2016 Nobel Prize in Chemistry for Molecular Machines

The Royal Swedish Academy of Sciences has decided to award Jean-Pierre Sauvage, Sir James Fraser Stoddart and Bernard (Ben) L. Feringa the Nobel Prize in Chemistry 2016 “for the design and synthesis of molecular machines”. This is a high recognition for supramolecular chemistry utilizing building blocks of host-guest complexes including also cyclodextrin complexes.

The molecular machines mimic the movements of machines in a highly miniaturized scale. They need external fueling which is usually light or other energy. The first approach was topological entanglement (interlocked molecular assemblies). The building blocks are not covalently bound together but are entangled through loops and stoppers. Catenanes consisting of two interlocked rings and rotaxanes based on a ring threaded over an axle with stoppers are the main groups (Fig. 1).

Dramatic, reversible changes in the catenanes’ molecular shape were observed upon decomplexation and recomplexation of the metal coordination entities with Cu(I) as first examples of translational isomerism [3].

The group of Sir James Fraser Stoddart (University of Sheffield, UK) synthesized paraquat cyclophane structure threaded around an axle containing two hydroquinol units [4] (Fig. 2). The resulting rotaxane cyclophane ring could be shown to act as a molecular shuttle, able to move between the two hydroquinol stations on the axle. The trigger of the motion is electrochemical oxidation-reduction or pH change.
In parallel with the development of interlocked structures, systems based on isomerizable unsaturated bonds able to rotate unidirectionally in a controlled manner were synthesized. One of the first approaches published by Feringa’s group (University of Groningen, the Netherlands) is illustrated in Fig. 3 [5]. Taking together 4 such motors into one structure resembling to a 4-wheeled car, this group constructed the prototype of a ‘nanocar’ (four-wheeled molecule) [6].

Both linear and rotary motion was achieved on molecular scale providing artificial molecular machines built up from shuttles and switches (motors and pumps) where supplies of energy in the form of chemical fuel, electrochemical potential and light activation become a minimum requirement for them to function away from equilibrium [8].

**Activity of Nobel laureates with cyclodextrins**

According to Scopus all the three Nobel-Prize laureates have abundantly published their findings (Table 1). Although all of them mentioned CDs in their reviews or introduction of their research papers, only Stoddart was active in the development of novel structures including CD as building block.
Table 1 Publications statistics (Scopus, accessed on 24 November 2016)

<table>
<thead>
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<th>No. of papers</th>
<th>No. of papers mentioning CDs</th>
<th>CDs in the title, abstract or keywords</th>
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<td>Stoddart, J.F.</td>
<td>904</td>
<td>279</td>
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<td>Sauvage, J.P.</td>
<td>533</td>
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<td>Feringa, B.J.</td>
<td>739</td>
<td>26</td>
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Stoddart was born in 1942 and studied at Edinburgh University. Later on he made research at various universities in the US, UK and Canada. He was made a Knight Bachelor by Her Majesty Queen Elizabeth II. in 2007 for his services in chemistry and molecular nanotechnology.

Sir J.F. Stoddart was identified as one of the most-cited chemists in 1995–2005 period with over 11000 citations [9]. In October 2016 he had 83941 citations, 35439 since 2011 (Google Scholar, accessed on 20 November, 2016) with 7 papers of over 1000 citations. The three most cited papers are:

- Artificial molecular machines (Angew. Chemie [10], No. of citations: 2102)
- Self-assembly in natural and unnatural systems (Angew. Chemie [11], No. of citations: 1919)
- Electronically configurable molecular-based logic gates (Science [4], No. of citations: 1823)

Stoddart started to use the following expressions in his papers: switchable molecular devices [12], artificial molecular pumps [13], supramolecular devices, mechanically linked polymers, molecular elevators [14], molecular computers, molecular electronics [15], molecular logic gates [16], etc.

His CD-related activity covered also other topics, such as gold recovery, catalysis, metal-organic frameworks, sensors, etc.

**Molecular machines with CDs**

**Preparation of interlocked systems**

The very first attempt to thread CD on an axle molecule was a catenane prepared by the group of Friedrich Cramer (Fig. 4) preceding the works of the present Nobel laureates.

![Fig. 4. Scheme of the very first catenane using αCD prepared by Cramer’s group published in 1958 [17]](image-url)
The very first *rotaxane* containing CD was prepared by Hiroshi Ogino (Tohoku University, Japan) utilizing the non-covalent interaction between α,ω-diaminoalkenes and CD using CoCl(ethylenediamine)$_2$ bulky groups as stoppers [18].

The first *polyrotaxanes* containing several CDs threaded on an axle molecule was published in the same year (in 1992) by Harada et al. and Wenz et al. (Fig. 5) [19, 20]. Harada used diamine-terminated polyethylene glycol and αCD to get a molecular necklace attaching dinitrofluorobenzene groups as stoppers, while Wenz stringed αCD rings on polyiminooligomethylene chains and terminated the chains with nicotinoyl groups. However, these systems did not show controllable motion.

![Fig. 5. Scheme of polyrotaxanes](image)

**Stimuli-responsive molecular devices and molecular machines with CDs**

Typical photoswitchable molecular devices based on *cis–trans* photoisomerization of azobenzene moity (Fig. 6) were prepared by several groups [21, 22]. Light-driven rotaxane molecular shuttles and nanovalves containing αCD and azobenzene unit were constructed. The *cis–trans* photoisomerization of azobenzene moiety induces reversible motion of the CD ring on the effect of UV (hv) and visible (hv$^1$) irradiation (Fig. 6 and 7) [23].

![Fig. 6. Photoisomerization of azobenzene](image)

CD selectively binds to *trans*-azobenzene, which is less hydrophilic than the *cis* isomer. Upon irradiation the *trans*-azobenzene is transformed into the *cis* form causing αCD to unthread. Thermal relaxation allows *cis*-azobenzene to transform back to *trans* isomer and αCD to rebind.
Various other stimuli-responsive systems have been published. For instance, pH-responsive materials (Fig. 8) [24], redox-switchable molecular machines [25], etc. Some recent reviews give detailed overview on such systems [26–30].

It is a great honor to the entire cyclodextrin society of the world that molecular machines were selected for 2016 Nobel Prize, a field of supramolecular chemistry including advances in cyclodextrin chemistry.
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Toxicity, Fluorescence quenching, Inclusion complex
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Transport efficiency, Cellular uptake, Colorectal cancer
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Initial burst release, Risperidone

Enhancing effect of γ-cyclodextrin on wound dressing properties of sacran hydrogel film
Cross-linked hydrogel film, Swelling ratio, Porosity, α-CD, β-CD, γ-CD


Fabrication of non-spherical Pickering emulsion droplets by cyclodextrins mediated molecular self-assembly

Average roundness, Castor oil, Drug delivery system

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Copper-catalyzed azide-alkyl cycloaddition reaction, Microwave activation, Oseltamivir, Oleanolic acid, Hemagglutinin

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1-Dodecanethiol, Per-6-thiol-β-CD, Rhodamine B, Anticancer effect on mouse hepatoma Hepa 1-6 cells, Disulfide bond formation


Dual pH and temperature responsive hydrogels based on β-cyclodextrin derivatives for atorvastatin delivery

2-Methylacrylic acid modified β-cyclodextrin, 2-Methylacrylic acid, N,N’-methylene diacrylamide, Swelling rate, Drug release

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Herbal medicines, Binding behaviors

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**Stimuli-sensitive hollow spheres from chitosan-graft-β-cyclodextrin for controlled drug release**

*Sodium tripolyphosphate, Doxorubicin, Cytotoxicity tests, Polymeric hollow spheres*


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**Preparation, characterisation and antitumour activity of β-, γ- and HP-β-cyclodextrin inclusion complexes of oxaliplatin**

*Job plot, Cytotoxicity*


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**Curcumin-cyclodextrin complexes enhanced the anti-cancer effects of curcumin**

*Saturated aqueous solution method, Cell cycle arrest, Apoptosis*

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*HPBCD, Soluble β-CD polymer crosslinked with epichlorohydrin, Curcumin-loaded Pluronic 105 + 123 mixed micelles with β-CD*


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*Hydroxypropyl-β-cyclodextrin, Accumulation in the lipid raft microdomain, Cytotoxicity, Caveolin-1*

The Journal of Nutritional Biochemistry, 2016, 27, 266-277; DOI:10.1016/j.jnutbio.2015.09.018

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**Neuronal gene repression in Niemann–Pick type C models is mediated by the c-Abl/HDAC2 signaling pathway**
Treatment with methyl-β-cyclodextrin and vitamin E, Histone deacetylase 2, Tyrosine kinase c-Abl, Imatinib

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Cleavable PEGylated β-cyclodextrin-polyethyleneimine conjugate, In innate and adaptive immunogenicity of adenovirus particles, Cancer gene therapy

Acta Biomaterialia, 2016, 30, 94-105; DOI:10.1016/j.actbio.2015.11.005


Effect of O-methyl-β-cyclodextrin-modified magnetic nanoparticles on the uptake and extracellular level of L-glutamate in brain nerve terminals

Extraction of cholesterol from the plasma membrane, Triethoxy(3-isocyanatopropyl)silane, Magnetic manipulation, Maghemite nanoparticles

Colloids and Surfaces B: Biointerfaces, 2017, 149, 64-71; DOI:10.1016/j.colsurfb.2016.10.007

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Cholesterol-loaded cyclodextrins prevent cryocapacitation damages in buffalo (Bubalus bubalis) cryopreserved sperm

Viability/capacitation status, Fertilizing ability


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2-Hydroxypropyl-β-cyclodextrin, Atherosclerosis, Inflammasome, Interleukin-1β

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Cholesterol depletion by methyl-β-cyclodextrin, Plasma membrane, Infectivity

Virus Research, 2016, 211, 186-193; DOI:10.1016/j.virusres.2015.10.013


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Cholesterol-loaded-cyclodextrins, Phospholipids, Induced acrosome reaction, Membrane fluidity, Membrane integrity

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**Cholesterol-rich membrane microdomains modulate Wnt/β-catenin morphogen gradient during *Xenopus* development**

*Disruption by methyl-beta-cyclodextrin, Head development, Embryo*


**Combination of n-3 polyunsaturated fatty acids reduces atherogenesis in apolipoprotein E-deficient mice by inhibiting macrophage activation**

*Lipid raft disruption by methyl-β-cyclodextrin, Inflammation, Toll-like receptor 4*


**Biased signalling is an essential feature of TLR4 in glioma cells**

*Treatment with methyl-β-cyclodextrin, Lipopolysaccharides, Inflammatory balance, Biased agonism*


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**Characterization of beta-cyclodextrin inclusion complexes containing an essential oil component**

*Active packaging, Co-precipitation method, 2-Nonanone, Antimicrobial*

Food Chemistry, 2016, 196, 968-975; DOI:10.1016/j.foodchem.2015.10.023

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**Computational study of inclusion complex formation between carvacrol and β-cyclodextrin in vacuum and in water: Charge transfer, electronic transitions and NBO analysis**

*Hydrophobic interaction, Hydrogen bonding, PM3, ONIOM2, DFT, TD-DFT*


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**On the use of differential solubility in aqueous ethanol solutions to narrow the DP range of food-grade starch hydrolysis products**

*Corn syrup solids, Maltooligosaccharides, Maltopolysaccharides, Ethanol-fractionation, Dispersity*

Food Chemistry, 2016, 197, Part A, 872-880; DOI:10.1016/j.foodchem.2015.10.120

**Interactions of free and encapsulated hydroxycinnamic acids from green coffee with egg ovalbumin, whey and soy protein hydrolysates**

*Proteolytic digestion, Availability from processed food, β-Cyclodextrin*

LWT - Food Science and Technology, 2016, 65, 823-831; DOI:10.1016/j.lwt.2015.09.001

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*Chiral terpene alcohols, 2:2 stoichiometry*

Chemical Physics Letters, 2016, 651, 192-197; DOI:10.1016/j.cplett.2016.03.051

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**Cellulose sulfate based film with slow-release antimicrobial properties prepared by incorporation of mustard essential oil and β-cyclodextrin**

*Edible film, Coating for packaging*

Food Hydrocolloids, 2016, 55, 100-107; DOI:10.1016/j.foodhyd.2015.11.009

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**Kenaf (Hibiscus cannabinus L.) seed oil-in-water Pickering nanoemulsions stabilised by mixture of sodium caseinate, Tween 20 and β-cyclodextrin**

*Emulsifier mixtures, Synergistic effect*

Food Hydrocolloids, 2016, 52, 934-941; DOI:10.1016/j.foodhyd.2015.09.005

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**An inclusion complex of eugenol into β-cyclodextrin: Preparation, and physicochemical and antifungal characterization**

*Postharvest fresh litchi fruits, In vivo assays, Damage to hyphal and/or sporangiophore cell walls and membrane structures*

Food Chemistry, 2016, 196, 324-330; DOI:10.1016/j.foodchem.2015.09.052

Ho, B. T.; Hofman, P. J.; Joyce, D. C.; Bhandari, B. R.

**Uses of an innovative ethylene-α-cyclodextrin inclusion complex powder for ripening of mango fruit**

*Fruit colour and firmness, In-transit ripening*

Postharvest Biology and Technology, 2016, 113, 77-86; DOI:10.1016/j.postharvbio.2015.11.005


**Efficient antimicrobial activity and reduced toxicity of 1-dodecyl-3-methylimidazolium tetrafluoroborate ionic liquid/β-cyclodextrin complex**

*Imidazolium ionic liquid, Acute toxicity studies*

Chemical Engineering Journal, 2016, 284, 1136-1145; DOI:10.1016/j.cej.2015.09.041
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**Solubility, photostability and antifungal activity of phenylpropanoids encapsulated in cyclodextrins**

*Freeze-dried inclusion complexes, Phytopathogenic fungi, Encapsulation efficiency*

Food Chemistry, 2016, 196, 518-525; DOI:10.1016/j.foodchem.2015.09.078

Laokuldilok, N.; Thakeow, P.; Kopermsub, P.; Utama-ang, N.

**Optimisation of microencapsulation of turmeric extract for masking flavour**

*Binary blend of wall materials, Brown rice flour, β-CD, HPLC, Headspace GC–MS*

Food Chemistry, 2016, 194, 695-704; DOI:10.1016/j.foodchem.2015.07.150

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**Identification of a cyclodextrin inclusion complex of antimicrobial peptide CM4 and its antimicrobial activity**

*Novel food preservative, Susceptibility to proteinases, β-Cyclodextrin, Antibacterial assay, Stability*

Food Chemistry, 2016, In Press; DOI:10.1016/j.foodchem.2016.10.040

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**Improved stability of (+)-catechin and (−)-epicatechin by complexing with hydroxypropyl-β-cyclodextrin: Effect of pH, temperature and configuration**

*HP-β-CD, Protection effect, Isothermal titration calorimetry, Fluorescence spectroscopy, Stability*


Mendes, A. C.; Stephansen, K.; Chronakis, I. S.

**Electrospinning of food proteins and polysaccharides**

*Biopolymers, Nanofibers, Microfibers*

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Navarro, R.; Arancibia, C.; Herrera, M. L.; Matiacevich, S.

**Effect of type of encapsulating agent on physical properties of edible films based on alginate and thyme oil**

*Organoleptic characteristics, Trehalose, β-Cyclodextrin, Tween 20, Emulsions*

Food and Bioproducts Processing, 2016, 97, 63-75; DOI:10.1016/j.fbp.2015.11.001


**Fluorescence spectroscopic investigation of the interaction of citrinin with native and chemically modified cyclodextrins**

*Nephrotoxic mycotoxin, Contaminant of different foods and drinks, Methylated β-cyclodextrins, Fluorescence enhancement, Toxin binder*

Rutenberg, R.; Bernstein, S.; Paster, N.; Fallik, E.; Poverenov, E.

**Antimicrobial films based on cellulose-derived hydrocolloids. A synergetic effect of host–guest interactions on quality and functionality**

*Fresh harvested wheat grains, Bio-active hydrocolloids, Controlled release, β-Cyclodextrin, Propionic acid*

Colloids and Surfaces B: Biointerfaces, 2016, 137, 138-145; DOI:10.1016/j.colsurfb.2015.06.022

Sukhtezari, S.; Almasi, H.; Pirsa, S.; Zandi, M.; Pirouzifard, M.

**Development of bacterial cellulose based slow-release active films by incorporation of Scrophularia striata Boiss. extract**

*Intrinsic compactness, Food active packaging, β-Cyclodextrin, Physical properties, Antioxidant activity, Controlled release*

Carbohydrate Polymers, 2017, 156, 340-350; DOI:10.1016/j.carbpol.2016.09.058


**Fabrication of electrospun polylactic acid nanofilm incorporating cinnamon essential oil/β-cyclodextrin inclusion complex for antimicrobial packaging**

*Co-precipitation method, Minimum inhibitory concentration, Minimum bactericidal concentration*

Food Chemistry, 2016, 196, 996-1004; DOI:10.1016/j.foodchem.2015.10.043


**Encapsulation of cinnamon essential oil in electrospun nanofibrous film for active food packaging**

*Prolong the shelf-life of strawberry, Polyvinyl alcohol, Antimicrobial activity*

Food Control, 2016, 59, 366-376; DOI:10.1016/j.foodcont.2015.06.005

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**Chimonanthus praecox extract/cyclodextrin inclusion complexes: Selective inclusion, enhancement of antioxidant activity and thermal stability**

*Flavonoids, Food additive, Natural antioxidants*

Industrial Crops and Products, 2017, 95, 60-65; DOI:10.1016/j.indcrop.2016.09.033

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**β-Cyclodextrin incorporated nanoporous carbon: Host–guest inclusion for removal of p-nitrophenol and pesticides from aqueous solutions**

*1,4-Phenylene diisocyanate linker, DDT, DDD, DDE, Adsorption*

Chemical Engineering Journal, 2016, 283, 1424-1434; DOI:10.1016/j.cej.2015.08.110
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A new polyamide adjusted triazinyl-β-cyclodextrin side group embedded magnetic nanoparticles for bacterial capture
One-pot co-precipitation, Triphenyl phosphite, Monochlorotriazinyl-β-cyclodextrin, Nano-adsorbent, Poly(isophthalamid), Direct polycondensation

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Enhancement of methanol resistance of Yarrowia lipolytica lipase 2 using β-cyclodextrin as an additive: Insights from experiments and molecular dynamics simulation
Enzymatic biodiesel production, Surface modification
Enzyme and Microbial Technology, 2016, In Press; DOI:10.1016/j.enzmictec.2016.10.007

Celebioglu, A.; Sen, H. S.; Durgun, E.; Uyar, T.
Molecular entrapment of volatile organic compounds (VOCs) by electrospun cyclodextrin nanofibers
HP-βCD, HP-γCD, Aniline, Benzene, Electrospinning, Air filtration
Chemosphere, 2016, 144, 736-744; DOI:10.1016/j.chemosphere.2015.09.029

A new extraction method to assess the environmental availability of ciprofloxacin in agricultural soils amended with exogenous organic matter
Borax, Na₂EDTA, 2-Hydroxypropyl-β-cyclodextrin, Soil/compost mixtures, Available fraction level
Chemosphere, 2016, 165, 460-469; DOI:10.1016/j.chemosphere.2016.09.040

Fabrication of β-cyclodextrin/poly(l-glutamic acid) supported magnetic graphene oxide and its adsorption behavior for 17β-estradiol
Film diffusion, Intraparticle diffusion, Regeneration experiments

Kubli, M. R.; Yatsimirsky, A. K.
Phosphodiester cleavage by trivalent lanthanides in the presence of native cyclodextrins
Binuclear polyhydroxocomplexes, Metal–β-CD and phosphodiester–β-CD interactions, Kinetics, Hydrolysis, Catalysis
Kuklin, S.; Maximov, A.; Zolotukhina, A.; Karakhanov, E.

**New approach for highly selective hydrogenation of phenol to cyclohexanone: Combination of rhodium nanoparticles and cyclodextrins**

_Catalysis Communications, 2016, 73, 63-68; DOI:10.1016/j.catcom.2015.10.005_

Lannoy, A.; Kania, N.; Bleta, R.; Fourmentin, S.; Machut-Binkowski, C.; Monflier, E.; Ponchel, A.

**Photocatalysis of volatile organic compounds in water: Towards a deeper understanding of the role of cyclodextrins in the photodegradation of toluene over titanium dioxide**

_α-CD, β-CD, γ-CD, RAME-β-CD, Delay in the photodegradation process, Adsorption, Inclusion complex_


Li, X.; Shi, J.; Wu, K.; Luo, F.; Zhang, S.; Guan, X.; Lu, M.

**A novel pH-sensitive aqueous supramolecular structured photoinitiator comprising of 6-modified per-methylated β-cyclodextrin and 1-hydroxycyclohexyl phenyl ketone**

_6'-Acryloyl ethylenediamine-6'-deoxy-2',3'-di-O-methyl-hexakis (2''-vii, 3''-vii, 6''-vii-tri-O-methyl)-β-cyclodextrin, Water-souble_


Liu, J.; Xiao, Y.; Liao, K.-S.; Chung, T.-S.

**Highly permeable and aging resistant 3D architecture from polymers of intrinsic microporosity incorporated with beta-cyclodextrin**

_Gas separation performance, CO₂ permeability, Physical aging_

_Journal of Membrane Science, 2017, 523, 92-102; DOI:10.1016/j.memsci.2016.10.001_

Liu, Y.; Zou, C.; Li, C.; Lin, L.; Chen, W.

**Evaluation of β-cyclodextrin–polyethylene glycol as green scale inhibitors for produced-water in shale gas well**

_Agggregation of calcium carbonate crystals, Environmentally friendly, Water treatment_

_Desalination, 2016, 377, 28-33; DOI:10.1016/j.desal.2015.09.007_

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**Supramolecular enzyme mimics**

_Review, Artificial metalloenzyme, Cyclodextrin-based artificial enzymes, Supramolecular cages, Proteins, DNA, Molecular recognition, Dative and supramolecular anchoring_

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Peng, K.; Chen, C.; Pan, W.; Liu, W.; Wang, Z.; Zhu, L.

**Preparation and properties of β-cyclodextrin/4,4'-diphenylmethane diisocyanate/polyethylene glycol (β-CD/MDI/PEG) crosslinking copolymers as polymeric solid–solid phase change materials**
Crosslinking density, Thermal energy storage


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Fabrication of a dye-sensitized solar cell containing a noncarboxylated spiropyran-derived photomerocyanine with cyclodextrin

Carboxymethyl-β-cyclodextrin sodium salt (CM-β-CD), Photovoltaic conversion, Photoresponsivity, Inclusion complex


Tang, K.; Wang, Y.; Zhang, P.; Huang, Y.; Hua, J.

Optimization study on continuous separation of equol enantiomers using enantioselective liquid–liquid extraction in centrifugal contactor separators

Multistage enantioselective liquid–liquid extraction, HP-β-CD, Countercurrent cascade of centrifugal contactor separators, Simulation, Chiral separation

Process Biochemistry, 2016, 51, 113-123; DOI:10.1016/j.procbio.2015.11.021

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Preparation of Auₙ quantum clusters with catalytic activity in β-cyclodextrin polyurethane nanosponges

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Carbohydrate Polymers, 2016, 136, 54-62; DOI:10.1016/j.carbpol.2015.09.010

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High performance carbon-coated lithium zinc titanate as an anode material for lithium-ion batteries

β-CD as the carbon source

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Incorporating a novel metal-free interlayer into g-C₃N₄ framework for efficiency enhanced photocatalytic H₂ evolution activity

Thermal polymerization of the β-cyclodextrin and melamine, Charge transfer

Applied Catalysis B: Environmental, 2017, 203, 65-71; DOI:10.1016/j.apcatb.2016.09.075

Yu, L.; Vazquez-Cuevas, G.; Duan, L.; Semple, K. T.

Buffered cyclodextrin extraction of ¹⁴C-phenanthrene from black carbon amended soil

Soil organic matter, Hydroxylpropyl-β-cyclodextrin extraction, Mineralization, pH

Environmental Technology & Innovation, 2016, 6, 177-184; DOI:10.1016/j.eti.2016.09.002

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application in preconcentration of rare earth elements in seawater

La(III), Ce(III), and Eu(III), Multi-component adsorption

7. CDs in Sensing and Analysis

Enantioselective analysis of fluoxetine in pharmaceutical formulations by capillary zone electrophoresis
Cyclodextrin modified capillary electrophoresis, TRIMEB, Selective serotonin reuptake inhibitor, Chiral separation

Fanali, S.
Nano-liquid chromatography applied to enantiomers separation
Chiral selectors, Cyclodextrins, Glycopeptide antibiotics, Polysaccharides

Gao, J.; Zhang, S.; Liu, M.; Tai, Y.; Song, X.; Qian, Y.; Song, H.
Synergistic combination of cyclodextrin edge-functionalized graphene and multiwall carbon nanotubes as conductive bridges toward enhanced sensing response of supramolecular recognition
Dopamine, Uric acid, Tryptophan, Oxidation peak currents, β-Cyclodextrin, Conductive network

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Optical sensing composites for cysteine detection: Combining rhodamine-based chemosensors with up-conversion nanocrystals
Nanocrystals, α-Cyclodextrin, Emission decay lifetime

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Carbon nanotube β-cyclodextrin modified electrode as enhanced sensing platform for the determination of fungicide pyrimethanil
Pome fruit, Electrocatalytic oxidation, Voltammetric sensor
Food Control, 2016, 60, 7-11; DOI:10.1016/j.foodcont.2015.07.001

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A porous glass-based ozone sensing chip impregnated with potassium iodide and α-cyclodextrin
Supressing volatilization of iodine

An optical sensing composite for cysteine detection using up-conversion nanoparticles and a rhodamine-derived chemosensor: Construction, characterization, photophysical feature and sensing performance

α-Cyclodextrin, Excitation host

Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy, 2016, 155, 81-87; DOI:10.1016/j.saa.2015.11.009

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Mercapto-β-cyclodextrin, Gold nanoparticles, Multi-walled carbon nanotubes, Hydroquinone, Electrochemical marker, Sensitivity

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Ionic liquid, Gold nanoparticles, Imprinted electrochemical sensor

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Thermosensitive polymer-modified gold nanoparticles with sensitive fluorescent properties

Low critical solution temperature, Solvent, β-CD

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3,3’-Dihydroxybenzidine:α-cyclodextrin, Co-precipitation, Kneading method, Fluorescence enhancement, Bio-imaging


Miękus, N.; Olędzka, I.; Plenis, A.; Kowalski, P.; Bień, E.; Miękus, A.; Krawczyk, M. A.; Adamkiewicz-Drożyńska, E.; Bączek, T.

Determination of urinary biogenic amines’ biomarker profile in neuroblastoma and pheochromocytoma patients by MEKC method with preceding dispersive liquid–liquid microextraction
Moreira, F. T.; Sales, M. G. F.

Smart naturally plastic antibody based on poly(α-cyclodextrin) polymer for β-amyloid-42 soluble oligomer detection

Protein imprinting, Peptide biomarker, Alzheimer disease, α-CD, Natural building blocks, Screen-printed electrodes, Biosensor

Sensors and Actuators B: Chemical, 2017, 240, 229-238; DOI:10.1016/j.snb.2016.08.150


Preparation of β-cyclodextrin entrapped graphite composite for sensitive detection of dopamine

Electrochemical sensor, Screen-printed carbon electrode, Differential pulse voltammetry

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Pyrene attached on mononucleotides


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β-CD, Antipsychotic, Experimental design

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*Core-shell heterostructure*

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