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FUNCTIONAL SUPRAMOLECULAR SYSTEMS BASED ON AMPHIPHILIC (THIA)CALIX[4]ARENES DERIVATIVES

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Supramolecular chemistry is one of the most actively developing areas of modern science. The inexhaustible interest in supramolecular structures stems from their ability to self-assemble, that allows to create systems modeling processes occurring in living organisms, as well as to use nature's approaches to create such functional systems as molecular receptors, catalysts, nanoreactors, molecular machines, etc. For this reason, special attention of researchers working in the field of supramolecular chemistry is focused on amphiphilic molecules which are able to form highly ordered molecular ensembles in aqueous solutions. Amphiphilic macrocycles are of particular interest. A distinctive feature of amphiphilic macrocycles is their ability to high molecular recognition due to multipoint interactions.

The modular approach of click chemistry (especially the copper-catalysed cycloaddition reaction of azides and alkynes, CuAAC), proposed by Sharpless in 2001 [1], is extremely suitable for the construction of amphiphilic structures based on macrocycles due to its exceptional tolerance to the introduced functional groups, allowing the direct introduction of even ionized fragments without the use of protecting groups. So, it is possible to synthesize libraries of various amphiphilic compounds by the changing of azide- or alkyne-containing structural modules [2,3] (Figure 3).

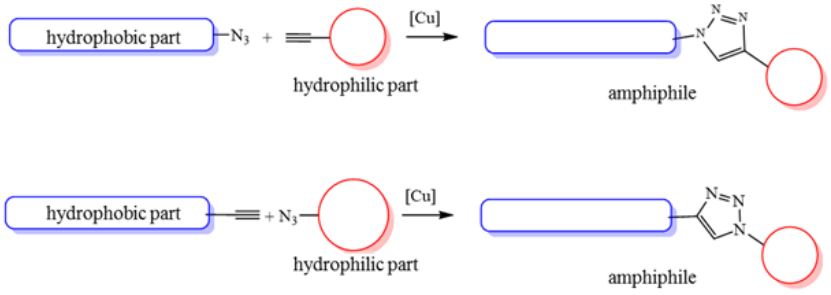


Figure 3. Design of amphiphilic compounds using CuAAC reaction.

Earlier the click chemistry approach has been applied to the preparation of amphiphilic derivatives based on platform of classical calix[4]arene in the *cone* configuration [4-6] using only tetra- or di-azidomethylene derivatives. For this reason the main aim of our work was the synthesis of novel macrocyclic click chemistry precursors with different of azide fragments number, different macrocycle stereoisomeric form, different types of lipophilic fragments, including both conventional long-chain alkyl and photopolymerisable diacetylene fragments, as well as the design of new functional supramolecular systems with practically useful properties on the basis of the obtained amphiphilic compounds [6-9].

Amphiphilic triazole derivatives of (thia)calix[4]arene

Thiacalix[4]arene platform due to its greater conformational mobility compared to the classical calix[4]arene allows easily to form in the macrocycle a spatial separation of lipophilic/hydrophilic domains on the base of bifunctional derivatives in the *1,3-alternate* stereoisomeric form.

The strategy for the synthesis of amphiphilic molecules based on *p-tert*-butylthiacalix[4]arene (fig. 4) involves the preliminary modification of the macrocycles by alkyl substituents of different lengths (compounds **1.1**-**1.3**) and further introduction of terminal alkynyl groups (way A) or azide fragments *via* di-bromo derivatives (way B). It is important that di-bromo intermediates can also be used for the synthesis of cationic amphiphiles by quaternization with N-nucleophiles (way C). For the synthesis of propargyl-containing precursors distally di-substituted derivatives **1.1**-**1.3** were reacted with propargyl bromide. It is important that products were isolated as a mixture of *1,3-alternate:partial cone* stereoisomers in a ratio of 2:1 [10] which was used in further transformations (fig. 9). Thiacalixarene derivatives **1.7**-**1.9** with two or four *O*-propargylethylene glycol fragments were obtained by Mitsunobu reaction [11]. In this case, the compounds were isolated exclusively in the *1,3-alternate* configuration.

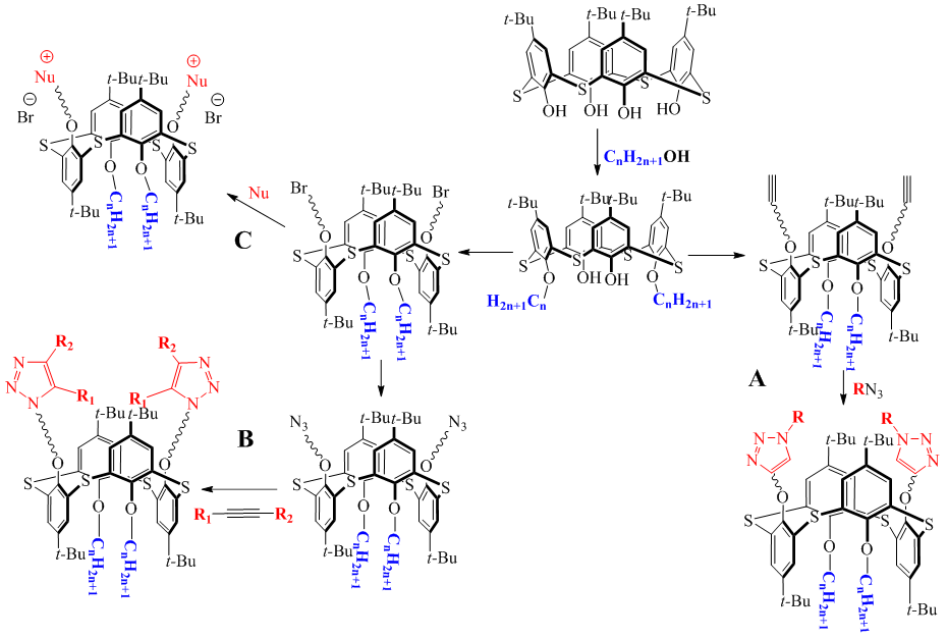


Figure 4. General strategy for the synthesis of amphiphilic compounds using CuAAC reaction or Menshutkin reaction on the *p-tert*-butylthiacalix[4]arene platform.

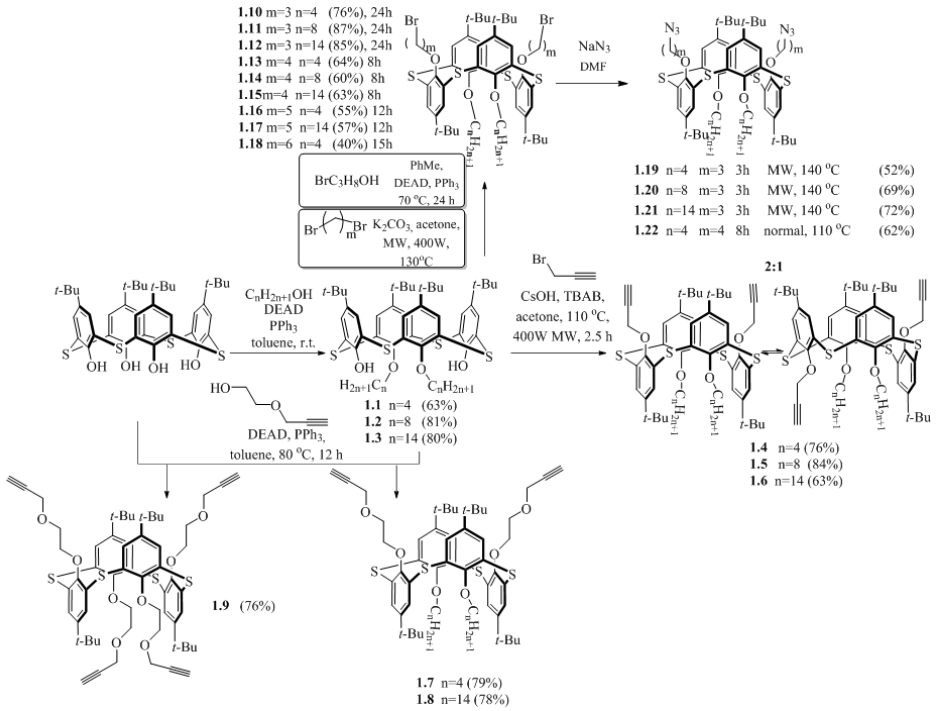


Figure 5. Synthetic approach of CuAAC precursors on a *p-tert*-butylthiacalix[4]arene platform.

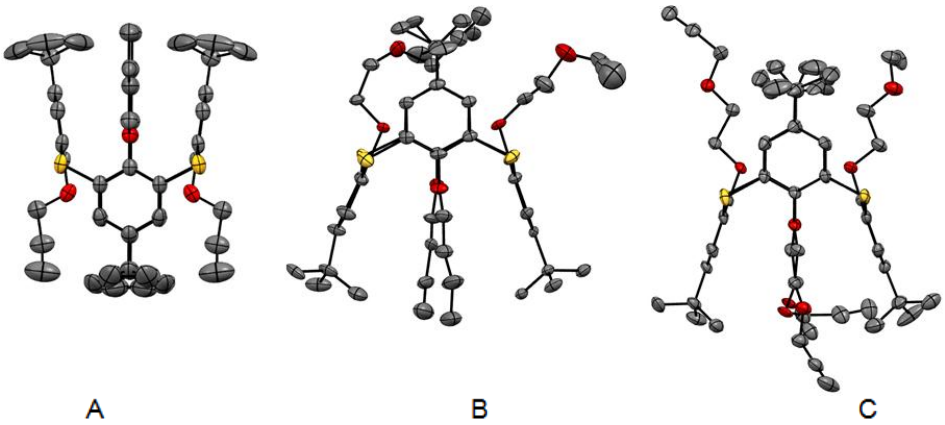


Figure 6. Structures of **1.4** (A), **1.7** (B) and **1.9** (C) macrocycles according to X-ray data.

The structure of compounds **1.4**, **1.7** and **1.9** was confirmed by single crystall X-ray diffraction analysis (fig. 6). Bromo-(**1.10**-**1.18**) and azide-containing (**1.19**-**1.22**) derivatives of *p*-*tert*-butylthiacalix[4]arene were also synthesized [12-14]. For this purpose, dialkyl-substituted macrocycles **1.1**-**1.3** were involved in Mitsunobu reaction (in the case of 3-bromopropanol) or Williamson reaction (in the case of longer-chain dibromalkyl derivatives). The obtained dibromides were reacted with sodium azide. It was found that the reaction with bromopropyl-containing derivatives **1.10**-**1.12** proceeded only under microwave activation. In the case of the linker containing four methylene groups the reaction took place under conventional heating.

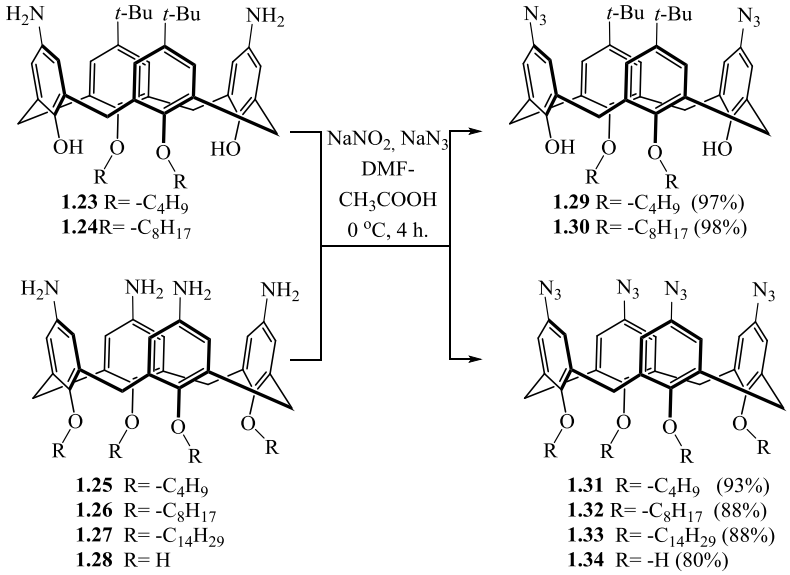
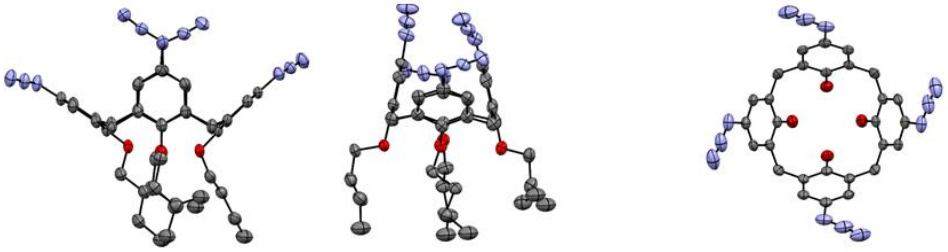


Figure 7. Synthesis of arylazide derivatives of calix[4]arene.

Click chemistry precursors based on classical calixarene were obtained in the *cone* conformation [15-18]: azide fragments are located on upper rim and alkyl substituents - on the lower rim of the macrocycle. The azide fragments on the upper rim were introduced by diazotization reaction of corresponding aminocalixarenes (**1.23** – **1.28**) and followed by diazo group substitution. A mixture of DMF and acetic acid (1:3) was found to be optimal solution for diazotization. The target di- (**1.29**-**1.30**) and tetraazides (**1.31**-**1.34**) were obtained in almost quantitative yields.



A B

Figure 8. Structures of **1.31** (A) and **1.34** (B) according to X-ray data.

Macrocycles **1.4**-**1.6** were involved into azide-alkyne cycloaddition reaction with a number of model azides. It was found [10] that these reactions occurs stereospecifically. A mixture of *partial cone*:*1,3-alternate* stereoisomers (ratio 1:2) of compound **1.4**-**1.6** forming at the first step (fig. 5), leads to the formation of cycloaddition product in only *1,3-alternate* stereo isomeric form (fig. 9).

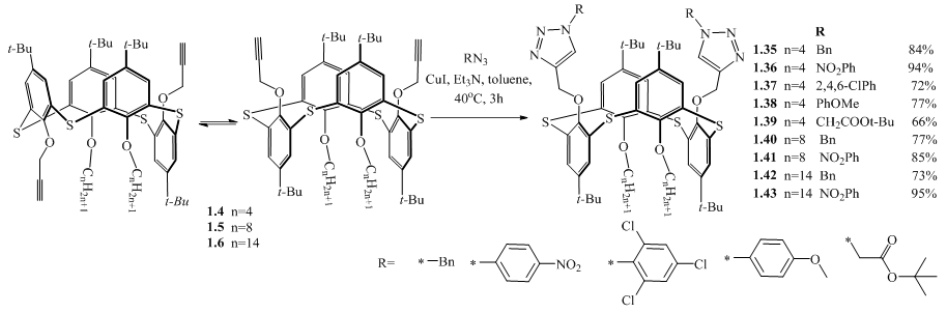


Figure 9. Synthesis of triazoles on the basis of dipropargyl derivatives **1.4**-**1.6**.

Bulky polar dendrons with terminal hydroxyl groups based on gallic acid were also introduced into propargyl-containing calixarenes **1.7**-**1.9** [11]. Amphiphilic (**1.44** and **1.45**) and symmetric (**1.46**) dendrimers in *1,3-alternate* configuration were obtained in high yields (fig. 10).

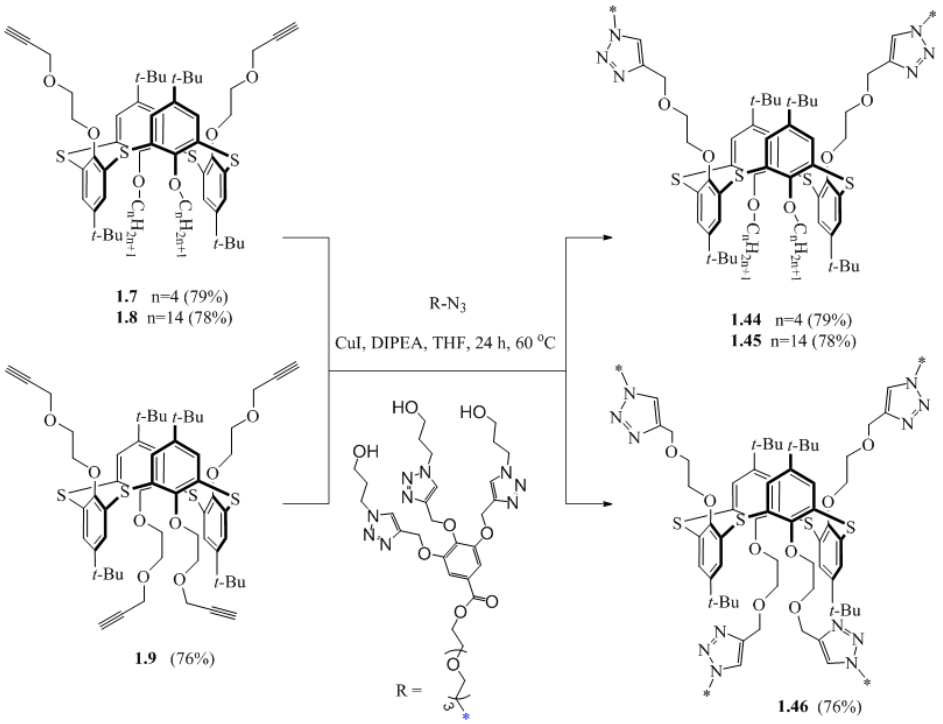


Figure 10. Synthesis of triazoles on the basis of propargyl derivatives **1.7**-**1.9**.

Despite on the stereoselectively of CuAAC reaction of alkynyl derivatives of thiacalix[4]arene with organic azides (fig. 9) this way to amphiphilic macrocycles looks rather complicated due to the instability and consequently the inaccessibility of low molecular weight azides. In this context the application of stable macrocyclic azides allows to involve into [3+2] cycloaddition a lot of either activated or non-activated acetylenes. Some examples of synthesized macrocycles are presented on figure 11, in particularly, containing anionic headgroups **1.47**-**1.51** (carboxyl and sulfonate [13]) and cationic headgroups **1.52**-**1.60** (triethylammonium and diethylenetriamine, [19-21]). The conjugate of *p-tert*-butylthiacalix[4]arene with oxyethyl-containing fluorescein **1.61** was prepared for further use in photocatalysis [22-23].

Calixareneazides **1.23**-**1.28** based on calix[4]arene platform were also involved in azide-alkyne cycloaddition reactions with both terminal acetylenes and activated acetylene dicarboxylic acid [15-17, 24]. The final triazoles were isolated in high yields (fig. 12). The cytotoxic properties of obtained amines **1.71** and **1.72** against MCF7 breast adenocarcinoma and PC-3 prostate carcinoma cell lines were investigated. The IC50 values (*μmol*) for **1.72** were 3.3 and 7.4 for MCF7 and PC-3, respectively, com-

pared to 21.3 for the normal cell line, suggesting some selectivity towards tumor cells.

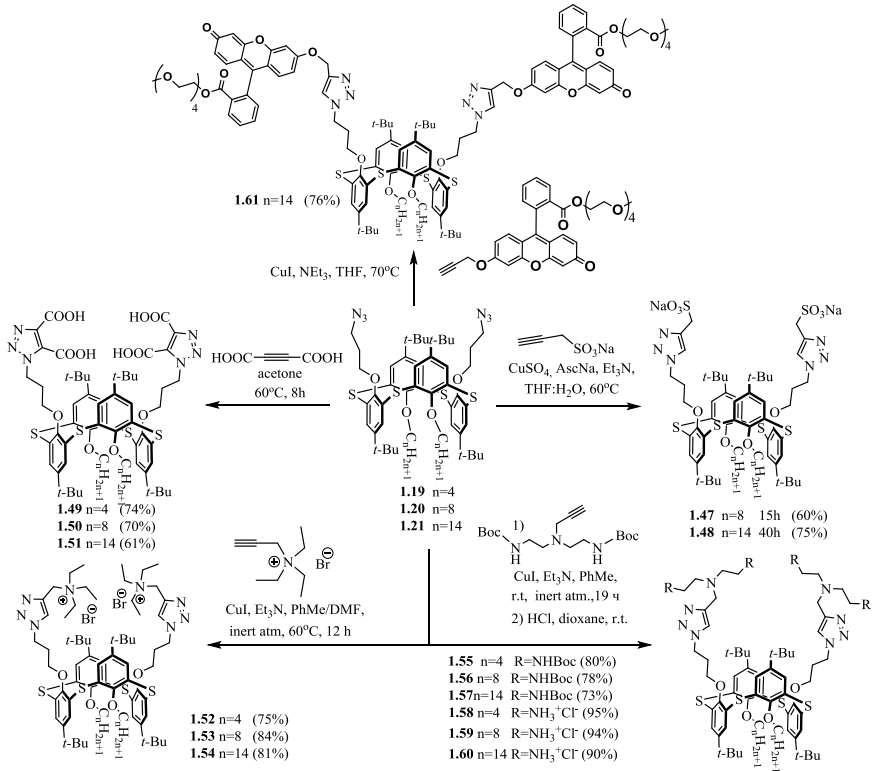


Figure 11. Synthesis of triazoles based on azide derivatives of *p-tert*-butylthiacalix[4]arene **1.19**-**1.21**.

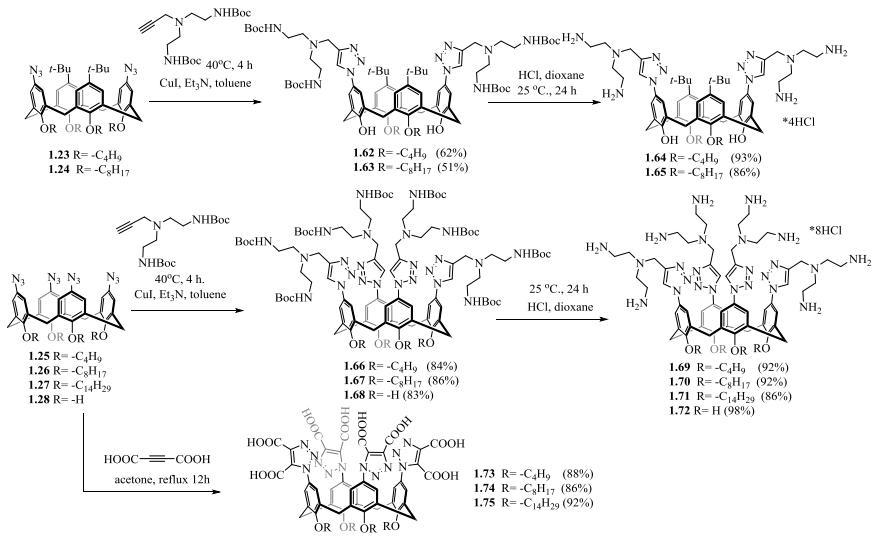


Figure 12. Synthesis of triazoles based on azide derivatives of calix[4]arene **1.23**-**1.28**.

Chemo/biosensors with optical response are of great demand since they allow the rapid determination of various analytes by simple color/fluorescence change. We found that the fluorescence of the anionic dye eosin is very sensitive to any changes occurring in macrocyclic aggregates. Fluorescence of eosin is quenched in the presence of cationic macrocycle monomers; after reaching of critical aggregation concentration (CAC), eosin migrates into the hydrophobic zone of the aggregates, which is reflected in a bathochromic shift and an increase in the fluorescence intensity of the dye. Competitive displacement of eosin upon interaction with analyte provides an optical signal (fig.13).

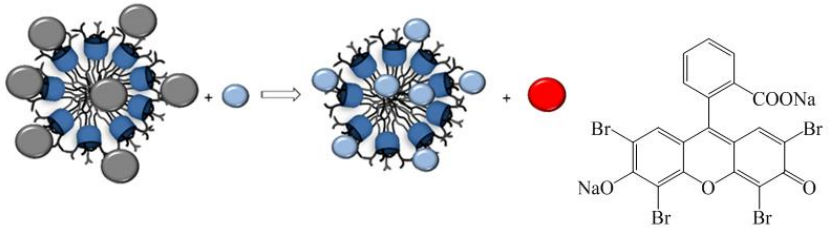
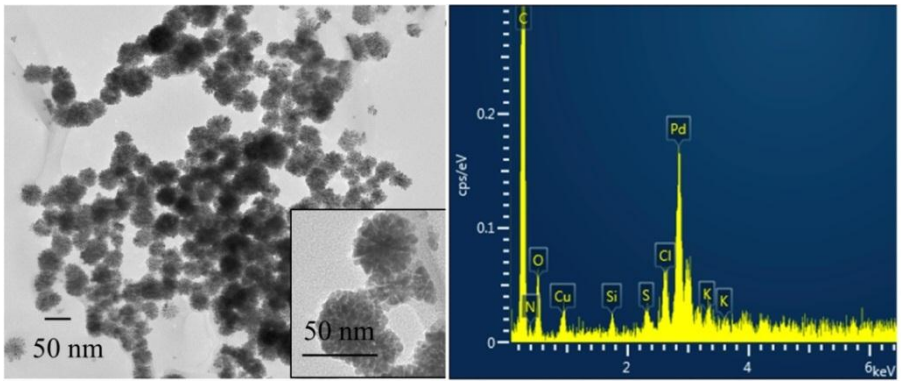


Figure 13. General operating principle of sensor systems based on dye displacement from aggregates.

Thus, a system based on ammonium thiacalixarenes **1.52**-**1.54** with eosin [19] was able to selectively detect alkyl sulphates (sodium lauryl and laureth sulphates), which cause the restructuring of aggregates and the release of eosin. The detection limit for alkyl sulphates was 3.5 μM. Using a similar approach, the adenosine phosphate-sensitive system based on the classical calixarenes **1.64**-**1.65** and **1.69**-**1.70** and eosin as an indicator was obtained [15]. Adenosine di- and triphosphates were found to induce an optical response when adenosine phosphates were added to the dye-calixarene dual system. A selectivity towards adenosine diphosphate was found in the case of disubstituted macrocycles. According to quantum-chemical calculations, adenosine diphosphate more effectively embedded into molecular cleft formed by two ammonium moieties due to a good host-guest geometrical and energetic complementarity.

Compounds containing diethylenetriamine fragments, both on the thiacalixarene platform [20] (**1.58**-**1.60**) and on calixarene platform [17, 18] (**1.69**-**1.72**) were able to interact efficiently with calf thymus DNA, causing its compaction into stable nanoparticles with an average size of 20-50 *nm*. It was found that macrocycle **1.72** with "free" lower rim is also capable of compacting DNA into 20 *nm* nanoparticles due to its conformational mobility and ability to bind multiple DNA strands.

A number of the obtained amphiphilic derivatives were also effective in catalytic transformations. Thus, using gallic-acid based dendrimers **1.44-1.46** as stabilizers [11], Pd nanodendrites located on the surface of dendrimer aggregates were obtained (fig.14). The resulting Pd nanodendrites were found as effective catalysts for the Suzuki coupling and the reduction of *p*-nitrophenol to *p*-aminophenol in aqueous solution.



A B

Figure 14. TEM micrographs of palladium nanodendrites stabilized on **1.45** (A) and their EDX spectrum (B) proving the elemental composition of the particles.

Macrocycles **1.73-1.75** were found to act as micellar catalysts [24] in the Suzuki coupling of phenylboronic acid with a number of aryl halides in water, significantly increasing the conversion of the reagents.

A photocatalytic system capable of operating in water based on the fluorescein derivative **1.61** was obtained [22]. Macrocycle **1.61** was found to be significantly more active in the photocatalytic reaction of *ipso*-hydroxylation of phenylboronic acid compared to the initial fluorescein, due to its ability to self-assemble and solubilize reagents.

Diacetylene-containing derivatives of (thia)calix[4]arene

The introduction of diacetylene lipophilic fragments into the structure of amphiphilic calix- and thiacalix[4]arenes significantly expands the potential applications of such systems due to the ability of 1,3-butadiyne fragments to undergo 1,4-type polymerization under UV light. The presence of extended conjugated en-yne chains causes coloration of the polymer. Upon stimuli, (mechanical, thermal, chemical), the efficiency of orbitals' overlapping decreases. This is reflected in the color change (hypsochromic shift) and the appearance of fluorescent properties (fig.15). Arming diacetylenes with receptor fragments makes it possible to obtain a variety of colorimetric sensors.

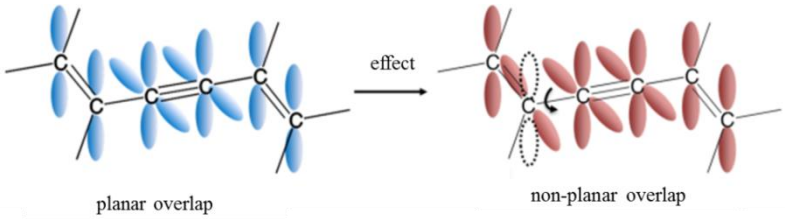


Figure 15. Optical signal generation by polydiacetylene matrix upon stimuli.

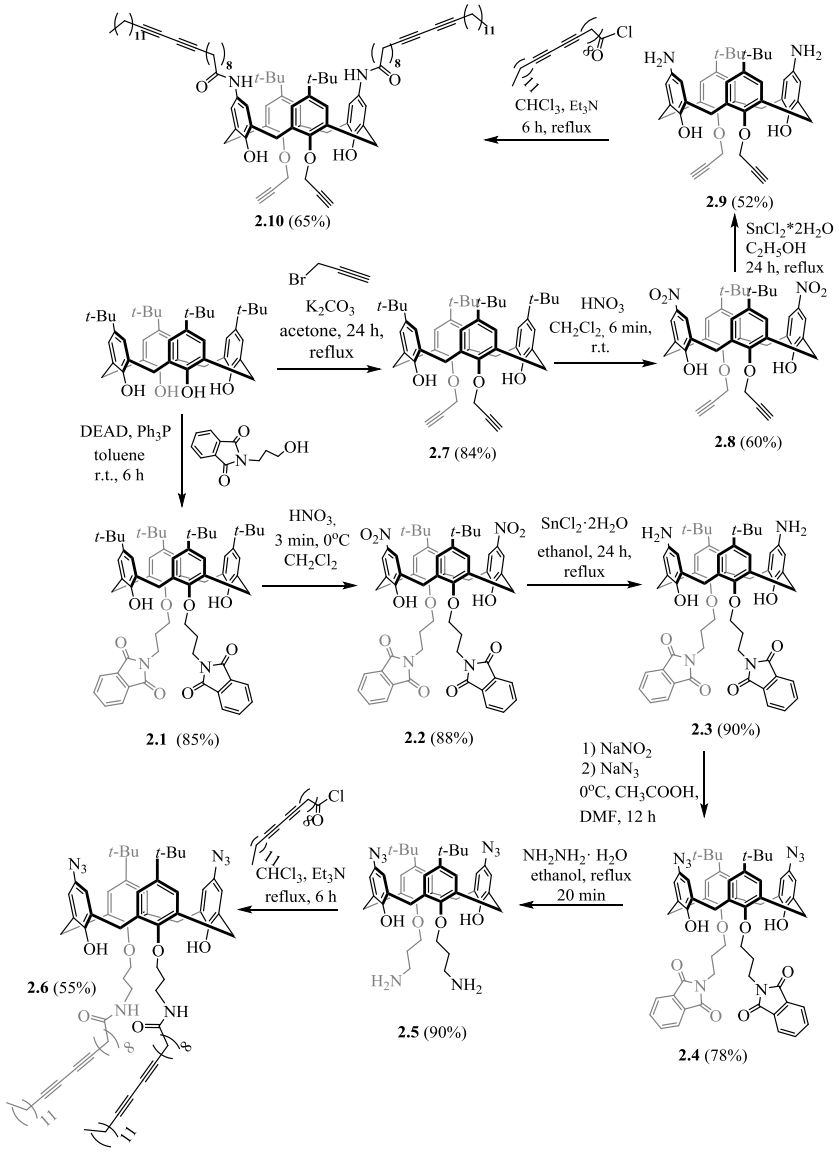


Figure 16. The synthesis of diacetylene derivatives of classical calix[4]arene.

Through the possibility of stepwise modification of calix[4]arene platform, diacetylene and functional alkynyl or azide fragments can be introduced on either the lower [25] (compound **2.6**) or the upper rim [26] (compound **2.10**) (fig.16).

Stepwise modification of the thiacalix[4]arene platform in its *1,3-alternate* configuration is a convenient alternative to modifying the classical calix[4]arene, since only the lower rim of a macrocycle is modified. Using this approach, a *p-tert*-butylthiacalix[4]arene **2.12** containing 5-phenylpenta-2,4-diyne fragments [27] and a macrocycle **2.15** containing 10,12-pentacosadiynoic acid residues [28] were synthesized by the Mitsunobu reaction (fig.17).

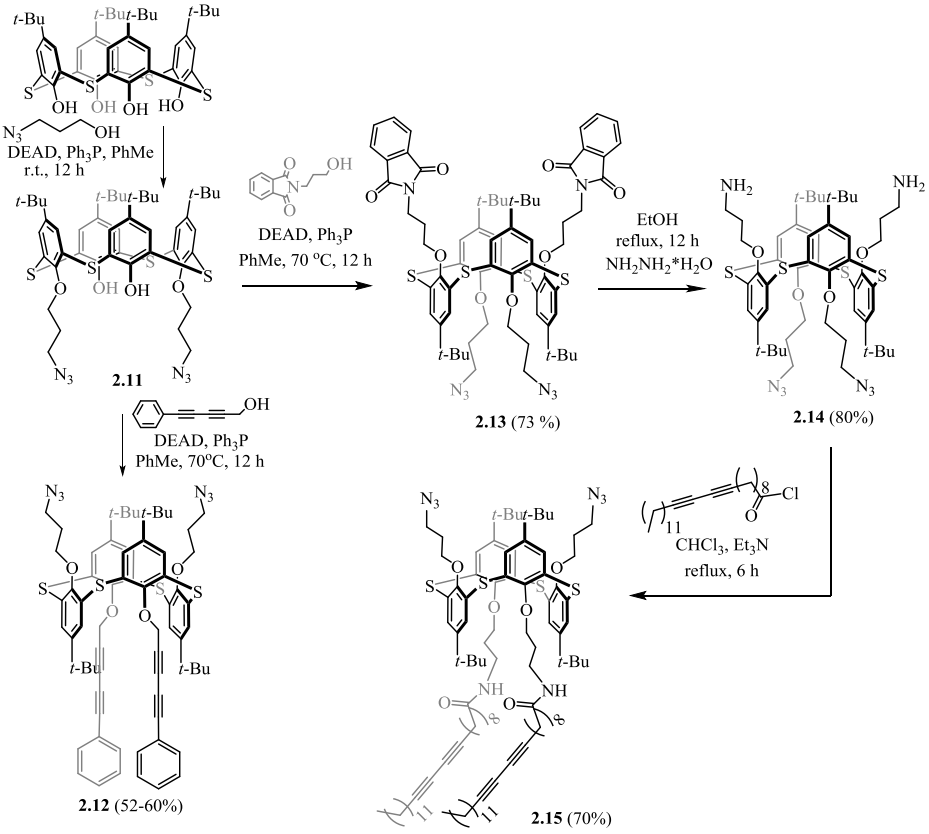


Figure 17. The synthesis of diacetylene derivatives of thiacalix[4]arene.

The diacetylene-containing macrocycles **2.12**, **2.15** and **2.16** were also introduced into reaction with acetylenedicarboxylic acid (fig.18) using an approach previously tested on alkyl-containing (thia)calix[4]arenes. The sulphonate derivative **2.17** was also synthesized using a copper(I) catalyst. Along with diacetylene derivatives containing anionic headgroups, cationic

amino derivatives of both thia and classical calix[4]arene **2.19**, **2.22** and **2.24** were also synthesized. Thus, the click chemistry approach was also effective for the precision modification of macrocyclic derivatives containing lipophilic diacetylene fragments.

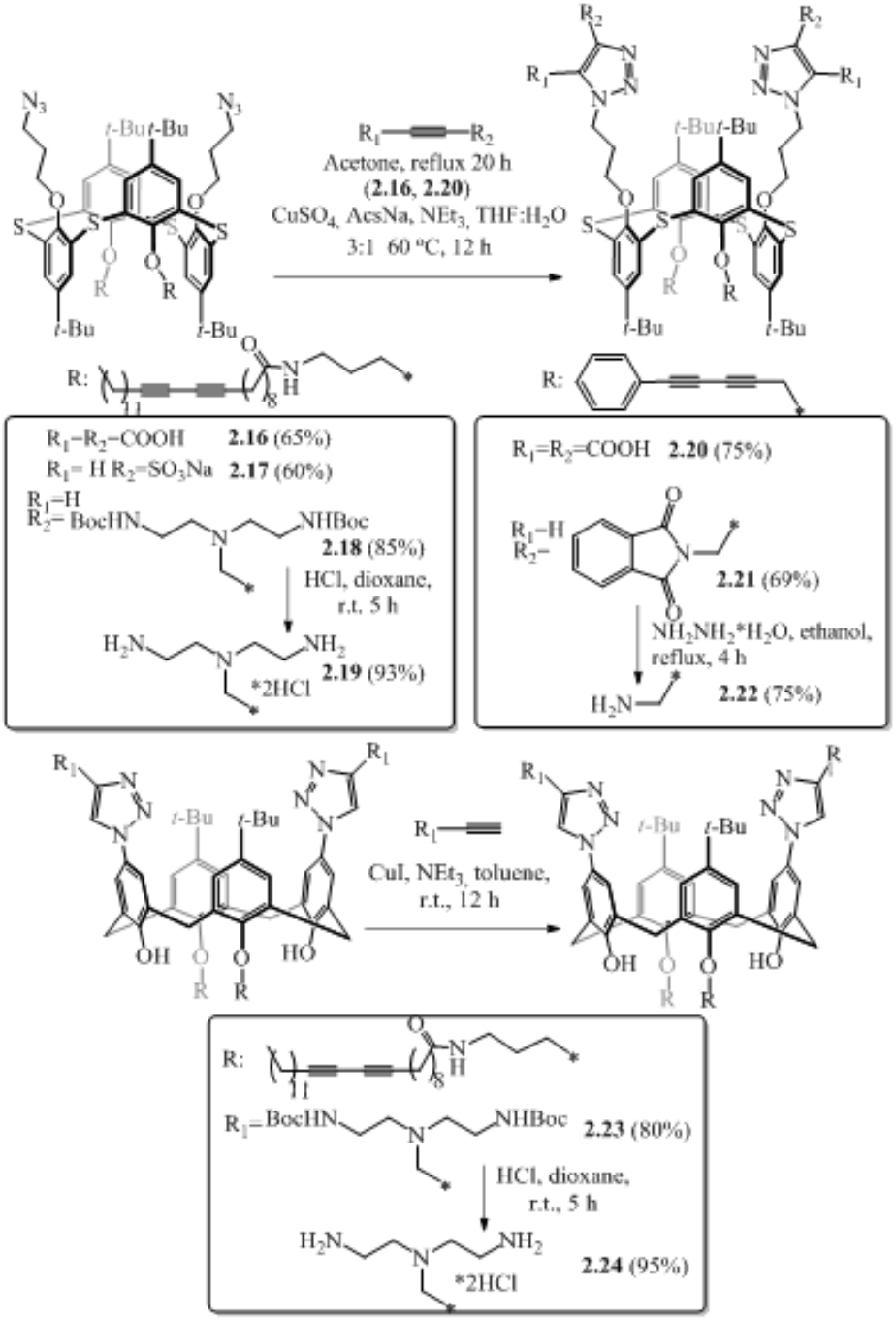


Figure 18. The synthesis of diacetylene (thia)calix[4]arene triazoles.

Using the film hydration method, polydiacetylene (PDA) particles of macrocycles **2.16** and **2.17** with 10,12-pentacosadiynoic acid (PCDA) as a base lipid were obtained [28]. According to the obtained data (fig.19), the prepared PDA particles have an intense colorimetric response towards lanthanide ions. The most intense response is observed for lanthanum, which is the bulkiest ion in the studied series. The coordination of bulk hydrated ions causes distortion of the macrocyclic platform, which also reflects on the distortion of the PDA polymer chain. Furthermore, the addition of lanthanide ions causes coagulation of PDA particles, which also induces a colorimetric response.

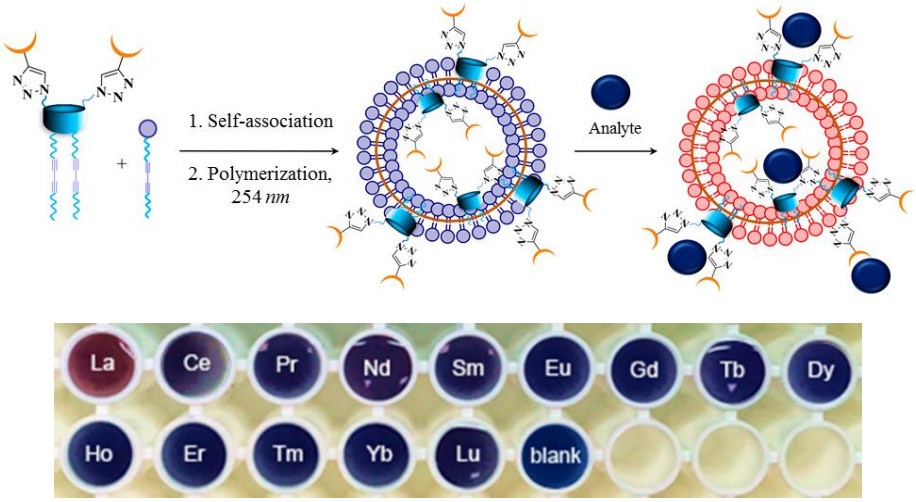


Figure 19. Scheme of PDA-particle production and photograph of a plate containing **2.16** - PDA-particles in the presence/absence of lanthanide nitrates. C(**2.16**) = 0.07 *mM*, C(PCDA) = 0.7 *mM*, TRIS 10 *mM*, pH 7.4, C(metal) = 0.7 *mM*.

Macrocycles with positively charged amino groups have also been used to prepare PDA-particles [29] using N-(2-aminoethyl)-10,12-pentacosadiynamide (AEPCDA) as the base lipid. PDA particles made from AEPCDA and thiacalixarene **2.19** were able to detect calf thymus DNA, whereas vesicles containing classical calixarene **2.24** were able to detect adenosine triphosphate.

Diacetylene-containing derivatives have attracted attention since the diacetylene motif is a precursor to a wide range of heterocycles. In an attempt to synthesize macrocyclic pyrazole derivatives, it was discovered [30] that in the presence of hydrazine hydrate the calix[4]arene derivative **2.25** with two 5-phenylpenta-2,4-diynyl fragments (fig. 20) is capable of reductive cleavage. It has been shown [31] that isostructural derivatives containing phenylpropargyl or propargyl fragments **2.26** and **2.27** are also reductively cleavable in the presence of hydrazine hydrate. The possibility of a one-pot reductive depropargylation reaction with reduction of nitro

groups in the corresponding nitro derivatives to give amines **2.35** and **2.36** upon addition of a nickel catalyst to hydrazine hydrate has been demonstrated.

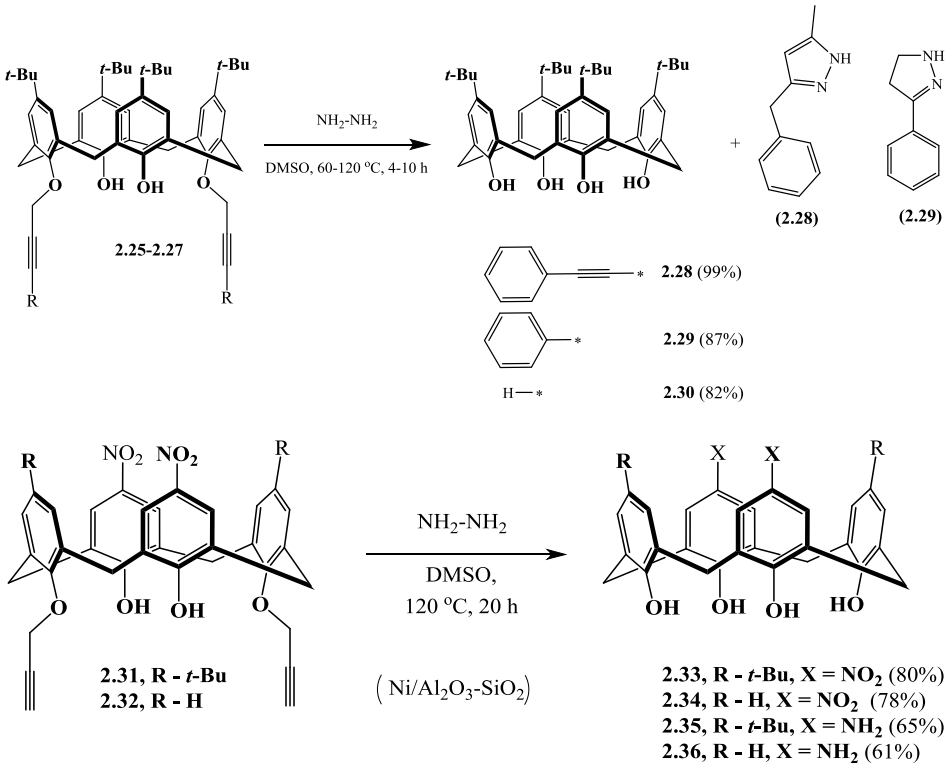


Figure 20. Reductive dealkylation reactions with hydrazine hydrate in diacetylene- or acetylene-substituted calixarene derivatives.

Bifunctional imidazolium derivatives of calix[4]arene

The potential of calixarene macrocycles can be significantly enhanced by introducing additional imidazolium fragments along with azide and alkynyl fragments. The macrocycles can form aggregates due to the presence of cationic headgroups. Upon addition of a suitable copper catalyst, these aggregates can be cross-linked through the CuAAC reaction to form covalently cross-linked polytriazole particles.

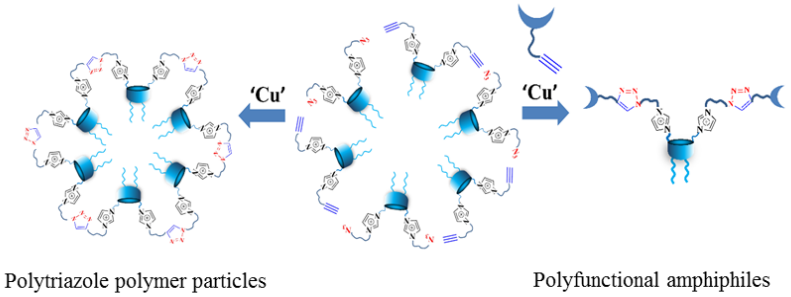


Figure 21. Potential applications of click chemistry precursors with imidazolium moieties.

When azide-containing imidazolium salts interact with polar alkynes, a series of polyfunctional amphiphiles containing additional important fragments in the polar region can be obtained.

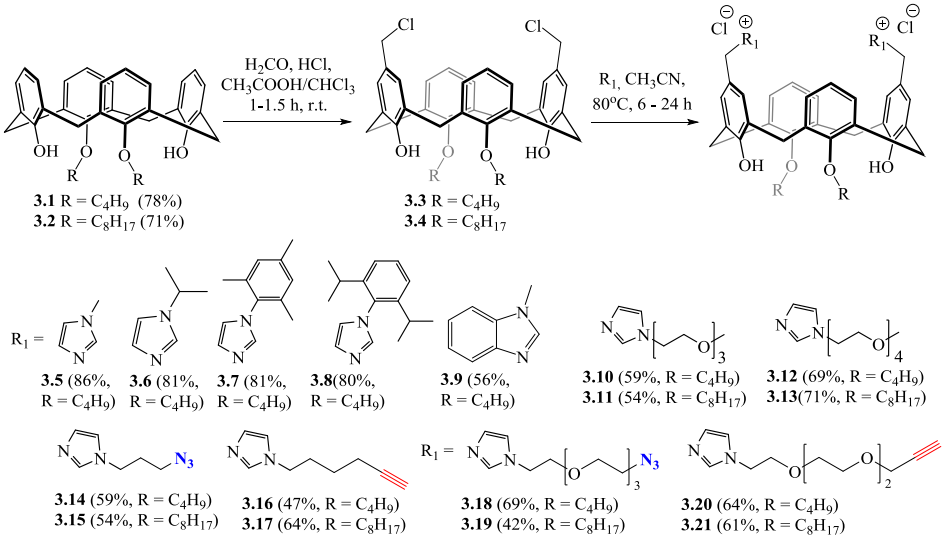


Figure 22. The synthesis of a series of imidazolium/benzimidazolium derivatives of calix[4]arene.

Chloromethylated macrocycles **3.3** and **3.4** containing mobile benzyl-type halogens seem to be the most convenient platform for the construction of such systems (fig. 22). These compounds have been obtained [32] by the Blank chloromethylation of disubstituted calix[4]arenes after one hour with quantitative yields. Taking into account that bis-imidazolium macrocycles can act as precursors of N-heterocyclic carbenes (NHC), imidazolium salts with bulk alkyl and aryl, hydrophilic oxyethyl and azidoalkyl/alkynyl fragments were produced for further reaction with chloromethylated calixarenes. Macrocycles **3.3** and **3.4** were reacted with the obtained imidazoles in acetonitrile. The products **3.5** to **3.21** were isolated in high yields [33-36]. The effect of compounds **3.5**-**3.9** on the course of the Suzuki-Miyaura

coupling was studied [33] on a model coupling reaction of phenylboronic acid with *p*-bromo-nitrobenzene, conducted in water with 0.5 *mol %* catalyst ($Pd(OAc)_2$). The addition of macrocycles improved the conversion of the aryl halide with the best results found for N-methyl substituted macrocycle **3.5**. As mentioned above, aggregates of imidazolium derivatives containing azide/alkynyl fragments can be covalently cross-linked using the CuAAC reaction. Crosslinking was carried out using compounds **3.14** and **3.16** with the concentrations of the macrocycles above their CAC [34]. Polydisperse polymers with the average weight about 5000 *kDa* were obtained. Presumably, due to the insufficient lipophilicity of the butyl fragments in **3.14** and **3.16**, the aggregates disintegrated during polymerization to form linear polymers. Indeed, the involvement of more lipophilic octyl macrocycles **3.15** and **3.17** [35] into the CuAAC polymerization significantly reduced the molecular weight of the polymer up to 95 *kDa* with a monomodal size distribution. The obtained polytriazole particles were then used to stabilize palladium nanoclusters produced by chemical reduction of Na_2PdCl_4 with ascorbic acid (fig. 23).

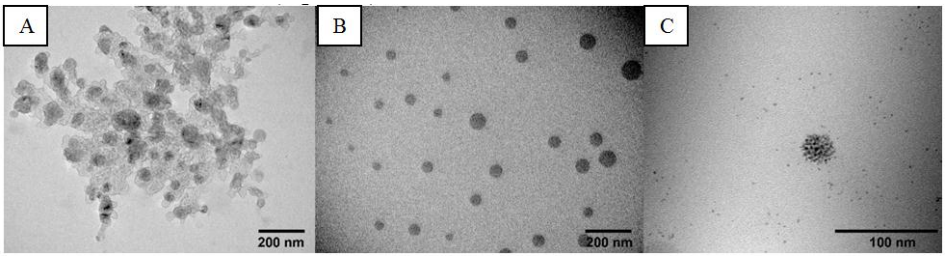


Figure 23. TEM micrographs of **3.15** + **3.17** polymer particles without (A) and with palladium deposited on the surface (B and C).

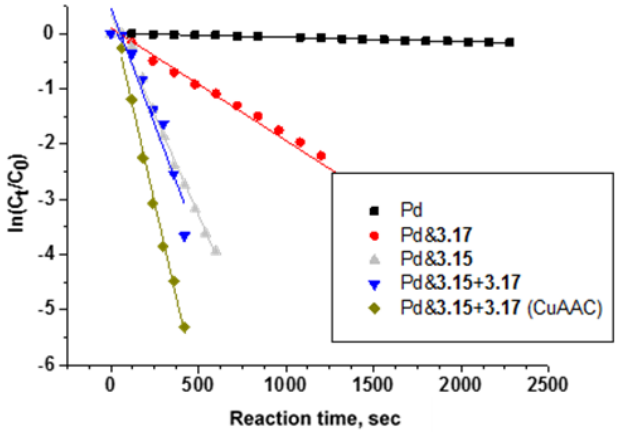


Figure 24. Plot of $\ln(C_t/C_0)$ *vs* catalytic reaction time for different Pd-containing catalytic systems. C(PNP) = 0.1 *mM*, $C(NaBH_4)$ = 5 *mM*, C(macrocycles, polymers or $Pd(OAc)_2$) = 0.2 *μM*, H_2O, 25 *℃*.

The comparative catalytic activity of palladium in the absence and presence of both individual macrocycles and their mixtures and polymer particles was investigated (fig. 24) using a common model reaction of *p*-nitrophenol (PNP) reduction in the presence of $NaBH_4$. The stabilization of Pd nanoparticles even on unpolymerized macrocycles increased a specific catalytic activity by several orders of magnitude. The use of a polymer support proved to be the most effective. The better results can be attributed to the higher roughness of the support, which prevents the rearrangement of palladium particles and formation of inactive palladium black. Taking into account the very low Pd loading (3.2 *nmol*), the obtained catalytic systems exceed the literature analogues in terms of PNP reduction rate.

Imidazolium derivatives of thiacalix[4]arene and their NHC - Pd(II) complexes

The introduction of imidazolium fragments into the macrocyclic platform opens the way to the synthesis of NHC ligands for transition metal complexes. Convenient method for the synthesis of amphiphilic macrocycles is the introduction of imidazolium salts on one side of the macrocycle with the presence of lipophilic fragments on the other side. The thiacalix[4]arene platform is very promising for such transformations because the synthesis of initial halogen derivatives containing lipophilic alkyl fragments is carried out in only two steps by sequential introduction of alkyl and bromalkyl fragments under Mitsunobu or sequential Mitsunobu/Williamson reactions.

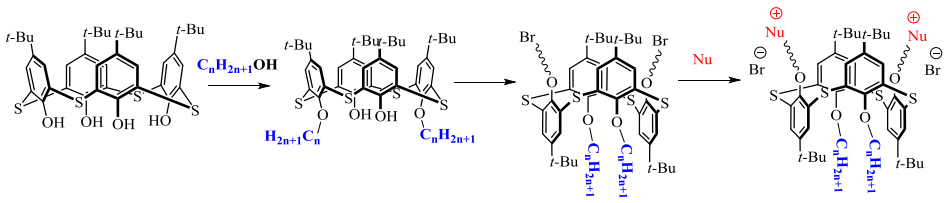
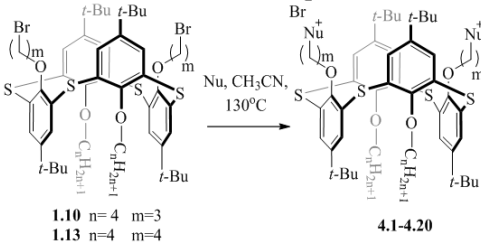


Figure 25. General strategy for the synthesis of amphiphilic quaternized derivatives of *p-tert*-butylthiacalix[4]arene.

The initial selection of the quaternization conditions was carried out using triethylamine [37-40]. However, the reaction of **1.10** did not start with triethylamine as well as N-methylmorpholine or N,N-dimethylbenzylamine. Products in nearly quantitative yields were obtained by introducing planar heterocycles such as pyridine or N-methylimidazole (fig. 26). Carrying out a similar reactions with macrocycle **1.13** containing longer bromobutyl fragments resulted in a significant decrease in the reaction time. The reaction also proceeded with N-methylmorpholine. Considering that the

nucleophilicity of triethylamine is higher than that of pyridine, this reaction course is mainly due to steric factors.

	Nu	n	m	Time (h)	Yield (%)
4.1		4	3	37	88
4.2		4	3	34	87
4.3		4	4	12	84
4.6		14	4	25	79
4.4		4	4	10	85
4.7		14	4	23	75
4.5		4	4	45	81
4.8		14	4	31	73



1.10 n= 4 m=3
1.13 n=4 m=4
1.15 n=14 m=4

4.1-4.20

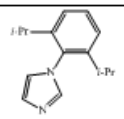
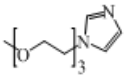
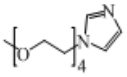
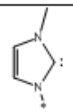
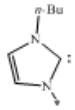
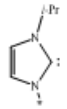
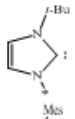
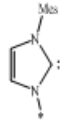
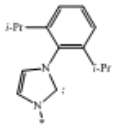
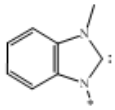
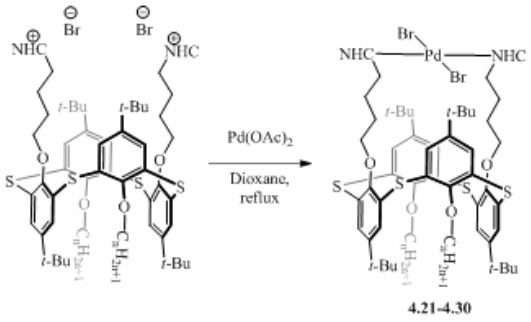
	Nu	n	Yield (%)	Time (h)		Nu	n	Yield (%)	Time (h)
4.9		4	82	27	**4.15**		4	70	50
4.10		14	70	27	**4.16**		4	70	50
4.11		4	87	27	**4.17**		4	75	50
4.12		14	70	48	**4.19**		14	74	30
4.13		4	74	50	**4.18**		4	80	50
4.14		4	87	50	**4.20**		14	75	30

Figure 26. Compound numbers, time and yields of reaction products **1.10**, **1.13** and **1.15** with N-nucleophiles.

NHC complexes of Pd(II) were synthesized using *p-tert*-butylthiacalix[4]arene imidazolium salts [39]. Compounds **4.2** and **4.4** were used to optimize the conditions for the synthesis of the metal complexes (fig. 27). It was found that the reaction of the macrocycle **4.2** with $Pd(OAc)_2$ in boiling dioxane did not start even after two days. Complex **4.21** was obtained in almost quantitative yield when a similar reaction was carried out with macrocycle **4.4**. Reaction was carried out with other macrocyclic derivatives of imidazole and N-methylbenzimidazole to give a series of Pd(II) NHC complexes.

	NHC	n	Yield (%)	Time (h)
4.21		4	99	27
4.22		14	86	30
4.23		4	70	28
4.24		14	84	31
4.25		4	70	48
4.26		14	67	48
4.27		4	70	50
4.28		4	52	38
4.29		4	50	60
4.30		4	50	30



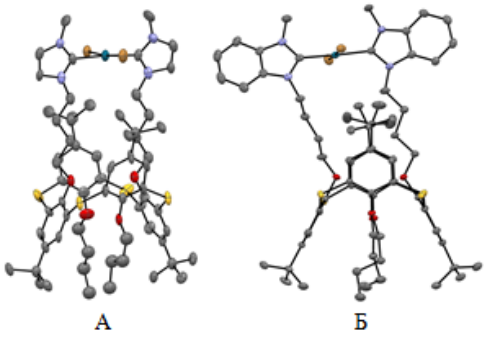
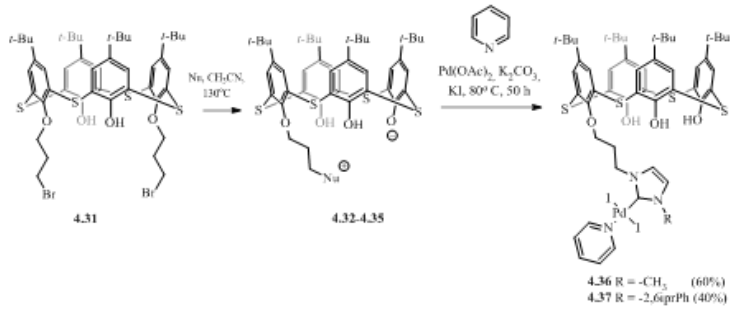
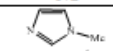
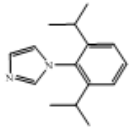


Figure 27. Compound numbers, time and yields of NHC-Pd(II)complexes; structures of complexes **4.21** (A) and **4.30** (B) according to X-ray data.

Pd(II) metal complexes based on dibromopropyl-substituted *p-tert*-butylthiacalix[4]arene **4.31** were synthesized [41, 42] (Figure 28). The monosubstituted zwitterionic product **4.32** instead of the expected disubstituted one was isolated by reaction with N-methylimidazole under conditions previously defined for quaternization of tetra-substituted *p-tert*-butylthiacalix[4]arene derivatives. According to the high-resolution mass spectrometry data, the monosubstituted product is formed *via* the intermediate disubstituted salt, which is self-dealkylated by nucleophilic attack of the bromide ion. Pd(II) PEPPSI-type complexes (Pyridine-Enhanced Precatalyst: Preparation, Stabilization and Initiation) were obtained on the basis of macrocycles **4.32** and **4.33** with imidazolium fragments in good yields.



	Nu	Time, h	Yield, %
4.32		30	88
4.33		65	81
4.34		60	76
4.35		30	84

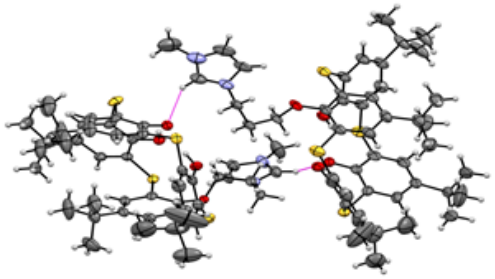
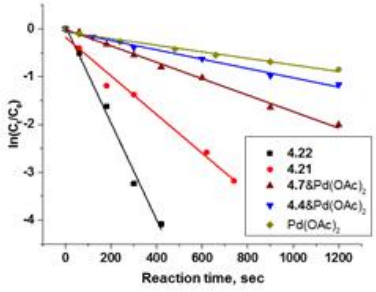


Figure 28. Compound numbers, time and yields of quaternized derivatives and PEPPSI-type NHC-Pd(II) complexes; structure of **4.32** according to X-ray data.

The catalytic properties for the *bis*-NHC complexes **4.21** and **4.22** and their precursors **4.4** and **4.7** *in situ* with $Pd(OAc)_2$ were studied in the model PNP reduction reaction [39] (fig. 29). The use of macrocycles **4.4** and **4.7** resulted in a slight increase in catalytic activity of $Pd(OAc)_2$. However, a significant increase in the specific catalytic activity was observed when using the prepared complexes **4.21** and especially **4.22**. Thus, the **4.22** complex showed activity comparable to the previously shown polymer-stabilized Pd nanoparticles (fig.24). According to the TEM data, the treatment of **4.22** with $NaBH_4$ produced Pd(0) nanoclusters with a size of about 2 nm, uniformly distributed on the organic support. This is responsible for the effective catalysis in the reduction reaction of PNP.



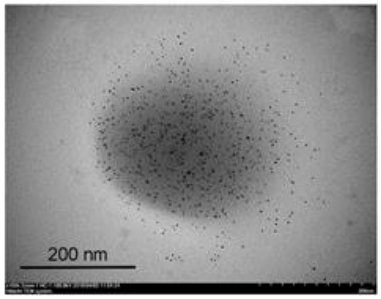


Figure 29. Plot of $\ln(C_t/C_0)$ *vs* catalytic reaction time for different Pd-containing catalytic systems. C(PNP) = 0.1 *mM*, $C(NaBH_4)$ = 5 *mM*, C(macrocycles or $Pd(OAc)_2$) = 0.2 *μ*M, H_2O, 25 ℃ and TEM image of **4.22**.

Thus, herein we presented a universal synthetic approach for the preparation of vide series of amphiphilic (thia)calix[4]arene compounds, including bifunctional amphiphiles with polymerizable diacetylene fragments, CuAAC-polymerizable amphiphiles as well as NHC – Pd(II) complexes by the use of CuAAC/Menshutkin reactions. A variety of applications of the obtained systems were demonstrated.

ԱՄՖԻՖԻԼԱՑԻՆ (ԹԻԱ)ԿԱԼԻՔՍ[4]ԱՐԵՆՆԵՐԻ ԱԾԱՆՑՎԱԼՆԵՐԻ ՀԵՆՔԻ ՎՐԱ ԿԱՌՈՒՑՎԱԾ ՖՈՒՆԿՑԻՈՆԱԼ ՍՈՒՊՐԱՄՈԼԵԿՈՒԼԱՑԻՆ ՀԱՄԱԿԱՐԳԵՐ

Վ.Ա. ԲՈՒՐԻԼՈՎ, Մ. ՄԱՑԻԼՑԱՆ, Ս.Է. ՍՈԼՈՎԻԵՎԱ, Ի.Ս. ԱՆՏԻՊԻՆ

Ակնարկային աշխատանքը ներկայացնում է համընդհանուր սինթետիկ մոտեցում մի շարք ամֆիֆիլային (թիա)կալիքս[4]արենների պատրաստմանը, ներառյալ երկֆունկցիոնալ ամֆիֆիլները՝ պոլիմերվող դիացետիլենային հատվածներով, CuAAC-պոլիմերացվող ամֆիֆիլներ, ինչպես նաև NHC–Pd(II) համալիրներ՝ օգտագործելով CuAAC/Մենշուտկինի ռեակցիան: Հոդվածում բերվում են ստացված համակարգերի կիրառության մի քանի ուղղություններ և բնագավառներ:

ФУНКЦИОНАЛЬНЫЕ СУПРАМОЛЕКУЛЯРНЫЕ СИСТЕМЫ НА ОСНОВЕ АМФИФИЛЬНЫХ ПРОИЗВОДНЫХ (ТИА)КАЛИКС[4]АРЕНОВ

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В настоящей работе представлен универсальный синтетический подход для получения ряда амфифильных (тиа)каликс[4]аренов, включающих бифункциональные амфифилы с полимеризуемыми диацетиленовыми фрагментами, CuAAC-полимеризуемые амфифилы, а также комплексы NHC – Pd(II) путем использование реакции CuAAC/Меншуткина. В обзоре продемонстрированы различные направления применения полученных систем.

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