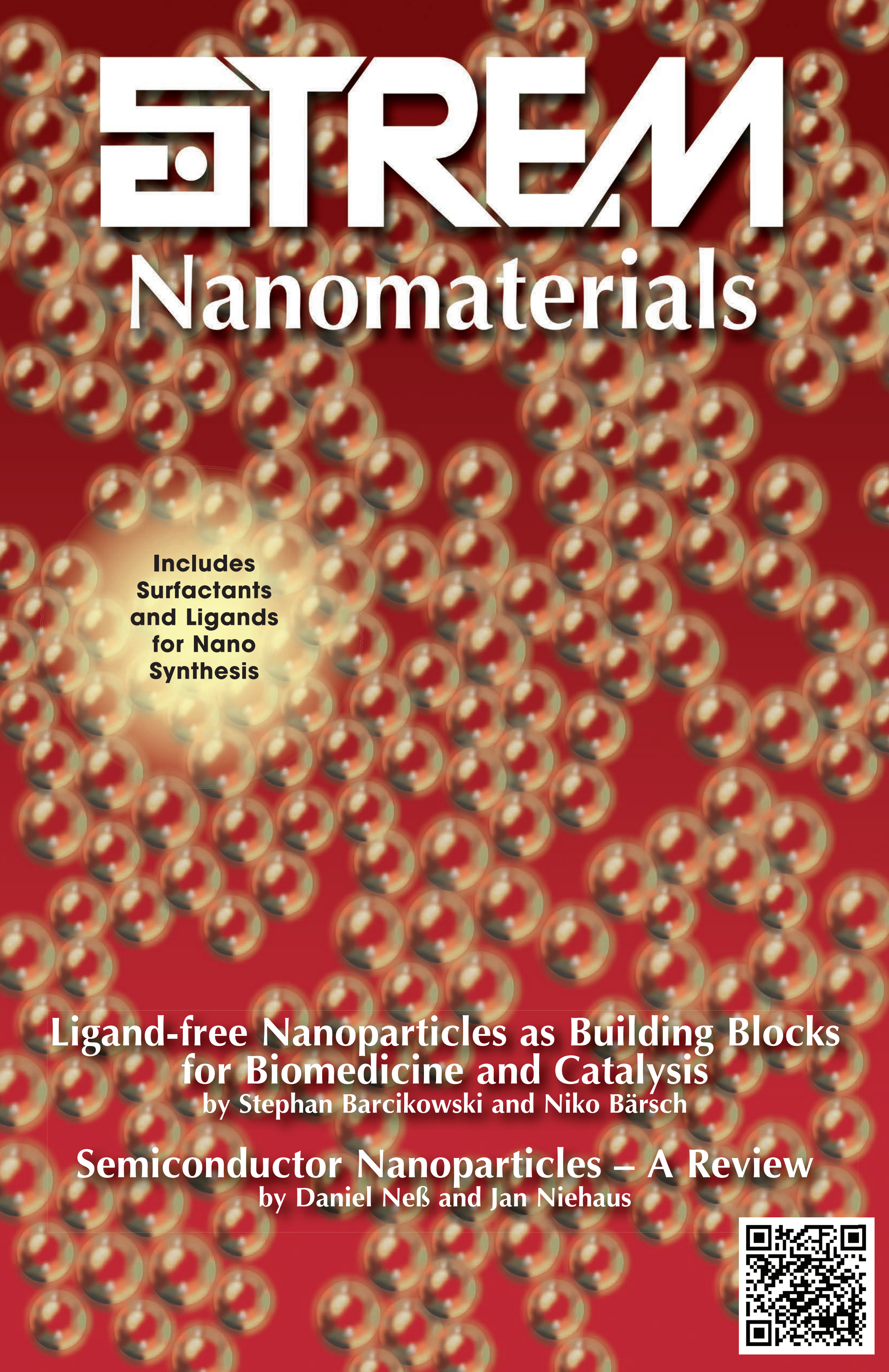

STREM Nanomaterials

Includes Surfactants and Ligands for Nano Synthesis

Ligand-free Nanoparticles as Building Blocks for Biomedicine and Catalysis

by Stephan Barcikowski and Niko Bärsch

Semiconductor Nanoparticles – A Review

by Daniel Neß and Jan Niehaus

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Strem Chemicals, Inc., established in 1964, is an employee-owned company that manufactures and markets specialty chemicals of high purity. Our clients include academic, industrial and government research and development laboratories as well as commercial scale businesses in the pharmaceutical, microelectronics, chemical and petrochemical industries.

As part of our ongoing commitment to quality, we have achieved ISO 9001 certification for the Quality Management System (QMS) at our corporate headquarters in Newburyport, Massachusetts.

Since 2004, we have manufactured a number of metal-based nanomaterials including clusters, colloids, particles and powders. These are produced by a variety of wet chemical means under patented processes. High-purity metal precursors as well as surfactants and ligands for nanomaterial synthesis are also available. In 2008, we expanded our US-based nanomaterials initiative and established a Nanochemistry Laboratory in Europe at the Institut de Science et d'Ingenierie Supramoleculaires at the University of Strasbourg, France. The European lab works closely with our U.S. headquarters. The goal of the European facility is to serve R&D groups worldwide with custom-made nanostructured materials.

At Strem, we also offer a wide variety of catalysts, ligands and CVD/ALD precursors. Quality is the most critical component of all of our products and services. Most products are of high purity, typically at 99%, while some are as high as 99.9999% metals purity. In addition, custom synthesis services are provided on a contract basis. For pharmaceutical applications, manufacturing is conducted under current Good Manufacturing Practices (cGMP) in FDA inspected kilo-lab suites. Complete documentation is available, including validation and stability studies. Active Drug Master Files (DMF's) are maintained in North America and Europe.

Please contact Strem for your custom nanomaterial requirements.

NANO 05/17

Glossary of Terms

$[\alpha]_D$	Specific rotation
AAS	Atomic Absorption Standard
ACS	Conforms to American Chemical Society specifications
air sensitive	Product may chemically react with atmospheric oxygen or carbon dioxide at ambient conditions. Handle and store under an inert atmosphere of nitrogen or argon.
amp	Ampouled
b.p.	Boiling point in °C at 760mm, unless otherwise noted
d.	Density
dec.	Decomposes
elec. gr.	Electronig Grade, suitable for electronic applications
f.p.	Flash point in °F
gran.	Granular
heat sensitive	Product may chemically degrade if stored for prolonged periods of time at ambient temperatures or higher. Store at 5°C or lower.
hydrate	Unspecified water content which may vary slightly from lot to lot
hygroscopic	Product may absorb water if exposed to the atmosphere for prolonged periods of time (dependent on humidity and temperature). Handle and store under an inert atmosphere of nitrogen or argon.
light sensitive	Product may chemically degrade if exposed to light
liq.	Liquid
m.p.	Melting point in °C
moisture sensitive	Product may chemically react with water. Handle and store under an inert atmosphere of nitrogen or argon.
NMR grade	Suitable as a Nuclear Magnetic Resonance reference standard
optical grade	For optical applications
pwdr.	Powder
primary standard	Used to prepare reference standards and standardize volumetric solutions
PURATREM	Product has a minimum purity of 99.99% (metals basis)
purified	A grade higher than technical, often used where there are no official standards
P. Vol.	Pore volume
pyrophoric	Product may spontaneously ignite if exposed to air at ambient conditions
reagent	High purity material, generally used in the laboratory for detecting, measuring, examining or analyzing other substances
REO	Rare Earth Oxides. Purity of a specific rare-earth metal expressed as a percentage of total rare-earths oxides.
SA	Surface area
store cold	Product should be stored at -18°C or 4°C, unless otherwise noted (see product details)
subl.	Sublimes
superconductor grade	A high purity, analyzed grade, suitable for preparing superconductors
tech. gr.	Technical grade for general industrial use
TLC	Suitable for Thin Layer Chromotography
v.p.	Vapor pressure mm of Hg
xtl.	Crystalline

About Purity

Chemical purity	is reported after the chemical name, e.g. Ruthenium carbonyl, 99%
Metals purity	is reported in parentheses with the respective element, e.g. Gallium (III) bromide, anhydrous, granular (99.999%-Ga) PURATREM where 100% minus the metal purity is equal to the maximum allowable percentage of trace metal impurity

Ligand-free Nanoparticles as Building Blocks for Biomedicine and Catalysis

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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.

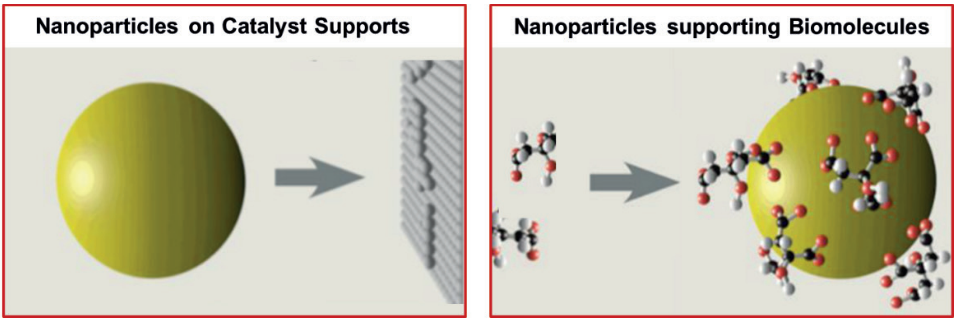

Fig. 1: *Clean (ligand-free) nanoparticles as building blocks in catalysis and biomedicine. Left: Deposition of colloidal nanoparticles (e.g. platinum, palladium, rhodium) on inorganic supports (e.g. TiOx, ZnO), driven and self-organized by free surface potential attraction. Right: Direct conjugation 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]

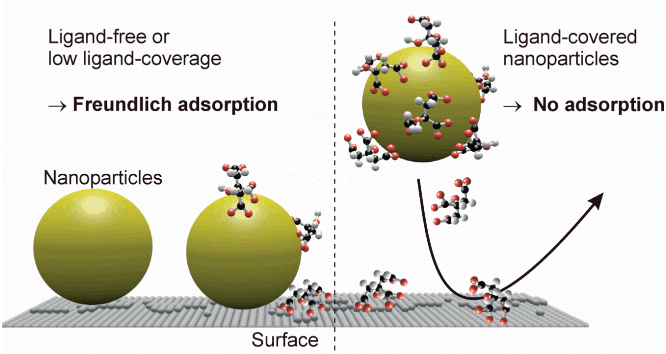

***Fig. 2:** Proposed mechanism of ligand-controlled nanoparticle adsorption.[10] Ligand-free colloids or low ligand loads allow efficient adsorption. In contrary, highly covered nanoparticles (in this case, a half monolayer of citrate) are blocked and do not adsorb efficiently. Reprinted with permission 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.

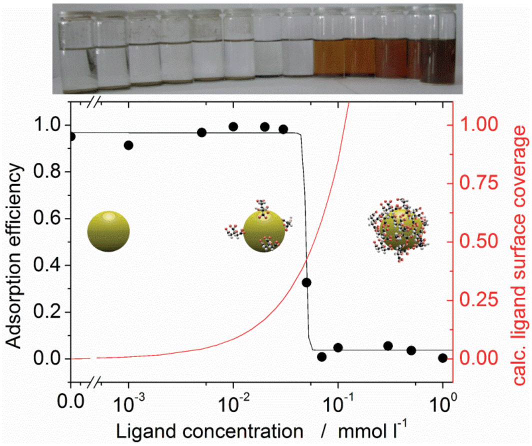

***Fig. 3:** Supported nanoparticles, synthesized by mixing the colloid with suspended microparticles[10]: adsorption efficiency and ligand surface coverage of pure nanoparticles as a function of ligand concentration. Top: samples containing the same nanoparticle mass concentration, stabilized with increasing 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)*.

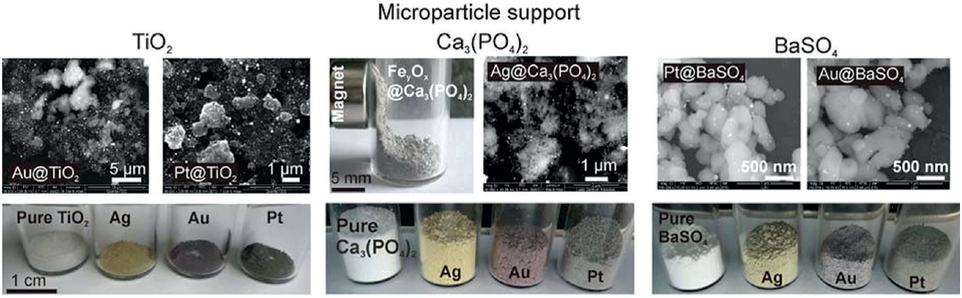

***Fig. 4:** Transferability of the method [10]: Combinations of adsorbate (ligand-free silver, gold, platinum nanoparticles) and adsorbent (TiO_2, $Ca_3(PO_4)_2$ and $BaSO_4$): SEM micrographs and sample images. Reprinted with permission from Langmuir, 2012, 28 (14), pp 6132–6140. Copyright 2012 American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

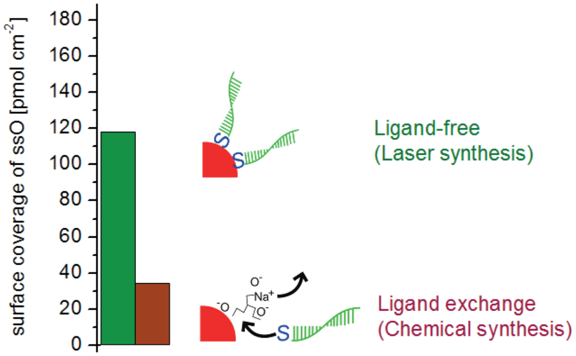

Fig. 5: *Grafting density (maximal surface coverage) on ligand-free and citrate-blocked gold nanoparticles.[9] Pure nanoparticle surface yields far higher particle load with biomolecules (here: thiolated oligonucleotide).*

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)*.

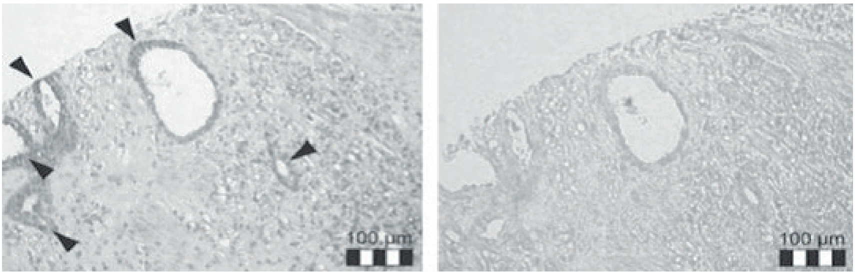

Fig. 6: *Specific labeling of antigen by laser-generated gold nanoparticles functionalized with an antigen-specific aptamer sequence.[12] (a) Detection and labeling of prostate-specific membrane antigen (PSMA) positive structures in prostate cancer tissue sections by immunohistochemical staining using 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)*.

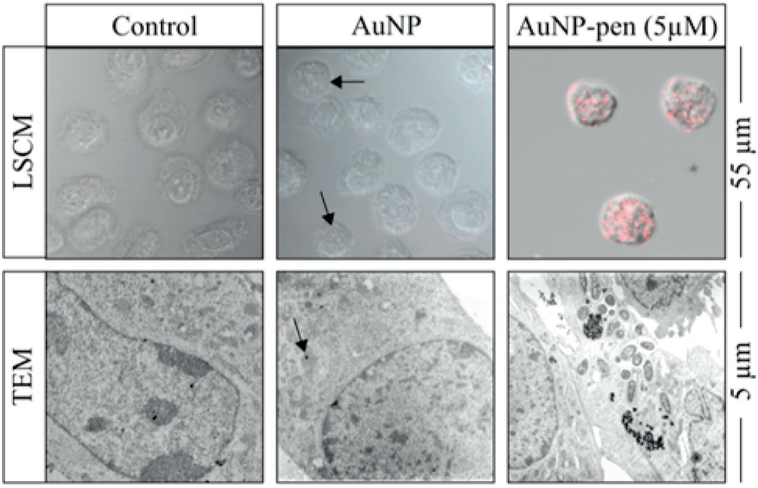

Fig. 7: Application of citrate-free gold nanoparticles with and without bioconjugation to a cell penetrating peptide.[9] Influence of penetratin conjugation on cellular gold nanoparticle internalization: Representative laser scanning confocal microscopy images (top, spots represent nanoparticle backscattering 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].

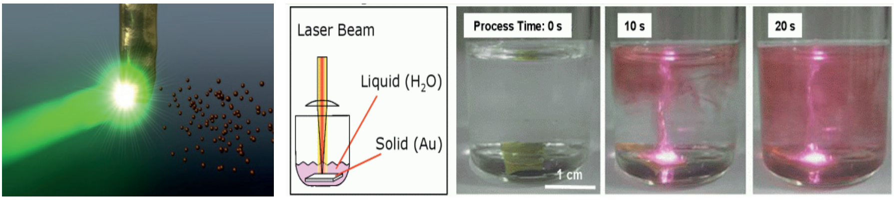

Fig. 8: Nanoparticle formation by laser ablation in liquids. Left: Sketch of wire ablation in liquid flow (by M. Langhammer).[3] Right: Sketch and photos taken during synthesis of ligand-free gold nanoparticles by laser ablation of solid gold in pure water.[15]

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 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.

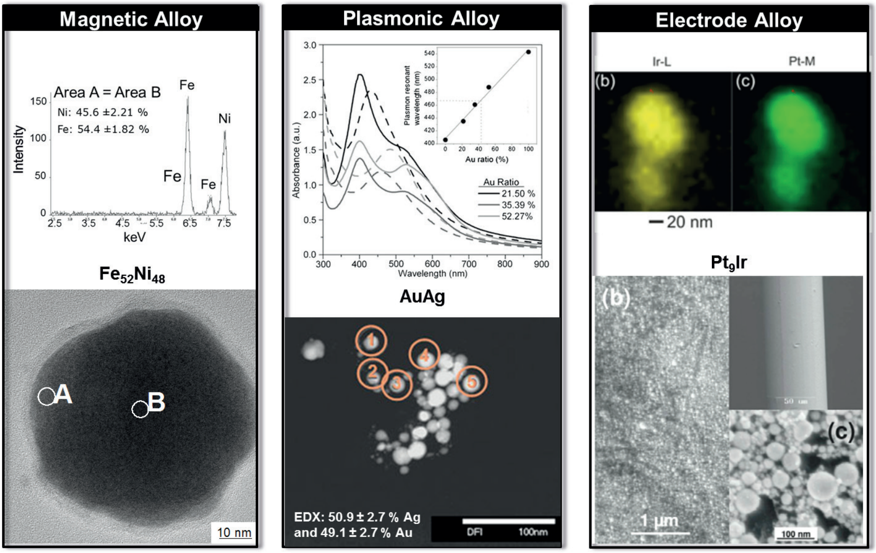

Fig. 9: Alloy nanoparticles, synthesized by laser ablation of solid alloy targets. Left: magnetic FeNi alloy nanoparticle, with elemental analysis data (EDX) and TEM picture.[18] Center: plasmonic AgAu nanoparticles with tunable peak wavelength (UV-vis spectrum) and insert with linear fit of nanoparticle 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 nanotechnology 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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Selection Matrix for Nanoparticles prepared using Laser Ablation

Strem offers a wide range of residue-free nanoparticles prepared via Laser Ablation by Particular GmbH.

Selection Matrix: pick element, size, concentration and solvent from available list

Element	Size	Concentration		Solvent			
		100mg/L	500mg/L	water	acetone	ethylene glycol	iso propanol
Ag	<20nm	x	x	x	100mg/L only		
	50-70nm	x			x		
Au	<20nm	x	x	x	100mg/L only		100mg/L only
	50-70nm	x					x
Pt	<20nm	x	x	x	100mg/L only		100mg/L only
	50-70nm	x			x		x
Pd	<20nm	x	x	x	100mg/L only		
	50-70nm	x			x		
Rh	<20nm	x	x	x	100mg/L only		100mg/L only
Ru	50-70nm	x			x		
Cu	<20nm	x			x		
Ti	<20nm	x			x		
	50-70nm	x				x	x

x = available

Stability: 12 months (2 months in water)

For full listing of products see following pages:

Cu (p27), Au (p30-31), Pd (p40), Pt (p43), Rh (p44), Ru (p44), Ag (p46), Ti (p46)

Semiconductor Nanoparticles – A Review

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The synthesis, characterization and applications of nanocrystals were the subject of extensive research in the past decade. Nanocrystals are crystalline objects that are less than 100 nm in at least two dimensions.[1] As a result, nanoparticles are made up of a small number of atoms and found in the transition region between atoms or molecules and infinitely large solids. This is why the electronic, optical, structural and thermodynamic properties can be a function of the crystallite dimensions and thus change with the radius.[2-7]

Since semiconductors are of widespread use in electronic and optical applications the possibility of being able to adjust the bandgap in semiconductor nanoparticles to the required specifications by varying the size alone and not the chemical composition makes them extremely interesting.

Size quantization effect:

It was observed for the first time in 1981 that in nanocrystalline $CuCl_2$ the band gap apparently increases with decreasing particle size.[8] Because the size of the band gap E_g determines the frequency at which the onset of absorption takes place, this effect can be observed with the naked eye in nanoparticles that have a band gap E_g of 1.8 – 3.1 eV and already start to absorb in the visible range. For example, it is possible to adjust the band gap of CdSe, which in the solid state is 1.7 eV, to up to 2.5 eV by reducing particle size.

Shown in Figure 1 are colloidal solutions of CdSe nanoparticles. The material in every cuvette has the same chemical composition. The samples differ only in their particle size from 3 nm (blue) to 7 nm (red).

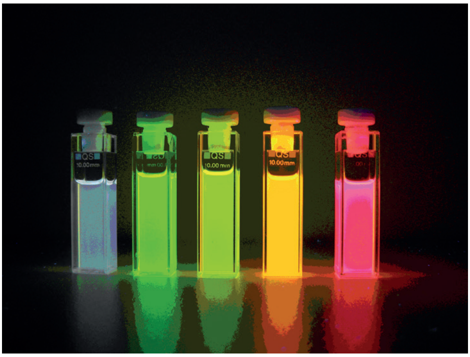

Fig. 1: *Colloidal solutions of CdSe nanoparticles of different size*

This phenomenon is called the size quantization effect. It is due to formation of two charge carriers confined to a finite area by excitation of an electron from the valence band to the conduction band during light absorption. This electron/hole pair, also termed an exciton, has a structure very similar to that of the hydrogen atom but usually a low binding energy due to the small effective masses and therefore a large radius. Accordingly, the binding energy of the hydrogen atom in the ground state is 13.51 eV and its radius 0.53 Å, while for CdSe the binding energy of the exciton is only 0.02 eV and the resulting radius 49 Å.[9]

The radius of the electron/hole pair is a decisive factor in the properties of nanoparticles. If absorption takes place in a nanocrystal that has dimensions similar to or even smaller than the Bohr radius of the exciton, then the exciton can no longer be in the ground state but must have a higher kinetic energy. Hence, the energy level of the exciton is influenced by the particle walls. This quantum mechanical effect described as a particle-in-a-box is stronger the smaller the dimensions of the particle, i.e. the box, becomes. The band gap E_g increases with decreasing particle size, and the onset of light absorption shifts to shorter wavelengths.[4]

The particle-in-a-box model allows calculation of the size quantization effect.[10,11] By assuming a box potential with infinitely high potential barriers and taking into consideration the Coulomb interaction between the electron and hole, the following expression, the so-called Brus equation, is obtained for the change in the band gap as a function of the particle radius[12]:

$$\Delta E = \frac{\pi^2 \cdot \hbar^2}{2 \cdot R^2}\left(\frac{1}{m_e} + \frac{1}{m_h}\right) - \frac{1.8 \cdot e^2}{4 \cdot \pi \cdot \varepsilon} \cdot \frac{1}{R}$$

Equation 1

where ΔE change in band gap E_g relative to macroscopic solid
R radius of nanoparticle
$m_{e/h}$ effective mass electron / hole
ε dielectric constant

The first term includes the relationship known from the particle-in-a-box that the energy is a function of $1/R^2$. The second term includes the Coulomb interaction. This equation can also be used very effectively to calculate the radius of semiconductor nanoparticles from the absorption spectrum alone.

However, because the values used to calculate the effective masses are derived from microcrystalline solids and the assumption of a box potential is a stark simplification as well, the calculated values agree approximately with the measured values only for larger particles. For smaller radiuses, very large deviations are obtained, making it necessary to perform significantly more precise and hence also more complicated calculations.

The change in electronic structure on transition from the atom to the macrocrystalline solid can be explained using the LCAO approach.[13-15] To understand the special properties of nanoparticles, however, it is better to start from the bulk solid and observe the changes in the electronic structure from there. This is shown in Figure 2.

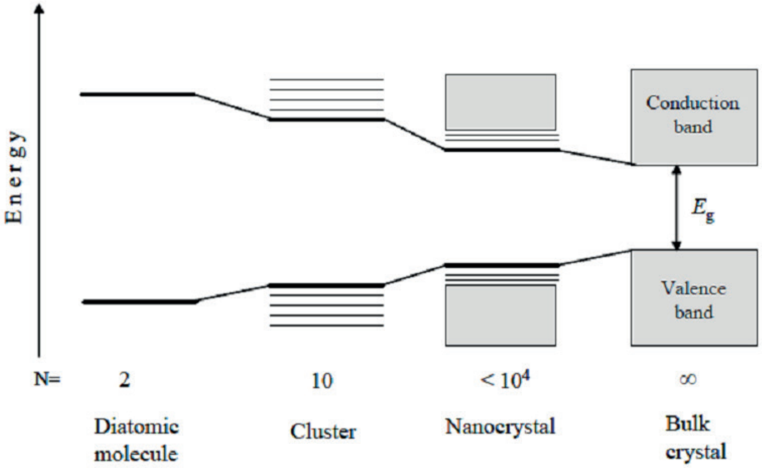

Fig. 2: *Diagram of the change in energy levels with increasing agglomeration number N*[16]

Separating the conduction and valence band edge in nanocrystals is influenced not only by the particle structure, the surface characteristics, lattice voltages and environment (solvent) but also by the size of the particles, the peak is usually very broad.

It is noticeable in Figure 3 that the emission spectrum, unlike the absorption spectrum, shows only one transition at 580 nm. This radiation-emitting transition always occurs from the bottom band edge of the conduction band to the top band edge of the valence band. All other transitions within the conduction band release only little energy and can therefore proceed radiationless. This energy is transferred to the lattice as vibrational energy.[18]

Furthermore, in this sample the emission maximum is shifted by 11 nm from the first absorption maximum. This phenomenon is called the Stokes shift and reduces the reabsorption of emitted light by semiconductor particles. This leads to an increase of the measured intensity. The Stokes shift is strongly affected by the particle shape. For dots 10 to 20 nm are common values.

Core particles:
The simplest semiconductor nanoparticles are composed of a homogeneous, crystalline core with a surface coating of stabilizing molecules to saturate free valences. These molecules, commonly called ligands, also prevent agglomeration of the particles and thus allow formation of a homogeneous dispersion of long-term stability. Typical examples of this substance class are CdSe, CdTe and PbS nanoparticles, with the CdSe-based particles covering the VIS (480 – 650 nm), the CdTe-based the NIR (600 - 800 nm) and the PbS-based the IR range (1000 – 1600 nm). All of these materials show the direct correlation of core size with band gap already described. Figure 4 presents the absorption and emission spectra of CdSe particles of different size.

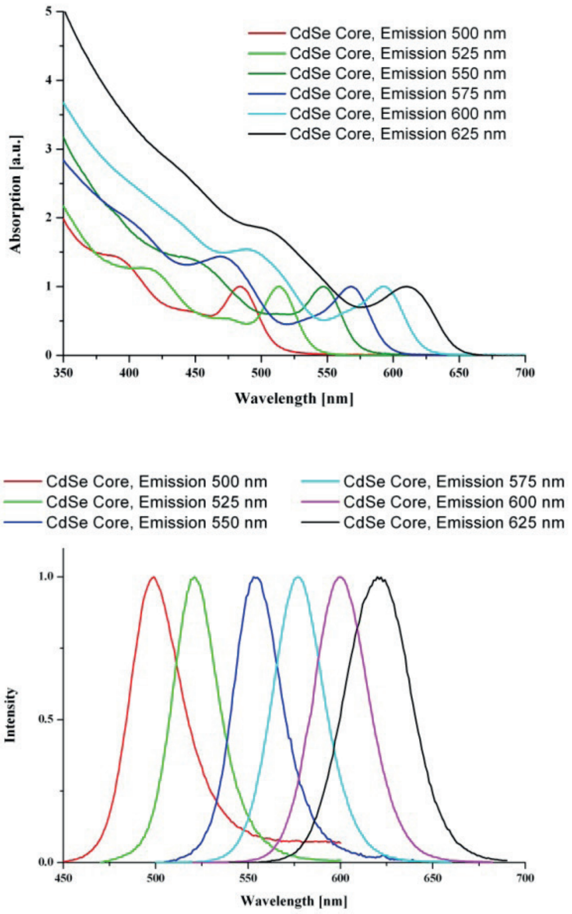

Fig. 4: *Absorption and emission spectra of CdSe nanoparticles 3 to 7 nm in size*

Because the structure of these particles results in direct contact of the free charge carriers with the particle surface after excitation, they usually are not very stable and have a quantum yield of less than 20%. These particles are, however, very suitable for applications where nanoparticles are to serve as the absorber material and not the fluorescent color. This is the case especially in the field of solar cell research.

Core/shell particles:

Core/shell particles have a conventional nanoparticle as the core on which a shell made up of another substance is grown. In the case of semiconductor nanoparticles, growth of an external coating passivates the valences on the core surface, thereby increasing the stability and quantum yield. [19,20]

The alignment of the valence and conduction bands of the core and shell material is very important for achieving the desired positive effect on the quantum yield. In a type I core/shell particle the valence band of the shell material is lower energetically than the valence band of the core and the conduction band of the shell material higher than the conduction band of the core material. Consequently, after generation of an exciton by absorption both charge carriers are confined in the core. Valences on the outside of the shell therefore do not affect the quantum yield and there is no change in the band gap. The quantum yield of these particles is significantly higher than that of core particles.

In type II core/shell particles the conduction band of the core material is lower than the conduction band of the core material. Whereas the hole remains confined to the core, the probability of finding the electrons in the shell material is high. Because of the spacial separation of both charge carriers hardly any recombination takes place and the quantum yield is very low. Moreover, the real band gap decreases and absorption and emission show a strong red shift.[19] Both possibilities can be seen in Figure 5.

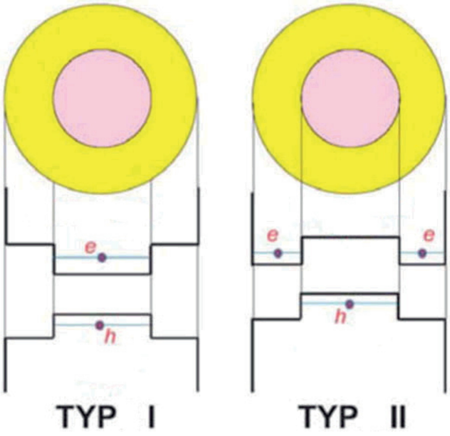

Fig. 5: *Type I and Type II core/shell particles*

Core/shell/shell particles:

For the shell to grow, the lattice constants of the core and shell materials should not be too different. For example, it would be preferable to grow a ZnS shell on a CdSe core because the band gap of zinc sulfide is much larger and confinement of the charge carriers in the core would be much greater. Both semiconductors have a zinc blende (sphalerite) crystal structure but the lattice constants differ by 12% (6.05Å for CdSe, 5.42 Å for ZnS). Therefore a CdS layer is grown between the core and outer shell that has a lattice constant lying between that of CdSe and ZnS.[21] This band gap alignments and lattice mismatches are shown in Figure 6:

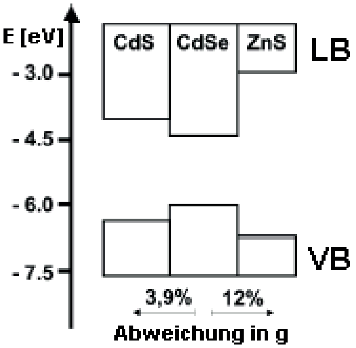

Fig. 6: *Alignment of bands in CdSe, CdS and ZnS*[21]

In such cases a core/shell/shell system is fabricated to maintain a small difference between lattice constants of adjacent materials. The result is primarily a higher stability than in conventional core/shell systems. These particles are therefore especially suited forery demanding applications such as an LED fluorescent material or transfer into aqueous media.

Organometallic synthesis:

Nanoparticles can be produced by many different methods that generally can be classified into two groups: “top down” and “bottom up”.

The “top down” methods are processes in which macroscopic material is broken down. This is accomplished primarily by crushing or laser fragmentation. The advantages of these production methods are relatively low costs and normally large production volumes. The disadvantages are a mostly large particle size distribution, production of particles with no stabilizing surface ligands and restriction to simple core structures. These disadvantages make these production methods for the most part unsuitable for semiconductor nanoparticles.

The ”bottom up“ methods are generally processes in which nanoparticles are built up from their atomic building blocks. These syntheses are often carried out in solution and enable a high degree of size control and stabilization of the particles. However, the normally smaller production volumes and significantly higher costs are disadvantages.[22]

The so-called hot injection method is a very common example of this type of synthesis. In this method a starting component is combined with surface ligands in a flask, heated to the nucleation temperature and then rapidly combined with the second component. This instantly results in nucleation and subsequent growth. By varying the reaction conditions it is possible to influence the size of the nanocrystals formed. Increasing the reaction time normally results in larger particles because more material can attach to the seeds. Another phenomenon known as Ostwald ripening additionally leads to an increase in the mean particle diameter.[25] Here larger particles grow while smaller particles, which are energetically less favored due to a large surface, dissolve. This is only possible, however, if the attachment step of the educts to a nanoparticle is reversible.[20,22,23] Presented in Figure 7 are TEM micrographs of three PbS samples after different reaction times.[24]

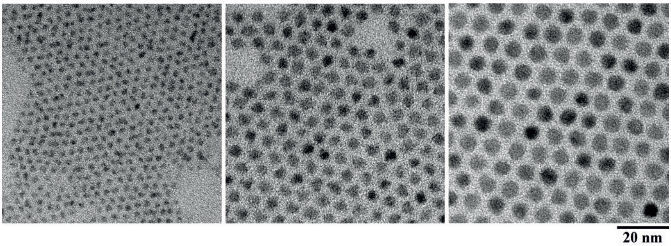

Fig. 7: *PbS nanoparticles with an emission of 1000 nm (left), 1400 nm (center) and 1600 nm (right)*[24]

The disadvantage of the “hot injection” method is a limited production volume because the amount injected cannot be increased indefinitely. Batch-to-batch reproducibility of the optical properties is also problematic because both nucleation and growth of the particles must take place consecutively in the same flask.

These problems can be avoided by synthesizing the particles in a continuous flow reactor. The system developed by CAN GmbH in collaboration with the University of Hamburg is based on the layout shown in Figure 8.

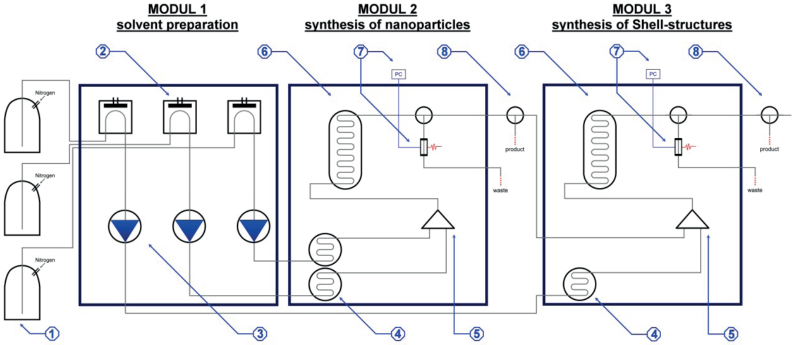

Fig. 8: *Layout of a continuous flow unit for synthesis of semiconductor nanoparticles*

This system is set up to emulate the “hot injection” process. The precursor solutions are stored under an inert atmosphere (1) and can be degassed before the reaction (2). Pulsation-free pumps (3) are used to pump the fluids to the reaction module 2. The solutions are heated separately to the nucleation temperature (4) before they are mixed in the micro fluidic mixing chamber (5). There nucleation of the particles takes place. Because the inner volume of the mixing chamber is only a few µL, the nuclei are immediately pumped to the growth oven (6). This oven is usually heated to a temperature slightly below that of the mixing chamber to prevent further nucleation. After the growth process, the solution is cooled to room temperature and absorption and emission spectra can be recorded with the in-situ spectroscopy unit (7). This separation of nucleation and the growth process leads to a high reproducibility of the particle properties. Figure 9 shows absorption and emission spectra of three different batches of quantum dots. Using “design of experiments” calculations it can be shown that the significance is lower than 0.1%. If further inorganic shells are needed, the solution containing the core particles leaving module 2 can be pumped to module 3, where further precursors can be added. For example, this can be used to produce CdSe/ZnS core/shell particles with enhanced optical properties.

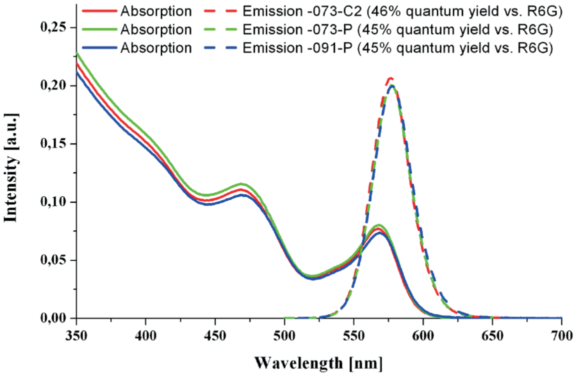

Fig. 9: *Absorption and emission spectra of three continuously produced CdSe samples*

Applications:

Because of their unique properties semiconductor nanoparticles have a broad range of applications. Adjustment of the band gap through variation of the particle size allows their use everywhere that absorption materials or fluorescent colors for specific wavelengths are required. Due to the inorganic nature of the particle semiconductor nanocrystals show a superior stability compared to common organic dyes. This comes to great effect especially in applications where the fluorescent component is exposed to heat, intensive light or aggressive chemicals like acids during the process. Because of the exchangeability of the surface ligands the same kind of nanoparticle can be used in different solvents or can be homogeneously incorporated in different materials without a change of the optical properties.[4]

Another advantage of the semiconductor quantum dots is the broad absorption of light which is shown in Figure 3 and 9. In contrast to organic dyes, which usually exhibit a quite narrow absorption range, the particles can be excited with nearly every wavelength shorter than the emission maximum. For example all CdSe samples shown in Figure 4 can be excited with radiation below 480 nm simultaneously. This can be very useful for all applications where different colors have to be detected in one sample, because this can be done with one excitation wavelength and one emission scan.

Core particles are especially well suited for use in solar cells. The nanoparticle is excited by the incident light and the resulting charge carriers are sucked through the cell. Further isolating shells would reduce the efficiency of the cells in this process taking place on the nanoparticle surface. The CdSe particles used should, however, be as large as possible in order to absorb as much of the solar radiation range as possible. Even more effective are PbS particles, which in addition to visible light convert also IR radiation up to 1000 nm into charge carriers.

Core/shell particles are characterized by a higher stability and quantum yield than core particles. This makes them a less expensive alternative to core/shell/shell particles, for example, as fluorescent material in LEDS or as fluorescent markers in nonpolar organic media.

Core/shell/shell particles have the highest fluorescence intensity and stability against environmental influences and should therefore be used for all demanding applications. They are especially well suited for transfer into aqueous media and hence for use in the biomedical field. After functionalization they can be used there, for example, in cancer research.

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NANOMATERIALS - ALUMINUM (Compounds)

13-1400	**Aluminum oxide nanopowder** *(1344-28-1)* Al_2O_3; FW: 101.96; white pwdr.	50g 250g

Specific Surface Area (BET): ≤275 m^2/g; **True Density:** 3.9 g/cc; **Crystallite Size**: Amorphous; **Mean Aggregate Size:**1.5 µm; **Average Pore Diameter:** 28Å; **Loss on Ignition:** 2.1%; **Total Pore Volume:** ≥0.15 cc/g; **Al Content (Based on Metal):** >99.8%; **Bulk Density:** 0.5 g/cc

NANOMATERIALS - CADMIUM (Compounds)

	CANdot® Quantum Dots *(1306-24-7)* *air sensitive, (store cold)* Note: Sold in collaboration with CAN for research purposes. Cadmium selenide CANdot® quantum dot (core) kit components. *See* page 51	5ml 25ml
48-1011 HAZ	**Cadmium selenide CANdot® quantum dot (CdSe core), 50umol/L in hexanes, 525nm peak emission** *(1306-24-7)* CdSe; orange liq.	
48-1017 HAZ	**Cadmium selenide CANdot® quantum dot (CdSe core), 50umol/L in hexanes, 550nm peak emission** *(1306-24-7)* CdSe; red-orange liq.	
48-1023 HAZ	**Cadmium selenide CANdot® quantum dot (CdSe core), 50umol/L in hexanes, 575nm peak emission** *(1306-24-7)* CdSe; red liq.	
48-1030 HAZ	**Cadmium selenide CANdot® quantum dot (CdSe core), 50umol/L in hexanes, 600nm peak emission** *(1306-24-7)* red liq.	
48-1035 HAZ	**Cadmium selenide CANdot® quantum dot (CdSe core), 50umol/L in hexanes, 625nm peak emission** *(1306-24-7)* red liq.	
96-0800	**Cadmium selenide CANdot® quantum dot (CdSe core) kit, 50umol/L in hexanes, 525-625nm peak emissions** *(1306-24-7)* *See* page 51	
	CANdot® Quantum Rods *(1306-24-7)* Store at 2-8°C in dark under inert atmosphere. Do not freeze. Stable for >12 months Note: Sold in collaboration with CAN for research purposes. Cadmium selenide/cadmium sulfide CANdot® quantum rod kit components. *See* page 51	0.5ml 2ml
48-1053 HAZ	**Cadmium selenide/cadmium sulfide CANdot® quantum rod (CdSe/CdS elongated core/shell), 5 mg/ml in hexanes, 560nm peak emission** *(1306-24-7)* CdSe/CdS; dispersed, yellow solution; *(store cold)*	
48-1056 HAZ	**Cadmium selenide/cadmium sulfide CANdot® quantum rod (CdSe/CdS elongated core/shell), 5 mg/ml in hexanes, 590nm peak emission** *(1306-24-7)* CdSe/CdS; dispersed, orange solution; *(store cold)*	
48-1059 HAZ	**Cadmium selenide/cadmium sulfide CANdot® quantum rod (CdSe/CdS elongated core/shell), 5 mg/ml in hexanes, 620nm peak emission** *(1306-24-7)* CdSe/CdS; dispersed, red solution; *(store cold)*	
96-0813	**Cadmium selenide/cadmium sulfide CANdot® quantum rod kit (CdSe/CdS elongated core/shell), 5 mg/ml in hexanes, 560nm, 590nm, 620nm peak emissions** *(1306-24-7)* *See* page 51	

NANOMATERIALS - CADMIUM (Compounds)

CdSe/ZnS - Solid Quantum Dots

10mg
50mg

Note: Each product below is a group of highly purified CdSe/ZnS quantum dots in solid form. The surface ligand is octadecylamine. The quantum dots can be dispersed in most organic solvents such as toluene, chloroform, and hexane. These quantum dots are specifically designed as emitters for optoelectronic applications such as LEDs.

48-1618 HAZ
Cadmium selenide/Zinc sulfide quantum dots in solid form, Emission peak: 520nm, FWHM <35nm, QY >50%
orange to red pwdr.

Technical Note:
1. See 48-1614 (page 19)

48-1620 HAZ
Cadmium selenide/Zinc sulfide quantum dots in solid form, Emission peak: 560nm, FWHM <35nm, QY >50%
orange pwdr.

Technical Note:
1. See 48-1614 (page 19)

48-1622 HAZ
Cadmium selenide/Zinc sulfide quantum dots in solid form, Emission peak: 600nm, FWHM <25nm, QY >50%
red pwdr.

Technical Note:
1. See 48-1614 (page 19)

48-1624 HAZ
Cadmium selenide/Zinc sulfide quantum dots in solid form, Emission peak: 630nm, FWHM <25nm, QY >50%
red pwdr.

Technical Note:
1. See 48-1614 (page 19)

CdSe/ZnS - Solid Quantum Dots with Amine in water

2nmole
10nmole

Note: A water-soluble CdS/ZnS or CdSSe/ZnS core/shell quantum dots with amphiphilic polymer and PEG coating. Reactive group is an amine.

48-1666 HAZ
Cadmium selenide/Zinc sulfide core/shell quantum dots with Amine in water Emission peak: 580 nm FWHM <25nm QY>50%
orange liq

Technical Note:
1. See 48-1658 (page 20)

48-1668 HAZ
Cadmium selenide/Zinc sulfide core/shell quantum dots with Amine in water Emission peak: 620 nm FWHM <25nm QY>50%
red liq.

Technical Note:
1. See 48-1658 (page 20)

CdSe/ZnS - Solid Quantum Dots with carboxylic acid in water

4nmole
20nmole

Note: A water-soluble CdSe/ZnS core/shell quantum dots with amphiphilic polymer and PEG coating. Reactive group is a carboxylic acid.

48-1638 HAZ
Cadmium selenide/Zinc sulfide core/shell quantum dots with carboxylic acid in water Emission peak: 580 nm FWHM <25nm QY>50%
orange liq.

Technical Note:
1. See 48-1630 (page 20)

48-1640 HAZ
Cadmium selenide/Zinc sulfide core/shell quantum dots with carboxylic acid in water Emission peak: 620 nm FWHM <25nm QY>50%
red liq.

Technical Note:
1. See 48-1630 (page 20)

CdSe/ZnS - Solid Quantum Dots with PEG in water

2nmole
10nmole

Note: A water-soluble CdSe/ZnS core/shell quantum dots with amphiphilic polymer and PEG coating. Reactive group is a carboxylic acid.

48-1652 HAZ
Cadmium selenide/Zinc sulfide core/shell quantum dots with PEG in water
Emission peak: 580 nm FWHM <25nm QY>50%
orange liq.

Technical Note:
1. See 48-1644 (page 21)

48-1654 HAZ
Cadmium selenide/Zinc sulfide core/shell quantum dots with PEG in water
Emission peak: 620 nm FWHM <25nm QY>50%
red liq.

Technical Note:
1. See 48-1644 (page 21)

CdSSe/ZnS - Solid Quantum Dots

10mg
50mg

Note: Group of highly purified CdSSe/ZnS quantum dots in solid form. The surface ligand is oleic acid. The quantum dots can be dispersed in most organic solvents such as toluene, chloroform, and hexane. These quantum dots are specifically designed as emitters for optoelectronic applications such as LEDs.

48-1602 HAZ
Cadmium sulfide selenide/Zinc sulfide quantum dots in solid form
Emission peak: 450nm, FWHM <35nm, QY >50%
green pwdr.

48-1604 HAZ
Cadmium sulfide selenide/Zinc sulfide quantum dots in solid form
Emission peak: 490nm, FWHM <35nm, QY >50%
green pwdr.

48-1606 HAZ
Cadmium sulfide selenide/Zinc sulfide quantum dots in solid form
Emission peak: 540nm, FWHM <35nm, QY >50%
orange pwdr.

48-1608 HAZ
Cadmium sulfide selenide/Zinc sulfide quantum dots in solid form
Emission peak: 600nm, FWHM <35nm, QY >50%
red pwdr.

48-1610 HAZ
Cadmium sulfide selenide/Zinc sulfide quantum dots in solid form
Emission peak: 630nm, FWHM <35nm, QY >50%
red pwdr.

48-1612 HAZ
Cadmium sulfide selenide/Zinc sulfide quantum dots in solid form
Emission peak: 665nm, FWHM <35nm, QY >50%
brown pwdr.

CdSSe/ZnS - Solid Quantum Dots with Amine in water

2nmole
10nmole

Note: A water-soluble CdS/ZnS or CdSSe/ZnS core/shell quantum dots with amphiphilic polymer and PEG coating. Reactive group is an amine.

48-1662 HAZ
Cadmium sulfide selenide/Zinc sulfide core/shell quantum dots with Amine in water
Emission peak: 490 nm FWHM <35nm QY>50%
yellow liq

Technical Note:
1. See 48-1658 (page 20)

48-1664 HAZ
Cadmium sulfide selenide/Zinc sulfide core/shell quantum dots with Amine in water
Emission peak: 525 nm FWHM <35nm QY>50%
yellow-green liq

Technical Note:
1. See 48-1658 (page 20)

48-1670 HAZ
Cadmium sulfide selenide/Zinc sulfide core/shell quantum dots with Amine in water
Emission peak: 665 nm FWHM <35nm QY>50%
dark red liq.

Technical Note:
1. See 48-1644 (page 21)

NANOMATERIALS - CADMIUM (Compounds)

CdSSe/ZnS - Solid Quantum Dots with carboxylic acid in water

4nmole
20nmole

Note: A water-soluble CdSSe/ZnS core/shell quantum dots with amphiphilic polymer and PEG coating. Reactive group is a carboxylic acid.

48-1634
HAZ
Cadmium sulfide selenide/Zinc sulfide core/shell quantum dots with carboxylic acid in water Emission peak: 490 nm FWHM <35nm QY>50%
yellow liq.

Technical Note:

1. See 48-1630 (page 20)

48-1636
HAZ
Cadmium sulfide selenide/Zinc sulfide core/shell quantum dots with carboxylic acid in water Emission peak: 525 nm FWHM <35nm QY>50%
yellow-green liq.

Technical Note:

1. See 48-1630 (page 20)

48-1642
HAZ
Cadmium sulfide selenide/Zinc sulfide core/shell quantum dots with carboxylic acid in water Emission peak: 665 nm FWHM <35nm QY>50%
dark red liq.

Technical Note:

1. See 48-1630 (page 20)

CdSSe/ZnS - Solid Quantum Dots with PEG in water

2nmole
10nmole

Note: A water-soluble CdSSe/ZnS core/shell quantum dots with amphiphilic polymer and PEG coating. Reactive group is a carboxylic acid.

48-1648
HAZ
Cadmium sulfide selenide/Zinc sulfide core/shell quantum dots with PEG in water Emission peak: 490 nm FWHM <35nm QY>50%
yellow liq.

Technical Note:

1. See 48-1644 (page 21)

48-1650
HAZ
Cadmium sulfide selenide/Zinc sulfide core/shell quantum dots with PEG in water Emission peak: 525 nm FWHM <35nm QY>50%
yellow-green liq.

Technical Note:

1. See 48-1644 (page 21)

48-1656
HAZ
Cadmium sulfide selenide/Zinc sulfide core/shell quantum dots with PEG in water Emission peak: 665 nm FWHM <35nm QY>50%
dark red liq.

Technical Note:

1. See 48-1644 (page 21)

CdS/ZnS - Solid Quantum Dots

10mg
50mg

48-1614
HAZ
Cadmium sulfide/Zinc sulfide quantum dots in solid form, Emission peak: 400nm, FWHM <35nm, QY >50%
white pwdr.

Technical Note:

1. Group of highly purified CdS/Zns or CdSe/ZnS quantum dots in solid form. The surface ligand is octadecylamine. The quantum dots can be dispersed in most organic solvents such as toluene, chloroform, and hexane. These quantum dots are specifically designed as emitters for optoelectronic applications such as LEDs.

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11. *Nano Letters,* **2007**, *7*, 3803

CdS/ZnS - Solid Quantum Dots

10mg
50mg

48-1616 HAZ **Cadmium sulfide/Zinc sulfide quantum dots in solid form, Emission peak: 420nm, FWHM <35nm, QY >50%**
yellow pwdr.

Technical Note:

1. See 48-1614 (page 19)

CdS/ZnS - Solid Quantum Dots with Amine in water

Note: A water-soluble CdS/ZnS or CdSSe/Zn core shell quantum dots with amphiphilic polymer and PEG coating. Reactive group is an amine.

2nmole
10nmole

48-1658 HAZ **Cadmium sulfide/Zinc sulfide core/shell quantum dots with Amine in water Emission peak: 400 nm FWHM <35nm QY>50%**
light yellow liq.

Technical Notes:

1. Zeta potential of QSA is from -20mV to +10 mV.
2. Organic layers consist of a monolayer of oleic acid/octadecylamine, a monolayer of amphiphilic polymer, and a monolayer of PEG.
3. Total thickness of organic layers is ~6 nm.
4. The hydrodynamic size of the QDs is about 12-14 nm larger than their inorganic core size as measured by TEM.
5. QSA is very stable in most buffer solutions in the pH range of 5-10, and can survive autoclaving processes of 121°C for 30 mins.
6. Amine density is low due to the long PEG chain.

References:

1. *Small,* **2009**, *5*, 235

48-1660 HAZ **Cadmium sulfide/Zinc sulfide core/shell quantum dots with Amine in water Emission peak: 450 nm FWHM <35nm QY>50%**
yellow liq.

Technical Note:

1. See 48-1658 (page 20)

CdS/ZnS - Solid Quantum Dots with carboxylic acid in water

Note: A water-soluble CdS/ZnS core/shell quantum dots with amphiphilic polymer and PEG coating. Reactive group is a carboxylic acid

4nmole
20nmole

48-1630 HAZ **Cadmium sulfide/Zinc sulfide core/shell quantum dots with carboxylic acid in water Emission peak: 400 nm FWHM <35nm QY>50%**
light yellow liq.

Technical Notes:

1. Zeta potential of QSA is from -30mV to -50 mV.
2. Organic layers consist of a monolayer of oleic acid/octadecylamine and a monolayer of amphiphilic polymer.
3. Total thickness of organic layers is ~4 nm.
4. The hydrodynamic size of the QDs is about 8-10 nm larger than their inorganic core size as measured by TEM.
5. QSH is very stable in most buffer solutions in the pH range of 5-10, and can survive autoclaving processes of 121°C for 30 mins.

References:

1. *Small,* **2009**, *5*, 235

48-1632 HAZ **Cadmium sulfide/Zinc sulfide core/shell quantum dots with carboxylic acid in water Emission peak: 450 nm FWHM <35nm QY>50%**
yellow liq.

Technical Note:

1. See 48-1630 (page 20)

NANOMATERIALS - CADMIUM (Compounds)

CdS/ZnS - Solid Quantum Dots with PEG in water

2nmole
10nmole

Note: A water-soluble alloy CdSSe/ZnS or CdSe/Zn core/shell quantum dots with amphiphilic polymer. Their reacttive group is a carboxylic acid.

48-1644 **Cadmium sulfide/Zinc sulfide core/shell quantum dots with PEG in water**
HAZ **Emission peak: 400 nm FWHM <35nm QY>50%**
light yellow liq.

Technical Notes:

1. Zeta potential of QSA is from -30mV to -50 mV.
2. Total thickness of organic layers is ~4 nm.
3. The organic layers consist of a monolayer of oleic acid/octadeylamine and s monolayer of amphiphilic polymer.
4. The hydrodynamic size of the quantum dots is about 8-10 nm larger than their inorganic core size as measured by TEM.
5. The product is stable in most buffer solutions in the pH range of 5-10.

48-1646 **Cadmium sulfide/Zinc sulfide core/shell quantum dots with PEG in water**
HAZ **Emission peak: 450 nm FWHM <35nm QY>50%**
yellow liq.

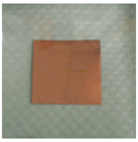
Technical Note:

1. See 48-1644 (page 21)

NANOMATERIALS - CARBON (Elemental Forms)

Carbon, Graphene

06-0274 **Graphene film, monolayer, on copper foil (1cm x 1cm)** *(1034343-98-0)* 2pcs
C; foil



100% coverage, >95% single atomic layer
Average grain (crystal/domain) size: >~100 micron
Average sheet resistance (on non-conductive substrate): 400 OPS (+/- 200 OPS)
Average transmission: T >96% (on transparent substrate, i.e. ~4% lower than substrate T)

06-0310 **Graphene film, monolayer, on Si/SiO$_2$ wafer (1cm x1cm), by CVD** 1pc
NEW *(1034343-98-0)*
C; FW: 12.011; wafer

06-0323 **Graphene oxide (0.8-1.2nm thick x 1-15 microns wide, made by the Staudenmaier Method)** 250mg
NEW 1g
black pwdr.; SA: 5-10 m^2/g

06-2545 **Graphene oxide (4mg/ml water dispersion)** *(1034343-98-0)* 50ml
NEW 250ml
yellow-brown liq. dispersion

Physical Properties:
Form: Dispersion of graphene oxide sheets; *Sheet dimension*: Variable; *Color*: Yellow-brown; *Dispersibility*: Polar solvents; *Solvent*: Water; *pH*: 2.2-2.5; *Concentration*: 4 mg/mL; *Monolayer content (measured in 0.5 mg/mL)*: >95%*
*Note: 4 mg/mL tends to agglomerate the GO flakes and dilution followed by slight sonication is required in order to obtain a higher percentage of monolayer flakes

Elemental Analysis: (sample preparation: 2g of 4 wt% GO in water were dried under vacuum at 60°C overnight)
Carbon: 49-56%; *Hydrogen*: 0-1%; *Nitrogen*: 0-1%; *Oxygen*: 41-50%; *Sulfur*: 0-2%

Quality Control:
Amount of residue on evaporation
pH control
Elemental analysis

Applications: Graphene/polymer composite materials, batteries, biomedical, solar cells, supercapacitors, support for metallic catalysts, low permeability materials, biosensors, multifunctional materials, graphene research

References:

1. *J. Mater. Chem.*, **2011**, *21*, 9762.
2. *Environ. Sci. Technol.*, **2013**, *47*, 3715.
3. *Phys. Chem. Chem. Phys.*, **2013**, *15*, 2321.

NANOMATERIALS - CARBON (Elemental Forms)

Carbon, Graphene

06-2550 NEW **Graphene oxide, reduced** 250mg
(1034343-98-0) 1g
black pwdr.

Physical Properties:
Form: powder; *Reduction method*: chemically reduced; *Sheet dimension*: variable; *Color*: black; *Solubility*: insoluble; *Dispersability*: <0.1 mg/mL in NMP, DMF, DMSO; *Humidity (Karl Fisher, TGA)*: 3.7-4.2%; *Electrical conductivity*: 666,7 S/m (measured in a 20 nm film thickness); *BET surface area*: 422.69 - 499.85 m^2/g; *Density*: 1.91 g/cm^3
Elemental Analysis: (sample preparation: 2g of 4 wt% GO in water were dried under vacuum at 60°C overnight)
Carbon: 77-87%; *Hydrogen*: 0-1%; *Nitrogen*: 0-1%; *Oxygen*: 13-22%; *Sulfur*: 0%
Quality Control: Elemental analysis
Applications: Batteries, biomedical, solar cells, supercapacitors, printable graphene electronics, graphene research
References:

1. *Nano Letters*, **2010**, *10*, 92.
2. *J. Phys. Chem. Lett.*, **2013**, *4*, 1347.

06-0318 NEW **Graphene powder (1-5 layers thick x 0.5-5 microns wide, surface area 650-750 m^2/g)** *(1034343-98-0)* 250mg 1g
C; FW: 12.011; black pwdr.

06-0313 NEW **Graphene powder (single layer, surface area 400-1000 m^2/g)** *(1034343-98-0)* 50mg
C; FW: 12.011; black pwdr.

06-2510 NEW **Monolayer Graphene on Cu (10 mm x 10 mm)** *(1034343-98-0)* 4pcs
C; FW: 12.011; wafer

Physical Properties:
Growth Method: Chemical Vapor Deposition (CVD synthesis); *Appearance*: Transparent; *Transparency*: >97%; *Coverage*: 98%; *Layers*: 1; *Thickness (theoretical)*: 0.345 nm; *FET Electron Mobility on Al_2O_3*: 2000 cm^2/Vs; *FET Electron Mobility on SiO_2*: 4000 cm^2/Vs; *Sheet Resistance on SiO_2/Si*: 410-490 Ω/sq (1 cm x 1 cm); *Grain size*: Up to 10 µm
Substrate Cu foil:
Thickness: 18 µm
Pretreated for easier bottom layer removal: Monolayer graphene on the back side of Copper is partially removed, but not completely, so an additional treatment like RIE is needed before transfer to eliminate the bottom layer totally
Applications: Flexible batteries, electronics, aerospace, MEMS and NEMS, Microactuators, Conductive coatings
Quality Control: Raman Spectroscopy and Optical Microscopy
References:

1. *J. Electrochem. Soc.*, **2012**, *159*, A752.
2. *J. Mater. Chem. A.*, **2013**, *1*, 3177.

06-2518 NEW **Monolayer Graphene on Cu (60 mm x 40 mm)** *(1034343-98-0)* 1pc
C; FW: 12.011; wafer

Physical Properties:
Growth Method: Chemical Vapor Deposition (CVD synthesis); *Appearance*: Transparent; *Transparency*: >97%; *Coverage*: 95%; *Layers*: 1; *Thickness (theoretical)*: 0.345 nm; *FET Electron Mobility on Al_2O_3*: 2000 cm^2/Vs; *FET Electron Mobility on SiO_2*: 4000 cm^2/Vs; *Sheet Resistance on SiO_2/Si*: 410-490 Ω/sq (1 cm x 1 cm); *Grain size*: Up to 10 µm
Substrate Cu foil:
Thickness: 18 µm
Pretreated for easier bottom layer removal: Monolayer graphene on the back side of Copper is partially removed, but not completely, so an additional treatment like RIE is needed before transfer to eliminate the bottom layer totally
Applications: Flexible batteries, electronics, aerospace, MEMS and NEMS, Microactuators, Conductive coatings
Quality control: Raman Spectroscopy and Optical Microscopy
References:

1. *J. Electrochem. Soc.*, **2012**, *159*, A752.
2. *J. Mater. Chem. A.*, **2013**, *1*, 3177.

NANOMATERIALS - CARBON (Elemental Forms)

Carbon, Graphene

06-2523 **Monolayer Graphene on Cu with PMMA coating (60mm x 40mm)** *(1034343-98-0)* 1pc

NEW

C; FW: 12.011; wafer

Physical Properties:

Growth Method: Chemical Vapor Deposition (CVD synthesis); *Appearance*: Transparent; *Transparency*: >97%; *Coverage*: 95%; *Layers*: 1; *Thickness (theoretical)*: 0.345 nm; *FET Electron Mobility on Al_2O_3*: 2000 cm^2/Vs; *FET Electron Mobility on SiO_2*: 4000 cm^2/Vs; *Sheet Resistance on SiO_2/Si*: 410-490 Ω/sq (1 cm x 1 cm); *Grain size*: Up to 10 µm

Substrate Cu foil:

Thickness: 18 µm

Pretreated for easier bottom layer removal: Monolayer graphene on the back side of Copper is partially removed, but not completely, so an additional treatment like RIE is needed before transfer to eliminate the bottom layer totally

Applications: Flexible batteries, electronics, aerospace, MEMS and NEMS, Microactuators, Conductive coatings

Quality control: Raman Spectroscopy and Optical Microscopy

References:

1. *J. Electrochem. Soc.*, **2012**, *159*, A752.
2. *J. Mater. Chem. A.*, **2013**, *1*, 3177.

06-2534 **Monolayer Graphene on SiO_2/Si (10mm x 10mm)** *(1034343-98-0)* 4pc

NEW

C; wafer

Physical Properties:

Growth Method: Chemical Vapor Deposition (CVD synthesis); *Appearance*: Transparent; *Transparency*: >97%; *Coverage*: 95%; *Layers*: 1; *Thickness (theoretical)*: 0.345 nm; *FET Electron Mobility on Al_2O_3*: 2000 cm^2/Vs; *FET Electron Mobility on SiO_2*: 4000 cm^2/Vs; *Sheet Resistance on SiO_2/Si*: 410-490 Ω/sq (1 cm x 1 cm); *Grain size*: Up to 10 µm

Substrate Cu foil:

Dry Oxide Thickness: 285-315 nm; *Type/Dopant*: P/Bor; *Orientation*: <100>; *Resistivity*: <0.005 Ohm·cm; *Thickness*: 505-545 µm; *Front surface*: single side polished; *Back surface*: etched; *Particles*: <10@0.3 µm

Applications: Flexible batteries, electronics, aerospace, MEMS and NEMS, Microactuators, Conductive coatings

Quality control: Raman Spectroscopy and Optical Microscopy

References:

1. *J. Electrochem. Soc.,* **2012**, *159*, A752
2. *J. Mater. Chem. A.,* **2013**, *1*, 3177

Graphene Nanoplatelets

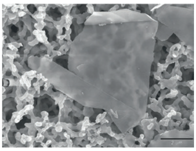
06-0222 **Graphene nanoplatelets, (2-10nm thick x ~5 microns wide)** *(1034343-98-0)* 5g
25g

NEW

C; black solid

06-0210 **Graphene nanoplatelets (6-8 nm thick x 5 microns wide)** *(1034343-98-0)* 25g, 100g

C; black platelet



Note: Graphene nanoplatelets are unique nanoparticles consisting of short stacks of graphene sheets having a platelet shape. They have an average thickness of approximately 6 - 8 nanometers and a typical surface area of 120 to 150 m^2/g. The unique size and platelet morphology of the graphene nanoplatelets makes these particles especially effective at providing barrier properties and improving mechanical properties, while their pure graphitic composition makes them excellent electrical and thermal conductors.

Technical Note:

1. For detailed note visit www.strem.com.

06-0215 **Graphene nanoplatelets (6-8 nm thick x 15 microns wide)** *(1034343-98-0)* 25g, 100g

C; black platelet

Technical Note:

1. See 06-0210 (page 23)

06-0220 **Graphene nanoplatelets (6-8 nm thick x 25 microns wide)** *(1034343-98-0)* 25g, 100g

C; black platelet

Technical Note:

1. See 06-0210 (page 23)

NANOMATERIALS - CARBON (Elemental Forms)

Graphene Nanoplatelets

06-0225	**Graphene nanoplatelets aggregates (sub-micron particles, surface area 300m^2/g)** *(1034343-98-0)* black platelet Note: Graphene nanoplatelet aggregates are unique nanoparticles consisting of short stacks of graphene sheets having a platelet shape. They typically consist of aggregates of sub-micron platelets that have a particle diameter of less than 2 microns and a typical particle thickness of a few nanometers, depending on the surface area. The unique size and platelet morphology of the graphene nanoplatelets makes these particles especially effective at providing barrier properties and improving mechanical properties, while their pure graphitic composition makes them excellent electrical and thermal conductors.	25g 100g

Technical Note:

1. For detailed note visit www.strem.com.

06-0230	**Graphene nanoplatelets aggregates (sub-micron particles, surface area 500m^2/g)** *(1034343-98-0)* black platelet	25g 100g

Technical Note:

1. See 06-0225 (page 24)

06-0235	**Graphene nanoplatelets aggregates (sub-micron particles, surface area 750m^2/g)** *(1034343-98-0)* black platelet	25g 100g

Technical Note:

1. See 06-0225 (page 24)

Graphene Quantum Dots *(1034343-98-0)*

light sensitive, (store cold)

Note: Particle diameter: <5 nm. Sold in collaboration with Dotz Nano Ltd. for research purposes only. Suggested use within 6 months of purchase. Do not freeze. Store in DARK.

06-0330 NEW	**Graphene Quantum Dots (GQDs), Aqua-Green Luminescent** *(1034343-98-0)* C; dark red-brown pwdr.	100mg

Suggested Applications:

Graphene quantum dots (GQDs), sheets of few-layered graphene and lateral dimensions smaller than 100nm possess strong quantum confinement and edge effects. Thus, they possess unique physical properties such as strong photoluminescence, which can be tailored for specific applications by controlling their size, shape, defects and functionality.

In contrast to classic QDs, such as metal or silicon quantum dots, GQDs are biocompatible, photostable and inherit superior thermal, electrical and mechanical properties from the graphene. These features can greatly contribute to various state-of-the-art applications: optical brighteners, taggants for security applications[1], bioimaging markers[2], fluorescent polymers[3], antibacterial[4], antibiofouling[5], and disinfection systems[6], heavy metals[7], humidity and pressure[8] sensors, batteries[9], flash memory devices[10], photovoltaic devices[11] and light-emitting diodes[12].

Item #	**Photoluminescence**			
	QY$^+$ *	**λ_{max} ***	**Max emission**	**FWHM ***
06-0330 / 06-0332	>17%	485 nm	525 nm	70 nm
06-0334 / 06-0336	>65%	350 nm	445 nm	65 nm
06-0338 / 06-0340	>25%	420 nm	490 nm	80 nm

Abbreviations

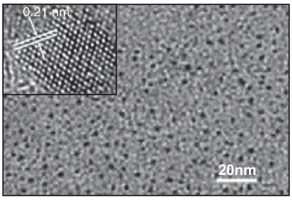
QY$^+$	Quantum Yield
λ_{max}	Maximum excitation wavelength
FWHM	Full width at half maximum

NANOMATERIALS - CARBON (Elemental Forms)

Graphene Quantum Dots *(1034343-98-0)*

light sensitive, (store cold)

Note: Particle diameter: <5 nm. Sold in collaboration with Dotz Nano Ltd. for research purposes only. Suggested use within 6 months of purchase. Do not freeze. Store in DARK.



References:

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2. http://onlinelibrary.wiley.com/doi/10.1002/ppsc.201400219/abstract
3. http://pubs.acs.org/doi/abs/10.1021/acsami.5b06057
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5. http://www.nature.com/articles/srep20142
6. http://pubs.acs.org/doi/abs/10.1021/nn501640q
7. http://www.sciencedirect.com/science/article/pii/S0013468615000468
8. http://pubs.acs.org/doi/abs/10.1021/nl4003443
9. http://pubs.acs.org/doi/abs/10.1021/nl504038s
10. http://iopscience.iop.org/article/10.1088/0957-4484/25/25/255203/meta
11. http://onlinelibrary.wiley.com/doi/10.1002/anie.200906291/abstract
12. http://link.springer.com/article/10.1007/s10853-012-7016-8

06-0332 **Graphene Quantum Dots (GQDs) in water, Aqua-Green Luminescent** *(1034343-98-0)* 100ml
NEW
C; cloudy orange liq.
Note: Concentration: 1 mg/ml.

Technical Note:

1. See 06-0330 (page 24)

06-0334 **Graphene Quantum Dots (GQDs), Blue Luminescent** *(1034343-98-0)* 100mg
NEW
C; dark brown pwdr.

Technical Note:

1. See 06-0330 (page 24)

06-0336 **Graphene Quantum Dots (GQDs) in water, Blue Luminescent** *(1034343-98-0)* 100ml
NEW
C; cloudy colorless liq.
Note: Concentration: 1 mg/ml.

Technical Note:

1. See 06-0330 (page 24)

06-0338 **Graphene Quantum Dots (GQDs), Cyan Luminescent** *(1034343-98-0)* 100mg
NEW
C; dark brown pwdr.

Technical Note:

1. See 06-0330 (page 24)

06-0340 **Graphene Quantum Dots (GQDs) in water, Cyan Luminescent** *(1034343-98-0)* 100ml
NEW
C; cloudy brown liq.
Note: Concentration: 1 mg/ml.

Technical Note:

1. See 06-0330 (page 24)

96-7410 **Graphene Quantum Dots (GQDs) Master Kit** *(1034343-98-0)*
See page 54

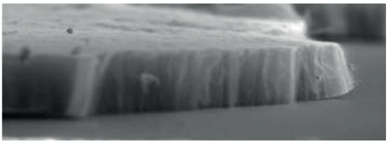
96-7425 **Graphene Quantum Dots (GQDs) Mini Kit (Powders)** *(1034343-98-0)*
See page 55

96-7420 **Graphene Quantum Dots in water (GQDs) Mini Kit (Liquids)** *(1034343-98-0)*
See page 55

NANOMATERIALS - CARBON (Elemental Forms)

Carbon Nanotubes

06-0440 **Carbon nanotube array, multi-walled, on quartz (diameter= 100nm, length=30 microns)** *(308068-56-6)* — 1pc
black microfibers; (diameter=100nm, length=30microns)



Technical Note:

1. Arrays grown on 10x10x1mm quartz substrate using a single source CVD process that yields vertically aligned MWNTs (< 1% catalyst impurity). Arrays are 30µm tall (± 3µm) and are composed of MWNTs 100nm in diameter (± 10nm). Arrays up to 150µm an be provided on request.

06-0470 **Carbon nanotubes, multi-walled (diameter = ~140nm, length = ~7 microns) (>90% nanotubes)** *(308068-56-6)* — 1g, 5g
black pwdr.

Technical Note:

1. Produced by chemical vapor deposition. Typical metal content is <0.1%.

06-0475 **Carbon nanotubes, multi-walled (diameter = ~20-25nm, length = ~1-5 microns) (85% nanotubes)** *(308068-56-6)* — 250mg, 1g
black pwdr.

Technical Note:

1. Produced by chemical vapor deposition. Typical metal content is 4-5 wt %.

06-0720 **Carbon nanotubes, multi-walled, arc-produced (diameter = 2-50nm, length = >2 microns) (55-65wt% nanotubes)** *(308068-56-6)* — 250mg, 1g
black pwdr.

Technical Note:

1. Arc-produced, multi-walled carbon nanotubes contain 55-65 wt% nanotubes and 35-45wt% graphite nanoparticles. The tubes have a diameter distribution of 2-50 nm, and a typical length of >2 microns (straight tubes). The chemical composition is 100% carbon, with no metal impurities. Because the nanotubes are grown at very high temperatures (3000-4000°C), the product contain far less defects than nanotubes produced by other methods. The nanotubes are stable in air up to 700°C.

06-0504 **Carbon nanotubes, multi-walled, as produced cathode deposit** *(308068-56-6)* — 1g, 5g
pieces

06-0505 **Carbon nanotubes, multi-walled, core material** *(308068-56-6)* — 1g, 5g
pieces (20-40% nanotubes)

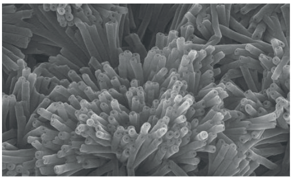
06-0506 **Carbon nanotubes, multi-walled, ground core material** *(308068-56-6)* — 250mg, 1g, 5g
-270 mesh pwder. (20-40%nanotubes)

06-0508 **Carbon nanotubes, single-walled/double-walled, 90%** *(308068-56-6)* — 250mg, 1g
pwdr.

Technical Note:

1. This product is nanotubes, single-walled/double-walled, 90%. The tubes are 1-2nm in diameter with lengths of 5-30 microns. Ash is <1.5wt%.

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



Technical Note:

1. 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 cycles.

NANOMATERIALS - CERIUM (Compounds)

58-0870 HAZ	**Mixed metal oxides of cerium(IV) [contains some Ce(III)] and iron(III) in octanoic acid and Kensol 50H (CEF-KE02)** rose-colored mixture; f.p. 230°; d. 0.84 *(store cold)* Note: Store at 5 to 25°C. Do not freeze. Suggested use within 12 months of receipt. Sold in collaboration with Cerion for research purposes only.	50g 250g

% Solids: 2.0 +/- 0.05%
Mean Number Weighted Particle Diameter: 2.5 ,Äì 5.0 nm (by Dynamic Light Scattering)
Polydispersity Index: <0.25
Chemical Composition (particles): 40-58 wt% CeO_2 balance Fe_2O_3% by XRF
Residual Water: <0.35 wt% (by Karl Fischer)
Flashpoint: 230ºF/110ºC

58-0865 HAZ	**Mixed metal oxides of cerium(IV) [contains some Ce(III)] and iron(III) in water at pH 4.75 +-0.25 (CEF-W420)** CeO2/Fe_2O_3; red-brown mixture; d. 1.23 *(store cold)* Note: Store at 5 to 25°C. Do not freeze. Suggested use within 12 months of receipt. Sold in collaboration with Cerion for research purposes only.	25g 100g 500g

pH: 4.75 +/- 0.25
Useable pH Range: 3 - 5
Mean Number Weighted Particle Diameter: <5 nm (by Dynamic Light Scattering)
Polydispersity Index: <0.25
Chemical Composition (particles by XRF): 40 - 58wt% CeO_2, balance Fe_2O_3

58-0850 HAZ	**Cerium(IV) oxide [contains some Ce(III)] in water at pH = 9.0 +-0.5 (CEO-W290)** *(1306-38-3)* CeO_2; FW: 172.12; <5.0 nm, reddish-brown mixture; d. 1.23 *(store cold)* Note: Store at 5 to 25°C. Do not freeze. Suggested use within 12 months of receipt. Sold in collaboration with Cerion for research purposes only.	25g 100g 500g

% Solids: 20.0 +/- 0.5%
pH: 9.0 +/- 0.5
Useable pH Range: 6-10
Mean Number Weighted Particle Diameter: 2.0 nm (by Dynamic Light Scattering)
Polydispersity Index: <0.25
Chemical Composition (particles): >99.5% CeO_2
Thermal Stability: Stable for >72 hours at 60ºC

58-0860 HAZ	**Cerium(IV) oxide [contains some Ce(III)] in water at pH = 3.5 +-0.75 (CEO-W320)** *(1306-38-3)* CeO_2; FW: 172.12; red-brown mixture; d. 1.23 *(store cold)* Note: Store at 5 to 25°C. Do not freeze. Suggested use within 12 months of receipt. Sold in collaboration with Cerion for research purposes only.	25g 100g 500g

% Solids: 20 +/- 0.5%
pH: 3.5 +/- 0.75
Useable pH Range: 2-5
Mean Number Weighted Particle Diameter: 3.0 nm (by Dynamic Light Scattering)
Polydispersity Index: <0.25
Chemical Composition (particles): >99.5% CeO_2

58-1400	**Cerium(IV) oxide nanopowder** *(1306-38-3)* CeO_2; FW: 172.12; yellow pwdr.	25g 100g

NANOMATERIALS - COPPER (Elemental Forms)

29-0092 HAZ	**Copper nanoparticles, pure, (<20nm) in acetone at 100mg/L (surfactant and reactant-free)** *(7440-50-8)* brown liq. Note: Made to order. Manufactured by laser ablation. Store at room temperature (up to 25°C). Do not freeze. Shelf life 12 months. Sold in collaboration with Particular® for research purposes only.	25ml 100ml

NANOMATERIALS - GOLD (Elemental Forms)

Gold AURO*lite*™ Heterogeneous Catalysts

10g
50g

(store cold)

Note: Sold in collaboration with Project AuTEK for research purposes. Reverse engineering and product modification prohibited. Only open before use, store cold in dark. See web for more details.

79-0160 **Gold 1% on aluminum oxide extrudates (AUROlite™ Au/Al_2O_3)** *(7440-57-5)*
dark purple extrudates ~1.2mm dia. x 5mm (avg)

Technical Note:

1. Useful product for the catalytic oxidation of a variety of substrates including carbon monoxide, aldehydes, alkenes, methane and ethanol. Average gold crystallite size is ~2-3nm.

Analysis: Au 1 wt% ± 0.1%; Al_2O_3 98 wt%; Na+, Cl- <1500ppm
Bulk density: 0.6–0.8 g/ml

References:

1. *J. Catal.,* **2007**, *252*, 119
2. *J. Catal.,* **2008**, *260*, 86
3. *Green Chem.,* **2008**, *10*, 168
4. *Gold Bulletin,* **2008**, *41*, 296
5. *Appl. Catal. B.,* **2013**, *132*, 195
6. *Chem. Rev.,* **2012**, *112*, 4469

79-0165 **Gold 1% on titanium dioxide extrudates (AUROlite™ Au/TiO_2)** *(7440-57-5)*
dark purple/gray extrudates 1.5mm dia. x 5mm (avg)

Technical Note:

1. Useful product for the catalytic oxidation of a variety of substrates including carbon monoxide, aldehydes, alkenes, methane and ethanol. Average gold crystallite size is ~2-3nm.

Analysis: Au 1 wt% ± 0.1%; TiO_2 98 wt%; Na+, Cl- <1500ppm
Bulk density: 0.85–0.95 g/ml

References:

1. *J.Catal.,* **2007**, *252*, 119
2. *J.Catal.,* **2008**, *260*, 86
3. *Green Chem.,* **2008**, *10*, 168
4. *Gold Bulletin,* **2008**, *41*, 296
5. *Appl. Catal. B.,* **2013**, *132*, 195
6. *Chem. Rev.,* **2012**, *112*, 4469

79-0170 **Gold 1% on zinc oxide granulate (AUROlite™ Au/ZnO)** *(7440-57-5)*
dark purple granulate 1-2mm dia.
Note: PCT WO2005115612.

Technical Note:

1. Useful product for the catalytic oxidation of a variety of substrates including carbon monoxide, aldehydes, alkenes, methane and ethanol. Average gold crystallite size is ~2-3nm.

Analysis: Au 1 wt% ± 0.1%; ZnO 88 wt% (contains Al2O3); Na+, Cl- <1500ppm
Bulk density: 1-1.2 g/ml

References:

1. *J.Catal.,* **2007**, *252*, 119
2. *J.Catal.,* **2008**, *260*, 86
3. *Green Chem.,* **2008**, *10*, 168
4. *Gold Bulletin,* **2008**, *41*, 296
5. *Appl. Catal. B.,* **2013**, *132*, 195
6. *Chem. Rev.,* **2012**, *112*, 4469

Gold - Colloid

250mg
1g

Note: Made to order. Long term shelf life not established.

79-0080 **Gold/tetra-n-octylammonium chloride colloid** *(7440-57-5)*
Au/$(C_8H_{17})_4NCl$; 2.6 nm ±1.1 nm; brown-orange soli
(store cold)

Technical Note:

1. Soluble in toluene. Precursor for CO-oxidation catalysts.

NANOMATERIALS - GOLD (Elemental Forms)

Gold Nanochain

25ml

79-0134 **Gold Nanochain [AuNP-Chain: 1-2 µm (Gum Arabic)]** *(7440-57-5)*
maroon-red liq.
(store cold)

Properties: Water soluble, stable at pH 7.0; **Chain length:**1-2 µm; **Shape**: Chain; **UV-Vis (nm):**760 nm; **Stability**: Stable for 90 days; Size: 7 ±3mm

Ordering Specifications: Minimum 2 weeks required to process the order.

Supplied in aqueous solutions. Contains gum arabic stabilizer. Suitable for spin coating, self-assembly and monolayer formation. Sensor design, nanoelectronics and MEMS applications.

Gold Nanoparticles - Solid and Functionalized

79-0235 **Gold nanoparticles powder, 6nm, organic solvent-dispersible** *(7440-57-5)* — 5mg, 25mg
black pwdr.
Note: 79-0235 is an organic soluble solid. The surface ligand is dodecanethiol. The hydrodynamic size of the nanoparticles is about 8-10nm larger than their inorganic core size measured by TEM.

79-0238 **Gold nanoparticles with amine surface functional group, 6nm, in water** *(7440-57-5)* — 5mg, 25mg
dark red liq.
Note: 79-0238 is a group of water-soluble gold nanoparticles with amphiphilic polymer and PEG coating. The reactive group is an amine.

Technical Notes:

1. Zeta potential of 79-0238 is from -10mV to 0 mV.
2. Total thickness of organic layers is ~6 nm.
3. The organic layers consist of a monolayer of dodecanethiol, a monolayer of amphipilic polymer and a monolayer of PEG.
4. The hydrodynamic size of the nanocrystals is about 12-14 nm larger than their inorganic core size as measured by TEM.
5. 79-0238 is very stable in buffer solutions in the pH range of 4-10 and can survive the autoclaving (121°C for 30 mins.).
6. The long term stability is not as good as that of 79-0240.
7. Check expiration date before conjugating.
8. 79-0238 can be conjugated to carbonyl or thiol-containing molecules.

79-0240 **Gold nanoparticles with carboxylic acid surface functional group, 6nm, in water** *(7440-57-5)* — 10mg, 50mg
dark red liq.
Note: 79-0240 is a group of water-soluble gold nanoparticles with amphiphilic polymer. The reactive group is a carboxylic acid.

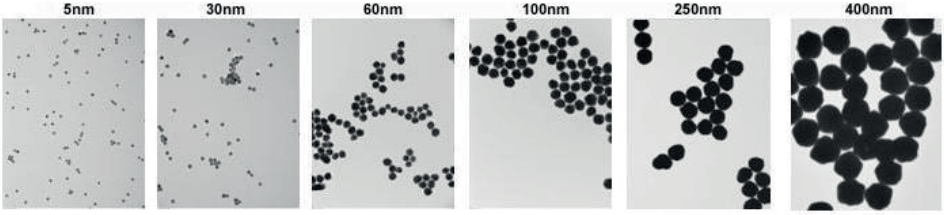
Technical Notes:

1. Zeta potential is from -30mV to -50 mV.
2. Total thickness of organic layers is ~4 nm.
3. The organic layers consist of a monolayer of dodecanethiol and a monolayer of amphihpilic polymer.
4. The hydrodynamic size of the nanoparticles is about 8-10 nm larger than their inorganic core size as measured by TEM.
5. 79-0240 is very stable in buffer solutions in the pH range of 4-10 and can survive the autoclaving (121°C for 30 min.)
6. 79-0240 can be conjugated to protein, peptide, and other amine-containing molecules.

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.
light sensitive; (store cold)



Gold Nanoparticles (1 OD, stabilized suspension in phosphate-buffered saline) reactant free *(7440-57-5)*

25ml
100ml

Catalog #	Diameter	Color and form	Absorption max.
79-0180*	5nm	red liq.	515-520nm
79-0184*	10nm	red liq.	520nm
79-0186*	15nm	red liq.	520nm
79-0188*	20nm	red liq.	524nm
79-0190*	30nm	red liq.	526nm
79-0192*	40nm	red liq.	530nm
79-0194	50nm	red liq.	535nm
79-0196	60nm	pink to bright-red liq.	539nm
79-0198	80nm	pink to bright-red liq.	
79-0202	80nm	pink to bright-red liq.	
79-0204	90nm	pink to bright-red liq.	
79-0206	100nm	pink to bright-red liq.	
79-0208	150nm	pink to bright-red liq.	
79-0220	200nm	pink to bright-red liq.	
79-0222	250nm	pink to bright-red liq.	
79-0224	300nm	pink to bright-red liq.	
79-0228	400nm	pink to bright-red liq.	

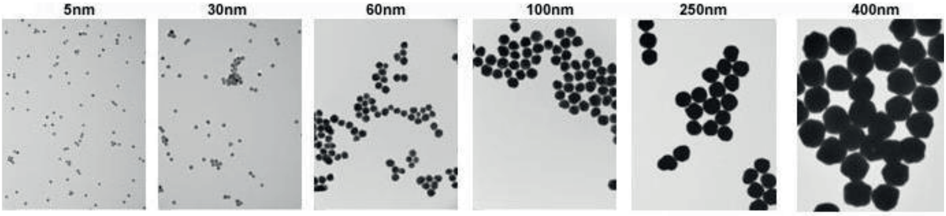
*Gold Nanoparticles Kit, Reactant Free component. *See* page 53

96-1545 **Gold Nanoparticles Kit, Reactant-Free (5nm-40nm diameter, OD 1, suspension in phosphate-buffered saline, 515-530nm abs. max.)** *(7440-57-5)*
See page 53

NANOMATERIALS - GOLD (Elemental Forms)

Gold Nanoparticles - Stabilizing Surfactant (1 OD, supplied in 0.1mM stabilizing surfactant)

Store away from direct sunlight at 4°C. Do not freeze. Shelf life 6 months.
light sensitive, (store cold)



Gold Nanoparticles (1 OD, supplied in 0.1mM stabilizing surfactant) *(7440-57-5)*

25ml
100ml

Catalog #	Diameter	Color and form	Absorption max.
79-0182*	5nm	red liq.	515-520nm
79-0210*	10nm	red liq.	515-520nm
79-0212*	15nm	red liq.	520nm
79-0214*	20nm	red liq.	524nm
79-0216*	30nm	red liq.	526nm
79-0218*	40nm	red liq.	530nm
79-0260	50nm	pink to bright-red liq.	535nm
79-0262	60nm	pink to bright-red liq.	540nm
79-0264	70nm	pink to bright-red liq.	548nm
79-0266	80nm	pink to bright-red liq.	553nm
79-0268	90nm	pink to bright-red liq.	564nm
79-0270	100nm	pink to bright-red liq.	572nm
79-0272	150nm	pink to bright-red liq.	
79-0274	200nm	pink to bright-red liq.	
79-0276	250nm	pink to bright-red liq.	
79-0278	300nm	pink to bright-red liq.	
79-0280	400nm	pink to bright-red liq.	

*Gold Nanoparticles Kit, stabilized suspension citrate buffer component. *See* page 51

96-1547 **Gold Nanoparticles Kit (5nm-40nm diameter, OD 1, stabilized suspension citrate buffer)** *(7440-57-5)*
See page 52

NANOMATERIALS - GOLD (Elemental Forms)

Gold Nanoparticles - Spherical

5ml
25ml

Concentration: 0.03mg/ml (±10%)
Storage Conditions: *(store cold),* store at ~4ºC (do not freeze)
Shelf Life: 6 months

79-6040 **Spherical Gold Nanoparticles (30 nm)** *(7440-57-5)*
orange pink liq.
Note: Spherical Gold Nanoparticles Kit component.

79-6045 **Spherical Gold Nanoparticles (50 nm)** *(7440-57-5)*
pink liq.
Note: Spherical Gold Nanoparticles Kit component.

79-6050 **Spherical Gold Nanoparticles (70 nm)** *(7440-57-5)*
pink liq.
Note: Spherical Gold Nanoparticles Kit component.

79-6055 **Spherical Gold Nanoparticles (90 nm)** *(7440-57-5)*
violet liq.
Note: Spherical Gold Nanoparticles Kit component.

96-1540 **Gold Nanospheres Kit (30-90 nm)** *(7440-57-5)*
See page 54

Gold Nanoparticles - Sugar Coated

5ml

(store cold)

79-0124 **Sugar Coated Gold Nanoparticles [AuNP: 1-2 nm (Lactose)]** *(7440-57-5)*
maroon-red liq.

Properties: Water soluble; **Size**: 22-38, 4-16, 6-10 or 1-2 nm; **Shape**: Sphere; **UV-Vis (nm):** 535, 535, 540 or 540 nm; **Stability**: After generation from kit components - Stable for 1 day.
Supplied as kit. Suitable for in vitro use and sensor design applications.

79-0122 **Sugar Coated Gold Nanoparticles [AuNP: 6-10 nm (Maltose)]** *(7440-57-5)*
maroon-red liq.

Properties: Water soluble; **Size**: 22-38, 4-16, 6-10 or 1-2 nm; **Shape**: Sphere; **UV-Vis (nm):** 535, 535, 540 or 540 nm; **Stability**: After generation from kit components - Stable for 1 day.
Supplied as kit. Suitable for in vitro use and sensor design applications.

Gold Nanoparticles - Surfactant and Reactant-Free (Pure), Manufactured via Laser Ablation

25ml
100ml

Note: Made to order. Manufactured by laser ablation. Store at room temperature (up to 25°C). Do not freeze. Shelf life 12 months. Sold in collaboration with Particular® for research purposes only.

79-0412
HAZ
Gold nanoparticles, pure, (<20nm) in acetone at 100mg/L (surfactant and reactant-free) *(7440-57-5)*
red liq.

79-0416
HAZ
Gold nanoparticles, pure, (<20nm) in isopropanol at 100mg/L (surfactant and reactant-free) *(7440-57-5)*
red liq.

79-0426
HAZ
Gold nanoparticles, pure, (50-70nm) in isopropanol at 100mg/L (surfactant and reactant-free) *(7440-57-5)*
red liq.
Note: Particle size of 50-70 nm is measured via DLS, colloid may also contain significant fractions of smaller particles. ***Limited quantities available***

79-0410 **Gold nanoparticles, pure, (<20nm) in water at 100mg/L (surfactant and reactant-free, OD>1, stabilized with < 0.01 mmol/l of citrate)** *(7440-57-5)*
red. liq.

79-0418 **Gold nanoparticles, pure, (<20nm) 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.

NANOMATERIALS - GOLD (Elemental Forms)

Gold Nanoparticles - Surfactant and Reactant-Free (Supported), Manufactured via Laser Ablation

(7440-57-5), (store cold)

Note: Manufactured by laser ablation. Sold in collaboration with Particular® for research purposes only.

79-0921 NEW	**Gold nanoparticles, 1% on carbon black (surfactant and reactant-free)** *(7440-57-5)* Au; FW: 196.70; black solid	5g 25g
79-0916 NEW	**Gold nanoparticles, 1% on Titania (anatase) (surfactant and reactant-free)** *(7440-57-5)* Au; FW: 196.70; dark purple pwdr.	5g 25g
79-0905 NEW	**Gold nanoparticles, 1% on Titania (rutile) (surfactant and reactant-free)** *(7440-57-5)* Au; FW: 196.70; purple solid	5g 25g
79-0926 NEW	**Gold nanoparticles, 5% on carbon black (surfactant and reactant-free)** *(7440-57-5)* Au; FW: 196.70; black solid	5g 25g
79-0935 NEW	**Gold nanoparticles, 10% on Titania (anatase) (surfactant and reactant-free)** *(7440-57-5)* Au; FW: 196.70; purple solid	1g 5g
79-0930 NEW	**Gold nanoparticles, 10% on Titania (rutile) (surfactant and reactant-free)** *(7440-57-5)* Au; FW: 196.70; dark purple solid	1g 5g

Gold Nanoparticles - Water Soluble

(store cold)

25ml
100ml

79-0110 **Water Soluble Gold Nanoparticles [AuNP: 3nm (Citrate)]** *(7440-57-5)*
wine-red liq.

Properties: Water soluble; **Size:** 3 nm, 5 nm, 10 or 15 nm; **Shape:** Sphere; **UV-Vis (nm):** 520, 525, 520 or 525 nm; **Stability:** Stable for 90 days in aqueous media.

Supplied in aqueous solutions. Contains citrate stabilizer. Suitable for spin coating, self-assembly and monolayer formation.

79-0112 **Water Soluble Gold Nanoparticles [AuNP: 5nm (Citrate)]** *(7440-57-5)*
wine-red liq.

Properties: Water soluble; **Size**: 3 nm, 5 nm, 10 or 15 nm; **Shape**: Sphere; **UV-Vis (nm):** 520, 525, 520 or 525 nm; **Stability**: Stable for 90 days in aqueous media.

Supplied in aqueous solutions. Contains citrate stabilizer. Suitable for spin coating, self-assembly and monolayer formation.

79-0114 **Water Soluble Gold Nanoparticles [AuNP: 10 nm (Citrate)]** *(7440-57-5)*
wine-red liq.

Technical Note:

1. See 79-0110 (page 33)

79-0116 **Water soluble Gold Nanoparticles [AuNP: 15 nm (Citrate)]** *(7440-57-5)*
wine-red liq.

Technical Note:

1. See 79-0110 (page 33)

79-0126 **Water Soluble Gold Nanoparticles [AuNP: 11-20 nm (Gelatin)]** *(7440-57-5)*
wine-red liq.

Properties: Water soluble; **Size**: 11-20 nm; **Shape**: Sphere; **UV-Vis (nm):** 540 nm; **Stability**: Stable for 90 days in aqueous media. Suitable for spin coating, self-assembly and monolayer formation. Suitable for in vitro use and sensor design applications.

79-0108 **Water Soluble Gold Nanoparticles [AuNP: 12-16 nm (Starch)]** *(7440-57-5)*
maroon-red liq.

Properties: Water soluble, stable at pH 7.0; **Size:** 30-40 nm; **Shape:** Sphere; **UV-Vis (nm):** 535 nm; **Stability:** Stable for 30 days in aqueous media.

Supplied in aqueous solutions. Contains starch stabilizer. Suitable for spin coating, self-assembly and monolayer formation.

References:

1. *Appl. Phys. Lett.*, **2006**, *88*, 153114
2. *J. Am. Chem. Soc.*, **2006**, *128*, 11342

NANOMATERIALS - GOLD (Elemental Forms)

Gold Nanorods

5ml

79-0136 **Gold Nanorods [AuNP-Rod: Aspect Ratio: 3-3.5 (CTAB)]** *(7440-57-5)*
maroon-red liq.
(store cold)

Properties: Water soluble; **Aspect Ratio:** 3-3.5; **Shape**: Rod; **UV-Vis (nm):** 680 nm; **Stability**: Stable for 14 days Supplied in aqueous solutions. Contains CTAB stabilizer. Ready for biomolecule conjugation. Suitable for in vitro use and sensor design applications.

Gold Nanorods (Axial Diameter - 25nm) *(7440-57-5)*

Storage Conditions: *(store cold)* Store at 4°C. Do not freeze. Shelf Life: 6 months

5ml
25ml

Technical Note:

Catalog #	79-6000	79-6005	79-6010	79-6015
Concentration	171 ug/ml (±10%)	235 ug/ml (±10%)	150 ug/ml (±10%)	91 ug/ml (±10%)
Axial diameter (nm)	25 (±10%)	25 (±10%)	25 (±10%)	25 (±10%)
Longitudinal Size (nm)	34 (±10%)	47 (±10%)	60 (±10%)	73 (±10%)
Peak Longitudinal Surface Plasmon Resonance Wavelength (nm)	550	600	650	700
Peak Axial Surface Plasmon Resonance Wavelength (nm)	530	530	530	530
Color and Form	red liq.	blue liq.	blue liq.	gray liq.

*Gold Nanorods Kit (Axial Diameter - 25nm) component. *See* page 53

79-6000 **Gold Nanorods (Axial Diameter - 25 nm) (Wavelength 550 nm)** *(7440-57-5)*
79-6005 **Gold Nanorods (Axial Diameter - 25 nm) (Wavelength 600 nm)** *(7440-57-5)*
79-6010 **Gold Nanorods (Axial Diameter - 25 nm) (Wavelength 650 nm)** *(7440-57-5)*
79-6015 **Gold Nanorods (Axial Diameter - 25 nm) (Wavelength 700 nm)** *(7440-57-5)*
96-1530 **Gold Nanorods Kit (Axial Diameter - 25 nm, wavelength 550-700 nm)** *(7440-57-5)*
See page 53

Gold Nanorods (Axial Diameter - 10nm) *(7440-57-5)*

Storage Conditions: *(store cold)* Store at 4°C. Do not freeze. Shelf Life: 6 months

5ml
25ml

Technical Note:

Catalog #	79-6020	79-6025	79-6030	79-6035
Concentration	30 ug/ml (±10%)	34 ug/ml (±10%)	35 ug/ml (±10%)	36 ug/ml (±10%)
Axial diameter (nm)	10 (±10%)	10 (±10%)	10 (±10%)	10 (±10%)
Longitudinal Size (nm)	29 (±10%)	35 (±10%)	38 (±10%)	41 (±10%)
Peak Longitudinal Surface Plasmon Resonance Wavelength (nm)	700	750	780	808
Peak Axial Surface Plasmon Resonance Wavelength (nm)	512	512	512	512
Color and Form	pale red-brown liq.	pale red liq.	pale red solution	pale red liq.

*Gold Nanorods Kit (Axial Diameter - 10nm) component. *See* page 53

79-6020 **Gold Nanorods (Axial Diameter - 10 nm) (Wavelength 700 nm)** *(7440-57-5)*
79-6025 **Gold Nanorods (Axial Diameter - 10 nm) (Wavelength 750 nm)** *(7440-57-5)*
79-6030 **Gold Nanorods (Axial Diameter - 10 nm) (Wavelength 780 nm)** *(7440-57-5)*
79-6035 **Gold Nanorods (Axial Diameter - 10 nm) (Wavelength 808 nm)** *(7440-57-5)*
96-1535 **Gold Nanorods Kit (Axial Diameter - 10 nm, wavelength 550-700 nm)** *(7440-57-5)*
See page 53

Gold Nanorods, CTAB Free

5ml
25ml

light sensitive, (store cold)

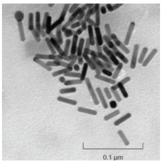
Note: Rods are synthesized without CTAB. Store at 4°C - 8°C. Do not freeze. At storage temperature the product may appear opaque. Follow the procedure for re-dispersing surfactants as described in the technical note. Complete this process before use to dissolve precipitated stabilizer. Sold in Collaboration with SONA Nanotech for research purposes only. Gold Gemini Nanorods Kit component.

79-7010 NEW **Gold Gemini Nanorods, CTAB Free (Wavelength 650 nm)** *(7440-57-5)*
Au; violet liq.

Technical Note:

Item #	LPSR Maximum (nm)	Length (nm)	Width (nm)	Aspect Ratio	Color & Form
79-7010	640 - 670	25 - 31	13 - 18	1.7 - 1.9	violet liq.
79-7015	685 - 715	37 - 43	13 - 18	2.4 - 2.8	blue liq.
79-7020	735 - 765	37 - 44	10 - 13	3.4 - 3.7	red-purple liq.
79-7025	785 - 815	40 - 50	10 - 13	3.8 - 4.1	red-orange liq.
79-7030	835 - 865	48 - 55	9 - 12	4.6 - 5.3	maroon-purple liq.

Concentration: >30 μg/ml
pH: 5.5 - 7.5
Stabilizer: Amphiphilic Agents
Solvent: Stabilized with amphiphilic agents in conductivity grade water (18.0 MΩ cm^{-1})
Optical Density: 1.0 - 1.2
Shelf Life: 12 months



79-7015 NEW **Gold Gemini Nanorods, CTAB Free (Wavelength 700 nm)** *(7440-57-5)*
Au; blue liq.

Technical Note:
1. See 79-7010 (page 35)

79-7020 NEW **Gold Gemini Nanorods, CTAB Free (Wavelength 750 nm)** *(7440-57-5)*
Au; red-purple liq.

Technical Note:
1. See 79-7010 (page 35)

79-7025 NEW **Gold Gemini Nanorods, CTAB Free (Wavelength 800 nm)** *(7440-57-5)*
Au; red-orange liq.

Technical Note:
1. See 79-7010 (page 35)

79-7030 NEW **Gold Gemini Nanorods, CTAB Free (Wavelength 850 nm)** *(7440-57-5)*
Au; maroon-purple liq.

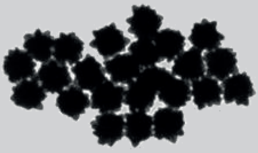
Technical Note:
1. See 79-7010 (page 35)

96-1549 **Gold Gemini Nanorods Kit, CTAB Free (Wavelength 650-850 nm)**
See page 52

NANOMATERIALS - GOLD (Elemental Forms)

Gold NanoUrchins (1 OD, 0.1 mM in phosphate-buffered saline) >95.0% reactant free
20ml
100ml

blue liq.
light sensitive, (store cold)
Note: Store away from direct sunlight at 4°C. Do not freeze.
Shelf life 6 months.



Technical Note:

Product #	Diameter	Color and form	Absorption max
79-0310	50nm	blue liq.	585nm
79-0313	60nm	blue liq.	585nm
79-0315	70nm	blue liq.	600nm
79-0318	80nm	blue liq.	620nm
79-0320	90nm	blue liq.	630nm
79-0323	100nm	blue liq.	680nm

NANOMATERIALS - GOLD (Compounds)

79-2015 **Diphenyl(m-sulfonatophenyl)phosphine-gold nanocluster (water soluble) (1-3 nm)**
100mg
500mg
dark red solid; particle size: 1-3 nm
Note: Made to order. Long term shelf life not established.

79-2035 **Hexachlorododecakis[diphenyl(m-sulfontophenyl)phosphine]pentapentacontagold, dodecasodium salt (water soluble) Schmid Au_{55} Cluster** *(115804-59-6)*
10mg
$Na_{12}\{Au_{55}[P(C_6H_5)_2(C_6H_4SO_3)]_{12}Cl_6\}$; FW: 15417.85; black solid

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79-2030 **Hexachlorododecakis(triphenylphosphine)pentapentacontagold Schmid Au_{55} Cluster** *(104619-10-5)*
10mg
50mg
$A_{55}[P(C_6H_5)_3]_{12}Cl_6$; FW: 14193.30; black solid

NANOMATERIALS - IRIDIUM (Compounds)

Antimony Tin Oxide/Iridium Het-WOC core/shell nanopowder (conductive and acid-stable)
50g
250g
HAZ; blue pwdr.; ATO Composition: 90% SnO_2, 10% Sb_2O_3 (w/w)
Note: Sold under license from Catalytic Innovations, LLC for research purposes only. US Patent Publication No. US20150021194 A1.

Technical Note:

Product #	Particle Size	BET Surface Area	Resistivity
77-0030	20nm	50 - 60m²/g	0.3 - 0.7 Ω▪cm
77-0035	50nm	40 - 50m²/g	0.05 - 0.08 Ω▪cm
77-0040	100nm	5 - 10m²/g	0.05 - 0.08 Ω▪cm

NANOMATERIALS - IRON (Compounds)

Iron Magnetic Fluids
2ml
10ml

26-0032 **Iron(II,III) oxide (Magnetite) aqueous magnetic fluid [3.5 vol%, Ms = 15-16 kA/m]** *(1317-61-9)*
Fe_3O_4; black solid (water suspension)

26-0036 **Iron(II,III) oxide (Magnetite) aqueous magnetic fluid [7.0 vol%, Ms = 30-31 kA/m]** *(1317-61-9)*
Fe_3O_4; black solid (water suspension)

NANOMATERIALS - IRON (Compounds)

Iron Magnetic Fluids

2ml
10ml

26-0022 HAZ
Iron(II,III) oxide (Magnetite) magnetic fluid in kerosene with oleic acid [7-9 vol%, Ms = 35-45 kA/m] *(1317-61-9)*
black, viscous liq.

26-0024 HAZ
Iron(II,III) oxide (Magnetite) magnetic fluid in kerosene with oleic acid [15-18 vol%, Ms = 50-70 kA/m] *(1317-61-9)*
black, viscous liq.

Iron Nanoparticles

Note: Store at 5 to 25°C. Do not freeze. Suggested use within 12 months of receipt. Sold in collaboration with Cerion for research purposes only.

25g
100g
500g

26-2758 HAZ
Iron(III) oxyhydroxide in water at pH = 3.0 +- 0.5 (FEO-W320) *(20344-49-4)*
FeO(OH); FW: 88.85; d. 1.19
(store cold)

% Solids: 20.0 +/- 0.5 as Fe2O3
pH: 3.0 +/- 0.5
Mean Number Weighted Particle Diameter: <5.0 nm (by Dynamic Light Scattering)
Polydispersity Index: <0.25
Chemical Composition (particles): >99.5% FeOOH

Iron Nanoparticles - Solid form (with amine surface functional group)

Note: A water-soluble iron oxide nanoparticles with amphiphilic polymer and PEG coating. The reactive group is an amine.

5mg
25mg

26-2711
Iron oxide nanoparticles in water, 10nm, with amine surface functional group *(1309-37-1)*
brown liq.

Technical Notes:
1. Zeta potential is -10mv to +10mV.
2. The organic layers consist of a monolayer of oleic acid and a monolayer of ampiphilic polymer.
3. The overall thickness of the organic layers about 6 nm.
4. The hydrodynamic size of the nanoparticles is about 12-14 nm larger than their inorganic core size measured by TEM.
5. Very stable in most buffer solutions in the pH range of 4-10. Solution can survive autoclaving process (121°C for 30 minutes).
6. Light precipitation may occur during storage. Check expiration date before conjugation.
7. The amine density is low due to the long PEG chain.
8. Can be conjugated to carbonyl or thio-containing molecules.

References:
1. *Clinical Cancer Research,* **2009**, *15*, 4722
2. *Gastroenterlogy,* **2009**, *136*, 1514
3. *Small,* **2009**, *5*, 235
4. *The Analysis,* **2008**, *133*, 154
5. *The Journal of Physical Chemistry C,* **2008**, *112*, 8127
6. *International Journal of Nanomedicine,* **2008**, *3*, 311
7. *Journal of Biomedical Nanotechnology,* **2008**, *4*, 439

26-2713
Iron oxide nanoparticles in water, 20nm, with amine surface functional group *(1309-37-1)*
black liq.

Technical Note:
1. See 26-2711 (page 37)

26-2715
Iron oxide nanoparticles in water, 30nm, with amine surface functional group *(1309-37-1)*
black liq.

Technical Note:
1. See 26-2711 (page 37)

NANOMATERIALS - IRON (Compounds)

Iron Nanoparticles - Solid form (with carboxylic acid surface functional group)

10mg
50mg

Note: A water-soluble iron oxide nanoparticles with amphiphilic polymer coating. The reactive group is a carboxylic acid.

26-2705 **Iron oxide nanoparticles in water, 10nm, with carboxylic acid surface functional group**
(1309-37-1)
brown liq.

Technical Notes:

1. Zeta potential of 26-2705 -30mv to -50mV.
2. The organic layers consist of a monolayer of oleic acid and a monolayer of ampiphilic polymer.
3. The overall thickness of the organic layers about 4 nm.
4. The hydrodynamic size of the nanoparticles is about 8-10 nm, larger than their inorganic core size measured by TEM.
5. Very stable in most buffer solutions in the pH range of 4-10. Solution can survive autoclaving process (121°C for 30 minutes).

References:

1. *Clinical Cancer Research,* **2009**, *15*, 4722
2. *Gastroenterlogy,* **2009**, *136*, 1514
3. *Small,* **2009**, *5*, 235
4. *The Analysis,* **2008**, *133*, 154
5. *The Journal of Physical Chemistry C,* **2008**, *112*, 8127
6. *International Journal of Nanomedicine,* **2008**, *3*, 311
7. *Journal of Biomedical Nanotechnology,* **2008**, *4*, 439

26-2707 **Iron oxide nanoparticles in water, 20nm, with carboxylic acid surface functional group**
(1309-37-1)
black liq.

Technical Note:

1. See 26-2705 (page 38)

26-2709 **Iron oxide nanoparticles in water, 30nm, with carboxylic acid surface functional group**
(1309-37-1)
black liq.

Technical Note:

1. See 26-2705 (page 38)

Iron Nanoparticles - Solid form (organic solvent-dispersible)

50mg
500mg

Note: A water-soluble iron oxide nanoparticles with amphiphilic polymer and PEG coating. No linkable reactive group on the surface.

26-2728 **Iron oxide nanoparticles, 10nm, organic solvent-dispersible (in chloroform)**
(1309-37-1)
brown liq.

Technical Notes:

1. Zeta potential is -10mv to 0.
2. Total thickness of organic layers is ~6 nm.
3. The hydrodynamic size of the nanoparticles is about 12-14 nm larger than their inorganic core size as measured by TEM.
4. The colloidal stability is exceptionally high.
5. Stable in most buffer solutions in the pH range of 4-10. Solution can survive autoclaving process (121°C for 30 minutes).

References:

1. *Clinical Cancer Research,* **2009**, *15*, 4722
2. *Gastroenterlogy,* **2009**, *136*, 1514
3. *Small,* **2009**, *5*, 235
4. *The Analysis,* **2008**, *133*, 154
5. *The Journal of Physical Chemistry C,* **2008**, *112*, 8127
6. *International Journal of Nanomedicine,* **2008**, *3*, 311
7. *Journal of Biomedical Nanotechnology,* **2008**, *4*, 439

26-2730 **Iron oxide nanoparticles, 20nm, organic solvent-dispersible (in chloroform)**
(1309-37-1)
black liq.

Technical Note:

1. See 26-2728 (page 38)

26-2732 **Iron oxide nanoparticles, 30nm, organic solvent-dispersible (in chloroform)**
(1309-37-1)
black liq.

Technical Note:

1. See 26-2728 (page 38)

NANOMATERIALS - IRON (Compounds)

Iron Nanoparticles - Solid Form (in water with PEG) 5mg

Note: A water-soluble iron oxide nanoparticles with amphiphilic polymer and PEG coating. No linkable reactive group on the surface. 25mg

26-2722 **Iron oxide nanoparticles in water, 10nm, with PEG** *(1309-37-1)*
brown liq.

Technical Notes:

1. Zeta potential is -10mv to 0.
2. Total thickness of organic layers is ~6 nm.
3. The hydrodynamic size of the nanoparticles is about 12-14nm larger than their inorganic core size as measured by TEM.
4. The colloidal stability is exceptionally high.
5. Stable in most buffer solutions in the pH range of 4-10. Solution can survive autoclaving process (121°C for 30 minutes).

References:

1. *Clinical Cancer Research,* **2009**, *15*, 4722
2. *Gastroenterlogy,* **2009**, *136*, 1514
3. *Small,* **2009**, *5*, 235
4. *The Analysis,* **2008**, *133*, 154
5. *The Journal of Physical Chemistry C,* **2008**, *112*, 8127
6. *International Journal of Nanomedicine,* **2008**, *3*, 311
7. *Journal of Biomedical Nanotechnology,* **2008**, *4*, 439

26-2724 **Iron oxide nanoparticles in water, 20nm, with PEG** *(1309-37-1)*
black liq.

Technical Note:

1. See 26-2722 (page 39)

26-2726 **Iron oxide nanoparticles in water, 30nm, with PEG** *(1309-37-1)*
black liq.

Technical Note:

1. See 26-2722 (page 39)

NANOMATERIALS - LEAD (Compounds)

Lead Sulfide Quantum Dots

Note: Sold in collaboration with CAN for R&D purposes. Suggest use within 6 months of purchase. Do not freeze. Store in DARK.

82-1081 **Lead sulfide CANdot® quantum dot (PbS core - ~3nm), 10 mg/mL in toluene,** 2ml
HAZ **1000nm peak emission** *(1314-87-0)* 10ml
PbS; FW: 239.25; dark-red liq.

82-1083 **Lead sulfide CANdot® quantum dot (PbS core - ~4.5nm), 10 mg/mL in toluene,** 1ml
HAZ **1200nm peak emission** *(1314-87-0)* 5ml
PbS; FW: 239.25; dark-red liq.

82-1085 **Lead sulfide CANdot® quantum dot (PbS core - ~6nm), 10 mg/mL in toluene,** 1ml
HAZ **1400nm peak emission** *(1314-87-0)* 5ml
PbS; FW: 239.25; dark-red liq.

82-1090 **Lead sulfide CANdot® quantum dot (PbS core - ~8nm), 10 mg/mL in toluene,** 1ml
HAZ **1600nm peak emission** *(1314-87-0)* 5ml
PbS; FW: 239.25; dark-red liq.

NANOMATERIALS - MAGNESIUM (Compounds)

12-1405 **Magnesium oxide nanopowder** *(1309-48-4)* 25g
MgO; FW: 40.31; white pwdr. 100g
Note: APS 20nm; SSA 50m^2/g

NANOMATERIALS - NICKEL (Compounds)

28-0008 **Nickel/tetra-n-octylammonium bromide colloid, purified (65-70% Ni)** *(7440-02-0)* 100mg
HAZ $Ni/(C_8H_{17})_4NBr$; 2.8 nm (average); black pwdr. 500mg
pyrophoric
Note: Made to order. Suggest use within 3 months of receipt. Long term shelf life not established.

Technical Note:

1. Soluble in THF, toluene, acetone and methylene chloride. Insoluble in ethanol, ether and pentane.

References:

1. *J. Mol. Catal.,* **1994**, *86*, 129
2. *Eur. J. Inorg. Chem.,* **2001**, *2455*
3. *Catalysis and Electrocatalysis at Nanoparticles Surfaces, Chapter* **10**, *p*, 343, 377. Marcel Dekker, NY, **2003**.
4. *Advanced Catalysts and Nanostructured Materials, Chapter* **7**, *Academic*, Press, San Diego, **1996**, 165-196.

NANOMATERIALS - PALLADIUM (Elemental Forms)

Palladium Heterogeneous Catalyst

5g
25g

46-1710 **Palladium, 0.6% on activated carbon, 50% water-wet paste (NanoSelect LF 100)**
(7440-05-3)
black solid (d50=25 µm)
Note: Sold in collaboration with BASF for research purposes only. BASF Heterogeneous Catalyst Kit *(96-6717)* component. BASF Palladium Catalyst Kit *(96-6719)* component.

Technical Note:

1. NanoSelect LF 100 is a lead-free, water-wet, catalyst containing metal crystallites sizes of around 7 nm, and a mean particle size of 25 microns. The metal crystallites are supported on a carbon powder. The presence of nanometer-sized metal particles greatly increases the metal surface area available per gram of catalyst, and boosts catalytic activity. The catalyst is recommended for use in hydrogenation reactions leading to the partial reduction of functional groups. It is specifically suited for the selective hydrogenation of alkynes to alkenes, with a high selectivity for cis-alkenes.

Palladium Nanoparticles

(store cold)

25ml
100ml

46-0407 **Palladium Nanoparticles [PdNP: 2-4 nm (gum Arabic)]** *(7440-05-3)*
yellowish-brown liq.

Properties: Water soluble; **Size**: 2-4 nm; **Shape**: Sphere; **Specification**: Stable for 60 days.
Supplied in aqueous media, contains gum arabix stabilizer. Suitable for in vitro use and sensor design applications. Suitable for spin coating, self-assembly and monolayer formation. Potential new Catalysts.

46-0409 **Palladium Nanoparticles [PdNP: 2-3 nm (Gelatin)]** *(7440-05-3)*
yellowish-brown liq.

Properties: Water soluble; **Size**: 2-3 nm; **Shape**: Sphere; **Specification**: Stable for 60 days.
Supplied in aqueous media, contains gelatin stabilizer. Suitable for in vitro use and sensor design applications. Suitable for spin coating, self-assembly and monolayer formation. Potential new Catalysts.

Palladium Nanoparticles - Surfactant and Reactant-Free (Pure), Manufactured via Laser Ablation

25ml
100ml

Note: Made to order. Manufactured by laser ablation. Store at room temperature (up to 25°C). Do not freeze. Shelf life 12 months. Sold in collaboration with Particular® for research purposes only.

46-4012 **Palladium nanoparticles, pure, (<20nm) in acetone at 100mg/L (surfactant and reactant-free)** *(7440-05-3)*
HAZ
grey-brown liq.

46-4010 **Palladium nanoparticles, pure, (<20nm) in water at 100mg/L (surfactant and reactant-free, stabilized with < 0.01 mmol/l of citrate)** *(7440-05-3)*
grey-brown liq.

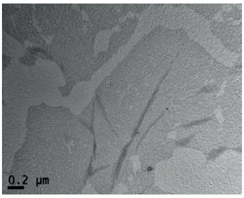
46-4018 **Palladium nanoparticles, pure, (<20nm) in water at 500mg/L (surfactant and reactant-free, stabilized with < 0.01 mmol/l of citrate)** *(7440-05-3)*
black liq.

46-4022 **Palladium nanoparticles, pure, (50-70nm) in acetone at 100mg/L (surfactant and reactant-free)** *(7440-05-3)*
HAZ
grey liq.
Note: Particle size of 50-70 nm is measured via DLS, colloid may also contain significant fractions of smaller particles. ***Limited quantities available***

28-0015 NEW

Nickel/palladium alloy nanoparticle on graphene (G-$Ni_{33}Pd_{67}$)
black pwdr.
Note: U.S. Patent Application 14/667,859.

25mg
100mg

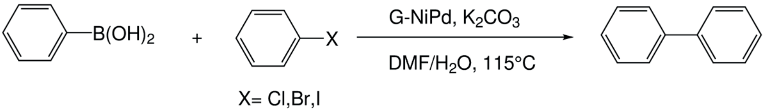


Technical Note:

1. NiPd NPs are useful catalysts for the tandem dehydrogenation of ammoniaborane and hydrogenation of R-NO_2 or R-CN to R-NH_2. NiPd nanoparticles also catalyze Suzuki-Miyaura and Heck cross-coupling reactions. The product is synthesized via the borane reduction of nickel and palladium salts in oleylamine, followed by dispersing the resulting mixture of Ni/Pd nanoparticles on graphene. The catalyst is 100% recyclable and shows no drop in catalytic activity after one month, when stored in air/argon at ambient temperatures.

$$R{-}NO_2 \xrightarrow[\text{water/methanol, rt}]{\text{4mg G-NiPd, 3 mmol } NH_3BH_3} R{-}NH_2$$

$$R{-}CN \xrightarrow[\text{water/methanol, rt}]{\text{4mg G-NiPd, 3 mmol } NH_3BH_3} R{-}CH_2NH_2$$



References:

1. *Nano Research,* **2013,** *6*, 10.
2. *ACS Catal.*, **2014**, *4*, 1777.

NANOMATERIALS - PLATINUM (Elemental Forms)

Platinum Colloids

250mg
1g

Note: Made to order. Suggest use within 3 months of receipt. Long term shelf life not established.

78-0055 **Platinum/tetra-n-octylammonium chloride colloid, purified (70-85% Pt)**
HAZ *(7440-06-4)*
🚚 Pt/$(C_8H_{17})_4$NCl; 2.8 nm ±0.5 nm; grayish-black pwdr
🚢 *pyrophoric*

Technical Note:

1. Soluble in THF. Insoluble in toluene, acetone, ether and ethanol.

References:

1. *J. Mol. Catal.,* **1994**, *86*, 129
2. *Eur. J. Inorg. Chem.,* **2001**, 2455.
3. *Synthetic Methods of Organometallic and Inorganic Chemistry*, Vol.10, Chapter 20, p. 209-223, Theime Verlag, NY, 2002.
4. *Catalysis and Electrocatalysis at Nanoparticles Surfaces*, Chapter 10, p. 343, 377, Marcel Dekker, NY, 2003.

78-0062 **Platinum-ruthenium/tetra-n-octylammonium chloride colloid (~7 wt% Pt, ~3.5 wt% Ru)** *(7440-06-4)*
HAZ
$Pt_{50}Ru_{50}/(C_8H_{17})_4$NCl; 1.7 nm ±0.5 nm; waxy, black residue

Technical Note:

1. Very soluble in THF. Soluble in toluene. Precursor for fuel cell catalysts.

References:

1. *J. Mol. Catal.,* **1994**, *86*, 129
2. *Synthetic Methods of Organometallic and Inorganic Chemistry,* Vol. 10, Chapter 20, p. 209-223, Theime Verlag, NY, 2002.
3. *Catalysis and Electrocatalysis at Nanoparticles Surfaces*, Chapter 10, p. 343-377, Marcel Dekker, NY, 2003.

Platinum Fuel Cell Catalysts

100mg

78-1685 **Dealloyed Pt-Co core-shell fuel cell catalyst on carbon**
HAZ PtCo; black solid

Technical Note:

1. For detailed note visit www.strem.com.

78-1688 **Dealloyed Pt-Cu core-shell fuel cell catalyst on carbon**
HAZ PtCu; black solid

Technical Note:

1. For detailed note visit www.strem.com.

Platinum Nanoparticles

78-0007 **Platinum, 97% (2-5 nanometers)** *(7440-06-4)* 250mg
HAZ Pt; black pwdr. 1g
🚚 *pyrophoric*
🚢 Note: Made to order. Suggest use within 3 months of receipt. Long term shelf life not established.

References:

1. *J. Mol. Catal.,* **1994**, *86*, 129

78-0405 **Platinum Nanoparticles [PtNP: 2-3 nm (gum Arabic)]** *(7440-06-4)* 25ml
yellowish-brown liq. 100ml
(store cold)

Properties: Water soluble; **Size**: 2-3 nm; **Shape**: Sphere; **UV Vis (nm):**405-410 nm; **Specification**: Stable for 60 days Supplied in aqueous media, contains gum arabic stabilizer. Suitable for in vitro use and sensor design applications. Suitable for spin coating, self-assembly and monolayer formation. Potential new Catalysts.

NANOMATERIALS - PLATINUM (Elemental Forms)

Platinum Nanoparticles - Surfactant and Reactant-Free (Pure), Manufactured via Laser Ablation

Note: Made to order. Manufactured by laser ablation. Store at room temperature (up to 25°C). Do not freeze. Shelf life 12 months. Sold in collaboration with Particular® for research purposes only.

78-1405	**Platinum nanoparticles, pure, (<20nm) in water at 30mg/L (surfactant and reactant-free, stabilized with <0.01 mmol/l of citrate)** *(7440-06-4)* grey-brown liq.	100ml
78-1402	**Platinum nanoparticles, pure, (<20nm) in water at 100mg/L (surfactant and reactant-free, stabilized with < 0.01 mmol/l of citrate)** *(7440-06-4)* grey-brown liq.	25ml 100ml
78-1404 HAZ	**Platinum nanoparticles, pure, (<20nm) in acetone at 100mg/L (surfactant and reactant-free)** *(7440-06-4)* grey-brown liq.	25ml 100ml
78-1408 HAZ	**Platinum nanoparticles, pure, (<20nm) in isopropanol at 100mg/L (surfactant and reactant-free)** *(7440-06-4)* grey-brown liq.	25ml 100ml
78-1410	**Platinum nanoparticles, pure, (<20nm) in water at 500mg/L (surfactant and reactant-free, stabilized with < 0.01 mmol/l of citrate)** *(7440-06-4)* black liq.	25ml 100ml
78-1414 HAZ	**Platinum nanoparticles, pure, (50-70nm) in acetone at 100mg/L (surfactant and reactant-free)** *(7440-06-4)* grey liq. Note: Particle size of 50-70 nm is measured via DLS, colloid may also contain significant fractions of smaller particles. ***Limited quantities available***	25ml 100ml
78-1418 HAZ	**Platinum nanoparticles, pure, (50-70nm) in isopropanol at 100mg/L (surfactant and reactant-free)** *(7440-06-4)* grey liq. Note: Particle size of 50-70 nm is measured via DLS, colloid may also contain significant fractions of smaller particles. ***Limited quantities available***	25ml 100ml

Platinum Nanoparticles - Surfactant and Reactant-Free (Supported), Manufactured via Laser Ablation

(store cold) Note: Manufactured by laser ablation. Sold in collaboration with Particular® for research purposes only.

78-3015 NEW	**Platinum nanoparticles, 1% on carbon black (surfactant and reactant-free)** *(7440-06-4)* Pt; FW: 195.10; black solid	5g 25g
78-3020 NEW	**Platinum nanoparticles, 5% on carbon black (surfactant and reactant-free)** *(7440-06-4)* Pt; FW: 195.10; black solid	5g 25g
78-3030 NEW	**Platinum nanoparticles, 10% on carbon black (surfactant and reactant-free)** *(7440-06-4)* Pt; FW: 195.10; black solid	1g 5g
78-3032 NEW	**Platinum nanoparticles, 20% on carbon black (surfactant and reactant-free)** *(7440-06-4)* Pt; FW: 195.10; black solid	1g 5g
78-3035 NEW	**Platinum nanoparticles, 30% on carbon black (surfactant and reactant-free)** *(7440-06-4)* Pt; FW: 195.10; black solid	1g 5g
78-3012 NEW	**Platinum nanoparticles, 1% on Titania (anatase) (surfactant and reactant-free)** *(7440-06-4)* Pt; FW: 195.10; gray solid	5g 25g
78-3005 NEW	**Platinum nanoparticles, 1% on Titania (rutile) (surfactant and reactant-free)** *(7440-06-4)* Pt; FW: 195.10; light gray solid	5g 25g
78-3026 NEW	**Platinum nanoparticles, 10% on Titania (anatase) (surfactant and reactant-free)** *(7440-06-4)* Pt; FW: 195.10; dark gray solid	1g 5g
78-3023 NEW	**Platinum nanoparticles, 10% on Titania (rutile) (surfactant and reactant-free)** *(7440-06-4)* Pt; FW: 195.10; dark gray solid	1g 5g

NANOMATERIALS - RHODIUM (Elemental Forms)

Rhodium Colloids

Note: Made to order. Suggest use within 3 months of receipt. Long term shelf life not established.

45-1550 **Rhodium colloid (polyethyleneglycol-dodecylether hydrosol) (~9 wt% Rh)** 1g
(7440-16-6) 5g
Rh/alkoxyethers; ~2 nm; brown-black viscous substance
Note: *Limited quantities available*

Technical Note:

1. Soluble in ether, alcohol, and water.

References:

1. *Eur. J. Inorg. Chem.,* **2001**, *2455*

45-1660 **Rhodium/tetra-n-octylammonium chloride colloid, purified (70-75% Rh)** 250mg
HAZ *(7440-16-6)* 1g
🚚 Rh/$(C_8H_{17})_4$NCl; 2.0 nm ±0.5 nm; gray pwdr
🚢 *pyrophoric*

Technical Note:

1. Very soluble in THF, soluble in acetone, slightly soluble in toluene, insoluble in ether.

References:

1. *J. Mol. Catal.,* **1994**, *86*, 129
2. *Eur. J. Inorg. Chem.,* **2001**, *2455*
3. *Catalysis and Electrocatalysis at Nanoparticles Surfaces, Chapter* **10**, *p*, 343, 377. Marcel Dekker, NY, **2003**.
4. *Advanced Catalysts and Nanostructured Materials, Chapter* **7**, *Academic*, Press, San Diego, **1996**, 165-196.

Rhodium Nanoparticles - Surfactant and Reactant-Free (Pure), Manufactured via Laser Ablation

25ml
100ml

Note: Made to order. Manufactured by laser ablation. Store at room temperature (up to 25°C).
Do not freeze. Shelf life 12 months. Sold in collaboration with Particular® for research purposes only.

45-1324 **Rhodium nanoparticles, pure, (<20nm) in acetone at 100mg/L (surfactant and reactant-free)** *(7440-16-6)*
HAZ
grey-brown liq.

45-1328 **Rhodium nanoparticles, pure, (<20nm) in isopropanol at 100mg/L (surfactant and reactant-free)** *(7440-16-6)*
HAZ
grey-brown liq.

45-1322 **Rhodium nanoparticles, pure, (<20nm) in water at 100mg/L (surfactant and reactant-free, stabilized with < 0.01 mmol/l of citrate)** *(7440-16-6)*
grey-brown liq.

45-1330 **Rhodium nanoparticles, pure, (<20nm) in water at 500mg/L (surfactant and reactant-free, stabilized with < 0.01 mmol/l of citrate)** *(7440-16-6)*
black liq.

NANOMATERIALS - RUTHENIUM (Elemental Forms)

Ruthenium Nanoparticles - Surfactant and Reactant-Free (Pure), Manufactured via Laser Ablation

25ml
100ml

Note: Made to order. Manufactured by laser ablation. Store at room temperature (up to 25°C).
Do not freeze. Shelf life 12 months. Sold in collaboration with Particular® for research purposes only.

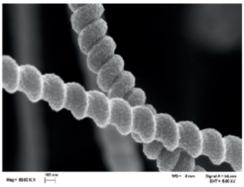
44-2812 **Ruthenium nanoparticles, pure, (<20nm) in acetone at 100mg/L (surfactant and reactant-free)** *(7440-18-8)*
HAZ
grey-brown liq.
Note: ***Limited quantities available***

44-2822 **Ruthenium nanoparticles, pure, (50-70nm) in acetone at 100mg/L (surfactant and reactant-free)** *(7440-18-8)*
HAZ
grey liq.
Note: Particle size of 50-70 nm is measured via DLS, colloid may also contain significant fractions of smaller particles. ***Limited quantities available***

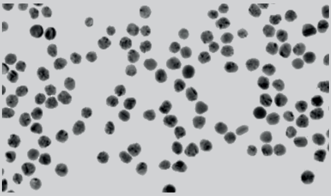
NANOMATERIALS - SILICON (Elemental Forms)

14-0655 **Silicon powder (amorphous), min. 97%** *(7440-21-3)* 5g
HAZ Si; brown pwdr.; SA: >50 m^2/g 25g
air sensitive

NANOMATERIALS - SILICON (Elemental Forms)

14-0650 HAZ	**Silicon powder (nanocrystalline), min. 97%** *(7440-21-3)* Si; brown pwdr.; SA: <20 m²/g *air sensitive*	5g 25g
14-6052	**Silica Nanosprings™ coated with zinc oxide and grown on fiber glass substrate (3.5 x 8cm)** *(7631-86-9)* white to beige plate Note: ***Limited quantities available.*** 	1pc

NANOMATERIALS - SILVER (Elemental Forms)

Silver Nanoparticles - in citrate buffer *light sensitive, (store cold)* Note: Store away from direct sunlight at 4°C. Do not freeze. Shelf life 6 months. 	20ml 100ml

Technical Note:

Product #	Diameter	Color and form	Absorption max
47-0620	10nm	yellow liq.	390-400nm
47-0623	20nm	yellow liq.	405nm
47-0626	30nm	yellow liq.	410nm
47-0630	40nm	yellow liq.	416nm
47-0633*	50nm	yellow liq.	425nm
47-0635	60nm	yellow liq.	430nm
47-0638	80nm	yellow liq.	457nm
47-0640	100nm	yellow liq.	490nm

Silver Nanoparticles - Reactant-Free *light sensitive, (store cold)* Note: Store away from direct sunlight at 4°C. Do not freeze. Shelf life 6 months.	20ml 100ml

Technical Note:

Product #	Diameter	Color and form	Absorption max
47-0655	10nm	yellow liq.	390-400nm
47-0658	20nm	yellow liq.	405nm
47-0660	30nm	yellow liq.	410nm
47-0663	40nm	yellow liq.	416nm
47-0665	50nm	yellow liq.	425nm
47-0668	60nm	yellow liq.	430nm
47-0670	80nm	yellow liq.	457nm
47-0672	100nm	yellow liq.	490nm

NANOMATERIALS - SILVER (Elemental Forms)

Silver Nanoparticles - Surfactant and Reactant-Free (Pure), Manufactured via Laser Ablation
25ml
100ml

Note: Made to order. Manufactured by laser ablation. Store at room temperature (up to 25°C). Do not freeze. Shelf life 12 months. Sold in collaboration with Particular® for research purposes only.

47-0712
HAZ
Silver nanoparticles, pure, (<20nm) in acetone at 100mg/L (surfactant and reactant-free) *(7440-22-4)*
yellowish-brown liq.

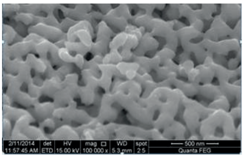
47-0710
Silver nanoparticles, pure, (<20nm) in water at 100mg/L (surfactant and reactant-free, stabilized with < 0.01 mmol/l of citrate) *(7440-22-4)*
yellow liq.

47-0718
Silver nanoparticles, pure, (<20nm) in water at 500mg/L (surfactant and reactant-free, stabilized with < 0.01 mmol/l of citrate) *(7440-22-4)*
yellowish-grey liq.

47-0722
HAZ
Silver nanoparticles, pure, (50-70nm) in acetone at 100mg/L (surfactant and reactant-free) *(7440-22-4)*
yellowish-brown liq.
Particle size of 50-70 nm is measured via DLS, colloid may also contain significant fractions of smaller particles. ***Limited quantities available***

Silver Nanoporous Catalyst
1g
5g
25g

47-0645
NEW
HAZ
Silver Nano-Porous Catalyst (promoted with zirconium oxide)
Ag; grey pwdr.
Note: Sold under license from OXENERGY for research purposes only. US Patent No 8,142,938.



Specifications:
*Average cluster (particle) size, micron:*12-17; *Average cluster porosity, %:*38-42; *Average pore size, nm:* 30-50; *Specific surface area, m²/g:/ 6.0-7.0; Apparent density, g/ml:* 0.9-1.1

NANOMATERIALS - TIN (Compounds)

50-0518
NEW
Tin(IV) oxide, nanoparticle (30-60 nm), (99.7%-Sn) *(18282-10-5)*
SnO_2; FW: 150.69; white pwdr.; SA: 18.55 m²/g; m.p. 1630°; d. 6.95
25g
100g

NANOMATERIALS - TITANIUM (Elemental Forms)

Titanium Nanoparticles - Surfactant and Reactant-Free (Pure), Manufactured via Laser Ablation

Note: Made to order. Manufactured by laser ablation. Store at room temperature (up to 25°C). Do not freeze. Shelf life 12 months. Sold in collaboration with Particular® for research purposes only.

22-0192
HAZ
Titanium nanoparticles, pure, (<20nm) in acetone at 100mg/L (surfactant and reactant-free) *(7440-32-6)*
grey liq.
Note: ***Limited quantities available***
25ml
100ml

22-0198
Titanium nanoparticles, pure, (50-70nm) in ethylene glycol at 100mg/L (surfactant and reactant-free) *(7440-32-6)*
grey liq.
Note: Particle size of 50-70 nm is measured via DLS, colloid may also contain significant fractions of smaller particles. ***Limited quantities available***
25ml

22-0203
HAZ
Titanium nanoparticles, pure, (50-70nm) in isopropanol at 100 mg/L (surfactant and reactant-free) *(7440-32-6)*
grey liq.
Note: Particle size of 50-70 nm is measured via DLS, colloid may also contain significant fractions of smaller particles. ***Limited quantities available***
100ml

NANOMATERIALS - TITANIUM (Compounds)

22-1400	**Titanium(IV) oxide nanopowder Anatase** *(1317-80-2)* TiO_2; FW: 79.90; white pwdr.	5g 25g

Specific Surface Area (BET): ≥500 m^2/g; **True Density:** 3.7 g/cc; **Crystallite Size:** Amorphous; **Mean Aggregate Size**: 5 µm; **Average Pore Diameter:** 32Å; **Loss on Ignition:** ≤12%; **Total Pore Volume:** ≥0.4 cc/g; **Moisture Content:** ≤4%; **Bulk Density:** 0.6 g/cc; **Ti Content (Based on Metal):**> 99.999%

NANOMATERIALS - ZINC (Elemental Forms)

30-1500 HAZ	**Nano Zinc Metallic Powder** *(7440-66-6)* Zn; gray pwdr.; Average particle size: 75-125 nm; Morphology: spherical; SA: 4-6 m^2/g *moisture sensitive*	1g 5g

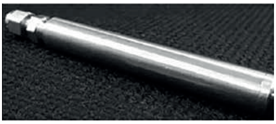
Technical Note:

1. Nano zinc powder is a highly reactive metal with a small particle size and high surface area. The product is exceptionally reactive with organic halides forming organozinc compounds, and in azo-cooupling reactions. The nano zinc can be deagglomerized into primary nanoparticles of 35nm by sonication.

NANOMATERIALS - ZINC (Compounds)

30-1405	**Zinc oxide nanopowder** *(1314-13-2)* ZnO; FW: 81.37; white pwdr.	25g 100g

NANOMATERIALS - OTHER

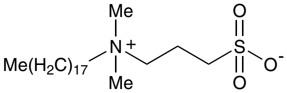
96-0900	**Enzymatic Flow Reactor** **(2.5 inch tube x 0.25 inch I.D.)**		1ea

Technical Note:

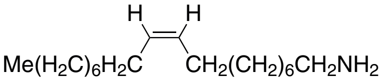
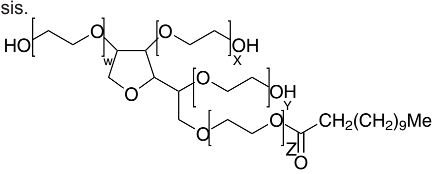
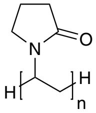
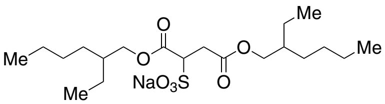
The EFR is a 2.5 inch long, 0.25 inch i.d. tube that is packed with stainless steel mesh coated with a total of approximately 50mg of silica nanosprings.

The surfaces of these nanosprings are functionalized with free sulfhydryl groups at the end of a three carbon chain that can react with an appropriately activated enzyme.

NANOMATERIALS (Surfactants & Ligands for Nano Synthesis)

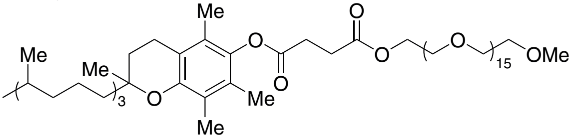
07-0440	**L-Cysteine ethyl ester hydrochloride, 98%** *(868-59-7)* $HSCH_2CH(NH_2)COOC_2H_5 \cdot HCl$; FW: 185.67; white solid; m.p. 123-125° Note: Surfactant for nanomaterial synthesis.	25g 100g
02-5043	**3-(Decyldimethylammonio)propanesulfonate (Sulfobetaine 10)** *(15163-36-7)* $[CH_3(CH_2)_9N]^+[(CH_3)_2(CH_2)_3SO_3]^-$; FW: 307.49; white solid Note: Surfactant for nanomaterial synthesis.	1g 5g
07-1677	**Didodecylamine, min. 97%** *(3007-31-6)* $[CH_3(CH_2)_{10}CH_2]_2NH$; FW: 353.67; white xtl. Note: Surfactant for nanomaterial synthesis.	1g
02-5055	**N-Dodecyl-N,N-dimethyl-3-ammonio-1-propanesulfonate (Sulfobetaine 12)** *(14933-08-5)* $CH_3(CH_2)_{11}N^+(CH_3)_2CH_2CH_2CH_2SO_3^-$; FW: 335.55; white pwdr. Note: Surfactant for nanomaterial synthesis.	10g 50g
02-5045 HAZ	**Hexadecyltrimethylammonium bromide, 99+% CTAB** *(57-09-0)* $[CH_3(CH_2)_{15}N(CH_3)_3]^+Br^-$; FW: 364.45; white solid; m.p. 248-251° Note: Surfactant for nanomaterial synthesis.	50g 250g
03-1180	**Lithium dodecyl sulfate, min. 98%** *(2044-56-6)* $CH_3(CH_2)_{11}OSO_3^-Li^+$; FW: 272.33; white solid Note: Surfactant for nanomaterial synthesis.	1g 5g
02-5056	**N-Octyldecyl-N,N-dimethyl-3-ammonio-1-propanesulfonate (Sulfobetaine 18)** *(13177-41-8)* FW: 419.70; white solid Note: Surfactant for nanomaterial synthesis.  	5g 25g

NANOMATERIALS (Surfactants & Ligands for Nano Synthesis)

06-4010	**Oleic acid, 99%** *(112-80-1)* $CH_3(CH_2)_7=CH(CH_2)_7COOH$; FW: 282.46; liq.; m.p. 13°; b.p. 194-195° (1.2mm); d. 0.89 Note: Surfactant for nanomaterial synthesis.	5g 25g
07-1665	**Oleylamine, min. 70%** *(112-90-3)* $CH_3(CH_2)_7CH=CH(CH_2)_7CH_2NH_2$; FW: 267.49; colorless liq.; m.p. 18-26°; b.p. 348-350°; d. 0.813 Note: Surfactant for nanomaterial synthesis.	5g 25g
07-1668	**Oleylamine, min. 95%** *(112-90-3)* $CH_3(CH_2)_7CH=CH(CH_2)_7CH_2NH_2$; FW: 267.49; colorless liq.; m.p. 18-26°; b.p. 348-350°; d. 0.813 Note: Surfactant for nanomaterial synthesis. 	5g 25g
09-5950	**Perfluorotetradecanoic acid, min. 97%** *(376-06-7)* $CF_3(CF_2)_{12}COOH$; FW: 714.11; white solid; m.p. 130-135°; b.p. 270° (740mm); d. 0.89 Note: Surfactant for nanomaterial synthesis.	1g
06-5075	**Polyethylene glycol dodecyl ether (Brij™ 35)** *(9002-92-0)* $CH_3(CH_2)_{10}CH_2(OCH_2CH_2)nOH$ (n~23); FW: ~1199.54; liq. (white solid @ room temperature); m.p. 41-45° Note: Surfactant for nanomaterial synthesis.	250g 1kg
08-1650	**Polyethylene glycol sorbitan monolaurate (TWEEN® 20)** *(9005-64-5)* FW: ~1228; viscous liq.; d. 1.095 Note: Surfactant for nanomaterial synthesis. 	5g 25g
07-1815	**Polyvinylpyrrolidone (average mol. Wt. 10,000) PVP10** *(9003-39-8)* $(C_6H_9NO)n$; white pwdr. Note: Surfactant for nanomaterial synthesis. 	50g 250g
07-1817	**Polyvinylpyrrolidone (average mol.wt. 40,000) PVP40** *(9003-39-8)* $(C_6H_9NO)n$; white pwdr. Note: Surfactant for nanomaterial synthesis.	50g 250g
11-2750	**Sodium dioctylsulfosuccinate (AOT), min. 95%** *(577-11-7)* $C_{20}H_{36}NaO_7S$; FW: 444.56; white pwdr.; m.p. 176° Note: Surfactant for nanomaterial synthesis. 	50g 250g
11-1140	**Sodium dodecylsulfate, 98+%** *(151-21-3)* $CH_3(CH_2)_{11}OSO_3Na$; FW: 288.38; white xtl.; m.p. 204-207°	25g 100g
11-1285	**Sodium dodecylsulfate, min. 99%** *(151-21-3)* $CH_3(CH_2)_{11}OSO_3^-Na^+$; FW: 288.38; white solid; m.p. 204-207° Note: Surfactant for nanomaterial synthesis.	50g 250g
11-1280	**Sodium oleate, 99%** *(143-19-1)* $CH_3(CH_2)_7CH=CH(CH_2)_7COO^-Na^+$; FW: 304.44; white pwdr.; m.p. 232-235° Note: Surfactant for nanomaterial synthesis.	5g 25g
02-5065 HAZ	**Tetramethylammonium hydroxide pentahydrate, min. 95%** *(10424-65-4)* $(CH_3)_4N(OH)\cdot 5H_2O$; FW: 181.23; white solid; m.p. 67-70° Note: Surfactant for nanomaterial synthesis.	10g 50g

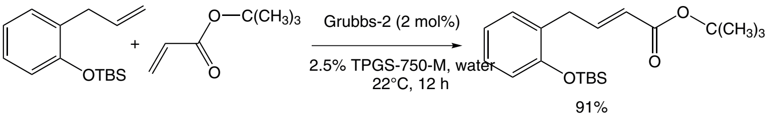
NANOMATERIALS (Surfactants & Ligands for Nano Synthesis)

02-5040	**Tetraoctylammonium chloride, min. 97%** *(3125-07-3)* $[CH_3(CH_2)_7]_4N^+Cl^-$; FW: 502.34; white xtl. Note: Surfactant for nanomaterial synthesis.	1g
08-2180	**DL-α-Tocopherol methoxypolyethylene glycol succinate solution (2 wt% in water) TPGS-750-M** $C_{66}H_{117}O_{21}$; FW: 1246.62; colorless liq. Note: Surfactant for nanomaterial synthesis.	10ml 50ml

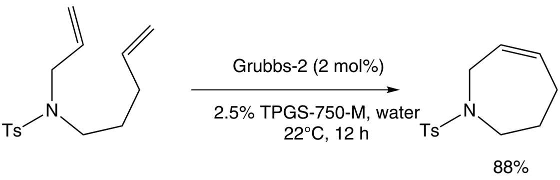


Technical Notes:

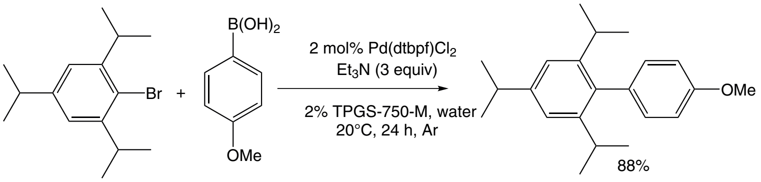
1. Grubbs-2 catalyst used in conjunction with the lypophilic amphiphile TPGS-750-M , for ring-closing and cross- metathesis reactions in water, at room temperature.
2. A variety of widely used palladium-catalyzed, cross-coupling reactions (including Heck, Suzuki-Miyaura, Sonogashira, and Buchwald-Hartwig aminations) can be run under mild, ambient conditions in water with TPGS-750-M .
3. C-H activation reaction utilizing a cationic palladium complex in combination with stoichiometric oxidant benzoquinone.



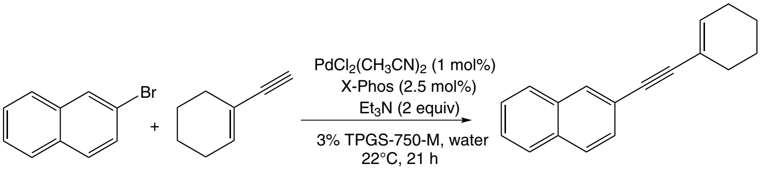
Tech. Note (1)
Ref. (1)



Tech. Note (1)
Ref. (1)



Tech. Note (2)
Ref. (1)



Tech. Note (2)
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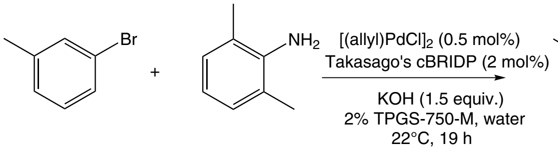
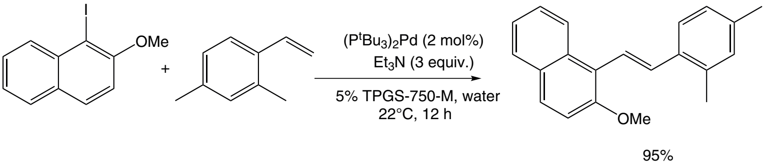


Tech. Note (2)
Ref. (1)

NANOMATERIALS (Surfactants & Ligands for Nano Synthesis)



Tech. Note (2)
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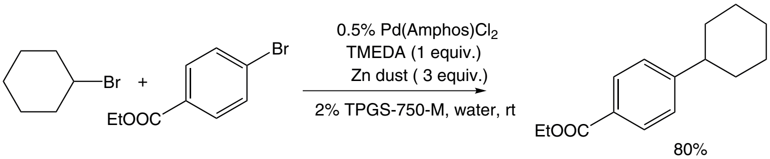

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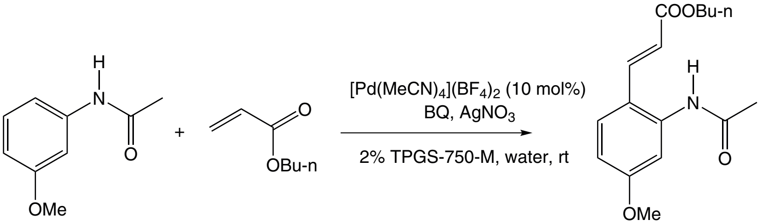
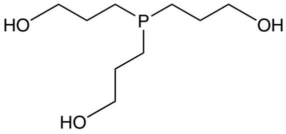
Ref. (1)



Tech. Note (3)
Ref. (1)

References:

1. *J. Org.Chem.,* **2011**, *76*, 4379

15-6655 HAZ	**Tri-n-octylphosphine, min. 97% TOP** *(4731-53-7)* $(C_8H_{17})_3P$; FW: 370.60; colorless to pale yellow liq.; m.p. 30°; b.p. 175°/0.3mm; f.p. 280°F; d. 0.83 *air sensitive* Note: Surfactant for nanomaterial synthesis.	25g 100g 500g
15-6660 HAZ	**Trioctylphosphine oxide, min. 90% TOPO** *(78-50-2)* $(n\text{-}C_8H_{17})_3PO$; FW: 386.65; off-white xtl.; m.p. 51-52°; f.p. >230°F; d. 0.88 *hygroscopic* Note: Surfactant for nanomaterial synthesis.	100g 500g
15-6661 HAZ	**Trioctylphosphine oxide, 99% TOPO** *(78-50-2)* $(n\text{-}C_8H_{17})_3PO$; FW: 386.65; white to off-white solid; m.p. 51-52°; f.p. >230°F; d. 0.88 *hygroscopic* Note: Surfactant for nanomaterial synthesis.	25g 100g
15-6375 amp HAZ	**Tris(3-hydroxypropyl)phosphine, min. 80%** *(4706-17-6)* $(HOC_3H_6)_3P$; FW: 208.24; viscous liq. *air sensitive* Note: Surfactant for nanomaterial synthesis. 	2g 10g 50g

KITS - CADMIUM SELENIDE CANdot® QUANTUM DOT (CdSe core) KIT

96-0800 **Cadmium selenide CANdot® quantum dot (CdSe core) kit, 50umol/L in hexanes, 525-625nm peak emissions**
HAZ
Sold in collaboration with CAN for research purposes.
Components also available for individual sale.
Contains the following:

48-1011	Cadmium selenide CANdot® quantum dot (CdSe core), 50umol/L in hexanes, 525nm peak emission *(1306-24-7)*	5ml	See page 16
48-1017	Cadmium selenide CANdot® quantum dot (CdSe core), 50umol/L in hexanes, 550nm peak emission *(1306-24-7)*	5ml	See page 16
48-1023	Cadmium selenide CANdot® quantum dot (CdSe core), 50umol/L in hexanes, 575nm peak emission *(1306-24-7)*	5ml	See page 16
48-1030	Cadmium selenide CANdot® quantum dot (CdSe core), 50umol/L in hexanes, 600nm peak emission *(1306-24-7)*	5ml	See page 16
48-1035	Cadmium selenide CANdot® quantum dot (CdSe core), 50umol/L in hexanes, 625nm peak emission *(1306-24-7)*	5ml	See page 16

Item #	Peak Emission	Particle size (diameter)	Quantum Yield
48-1011	525nm	2.8nm	>20%
48-1017	550nm	3.5nm	>10%
48-1023	575nm	3.9nm	>10%
48-1030	600nm	4.7nm	>20%
48-1035	625nm	5.3nm	>20%

Kit contains 5ml of each of the above 5 products. Ligand capping agent oleylamine. Stable in dispersions > 6 months.
*Particle size reported excludes ligand capping agent. All sizes determined by TEM.
† Available at nanoparticle concentration of 50μmol per liter.

KITS - CADMIUM SELENIDE/CADMIUM SULFIDE CANdot® QUANTUM ROD KIT

96-0813 **Cadmium selenide/cadmium sulfide CANdot® quantum rod kit (CdSe/CdS elongated core/shell), 5 mg/ml in hexanes, 560nm, 590nm, 620nm peak emissions**
HAZ
Sold in collaboration with CAN for research purposes.
Components also available for individual sale.
Contains the following:

48-1053	Cadmium selenide/cadmium sulfide CANdot® quantum rod (CdSe/CdS elongated core/shell), 5 mg/ml in hexanes, 560nm peak emission *(1306-24-7)*	0.5ml	See page 16
48-1056	Cadmium selenide/cadmium sulfide CANdot® quantum rod (CdSe/CdS elongated core/shell), 5 mg/ml in hexanes, 590nm peak emission *(1306-24-7)*	0.5ml	See page 16
48-1059	Cadmium selenide/cadmium sulfide CANdot® quantum rod (CdSe/CdS elongated core/shell), 5 mg/ml in hexanes, 620nm peak emission *(1306-24-7)*	0.5ml	See page 16

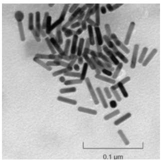
KITS - GOLD GEMINI NANORODS KIT (CTAB FREE)

96-1549 NEW	**Gold Gemini Nanorods Kit, CTAB Free (Wavelength 650-850 nm)** Rods are synthesized without CTAB. Store at 4°C - 8°C. Do not freeze. At storage temperature the product may appear opaque. Follow the procedure for re-dispersing surfactants as described in the technical note. Complete this process before use to dissolve precipitated stabilizer. Sold in collaboration with SONA Nanotech for research purposes only. Components also available for individual sale. Contains the following:

79-7010	Gold Gemini Nanorods, CTAB Free (Wavelength 650 nm) *(7440-57-5)*	5ml	See page 35
79-7015	Gold Gemini Nanorods, CTAB Free (Wavelength 700 nm) *(7440-57-5)*	5ml	See page 35
79-7020	Gold Gemini Nanorods, CTAB Free (Wavelength 750 nm) *(7440-57-5)*	5ml	See page 35
79-7025	Gold Gemini Nanorods, CTAB Free (Wavelength 800 nm) *(7440-57-5)*	5ml	See page 35
79-7030	Gold Gemini Nanorods, CTAB Free (Wavelength 850 nm) *(7440-57-5)*	5ml	See page 35

Item #	LPSR Maximum (nm)	Length (nm)	Width (nm)	Aspect Ratio	Color & Form
79-7010	640 - 670	25 - 31	13 - 18	1.7 - 1.9	violet liq.
79-7015	685 - 715	37 - 43	13 - 18	2.4 - 2.8	blue liq.
79-7020	735 - 765	37 - 44	10 - 13	3.4 - 3.7	red-purple liq.
79-7025	785 - 815	40 - 50	10 - 13	3.8 - 4.1	red-orange liq.
79-7030	835 - 865	48 - 55	9 - 12	4.6 - 5.3	maroon-purple liq.

Concentration: >30 µg/ml
pH: 5.5 - 7.5
Stabilizer: Amphiphilic Agents
Solvent: Stabilized with amphiphilic agents in conductivity grade water (18.0 MΩ cm^{-1})
Optical Density: 1.0 - 1.2
Shelf Life: 12 months



KITS - GOLD NANOPARTICLES KIT

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

79-0182	Gold Nanoparticles (5nm, 1 OD, supplied in 0.1mM stabilizing surfactant, 515-520nm abs. max.) *(7440-57-5)*	25ml	See page 31
79-0210	Gold Nanoparticles (10nm, 1 OD, supplied in 0.1mM stabilizing surfactant, 515-520nm abs. max.) *(7440-57-5)*	25ml	See page 31
79-0212	Gold Nanoparticles (15nm, 1 OD, supplied in 0.1mM stabilizing surfactant, 520nm abs. max.) *(7440-57-5)*	25ml	See page 31
79-0214	Gold Nanoparticles (20nm, 1 OD, supplied in 0.1mM stabilizing surfactant, 524nm abs. max.) *(7440-57-5)*	25ml	See page 31
79-0216	Gold Nanoparticles (30nm, 1 OD, supplied in 0.1mM stabilizing surfactant, 526nm abs. max.) *(7440-57-5)*	25ml	See page 31
79-0218	Gold Nanoparticles (40nm, 1 OD, supplied in 0.1mM stabilizing surfactant, 530nm abs. max.) *(7440-57-5)*	25ml	See page 31

KITS - GOLD NANOPARTICLES KIT (Reactant-Free)

96-1545 **Gold Nanoparticles Kit, Reactant-Free (5nm-40nm diameter, OD 1, suspension in phosphate-buffered saline, 515-530nm abs. max.)**
Components also available for individual sale.
Contains the following:

79-0180	Gold Nanoparticles (5 nm diameter, 1 OD, stabilized suspension in phosphate-buffered saline, 515-520 nm abs. max.) reactant free *(7440-57-5)*	25ml	See page 30
79-0184	Gold Nanoparticles (10nm diameter, 1 OD, stabilized suspension in phosphate-buffered saline, 520nm abs. max.) reactant free *(7440-57-5)*	25ml	See page 30
79-0186	Gold Nanoparticles (15nm diameter, 1 OD, stabilized suspension in phosphate-buffered saline, 520nm abs. max.) reactant free *(7440-57-5)*	25ml	See page 30
79-0188	Gold Nanoparticles (20nm diameter, 1 OD, stabilized suspension in phosphate-buffered saline, 524nm abs. max.) reactant free *(7440-57-5)*	25ml	See page 30
79-0190	Gold Nanoparticles (30nm diameter, 1 OD, stabilized suspension in phosphate-buffered saline, 526nm abs. max.) reactant free *(7440-57-5)*	25ml	See page 30
79-0192	Gold Nanoparticles (40nm diameter, 1 OD, stabilized suspension in phosphate-buffered saline, 530nm abs. max.) reactant free *(7440-57-5)*	25ml	See page 30

KITS - GOLD NANORODS KIT (Axial Diameter-25nm, Wavelength 550-700nm)

96-1530 **Gold Nanorods Kit (Axial Diameter - 25 nm, wavelength 550-700 nm)**
Components also available for individual sale.
Contains the following:

79-6000	Gold Nanorods (Axial Diameter - 25 nm) (Wavelength 550 nm) *(7440-57-5)*	25ml	See page 34
79-6005	Gold Nanorods (Axial Diameter - 25 nm) (Wavelength 600 nm) *(7440-57-5)*	25ml	See page 34
79-6010	Gold Nanorods (Axial Diameter - 25 nm) (Wavelength 650 nm) *(7440-57-5)*	25ml	See page 34
79-6015	Gold Nanorods (Axial Diameter - 25 nm) (Wavelength 700 nm) *(7440-57-5)*	25ml	See page 34

KITS - GOLD NANORODS KIT (Axial Diameter-10nm, Wavelength 700-808nm)

96-1535 **Gold Nanorods Kit (Axial Diameter - 10 nm, wavelength 700-808 nm)**
Components also available for individual sale.
Contains the following:

79-6020	Gold Nanorods (Axial Diameter - 10 nm) (Wavelength 700 nm) *(7440-57-5)*	25ml	See page 34
79-6025	Gold Nanorods (Axial Diameter - 10 nm) (Wavelength 750 nm) *(7440-57-5)*	25ml	See page 34
79-6030	Gold Nanorods (Axial Diameter - 10 nm) (Wavelength 780 nm) *(7440-57-5)*	25ml	See page 34
79-6035	Gold Nanorods (Axial Diameter - 10 nm) (Wavelength 808 nm) *(7440-57-5)*	25ml	See page 34

KITS - GOLD NANOSPHERES KIT

96-1540 **Gold Nanospheres Kit (30-90 nm)**
Components also available for individual sale.
Contains the following:

79-6040	Spherical Gold Nanoparticles (30 nm) *(7440-57-5)*	25ml	See page 32
79-6045	Spherical Gold Nanoparticles (50 nm) *(7440-57-5)*	25ml	See page 32
79-6050	Spherical Gold Nanoparticles (70 nm) *(7440-57-5)*	25ml	See page 32
79-6055	Spherical Gold Nanoparticles (90 nm) *(7440-57-5)*	25ml	See page 32

KITS - GRAPHENE QUANTUM DOTS (GQDs) MASTER KIT

96-7410 **Graphene Quantum Dots (GQDs) Master Kit**
NEW
Sold in collaboration with Dotz Nano Ltd. for research purposes only. Suggested use within 6 months of purchase. Do not freeze. Store in DARK.
Components also available for individual sale.
Contains the following:

06-0330	Graphene Quantum Dots (GQDs), Aqua-Green Luminescent *(1034343-98-0)*	100mg	See page 24
06-0332	Graphene Quantum Dots (GQDs) in water, Aqua-Green Luminescent *(1034343-98-0)*	100ml	See page 25
06-0334	Graphene Quantum Dots (GQDs), Blue Luminescent *(1034343-98-0)*	100mg	See page 25
06-0336	Graphene Quantum Dots (GQDs) in water, Blue Luminescent *(1034343-98-0)*	100ml	See page 25
06-0338	Graphene Quantum Dots (GQDs), Cyan Luminescent *(1034343-98-0)*	100mg	See page 25
06-0340	Graphene Quantum Dots (GQDs) in water, Cyan Luminescent *(1034343-98-0)*	100ml	See page 25

Item #	Photoluminescence			
	QY$^+$ *	λ_{max} *	Max emission	FWHM *
06-0330 / 06-0332	>17%	485 nm	525 nm	70 nm
06-0334 / 06-0336	>65%	350 nm	445 nm	65 nm
06-0338 / 06-0340	>25%	420 nm	490 nm	80 nm
Abbreviations				
QY$^+$	Quantum Yield			
λ_{max}	Maximum excitation wavelength			
FWHM	Full width at half maximum			

KITS - GRAPHENE QUANTUM DOTS (GQDs) MINI KIT (Powders)

96-7425 NEW

Graphene Quantum Dots (GQDs) Mini Kit (Powders)

Sold in collaboration with Dotz Nano Ltd. for research purposes only. Suggested use within 6 months of purchase. Do not freeze. Store in DARK.

Components also available for individual sale.

Contains the following:

06-0330	Graphene Quantum Dots (GQDs), Aqua-Green Luminescent *(1034343-98-0)*	100mg	See page 24
06-0334	Graphene Quantum Dots (GQDs), Blue Luminescent *(1034343-98-0)*	100mg	See page 25
06-0338	Graphene Quantum Dots (GQDs), Cyan Luminescent *(1034343-98-0)*	100mg	See page 25

Item #	Color & Form	Photoluminescence			
		QY$^+$ *	λ max *	Max emission	FWHM *
06-0330	dark red-brown pwdr.	>17%	485 nm	525 nm	70 nm
06-0334	dark brown pwdr.	>65%	350 nm	445 nm	65 nm
06-0338	dark brown pwdr.	>25%	420 nm	490 nm	80 nm
Particle diameter: <5 nm **Topographic height:** 1.0 - 2.0 nm					
Abbreviations: QY$^+$ = *Quantum Yield*; λ max = *Maximum excitation wavelength*; FWHM = *Full width at half maximum*					

KITS - GRAPHENE QUANTUM DOTS (GQDs) MINI KIT (Liquids)

96-7420 NEW

Graphene Quantum Dots in water (GQDs) Mini Kit (Liquids)

Sold in collaboration with Dotz Nano Ltd. for research purposes only. Suggested use within 6 months of purchase. Do not freeze. Store in DARK.

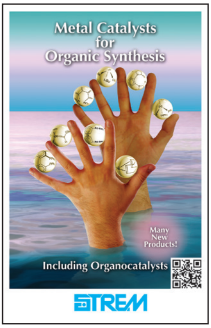
Components also available for individual sale.

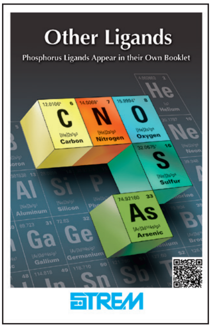
Contains the following:

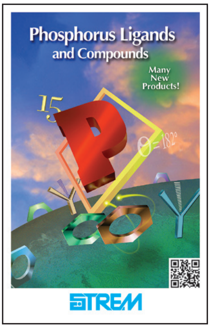
06-0332	Graphene Quantum Dots (GQDs) in water, Aqua-Green Luminescent *(1034343-98-0)*	100ml	See page 25
06-0336	Graphene Quantum Dots (GQDs) in water, Blue Luminescent *(1034343-98-0)*	100ml	See page 25
06-0340	Graphene Quantum Dots (GQDs) in water, Cyan Luminescent *(1034343-98-0)*	100ml	See page 25

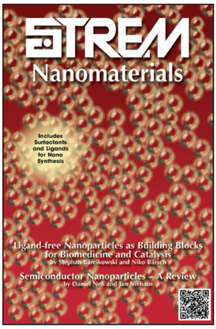
Item #	Color & Form	Photoluminescence			
		QY$^+$ *	λ max *	Max emission	FWHM *
06-0332	cloudy orange liq.	>17%	485 nm	525 nm	70 nm
06-0336	cloudy colorless liq.	>65%	350 nm	445 nm	65 nm
06-0340	cloudy brown liq.	>25%	420 nm	490 nm	80 nm
Particle diameter: <5 nm **Topographic height:** 1.0 - 2.0 nm **Concentration:** 1mg/ml					
Abbreviations: QY$^+$ = *Quantum Yield*; λ max = *Maximum excitation wavelength*; FWHM = *Full width at half maximum*					

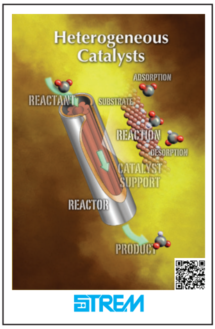
Available Booklets

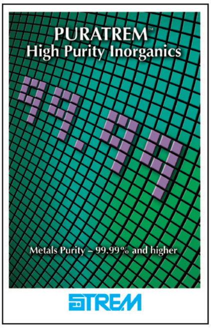


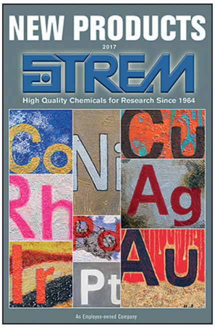


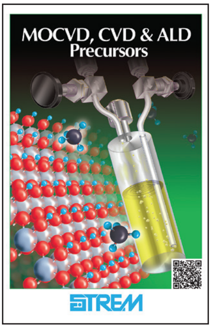


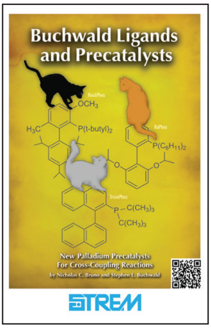


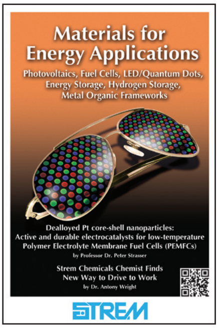












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