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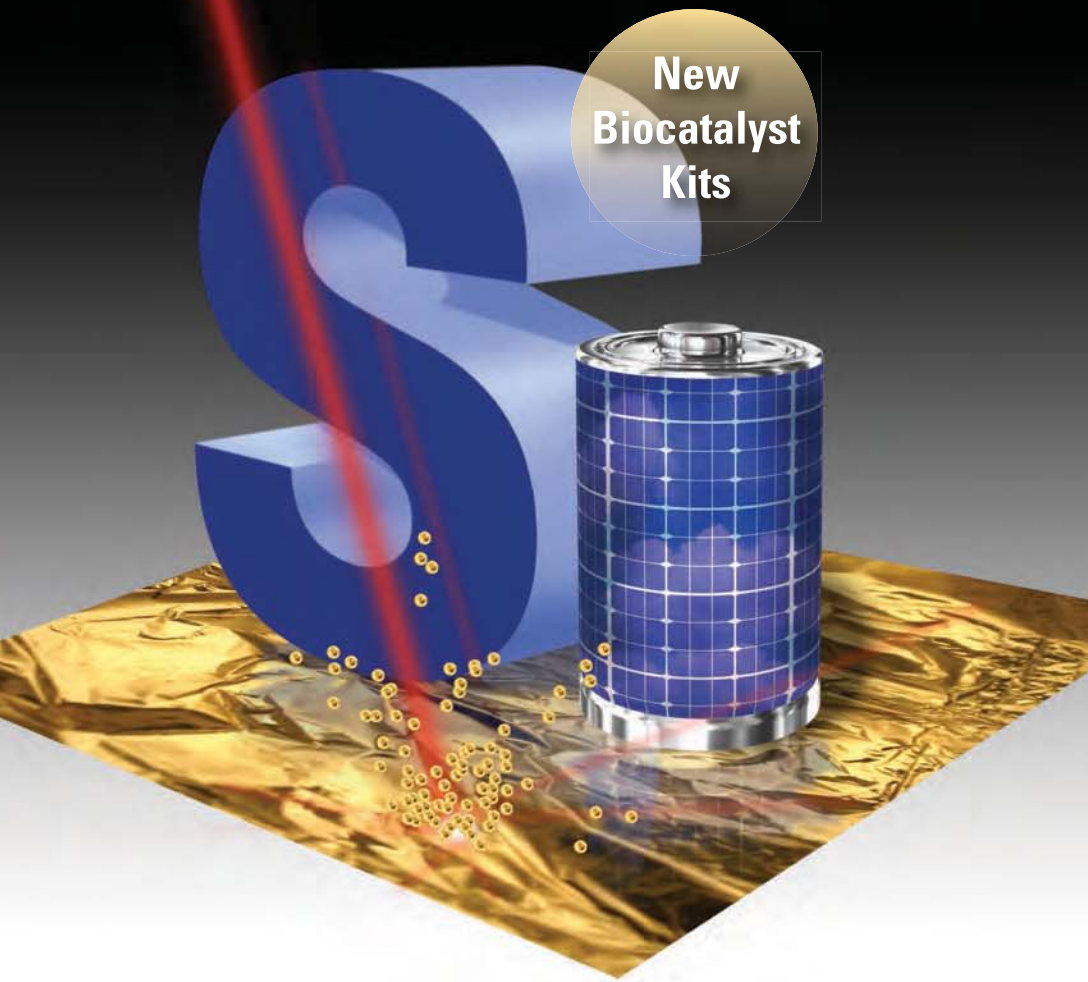


## Ligand-free Nanoparticles as Building Blocks for Biomedicine and Catalysis

by Stephan Barcikowski and Niko Bärsch

## Nanocrystalline, high-surface-area silicon from gas-phase synthesis: A highly promising material for sustainable energy technology

by Tim P. Hülser, Sophie M. Schnurre, Hartmut Wiggers and Christof Schulz

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**Headquarters:**
**Strem Chemicals, Inc.**
7 Mulliken Way
Newburyport, MA 01950-4098
USA
Tel.: (978) 499-1600
Fax: (978) 465-3104
(Toll-free numbers below US & Canada only)
Tel.: (800) 647-8736
Fax: (800) 517-8736
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**European Offices:**
15, rue de l'Atome
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**Strem Chemicals UK Ltd.**
41 Hills Road
Cambridge, England CB2 1NT
Tel.: 0845 643 7263
Fax: 0845 643 7362
Email: enquiries@strem.co.uk



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## Biographical Sketches


**Niko Bärsch**

Dr.-Ing. Niko Bärsch,
CEO Particular GmbH,
Hollerithallee 8, 30419 Hannover
Germany

Tel.: +49 (0)511 - 2788-313
Internet: http://particular.eu/
Email: baersch@particular.eu


Niko Bärsch studied Mechanical Engineering at RWTH Aachen and received his doctorate degree at Leibniz University of Hannover, for work on ultrashort-pulsed laser ablation at Laser Zentrum Hannover e.V. (LZH). Together with Stephan Barcikowski, he initiated the research on nanoparticle generation by laser ablation in liquids in the Nanomaterials group at LZH and started Particular GmbH as a research spin-off in July 2010. Since then, Particular has been selling pure, laser-manufactured nanoparticle dispersions to world-wide customers from industry and research.


**Stephan Barcikowski**

Prof. Dr.-Ing. Stephan Barcikowski,
Chair of Technical Chemistry I, University of Duisburg-Essen,
and Center for Nanointegration Duisburg-Essen (CENIDE),
Universitaetsstr. 7, 45141 Essen, Germany

Tel.: +49 (0)201 - 183 3150
Internet: http://www.uni-due.de/barcikowski/
YouTube Channel:
http://www.youtube.com/user/nanofunction/videos
Email: stephan.barcikowski@uni-due.de


Stephan Barcikowski studied chemistry at TU Braunschweig and Leibniz University of Hannover and worked for the laser manufacturer Rofin-Sinar AG. After his doctorate award in Mechanical Engineering, he received the “first prize for scientific work” by the Foundation of Industrial Research (Stiftung Industrieforschung). At Laser Zentrum Hannover e.V. (LZH), a private-non-profit research center, Barcikowski built up the Nanomaterials group and the research group “Nanoparticles” in the Cluster of Excellence “REBIRTH”, and led the institute’s Material Processing Department. In 2011, he accepted the call to the Chair of Technical Chemistry I, University of Duisburg-Essen.

Stephan Barcikowski is working on applications of liquid-supported laser material processing in chemistry. His research fields reach from up-scaling process technology for laser-based nanomaterial synthesis to the functionalization of nanoparticles and nanocomposites for biotechnology, biomedicine and energy technology.

**Prof. Dr. Christof Schulz**

IVG, Institute for Combustion and Gasdynamics,
University of Duisburg-Essen, 47048 Duisburg, Germany

CeNIDE, Center for Nanointegration Duisburg-Essen,
47057 Duisburg

Prof. Dr. Christof Schulz studied Chemistry at the University of Karlsruhe from 1988-94. He received his Ph.D. at the Physical Chemistry Institute at the University of Heidelberg in 1997. From 1997-2004 he headed the group on "Laser diagnostics in combustion processes" in the same institute where he also received his Habilitation in 2002. During this time he was for several subsequent research periods at Stanford University, from 2000-02 as Visiting Scholar and from 2002-04 as Consulting Associate Professor. Since 2004 he directs the Institute for Combustion and Gasdynamics, IVG, at the University of Duisburg-Essen with a group of 45 scientists. His research focuses on reactive fluids with applications in combustion processes and nanomaterials synthesis. Elementary processes are studied in shock tubes and laser-diagnostics are developed and applied for in-situ measurements of concentrations and temperature. Processes are studied in well-controlled lab-scale devices as well as in optically accessible combustion engines and pilot-plant-scale reactors for materials synthesis with the aim to control processes based on a fundamental understanding. This expertise and the equipment available provides the capabilities to synthesizing a wide range of metal and metal oxide nanomaterials.

Prof. Schulz is the Director of CeNIDE, the Center for Nanointegration Duisburg-Essen, an organization with more than 50 participating Principal Investigators and their research groups in the field of nanoscience. He is also member of the Board of Directors of IUTA, The Institute for Energy and Environmental Technology in Duisburg.

**Dr. Hartmut Wiggers**

IVG, Institute for Combustion and Gasdynamics,
University of Duisburg-Essen, 47048 Duisburg, Germany

CeNIDE, Center for Nanointegration Duisburg-Essen,
47057 Duisburg

Dr. Hartmut Wiggers graduated from Münster University in chemistry and received his PhD from Essen University. During his postgraduate research he was involved in the characterization of charge carrier transport processes in semi-conducting and quantum-sized materials. He is heading the nanomaterials group at the Institute for Combustion and Gas Dynamics at University Duisburg-Essen. His current research interests are the formation, chemistry and physics of crystalline, nanosized inorganic materials.

**Dr. Sophie Marie Schnurre**

IUTA, Institute for Energy and Environmental Technology
47229 Duisburg Germany

Dr. Sophie Marie Schnurre graduated from Clausthal University of Technology in mathematics and received her PhD at the Institute of Metallurgy at Clausthal University of Technology. After working several years as quality manager for an automotive supplier she went back to research and started as scientific assistant in the division “Conversion & Storage of Energy” at the Institute for Energy and Environmental Technology (IUTA) in Duisburg. Here she became project manager for the build up of the pilot plant facility and the new division "Nanomaterials Synthesis & Process Technology".

**Tim Hülser**

IUTA, Institute for Energy and Environmental Technology
47229 Duisburg Germany

Tim Hülser graduated from Duisburg University in physics and worked afterwards for four years at the Institute for Combustion and Gasdynamics, IVG, at the University of Duisburg-Essen in the field of nanoparticle characterization and gas sensing properties of nanoparticulate semi-conducting materials. Then he moved to the Association of German Engineers (VDI) and worked as consultant in the field of future technologies with emphasis on wireless data transport and automotive applications. Currently he directs the division "Nanomaterials Synthesis & Process Technology" at the Institute of Energy and Environmental Technology, IUTA, where highly-specific nanoparticles are synthesized from the gas-phase on the pilot-plant scale.

# Ligand-free Nanoparticles as Building Blocks for Biomedicine and Catalysis

**Prof. Dr.-Ing. Stephan Barcikowski**
Chair of Technical Chemistry I, University of Duisburg-Essen, Essen, Germany
**Dr.-Ing. Niko Bärsch**
CEO at Particular GmbH, Hannover, Germany

Metallic nanoparticles play an essential role in emerging nanotechnology markets such as biotechnology and energy conversion, in which they already had a market volume of 300 billion Euro in 2010 [1]. Their applications make use of differerent effects on the nano-scale, including catalytic behavior, optical absorption, antibacterial properties, bio-imaging, electrical or thermal conductivity in composites – and especially their binding behavior to surrounding media and molecules that brings them into applications and products.

Many of their applications require a specific **surface activity** of the nanomaterial. Simply speaking, an increasing amount of molecules (ligands) on the surface of a nanoparticle decreases its activity. Nanoparticles without any precursor residues and stabilizing ligands verifiably show stronger effects, which applies to applications in catalysis as well as medical technology, biotechnology and other nanotechnology fields *(Fig. 1)*. In chemical nanotechnology, this requirement has led to expensive follow-up treatments and cleaning steps after nanoparticle synthesis [2], such as the calcination of catalyst supports or the filtration of bio-conjugates.

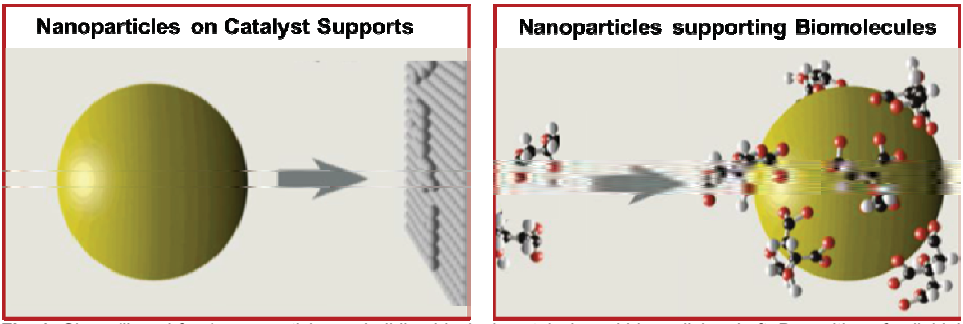


**Fig. 1:** Clean (ligand-free) nanoparticles as building blocks in catalysis and biomedicine. Left: Deposition of colloidal nanoparticles (e.g. platinum, palladium, rhodium) on inorganic supports (e.g. TiOx, ZnO), driven and self-organized by free surface potential attraction. Right: Direct conjugation of biomolecules to gold nanoparticles without ligand exchange, driven by affinity of soft Lewis acids (e.g. disulfide bridge within peptides, terminal thiol-linker at DNA…) to gold.

As an alternative method for synthesis, several research groups have been proposing **laser ablation in liquids** for the generation of ligand-free nanoparticle dispersions, addressing some major drawbacks of established fabrication methods [3,4,5]. Meanwhile, Particular GmbH from Germany is producing such nanomaterials as the first commercial provider and is distributing them together with STREM Chemicals.

**What makes the difference?**

Laser ablation in liquids involves focused, short laser pulses, usually in the IR range, to ablate nanoparticles from solid material targets directly in a liquid environment. This synthesis route is independent of chemical precursors (such as metal-organic substances) and of any further by-products of chemical reactions that can adsorb onto the nanoparticle surface.

Such adsorbates reduce the surface activity (by blocking the free metal surface) and can, at the same time, impose toxicological implications [6]: uncontrolled biological reactions that are not caused by the nanoparticle itself, but by molecules on its surface. Ligand-free nanoparticles, on the other hand, benefit from a wider therapeutic window during cell

transfection [7] and a larger surface activity that has been quantified in terms of their conjugation efficiency (for biomedical applications) and adsorption capacity (for catalysis applications) [8,9,10].

In the following, examples are given that harvest the unique properties of ligand-free colloidal nanoparticles in the fields of **biomedicine** and **catalysis.** In biomedicine, the clean nanoparticle surface is the host which supports functional biomolecules, whereas in catalysis, the nanoparticle itself is supported by inorganic carriers *(Fig. 1)*.

**Catalysis: supported building blocks**

Laser-generated nanoparticles can be provided with a large material variety and high purity - two aspects that predestine this synthesis technology for the development of nanoparticle catalysts [3]. Purity leads to a significant increase of the particles' sorption efficiency, and ligand-free heterogeneous catalysts do not require any additional cleaning. Moreover, cleaning would involve thermochemical treatment which in known to alter the nanoparticle size, causing sintering of the nanoparticles on the surface of the support and loss of defect density or catalytic activity.

Due to surface defects, laser-generated particles exhibit an electrical surface charge which stabilizes them electrostatically without the use of ligands. The absence of a ligand layer has a positive effect on the affinity of nanoparticles to the carrier surface *(Fig. 2),* and this increases the activity of these materials, since no catalytic centers are blocked by ligands. When comparing laser-generated nanoparticles with chemically synthesized nanoparticles (containing residual citrate), the deposition efficiency (adsorption rates on support) of laser-generated nanoparticles in the ligand-free state was 20 times higher than that of citrate-stabilized nanoparticles [10].

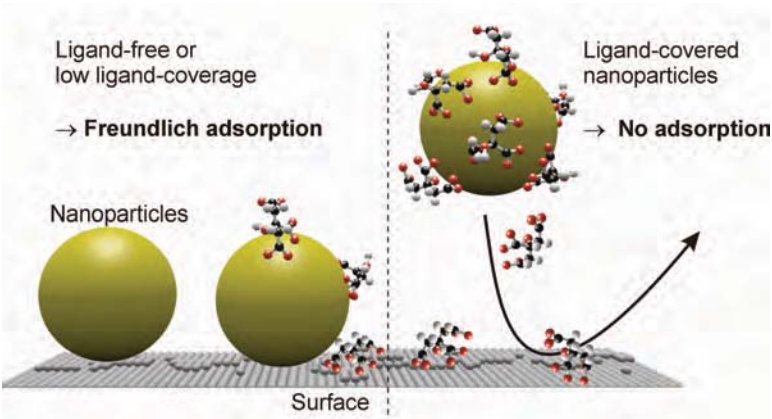


**Fig. 2:** Proposed mechanism of ligand-controlled nanoparticle adsorption [10]. Ligand-free colloids or low ligand loads allow efficient adsorption. In contrary, highly covered nanoparticles (in this case, a half monolayer of citrate) are blocked and do not adsorb efficiently. *Reprinted with permission from Langmuir, 2012, 28 (14), pp 6132–6140. Copyright 2012 American Chemical Society.*

In a comparative study, the adsorption of nanoparticles with and without citrate on chemically inert microparticle supports was investigated, using completely ligand-free metal nanoparticles and nanoparticles with a controlled citrate contamination [10].

At the example of silver nanoparticles, the adsorption to microparticle supports was shown to be a quantitative, nonreversible process following the Freundlich adsorption isotherm. The adsorption efficiency was very sensitive to the concentration of citrate ligands applied during laser ablation of the silver nanoparticles. A citrate concentration of 50 µmol/l and above, corresponding to a nanoparticle surface ligand coverage of about 50 % and above, led to electrosteric repulsion on the nanoparticle surface and prevented the adsorption to the microparticles and following sedimentation of the silver *(Fig. 3)*. So above a specific threshold of residual ligands covering the particle surface, nanoparticle adsorption is almost completely prevented.

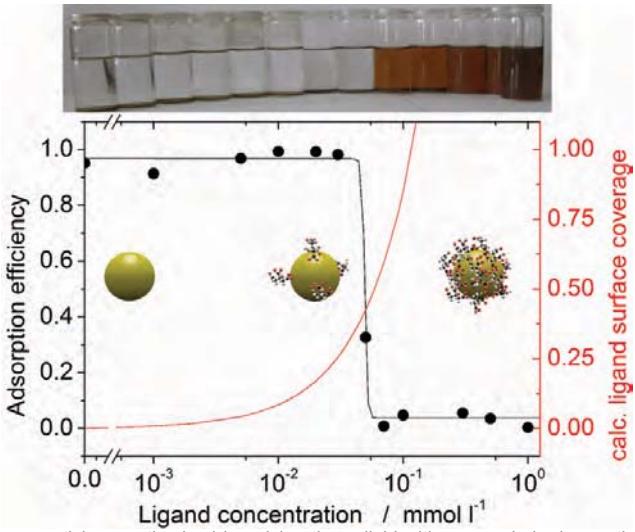


**Fig. 3:** Supported nanoparticles, synthesized by mixing the colloid with suspended microparticles [10]: adsorption efficiency and ligand surface coverage of pure nanoparticles as a function of ligand concentration. Top: samples containing the same nanoparticle mass concentration, stabilized with increasing ligand concentrations (from left to right) after mixing with supporting microparticles. The adsorption efficiency decreases by a factor of 25 when ligand concentrations exceed 50 µmol/l. *Reprinted with permission from Langmuir, 2012, 28 (14), pp 6132–6140. Copyright 2012 American Chemical Society.*

This principle of nanoparticle adsorption on supports has been demonstrated at the example of various combinations of laser-generated metal nanoparticles (silver, gold, platinum) and microparticle supports (titanium dioxide, calcium phosphate, barium sulfate). As ligand control can enhance catalytic activity, this offers extra value especially for applied heterogeneous catalysis *(Fig. 4)*.

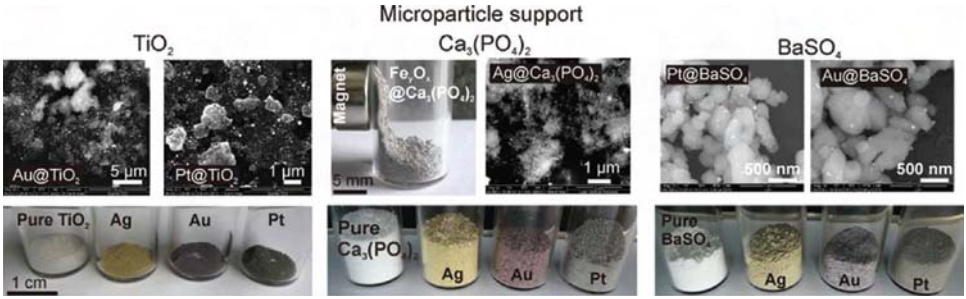


**Fig. 4:** Transferability of the method [10]: Combinations of adsorbate (ligand-free silver, gold, platinum nanoparticles) and adsorbent ($TiO_2$, $Ca_3(PO_4)_2$ and $BaSO_4$): SEM micrographs and sample images. *Reprinted with permission from Langmuir, 2012, 28 (14), pp 6132–6140. Copyright 2012 American Chemical Society.*

**Biomedicine: carrier building blocks**

An increasing number of biotechnology applications is realized with the help of gold nanoparticles. These can be visualized permanently (without bleaching) in both light and electron microscopy. In addition, gold is known to be bio-inert – an important aspect in many biological and medical applications. This can be taken advantage of by a conjugation to biomolecules, enabled by the chemical affinity of gold to thiol groups: biomolecules such as peptides, oligonucleotides, or antibodies, can be attached to gold surfaces by using covalent thiol bonding with or without spacer molecules. In any case, the gold surface must be accessible to the molecules directly or by means of ligand exchange (replacing surface ligands

that are already present on the surface by molecules of higher affinity). The obvious advantage of ligand-free nano-gold or significantly lower ligand coverage is that molecules attach to a free gold surface most efficiently.

Gold nanoparticles with the lowest possible ligand coverage are available by laser ablation at the moment of their generation. Using hybrid process chambers that combine laser ablation and conjugation, clean nano-gold can be conjugated with functional molecules with highest efficiency. Such conjugates can be used in all nano-gold applications that have been demonstrated in biotech research.

Compared to chemically synthesized materials, laser-generated conjugates excel by their higher reactivity [11] and lower toxicity [7], opening up a wider window for applications [3]. Their surface coverage with bio-functional ligands is up to 5 times higher than that of chemically synthesized nano-gold [9] *(Fig. 5)*. In case of antibodies, DNA, or aptamers [12], applications benefit especially from the high specificity, caused by the higher ligand grafting density.

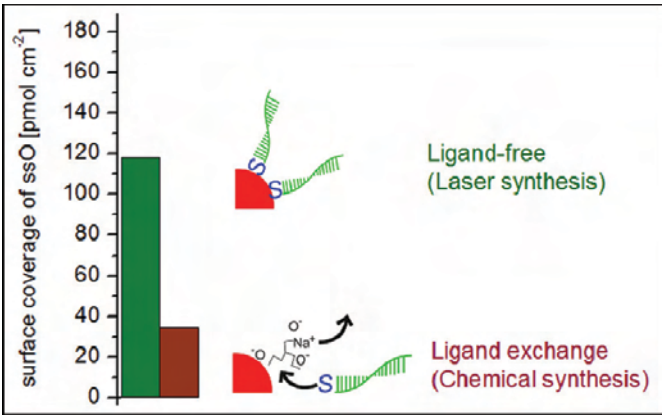


**Fig. 5:** Grafting density (maximal surface coverage) on ligand-free and citrate-blocked gold nanoparticles [9]. Pure nanoparticle surface yields far higher particle load with biomolecules (here: thiolated oligonucleotide).

The use of an aptamer directed against a prostate-specific membrane antigen (PSMA) for gold nanoparticle functionalization led to the same conclusion [12]: conjugation efficiency is higher if the aptamers are bound to ligand-free gold nanoparticles. This is especially relevant, as in the case of aptamers, the high conjugation yield saves very precious material. During functionality testing, the ligand-covered gold conjugates were found to strain prostate cancer tissue as efficiently as conventional fluorophore-labeled probes, compared to a negative control *(Fig. 6)*.

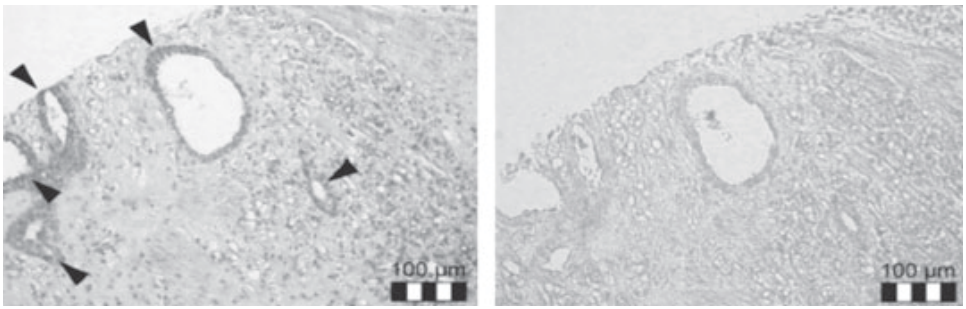


**Fig. 6:** Specific labeling of antigen by laser-generated gold nanoparticles functionalized with an antigen-specific aptamer sequence [12]. (a) Detection and labeling of prostate-specific membrane antigen (PSMA) positive structures in prostate cancer tissue sections by immunohistochemical staining using laser-generated gold nanoparticles functionalized with an anti-PSMA aptamer. (b) Unstained tissue after incubation with laser-generated gold nanoparticles functionalized with an anti-Streptavidin aptamer as negative control. *Reprinted from Journal of Nanobiotechnology 2010, 8:21.*

Conjugating ligand-free gold nanoparticles with a short cell-penetrating peptide (CPP) allows the rapid design of cell-penetrating nanomarkers for intracellular bio-imaging [13]. Since CPPs are typically cationic at neutral pH and highly charged, buffering pH at appropriate values during conjugation is important. Significantly enhanced penetratin conjugation efficiencies could be observed at higher pH values. This effect could be attributed to a higher extent of specific dative binding of the penetratin's sulfide to the gold nanoparticle surface at increased pH. A simple biological study revealed a successful uptake of gold-penetratin bioconjugates: within 2 hours, up to 100 % of coincubated cells were loaded with penetratin-conjugated gold nanoparticles *(Fig. 7)*.

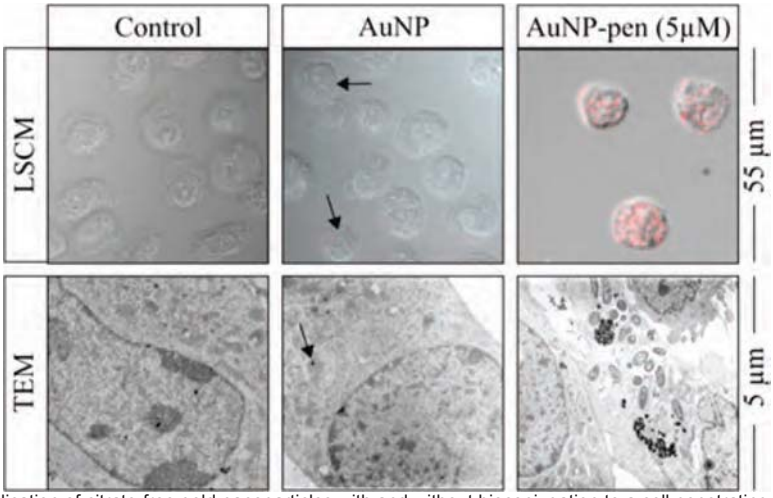


**Fig. 7:** Application of citrate-free gold nanoparticles with and without bioconjugation to a cell penetrating peptide [9]. Influence of penetratin conjugation on cellular gold nanoparticle internalization: Representative laser scanning confocal microscopy images (top, spots represent nanoparticle backscattering after excitation at 543 nm) and transmission electron microscopy images (bottom) of immortalized bovine endothelial cells (GM7373); from left to right: negative controls, coincubation with gold nanoparticles and gold-penetratin conjugates for two hours. *Reprinted with permission from J. Phys. Chem. C, 2011, 115 (12), pp 5152–5159. Copyright 2011 American Chemical Society.*

So the bioconjugates based on ligand-free nano-gold building blocks exhibit three advantages for biological applications compared to nanoparticles partly blocked by chemical residuals: an efficient binding to biomolecules (higher yield), a high ligand load (specificity of targeting) and a low cleaning effort (no interfering chemical residuals).

**Production of ligand-free nanoparticles**

The established route for the production of nanoparticles without ligands is based on physical ablation of bulk material in liquid environments *(Fig. 8)*. This approach allows the rapid design and manufacture of catalyst materials, gold biomarkers (bioimaging contrast agents) and other particle-based nanomaterial without the use of presursors or preserving agents.

By pulsed laser ablation, 100 percent pure nanomaterial is generated directly in aqueous or organic liquid. The target material for ablation can be metallic plates or wires from platinum, palladium, gold, silver and any other metal, including alloys. Short laser pulses in the visible or near infrared regime are focused through the medium. The required laser fluence for ablation is applied to the target surface and leads to the formation of a cavitation bubble, in which the nanoparticles nucleate and disperse into the liquid environment [3, 13].

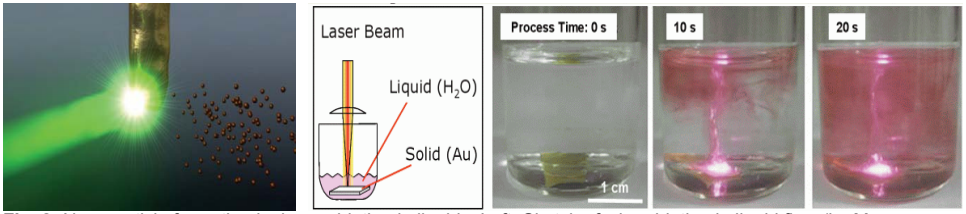


**Fig. 8:** Nanoparticle formation by laser ablation in liquids. Left: Sketch of wire ablation in liquid flow (by M. Langhammer) [3]. Right: Sketch and photos taken during synthesis of ligand-free gold nanoparticles by laser ablation of solid gold in pure water [15]

Resulting particle sizes depend on material and process parameters. The size classes are well defined, e.g. 50 nm, 10 nm, or 5 nm, with a polydispersity index (PDI) usually clearly below 0.3 (corresponding to the ISO definition of monodisperse colloids [16]). If conjugated to functional molecules immediately after nucleation, the size of gold nanoparticle conjugates can be confined to only few nanometers, typically 6 nm with monodisperse quality. Even higher quality can be achieved if anion charge transfer is applied, which is well controllable because or the bare surface of the colloidal particles. Recently, it has been shown that only trace amounts of table salt are required to allow laser-based generation of surfactant-free, ligand-free, monodisperse nanoparticles at 5 nm (PDI of 0.05). Moreover, the particles have been demonstrated to be long-term stable in albumin solution and even in cell culture media [17], which gives access to 100% pure nanoparticle reference material for bio-response testing without worrying about cross-effects.

**What´s next?**

Of course, not only the surface of the nanoparticle building block may be tuned for optimized function in life science and catalysis, but also the nanoparticle itself. Like in the macro-world, nano-alloying is the method of choice if two properties shall be combined in one material. Often, nano-alloy applications harvest higher magnetization, improved redox behavior, bioactivity/biocompatibility, or optical properties.

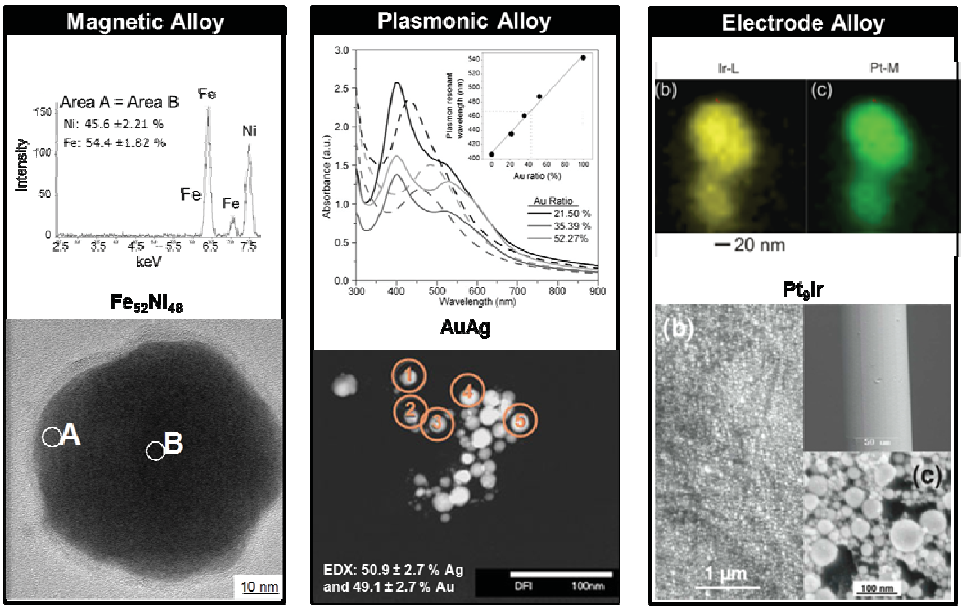


**Fig. 9:** Alloy nanoparticles, synthesized by laser ablation of solid alloy targets. Left: magnetic FeNi alloy nanoparticle, with elemental analysis data (EDX) and TEM picture [18]. Center: plasmonic AgAu nanoparticles with tunable peak wavelength (UV-vis spectrum) and insert with linear fit of nanoparticle composition vs peak position [19]. Right: platinum alloy nanoparticle for electrochemical or electrophysiological application, with elemental HR-TEM mapping of Pt and Ir content, and example of PtIr alloy nanoparticles deposited on a PtIr electrode [20].

For example, iron-nickel alloy nanoparticles *(Fig. 9, left)* have been fabricated in an organic liquid mixed with a polymer, and allowed the **aligned embedding** into a polymer matrix by applying a magnetic field during removal of the solvent. This results in filamentation of the magnetic nanoparticles, supported by the magnetic properties of this soft-magnetic alloy [18].

As another example, **plasmonic alloys** are relevant for surface-enhanced raman scattering (SERS) or bio-imaging applications with particles that have optical resonance in the visible region. By adapting the gold/silver ratio of AuAg alloy nanoparticles, the peak position can be freely adjusted between 405 nm and 540 nm *(Fig. 9, center)* [19]. It is also notable that gold alloying significantly stabilizes silver nanoparticles against oxidation and dissolution, facilitating storage and handling and suppressing silver ion release (possibly reducing toxicity issues).

Third, platinum can also be alloyed easily by laser ablation of alloy targets with elements miscible with the material. In addition to gold alloying of platinum, which is relevant for catalysis, alloying with iridium is often required for platinum-based electrodes. Elemental Pt and Ir mapping has proved that the particle pair consists of a homogeneous ultrastructure without relevant segregation *(Fig. 9, right)*. Since the particles made by laser ablation are always charged, they can be easily electro-deposited [20], e.g. on PtIr electrodes *(Fig. 9, right)*. A voltage of 30 V was applied for only 60 seconds to deposit the particles on the electrode's surface. Hence, the three-dimensional modification of the surface nanotopography of an alloy electrode using alloy nanoparticles of the identical composition is possible without changing the chemical composition of the substrate surface (and without inducing local elements that may cause corrosion) [20].

Properties of such alloy nanoparticles can be tuned and may therefore bear a great future with much applicational relevance, in particular if these novel building blocks are combined with bioconjugation or catalyst supports.

**Summary**

The availability of **nanoparticles without ligands** provides new possibilities in nano-technology even for "established" materials such as **platinum, palladium, gold, or silver**. In addition, laser ablation of alloy targets provides access to homogeneous alloy nanoparticles with highly defined composition, for example from PtIr, FeNi, or AuAg. Surfaces of ligand-free nanoparticles can be attached to supportive carriers or functional molecules, making the particles "building blocks" for applications in fields like catalysis and biotechnology.

For the production of ligand-free nanoparticles, target material of high purity is ablated in a liquid (water or organic solvents) using laser pulses at high intensities. This **physical method** does not employ chemical precursors or additional surfactants. The resulting nanoparticles excel by their purity and material variety and have proven their applicability as building blocks for different application fields.

For example, their large adsorption efficiency and surface activity allows to deposit **nano-catalysts** from various materials on microparticle supports for energy conversion applications. In a similar way, strong adsorption to ligand-free metal surfaces can be used to reach a high conjugation efficiency and yield when binding biomolecules to nano-gold. This "**bio-conjugation**" with functional groups is applied in biological and medical applications like lateral flow assays, bioimaging and drug targeting.

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**Products Referenced in the Article**

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| | | |
|---|---|---|
| **29-0092** NEW→ HAZ | **Copper nanoparticles, pure, (10-15nm) in acetone at 100mg/L (surfactant and reactant-free)** *[7440-50-8]* brown liq. Note: Shelf life 12 months. | 25ml 100ml |
| **29-0096** NEW→ HAZ | **Copper nanoparticles, pure, (50-70nm) in acetone at 100mg/L (surfactant and reactant-free)** *[7440-50-8]* brown liq. Note: Shelf life 12 months. | 25ml 100ml |
| **29-0098** NEW→ | **Copper nanoparticles, pure, (50-70nm) in ethylene glycol at 100mg/L (surfactant and reactant-free)** *[7440-50-8]* yellowish-brown liq. Note: Shelf life 12 months. | 25ml 100ml |

## *NANOMATERIALS* - GOLD (Elemental forms)

**Gold Nanoparticles – Manufactured by laser ablation.** Sold in collaboration with Particular® for research purposes only. Made to order. Store at room temperature (up to 25°C). Do not freeze.

| | | |
|---|---|---|
| **79-0410** NEW→ | **Gold nanoparticles, pure, (10-15nm) in water at 100mg/L (surfactant and reactant-free, OD>1, stabilized with < 0.01 mmol/l of citrate)** *[7440-57-5]* red. liq. Note: Shelf life 2 months. | 25ml 100ml |
| **79-0412** NEW→ HAZ | **Gold nanoparticles, pure, (10-15nm) in acetone at 100mg/L (surfactant and reactant-free)** *[7440-57-5]* red liq. Note: Shelf life 12 months. | 25ml 100ml |
| **79-0414** NEW→ | **Gold nanoparticles, pure, (10-15nm) in ethylene glycol at 100mg/L (surfactant and reactant-free)** *[7440-57-5]* reddish-purple liq. Note: Shelf life 12 months. | 25ml 100ml |
| **79-0416** NEW→ HAZ | **Gold nanoparticles, pure, (10-15nm) in isopropanol at 100mg/L (surfactant and reactant-free)** *[7440-57-5]* red liq. Note: Shelf life 12 months. | 25ml 100ml |
| **79-0418** NEW→ | **Gold nanoparticles, pure, (10-15nm) in water at 500mg/L (surfactant and reactant-free, OD>5, stabilized with < 0.01 mmol/l of citrate)** *[7440-57-5]* dark red liq. Note: Shelf life 2 months. | 25ml 100ml |
| **79-0420** NEW→ | **Gold nanoparticles, pure, (50-70nm) in water at 100mg/L (surfactant and reactant-free, OD>1, stabilized with < 0.01 mmol/l of citrate)** *[7440-57-5]* reddish-brown liq. Note: Shelf life 2 months. | 25ml 100ml |
| **79-0422** NEW→ HAZ | **Gold nanoparticles, pure, (50-70nm) in acetone at 100mg/L (surfactant and reactant-free)** *[7440-57-5]* red liq. Note: Shelf life 12 months. | 25ml 100ml |
| **79-0424** NEW→ | **Gold nanoparticles, pure, (50-70nm) in ethylene glycol at 100mg/L (surfactant and reactant-free)** *[7440-57-5]* reddish-brown liq. Note: Shelf life 12 months. | 25ml 100ml |
| **79-0426** NEW→ HAZ | **Gold nanoparticles, pure, (50-70nm) in isopropanol at 100mg/L (surfactant and reactant-free)** *[7440-57-5]* red liq. Note: Shelf life 12 months. | 25ml 100ml |
| **79-0428** NEW→ | **Gold nanoparticles, pure, (50-70nm) in water at 500mg/L (surfactant and reactant-free, OD>5, stabilized with < 0.01 mmol/l of citrate)** *[7440-57-5]* dark red liq. Note: Shelf life 2 months. | 25ml 100ml |

**Products Referenced in the Article**

## *NANOMATERIALS* - PALLADIUM (Elemental forms)

**Palladium Nanoparticles –Manufactured by laser ablation.** Sold in collaboration with Particular® for research purposes only. Made to order. Store at room temperature (up to 25°C). Do not freeze.

| | | |
|---|---|---|
| **46-4010** NEW→ | **Palladium nanoparticles, pure, (10-15nm) in water at 100mg/L (surfactant and reactant-free, stabilized with < 0.01 mmol/l of citrate)** *[7440-05-3]* grey-brown liq. Note: Shelf life 2 months. | 25ml 100ml |
| **46-4012** NEW→ HAZ | **Palladium nanoparticles, pure, (10-15nm) in acetone at 100mg/L (surfactant and reactant-free)** *[7440-05-3]* grey-brown liq. Note: Shelf life 12 months. | 25ml 100ml |
| **46-4018** NEW→ | **Palladium nanoparticles, pure, (10-15nm) in water at 500mg/L (surfactant and reactant-free, stabilized with < 0.01 mmol/l of citrate)** *[7440-05-3]* black liq. Note: Shelf life 2 months. | 25ml 100ml |
| **46-4020** NEW→ | **Palladium nanoparticles, pure, (50-70nm) in water at 100mg/L (surfactant and reactant-free, stabilized with < 0.01 mmol/l of citrate)** *[7440-05-3]* grey liq. Note: Shelf life 2 months. | 25ml 100ml |
| **46-4022** NEW→ HAZ | **Palladium nanoparticles, pure, (50-70nm) in acetone at 100mg/L (surfactant and reactant-free)** *[7440-05-3]* grey liq. Note: Shelf life 12 months. | 25ml 100ml |
| **46-4024** NEW→ | **Palladium nanoparticles, pure, (50-70nm) in ethylene glycol at 100mg/L (surfactant and reactant-free)** *[7440-05-3]* grey liq. Note: Shelf life 12 months. | 25ml 100ml |
| **46-4028** NEW→ | **Palladium nanoparticles, pure, (50-70nm) in water at 500mg/L (surfactant and reactant-free, stabilized with < 0.01 mmol/l of citrate)** *[7440-05-3 ]* dark-grey liq. Note: Shelf life 2 months. | 25ml 100ml |

## *NANOMATERIALS* - PLATINUM (Elemental forms)

**Platinum Nanoparticles –Manufactured by laser ablation.** Sold in collaboration with Particular® for research purposes only. Made to order. Store at room temperature (up to 25°C). Do not freeze.

| | | |
|---|---|---|
| **78-1405** NEW→ | **Platinum nanoparticles, pure, (10-15nm) in water at 30mg/L (surfactant and reactant-free, stabilized with <0.01 mmol/l of citrate)** *[7440-06-4]* grey-brown liq. Shelf life 6 months. Note: **FREE SAMPLE** - See Bonus Offer tab on web site. | 100ml |
| **78-1402** NEW→ | **Platinum nanoparticles, pure, (10-15nm) in water at 100mg/L (surfactant and reactant-free, stabilized with < 0.01 mmol/l of citrate)** *[7440-06-4]* grey-brown liq. Note: Shelf life 2 months. | 25ml 100ml |
| **78-1404** NEW→ HAZ | **Platinum nanoparticles, pure, (10-15nm) in acetone at 100mg/L (surfactant and reactant-free)** *[7440-06-4]* grey-brown liq. Note: Shelf life 12 months. | 25ml 100ml |
| **78-1408** NEW→ HAZ | **Platinum nanoparticles, pure, (10-15nm) in isopropanol at 100mg/L (surfactant and reactant-free)** *[7440-06-4]* grey-brown liq. Note: Shelf life 12 months. | 25ml 100ml |
| **78-1410** NEW→ | **Platinum nanoparticles, pure, (10-15nm) in water at 500mg/L (surfactant and reactant-free, stabilized with < 0.01 mmol/l of citrate)** *[7440-06-4]* black liq. Note: Shelf life 2 months. | 25ml 100ml |
| **78-1412** NEW→ | **Platinum nanoparticles, pure, (50-70nm) in water at 100mg/L (surfactant and reactant-free, stabilized with < 0.01 mmol/l of citrate)** *[7440-06-4]* grey liq. Note: Shelf life 2 months. | 25ml 100ml |

## *NANOMATERIALS* - PLATINUM (Elemental forms) (cont.)

**Platinum Nanoparticles –Manufactured by laser ablation.** Sold in collaboration with Particular® for research purposes only. Made to order. Store at room temperature (up to 25°C). Do not freeze.

| | | |
|---|---|---|
| **78-1414** NEW→ HAZ | **Platinum nanoparticles, pure, (50-70nm) in acetone at 100mg/L (surfactant and reactant-free)** *[7440-06-4]* grey liq. Note: Shelf life 12 months. | 25ml 100ml |
| **78-1416** NEW→ | **Platinum nanoparticles, pure, (50-70nm) in ethylene glycol at 100mg/L (surfactant and reactant-free)** *[7440-06-4]* grey liq. Note: Shelf life 12 months. | 25ml 100ml |
| **78-1418** NEW→ | **Platinum nanoparticles, pure, (50-70nm) in isopropanol at 100mg/L (surfactant and reactant-free)** *[7440-06-4]* grey liq. Note: Shelf life 12 months. | 25ml 100ml |
| **78-1422** NEW→ | **Platinum nanoparticles, pure, (50-70nm) in water at 500mg/L (surfactant and reactant-free, stabilized with < 0.01 mmol/l of citrate)** *[7440-06-4]* dark-grey liq. Note: Shelf life 2 months. | 25ml 100ml |

## *NANOMATERIALS* - RHODIUM (Elemental forms)

**Rhodium Nanoparticles –Manufactured by laser ablation.** Sold in collaboration with Particular® for research purposes only. Made to order. Store at room temperature (up to 25°C). Do not freeze.

| | | |
|---|---|---|
| **45-1322** NEW→ | **Rhodium nanoparticles, pure, (10-15nm) in water at 100mg/L (surfactant and reactant-free, stabilized with < 0.01 mmol/l of citrate)** *[7440-16-6]* grey-brown liq. Note: Shelf life 2 months. | 25ml 100ml |
| **45-1324** NEW→ HAZ | **Rhodium nanoparticles, pure, (10-15nm) in acetone at 100mg/L (surfactant and reactant-free)** *[7440-16-6]* grey-brown liq. Note: Shelf life 12 months. | 25ml 100ml |
| **45-1328** NEW→ HAZ | **Rhodium nanoparticles, pure, (10-15nm) in isopropanol at 100mg/L (surfactant and reactant-free)** *[7440-16-6]* grey-brown liq. Note: Shelf life 12 months. | 25ml 100ml |
| **45-1330** NEW→ | **Rhodium nanoparticles, pure, (10-15nm) in water at 500mg/L (surfactant and reactant-free, stabilized with < 0.01 mmol/l of citrate)** *[7440-16-6]* black liq. Note: Shelf life 2 months. | 25ml 100ml |
| **45-1332** NEW→ | **Rhodium nanoparticles, pure, (50-70nm) in water at 100mg/L (surfactant and reactant-free, stabilized with < 0.01 mmol/l of citrate)** *[7440-16-6]* grey liq. Note: Shelf life 2 months. | 25ml 100ml |
| **45-1334** NEW→ HAZ | **Rhodium nanoparticles, pure, (50-70nm) in acetone at 100mg/L (surfactant and reactant-free)** *[7440-16-6]* grey liq. Note: Shelf life 12 months. | 25ml 100ml |
| **45-1336** NEW→ | **Rhodium nanoparticles, pure, (50-70nm) in ethylene glycol at 100mg/L (surfactant and reactant-free)** *[7440-16-6]* grey liq. Note: Shelf life 12 months. | 25ml 100ml |
| **45-1338** NEW→ HAZ | **Rhodium nanoparticles, pure, (50-70nm) in isopropanol at 100mg/L (surfactant and reactant-free)** *[7440-16-6]* grey liq. Note: Shelf life 12 months. | 25ml 100ml |
| **45-1340** NEW→ | **Rhodium nanoparticles, pure, (50-70nm) in water at 500mg/L (surfactant and reactant-free, stabilized with < 0.01 mmol/l of citrate)** *[7440-16-6]* dark grey liq. Note: Shelf life 2 months. | 25ml 100ml |

**Products Referenced in the Article**

## *NANOMATERIALS* - RUTHENIUM (Elemental forms)

**Ruthenium Nanoparticles –Manufactured by laser ablation.** Sold in collaboration with Particular® for research purposes only. Made to order. Store at room temperature (up to 25°C). Do not freeze.

| | | |
|---|---|---|
| **44-2810** NEW→ | **Ruthenium nanoparticles, pure, (10-15nm) in water at 100mg/L (surfactant and reactant-free, stabilized with < 0.01 mmol/l of citrate)** *[7440-18-8]* grey-brown liq. Note: Shelf life 2 months. | 25ml 100ml |
| **44-2812** NEW→ HAZ | **Ruthenium nanoparticles, pure, (10-15nm) in acetone at 100mg/L (surfactant and reactant-free)** *[7440-18-8]* grey-brown liq. Note: Shelf life 12 months. | 25ml 100ml |
| **44-2816** NEW→ HAZ | **Ruthenium nanoparticles, pure, (10-15nm) in isopropanol at 100mg/L (surfactant and reactant-free)** *[7440-18-8]* grey liq. Note: Shelf life 12 months. | 25ml 100ml |
| **44-2818** NEW→ | **Ruthenium nanoparticles, pure, (10-15nm) in water at 500mg/L (surfactant and reactant-free, stabilized with < 0.01 mmol/l of citrate)** *[7440-18-8]* black liq. Note: Shelf life 2 months. | 25ml 100ml |
| **44-2820** NEW→ | **Ruthenium nanoparticles, pure, (50-70nm) in water at 100mg/L (surfactant and reactant-free, stabilized with < 0.01 mmol/l of citrate)** *[7440-18-8]* grey liq. Note: Shelf life 2 months. | 25ml 100ml |
| **44-2822** NEW→ HAZ | **Ruthenium nanoparticles, pure, (50-70nm) in acetone at 100mg/L (surfactant and reactant-free)** *[7440-18-8]* grey liq. Note: Shelf life 12 months. | 25ml 100ml |
| **44-2824** NEW→ | **Ruthenium nanoparticles, pure, (50-70nm) in ethylene glycol at 100mg/L (surfactant and reactant-free)** *[7440-18-8]* grey liq. Note: Shelf life 12 months. | 25ml 100ml |
| **44-2826** NEW→ HAZ | **Ruthenium nanoparticles, pure, (50-70nm) in isopropanol at 100mg/L (surfactant and reactant-free)** *[7440-18-8]* grey liq. Note: Shelf life 12 months. | 25ml 100ml |
| **44-2828** NEW→ | **Ruthenium nanoparticles, pure, (50-70nm) in water at 500mg/L (surfactant and reactant-free, stabilized with < 0.01 mmol/l of citrate)** *[7440-18-8]* dark grey liq. Note: Shelf life 2 months. | 25ml 100ml |

## *NANOMATERIALS* - SILVER (Elemental forms)

**Silver Nanoparticles –Manufactured by laser ablation.** Sold in collaboration with Particular® for research purposes only. Made to order. Store at room temperature (up to 25°C). Do not freeze.

| | | |
|---|---|---|
| **47-0710** NEW→ | **Silver nanoparticles, pure, (10-15nm) in water at 100mg/L (surfactant and reactant-free, stabilized with < 0.01 mmol/l of citrate)** *[7440-22-4]* yellow liq. Note: Shelf life 2 months. | 25ml 100ml |
| **47-0712** NEW→ HAZ | **Silver nanoparticles, pure, (10-15nm) in acetone at 100mg/L (surfactant and reactant-free)** *[7440-22-4]* yellowish-brown liq. Note: Shelf life 12 months. | 25ml 100ml |
| **47-0718** NEW→ | **Silver nanoparticles, pure, (10-15nm) in water at 500mg/L (surfactant and reactant-free, stabilized with < 0.01 mmol/l of citrate)** *[7440-22-4]* yellowish-grey liq. Note: Shelf life 2 months. | 25ml 100ml |
| **47-0720** NEW→ | **Silver nanoparticles, pure, (50-70nm) in water at 100mg/L (surfactant and reactant-free, stabilized with < 0.01 mmol/l of citrate)** *[7440-22-4]* yellow liq. | 25ml 100ml |
| **47-0722** NEW→ HAZ | **Silver nanoparticles, pure, (50-70nm) in acetone at 100mg/L (surfactant and reactant-free)** *[7440-22-4]* yellowish-brown liq. Note: Shelf life 12 months. | 25ml 100ml |

**Products Referenced in the Article**

## *NANOMATERIALS* - SILVER (Elemental forms) (cont.)

**Silver Nanoparticles –Manufactured by laser ablation.** Sold in collaboration with Particular® for research purposes only. Made to order. Store at room temperature (up to 25°C). Do not freeze.

| | | |
|---|---|---|
| **47-0728** NEW→ | **Silver nanoparticles, pure, (50-70nm) in water at 500mg/L (surfactant and reactant-free, stabilized with < 0.01 mmol/l of citrate)** *[7440-22-4]* yellowish-grey liq. Note: Shelf life 2 months. | 25ml 100ml |
| **47-0728** NEW→ | **Silver nanoparticles, pure, (50-70nm) in water at 500mg/L (surfactant and reactant-free, stabilized with < 0.01 mmol/l of citrate)** *[7440-22-4]* yellowish-grey liq. Note: Shelf life 2 months. | 25ml 100ml |

## *NANOMATERIALS* - TITANIUM (Elemental forms)

**Titanium Nanoparticles –Manufactured by laser ablation.** Sold in collaboration with Particular® for research purposes only. Made to order. Store at room temperature (up to 25°C). Do not freeze.

| | | |
|---|---|---|
| **22-0192** NEW→ HAZ | **Titanium nanoparticles, pure, (10-15nm) in acetone at 100mg/L (surfactant and reactant-free)** *[7440-32-6]* grey liq. Note: Shelf life 12 months. | 25ml 100ml |
| **22-0194** NEW→ | **Titanium nanoparticles, pure, (10-15nm) in ethylene glycol at 100mg/L (surfactant and reactant-free)** *[7440-32-6]* grey liq. Note: Shelf life 12 months. | 25ml 100ml |
| **22-0196** NEW→ HAZ | **Titanium nanoparticles, pure, (50-70nm) in acetone at 100mg/L (surfactant and reactant-free)** *[7440-32-6]* grey liq. Note: Shelf life 12 months. | 25ml 100ml |
| **22-0198** NEW→ | **Titanium nanoparticles, pure, (50-70nm) in ethylene glycol at 100mg/L (surfactant and reactant-free)** *[7440-32-6]* grey liq. Note: Shelf life 12 months. | 25ml 100ml |
| **22-0203** NEW→ HAZ | **Titanium nanoparticles, pure, (50-70nm) in isopropanol at 100 mg/L (surfactant and reactant-free)** *[7440-32-6]* grey liq. Note: Shelf life 12 months. | 25ml 100ml |

# Nanocrystalline, High-Surface-Area Silicon from Gas-Phase Synthesis: A Highly Promising Material for Sustainable Energy Technology

Tim P. Hülser[1], Sophie M. Schnurre[1], Hartmut Wiggers[2], Christof Schulz[2]
[1]IUTA, Institute for Energy and Environmental Technology, 47229 Duisburg
[2]IVG, Institute for Combustion and Gasdynamics, University of Duisburg-Essen, 47048 Duisburg, Germany and CeNIDE, Center for Nanointegration Duisburg-Essen, 47057 Duisburg

**Introduction**

For decades, silicon has been the leading material in microprocessor technology but its actual demand is driven by the photovoltaics industry that consumes about 80% of the high-purity silicon produced worldwide. The demand for silicon for solar cell applications has increased by about 350% from 2003 to 2010 [1] and has driven a couple of technologies to provide a sufficient amount of high-purity solar-grade silicon. One of the cheap technologies providing high purity silicon is based on the gas-phase pyrolysis of monosilane $SiH_4$ and has been developed at the University of Duisburg-Essen [2]. As has been shown, this material exhibits nanostructured crystallinity as a result of its formation process in the gas phase .However, the specific properties of the nanostructure are lost when the material is used for the production of polycrystalline solar cells. As a result, highly promising properties of the nanostructured silicon generated via the gas-phase approach are not yet used in a wide variety of industrial, energy-related applications like photovoltaics [3], battery technology [4], or thermoelectrics [5]. This opens highly rewarding application fields in a rapidly growing market.

Polycrystalline silicon solar cells are manufactured from the as-prepared silicon powder from silane pyrolysis by re-melting and directional solidification. One of the main driving forces for the industrial utilization of the gas-phase pyrolysis of silane was the impressive energy balance with respect to alternative methods. The JSSI company claims, that the demand for electrical energy via this route can be reduced by about 90% compared to the conventional Siemens process based on chlorosilanes [6] requiring more than 200 kWh/kg silicon. However, commercial utilization of cheap, nanosized silicon is not foreseeable (yet).

In Li-ion batteries, the high storage capacity of lithium is well known and in principle enables the development of high-capacity anodes. However, strong mechanical stress related to a dramatic volume expansion and contraction during lithium storage and release causes *bulk silicon* to rapidly degrade, but *nanosized silicon* is believed to enable a sufficient long-term stability [4].

Nanostructuring of semi-metals is also known to be a highly promising path towards a profound improvement of the figure of merit of thermoelectrics. Nanostructuring of the thermoelectric material promotes phonon scattering leading to thermoelectrics with significantly reduced thermal conductivity but still high electric conductivity. With respect to the long lasting experience in silicon technology, silicon-based thermoelectrics made from nanostructured raw material are highly rewarding materials with respect to sustainability and price. Two examples of the advantages of nanostructured silicon made from a continuously operating gas-phase synthesis process will be highlighted below.

**Silicon nanoparticle synthesis**

The silicon nanoparticles investigated in this work were produced in a hot-wall reactor (HWR) which is located in a pilot plant. Different process gases (sheath and carrier gases) and the precursor gases are injected at the top of the reactor. After precursor decomposition and particle formation in a hot zone, the particle-laden hot gases are pneumatically delivered to filtration. A pumping unit enabling a pressure range between 10 and 120 kPa and a thermal post-combustion system burning the off-gas from the pump are downstream the filters. The unit decomposes the gases (up to 200 l/min) at temperatures up to 1100°C.

The silicon particles were produced at different operating conditions varying the pressure range between 15 and 100 kPa and the temperature range between 800 and 1000°C. Typically, particles are formed at a precursor concentration of 10 vol% silane in a $H_2/N_2$ atmosphere. The resulting materials were analyzed with several techniques to investigate the relation between particle size, crystallinity, morphology, and synthesis conditions.

X-ray diffraction analysis (XRD) is used to analyze the influence of the synthesis conditions, especially the temperature, on the crystallinity. Figure 1 shows the typical XRD patterns of nanoparticulate silicon synthesized at 800 and 1000°C, respectively. The broadening of the peaks is attributed to the nanocrystalline structure within the materials. The crystallite size was calculated using Scherrers' equation and it was found that silicon nanoparticles produced at 1000°C and 100 kPa consist of crystallites in the size regime of about 30 nm, while samples produced at lower pressure and/or lower temperature show smaller particle sizes. At 800°C, almost amorphous material is produced as indicated by the broad signals and the high background (see top graph in Figure 1). However, the positions and the intensity of the measured Bragg reflexes are in good agreement with the values found for bulk silicon and, therefore, prove the formation of silicon during the synthesis.

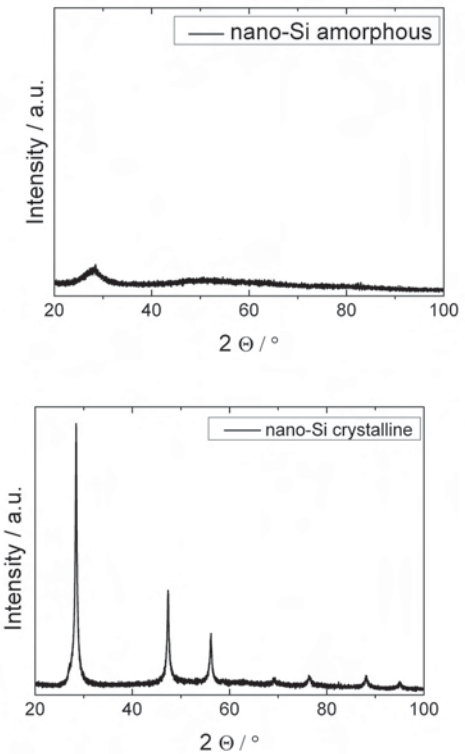


**Figure 1:** XRD patterns of silicon nanoparticles produced at 800°C (top) and 1000°C (bottom). The diffraction pattern show that the material synthesized at 800°C is almost amorphous while the silicon produced at 1000°C is highly crystalline with a crystallite size of ~30 nm.

Electron microscopy investigations were performed using transmission electron microscopy (TEM). Figure 2 shows a TEM micrograph of a typical sample of silicon nanoparticles from the hot-wall reactor. The particles always show a highly aggregated structure of smaller units (primary particles) with typical diameters smaller than 100 nm and distinct sintering necks to adjacent primary particles, while the overall aggregate size is much higher. Even the primary particles that form the large aggregates are polycrystalline as can be seen from the contrasts in Figure 2.

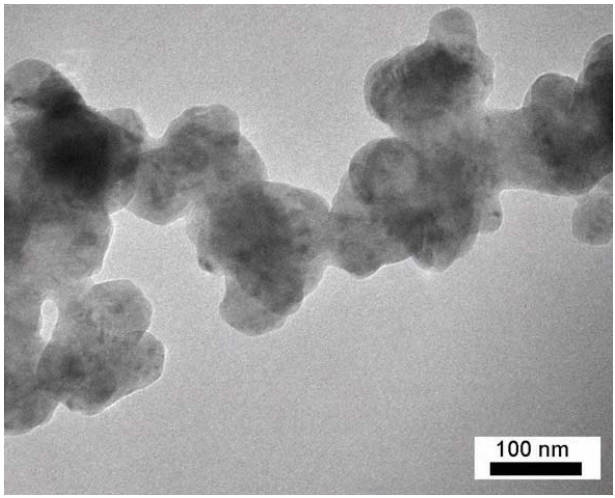


**Figure 2:** TEM Micrograph of aggregated Si nanoparticles from the HWR process.

Dispersibility and specific surface area were characterized using dynamic light scattering (DLS) and nitrogen adsorption according to Brunauer, Emmett and Teller (BET), respectively. For DLS, dispersions of silicon nanoparticles (synthesized at 1000°C) in acetone were produced using an ultrasonic bath for 1 hour at 200 W. Figure 3 shows the results of two representative materials. They reveal a decreasing mean particle diameter within the dispersion with decreasing process pressure. This typical finding is due to reduced aggregation of particles at lower pressures originating from reduced collision rates in the hot zone of the reactor.

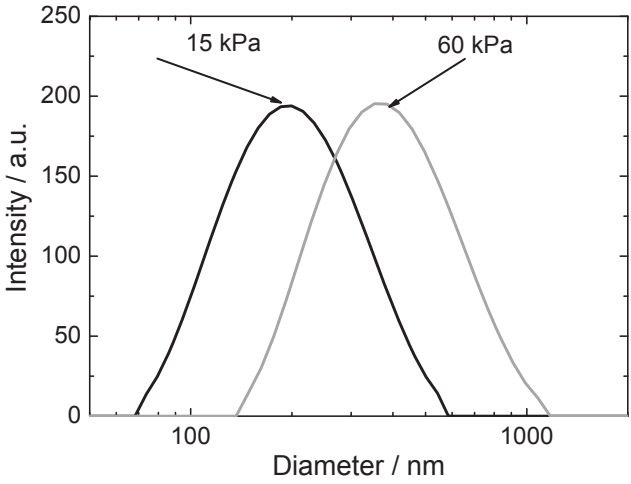


**Figure 3:** DLS measurement of silicon nanopowders dispersed in acetone produced at different pressures. The maxima of the normalized graphs indicate the mean particle size.

For BET analysis, silicon powders were taken from sealed product bags and analyzed after 24 h of outgassing under vacuum at 250°C. Figure 4 shows the specific surface area of silicon nanomaterials synthesized at 1000°C. The BET results show an increasing specific surface

area with decreasing process pressure which can be attributed to the decreasing residence time in the hot zone of the reactor, as it is expected for gas-phase synthesis routes [7].

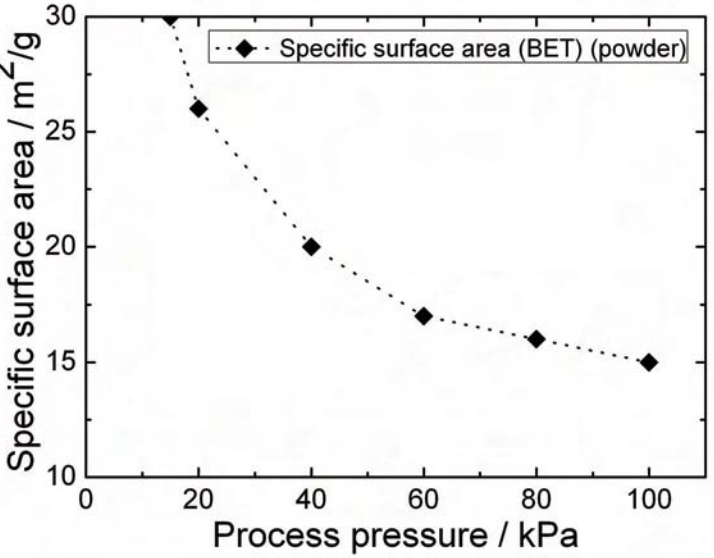


**Figure 4:** Specific surface area calculated from BET measurements on as-synthesized silicon nano-powder produced at different pressures.

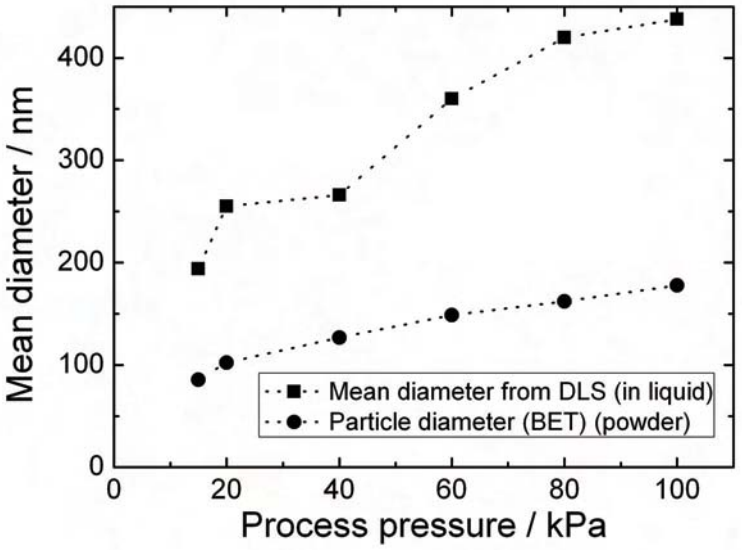


**Figure 5:** Mean particle-diameter determined from DLS and BET measurements on silicon nanomaterials produced at different pressures. The DLS investigation was performed in the liquid-phase (acetone) and BET measurements were done with the as-synthesized powder.

Figure 5 compares the mean particle diameter received from DLS measurements with those calculated from BET measurements assuming monodisperse, spherical particles. The

difference between DLS and BET diameter increases with increasing pressure. This obviously indicates that the agglomerate size increases due to higher collision rate and higher residence time.

To summarize the experimental findings of silicon nanoparticle synthesis: Depending on temperature, either almost amorphous (at lower temperature) or nanocrystalline (at higher temperature) silicon can be produced by pyrolysis of silicon in the gas phase. Typically, the materials consist of small, nanocrystalline or amorphous silicon building blocks that are sintered to primary particles with a typical size around 100 nm. These primary particles are found in TEM measurements, and BET investigations reveal a specific surface area that almost matches this result. Additionally, the primary particles form bigger, so-called hard agglomerates or aggregates, typically sizing slightly below 1 µm. These aggregates or hard agglomerates can be identified by DLS from liquid dispersions.

**Nanocrystalline silicon for lithium-ion batteries**

Silicon is known to exhibit a much higher storage capacity for lithium than the currently used graphite. Unfortunately, bulk silicon as well as microcrystalline silicon immediately decompose during the first few charge/discharge cycles, while nanocrystalline silicon shows significantly better performance.

To investigate the performance of our nanosized silicon for battery applications, silicon/graphite composite electrodes were prepared from silicon synthesized in the hot wall reactor at 1000°C. The electrodes were made of graphite, Super P as conducting agent, carboxymethylcellulose (CMC) as binder and 20 wt% silicon. The slurry was prepared by dispersing the mixture and then coated on a copper foil current collector.

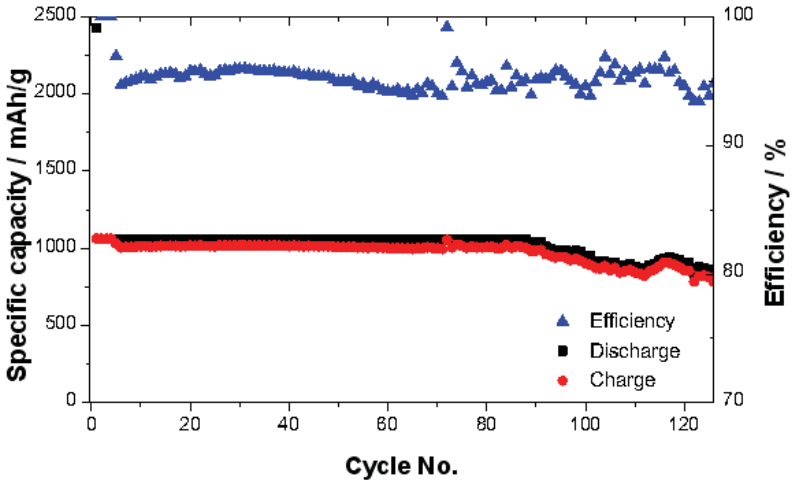


**Figure 6:** Cycling study of the graphite/silicon composite electrode.

The electrochemical behavior of our composite electrodes was tested by a cycling study (Figure 6) and the capacity was limited to 80% of the theoretical capacity. The results show that the composite electrode containing the nanocrystalline silicon can be processed for more than 120 full cycles with a slight degradation beginning after cycle 95 and an efficiency of about 95%. This is much better than reported for bulk- and microcrystalline silicon. Moreover, our results are very encouraging and among the best values found for silicon-containing electrodes.

**Nanocrystalline silicon for thermoelectrics**

Thermoelectric generators enable the direct transformation of thermal temperature gradient into electrical energy. Thermoelectrics are highly interesting for heat recovery, especially at high temperatures such as waste heat from processing plants or from automobile exhaust. Thermoelectric generators adapted to the exhaust of combustion engines can improve the fuel economy by conversion of waste heat to electric energy. One important route towards

designing of thermoelectric generators with high efficiency is based on the decoupling of heat and charge transport by keeping high electrical conductivity and decreasing thermal conductivity. This is possible due to the fact that the mean free pathway of electrons is in the range of about 10 nm while that of phonons is in the range of 100 nm [8]. Grain boundaries as well as lattice mismatches are known for their efficient phonon scattering leading to a decreased thermal conductivity. As a result, scientists investigate to further enhance the efficiency of thermoelectric materials by introduction of artificial nanostructures to yield materials with a significantly lowered thermal conductivity due to phonon scattering.

Typical thermoelectric materials, however, use either toxic and rare (e.g., tellurium) raw materials. One important aim of the current development, is to use non-toxic raw materials with unlimited availability instead. Doped nanocrystalline silicon from the hot wall reactor can ensure high electric conductivity while its nanostructure should be able to decrease phonon transport. To test our materials, gas-phase synthesized silicon nanopowder doped with 1% of boron was spark-plasma sintered for 180 s at a temperature of 1100°C into almost dense pellets. The electrical conductivity$\sigma$, the thermal conductivity $\lambda$ as well as the thermoelectric parameter, the Seebeck coefficient $\alpha$ were measured to determine the figure of merit *ZT*.

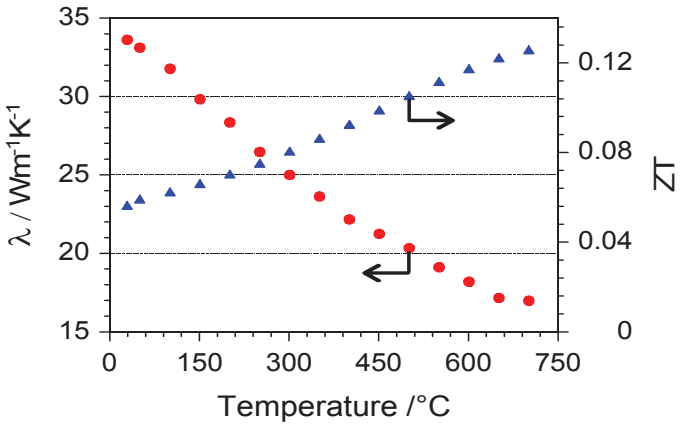


**Figure 7:** Thermal conductivity $\lambda$and figure of merit *ZT* of sintered, nanocrystalline, doped silicon from the hot-wall reactor.

Figure 7 shows the thermal conductivity $\lambda$ and the figure of merit ZT of a sintered sample as a function of temperature. The thermal conductivity is significantly reduced compared to that of bulk silicon which is in the range of 140 $Wm^{-1}K^{-1}$. The measured data were also used to calculate the figure of merit *ZT*. The sample exhibits a value of ~0.125 at 750°C, which is slightly higher compared to silicon bulk materials. With respect to the early stage of our experiments on thermoelectrics from hot-wall reactor material we are confident that there is plenty of room for further improvement. Nanocrystalline silicon materials synthesized from a microwave plasma process show that the thermal conductivity can be further reduced by minimizing the crystallite size of the used silicon nanoparticles [9].

**Summary**

Gas-phase synthesis is a highly suitable method to mass produce nanostructured materials. The examples given in this paper, such as high-capacity Li-Ion-battery anodes and silicon-based thermoelectrics make use of this particular advantage. However, many other applications could profit from the tunable “nanoproperties” accessible via gas-phase synthesis.

**References:**


1. A.F.B. Braga; S.P. Moreira; P.R. Zampieri; J.M.G. Bacchin; P.R. Mei, Sol. Energy Mater. Sol. Cells 92 (2008) 418-424.
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3. M. Stupca; M. Alsalhi; T. Al Saud; A. Almuhanna; M.H. Nayfeh, Appl. Phys. Lett. 91 (2007) 063107.
4. U. Kasavajjula; C.S. Wang; A.J. Appleby, J. Power Sources 163 (2007) 1003-1039.
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6. News, in: *elements Evonik Science Newsletter* 25 (2008) 11.
7. C. Janzen; H. Kleinwechter; J. Knipping; H. Wiggers; P. Roth, J. Aerosol. Sci. 33 (2002) 833-841.
8. L. Weber; E. Gmelin, Appl. Phys. A. 53 (1991) 136-140.
9. N. Petermann; N. Stein; G. Schierning; R. Theissmann; B. Stoib; M.S. Brandt; C. Hecht; C. Schulz; H. Wiggers, J. Phys. D 44 (2011) 174034.


## Products Referenced in the Article

| | | |
|---|---|---|
| ***NANOMATERIALS* - SILICON (Elemental forms)** | | |
| **14-0655**<br>NEW→<br>HAZ | **Silicon powder (amorphous), min. 97%** *[7440-21-3]*<br>1-2 micron, brown pwdr.<br>*air sensitive* | 5g<br>25g |
| **14-0650**<br>NEW→<br>HAZ | **Silicon powder (nanocrystalline), min. 97%** *[7440-21-3]*<br>20-50nm, brown pwdr.<br>*air sensitive* | 5g<br>25g |

## ALUMINUM (Compounds)

**98-4004** NEW→ HAZ

**Trimethylaluminum, min. 98%, 93-1360, contained in high-temp. 50 ml Swagelok® cylinder (96-1071) for CVD/ALD** *[75-24-1]*
$(CH_3)_3Al$; FW: 72.09; colorless liq.; m.p. 15.4°; b.p. 20°/8 mm; f.p. -1°F; d. 0.752 (20°)
*moisture sensitive, pyrophoric*

25g

## BARIUM (Compounds)

**56-8120** NEW→ HAZ

**Barium trifluoromethanesulfonimide, min. 97%** *[168106-22-7]*
$Ba(C_2F_6NO_4S_2)_2$; FW: 697.62; white to off-white pwdr.
*hygroscopic*

250mg
1g
5g

## BISMUTH (Compounds)

**83-2415** NEW→

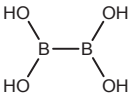
**Bismuth(III) 2-ethylhexanoate, ~30% wt/wt Bi in 2-ethylhexanoic acid (99.98%-Bi)** *[67874-71-9]*
$Bi[OOCCH(C_2H_5)C_4H_9]_3$; FW: 638.61; liq.

50g
250g

## BORON (Compounds)

**05-1015** NEW→

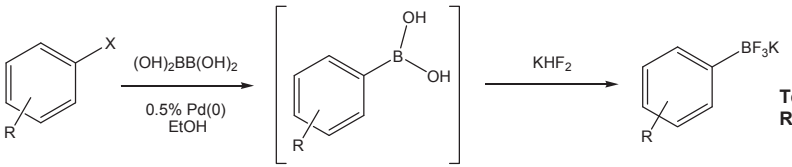
**Tetrahydroxydiboron, min. 95%** *[13675-18-8]*
$(OH)_2BB(OH)_2$; FW: 89.65; white solid
*moisture sensitive*



1g
5g
25g

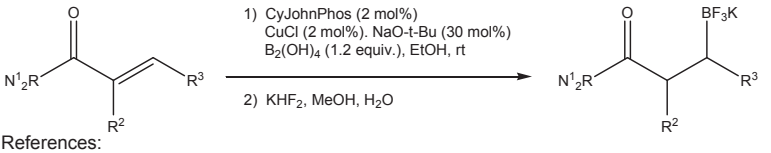
Technical Notes:

1. Reagent used for the palladium-catalyzed aryl borylation of aryl halides.
2. Reagent used for the copper-catalyzed β-boration of α,β-unsaturated carbonyl compounds.




**Tech. Note (1)**
**Ref. (1)**

X = Br, Cl, I, OTf




**Tech. Note (1)**
**Ref. (2)**

References:

1. *J. Am. Chem. Soc.,* **2012**, *134*, 11667.
2. *Org. Lett.,***2011**,*13*, 4684.

## CALCIUM (Compounds)

**20-5025** NEW→

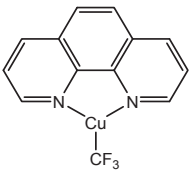
**Calcium trifluoromethanesulfonimide, min. 97%** *[165324-09-4]*
$Ca(C_2F_6NO_4S_2)_2$; FW: 600.37; white solid
*hygroscopic*

250mg
1g
5g

## COPPER (Compounds)

**29-6720** NEW→

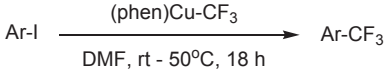
**Trifluoromethyl(1,10-phenanthroline) copper(I), 95% Trifluoromethylator®** *[1300746-79-5]*
$(C_{12}H_8N_2)CuCF_3$; FW: 312.76; orange solid
*air sensitive*
Note: Sold in collaboration with CATYLIX for research purposes only.




250mg
1g
5g

Technical Note:

1. Reagent used for the perfluoromethylation of arenes and aryl bromides and iodides.




**Tech. Note (1)**
**Ref. (1,2)**

## COPPER (Compounds) (cont.)

**29-6720** NEW→ **(cont.)** **Trifluoromethyl(1,10-phenanthroline)copper(I), 95% Trifluoromethylator®**
*[1300746-79-5]*

References:
1. *Angew Chem. Int .Ed.,* **2011**, *50*, 3793.
2. *Angew Chem. Int .Ed.,* **2012**, *51*, 536.

## IRIDIUM (Compounds)

**96-3745** NEW→ **Iridicycle Catalyst Kit**
*SEE KITS SECTION (page 51)*

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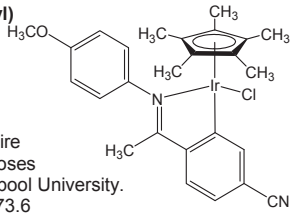
**77-0424** NEW→ **Chloro(pentamethylcyclopentadienyl) {5-cyano-2-{1-[(4-methoxyphenyl) imino-kN]ethyl}phenyl-kC} iridium(III), 99% Iridicycle-CN**
*[1258964-46-3]*
$C_{26}H_{28}ClIrN_2O$; FW: 612.18; red pwdr.
Note: Sold in collaboration with Yorkshire Process Technology for research purposes only. Developed by Prof. J. Xiao, Liverpool University. Patents GB 1206572.8 and GB 1206573.6
Iridicycle Catalyst Kit component. See (page 51).



100mg
500mg

Technical Note:
1. See 77-0418 (page 24).

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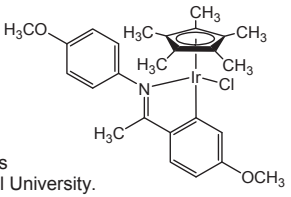
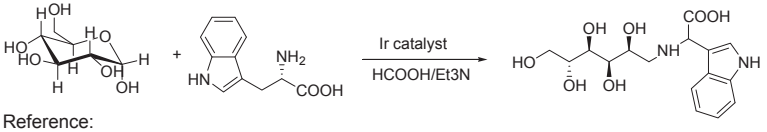
**77-0418** NEW→ **Chloro(pentamethylcyclopentadienyl) {5-methoxy-2-{1-[(4-methoxyphenyl) imino-kN]ethyl}phenyl-kC} iridium(III), 99% Iridicycle-MeO**
*[1258964-48-5]*
$C_{26}H_{31}ClIrNO_2$; FW: 617.20; orange pwdr.
Note: Sold in collaboration with Yorkshire Process Technology for research purposes only. Developed by Prof. J. Xiao, Liverpool University. Patents GB 1206572.8 and GB 1206573.6
Iridicycle Catalyst Kit component. See (page 51).



100mg
500mg

Technical Note:
1. Catalyst used in the reductive amination of carbonyl groups with unprecedented substrate scope, selectivity and activity.




**Tech. Note (1)**
**Ref. (1)**

Reference:
1. *Angew. Chem. Int. Ed.*, **2010**, *49*, 7548.

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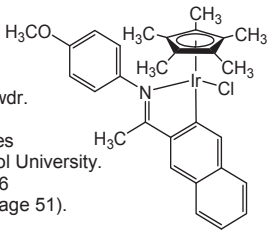
**77-0428** NEW→ **Chloro(pentamethylcyclopentadienyl) {2-{1-[(4-methoxyphenyl) imino-kN]ethyl}naphthyl-kC} iridium(III), 99% Iridicycle-Naphth**
$C_{29}H_{31}ClIrNO$; FW: 637.23; red-orange pwdr.
Note: Sold in collaboration with Yorkshire Process Technology for research purposes only. Developed by Prof. J. Xiao, Liverpool University. Patents GB 1206572.8 and GB 1206573.6
Iridicycle Catalyst Kit component. See (page 51).



100mg
500mg

Technical Note:
1. See 77-0418 (page 24).

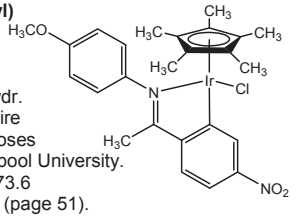
## IRIDIUM (Compounds) (cont.)

**77-0430** NEW→

**Chloro(pentamethylcyclopentadienyl) {5-nitro-2-{1-[(4-methoxyphenyl) imino-kN]ethyl}phenyl-kC} iridium(III), 99% Iridicycle-NO2**

$C_{25}H_{28}ClIrN_2O_3$; FW: 632.17; brown pwdr.

Note: Sold in collaboration with Yorkshire Process Technology for research purposes only. Developed by Prof. J. Xiao, Liverpool University. Patents GB 1206572.8 and GB 1206573.6 Iridicycle Catalyst Kit component. See (page 51).



100mg
500mg

Technical Note:

1. See 77-0418 (page 24).

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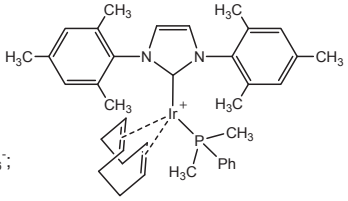
**77-1830** NEW→

**(Dimethylphenylphosphine) (1,5-cyclooctadiene) [1,3-bis(2,4,6-trimethyl-phenyl)imidazol-2-ylidene] iridium(I) hexafluoro-phosphate, min. 98%** *[1019853-03-2]*

$[Ir(C_8H_{12})(C_{21}H_{24}N_2)(C_8H_{11}P)]^+PF_6^-$; red xtl.



100mg
500mg

Technical Note:

1. See 77-1810 (page 25).

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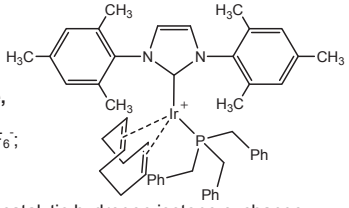
**77-1810** NEW→

**Tribenzylphosphine (1,5-cyclooctadiene) [1,3-bis(2,4,6-trimethyl-phenyl)imidazol-2-ylidene] iridium(I) hexafluorophosphate, min. 98%** *[1019853-01-0]*

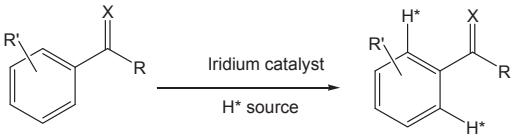
$[Ir(C_8H_{12})(C_{21}H_{24}N_2)(C_{21}H_{21}P)]^+PF_6^-$; FW: 1054.15; red xtl.



100mg
500mg

Technical Notes:

1. Highly active iridium(I) complex used for catalytic hydrogen isotope exchange.
2. Highly active iridium(I) complex used for catalytic hydrogenation processes.




**Tech. Note (1)**
**Ref. (1,2)**

References:

1. *Chem. Commun.*, **2008**, 1115.
2. *J. Label. Compd. Radiopharm.*, **2010**, *53*, 662.
3. *Chem. Commun.*, **2011**, *47*, 11653.

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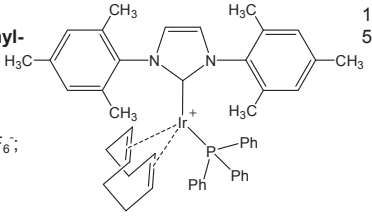
**77-1825** NEW→

**Triphenylphosphine(1,5-cyclo-octadiene)[1,3-bis(2,4,6-trimethyl-phenyl)imidazol-2-ylidene] iridium(I) hexafluoro-phosphate, min. 98%** *[1019852-99-3]*

$[Ir(C_8H_{12})(C_{21}H_{24}N_2)(C_{18}H_{15}P)]^+PF_6^-$; FW: 1012.08; red xtl.



100mg
500mg

Technical Note:

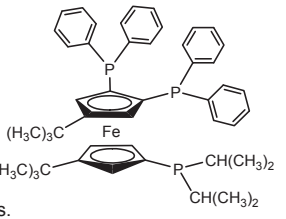
1. See 77-1810 (page 25).

## IRON (Compounds)

**26-0315** NEW→ **1',4-Bis(t-butyl)-1,2-bis(diphenylphosphino)-3'-(di-i-propylphosphino) ferrocene, 98% HiersoPHOS-1** 100mg 500mg

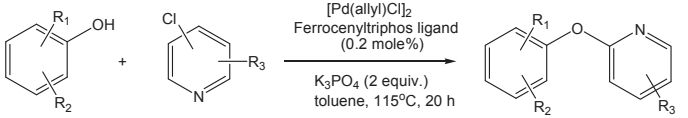
*[1313012-94-0]*

$C_{48}H_{57}FeP_3$; FW: 782.73; orange xtl.

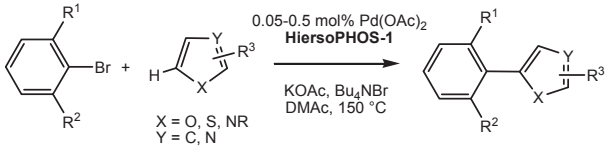


Technical Notes:

1. Ligand/palladium complex used for the etherification of functionalized phenols with chloroheteroarenes.
2. Direct arylation of heteroaromatics with congested, functionalized aryl bromides at low palladium loadings.




**Tech. Note (1)**
**Ref. (1)**




**Tech. Note (2)**
**Ref. (2)**

References:

1. *Adv. Synth. Catal.*, **2011**, *353(18)*, 3404.
2. *Chem. Eur. J.*, **2011**, 17, 6453.

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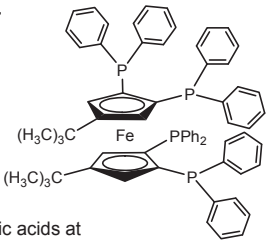
**26-0326** NEW→ **4,4'-Bis(t-butyl)-1,1',2,2'-tetrakis(diphenylphosphino)ferrocene, 98% HiersoPHOS-5** 100mg 500mg

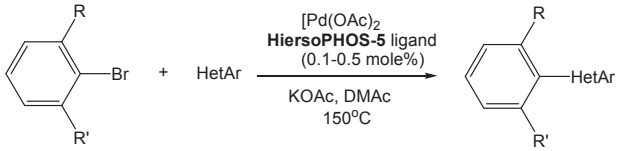
*[403815-19-0]*

$C_{66}H_{62}FeP_4$; FW: 1034.94; orange xtl.

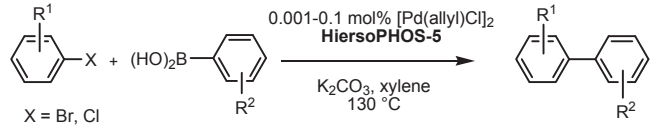


Technical Notes:

1. Ligand/palladium complex used in the direct arylation of heteroaromatic compounds with congested, functionalized aryl bromides.
2. Suzuki-Miyaura Coupling of Aryl Bromides and Chlorides bearing alkyl, methoxy, keto, nitrile, etc. substitution to phenyl- and methoxybenzene boronic acids at Low Palladium Loading.
3. Heck Coupling of Functionalized Aryl Bromides to *n*-butyl acrylate, styrene and *n*-butyl vinyl ether at Low Palladium Loading.
4. Additional catalyzed reaction include Allylic Amination of Monoterpene Derivatives including geranylacetate, nerylacetate, linalylacetate and perillylacetate at Low Palladium Loading (0.001-1.0 mol%, Ref. 2), and Sonogashira Cross-Coupling of Aryl Bromides by using stabilizing new copper-tetraphosphane adducts (Ref. 3).



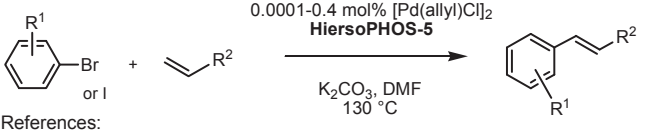

**Tech. Note (1)**
**Ref. (1)**




**Tech. Note (2)**
**Ref. (2)**

## IRON (Compounds) (cont.)

**26-0326** **4,4'-Bis(t-butyl)-1,1',2,2'-tetrakis(diphenylphosphino)ferrocene, 98% HiersoPHOS-5**
NEW→ *[403815-19-0]*
**(cont.)**




**Tech. Note (3)**
**Ref. (2)**

References:

1. *Chemistry – A European Journal*, **2011**, *17(23)*, 6453.
2. *Organometallics*, **2003**, *22*, 4490.
3. *Appl. Organometal. Chem.*, **2006**, *20*, 845.
4. *Organometallics*, **2008**, *27*, 1506.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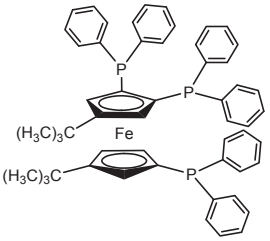
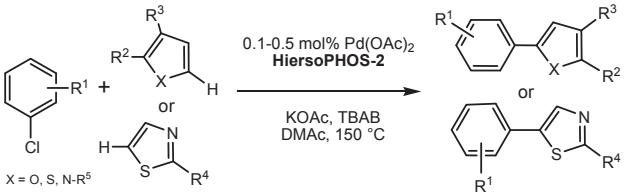
**26-0318** **1',4-Bis(t-butyl)-1,2,3'-tris(diphenylphosphino)ferrocene, 98% HiersoPHOS-2** *[1159850-42-6]*
NEW→
$C_{54}H_{53}FeP_3$; FW: 850.77; orange xtl.

100mg
500mg




Technical Notes:
1. Direct Arylation of Heteroaromatics with Functionalized Aryl Chlorides at Low Palladium Loading (0.1-0.5 mol%): furans, thiophenes, thiazoles, pyrroles functionalized with alkyl, ester, nitrile, and aldehyde groups coupling with *para*-, *meta*- and *ortho*-substituted chloroarenes bearing alkyl, formyl, nitriles, nitro, keto and ester groups.
2. Additional catalyzed reactions include Sonogashira Cross-Coupling of Aryl Bromides and Chlorides at Low Palladium and Copper Iodide Loading (0.05 to 0.4 mol%) by using stabilizing new copper-triphosphane adducts (Ref. 2).



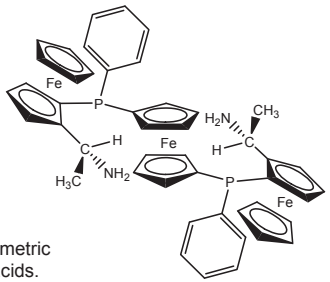

**Tech. Note (1)**
**Ref. (1)**

References:

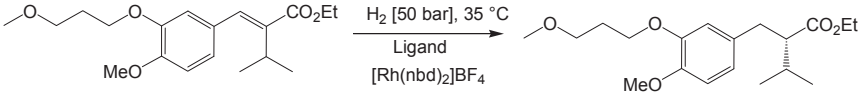
1. *Angew. Chem. Int. Ed.*, **2010**, *49*, 6650.
2. *Organometallics*, **2010,** *29*, 2815.

## IRON (Compounds) (cont.)

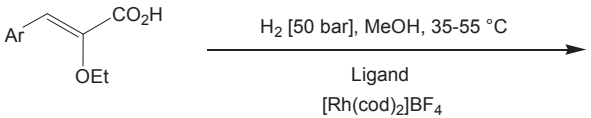
**26-1261** NEW→ **1,1'-Bis{1-[(R)-ferrocenyl-2-(S)-ethyl-1-(diethylamino) phenyl]-(R)-phosphino} ferrocene, min. 97% Trifer** *[900505-82-0]*
$C_{50}H_{54}Fe_3N_2P_2$; FW: 912.46; orange pwdr.
Note: Sold in collaboration with Solvias for research purposes only.
100mg 500mg 2g 10g



Technical Notes:
1. Ligand used for the Rh-catalyzed asymmetric hydrogenation of α-substituted acrylic acids.
2. Ligand used for the Rh-catalyzed asymmetric hydrogenation of 3-aryl-2-ethoxy-acrylic acids.




**Tech. Note (1)**
**Ref. (1)**




**Tech. Note (2)**
**Ref. (1)**

Reference:
1. *Angew. Chem. Int. Ed.* **2007**, *46*, 4141.

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**26-1260** NEW→ **1,1'-Bis{1-[(S)-ferrocenyl-2-(R)-ethyl-1-(dimethylamino)phenyl]-(S)-phosphino}ferrocene, min. 97% Trifer** *[899811-43-9]*
$C_{50}H_{54}Fe_3N_2P_2$; FW: 912.46; orange pwdr.
Note: Sold in collaboration with Solvias for research purposes only.
100mg 500mg 2g 10g

Technical Note:
1. See 26-1261 (page 28).

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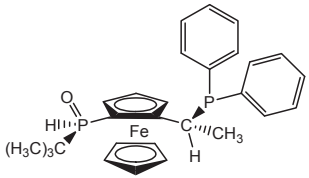
**26-1270** NEW→ **(R,S(p), R(SPO)-(1-t-Butyl-phosphinoyl)-2-[1-(diphenyl-phosphino)ethyl]ferrocene, min. 97% JoSPOphos** *[1221746-31-1]*
$C_{28}H_{32}FeOP_2$; FW: 502.35; orange pwdr.
Note: Sold in collaboration with Solvias for research purposes only.
100mg 500mg 2g 10g



Technical Note:
1. See 26-1268 (page 29).

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**26-1271** NEW→ **(S, R(p), S(SPO)-(1-t-Butylphosphinoyl)-2-[1-(diphenyl-phosphino)ethyl]ferrocene, min. 97% JoSPOphos** *[1221746-31-1]*
$C_{28}H_{32}FeOP_2$; FW: 502.35; orange pwdr.
Note: Sold in collaboration with Solvias for research purposes only.
100mg 500mg 2g 10g

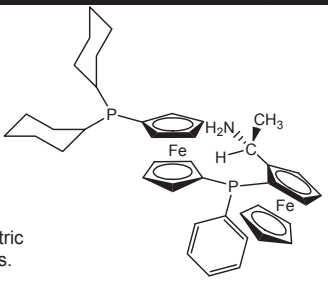
Technical Note:
1. See 26-1268 (page 29).

## IRON (Compounds) (cont.)

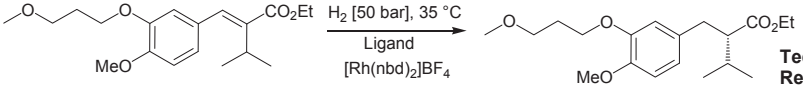
**26-1266** NEW→

**1-{[(R)-Ferrocenyl-2-(S)-ethyl-1-dimethylamino)phenyl]-(R)-phosphino}-1'-dicyclohexyl-phosphinoferrocene, min. 97% Chenphos** *[1036373-39-3]*
$C_{42}H_{53}Fe_2NP_2$; FW: 745.51; orange pwdr.
Note: Sold in collaboration with Solvias for research purposes only.

100mg
500mg
2g
10g




Technical Note:
1. Ligand used for the Rh-catalyzed asymmetric hydrogenation of α-substituted acrylic acids.




**Tech. Note (1)**
**Ref. (1)**

Reference:
1. Patent number US 8,106,227 B2.

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**26-1265** NEW→

**1-{[(S)-Ferrocenyl-2-(R)-ethyl-1-dimethylamino)phenyl]-(S)-phosphino}-1'-dicyclohexylphosphinoferrocene, min. 97% Chenphos** *[952586-19-5]*
$C_{42}H_{53}Fe_2NP_2$; FW: 745.51; orange pwdr.
Note: Sold in collaboration with Solvias for research purposes only.

100mg
500mg
2g
10g

Technical Note:
1. See 26-1266 (page 29).

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**26-2520** NEW→ HAZ

**Iron 2-ethylhexanoate, 6% (Fe) in mineral spirits (99.998+%-Fe) PURATREM** *[7321-53-1]*
$Fe[OOCCH(C_2H_5)C_4H_9]_3$; FW: 485.46; liq.

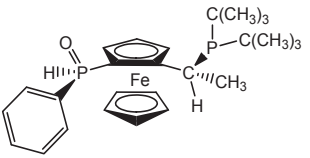
50g
250g

---

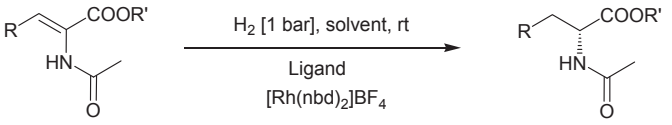
**26-1268** NEW→

**(R,S(p), R(SPO)-1-Phenyl-phosphinoyl)-2-[1-(t-butyl-phosphino)ethyl] ferrocene, min. 97% JoSPOphos** *[1221746-66-2]*
$C_{26}H_{36}FeOP_2$; FW: 482.36; orange pwdr.
Note: Sold in collaboration with Solvias for research purposes only.

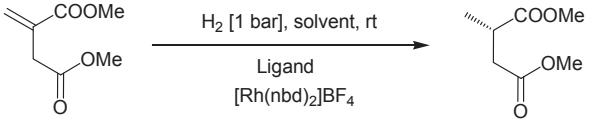
100mg
500mg
2g
10g




Technical Notes:
1. Ligands used for the Rh-catalyzed asymmetric hydrogenation of functionalized alkenes.
2. Ligands used for the Ru-catalyzed asymmetric hydrogenation of β-ketoesters.
3. Ligands used for the Rh-catalyzed asymmetric hydrogenation of α-ketoesters.



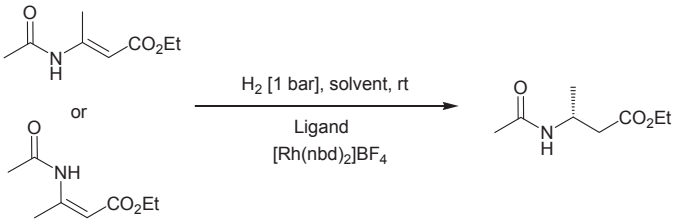

**Tech. Note (1)**
**Ref. (1)**



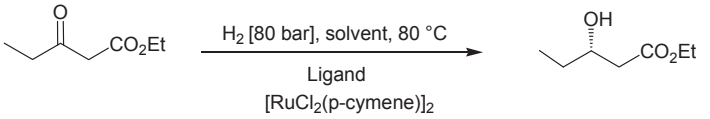

**Tech. Note (1)**
**Ref. (1)**

## IRON (Compounds) (cont.)

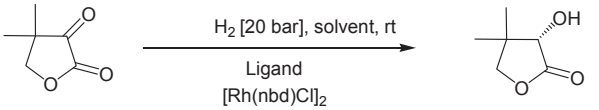
**26-1268** NEW→ **(cont.)** **(R,S(p), R(SPO)-1-Phenyl-phosphinoyl)-2-[1-(t-butyl-phosphino)ethyl] ferrocene, min. 97% JoSPOphos** *[1221746-66-2]*




**Tech. Note (1)**
**Ref. (1)**




**Tech. Note (2)**
**Ref. (1)**




**Tech. Note (3)**
**Ref. (1)**

Reference:
1. Angew. Chem. Int. Ed., **2010**, 49, 6873.

**26-1269** NEW→ **(S, R(p), S(SPO)-1-Phenylphosphinoyl)-2-[1-(t-butyl-phosphino)ethyl]ferrocene, min. 97% JoSPOphos** *[1221746-66-2]*
$C_{26}H_{36}FeOP_2$; FW: 482.36; orange pwdr.
Note: Sold in collaboration with Solvias for research purposes only.
100mg
500mg
2g
10g

Technical Note:
1. See 26-1268 (page 29).

## LEAD (Compounds)

**82-1050** NEW→ **Lead sulfide CANdot® quantum dot (PbS core), 50umol/L in toluene, 1000nm peak emission**
*SEE NANOMATERIALS SECTION (page 32)*

## LITHIUM (Compounds)

**03-0753** NEW→ HAZ **Lithium aluminum hydride 2.2M (10wt% ±1wt%) in 2-methyltetrahydrofuran** *[16853-85-3]*
$LiAlH_4$; FW: 37.94; liq.
*air sensitive, moisture sensitive*
Note: A product of Rockwood Lithium. Sold for R&D purposes only.
0.05mole
0.25mole

**03-0784** NEW→ HAZ **Lithium 2-methyl-2-butoxide 3.1M (40wt% ±1wt%) in heptane** *[53535-81-2]*
$[CH_3CH_2(CH_3)_2CO]_2Li$; FW: 94.08; liq.
*air sensitive, moisture sensitive*
Note: A product of Rockwood Lithium. Sold for R&D purposes only.
0.25mole

## MAGNESIUM (Compounds)

**98-4010** NEW→ HAZ
**Bis(ethylcyclopentadienyl)magnesium, min. 98%, 12-0510, contained in high-temp. 50ml Swagelok® cylinder (96-1071) for CVD/ALD** *[114460-02-5]*
$(C_2H_5C_5H_4)_2Mg$; FW: 210.60; colorless to pale yellow liq.
*air sensitive, moisture sensitive*
10g

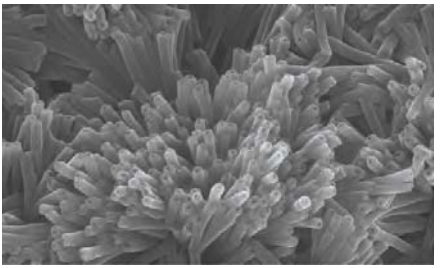
**98-4069** NEW→
**Bis(2,2,6,6-tetramethyl-3,5-heptanedionato)magnesium, anhydrous, min. 98% [Mg(TMHD)2] , 12-0900, contained in high-temp. 50 ml Swagelok® cylinder (96-1071) for CVD/ALD** *[21361-35-3]*
$Mg(C_{11}H_{19}O_2)_2$; FW: 390.85; white pwdr.; *hygroscopic*
15g

**12-0801** NEW→ HAZ
**Magnesium bis(di-i-propylamide) 0.7M (18wt% ±2wt%) in tetrahydrofuran** *[23293-23-4]*
$\{[(CH_3)_2CH]_2N\}_2Mg$; FW: 224.67; liq.
*air sensitive, moisture sensitive*
Note: A product of Rockwood Lithium. Sold for R&D purposes only.
0.05mole
0.25mole

## NANOMATERIALS - CARBON (Compounds)

**06-1060** NEW→
**Polydiacetylene nanotube (PDNT-12-8-22Br)**
purple solid
Note: Sold in collaboration with LIG Sciences for research purposes only. US Patent No. 7,666,911.
100mg
500mg

Polydiacetylene Nanotubes (PDNT) are self-assembled diacetylene nanotubes comprised of cross-linking of conjugated double and triple bonds. They are produced using a proprietary molecular self-assembly process that results in remarkably uniform, pure, air-stable blue nanotubes (ID 34nm, OD 98nm and length 1 - 3µm ). PDNT nanotubes exhibit thermochromism either on different substrates or in solvents. This unique thermo- and mechano-chromic behavior has been demonstrated to be completely reversible for hundreds of cycles.



## NANOMATERIALS - GOLD (Elemental forms)

**Gold Nanoparticles – Reactant Free**
>99% free of residual reactant, in 0.1mM phosphate buffer. Store away from direct sunlight at 4°C. Do not freeze. Shelf life 6 months.

**79-0180** NEW→
**Gold Nanoparticles (5 nm diameter, OD 1, stabilized suspension in phosphate-buffered saline) reactant free**
Note: Adsorption max 515-520nm. Gold Nanoparticles Kit, Reactant-Free component. See (page 50).
25ml
100ml

**79-0184** NEW→
**Gold Nanoparticles (10 nm diameter, OD 1, stabilized suspension in phosphate-buffered saline) reactant free**
Note: Adsorption max 520nm. Gold Nanoparticles Kit, Reactant-Free component. See (page 50).
25ml
100ml

**79-0186** NEW→
**Gold Nanoparticles (15 nm diameter, OD 1, stabilized suspension in phosphate-buffered saline) reactant free**
Note: Adsorption max 520nm. Gold Nanoparticles Kit, Reactant-Free component. See (page 50).
25ml
100ml

**79-0188** NEW→
**Gold Nanoparticles (20 nm diameter, OD 1, stabilized suspension in phosphate-buffered saline) reactant free**
Note: Adsorption max 524nm. Gold Nanoparticles Kit, Reactant-Free component. See (page 50).
25ml
100ml

**79-0190** NEW→
**Gold Nanoparticles (30 nm diameter, OD 1, stabilized suspension in phosphate-buffered saline) reactant free**
Note: Adsorption max 526nm. Gold Nanoparticles Kit, Reactant-Free component. See (page 50).
25ml
100ml

**79-0192** NEW→
**Gold Nanoparticles (40 nm diameter, OD 1, stabilized suspension in phosphate-buffered saline) reactant free**
Note: Adsorption max 530nm. Gold Nanoparticles Kit, Reactant-Free component. See (page 50).
25ml
100ml

## NANOMATERIALS - GOLD (Elemental forms) (cont.)

**Gold Nanoparticles – Reactant Free**
>99% free of residual reactant, in 0.1mM phosphate buffer. Store away from direct sunlight at 4°C. Do not freeze. Shelf life 6 months.

**96-1545** NEW→
**Gold Nanoparticles Kit, Reactant-Free (5nm-40nm diameter, OD 1, suspension in phosphate-buffered saline**
*SEE KITS SECTION (page 50)*

**Gold Nanoparticles – Citrate Stabilized**
In 0.1mg/ml citrate buffer. Store away from direct sunlight at 4°C. Do not freeze. Shelf life 6 months.

**79-0182** NEW→
**Gold Nanoparticles (5 nm diameter, OD 1, stabilized suspension citrate buffer)** 25ml 100ml
Note: Adsorption max 515-520nm. Gold Nanoparticles Kit component.
See (page 50).

**79-0210** NEW→
**Gold Nanoparticles (10 nm diameter, OD 1, stabilized suspension citrate buffer)** 25ml 100ml
Note: Adsorption max 515-520nm. Gold Nanoparticles Kit component.
See (page 50).

**79-0212** NEW→
**Gold Nanoparticles (15 nm diameter, OD 1, stabilized suspension citrate buffer)** 25ml 100ml
Note: Adsorption max 520nm. Gold Nanoparticles Kit component.
See (page 50).

**79-0214** NEW→
**Gold Nanoparticles (20 nm diameter, OD 1, stabilized suspension citrate buffer)** 25ml 100ml
Note: Adsorption max 524nm. Gold Nanoparticles Kit component.
See (page 50).

**79-0216** NEW→
**Gold Nanoparticles (30 nm diameter, OD 1, stabilized suspension citrate buffer)** 25ml 100ml
Note: Adsorption max 526nm. Gold Nanoparticles Kit component.
See (page 50).

**79-0218** NEW→
**Gold Nanoparticles (40 nm diameter, OD 1, stabilized suspension citrate buffer)** 25ml 100ml
Note: Adsorption max 530nm. Gold Nanoparticles Kit component.
See (page 50).

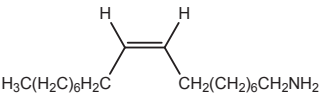
**96-1547** NEW→
**Gold Nanoparticles Kit (5nm-40nm diameter, OD 1, stabilized suspension citrate buffer)**
*SEE KITS SECTION (page 50)*

## NANOMATERIALS - LEAD (Compounds)

**82-1050** NEW→ HAZ
**Lead sulfide CANdot® quantum dot (PbS core), 50umol/L in toluene, 1000nm peak emission** *[1314-87-0]* 5ml 25ml
PbS; FW: 239.25; dark-red liq.
Note: Sold in collaboration with CAN for R&D purposes.
Suggest use within 6 months of purchase.

## NANOMATERIALS - (Surfactants & Ligands for Nano Synthesis)

**07-1668** NEW→
**Oleylamine, min. 95%** *[112-90-3]* 5g 25g
$CH_3(CH_2)_7CH{=}CH(CH_2)_7CH_2NH_2$;
FW: 267.49; colorless liq.;
m.p. 18-26°; b.p. 348-350°;
d. 0.813

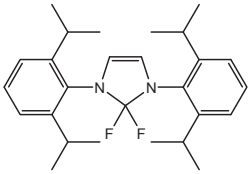



Note: Surfactant for nanomaterial synthesis.

## NITROGEN (Compounds)

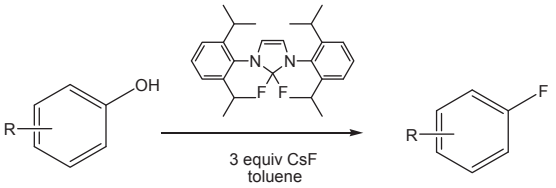
**07-0625** NEW→

**1,3-Bis(2,6-di-i-propylphenyl)-2,2-difluoroimidazoline, min. 95% (PhenoFluor™)** *[1314657-40-3]*
$C_{27}H_{36}F_2N_2$; FW: 426.59;
colorless solid
*moisture sensitive*
Note: Sold under license from SciFluor Life Sciences, LLC for research purposes only.



100mg
500mg

Technical Note:
1. New, and operationally simple, deoxyfluorination reagent.




**Tech. Note (1)**
**Ref. (1)**

Reference:
1. *J. Am. Chem. Soc*, **2011,** *133,* 11482.

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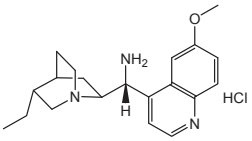
**07-1718** NEW→

**(8α, 9S)-10,11-Dihydro-6'-methoxy-cinchonan-9-amine hydrochloride, min. 90%** *[852913-53-2]*
$C_{20}H_{27}N_3O$·HCl; FW: 361.91;
white to off-white pwdr.
*(store cold)*
Note: Cinchona Alkaloid-Derived Organocatalyst Kit component.
See (page 49).




100mg
500mg

Technical Note:
1. See 07-1710 (page 34).

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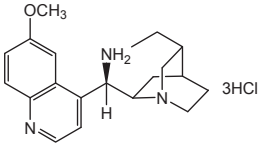
**07-1722** NEW→

**(9R)-10,11-Dihydro-6'-methoxy-cinchonan-9-amine trihydro-chloride, min. 90%**
*[931098-92-9]*
$C_{20}H_{27}N_3O$·3HCl; FW: 434.83;
white to off-white pwdr.
*(store cold)*
Note: Cinchona Alkaloid-Derived Organocatalyst Kit component.
See (page 49).

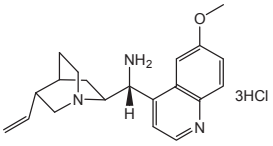



100mg
500mg

Technical Note:
1. See 07-1710 (page 34).

## NITROGEN (Compounds) (cont.)

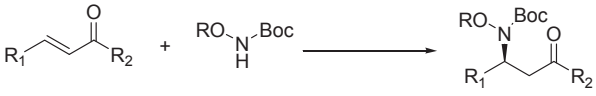
**07-1710** NEW→ **(8α, 9S)-6'-Methoxy-cinchonan-9-amine trihydrochloride, min. 90%** *[1231763-32-8]*
$C_{20}H_{25}N_3O \cdot 3HCl$; FW: 432.81;
pale yellow pwdr.
*(store cold)*
Note: Cinchona Alkaloid-Derived Organocatalyst Kit component. See (page 49).



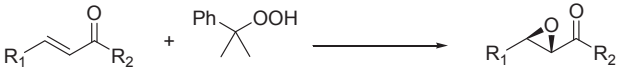

100mg
500mg

Technical Notes:

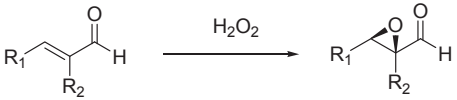
1. Aza-Michael reactions on α,β-unsaturated ketones.
2. Epoxidation of α,β-unsaturated ketones.
3. Epoxidation of α,β-unsaturated aldehydes.
4. Nitrocyclopropanation of α,β-unsaturated ketones.
5. Diels-Alder reaction.
6. Intramolecular aldolization of diketones.
7. Friedel-Crafts alkylation of indoles with α,β-unsaturated ketones.
8. Friedel-Crafts/amination cascade reactions with a-substituted α,β-unsaturated aldehydes.
9. Aziridination of acyclic α,β-unsaturated ketones.
10. Aziridination of cyclic α,β-unsaturated ketones.
11. Double Michael cascade process.
12. α-fluorination of cyclic ketones.



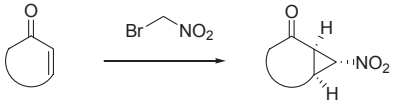

**Tech. Note (1)**
**Ref. (1)**



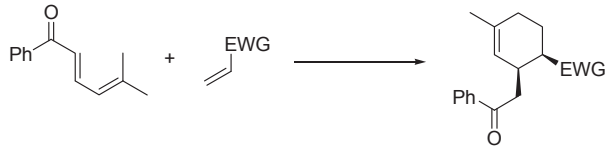

**Tech. Note (2)**
**Ref. (2)**




**Tech. Note (3)**
**Ref. (3)**




**Tech. Note (4)**
**Ref. (4)**




**Tech. Note (5)**
**Ref. (5)**


**Tech. Note (6)**
**Ref. (6)**

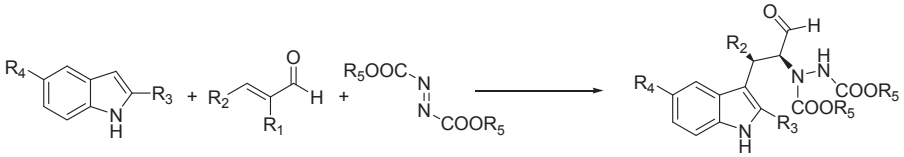

**Tech. Note (7)**
**Ref. (7)**

## NITROGEN (Compounds) (cont.)

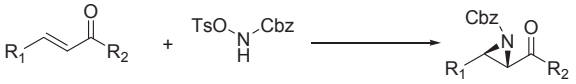
**07-1710** **(8α, 9S)-6'-Methoxy-cinchonan-9-amine trihydrochloride, min. 90%** *[1231763-32-8]*

NEW→

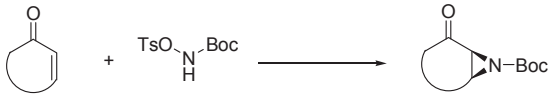
(cont.)



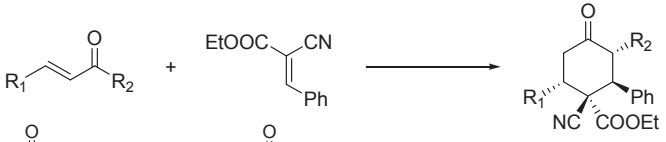
**Tech. Note (8)**
**Ref. (8)**



**Tech. Note (9)**
**Ref. (9)**



**Tech. Note (10)**
**Ref. (10)**



**Tech. Note (11)**
**Ref. (11)**

**Tech. Note (12)**
**Ref. (12)**

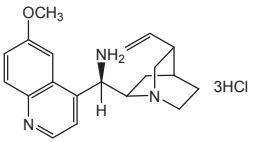
References:


1. *Angew. Chem. Int. Ed.*, **2008**, *47*, 7710.
2. *J. Am. Chem. Soc.*, **2008**, *130*, 8134.
3. *J. Am. Chem. Soc.*, **2010**, *132*, 10227.
4. *Chem. Eur. J.*, **2009**, *15*, 972.
5. *Angew. Chem. Int. Ed.*, **2012**, *51*, 4401.
6. *Angew. Chem. Int. Ed.*, **2008**, *47*, 7656.
7. *Org. Lett.*, **2007**, *9*, 1403.
8. Chem. Int. Ed., 2009, 48, 7892.
9. *Angew. Chem. Int. Ed.*, **2008**, *47*, 8703.
10. *Chem. Asian J.*, **2010**, *5*, 1652.
11. *Angew. Chem. Int. Ed.*, **2009**, *48*, 7196.
12. *J. Am. Chem. Soc.*, **2011**, *133*, 1738.


**07-1715** **(9R)-6'-Methoxy-cinchonan-9-amine trihydrochloride, min. 90%** 100mg 500mg

NEW→

$C_{20}H_{25}N_3O \cdot 3HCl$; FW: 432.81;
white to off-white pwdr.
*(store cold)*
Note: Cinchona Alkaloid-Derived Organocatalyst Kit component.
See (page 49).



Technical Note:

1. See 07-1710 (page 34).

**07-1668** **Oleylamine, min. 95%**

NEW→

*SEE NANOMATERIALS SECTION (page 32)*

## OSMIUM (Compounds)

**76-2210** NEW→ HAZ
**Osmium(III) chloride hydrate (99.95+%-Os)** *[14996-60-2]*
$OsCl_3$; FW: 296.56; black xtl.
250mg 1g 5g

**76-2958** NEW→ amp HAZ
**Osmium(VIII) oxide (99.99+%-Os) PURATREM** *[20816-12-0]*
$OsO_4$; FW: 254.20; pale yellow xtl.; m.p. 41-42°; d. 4.906
250mg 500mg 1g 5x1g

**76-2955** NEW→ amp HAZ
**Osmium(VIII) oxide (99.99+%-Os), 4% in water PURATREM**
*[20816-12-0]*
$OsO_4$; FW: 254.20; colorless liq.
2ml 5ml 2x5ml

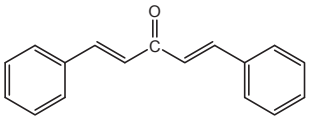
**76-3510** NEW→
**Potassium hexachloroosmate (IV), 99% (99.98+%-Os)**
*SEE POTASSIUM SECTION (page 45)*

**76-4050** NEW→
**Potassium osmate(VI) dihydrate, 99% (99.98+%-Os)**
*SEE POTASSIUM SECTION (page 45)*

**76-3520** NEW→
**Sodium hexachloroosmate((IV) hydrate (99.98+%-Os)**
*SEE SODIUM SECTION (page 46)*

## OXYGEN (Compounds)

**08-0625** NEW→
**1,5-Diphenyl-1,4-pentadien-3-one, min. 98% (Dibenzylideneacetone)**
*[538-58-9]*
$C_{17}H_{14}O$; FW: 234.30; yellow solid



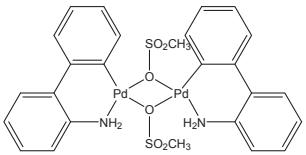

1g 5g

## PALLADIUM (Compounds)

**96-5505** NEW→
**Buchwald Palladacycle Precatalyst Kit 2**
*SEE KITS SECTION (page 48)*

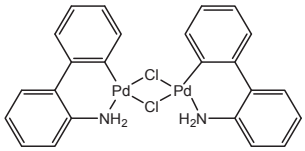
**96-5508** NEW→
**Buchwald Palladacycle Precatalyst Kit 3**
*SEE KITS SECTION (page 49)*

**46-1558** NEW→
**(2'-Amino-1,1'-biphenyl-2-yl) methanesulfonato-palladium(II) dimer, min. 98%**
$C_{26}H_{24}N_2O_6Pd_2S_2$; FW: 739.47; off-white to tan pwdr.




250mg 1g

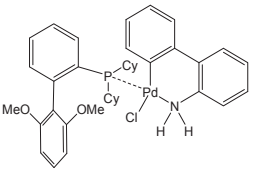
**46-1560** NEW→
**Chloro(2'-amino-1,1'-biphenyl-2-yl)palladium(II) dimer, min. 98%**
*[847616-85-7]*
$C_{24}H_{20}Cl_2N_2Pd_2$; FW: 620.17; pale gray pwdr.




250mg 1g

## PALLADIUM (Compounds) (cont.)

**46-0283** NEW→ **Chloro(2-dicyclohexylphosphino-2',6'-dimethoxy-1,1'-biphenyl)(2'-amino-1,1'-biphenyl-2-yl) palladium(II) min. 98% [SPhos Palladacycle]**
*[1375325-64-6]*
$C_{38}H_{45}ClNO_2PPd$; FW: 720.62;
white pwdr.
Note: Patents: US 6,395,916, US 6,307,087. Buchwald Palladacycle Precatalyst Kit 3 component. See (page 49).



250mg
1g

Technical Note:
1. See 46-0281 (page 37).

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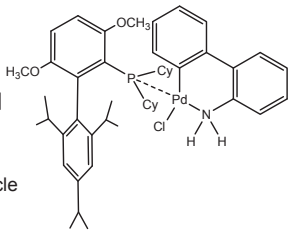
**46-0292** NEW→ **Chloro(2-dicyclohexylphosphino-3,6-dimeth-oxy-2',4',6'-tri-i-propyl-1,1'-biphenyl)(2'-amino-1,1'-biphenyl-2-yl)palladium(II), min. 98% [BrettPhos Palladacycle]**
$C_{47}H_{63}ClNO_2PPd$; FW: 846.86;
white pwdr.
Note: Patents: US 6,395,916, US 6,307,087. Buchwald Palladacycle Precatalyst Kit 3 component. See (page 49).



100mg
500mg
2g

Technical Note:
1. See 46-0281 (page 37).

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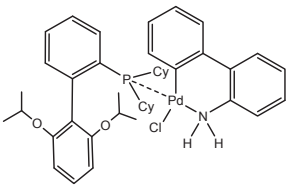
**46-0286** NEW→ **Chloro(2-dicyclohexylphosphino-2',6'-di-i-propoxy-1,1'-biphenyl)(2-amino-1,1'-biphenyl-2-yl) palladium(II), min. 98% [RuPhos Palladacycle]**
*[1375325-68-0]*
$C_{42}H_{53}ClNO_2PPd$; FW: 776.72;
white pwdr.
Note: Patents: US 6,395,916, US 6,307,087. Buchwald Palladacycle Precatalyst Kit 3 component. See (page 49).



250mg
1g

Technical Note:
1. See 46-0281 (page 37).

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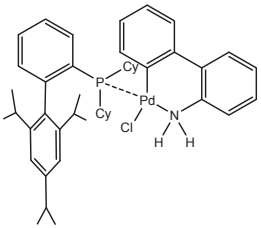
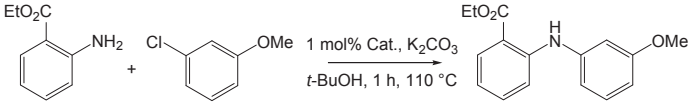
**46-0281** NEW→ **Chloro(2-dicyclohexylphosphino-2',4',6'-tri-i-propyl-1,1'-biphenyl)(2'-amino-1,1'-biphenyl-2-yl) palladium(II), min. 98% [XPhos Palladacycle]** *[1310584-14-5]*
$C_{45}H_{59}ClNPPd$; FW: 786.80;
white pwdr.
Note: Patents: US 6,395,916, US 6,307,087. Buchwald Palladacycle Precatalyst Kit 3 component. See (page 49).



250mg
1g

Technical Note:
1. Palladium precatalyst for fast Suzuki-Miyaura coupling reactions of unstable polyfluorophenyl and 2-heteroaryl boronic acids.

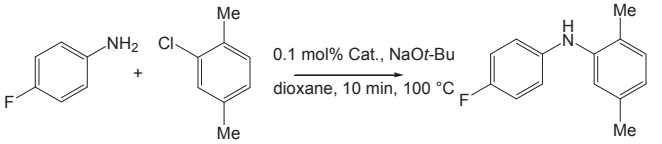



**Tech. Note (1)**
**Ref. (1)**

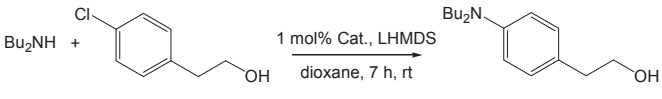
## PALLADIUM (Compounds) (cont.)

**46-0281** NEW→ **(cont.)**

**Chloro(2-dicyclohexylphosphino-2',4',6'-tri-i-propyl-1,1'-biphenyl)(2'-amino-1,1'-biphenyl-2-yl)palladium(II), min. 98% [XPhos Palladacycle]** *[1310584-14-5]*




**Tech. Note (2)**
**Ref. (1)**




**Tech. Note (3)**
**Ref. (1)**

Reference:
1. *J. Am. Chem. Soc.*, **2010,** *132,* 14073.

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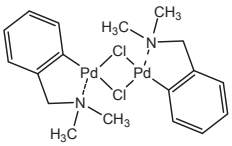
**46-0375** NEW→

**Di-μ-chlorobis{2-[(dimethylamino) methyl]phenyl}dipalladium, 99%** *[18987-59-2]*
$C_{18}H_{24}Cl_2N_2Pd_2$; FW: 552.14; yellow pwdr.




250mg
1g
5g

Technical Note:
1. Useful starting material for the preparation of N-heterocyclic-carbene palladium complexes.

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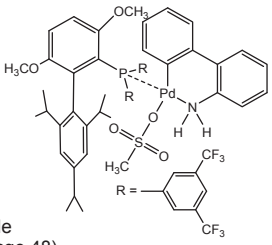
**46-0340** NEW→

**Methanesulfonato[2-bis(3,5-di(trifluoromethyl)phenylphosphino)-3,6-dimethoxy-2',4',6'-tri-i-propyl-1,1'-biphenyl](2'-amino-1,1'-biphenyl-2-yl)palladium(II), min. 98% [JackiePhos Palladacycle]**
$C_{52}H_{50}F_{12}NO_4PPdS$; FW: 1150.40; white pwdr.
Note: Patents: US 6,395,916, US 6,307,087. Buchwald Palladacycle Precatalyst Kit 2 component. See (page 48).




100mg
500mg

Technical Note:
1. See 46-0281 (page 37).

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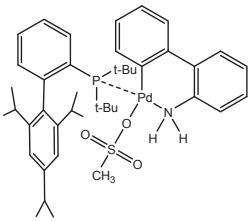
**46-0323** NEW→

**Methanesulfonato(2-di-t-butylphosphino-2',4',6'-tri-i-propyl-1,1'-biphenyl(2'-amino-1,1'-biphenyl-2-yl)palladium(II), min. 98% [t-BuXPhos Palladacycle]**
$C_{42}H_{58}NO_3PPdS$; FW: 794.38; yellow pwdr.
Note: Patents: US 6,395,916, US 6,307,087. Buchwald Palladacycle Precatalyst Kit 2 component. See (page 48).




250mg
1g

Technical Note:
1. See 46-0281 (page 37).

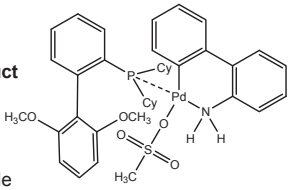
## PALLADIUM (Compounds) (cont.)

**46-0318** NEW→

**Methanesulfonato(2-dicyclohexylphosphino-2',6'-dimethoxy-1,1'-biphenyl)(2'-amino-1,1'-biphenyl-2-yl) palladium(II) dichloromethane adduct min. 98% [SPhos Palladacycle]**

$C_{39}H_{48}NO_5PPdS$; FW: 780.26; white pwdr.

Note: Patents: US 6,395,916, US 6,307,087. Buchwald Palladacycle Precatalyst Kit 2 component. See (page 48).



250mg
1g

Technical Note:
1. See 46-0281 (page 37).

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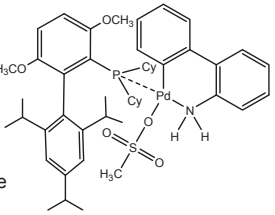
**46-0322** NEW→

**Methanesulfonato(2-dicyclohexylphosphino-3,6-dimethoxy-2',4',6'-tri-i-propyl-1,1'-biphenyl)(2'-amino-1,1'-biphenyl-2-yl)palladium(II), min. 98% [BrettPhos Palladacycle]**

$C_{48}H_{66}NO_5PPdS$; FW: 906.50; white pwdr.

Note: Patents: US 6,395,916, US 6,307,087. Buchwald Palladacycle Precatalyst Kit 2 component. See (page 48).



100mg
500mg
2g

Technical Note:
1. See 46-0281 (page 37).

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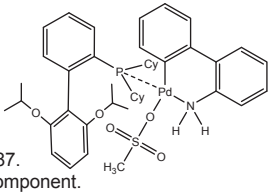
**46-0314** NEW→

**Methanesulfonato(2-dicyclohexylphosphino-2',6'-di-i-propoxy-1,1'-biphenyl)(2-amino-1,1'-biphenyl-2-yl) palladium(II), min. 98% [RuPhos Palladacycle]**

$C_{43}H_{56}NO_5PPdS$; FW: 836.37; white pwdr.

Note: Patents: US 6,395,916, US 6,307,087. Buchwald Palladacycle Precatalyst Kit 2 component. See (page 48).



250mg
1g

Technical Note:
1. See 46-0281 (page 37).

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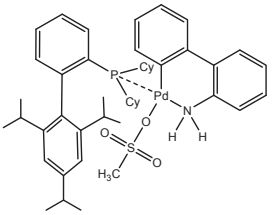
**46-0320** NEW→

**Methanesulfonato(2-dicyclohexylphosphino-2',4',6'-tri-i-propyl-1,1'-biphenyl) (2'-amino-1,1'-biphenyl-2-yl) palladium(II), min. 98% [XPhos Palladacycle]**

$C_{46}H_{62}NO_3PPdS$; FW: 846.45; white pwdr.

Note: Patents: US 6,395,916, US 6,307,087. Buchwald Palladacycle Precatalyst Kit 2 Component. See (page 48).



250mg
1g

Technical Note:
1. See 46-0281 (page 37).

## PALLADIUM (Compounds) (cont.)

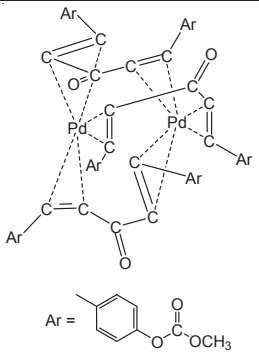
**46-3005** NEW→ **Tris[di(4-acetoxybenzylidene) acetone]dipalladium(0) di(4-acetoxybenzylidene) acetone adduct, min. 97%** 100mg 500mg

*[1196118-15-6]*

$C_{63}H_{54}O_{15}Pd_2$; FW: 1263.93; dark purple pwdr.

*air sensitive, moisture sensitive, (store cold)*

Note: U.S. Patent No. 12/259,001




Technical Note:

1. Useful catalyst for the Suzuki polycondensation reactions.

Reference:

1. *Macromolecules*, **2009**, *42*, 8611.

## PHOSPHORUS (Compounds)

**96-3780** NEW→ **PhenCar-Phos Ligand Kit**
See (page 51).

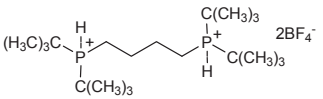
**26-0315** NEW→ **1',4-Bis(t-butyl)-1,2-bis(diphenylphosphino)-3'-(di-i-propylphosphino)ferrocene, 98% HiersoPHOS-1**
*See IRON SECTION (page 26)*

**26-0326** NEW→ **4,4'-Bis(t-butyl)-1,1',2,2'-tetrakis(diphenylphosphino)ferrocene, 98% HiersoPHOS-5**
*See IRON SECTION (page 26)*

**26-0318** NEW→ **1',4-Bis(t-butyl)-1,2,3'-tris(diphenylphosphino)ferrocene, 98% HiersoPHOS-2**
*See IRON SECTION (page 27)*

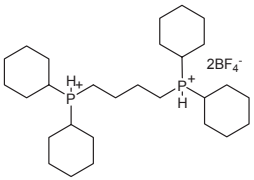
**15-9582** NEW→ **1,4-Bis(di-t-butylphosphonium) butane bis(tetrafluoroborate), min. 97%** 1g 5g

$(C_4H_9)_2PH^+CH_2CH_2CH_2CH_2PH^+ (C_4H_9)_2 (BF_4)_2$; FW: 522.14; white solid; m.p. 257-259°



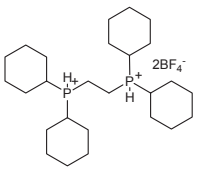

**15-9562** NEW→ **1,4-Bis(dicyclohexylphosphonium) butane bis(tetrafluoroborate), min. 97%** 1g 5g

$(C_6H_{11})_2PH^+CH_2CH_2CH_2CH_2PH^+ (C_6H_{11})_2 (BF_4)_2$; FW: 626.29; white solid; m.p. 236-238°



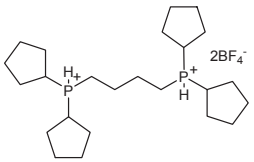

**15-9558** NEW→ **1,2-Bis(dicyclohexylphosphonium) ethane bis(tetrafluoroborate), min. 97%** 1g 5g

$(C_6H_{11})_2PH^+CH_2CH_2PH^+(C_6H_{11})_2 (BF_4)_2$; FW: 598.23; white solid; m.p. 236-239°

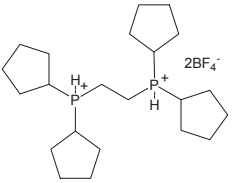



**15-9574** NEW→ **1,4-Bis(dicyclopentylphosphonium) butane bis(tetrafluoroborate), min. 97%** 1g 5g

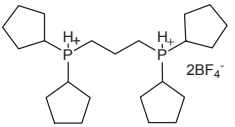
$(C_5H_9)_2PH^+CH_2CH_2CH_2CH_2PH^+ (C_5H_9)_2 (BF_4)_2$; FW: 570.18; white solid; m.p. 195-197°



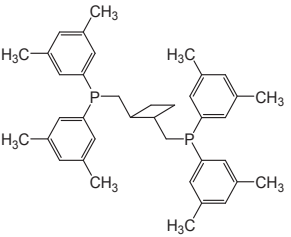
## PHOSPHORUS (Compounds) (cont.)

**15-9568** NEW→
**1,2-Bis(dicyclopentylphosphonium) ethane bis(tetrafluoroborate), min. 97%**
$(C_5H_9)_2PH^+CH_2CH_2PH^+(C_5H_9)_2(BF_4)_2$; FW: 542.13; white solid; m.p. 230-233°


1g
5g

**15-9572** NEW→
**1,3-Bis(dicyclopentylphosphonium) propane bis(tetrafluoroborate), min. 97%**
$(C_5H_9)_2PH^+CH_2CH_2CH_2PH^+(C_5H_9)_2\ (BF_4)_2$; FW: 556.15; white pwdr.; m.p. 141-143°


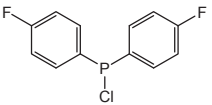
1g
5g

**15-5172** NEW→
**racemic-trans-1,2-Bis[di(3,5-dimethylphenyl)phosphinomethyl] cyclobutane**
$C_{38}H_{46}P_2$; FW: 564.72; white solid


250mg
1g

**26-1261** NEW→
**1,1'-Bis{1-[(R)-ferrocenyl-2-(S)-ethyl-1-(diethylamino)phenyl]-(R)-phosphino}ferrocene, min. 97% Trifer**
*SEE IRON SECTION (page 28)*

**26-1260** NEW→
**1,1'-Bis{1-[(S)-ferrocenyl-2-(R)-ethyl-1-(dimethylamino)phenyl]-(S)-phosphino}ferrocene, min. 97% Trifer**
*SEE IRON SECTION (page 28)*

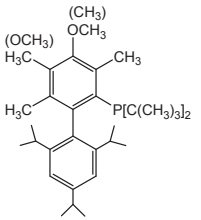
**15-7318** NEW→ HAZ
**Bis(4-fluorophenyl)chlorophosphine, min. 98%** *[23039-97-6]*
$(FC_6H_4)_2ClP$; FW: 256.62; pale yellow liq.
*moisture sensitive*


250mg
1g

**26-1270** NEW→
**(R,S(p), R(SPO)-(1-t-Butylphosphinoyl)-2-[1-(diphenylphosphino)ethyl]ferrocene, min. 97% JoSPOphos**
*SEE IRON SECTION (page 28)*

**26-1271** NEW→
**(S, R(p), S(SPO)-(1-t-Butylphosphinoyl)-2-[1-(diphenylphosphino)ethyl]ferrocene, min. 97% JoSPOphos**
*SEE IRON SECTION (page 28)*

**15-1095** NEW→ HAZ
**Di-1-adamantylchlorophosphine, min. 97%** *[157282-19-4]*
$(C_{10}H_{15})_2ClP$; FW: 336.88; colorless solid
*moisture sensitive*
250mg
1g

**15-1063** NEW→
**2-Di-t-butylphosphino-4-methoxy-3,5,6-trimethyl-2',4',6'-tri-i-propylbiphenyl, min. 98% [~1:1 mixture with regioisomer] 2-Di-t-butylphosphino-5-methoxy-3,4,6-trimethyl-2',4',6'-tri-i-propylbiphenyl]** *[1359986-21-2]*
$C_{33}H_{53}OP$; FW: 496.75; white pwdr.
Note: Patents: US 6,395,916, US 6,307,087


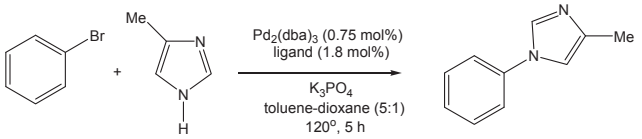
250mg
1g
5g

## PHOSPHORUS (Compounds) (cont.)

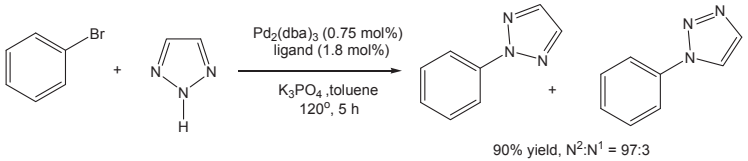
**15-1063** NEW→ **(cont.)** **2-Di-t-butylphosphino-4-methoxy-3,5,6-trimethyl-2',4',6'-tri-i-propylbiphenyl, min. 98% [~1:1 mixture with regioisomer] 2-Di-t-butylphosphino-5-methoxy-3,4,6-trimethyl-2',4',6'-tri-i-propylbiphenyl]** *[1359986-21-2]*

Technical Note:

1. A surrogate ligand for $Me_4$tBuXPhos in palladium-catalyzed C-N and C-O bond-forming reactions.




**Tech. Note (1)**
**Ref. (1)**




Reference:

1. *J. Org. Chem.*, **2012**, *77*, 2543.

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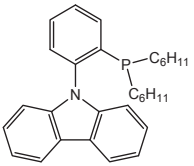
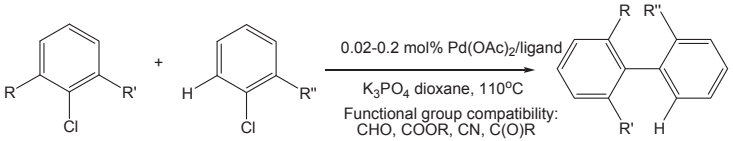
**15-0445** NEW→ **9-[2-(Dicyclohexylphosphino)phenyl]-9H-carbazole, min. 98% PhenCar-Phos** *[1308652-64-3]*
$C_{30}H_{34}NP$; FW: 439.57; white pwdr.
*air sensitive*
Note: PhenCar-Phos Ligand Kit component.
See (page 51).




250mg
1g

Technical Note:

1. Carbazolyl-derived phosphine ligand used in the highly-efficient, catalytic coupling of sterically hindered aryls.




**Tech. Note (1)**
**Ref. (1)**

Reference:

1. *Chem. Commun.*, **2011**, *47*, 5079.

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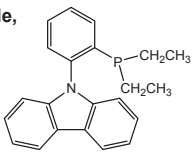
**15-0496** NEW→ **9-[2-(Diethylphosphino)phenyl]-9H-carbazole, min. 97% Et PhenCar-Phos** *[1308652-66-5]*
$C_{22}H_{22}NP$; FW: 331.39; white pwdr.
*air sensitive*
Note: PhenCar-Phos Ligand Kit component.
See (page 51).




100mg
500mg

Technical Note:

1. See 15-0445 (page 42).

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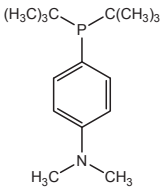
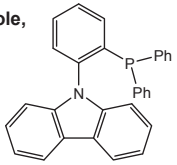
**15-1248** NEW→ **[4-(N,N-Dimethylamino)phenyl]di-t-butylphosphine, min. 95% AMPHOS** *[932710-63-9]*
$C_{16}H_{28}NP$; FW: 265.37;
white to light-brown xtl.; m.p. 57-61°




1g
5g

## PHOSPHORUS (Compounds) (cont.)

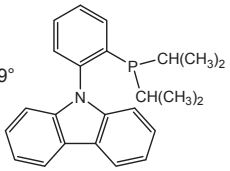
**15-0498** NEW→ **9-[2-(Diphenylphosphino)phenyl]-9H-carbazole, min. 97% Ph PhenCar-Phos** *[1308652-67-6]*
$C_{30}H_{22}NP$; FW: 427.48; white pwdr.
*air sensitive*
Note: PhenCar-Phos Ligand Kit component.
See (page 51).




250mg
1g

Technical Note:
1. See 15-0445 (page 42).

**15-0493** NEW→ **9-[2-(Di-i-propylphosphino)phenyl]-9H-carbazole, min. 97% i-Pr PhenCar-Phos**
*[1308652-65-4]*
$C_{24}H_{26}NP$; FW: 359.44; white pwdr.; m.p. 145-149°
*air sensitive*
Note: PhenCar-Phos Ligand Kit component.
See (page 51).



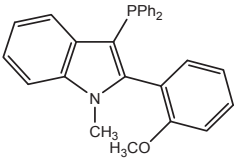

250mg
1g

Technical Note:
1. See 15-0445 (page 42).

**26-1266** NEW→ **1-{[(R)-Ferrocenyl-2-(S)-ethyl-1-dimethylamino)phenyl]-(R)-phosphino}-1'-dicyclohexylphosphinoferrocene, min. 97% Chenphos**
*SEE IRON SECTION (page 29)*

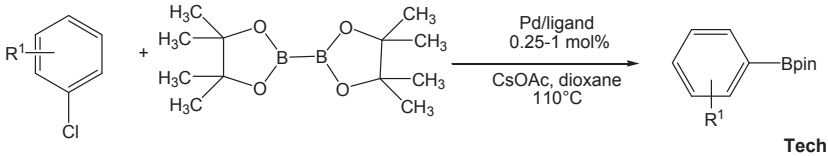
**26-1265** NEW→ **1-{[(S)-Ferrocenyl-2-(R)-ethyl-1-dimethylamino)phenyl]-(S)-phosphino}-1'-dicyclohexylphosphinoferrocene, min. 97% Chenphos**
*SEE IRON SECTION (page 29)*

**15-1091** NEW→ **2-(2-Methoxyphenyl)-1-methyl-3-diphenylphosphino)-1H-indole, min. 98% $PPh_2$-Andole-Phos**
$C_{28}H_{24}NOP$; FW: 421.47;
white to off-white pwdr.




500mg
2g

Technical Note:
1. Palladium-Indolylphosphine catalyzed borylation of nonactivated aryl chlorides.




**Tech. Note (1)**
**Ref. (1)**

Reference:
1. *J. Org. Chem.*, **2012**, *77*, 3543.

**26-1268** NEW→ **(R,S(p), R(SPO)-1-Phenylphosphinoyl)-2-[1-(t-butylphosphino)ethyl]ferrocene, min. 97% JoSPOphos**
*SEE IRON SECTION (page 29)*

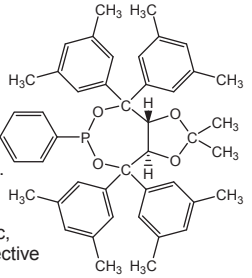
**26-1269** NEW→ **(S, R(p), S(SPO)-1-Phenylphosphinoyl)-2-[1-(t-butylphosphino)ethyl]ferrocene, min. 97% JoSPOphos**
*SEE IRON SECTION (page 30)*

## PHOSPHORUS (Compounds) (cont.)

**15-1511** NEW→ **(3aR,8aR)-(-)-4,4,8,8-Tetrakis(3,5-dimethylphenyl)tetrahydro-2,2-dimethyl-6-phenyl-1,3-dioxolo[4,5-e]dioxaphosphepin** 100mg 500mg

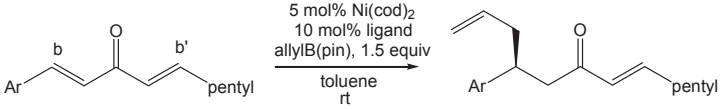
*[1019840-96-0]*

$C_{45}H_{49}O_4P$; FW: 684.84; white solid



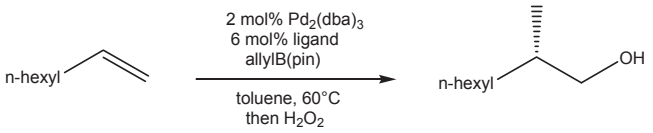
Technical Notes:

1. Chiral ligand used in the nickel-catalyzed, enantioselective, conjugate allylation of activated enones.
2. Chiral ligand used in the palladium-catalyzed, enantioselective diboration of terminal alkenes.
3. Chiral ligand used in the palladium-catalyzed, asymmetric, 1,4-dihydroxylation of 1,3-dienes via catalytic enantioselective diboration.

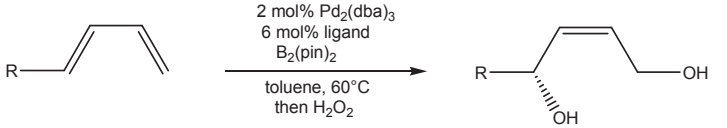



Ar = Ph b:b' = 17:1
Ar = o-tolyl b:b' = >20:1

**Tech. Note (1)**
**Ref. (1)**




**Tech. Note (2)**
**Ref. (2)**




**Tech. Note (3)**
**Ref. (3)**

References:

1. *J. Am. Chem. Soc.*, **2008**, *130,* 4978.
2. *J. Am. Chem. Soc.*, **2009**, *131,* 13210.
3. *J. Am. Chem. Soc.*, **2009**, *131,* 9135.

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**15-1512** NEW→ **(3aS,8aS)-(+)-4,4,8,8-Tetrakis(3,5-dimethylphenyl)tetrahydro-2,2-dimethyl-6-phenyl-1,3-dioxolo[4,5-e]dioxaphosphepin** 100mg 500mg

*[1169835-86-2]*

$C_{45}H_{49}O_4P$; FW: 684.84; white solid

Technical Note:

1. See 15-1511 (page 44).

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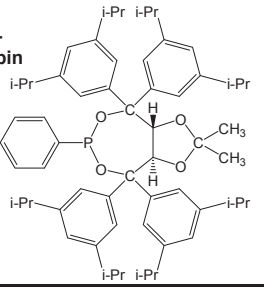
**15-1513** NEW→ **(3aR,8aR)-(-)-4,4,8,8-Tetrakis(3,5-di-i-propylphenyl)tetrahydro-2,2-dimethyl-6-phenyl-1,3-dioxolo[4,5-e]dioxaphosphepin** 100mg 500mg

*[1361146-90-8]*

$C_{61}H_{81}O_4P$; FW: 909.27; white pwdr.



Technical Note:

1. See 15-1511 (page 44).

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**15-1514** NEW→ **(3aS,8aS)-(+)-4,4,8,8-Tetrakis(3,5-di-i-propylphenyl)tetrahydro-2,2-dimethyl-6-phenyl-1,3-dioxolo[4,5-e]dioxaphosphepin** 100mg 500mg

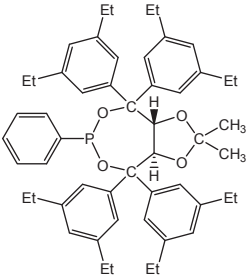
$C_{61}H_{81}O_4P$; FW: 909.27; white pwdr.

Technical Note:

1. See 15-1511 (page 44).

## PHOSPHORUS (Compounds) (cont.)

**15-1517** NEW→ **(3aR,8aR)-(-)-4,4,8,8-Tetrakis(3,5-diethylphenyl)tetrahydro-2,2-dimethyl-6-phenyl-1,3-dioxolo[4,5-e]dioxaphosphepin** *[1187446-93-0]*
$C_{53}H_{65}O_4P$; FW: 797.06;
white pwdr.



100mg
500mg

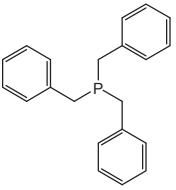
Technical Note:
1. See 15-1511 (page 44).

**15-1518** NEW→ **(3aS,8aS)-(+)-4,4,8,8-Tetrakis(3,5-diethylphenyl)tetrahydro-2,2-dimethyl-6-phenyl-1,3-dioxolo[4,5-e]dioxaphosphepin**
$C_5H_3H_{65}O_4P$; FW: 797.06; white pwdr.

100mg
500mg

Technical Note:
1. See 15-1511 (page 44).

**15-5730** NEW→ **Tribenzylphosphine, 98%** *[7650-89-7]*
$(C_6H_5CH_2)_3P$; FW: 304.37; white pwdr.
*air sensitive*



1g
5g

## PLATINUM (Compounds)

**78-1365** NEW→ **Tris(dibenzylideneacetone)diplatinum(0), min. 98%** *[63782-74-1]*
$(C_6H_5CH{=}CHCOCH{=}CHC_6H_5)_3Pt_2$; FW: 1093.03; purple-black solid
*air sensitive*

250mg
1g

Technical Note:
1. Useful starting material for the preparation of a variety of active platinum catalysts.

**78-1360** NEW→ **Tris(dibenzylideneacetone)platinum(0), min. 98%** *[11072-92-7]*
$(C_6H_5CH{=}CHCPCH{=}CHC_6H_5)_3Pt$; FW: 897.96; brown solid
*air sensitive*

250mg
1g

Technical Note:
1. Useful starting material for the preparation of a variety of active platinum catalysts.

## POTASSIUM (Compounds)

**19-1930** NEW→ **Potassium bis(fluorosulfonyl)imide, 99.5+%** *[14984-76-0]*
$K[N(SO_2F)_2]$; FW: 219.23; white pwdr.
*moisture sensitive*

1g
5g
25g

**76-3510** NEW→ **Potassium hexachloroosmate (IV), 99% (99.98+%-Os)**
*[16871-60-6]*
$K_2OsCl_6$; FW: 481.12; red to purple xtl.
*hygroscopic*

250mg
1g
5g

**76-4050** NEW→ HAZ **Potassium osmate(VI) dihydrate, 99% (99.98+%-Os)** *[10022-66-9]*
$K_2OsO_4{\cdot}2H_2O$; FW: 332.40 (368.43); purple pwdr.
*hygroscopic*

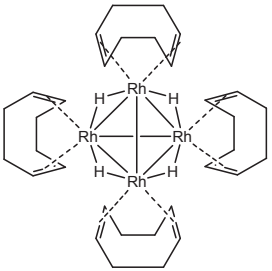
250mg
1g
5g

**19-1977** NEW→ **Potassium trifluoromethanesulfonimide, min. 97%** *[90076-67-8]*
$K(C_2F_6NO_4S_2)$; FW: 319.25; white pwdr.
*hygroscopic*

250mg
1g
5g

## RHODIUM (Compounds)

**45-2050** NEW→
**Tetrakis(1,5-cyclooctadiene) tetra-μ-hydridotetrarhodium, min. 98%** *[82660-97-7]*
$[RhH(C_8H_{12})]_4$; FW: 848.38; red xtl.
*air sensitive*




100mg
500mg

## RUTHENIUM (Compounds)

**98-4067** NEW→
**Bis(ethylcyclopentadienyl)ruthenium(II), 98% (99.9%-Ru), 44-0040, contained in high-temp. 50 ml Swagelok® cylinder (96-1071) for CVD/ALD** *[32992-96-4]*
$[(CH_3CH_2)C_5H_4]_2Ru$; FW: 287.37; pale yellow liq.; d. 1.3412
Note: Liquid ruthenium CVD precursor.

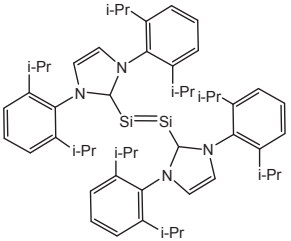
10g

## SILICON (Compounds)

**98-4037** NEW→ HAZ
**3-Aminopropyltriethoxysilane, 98%, 93-1402, contained in high- temp. 50 ml Swagelok® cylinder (96-1071) for CVD/ALD**
*[919-30-2]*
$H_2N(CH_2)_3Si(OC_2H_5)_3$; colorless liq.; b.p. 217°; f.p. 220°F; d. 0.943
*moisture sensitive*

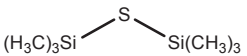
25g

**14-1050** NEW→
**1,2-Bis[1,3-bis(2,6-di-i-propylphenyl)imidazol-2-ylidene]disilene**
*[1070876-63-9]*
$C_{54}H_{72}N_4Si_2$; FW: 833.35; red xtl.
Note: Sold under license from the University of Georgia Research Foundation, Inc. for research purposes only.
US Patent 8,278,456.




50mg
250mg

**14-1015** NEW→ HAZ
**Bis(trimethylsilyl)sulfide, min. 98%**
*[3385-94-2]*
$(CH_3)_3SiSSi(CH_3)_3$; FW: 178.44; colorless liq.;
b.p. 164°; d. 0.846; STENCH
*(store cold)*




1g
5g
25g

## SODIUM (Compounds)

**11-1230** NEW→
**Sodium 2-ethylhexanoate, 60% in water** *[19766-89-3]*
$NaOOCH(C_2H_5)C_4H_9$; FW: 166.20; colorless liq.

50g
250g

**76-3520** NEW→
**Sodium hexachloroosmate((IV) hydrate (99.98+%-Os)** *[1307-81-9]*
$Na_2OsCl_6 \cdot XH_2O$; FW: 448.90; brown to black pwdr.
*hygroscopic*

500mg
2g

**11-0560** NEW→
**Sodium trifluoromethanesulfonimide, min. 97%** *[91742-21-1]*
$Na(C_2F_6NO_4S_2)$; FW: 303.14; white pwdr.
*hygroscopic*

250mg
1g
5g

## SULFUR (Compounds)

**14-1015** NEW→
**Bis(trimethylsilyl)sulfide, min. 98%**
*SEE SILICON SECTION (page 46)*

## TITANIUM (Compounds)

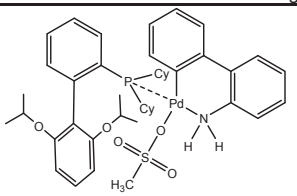
**98-4016** NEW→ HAZ
**Tetrakis(dimethylamino)titanium(IV), 99% TDMAT, 93-2240, contained in high-temp. 50 ml Swagelok® cylinder (96-1071) for CVD/ALD** *[3275-24-9]*
$Ti[N(CH_3)_2]_4$; FW: 224.20; yellow to orange liq.; b.p. 50°/0.5 mm; f.p. -22°F; d. 0.96
*moisture sensitive*
25g

## ZINC (Compounds)

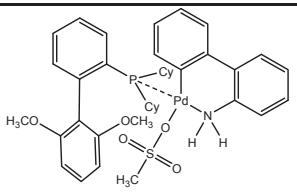
**98-4005** NEW→ HAZ NO UPS
**Diethylzinc, min. 95%, 93-3030, contained in high-temp. 50 ml Swagelok® cylinder (96-1071) for CVD/ALD** *[557-20-0]*
$Zn(C_2H_5)_2$; FW: 123.49; colorless liq.
*moisture sensitive, pyrophoric*
25g

## BUCHWALD PALLADACYCLE PRECATALYST KIT 2

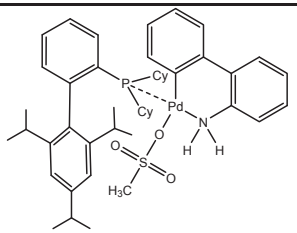
**96-5505** **Buchwald Palladacycle Precatalyst Kit 2**
NEW→
Components available for individual sale.
Contains the following:



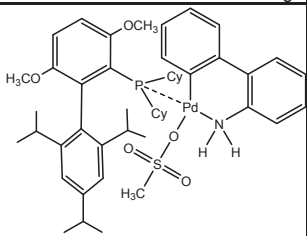
46-0314 250mg



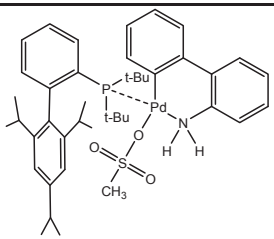
46-0318 250mg



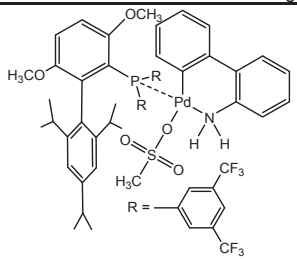
46-0320 250mg



46-0322 100mg



46-0323 250mg



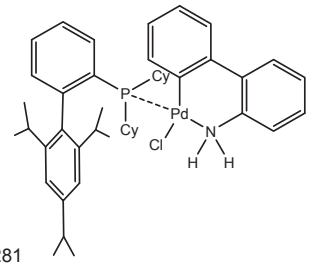
46-0340 100mg

Patents: US 6,395,916, US 6,307,087

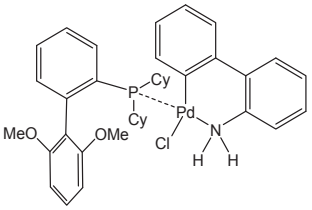
| | | |
|---|---|---|
| 46-0314 | Methanesulfonato(2-dicyclohexylphosphino-2',6'-di-i-propoxy-1,1'-biphenyl)(2-amino-1,1'-biphenyl-2-yl)palladium(II), min. 98% [RuPhos Palladacycle] | See page 39 |
| 46-0318 | Methanesulfonato(2-dicyclohexylphosphino-2',6'-dimethoxy-1,1'-biphenyl)(2'-amino-1,1'-biphenyl-2-yl)palladium(II) dichloromethane adduct min. 98% [SPhos Palladacycle] | See page 39 |
| 46-0320 | Methanesulfonato(2-dicyclohexylphosphino-2',4',6'-tri-i-propyl-1,1'-biphenyl)(2'-amino-1,1'-biphenyl-2-yl)palladium(II), min. 98% [XPhos Palladacycle] | See page 39 |
| 46-0322 | Methanesulfonato(2-dicyclohexylphosphino-3,6-dimethoxy-2',4',6'-tri-i-propyl-1,1'-biphenyl)(2'-amino-1,1'-biphenyl-2-yl)palladium(II), min. 98% [BrettPhos Palladacycle] | See page 39 |
| 46-0323 | Methanesulfonato(2-di-t-butylphosphino-2',4',6'-tri-i-propyl-1,1'-biphenyl)(2'-amino-1,1'-biphenyl-2-yl)palladium(II), min. 98% [t-BuXPhos Palladacycle] | See page 38 |
| 46-0340 | Methanesulfonato[2-bis(3,5-di(trifluoromethyl)phenyl-phosphino)-3,6-dimethoxy-2',4',6'-tri-i-propyl-1,1'-biphenyl](2'-amino-1,1'-biphenyl-2-yl) palladium(II), min. 98% [JackiePhos Palladacycle] | See page 38 |

## BUCHWALD PALLADACYCLE PRECATALYST KIT 3

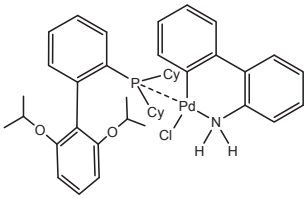
**96-5508** **Buchwald Palladacycle Precatalyst Kit 3**
NEW→
Components available for individual sale.
Contains the following:



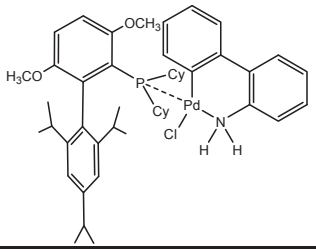

46-0281 250mg




46-0283 250mg




46-0286 250mg



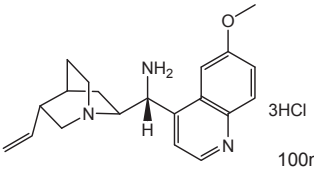

46-0292 100mg

Patents: US 6,395,916, US 6,307,087

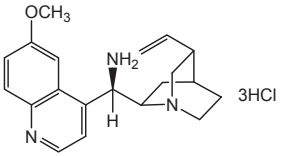
| | | |
|---|---|---|
| 46-0281 | Chloro(2-dicyclohexylphosphino-2',4',6'-tri-i-propyl-1,1'-biphenyl)(2'-amino-1,1'-biphenyl-2-yl) palladium(II), min. 98% [XPhos Palladacycle] *[1310584-14-5]* | See page 37 |
| 46-0283 | Chloro(2-dicyclohexylphosphino-2',6'-dimethoxy-1,1'-biphenyl)(2'-amino-1,1'-biphenyl-2-yl) palladium(II) min. 98% [SPhos Palladacycle] *[1375325-64-6]* | See page 37 |
| 46-0286 | Chloro(2-dicyclohexylphosphino-2',6'-di-i-propoxy-1,1'-biphenyl)(2-amino-1,1'-biphenyl-2-yl)palladium(II), min. 98% [RuPhos Palladacycle] *[1375325-68-0]* | See page 37 |
| 46-0292 | Chloro(2-dicyclohexylphosphino-3,6-dimethoxy-2',4',6'-tri-i-propyl-1,1'-biphenyl) (2'-amino-1,1'-biphenyl-2-yl) palladium(II), min. 98% [BrettPhos Palladacycle] | See page 37 |

## CINCHONA ALKALOID-DERIVED ORGANOCATALYST KIT – (ENANTIOPURE PRIMARY AMINES) FOR IMINIUM-ENAMIME ACTIVATION

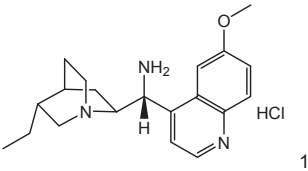
**96-1575** **Cinchona Alkaloid-Derived Organocatalyst Kit – (enantiopure primary amines) for Iminium-Enamime Activation**
NEW→
Components available for individual sale.
Contains the following:



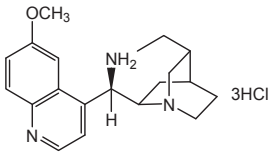

07-1710 100mg




07-1715 100mg




07-1718 100mg




07-1722 100mg

| | | |
|---|---|---|
| 07-1710 | (8α,9S)-6'-Methoxycinchonan-9-amine trihydrochloride, min. 90% *[1231763-32-8]* | See page 34 |
| 07-1715 | (9R)-6'-Methoxycinchonan-9-amine trihydrochloride, min. 90% | See page 35 |
| 07-1718 | (8α, 9S)-10,11-Dihydro-6'-methoxycinchonan-9-amine hydrochloride, min. 90% *[852913-53-2]* | See page 33 |
| 07-1722 | (9R)-10,11-Dihydro-6'-methoxycinchonan-9-amine trihydrochloride, min. 90% *[931098-92-9]* | See page 33 |

## GOLD NANOPARTICLES KIT (5nm-40nm DIAMETER, OD 1, STABILIZED SUSPENSION CITRATE BUFFER)

**96-1547** NEW→ **Gold Nanoparticles Kit (5nm-40nm diameter, OD 1, stabilized suspension citrate buffer)**
Components available for individual sale.
Contains the following:

| | | | |
|---|---|---|---|
| 79-0182 | Gold Nanoparticles (5 nm diameter, OD 1, stabilized suspension citrate buffer) | 25ml | See page 32 |
| 79-0210 | Gold Nanoparticles (10 nm diameter, OD 1, stabilized suspension citrate buffer) | 25ml | See page 32 |
| 79-0212 | Gold Nanoparticles (15 nm diameter, OD 1, stabilized suspension citrate buffer) | 25ml | See page 32 |
| 79-0214 | Gold Nanoparticles (20 nm diameter, OD 1, stabilized suspension citrate buffer) | 25ml | See page 32 |
| 79-0216 | Gold Nanoparticles (30 nm diameter, OD 1, stabilized suspension citrate buffer) | 25ml | See page 32 |
| 79-0218 | Gold Nanoparticles (40 nm diameter, OD 1, stabilized suspension citrate buffer) | 25ml | See page 32 |

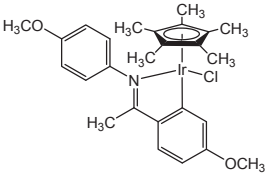
## GOLD NANOPARTICLES KIT, REACTANT-FREE (5nm-40nm DIAMETER, OD 1, SUSPENSION IN PHOSPHATE-BUFFERED SALINE

**96-1545** NEW→ **Gold Nanoparticles Kit, Reactant-Free (5nm-40nm diameter, OD 1, suspension in phosphate-buffered saline)**
Components available for individual sale.
Contains the following:

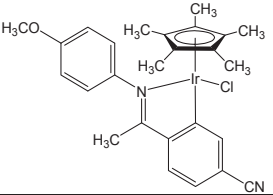
| | | | |
|---|---|---|---|
| 79-0180 | Gold Nanoparticles (5 nm diameter, OD 1, stabilized suspension in phosphate-buffered saline) reactant free | 25ml | See page 31 |
| 79-0184 | Gold Nanoparticles (10 nm diameter, OD 1, stabilized suspension in phosphate-buffered saline) reactant free | 25ml | See page 31 |
| 79-0186 | Gold Nanoparticles (15 nm diameter, OD 1, stabilized suspension in phosphate-buffered saline) reactant free | 25ml | See page 31 |
| 79-0188 | Gold Nanoparticles (20 nm diameter, OD 1, stabilized suspension in phosphate-buffered saline) reactant free | 25ml | See page 31 |
| 79-0190 | Gold Nanoparticles (30 nm diameter, OD 1, stabilized suspension in phosphate-buffered saline) reactant free | 25ml | See page 31 |
| 79-0192 | Gold Nanoparticles (40 nm diameter, OD 1, stabilized suspension in phosphate-buffered saline) reactant free | 25ml | See page 31 |

## IRIDICYCLE CATALYST KIT

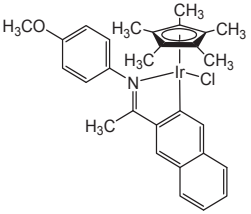
**96-3745** **Iridicycle Catalyst Kit**
NEW→
Components available for individual sale.
Contains the following:



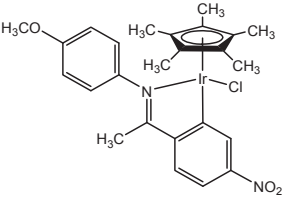

77-0418 100mg




77-0424 100mg




77-0428 100mg

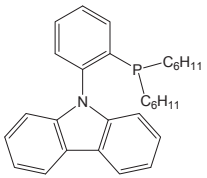



77-0430 100mg

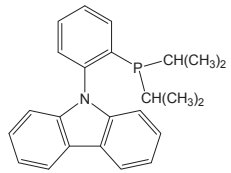
| | | |
|---|---|---|
| 77-0418 | Chloro(pentamethylcyclopentadienyl){5-methoxy-2-{1-[(4-methoxyphenyl) imino-kN]ethyl}phenyl-kC}iridium(III), 99% Iridicycle-MeO *[1258964-48-5]* | See page 24 |
| 77-0424 | Chloro(pentamethylcyclopentadienyl){5-cyano-2-{1-[(4-methoxyphenyl) imino-kN]ethyl}phenyl-kC}iridium(III), 99% Iridicycle-CN *[1258964-46-3]* | See page 24 |
| 77-0428 | Chloro(pentamethylcyclopentadienyl){2-{1-[(4-methoxyphenyl)imino-kN] ethyl}naphthyl-kC}iridium(III), 99% Iridicycle-Naphth | See page 24 |
| 77-0430 | Chloro(pentamethylcyclopentadienyl){5-nitro-2-{1-[(4-methoxyphenyl) imino-kN]ethyl}phenyl-kC}iridium(III), 99% Iridicycle-NO2 | See page 25 |

## PhenCar-Phos LIGAND KIT

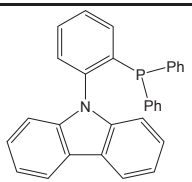
**96-3780** **PhenCar-Phos Ligand Kit**
NEW→
Components available for individual sale.
Contains the following:



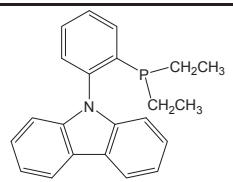

15-0445 250mg




15-0493 250mg



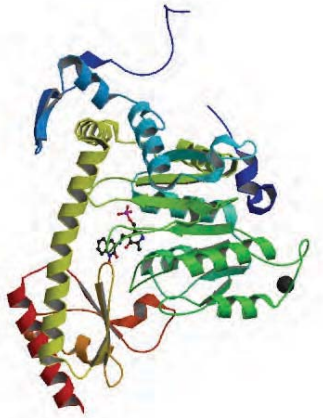

15-0498 250mg




15-0496 100mg

| | | |
|---|---|---|
| 15-0445 | 9-[2-(Dicyclohexylphosphino)phenyl]-9H-carbazole, min. 98% PhenCar-Phos *[1308652-64-3]* | See page 42 |
| 15-0493 | 9-[2-(Di-i-propylphosphino)phenyl]-9H-carbazole, min. 97% i-Pr PhenCar-Phos *[1308652-65-4]* | See page 43 |
| 15-0496 | 9-[2-(Diethylphosphino)phenyl]-9H-carbazole, min. 97% Et PhenCar-Phos *[1308652-66-5]* | See page 42 |
| 15-0498 | 9-[2-(Diphenylphosphino)phenyl]-9H-carbazole, min. 97% Ph PhenCar-Phos *[1308652-67-6]* | See page 43 |

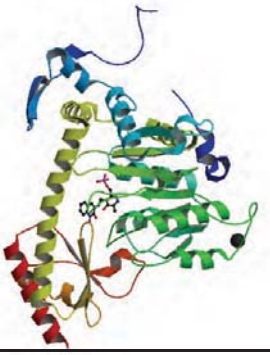
# *NEW*
# Biocatalyst Kits



## *Biocatalyst Kits* - ALCOHOL DEHYDROGENASE KIT

**96-4010** **Alcohol Dehydrogenase Kit (contains 35 variants)**

NEW→

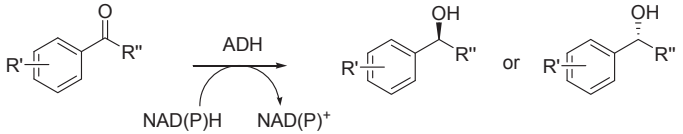


**Specific Alcohol Dehydrogenases in the Alcohol Dehydrogenases Kit (contains 35 variants):**
Alcohol Dehydrogenase A1 – A35

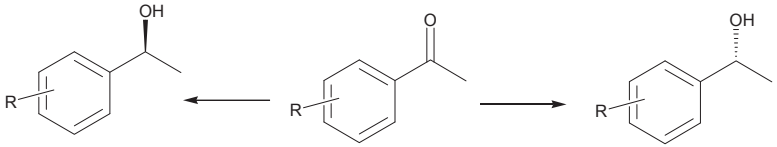
Note: Sold in collaboration with JM for research purposes only.

Technical Note:

1. Alcohol dehydrogenases with NADH/NADPH as cofactor catalyze the asymmetric reductions of a wide variety of carbonyl compounds, including aldehydes and aliphatic, aromatic and cyclic ketones, diketones, ketoacetals and ketoesters. The resultant chiral alcohols are produced with high enantioselectivity.




Careful selection of the dehydrogenase enzyme will enable the production of either the (R) or (S) enantiomer.




*(S)*-phenyl ethanol derivatives | Acetophenon derivatives | *(R)*-phenyl ethanol derivatives

**Contents:**
This kit contains 100 mg each of 35 variants of lyophilized alcohol dehydrogenases along with the necessary cofactor (50 mg NADH and 25 mg NADPH) and a phosphate buffer. Adequate buffer and NADH/NADPH are supplied in the kit for two reaction runs of each enzyme,

**Reaction Conditions:**
Reactions proceed with substrate concentrations up to 470 mM of ketone at a pH of 6.5 – 8.0 and a temperature in the range 25 – 37°C.

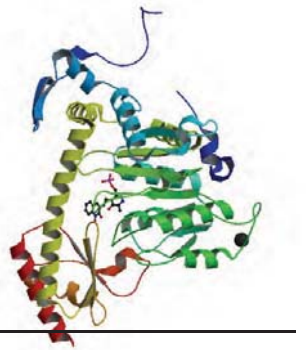
The enzymes exhibit a specific activity of 500 U/mg at 30°C with acetophenone, where 1 U corresponds to the amount of enzyme that reduces 1 µmol of acetophenone to phenylethanol per minute at pH 7.5 and 30°C.

The typical conversion for reactions with these alcohol dehydrogenases is 97%.

## *Biocatalyst Kits* - ALDEHYDE DEHYDROGENASE KIT

**96-4014** **Aldehyde Dehydrogenase Kit (contains 5 variants)**

NEW→

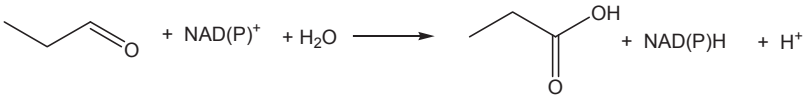


**Specific Aldehyde Dehydrogenases in the Aldehyde Dehydrogenase Kit (contains 5 variants):**
Aldehyde Dehydrogenase AD1-AD5

Note: Sold in collaboration with JM for research purposes only.

Technical Note:

1. Aldehyde dehydrogenases with $NAD^+$/ $NADP^+$ as cofactor catalyze the oxidation of aldehydes to carboxylic acids and have a broad substrate scope that includes both short and long chain aliphatic and aromatic aldehydes.




**Contents:**
This kit contains 100 mg each of 5 variants of lyophilized aldehyde dehydrogenases along with the necessary cofactor (50 mg NADH and 25 mg NADPH) and a phosphate buffer. Adequate buffer and NADH/NADPH are supplied in the kit for two reaction runs of each enzyme.

**Reaction Conditions:**
Reactions proceed with substrate concentrations up to 400 mM of aldehyde at a pH of 6.5 – 8.0 and a temperature in the range 25 – 37°C.

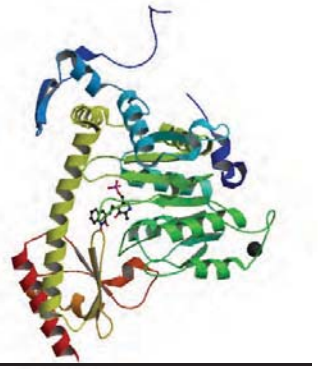
The enzymes exhibit an activity of 250 U/mg at 30°C with acetaldehyde, where 1 U corresponds to the amount of enzyme that oxidizes 1 µmol of acetaldehyde to acetic acid per minute at pH 7.5 and 30°C.

The typical conversion for reactions with these aldehyde dehydrogenases is 97%.

## *Biocatalyst Kits* - ALDEHYDE REDUCTASE KIT

**96-4016** **Aldehyde Reductase Kit (contains 10 variants)**

NEW→

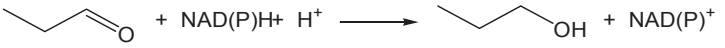


**Specific Aldehyde Reductases in the Aldehyde Reductase Kit (contains 10 variants):**
Aldehyde Reductase AR1 - AR10

Note: Sold in collaboration with JM for research purposes only.

Technical Note:

1. Aldehyde reductases with NADH/NADPH as cofactor catalyze the reduction of a wide range of aldehydes to the corresponding primary alcohols.




**Contents:**
This kit contains 100 mg each of 10 variants of lyophilized aldehyde reductases along with the necessary cofactor (50 mg NADH and 25 mg NADPH) and a phosphate buffer. Adequate buffer and NADH/NADPH are supplied in the kit for two reaction runs of each enzyme.

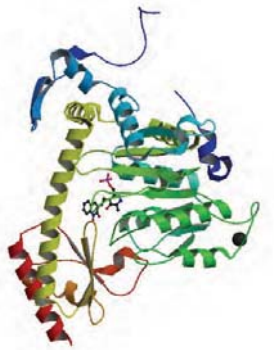
**Reaction Conditions:**
Reactions proceed with substrate concentrations up to 400 mM of aldehyde at a pH of 6.5 – 8.0 and a temperature in the range 25 – 37°C.

The enzymes exhibit a specific activity of 500 U/mg at 30°C with acetaldehyde, where 1 U corresponds to the amount of enzyme that reduces 1 µmol of acetaldehyde to ethanol per minute at pH 7.5 and 30°C.

The typical conversion for reactions with these aldehyde reductases is 97%.

## *Biocatalyst Kits* - COFACTOR RECYCLING ENZYMES KIT

**96-4012** **Cofactor Recycling Enzymes Kit (contains 8 cofactors)**
NEW→ Contains the following:



**Specific Enzymes in the**
**Cofactor Recycling Enzymes Kit (contains 8 cofactors):**

Malic decarboxylase variant A, NAD+-dependent, 20 U/mg

Malic decarboxylase variant B, NADP+-dependent, 30 U/mg
Glucose Dehydrogenase variant A, NADP+-dependent, both, 25 U/mg
Glucose Dehydrogenase variant B, NAD+-dependent, both, 15 U/mg

Phenylalanine Dehydrogenase, NAD+-dependent, 20 U/mg

Formate Dehydrogenase, NAD+-dependent, 0.5 U/mg

Alcohol Dehydrogenase A36, NADP+-dependent, 3 U/mg

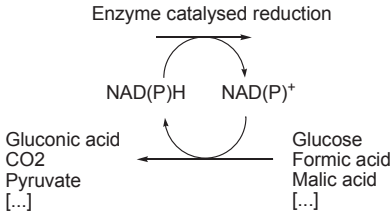
Isocitrate Dehydrogenase, NADP+-dependent, 3 U/mg

Note: Sold in collaboration with JM for research purposes only.

Technical Note:

1. The enzymes in the Cofactor Recycling Enzyme Kit are used for the reduction of $NAD^+$ or $NADP^+$, and are meant to be coupled with co-factor dependent enzymatic reductions.

For example:

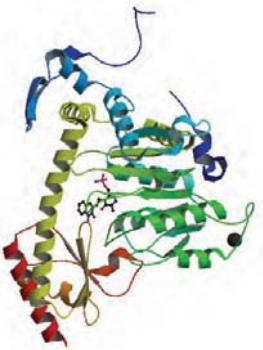



Adequate buffer and NADH/NADPH are supplied in the kit for two reaction runs of each enzyme.

## *Biocatalyst Kits* - ENE REDUCTASE KIT

**96-4024** **Ene Reductase Kit (contains 8 variants)**
NEW→ Contains the following:

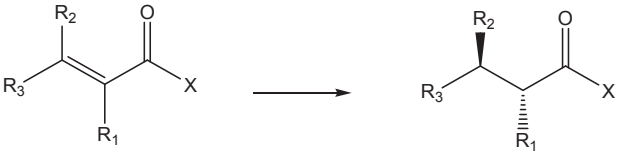
**Specific Ene Reductases in the**
**Ene Reductase Kit (contains 8 variants):**
Ene Reductase ENR1-ENR8



Note: Sold in collaboration with JM for research purposes only.

Technical Note:

1. Ene reductases with NADH/NADPH as cofactor catalyze the stereospecific reduction of alkenes, including non-activated enoates and activated olefins with electron withdrawing substituents, such as α,β-unsaturated ketones, aldehydes, nitriles, and nitro-derivatives, cyclic imides, and unsaturated carboxylic acids.




**Contents:**
This kit contains 100 mg each of 8 variants of lyophilized ene reductases along with the necessary cofactor (50 mg NADH and 25 mg NADPH) and a phosphate buffer. Adequate buffer and NADH/NADPH are supplied in the kit for two reaction runs of each enzyme.

**Reaction Conditions:**
Reactions proceed with substrate concentrations up to 200 g/L of alkene at a pH of 7.0 – 8.0 (optimum 7.0 – 7.5) and a temperature in the range 30 – 35°C.

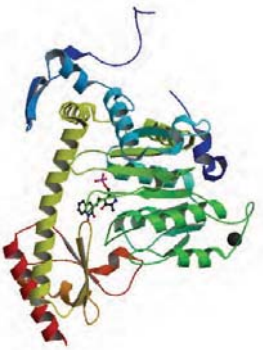
The enzymes exhibit a specific activity of up to 50 U/mg, where 1 U corresponds to the amount of enzyme that reduces 1 µmol of methyl vinyl ketone per minute at pH 7 and 25°C.

The typical conversion for reactions with these ene reductases is >95%.

## *Biocatalyst Kits* - ESTERASE KIT - LARGE

**96-4018** **Esterase Kit – Large (contains 50 variants)**
NEW→ Contains the following:

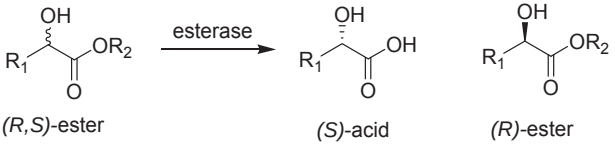
**Specific Esterases in the**
**Esterase Kit – Large (contains 50 variants):**
Esterase E1 – E50



Note: Sold in collaboration with JM for research purposes only.

Technical Note:

1. Esterases catalyze the enantioselective hydrolysis of esters to produce optically active alcohols or carboxylic acids, as well as the esterification of primary and secondary alcohols with short and long chain carboxylic acids and amino acids.


**Contents:**
This kit contains 100 mg each of 50 variants of lyophilized esterases along with the necessary a phosphate buffer. Adequate buffer is supplied in the kit for two reaction runs of each enzyme.

**Reaction Conditions:**
Reactions proceed with substrate concentrations up to 200 g/L of ester at a pH of 7.0 – 8.0 (optimum 8.0) and a temperature of 37°C.

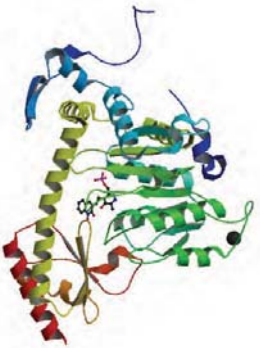
The enzymes exhibit a specific activity of up to 50 U/mg, where 1 U corresponds to the amount of enzyme that hydrolyzes 1 µmol of ethyl caproate per minute at pH 7.5 and 30°C.

The typical conversion for reactions with these esterases is 50%.

## *Biocatalyst Kits* - ESTERASE KIT - MEDIUM

**96-4020** **Esterase Kit – Medium (contains 30 variants)**

NEW→

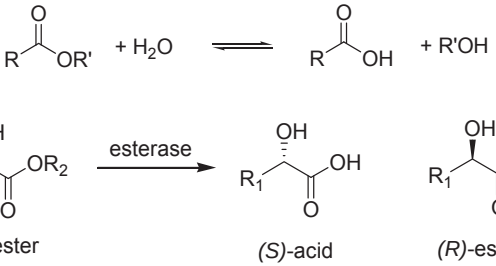


**Specific Esterases in the Esterase Kit – Medium (contains 30 variants):**
Esterase E1 – E30

Note: Sold in collaboration with JM for research purposes only.

Technical Note:

1. Esterases catalyze the enantioselective hydrolysis of esters to produce optically active alcohols or carboxylic acids, as well as the esterification of primary and secondary alcohols with short and long chain carboxylic acids and amino acids.




**Contents:**
This kit contains 100 mg each of 30 variants of lyophilized esterases along with a phosphate buffer. Adequate buffer is supplied in the kit for two reaction runs of each enzyme.

**Reaction Conditions:**
Reactions proceed with substrate concentrations up to 200 g/L of ester at a pH of 7.0 – 8.0 (optimum 8.0) and a temperature of 37°C.

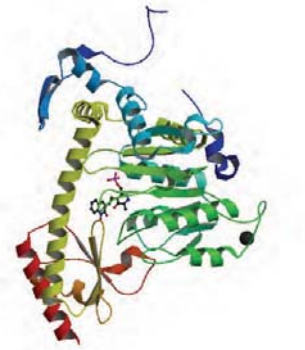
The enzymes exhibit a specific activity of up to 50 U/mg, where 1 U corresponds to the amount of enzyme that hydrolyzes 1 µmol of ethyl caproate per minute at pH 7.5 and 30°C.

The typical conversion for reactions with these esterases is 50%.

## *Biocatalyst Kits* - LIPASE KIT

**96-4022** **Lipase Kit (contains 12 variants)**

NEW→

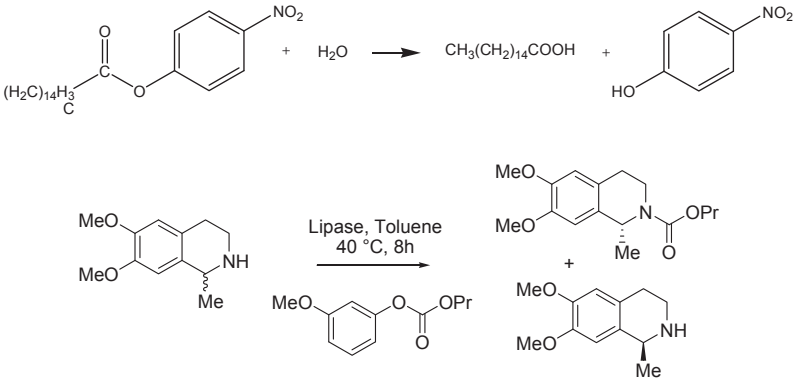


**Specific Lipases in the Lipase Kit (contains 12 variants):**
Lipase L1 – L12

Note: Sold in collaboration with JM for research purposes only.

Technical Note:

1. Lipases catalyze both the enantioselective hydrolysis and inter-esterification of the esters of primary and secondary alcohols. They also catalyze the enantioselective synthesis and hydrolysis of amides.




**Contents:**
This kit contains 100 mg each of 12 variants of lyophilized lipases along with a phosphate buffer. Adequate buffer is supplied in the kit for two reaction runs of each enzyme.

**Reaction Conditions:**
Reactions proceed with substrate concentrations up to 200 g/L of ester or alcohol at a pH of 7.0 – 8.0 (optimum 8.0) and a temperature of 37°C.

The enzymes exhibit an activity of up to 400 U/mg, where 1 U corresponds to the amount of enzyme that hydrolyzes 1 µmol of ethyl caproate per minute at pH 7.5 and 30°C. The highest activity is observed with long-chain substrates (C10-C18).

The typical conversion for reactions with these lipases is 50%.

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Since Catalog No. 1, Strem has reported the color and form of every product. These are good indicators of quality, especially for metal catalysts.

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Strem has manufactured the work-horse palladium catalyst “tetrakis” for many years. Various analytical techniques can be used to evaluate the quality of a catalyst and color can provide additional verification of quality. The tetrakis sample on the right demonstrates what can happen if it is not handled, packaged or stored under the right conditions. While the tan sample may pass several QC criteria, it would fail Strem’s color test. Color to the naked-eye can be good qualitative test of product quality!

**Sample with the “right” color.**

**Sample with the “wrong” color.**

Strem has many years of experience in the synthesis, isolation, handling, packaging and storage of this catalyst. If you need 25 grams or 25 kilograms, your tetrakis from Strem will be **bright yellow**.

**From grams**

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