271



1g
5g

3-Benzylbenzeneboronic acid pinacol ester, 97%

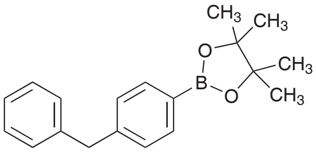
H28682



1g
5g

4-Benzylbenzeneboronic acid pinacol ester, 97%

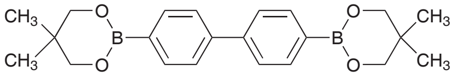
H28156
[11708-01-5]



1g
5g

4,4'-Biphenyldiboronic acid bis(neopentyl glycol) ester, 98%

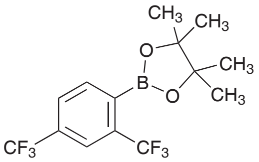
L17605
[5487-93-4]



1g
5g

2,4-Bis(trifluoromethyl)benzeneboronic acid pinacol ester, 96%

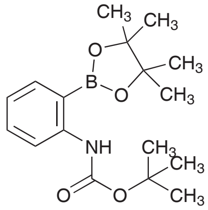
H26075



1g

2-(Boc-amino)benzeneboronic acid pinacol ester, 97%

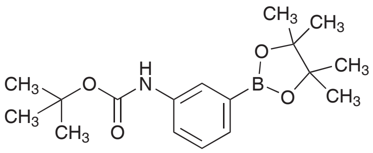
H29020
[159624-15-4]



1g
5g

3-(Boc-amino)benzeneboronic acid pinacol ester, 97%

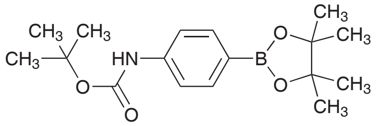
H27026
[330793-09-4]



1g
5g

4-(Boc-amino)benzeneboronic acid pinacol ester, 98%

L19653
[330793-01-6]

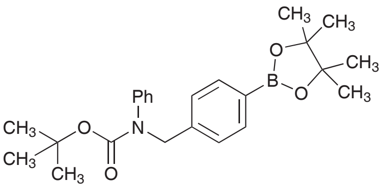


1g
5g

4-(N-Boc-phenylaminomethyl)benzeneboronic acid pinacol ester, 97%

H28289

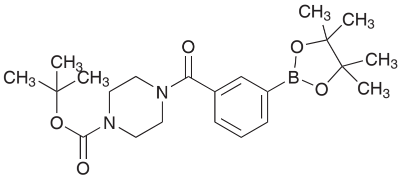
1g
5g



3-(4-Boc-1-piperazinylcarbonyl)benzeneboronic acid pinacol ester, 97%

H29275
[883738-41-8]

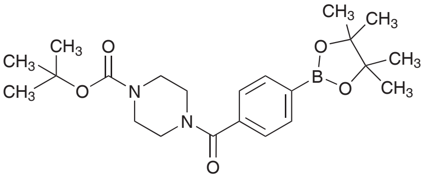
1g
5g



4-(4-Boc-1-piperazinylcarbonyl)benzeneboronic acid pinacol ester, 97%

H28905
[864754-13-2]

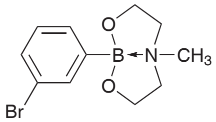
1g
5g



3-Bromobenzeneboronic acid N-methyldiethanolamine ester, 98%

L17796
[374538-00-8]

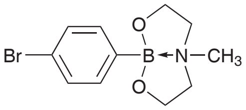
1g
5g



4-Bromobenzeneboronic acid N-methyldiethanolamine ester, 98%

L17775
[133468-58-3]

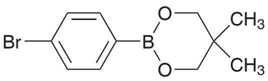
250mg
1g



4-Bromobenzeneboronic acid neopentyl glycol ester, 98+%

L17455
[183677-71-6]

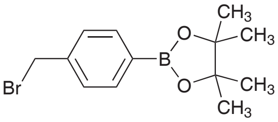
1g
5g



4-(Bromomethyl)benzeneboronic acid pinacol ester, 97%

L19954
[138500-85-3]

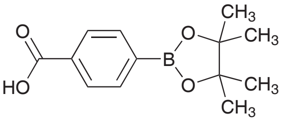
1g
5g



4-Carboxybenzeneboronic acid pinacol ester, 97%

H26825
[180516-87-4]

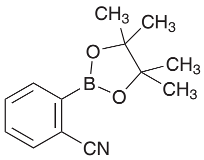
1g
5g



2-Cyanobenzeneboronic acid pinacol ester, 98%

H27469
[214360-48-2]

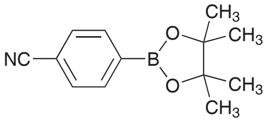
1g
5g
25g



4-Cyanobenzeneboronic acid pinacol ester, 97%

H28208
[171364-82-2]

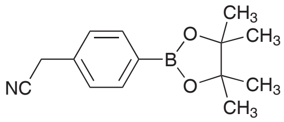
1g
5g



4-(Cyanomethyl)benzeneboronic acid pinacol ester, 95%

L19956
[138500-86-4]

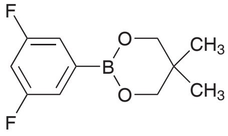
1g
5g



3,5-Difluorobenzeneboronic acid neopentyl glycol ester, 98+%

L17266
[216393-57-6]

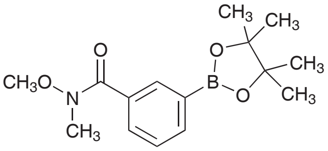
1g
5g



3-(N,O-Dimethylhydroxylaminocarbonyl) benzene-boronic acid pinacol ester, 97%

H27949

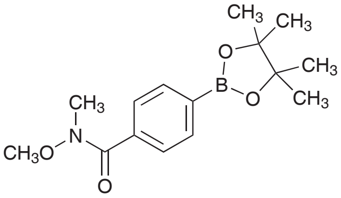
1g
5g



4-(N,O-Dimethylhydroxylaminocarbonyl) benzene-boronic acid pinacol ester, 97%

H28341

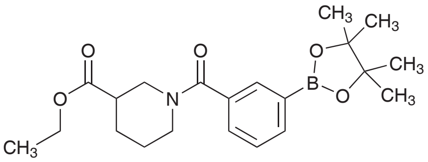
1g
5g



3-(3-Ethoxycarbonyl-1-piperidinylcarbonyl)-benzeneboronic acid pinacol ester, 97%

H28764

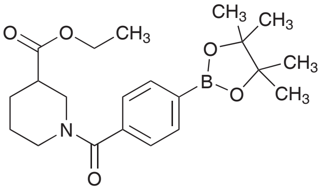
1g
5g



4-(3-Ethoxycarbonyl-1-piperidinylcarbonyl)-benzeneboronic acid pinacol ester, 97%

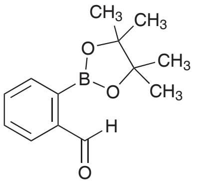
H28086
[850411-14-2]

1g
5g



2-Formylbenzeneboronic acid pinacol ester, 97%

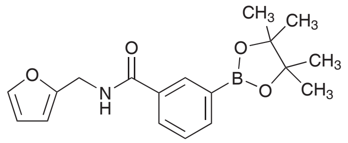
H28846
[380151-85-9]



1g
5g

3-(Furfurylaminocarbonyl)benzeneboronic acid pinacol ester, 97%

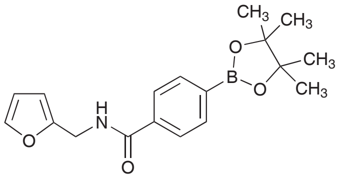
H28599



1g
5g

4-(Furfurylaminocarbonyl)benzeneboronic acid pinacol ester, 97%

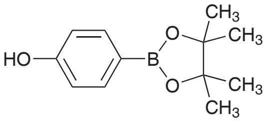
H29236



1g
5g

4-Hydroxybenzeneboronic acid pinacol ester, 97%

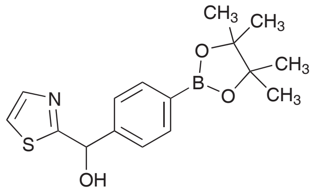
H27836
[269409-70-3]



1g
5g

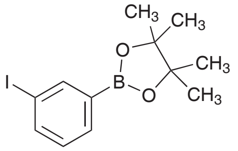
4-[Hydroxy(2-thiazolyl)methyl)]benzeneboronic acid pinacol ester, 97%

H28798



3-Iodobenzeneboronic acid pinacol ester, 97%

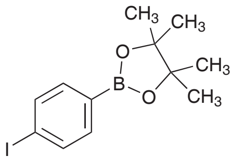
H28115
[408492-28-4]



1g
5g

4-Iodobenzeneboronic acid pinacol ester, 97%

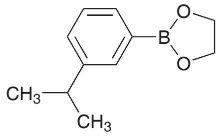
H28190
[73852-88-7]



1g
5g

3-Isopropylbenzeneboronic acid ethylene glycol ester, 96%

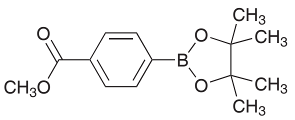
L17670
[374537-96-9]



250mg
1g

4-(Methoxycarbonyl)benzeneboronic acid pinacol ester, 97%

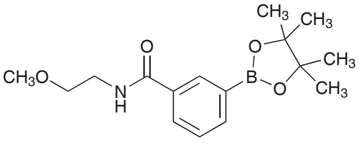
H28942
[171364-80-0]



1g
5g

3-(2-Methoxyethylaminocarbonyl) benzeneboronic acid pinacol ester, 97%

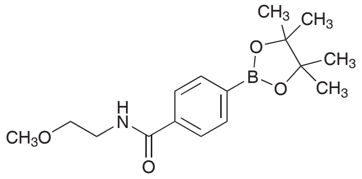
H28340



1g
5g

4-(2-Methoxyethylaminocarbonyl) benzeneboronic acid pinacol ester, 97%

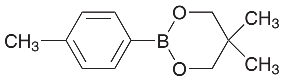
H27945



1g
5g

4-Methylbenzeneboronic acid neopentyl glycol ester, 99%

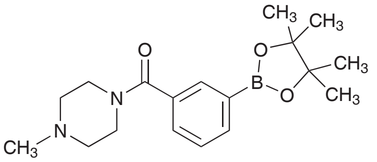
L19563
[380481-66-3]



1g
5g
25g

3-(4-Methyl-1-piperazinylcarbonyl) benzeneboronic acid pinacol ester, 97%

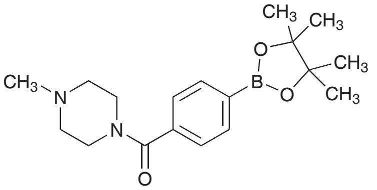
H29224
[883738-38-3]



1g
5g

4-(4-Methyl-1-piperazinylcarbonyl) benzeneboronic acid pinacol ester, 97%

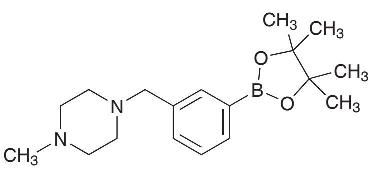
H28216
[832114-06-4]



1g
5g

3-(4-Methyl-1-piperazinylmethyl)benzeneboronic acid pinacol ester, 95%

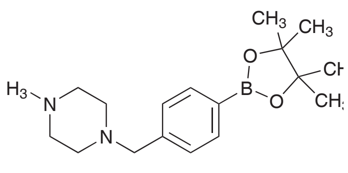
H28762
[883738-27-0]



1g
5g

4-(4-Methyl-1-piperazinylmethyl)benzeneboronic acid pinacol ester, 95%

H28495
[938043-30-2]

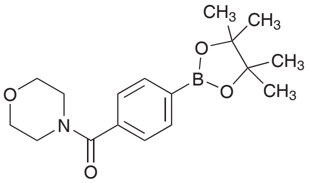


1g
5g

4-(4-Morpholinylcarbonyl)benzeneboronic acid pinacol ester, 97%

H28484
[656239-38-2]

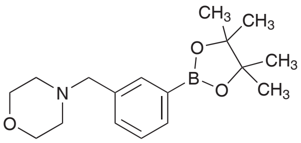
1g
5g



3-(4-Morpholinylmethyl)benzeneboronic acid pinacol ester, 97%

H28416
[364794-80-9]

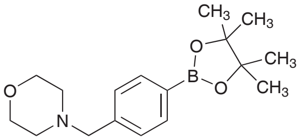
1g
5g



4-(4-Morpholinylmethyl)benzeneboronic acid pinacol ester, 97%

H28034
[364794-79-6]

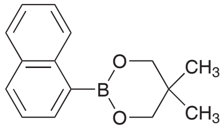
1g
5g



1-Naphthaleneboronic acid neopentyl glycol ester, 98%

L17612
[22871-77-8]

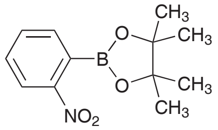
1g
5g



2-Nitrobenzeneboronic acid pinacol ester, 98+%

L19963
[190788-59-1]

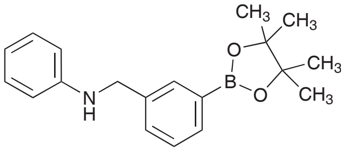
1g
5g



3-(Phenylaminomethyl)benzeneboronic acid pinacol ester, 97%

H28287

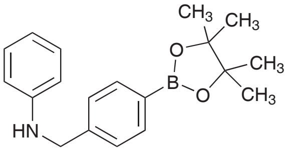
1g
5g



4-(Phenylaminomethyl)benzeneboronic acid pinacol ester, 97%

H29086

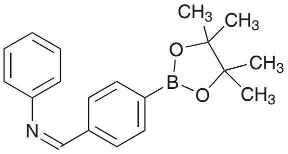
1g
5g



4-(Phenyliminomethyl)benzeneboronic acid pinacol ester, 97%

H28531

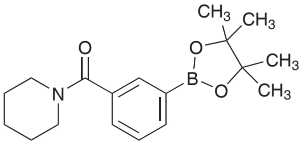
1g
5g



3-(1-Piperidinylcarbonyl)benzeneboronic acid pinacol ester, 97%

H29339

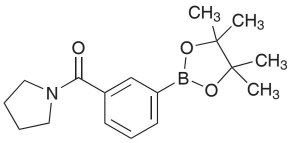
1g
5g



3-(1-Pyrrolidinylcarbonyl)benzeneboronic acid pinacol ester, 97%

H28801

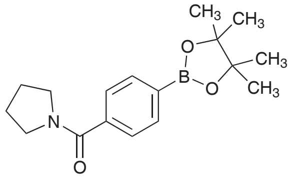
1g
5g



4-(1-Pyrrolidinylcarbonyl)benzeneboronic acid pinacol ester, 97%

H28187

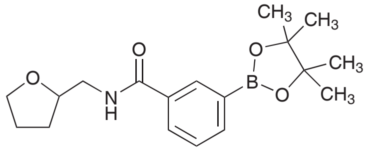
1g
5g



3-(Tetrahydrofurfurylaminocarbonyl)benzeneboronic acid pinacol ester, 97%

H28130

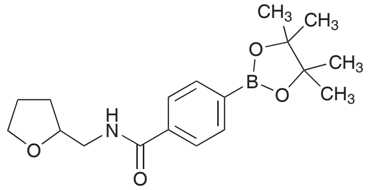
1g
5g



4-(Tetrahydrofurfurylaminocarbonyl)benzeneboronic acid pinacol ester, 97%

H28810

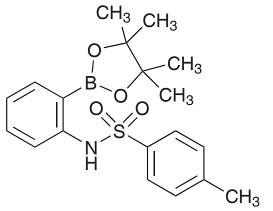
1g
5g



2-(*p*-Toluenesulfonylamino)benzeneboronic acid pinacol ester, 95%

H27250
[796061-07-9]

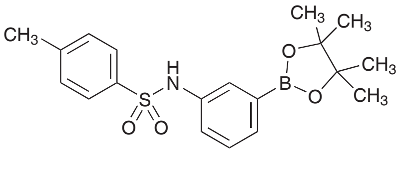
1g
5g



3-(*p*-Toluenesulfonylamino)benzeneboronic acid pinacol ester, 97%

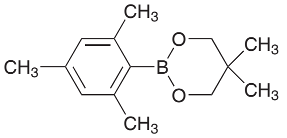
H27236
[796061-08-0]

1g
5g



2,4,6-Trimethylbenzeneboronic acid neopentyl glycol ester, 99%

L17232
[214360-78-8]

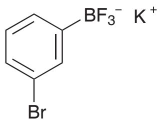


1g
5g

Aryltrifluoroborate salts

Potassium 3-bromophenyltrifluoroborate, 97%

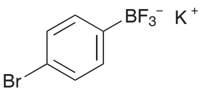
L17966
[374564-34-8]



1g
5g

Potassium 4-bromophenyltrifluoroborate, 97%

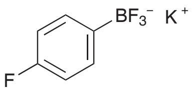
L17967
[374564-35-9]



1g
5g

Potassium 4-fluorophenyltrifluoroborate, 98%

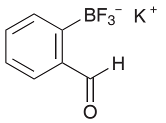
L17655
[192863-35-7]



1g
5g

Potassium 2-formylphenyltrifluoroborate, 97%

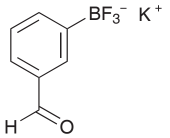
L17968
[192863-39-1]



1g

Potassium 3-formylphenyltrifluoroborate, 97%

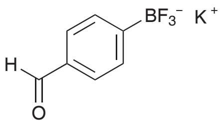
H28125
[871231-44-6]



1g

Potassium 4-formylphenyltrifluoroborate, 97%

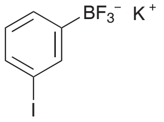
L17969
[374564-36-0]



1g
5g

Potassium 3-iodophenyltrifluoroborate, 96%

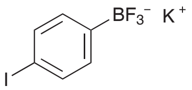
H29009



1g
5g

Potassium 4-iodophenyltrifluoroborate, 96%

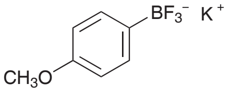
H28758
[912350-00-6]



1g
5g

Potassium 4-methoxyphenyltrifluoroborate, 95%

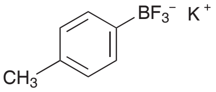
H27384
[192863-36-8]



1g
5g

Potassium 4-methylphenyltrifluoroborate, 98%

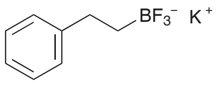
L17604
[216434-82-1]



1g
5g

Potassium 2-phenyethyltrifluoroborate, 98%

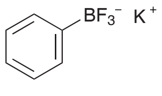
H25930
[329976-74-1]



1g
5g

Potassium phenyltrifluoroborate, 98%

L17568
[153766-81-5]

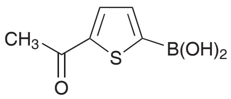


1g
5g

Heteroaryl boronic acids

5-Acetylthiophene-2-boronic acid, 98%

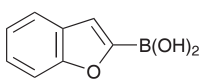
L15221
[206551-43-1]



1g
5g
25g

Benzo[*b*]furan-2-boronic acid, 98%

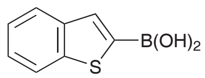
B23676
[98437-24-2]



1g
5g
25g

Benzo[*b*]thiophene-2-boronic acid, 98%

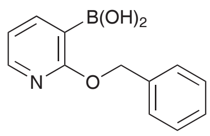
B22835
[98437-23-1]



1g
5g
25g

2-Benzyloxypyridine-3-boronic acid, 95

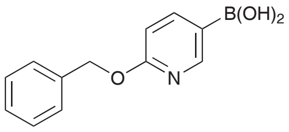
H26978



250mg
1g

6-Benzyloxypyridine-3-boronic acid, 95%

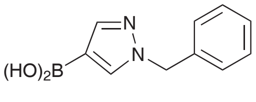
H27346
[929250-35-1]



250mg
1g

1-Benzyl-1*H*-pyrazole-4-boronic acid, 95%

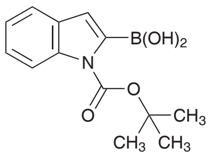
H27160
[852362-22-2]



250mg
1g

1-Boc-indole-2-boronic acid, 95%

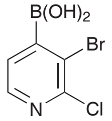
L18009
[213318-44-6]



250mg
1g
5g

3-Bromo-2-chloropyridine-4-boronic acid, 97%

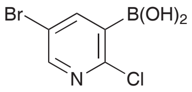
H29021
[501435-91-2]



250mg
1g
5g

5-Bromo-2-chloropyridine-3-boronic acid, 95%

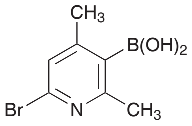
H26966



250mg
1g

6-Bromo-2,4-dimethylpyridine-3-boronic acid, 95%

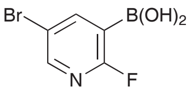
H27460



250mg
1g

5-Bromo-2-fluoropyridine-3-boronic acid, 98%

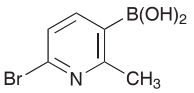
L19915
[501435-91-2]



250mg
1g
5g

6-Bromo-2-methylpyridine-3-boronic acid, 95%

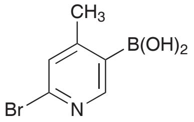
H27715



250mg
1g

6-Bromo-4-methylpyridine-3-boronic acid, 95%

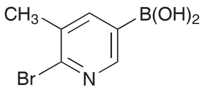
H27069



250mg
1g

6-Bromo-5-methylpyridine-3-boronic acid, 95%

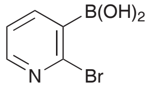
H27221



250mg
1g

2-Bromopyridine-3-boronic acid, 95%

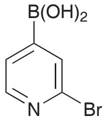
H27523
[452972-08-6]



250mg
1g

2-Bromopyridine-4-boronic acid, 95%

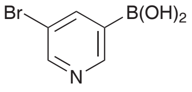
H27599
[458532-94-0]



250mg
1g

5-Bromopyridine-3-boronic acid, 95%

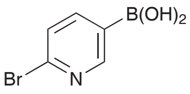
L20084
[452972-09-7]



250mg
1g
5g

6-Bromopyridine-3-boronic acid, 95%

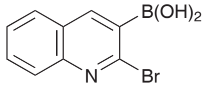
L20085
[223463-14-7]



250mg
1g
5g

2-Bromoquinoline-3-boronic acid, 97%

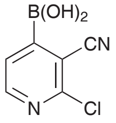
L20327
[745784-05-8]



250mg
1g
5g

2-Chloro-3-cyanopyridine-4-boronic acid, 95%

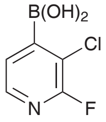
H27758
[878194-88-8]



250mg
1g

3-Chloro-2-fluoropyridine-4-boronic acid, 95%

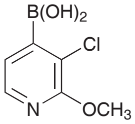
H27781



250mg
1g

3-Chloro-2-methoxypyridine-4-boronic acid, 95%

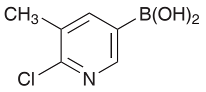
H26950
[957060-88-7]



250mg
1g
5g

6-Chloro-5-methylpyridine-3-boronic acid, 95%

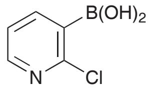
H27099
[1003043-40-0]



250mg
1g

2-Chloropyridine-3-boronic acid, 96%

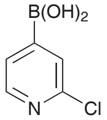
L20303
[381248-04-0]



1g
5g

2-Chloropyridine-4-boronic acid, 95%

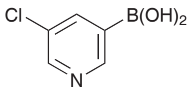
H27357
[458532-96-2]



1g
5g

5-Chloropyridine-3-boronic acid, 96%

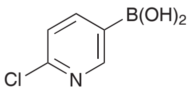
H27756
[872041-85-5]



1g
5g

6-Chloropyridine-3-boronic acid, 96%

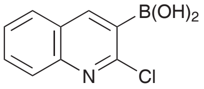
L20388
[444120-91-6]



250mg
1g
5g

2-Chloroquinoline-3-boronic acid, 97%

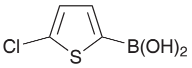
L20329
[128676-84-6]



250mg
1g
5g

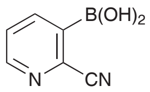
5-Chlorothiophene-2-boronic acid, 97%

B23193
[162607-18-3]
1g
5g
25g



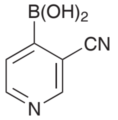
2-Cyanopyridine-3-boronic acid, 95%

H27045
[874290-88-7]
250mg
1g



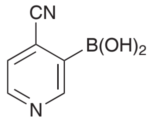
3-Cyanopyridine-4-boronic acid, 95%

H27090
[874290-89-8]
250mg
1g



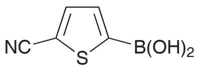
4-Cyanopyridine-3-boronic acid, 95%

H27118
[874290-90-1]
250mg
1g



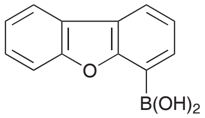
5-Cyanothiophene-2-boronic acid, 98%

L18523
[305832-67-1]
250mg
1g



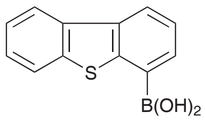
Dibenzofuran-4-boronic acid, 98+%

L19830
[100124-06-9]
1g
5g



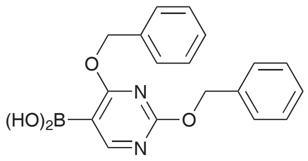
Dibenzothiophene-4-boronic acid

L19831
[108847-20-7]
1g
5g



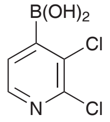
2,4-Dibenzyloxypyrimidine-5-boronic acid, 95%

H27870
[70523-24-9]
250g
1g



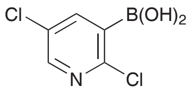
2,3-Dichloropyridine-4-boronic acid, 95%

H27668
[951677-39-7]
250mg
1g



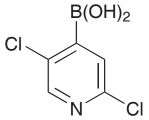
2,5-Dichloropyridine-3-boronic acid, 95%

H27849
[536693-97-7]
250mg
1g



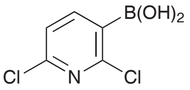
2,5-Dichloropyridine-4-boronic acid, 95%

H27170
[847664-64-6]
1g
5g



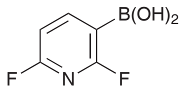
2,6-Dichloropyridine-3-boronic acid, 95%

H27406
[148493-34-9]
250mg
1g



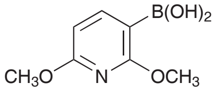
2,6-Difluoropyridine-3-boronic acid, 95%

H27509
[136466-94-9]
250mg
1g



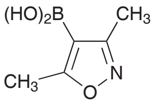
2,6-Dimethoxypyridine-3-boronic acid, 95%

L20389
[444120-91-6]
250mg
1g
5g



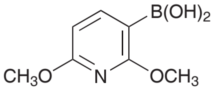
3,5-Dimethylisoxazole-4-boronic acid, 97%

H26893
[16114-47-9]
1g
5g



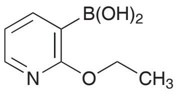
2,6-Dimethoxypyridine-3-boronic acid, 95%

L20389
[444120-91-6]
250mg
1g
5g



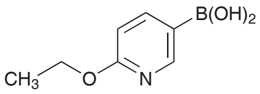
2-Ethoxypyridine-3-boronic acid, 98%

L20422
[854373-97-0]
250mg
1g
5g



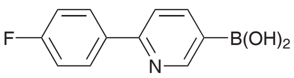
6-Ethoxypyridine-3-boronic acid, 98%

L20398
[612845-44-0]
250mg
1g
5g



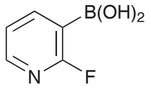
6-(4-Fluorophenyl)pyridine-3-boronic acid, 95%

H27257
250mg
1g



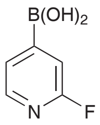
2-Fluoropyridine-3-boronic acid, 97%

L20108
[174669-73-9]
1g
5g



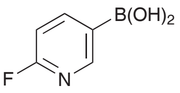
2-Fluoropyridine-4-boronic acid, 95%

H27630
[401815-98-3]
1g
5g



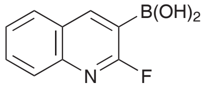
6-Fluoropyridine-3-boronic acid, 98%

L20387
[351019-18-6]
250mg
1g
5g



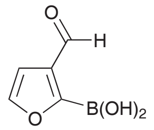
2-Fluoroquinoline-3-boronic acid, 97%

L20341
[745784-10-5]
250mg
1g
5g



3-Formylfuran-2-boronic acid, 97%

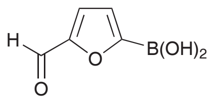
L15198
[27339-38-4]



1g
5g

5-Formylfuran-2-boronic acid

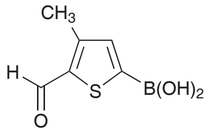
L17920
[27329-70-0]



250mg
1g
5g

5-Formyl-4-methylthiophene-2-boronic acid

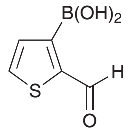
H25947
[352530-25-7]



1g
5g

2-Formylthiophene-3-boronic acid, 97%

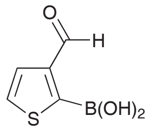
L15195
[4347-31-3]



1g
5g

3-Formylthiophene-2-boronic acid, 97%

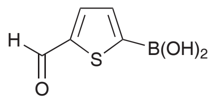
L15196
[17303-83-2]



1g
5g

5-Formylthiophene-2-boronic acid, 97%

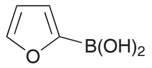
H29289
[47347-33-5]



1g
5g

Furan-2-boronic acid, 97%

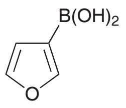
B23842
[13331-23-2]



1g
5g
25g

Furan-3-boronic acid, 97%

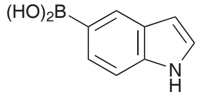
L19834
[55552-70-0]



1g
5g

Indole-5-boronic acid, 95%

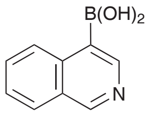
H27008
[144104-59-6]



1g

Isoquinoline-4-boronic acid, 97%

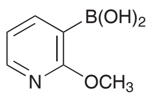
L20430
[192182-56-2]



250mg
1g
5g

2-Methoxypyridine-3-boronic acid, 98%

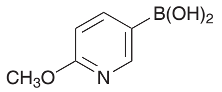
L20094
[163105-90-6]



1g
5g

6-Methoxypyridine-3-boronic acid, 98%

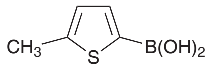
L20087
[163105-89-3]



250mg
1g
5g

5-Methylthiophene-2-boronic acid, 98%

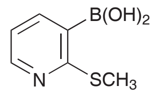
B23138
[162607-20-7]



1g
5g

2-(Methylthio)pyridine-3-boronic acid, 95%

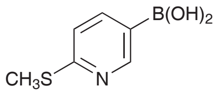
H27162



250mg
1g

6-(Methylthio)pyridine-3-boronic acid, 95%

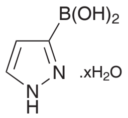
H27873
[321438-86-2]



250mg
1g

1H-Pyrazole-3-boronic acid hydrate, 95%

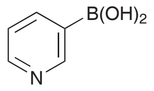
H27286
[376584-63-3]



1g
5g

Pyridine-3-boronic acid

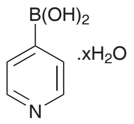
L15040
[1692-25-7]



1g
5g

Pyridine-4-boronic acid hydrate

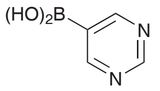
L15179
[1692-15-5]



1g
5g

Pyrimidine-5-boronic acid, 97%

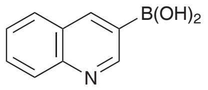
H29212
[109299-78-7]



1g
10g

Quinoline-3-boronic acid, 95%

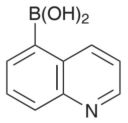
L20088
[191162-39-7]



250mg
1g
5g

Quinoline-5-boronic acid, 97%

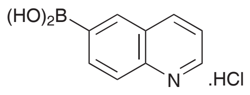
L19639
[355386-94-6]



250mg
1g

Quinoline-6-boronic acid hydrochloride, 95%

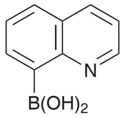
H30380



250mg
1g

Quinoline-8-boronic acid, 99%

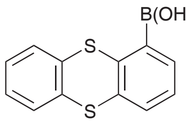
L19640
[86-58-8]



250mg
1g

Thianthrene-1-boronic acid, tech. 90%

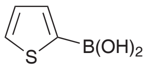
L19833
[108847-76-3]



1g
5g

Thiophene-2-boronic acid, 98+%

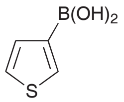
B23071
[6165-68-0]



1g
5g
25g

Thiophene-3-boronic acid, 98%

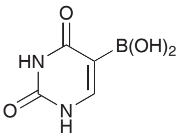
B23637
[6165-69-1]



1g
5g

Uracil-5-boronic acid, 95%

H27219
[70523-22-7]

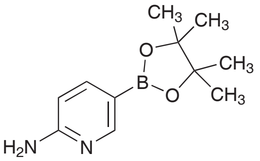


250mg
1g

Heteroaryl boronic esters

6-Aminopyridine-3-boronic acid pinacol ester, 97%

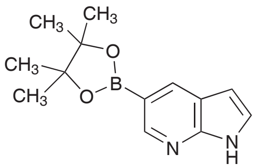
H27685
[827614-64-2]



1g
5g

7-Azaindole-5-boronic acid pinacol ester

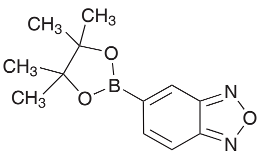
H50044
[754214-56-7]



250mg
1g

Benzofurazan-5-boronic acid pinacol ester, 97%

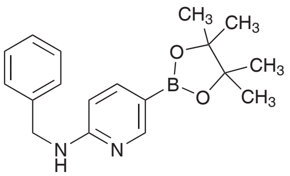
H29358



1g
5g

6-(Benzylamino)pyridine-3-boronic acid pinacol ester, 95%

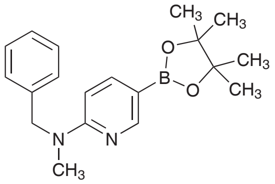
H27463



250mg
1g

6-[Benzyl(methyl)amino]pyridine-3-boronic acid pinacol ester, 95%

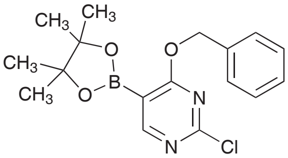
H27842



250mg
1g

4-Benzyloxy-2-chloropyrimidine-5-boronic acid pinacol ester, 95%

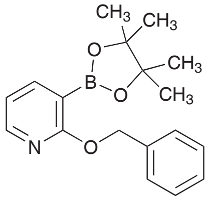
H27292



250mg
1g

2-Benzyloxypyridine-3-boronic acid pinacol ester, 95%

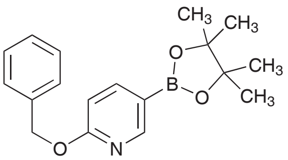
H26928



250mg
1g

6-Benzyloxypyridine-3-boronic acid pinacol ester, 95%

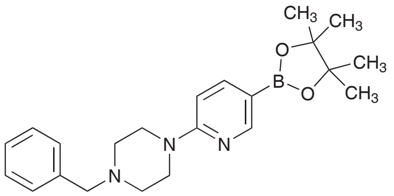
H27708
[832735-54-3]



250mg
1g

6-(4-Benzyl-1-piperazino)pyridine-3-boronic acid pinacol ester, 95%

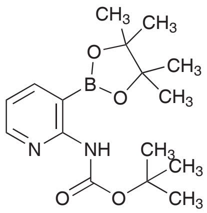
H27794
[1015242-03-1]



250mg
1g

2-(Boc-amino)pyridine-3-boronic acid pinacol ester

H50094

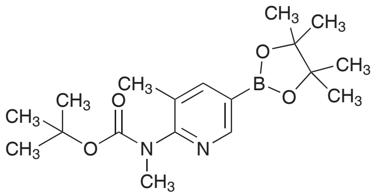


250mg
1g

6-(N-Boc-methylamino)-5-methylpyridine-3-boronic acid pinacol ester, 95%

H27500

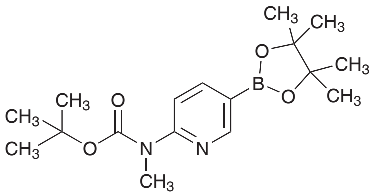
250mg
1g



6-(N-Boc-methylamino)pyridine-3-boronic acid pinacol ester, 95%

H27430

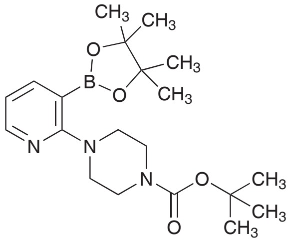
250mg
1g



2-(4-Boc-1-piperazino)pyridine-3-boronic acid pinacol ester

H50058

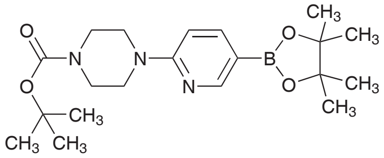
1g
5g



6-(4-Boc-1-piperazino)pyridine-3-boronic acid pinacol ester

H50145
[496786-98-2]

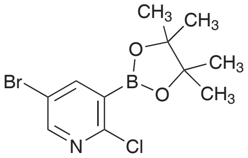
250mg
1g



5-Bromo-2-chloropyridine-3-boronic acid pinacol ester, 95%

H27666

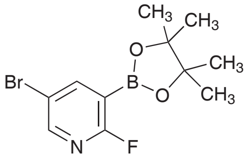
250mg
1g



5-Bromo-2-fluoropyridine-3-boronic acid pinacol ester, 95%

H27820

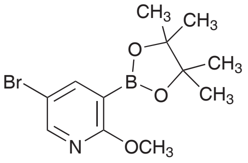
250mg
1g



5-Bromo-2-methoxypyridine-3-boronic acid pinacol ester

H50064

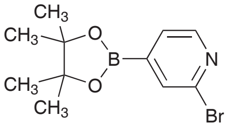
250mg
1g



2-Bromopyridine-4-boronic acid pinacol ester, 97%

H27813
[458532-82-6]

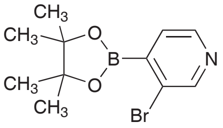
250mg
1g



3-Bromopyridine-4-boronic acid pinacol ester, 95%

H27041
[458532-92-8]

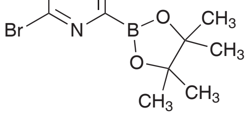
1g
5g



6-Bromopyridine-2-boronic acid pinacol ester, 95%

H27245
[651358-83-7]

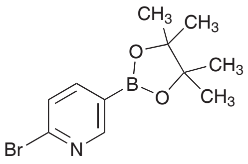
250mg
1g



6-Bromopyridine-3-boronic acid pinacol ester

H50072
[214360-62-0]

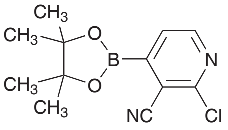
1g
5g



2-Chloro-3-cyanopyridine-4-boronic acid pinacol ester, 95%

H27284
[878194-94-6]

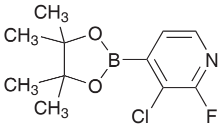
250mg
1g



3-Chloro-2-fluoropyridine-4-boronic acid pinacol ester, 95%

H27457

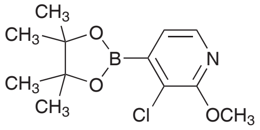
250mg
1g



3-Chloro-2-methoxypyridine-4-boronic acid pinacol ester, 95%

H27513

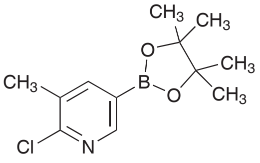
250mg
1g



6-Chloro-5-methylpyridine-3-boronic acid pinacol ester, 95%

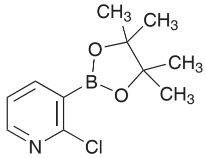
H27582

250mg
1g



2-Chloropyridine-3-boronic acid pinacol ester

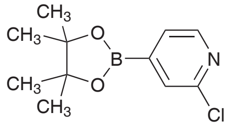
H50053
[452972-11-1]



1g
5g

2-Chloropyridine-4-boronic acid pinacol ester

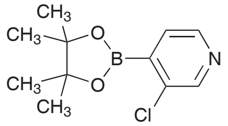
H50070
[458532-84-8]



1g
5g

3-Chloropyridine-4-boronic acid pinacol ester, 95%

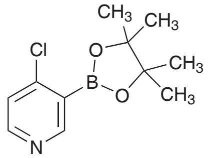
H27487
[458532-90-6]



250mg
1g

4-Chloropyridine-3-boronic acid pinacol ester, 95%

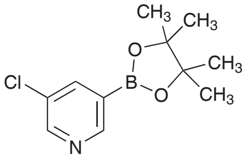
H27740
[452972-15-5]



1g
5g

5-Chloropyridine-3-boronic acid pinacol ester, 95%

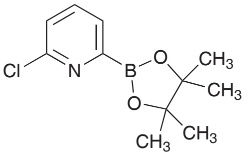
H27079
[865186-94-3]



250mg
1g

6-Chloropyridine-2-boronic acid pinacol ester, 95%

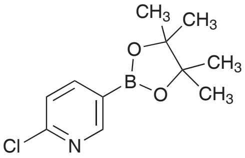
H27426
[652148-92-0]



250g
1g

6-Chloropyridine-3-boronic acid pinacol ester

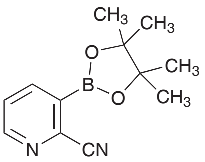
H50071
[444120-94-9]



1g
5g

2-Cyanopyridine-3-boronic acid pinacol ester, 95%

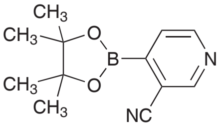
H27332
[878194-93-5]



250mg
1g

3-Cyanopyridine-4-boronic acid pinacol ester, 95%

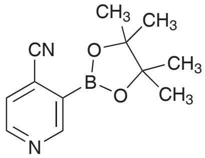
H27814
[878194-92-4]



250mg
1g

4-Cyanopyridine-3-boronic acid pinacol ester, 95%

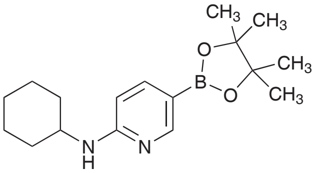
H27216
[444120-94-9]



250mg
1g

6-(Cyclohexylamino)pyridine-3-boronic acid pinacol ester, 95%

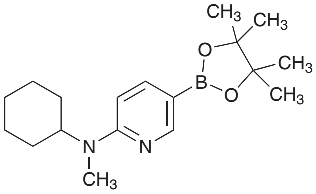
H27259



250mg
1g

6-[Cyclohexyl(methyl)amino]pyridine-3-boronic acid pinacol ester, 95%

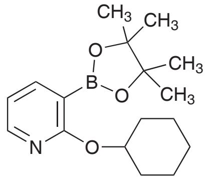
H27013



250mg
1g

2-(Cyclohexyloxy)pyridine-3-boronic acid pinacol ester

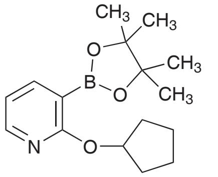
H50111



1g
5g

2-(Cyclopentyloxy)pyridine-3-boronic acid pinacol ester

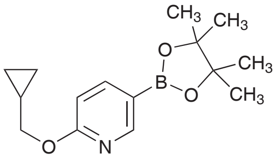
H50110



1g
5g

6-(Cyclopropylmethoxy)pyridine-3-boronic acid pinacol ester

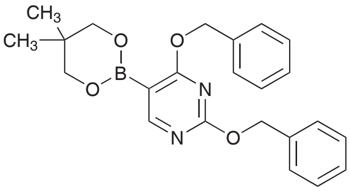
H50139
[947191-69-7]



250mg
1g

2,4-Dibenzyloxypyrimidine-5-boronic acid neopentyl glycol ester, 95%

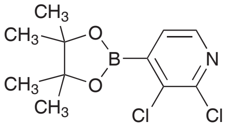
H27616



250mg
1g

2,3-Dichloropyridine-4-boronic acid pinacol ester, 95%

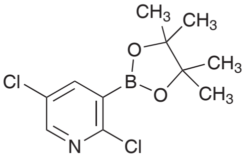
H27498



250mg
1g

2,5-Dichloropyridine-3-boronic acid pinacol ester, 94%

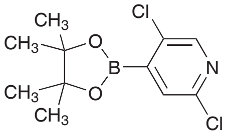
H27432



250mg
1g

2,5-Dichloropyridine-4-boronic acid pinacol ester, 94%

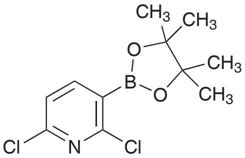
H27699



250mg
1g

2,6-Dichloropyridine-3-boronic acid pinacol ester, 95%

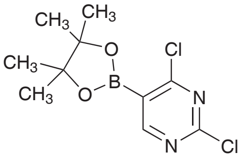
H27605



250mg
1g

2,4-Dichloropyrimidine-5-boronic acid pinacol ester, 95%

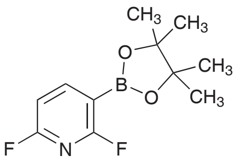
H26958



250mg
1g

2,6-Difluoropyridine-3-boronic acid pinacol ester, 95%

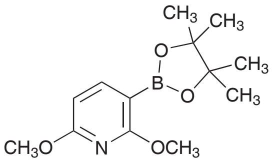
H26965



250mg
1g

2,6-Dimethoxypyridine-3-boronic acid pinacol ester, 95%

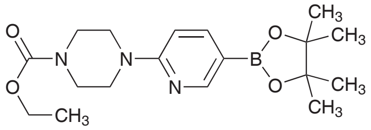
H27282
[214360-59-5]



250mg
1g

6-(4-Ethoxycarbonyl-1-piperazino)pyridine-3-boronic acid pinacol ester, 97%

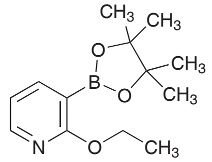
H27122



250mg
1g

2-Ethoxypyridine-3-boronic acid pinacol ester

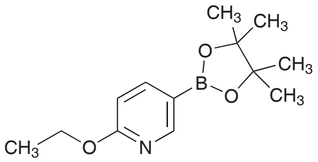
H50096
[848243-23-2]



1g
5g

6-Ethoxypyridine-3-boronic acid pinacol ester

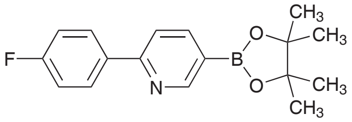
H50137



250mg
1g

6-(4-Fluorophenyl)pyridine-3-boronic acid pinacol ester, 95%

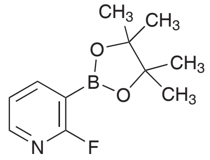
H27168



250mg
1g

2-Fluoropyridine-3-boronic acid pinacol ester, 95%

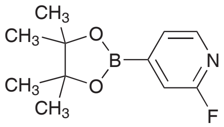
H27845
[452972-14-4]



250g
1g

2-Fluoropyridine-4-boronic acid pinacol ester, 95%

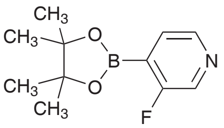
H27179
[458532-86-0]



1g
5g

3-Fluoropyridine-4-boronic acid pinacol ester

H50069
[458532-88-2]

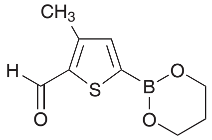


250mg
1g

5-Formyl-4-methylthiophene-2-boronic acid 1,3-propanediol ester, 95%

L17779
[374537-98-1]

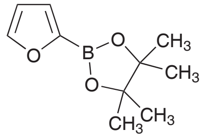
250mg
1g



Furan-2-boronic acid pinacol ester, 98%

L18366
[374790-93-9]

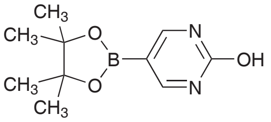
1g
5g



2-Hydroxypyrimidine-5-boronic acid pinacol ester, 95%

H26976

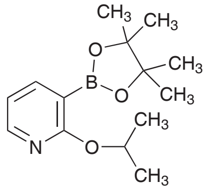
250mg
1g



2-Isopropoxypyridine-3-boronic acid pinacol ester

H50097
[848243-25-4]

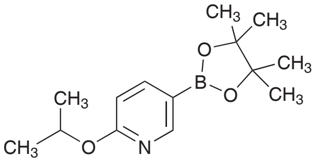
1g
5g



6-Isopropoxypyridine-3-boronic acid pinacol ester

H50141
[871839-91-7]

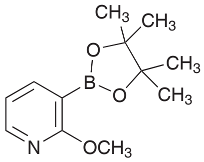
250mg
1g



2-Methoxypyridine-3-boronic acid pinacol ester

H50060
[532391-32-4]

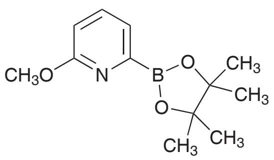
250mg
1g



6-Methoxypyridine-2-boronic acid pinacol ester, 95%

H27263

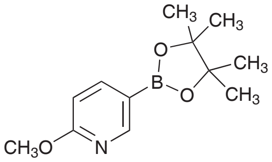
250mg
1g



6-Methoxypyridine-3-boronic acid pinacol ester

H50136
[445264-61-9]

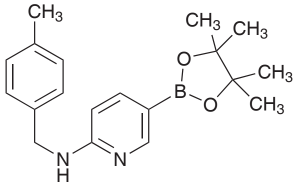
250mg
1g



6-(4-Methylbenzylamino)pyridine-3-boronic acid pinacol ester, 95%

H27434

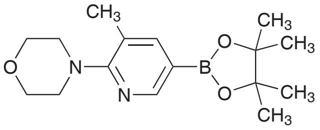
250mg
1g



5-Methyl-6-(4-morpholino)pyridine-3-boronic acid pinacol ester, 95%

H27227

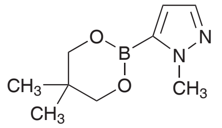
250mg
1g



1-Methyl-1H-pyrazole-5-boronic acid neopentyl glycol ester, 95%

H27703

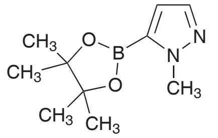
250mg
1g



1-Methyl-1H-pyrazole-5-boronic acid pinacol ester, 95%

H27094
[847818-74-0]

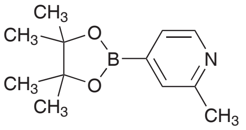
250mg
1g



2-Methylpyridine-4-boronic acid pinacol ester, 95%

H27450
[660867-80-1]

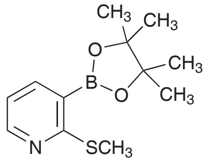
250mg
1g



2-(Methylthio)pyridine-3-boronic acid pinacol ester, 95%

H27610

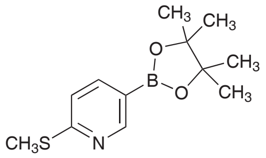
250mg
1g



6-(Methylthio)pyridine-3-boronic acid pinacol ester, 95%

H27061
[849934-89-0]

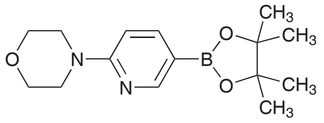
250mg
1g



6-(4-Morpholino)pyridine-3-boronic acid pinacol ester

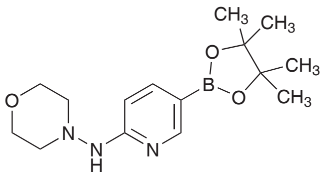
H50143

250mg
1g



6-(4-Morpholinylamino)pyridine-3-boronic acid pinacol ester, 95%

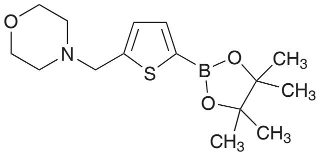
H26971



250mg
1g

5-(4-Morpholinylmethyl)thiophene-2-boronic acid pinacol ester, 97%

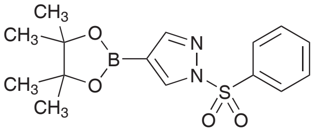
H28306
[950603-39-1]



1g
5g

1-Phenylsulfonyl-1H-pyrazole-4-boronic acid pinacol ester, 95%

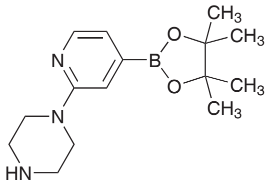
H26954



250mg
1g

2-(1-Piperazino)pyridine-4-boronic acid pinacol ester, 97%

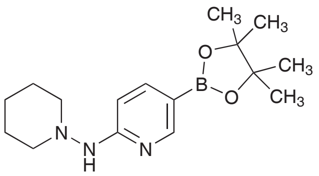
H27822
[957198-31-1]



1g

6-(1-Piperidinylamino)pyridine-3-boronic acid pinacol ester, 95%

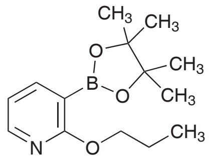
H27222



250mg
1g

2-n-Propoxypyridine-3-boronic acid pinacol ester

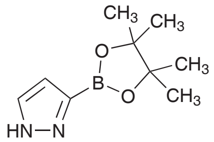
H50109



1g
5g

1*H*-Pyrazole-3-boronic acid pinacol ester, 95%

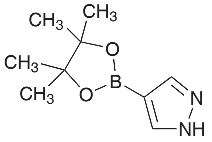
H27619
[844501-71-9]



1g
5g

1*H*-Pyrazole-4-boronic acid pinacol ester, 98%

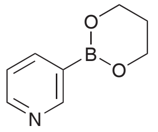
L19654
[269410-08-4]



1g
5g

Pyridine-3-boronic acid 1,3-propanediol ester, 98+%

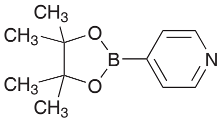
L17010
[131534-65-1]



250mg
1g
5g

Pyridine-4-boronic acid pinacol ester, 98%

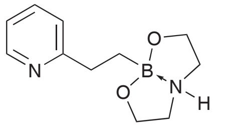
L17854
[181219-01-2]



250mg
1g

2-(2-Pyridyl)ethylboronic acid diethanolamine ester

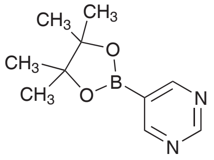
H27016



1g
5g
25g

Pyrimidine-5-boronic acid pinacol ester, 95%

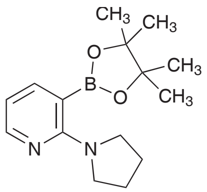
H27147
[321724-19-0]



1g
5g
25g

2-(1-Pyrrolidino)pyridine-3-boronic acid pinacol ester, 95%

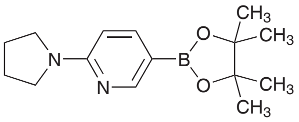
H27190



250mg
1g

6-(1-Pyrrolidino)pyridine-3-boronic acid pinacol ester, 95%

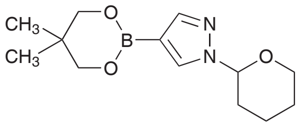
H27341
[933986-97-1]



250mg
1g

1-(2-Tetrahydropyranyl)-1H-pyrazole-4-boronic acid neopentyl glycol ester, 95%

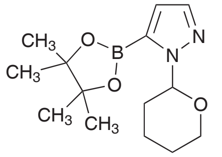
H27783



250mg
1g

1-(2-Tetrahydropyranyl)-1H-pyrazole-5-boronic acid pinacol ester, 95%

H27036
[903550-26-5]

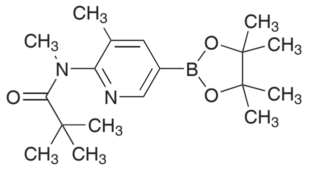


250mg
1g

6-(N,2,2,2-Tetramethylacetamido)-5-methylpyridine-3-boronic acid pinacol ester, 95%

H27211

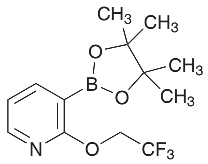
250mg
1g



2-(2,2,2-Trifluoroethoxy)pyridine-3-boronic acid pinacol ester

H50112

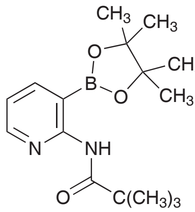
250mg
1g



2-(2,2,2-Trimethylacetamido)pyridine-3-boronic acid pinacol ester

H50015
[532391-30-3]

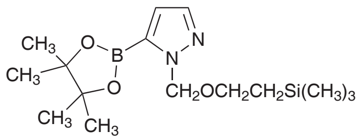
250mg
1g



1-(2-Trimethylsilylethoxy)methyl-1H-pyrazole-5-boronic acid pinacol ester, 95%

H27043

250mg
1g

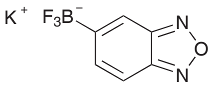


Heteroaryltrifluoroborate salts

Potassium benzofurazan-5-trifluoroborate, 97%

H28304

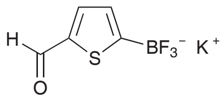
1g
5g



Potassium 5-formylthiophene-2-trifluoroborate, 97%

H28102

1g
5g

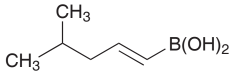


Alkenylboronic acids

4-Methyl-1-pentenylboronic acid, 97%

H27655
[214907-33-2]

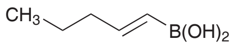
50mg
250mg



1-Pentenylboronic acid, 98%

L19677
[104376-24-1]

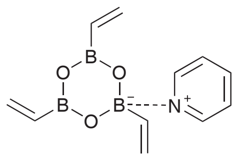
250mg
1g
5g



Vinylboronic anhydride pyridine complex, 97%

H28703
[95010-17-6]

1g
5g

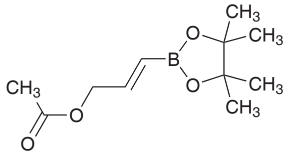


Alkenylboronic esters

3-Acetoxy-1-propenylboronic acid pinacol ester, 97%

L19700
[161395-97-7]

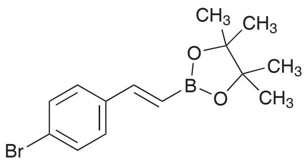
250mg
1g



***trans*-4-Bromo-β-styrylboronic acid pinacol ester,** 96%

H31412

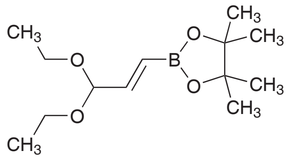
250mg
1g
5g



3,3-Diethoxy-*trans*-1-propenylboronic acid pinacol ester, 97%

L19579
[153737-25-8]

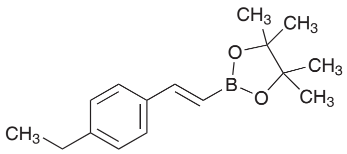
250mg
1g



4-Ethyl-*trans*-β-styrylboronic acid pinacol ester, 97%

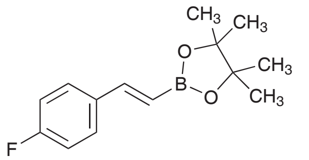
H30744
[870717-91-2]

250mg
1g
5g



4-Fluoro-*trans*-β-styrylboronic acid pinacol ester, 97%

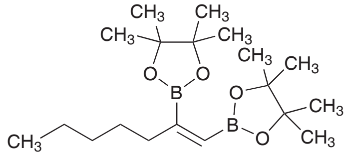
H30578
[504433-86-7]



250mg
1g
5g

(*E*)-1-Heptene-1,2-diboronic acid bis(pinacol) ester, 98%

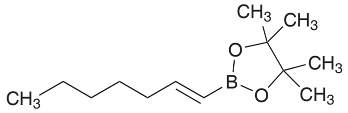
L19649
[307531-74-4]



1g
5g

trans-1-Hepten-1-ylboronic acid pinacol ester, 95%

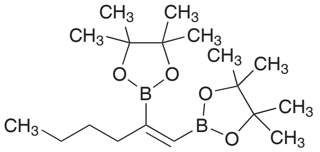
H27876
[169339-75-7]



5g

(*E*)-1-Hexene-1,2-diboronic acid bis(pinacol) ester, 98%

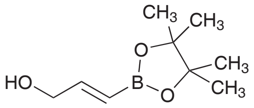
L19650
[185427-48-9]



1g
5g

trans-3-Hydroxy-1-propenylboronic acid pinacol ester

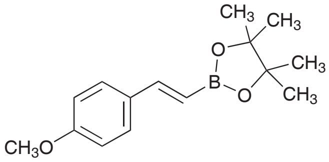
H27060
[167896-48-2]



1g
5g
25g

4-Methoxy-*trans*-β-styrylboronic acid pinacol ester, 98%

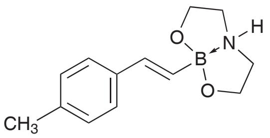
H30373
[149777-83-3]



250mg
1g
5g

4-Methyl-β-styrylboronic acid diethanolamine ester, 98+%

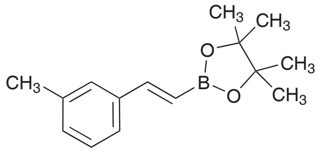
L19704
[608534-31-2]



100mg

3-Methyl-β-styrylboronic acid pinacol ester, 97%

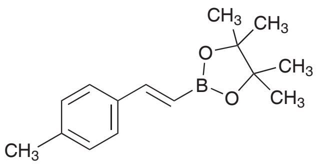
H30073



1g
5g
25g

4-Methyl-β-styrylboronic acid pinacol ester, 98%

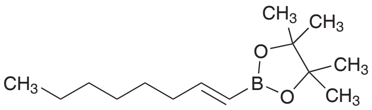
L19698
[149777-84-4]



250mg
1g

1-Octenylboronic acid pinacol ester, 97%

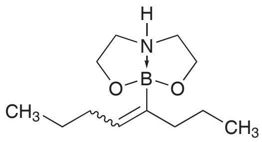
L19697
[170942-79-7]



250mg
1g

4-Octen-4-ylboronic acid diethanolamine ester, 97%

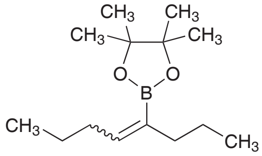
L19705
[608534-40-3]



100mg

4-Octen-4-ylboronic acid pinacol ester, 98%

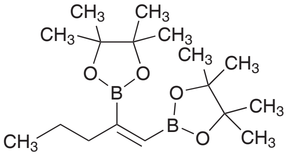
L19699
[177949-95-0]



250mg
1g

(*E*)-1-Pentene-1,2-diboronic acid bis(pinacol) ester, 98%

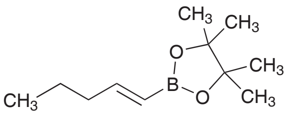
L19648
[177949-95-0]



1g
5g

(*E*)-1-Pentenylboronic acid pinacol ester, 98%

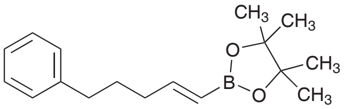
H27749
[161395-96-6]



1g
5g
25g

5-Phenyl-1-pentenylboronic acid pinacol ester, 96%

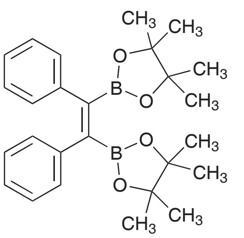
L19701
[154820-97-0]



250mg
1g

(*Z*)-Stilbenediboronic acid bis(pinacol ester), 98%

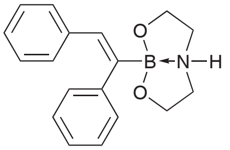
L19652
[221006-76-4]



1g
5g

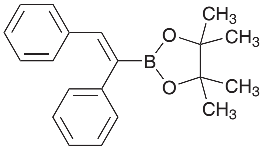
***cis*-Stilbeneboronic acid diethanolamine ester,** 98%

L19573 100mg
[501014-42-2]



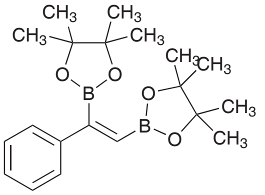
***cis*-Stilbeneboronic acid pinacol ester,** 99%

L19576 250mg
[264144-59-4] 1g



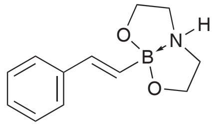
(*E*)-α,β-Styrenediboronic acid bis(pinacol) ester, 98%

L19651 1g
[173603-23-1] 5g



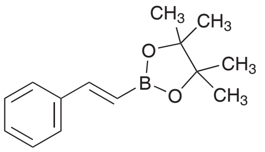
β-Styrylboronic acid diethanolamine ester, 99%

L19571 100mg
[411222-52-1]



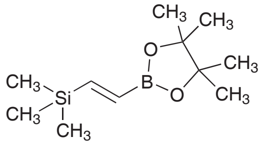
β-Styrylboronic acid pinacol ester, 99%

L19529 250mg
[78782-27-1] 1g



2-(Trimethylsilyl)vinylboronic acid pinacol ester, 95%

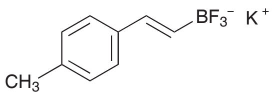
L19577 250mg
[126688-99-1] 1g



Alkenyltrifluoroborate salts

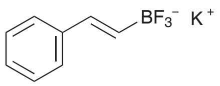
Potassium 4-methyl-β-styryltrifluoroborate, 95%

L17973 1g
[219718-86-2] 5g



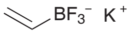
Potassium β-styryltrifluoroborate, 98%

L17971 1g
[201852-49-5] 5g



Potassium vinyltrifluoroborate, 97%

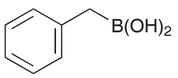
L17970 1g
[13682-77-4] 5g



Alkylboronic acids

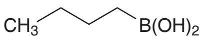
Benzylboronic acid, 95%

H27226 1g
[4463-42-75] 5g



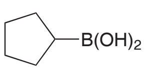
1-Butylboronic acid, 96%

A13725 1g
[4426-47-5] 5g
25g



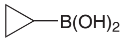
Cyclopentylboronic acid, 95%

H27081 1g
[63076-51-7] 10g



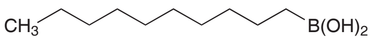
Cyclopropylboronic acid, tech. 85%

H26254 1g
[411235-57-9] 5g



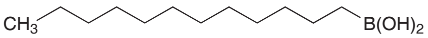
1-Decylboronic acid

L19957 1g
[24464-63-9] 5g
25g



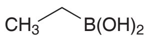
1-Dodecylboronic acid

L19958 1g
[24464-63-9] 5g
25g



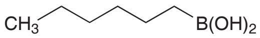
Ethylboronic acid, 98%

L19959 1g
[4433-63-0] 5g
25g



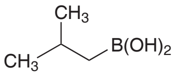
1-Hexylboronic acid, 98%

B22446 1g
[16343-08-1] 5g
25g



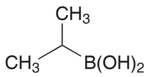
Isobutylboronic acid, 97%

H27698 1g
[84110-40-7] 5g



Isopropylboronic acid, 98%

L19962 1g
[80041-89-0] 5g
25g



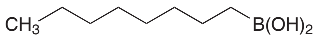
Methylboronic acid, 97%

L15589 1g
[13061-96-6] 5g

$CH_3B(OH)_2$

1-Octylboronic acid, 97%

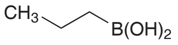
L19964
[28741-08-4]



1g
5g
25g

1-Propylboronic acid, 98%

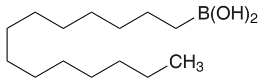
L19965
[17745-45-8]



1g
5g
25g

1-Tetradecylboronic acid

L19966
[100888-40-2]

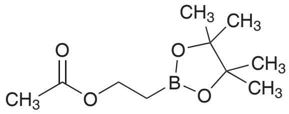


1g
5g
25g

Alkylboronic esters

2-Acetoxyethylboronic acid pinacol ester

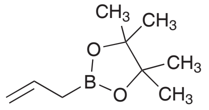
H27569
[177950-06-0]



1g
5g
25g

Allylboronic acid pinacol ester, 98+%

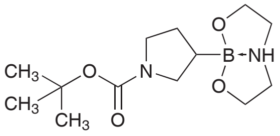
L16232
[72824-04-5]



1g
5g

1-Boc-pyrrolidine-3-boronic acid diethanolamine ester, 97%

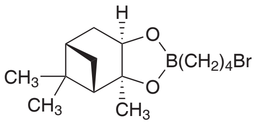
H26222



250mg
1g
5g

4-Bromobutylboronic acid (1S,2S,3R,5S)-(+)-2,3-pinanediol ester, 95%

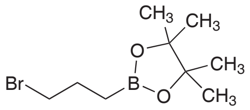
H27097



250mg
1g

3-Bromopropylboronic acid pinacol ester, 98%

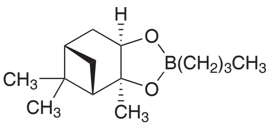
H30646
[124215-44-7]



1g
5g
25g

1-Butylboronic acid (1S,2S,3R,5S)-(+)-2,3-pinanediol ester, 95%

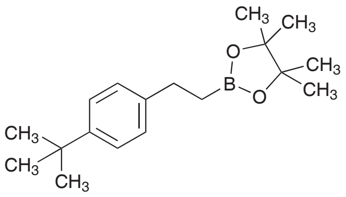
H27661



250mg
1g

2-(4-*tert*-Butylphenyl)ethylboronic acid pinacol ester, 95%

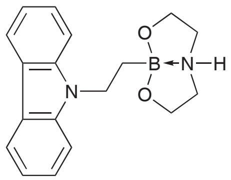
H27051



1g
5g
25g

2-(9*H*-Carbazolyl)ethylboronic acid diethanolamine ester, 98%

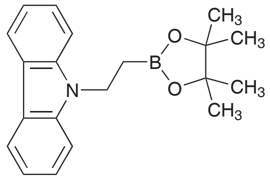
L19575
[501014-45-5]



100mg

2-(9*H*-Carbazolyl)ethylboronic acid pinacol ester, 98%

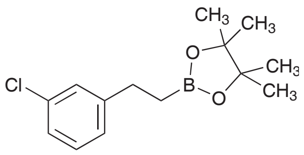
L19580
[608534-41-4]



250mg
1g

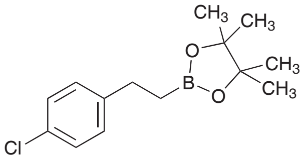
2-(3-Chlorophenyl)ethylboronic acid pinacol ester, 97%

H30464



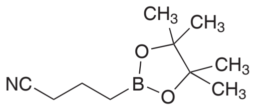
2-(4-Chlorophenyl)ethylboronic acid pinacol ester, 98%

H30303
[444094-88-6]



3-Cyano-1-propylboronic acid pinacol ester, 96%

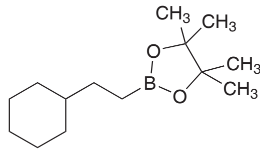
H27126
[238088-16-9]



1g
5g
25g

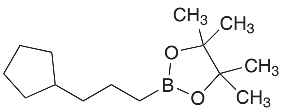
2-Cyclohexylethylboronic acid pinacol ester, 97%

H31156
[167692-95-7]



3-Cyclopentylpropylboronic acid pinacol ester, 97%

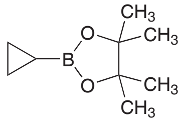
H31158



1g
5g
25g

Cyclopropylboronic acid pinacol ester, 96%

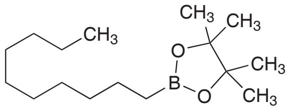
H27642
[126689-01-8]



1g
5g

1-Decylboronic acid pinacol ester, 98%

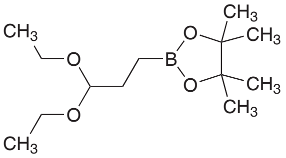
H30403
[141091-38-5]



1g
5g
25g

3,3-Diethoxy-1-propylboronic acid pinacol ester, 97%

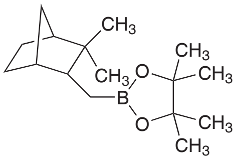
L19532
[165904-27-8]



250mg
1g

3,3-Dimethylbicyclo[2.2.1]hept-2-ylmethylboronic acid pinacol ester, mixture of isomers, 90+%

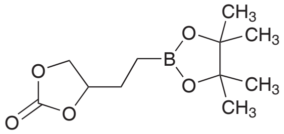
H27267



1g
5g
25g

2-(1,3-Dioxolan-2-on-4-yl)-1-ethylboronic acid pinacol ester, 97%

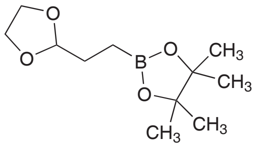
L19533
[501014-47-7]



250mg
1g

2-(1,3-Dioxolan-2-yl)-1-ethylboronic acid pinacol ester, 97%

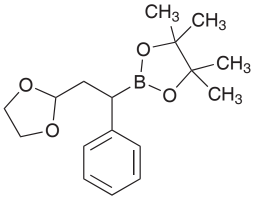
H26071



1g
5g

2-(1,3-Dioxolan-2-yl)-1-phenylethylboronic acid pinacol ester

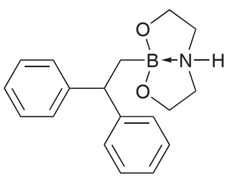
H27113



1g
5g
25g

2,2-Diphenyl-1-ethylboronic acid diethanolamine ester, 97%

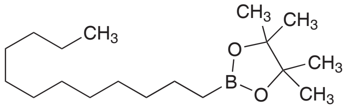
L19703
[608534-43-6]



100mg

1-Dodecylboronic acid pinacol ester, 98%

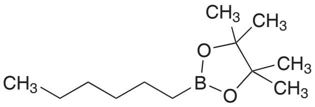
H31186
[177035-82-4]



1g
5g
25g

1-Hexylboronic acid pinacol ester, 98%

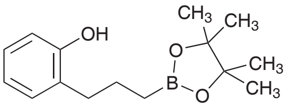
H27831
[86308-26-1]



1g
5g
25g

3-(2-Hydroxyphenyl)propylboronic acid pinacol ester, 97%

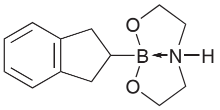
H27153



1g
5g
25g

2-Indanylboronic acid diethanolamine ester, 98%

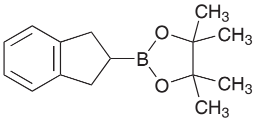
L19574
[501014-44-4]



100mg

2-Indanylboronic acid pinacol ester, 95%

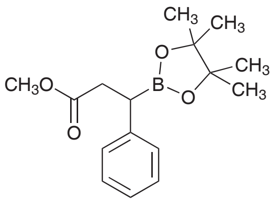
L19535
[608534-44-7]



250mg
1g

2-Methoxycarbonyl-1-phenylethylboronic acid pinacol ester

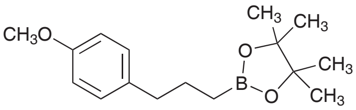
H26880



1g
5g
25g

3-(4-Methoxyphenyl)-1-propylboronic acid pinacol ester, 97%

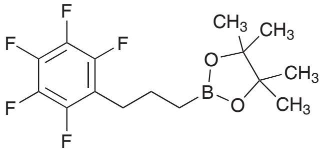
H28557



250mg
1g
5g

3-Pentafluorophenyl-1-propylboronic acid pinacol ester, 96%

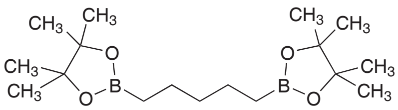
H31154



250mg
1g
5g

1,5-Pentanediboronic acid bis(pinacol ester)

H27438

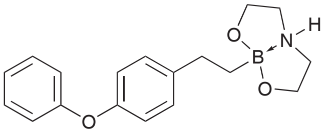


1g
5g
25g

2-(4-Phenoxyphenyl)ethylboronic acid diethanolamine ester, 97%

H31401

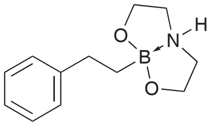
1g
5g
25g



2-Phenylethyl-1-boronic acid diethanolamine ester, 98+%

L19706
[4848-04-8]

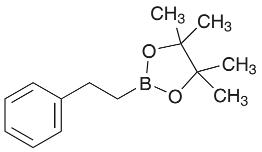
100mg



2-Phenylethyl-1-boronic acid pinacol ester, 99%

L19530
[165904-22-3]

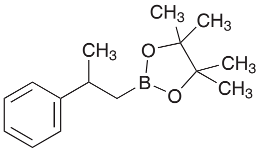
250mg
1g



2-Phenylethyl-1-boronic acid pinacol ester, 99%

H26931
[280559-30-0]

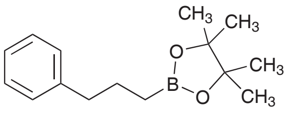
250mg
1g
5g



3-Phenyl-1-propylboronic acid pinacol ester, 97%

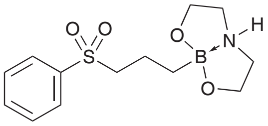
H28985
[329685-40-7]

1g
5g
25g



2-(3-Phenylsulfonylpropyl)boronic acid diethanolamine ester

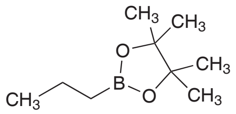
H31357



1-Propylboronic acid pinacol ester, 98%

H30441
[67562-19-0]

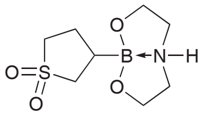
1g
5g
25g



Tetrahydrothiophene-1,1-dioxide-3-boronic acid diethanolamine ester, 97%

H31355

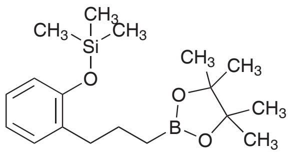
250mg
1g
5g



3-(2-Trimethylsiloxyphenyl)-1-propylboronic acid pinacol ester

H30323

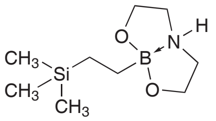
1g
5g
25g



2-Trimethylsilyl-1-ethylboronic acid diethanolamine ester, 98%

L19572
[501014-43-3]

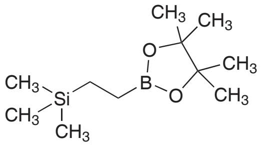
100mg



2-Trimethylsilyl-1-ethylboronic acid pinacol ester, 97%

L19534
[165904-22-3]

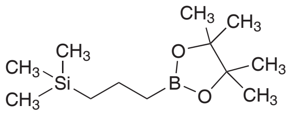
250mg
1g



3-Trimethylsilyl-1-propylboronic acid pinacol ester, 97%

H28413
[165904-32-5]

250mg
1g
5g



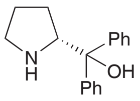
Other products

Selected Alfa Aesar products with applications in boronic acid chemistry. Most are referred to in the text of this publication.

Oxazaborolidine reagents

(R)-(+)-α,α-Diphenylprolinol, 99%

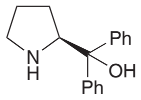
L09218
[22348-32-9]



250mg
1g

(S)-(-)- α,α-Diphenylprolinol, 98%

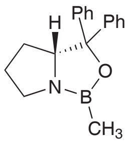
L09217
[112068-01-6]



1g
5g

(R)-2-Methyl-CBS-oxazaborolidine, 1M soln. in toluene

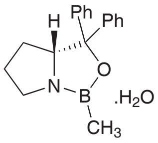
L14582
[112022-83-0]



1mL
5mL
25mL

(R)-2-Methyl-CBS-oxazaborolidine monohydrate, 94%

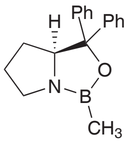
L09230



250mg
1g

(S)-2-Methyl-CBS-oxazaborolidine, 1M soln. in toluene

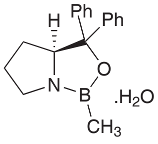
L14583
[112022-81-8]



1mL
5mL
25mL

(S)-2-Methyl-CBS-oxazaborolidine monohydrate, 94%

L09219



250mg
1g

Coupling and hydroboration catalysts

Bis(acetonitrile)dichloropalladium(II)

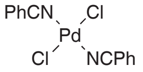
10002
[14592-56-4]

$(CH_3CN)_2PdCl_2$

1g
5g

***trans*-Bis(benzonitrile)dichloropalladium(II)**

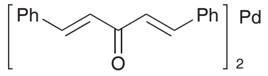
10006
[14220-64-5]



500mg
1g

Bis(dibenzylideneacetone)palladium(0)

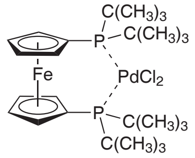
12764
[32005-36-0]



250mg
1g
5g

1,1'-Bis(di-tert-butylphosphino)ferrocene palladium dichloride

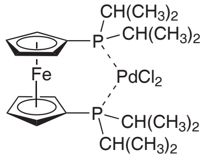
44829
[95408-45-0]



100mg
1g

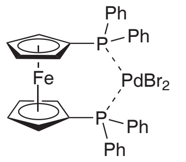
1,1'-Bis(diisopropylphosphino)ferrocene palladium dichloride

44978
[215788-65-1]



[1,1'-Bis(diphenylphosphino)ferrocene] palladium(II) bromide

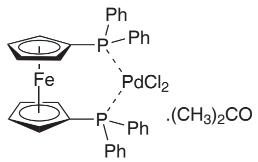
44980
[124268-93-5]



1g
5g

[1,1'-Bis(diphenylphosphino)ferrocene] palladium(II) chloride, complex with acetone

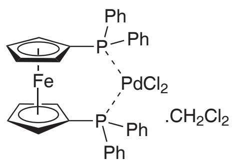
44972
[851232-71-8]



1g
5g

[1,1'-Bis(diphenylphosphino)ferrocene] palladium(II) chloride, complex with dichloromethane (1:1)

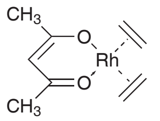
41225
[72287-26-4]



1g
5g
25g

Bis(ethylene)(2,4-pentanedionato)rhodium(I)

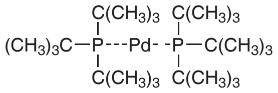
39288
[12082-47-2]



250mg
1g

Bis(tri-tert-butylphosphine)palladium(0)

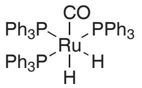
44845
[53199-31-8]


$[(CH_3)_3C]_3P{-}{-}{-}Pd{-}{-}{-}P[C(CH_3)_3]_3$

1g

Carbonyldihydridotris(triphenylphosphine) ruthenium(II), 99%

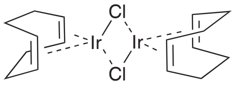
40524
[25360-32-1]



500mg
2g
10g

Chloro(1,5-cyclooctadiene)iridium(I) dimer

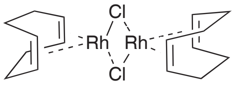
12749
[12112-67-3]



250mg
1g
5g

Chloro(1,5-cyclooctadiene)rhodium(I) dimer

10466
[12092-47-6]



250mg
1g

Chlorotris(triphenylphosphine)rhodium(I)

10468
[14694-95-2]

$(Ph_3P)_3RhCl$

250mg
1g
5g

Copper(II) acetate monohydrate

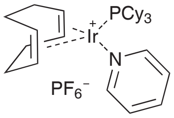
A16203
[6046-93-1]

$(CH_3COO)_2Cu\ .H_2O$

100g
500g
2.5kg

(1,5-Cyclooctadiene)(pyridine) (tricyclohexylphosphine)iridium(I) hexafluorophosphate, Crabtree's catalyst, 99%

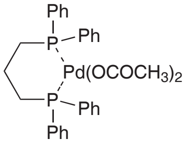
42057
[64536-78-3]



50mg
250mg
1g

Diacetato[1,3-bis(diphenylphosphino)propane] palladium(II)

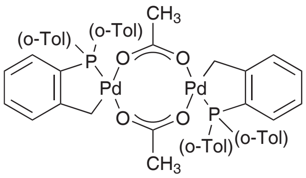
44970
[149796-59-8]



1g
5g

trans-Di-m-acetatobis[2-(di-o-tolylphosphino) benzyl]dipalladium(II), 98%

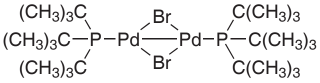
L16948
[172418-32-5]



250mg
1g

Dibromobis(tri-tert-butylphosphine) dipalladium(I)

44446
[185812-86-6]



100mg
500mg
2g

Dibromobis(tri-o-tolylphosphine)palladium(II)

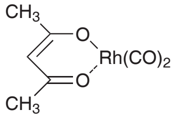
44979
[24554-43-6]

$[(o\text{-}Tol)_3P]_2PdBr_2$

1g
5g

Dicarbonyl(2,4-pentanedionato)rhodium(I), 99%

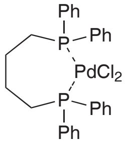
39295
[14874-82-9]



250mg
1g
5g

Dichlorobis(1,4-diphenylphosphinobutane) palladium(II)

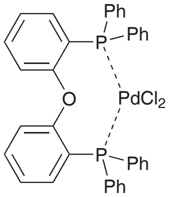
44971
[29964-62-3]



1g
5g

Dichlorobis(2-diphenylphosphinophenyl ether) palladium(II)

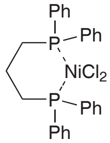
44977
[205319-06-8]



1g
5g

Dichlorobis(1,3-diphenylphosphinopropane) nickel(II)

30167
[15629-92-2]



2g
10g

Dichlorobis(tricyclohexylphoshine)palladium(II)

44844
[29934-17-6]

$[Cy_3P]_2PdCl_2$

1g

Dichlorobis(triphenylphosphine)nickel(II)

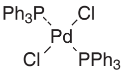
13930
[14220-64-5]

$(Ph_3P)_2NiCl_2$

5g
25g
100g

trans-Dichlorobis(triphenylphosphine) palladium(II)

10491
[13965-03-2]



1g
5g
25g

Dichlorobis(tri-o-tolylphosphine)palladium(II)

44976
[40691-33-6]

$[(o\text{-}Tol)_3P]_2PdCl_2$

1g
5g

Palladium, 5% on carbon powder, dry

A12623

10g
50g

Palladium, 5% on carbon powder, standard, reduced, 50% water wet

38300
5g
25g
100g

Palladium, 5% on carbon powder, standard, unreduced, 50% water wet

38301
5g
25g
100g

Palladium, 10% on carbon powder, dry

A12012
2g
10g
50g

Palladium, 10% on carbon powder, standard, reduced, 50% water wet

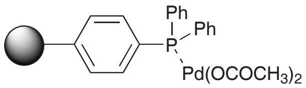
38304
5g
25g
100g

Palladium, 5% on carbon powder, standard, unreduced, 50% water wet

38305
5g
25g
100g

Palladium anchored homogeneous catalyst, FibreCat® 1001

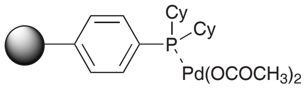
44111



5g
25g
100g

Palladium anchored homogeneous catalyst, FibreCat® 1007

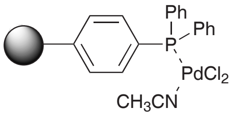
44110



5g
25g
100g

Palladium anchored homogeneous catalyst, FibreCat® 1026

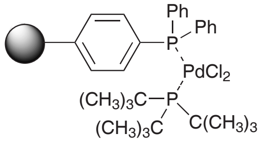
44981



5g
25g

Palladium anchored homogeneous catalyst, FibreCat® 1032

44730



5g

Palladium(II) acetate, trimer

10516
[3375-31-3]

$[(CH_3COO)_2Pd]_3$

1g
2g
10g

Palladium(II) chloride

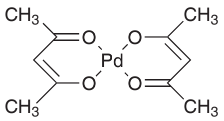
11034
[7647-10-1]

$PdCl_2$

1g
5g
25g

Palladium(II) 2,4-pentanedionate

10517
[14024-61-4]



1g
5g

Sodium tetrachloropalladate(II) hydrate

11886
[13820-53-6]

$Na_2PdCl_4 .xH_2O$

1g
5g

Tetrakis(triphenylphosphine)palladium(0), 99%

L00953
[14221-01-3]

$(Ph_3P)_4Pd$

1g
5g
25g

Tetrakis(triphenylphosphine)palladium(0), 99.8% **(metals basis)**

10548
[14221-01-3]

500mg
2g
10g

Tetrakis(triphenylphosphine)platinum(0), 98%

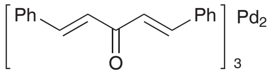
10549
[14221-02-4]

$(Ph_3P)_4Pt$

1g
5g

Tris(dibenzylideneacetone)dipalladium(0

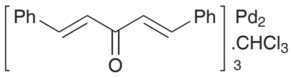
12760
[51364-51-3]



1g
5g

Tris(dibenzylideneacetone)dipalladium(0) chloroform adduct, 98%

L15980
[52522-40-4]

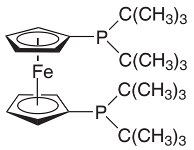


250mg
1g
5g

Phosphine ligands

1,1’-Bis(di-tert-butylphosphino)ferrocene, 98%

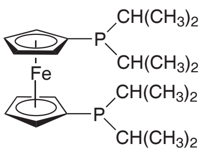
L19759
[84680-95-5]



500mg
2g

1,1’-Bis(diisopropylphosphino)ferrocene, 98%

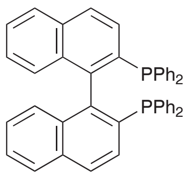
H27057
[97239-80-0]



1g
5g

(±)-2,2’-Bis(diphenylphosphino)-1,1’-binaphthyl, 98%

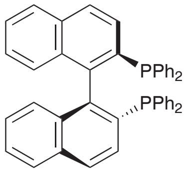
H26226
[98327-87-8]



5g
25g
100g

(R)-(+)-2,2’-Bis(diphenylphosphino)-1,1’-binaphthyl, 98%

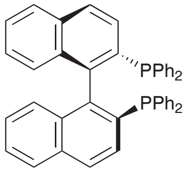
B23785
[76189-55-4]



250mg
1g
5g

(S)-(-)-2,2’-Bis(diphenylphosphino)-1,1’-binaphthyl, 97%

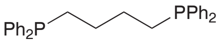
B23872
[76189-55-4]



250mg
1g
5g

1,4-Bis(diphenylphosphino)butane, 98%

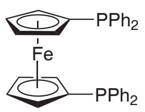
B21122
[100959-19-1]



1g
5g
25g

1,1’-Bis(diphenylphosphino)ferrocene, 97%

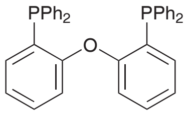
B21166
[12150-46-8]



1g
5g
25g

Bis[(2-diphenylphosphino)phenyl] ether, 98%

L18481
[166330-10-5]



1g
5g

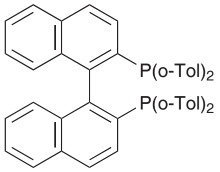
1,3-Bis(diphenylphosphino)propane, 97%

A12931
[6737-42-4]

5g
25g
100g

(±)-2,2’-Bis(di-p-tolylphosphino)-1,1’-binaphthyl, 98%

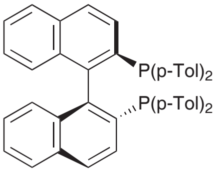
H27585
[153305-67-0]



250mg
1g
5g

(R)-(+)-2,2’-Bis(di-p-tolylphosphino)-1,1’-binaphthyl, 98%

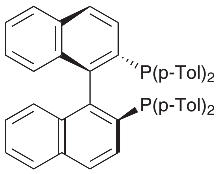
42119
[99646-28-3]



100mg
500mg
2g
10g

(S)-(-)-2,2’-Bis(di-p-tolylphosphino)-1,1’-binaphthyl, 98%

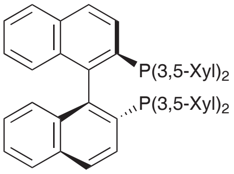
42120
[100165-88-6]



100mg
500mg
2g
10g

(R)-(+)-2,2’-Bis(di-3,5-xylylphosphino)-1,1’-binaphthyl, 98%

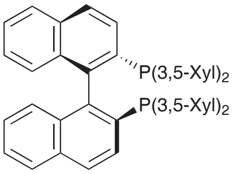
H27680
[137219-86-4]



100mg
500mg

(S)-(-)-2,2’-Bis(di-3,5-xylylphosphino)-1,1’-binaphthyl, 98%

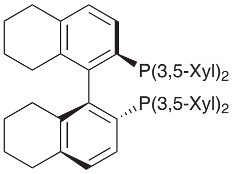
H26970
[135139-00-3]



100mg
500mg

(R)-(+)-2,2’-Bis(di-3,5-xylylphosphino)-5,5’,6,6’,7,7’,8,8’-octahydro-1,1’-binaphthyl

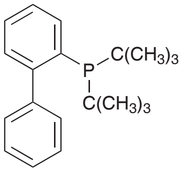
H27351
[190003-81-7]



50mg
250mg

2-(Di-tert-butylphosphino)biphenyl, 99%

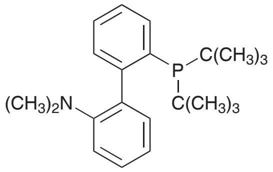
L19758
[224311-51-7]



500mg
2g
10g

2-(Di-tert-butylphosphino)-2’-(N,N-dimethylamino)biphenyl, 98%

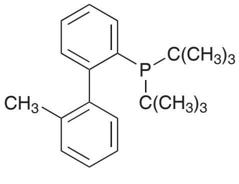
H27209
[224311-49-3]



250mg
1g

2-(Di-tert-butylphosphino)-2’-methylbiphenyl, 99%

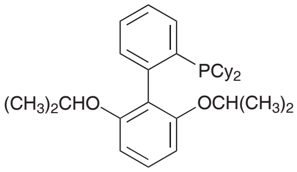
H27742
[255837-19-5]



250mg
1g

2-Dicyclohexylphosphino-2’,6’-diisopropoxy-1,1’-biphenyl, 98%

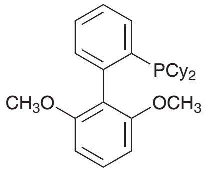
H27617
[787618-22-8]



1g
5g

2-Dicyclohexylphosphino-2',6'-dimethoxybiphenyl, 98+%

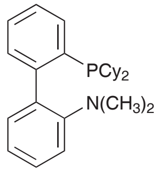
H27015
[657408-07-6]



1g
5g
25g

2-Dicyclohexylphosphino-2'-(N,N-dimethylamino)biphenyl, 98%

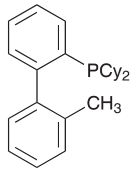
H27678
[213697-53-1]



1g
5g
25g

2-Dicyclohexylphosphino-2'-methylbiphenyl, 98%

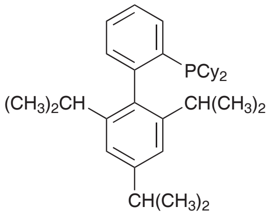
H27647
[251320-86-2]



1g
5g

2-Dicyclohexylphosphino-2',4',6'-triisopropylbiphenyl, 98+%

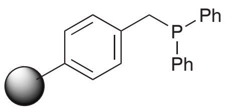
H27481
[564483-18-7]



1g
5g
25g

Diphenylmethylphosphine, polymer-supported, 0.9-1.4 mmol/g on polystyrene

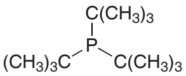
L19477



1g
5g
25g

Tri-tert-butylphosphine, 96%

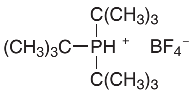
10178
[13716-12-6]


$P[C(CH_3)_3]_3$

1g
5g

Tri-tert-butylphosphonium tetrafluoroborate, 98%

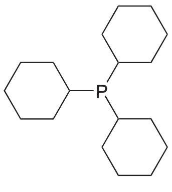
L19752
[131274-22-1]


$(CH_3)_3C-PH^+[C(CH_3)_3]_2 \quad BF_4^-$

1g
5g

Tricyclohexylphosphine, 97%

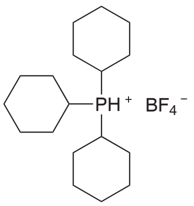
30386
[2622-14-2]



1g
5g
25g

Tricyclohexylphosphonium tetrafluoroborate, 99%

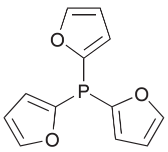
H27428
[58656-04-5]



1g
5g
25g

Tri(2-furyl)phosphine, 97%

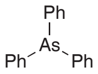
L13329
[5518-52-5]



1g
5g

Triphenylarsine, 98%

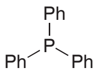
L03616
[603-32-7]


Ph_3As

5g
25g

Triphenylphosphine, powder, 99%

L02502
[603-32-7]


Ph_3P

50g
250g
1kg

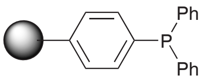
Triphenylphosphine, flake, 99%

A14089
[603-32-7]

250g
1kg
5kg

Triphenylphosphine, polymer-supported, 1.4-2.0 mmol/g on polystyrene

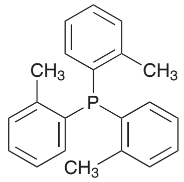
L19478



1g
5g
25g

Tri(o-tolyl)phosphine, 98+%

A12093
[6163-58-2]

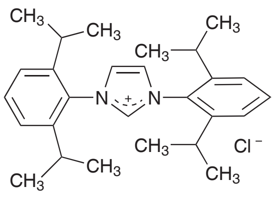


1g
5g
25g

Non-phosphine ligands

1,3-Bis(2,6-diisopropylphenyl)imidazolium chloride, 97+%

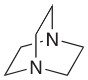
H27150
[250285-32-6]



1g
5g

1,4-Diazabicyclo[2.2.2]octane, 98%

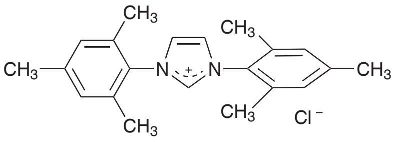
A14003
[280-57-9]



100g
500g

1,3-Dimesitylimidazolium chloride, 96%

H27535
[141556-45-83]

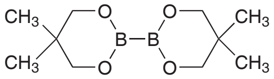


1g
5g

Borylation reagents

Bis(neopentyl glycolato)diboron, 97%

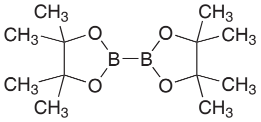
L18675
[201733-56-4]



250mg
1g
5g

Bis(pinacolato)diboron, 99%

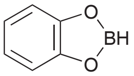
L16088
[73183-34-3]



1g
5g
25g

Catecholborane, 97%

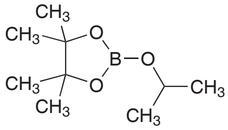
L14998
[274-07-7]



5g
25g

2-Isopropoxy-4,4,5,5-tetramethyl-1,3,2-dioxaborolane, 98%

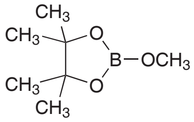
L17278
[61676-62-8]



1g
5g
25g

2-Methoxy-4,4,5,5-tetramethyl-1,3,2-dioxaborolane, 97%

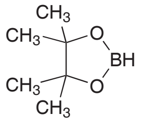
L19056
[1195-66-0]



5g
25g

Pinacolborane, 97%

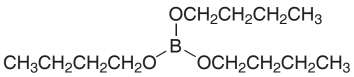
L17558
[25015-63-8]



5g
25g

Tri-n-butyl borate, 98%

A19322
[688-74-4]

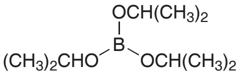


$CH_3CH_2CH_2CH_2O-\overset{OCH_2CH_2CH_2CH_3}{B}-OCH_2CH_2CH_2CH_3$

25mL
100mL
500mL

Triisopropyl borate, 98+%

A17592
[5419-55-6]

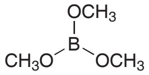


$(CH_3)_2CHO-\overset{OCH(CH_3)_2}{B}-OCH(CH_3)_2$

100mL
500mL
2.5L

Trimethyl borate, 99%

B20215
[121-43-7]



$CH_3O-\overset{OCH_3}{B}-OCH_3$

250mL
1L

NOTES

NOTES

How to Order/General Information

ORDERING

There is no minimum order. We welcome all orders, regardless of size. Lower value orders may be subject to a nominal handling fee.

PRICING

Most current pricing may be found at our web site. In cases where the selling price has changed significantly, we will contact you prior to filling your order. Our payment terms are net 30 days of invoice.

SHIPPING

Whenever possible, we will ship products by the method specified on your order.

TECHNICAL SERVICE

At your request, we will furnish technical assistance and information with respect to our products. Our Technical Service Representatives are trained in specific product lines to answer your questions regarding applications, specifications, product properties and handling.

MATERIAL SAFETY DATA SHEETS

A Material Safety Data Sheet (MSDS) for each product is available on our website and also automatically accompanies your order. If one is not immediately available, a copy will be sent via mail as soon as possible. If an MSDS is needed prior to shipment of a product please contact us or visit www.alfa.com.

CERTIFICATES OF ANALYSIS

Lot specific Certificates of Analysis for select regions are available online at www.alfa.com. Please contact us by phone, fax or email to request Certificates of Analysis as needed.

RETURN SHIPMENTS

Some materials are not returnable. Returned shipments cannot be accepted unless prior arrangements have been made. Requests for return authorization must be made within 30 days of your receiving the materials. Restocking fees may be charged on authorized returns.

TERMS OF SALE

Please refer to your local sales office for full details of Terms and Conditions.

NEW CUSTOMERS

We welcome new customers and setting up an account with Alfa Aesar is easy. Just contact us and a customer service representative will assist you.

Contact Alfa Aesar Worldwide

NORTH AMERICA

Tel: 1-888-343-8025
or 1-978-521-6401
e-mail: specialquotes@alfa.com

UNITED KINGDOM

Tel: 0800-801812
or +44 (0)1524 850506
e-mail: uksales@alfa.com

GERMANY

Tel: +49 721 84007 115
e-mail: EuroBulk@alfa.com

FRANCE

Tel: 0800 03 51 47
or +33 (0)3 8862 2690
e-mail: FrVentes@alfa.com

CHINA

Tel: 86 (010)-800 810-6000
or 86 (010)-8567-8600
e-mail: saleschina@alfa-asia.com

KOREA

Tel: 82-2-3140-6000
e-mail: saleskorea@alfa-asia.com

INDIA

Tel: 91 (0)44 2815 4153
e-mail: India@alfa.com

INTERNET

www.alfa.com
Our web catalog features up-to-date prices, stock availability, MSDS, Certificates of Analysis and a user-friendly e-commerce system.

Boronic Acids

ALFA AESAR NORTH AMERICA
(International Sales Headquarters)
26 Parkridge Road
Ward Hill, MA 01835 USA
Tel: 1-888-343-8025 or 1-978-521-6401
Fax: 1-978-521-6366
e-mail: specialquotes@alfa.com

ALFA AESAR UNITED KINGDOM
Shore Road, Port of Heysham Industrial Park
Heysham, Lancashire LA3 2XY
Tel: 0800-801812 or +44 (0)1524 850506
Fax: +44 (0)1524 850608
e-mail: uksales@alfa.com

ALFA AESAR GERMANY
Postbox 11 07 65
76057 Karlsruhe, Germany
Tel: +49 721 84007 115
Fax: +49 721 84007 201
e-mail: EuroBulk@alfa.com

ALFA AESAR FRANCE
12 allée d'Oslo
67300 Schiltigheim, France
Tel: 0800 03 51 47 or +33 (0)3 8862 2690
Fax: 0800 10 20 67
e-mail: FrVentes@alfa.com

ALFA AESAR CHINA
Room 1501B, 1509-1515
CBD International Building,
Yonganli: East Road No. 16
Chao Yang District, Beijing, China 100022
Tel: 86 (010)-800 810-6000 or 86 (010)-8567-8600
Fax: 86 (010)-8567-8601
e-mail: saleschina@alfa-asia.com

ALFA AESAR KOREA
6F Mirae Plaza Building
165–1 Donggyo-Dong, Mapo-Gu
Seoul, Korea 121–753
Tel: 82-2-3140-6000
Fax: 82-2-3140-6001
e-mail: saleskorea@alfa-asia.com

ALFA AESAR INDIA
(Johnson Matthey Chemicals India Pvt. Ltd.)
3rd Floor, 108 Sir Theagaraya Road
Pondy Bazaar, T. Nagar,
Chennai 600 017
Tel: 91 (0)44 2815 4153
Fax: 91 (0)44 2815 4154
e-mail: India@alfa.com

Alfa Aesar®
A Johnson Matthey Company

www.alfa.com