Labelling of Carbaboranyl Compounds with a Selenium Atom with a View to Applications in Boron-Neutron-Capture Therapy (BNCT) and Positron-Emission Tomography (PET)

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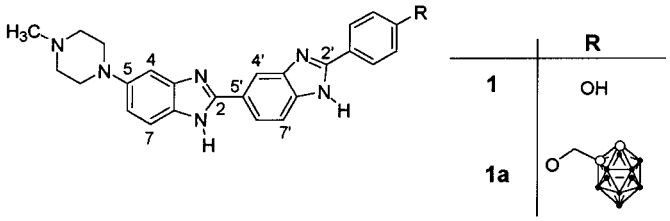
In memoriam Professor *Börje Larsson*

We synthesized 2′-carbaboranyl-2,5′-bi-1*H*-benzimidazoles containing 10 B-atoms and labeled with Se or the positron-emitting radionuclide ^{73}Se ($t_{1/2} = 7.1$ h), with a view to their application to cancer treatment by boron-neutron-capture therapy (BNCT) and to compound-distribution measurements *in vivo* by positron-emission tomography (PET). Thus, 2,2′-{{2′-{4-[1,2-dicarba-*closo*-dodecaboran(12)-2-ylmethoxy]phenyl}-[2,5′-bi-1*H*-benzimidazol]-5-yl}imino}bis[ethanol] (**26c**) was obtained by the reaction of 2,2′-[(3,4-diaminophenyl)-imino]bis[ethanol] (**19**) with ethyl 2-{4-[1,2-dicarba-*closo*-dodecaboran(12)-2-ylmethoxy]phenyl}-1*H*-benzimidazole-5-carboximidate hydrochloride (**25**), as well as the analogues **26a** and **26b** (*Scheme 6*). Tosylation of compound **26c** gave 4 regioisomers **27a**–**d**, which, after selenation, produced 2′-{4-[1,2-dicarba-*closo*-dodecaboran(12)-2-ylmethoxy]phenyl}-5-(tetrahydro-2*H*-1,4-selenazin-4-yl)-2,5′-bi-1*H*-benzimidazole (**29**) in 42% yield (*Scheme 7*).

Introduction. – Boron-neutron-capture therapy (BNCT) is a binary procedure for the treatment of different types of tumors. The non-radioactive isotope ^{10}B has a high thermal neutron-capture cross section (3840 barns), and the capture results in formation of an α-particle and ^{7}Li nuclei with a path length of *ca.* 9–10 μm (one cell diameter), and carrying 2.3 MeV of energy. Both particles are able to damage the DNA or other essential parts of tumor cells.

Many compounds have been synthesized that are able to transport ^{10}B atoms into tumor cells [1]. Our approach consisted of coupling the well-known DNA ligand 4-{5-(4-methylpiperazin-1-yl)[2,5′-bi-1*H*-benzimidazol]-2′-yl}phenol (**1**) (‘*Hoechst 33258*’) [2–3] with a carbaboranyl moiety [4]. While compound **1** was synthesized by a classical linear route [3][5], we found that benzimidazoles with both methylpiperazinyl and carbaboranyl residues can be prepared advantageously in a convergent synthesis starting from the carbaboranyl moiety of the molecule as shown by the synthesis of compound **1a** [4]. In the present paper, we continued this work by synthesizing two more 1,2-dicarbadodecaboranyl derivatives of **1**, *i.e.* compounds **9a** and **9b**.

Unfortunately, the atoms contained in these compounds have no radioactive isotopes with half-lives suited to their uptake process in tumors. As a result, it is difficult to study uptake and biodistribution of the BNCT drugs in patients by *in vivo* techniques and consequently to estimate the dosage of the BNCT therapy. As an alternative, the replacement of these atoms by heavier elements of the same group is desirable if the



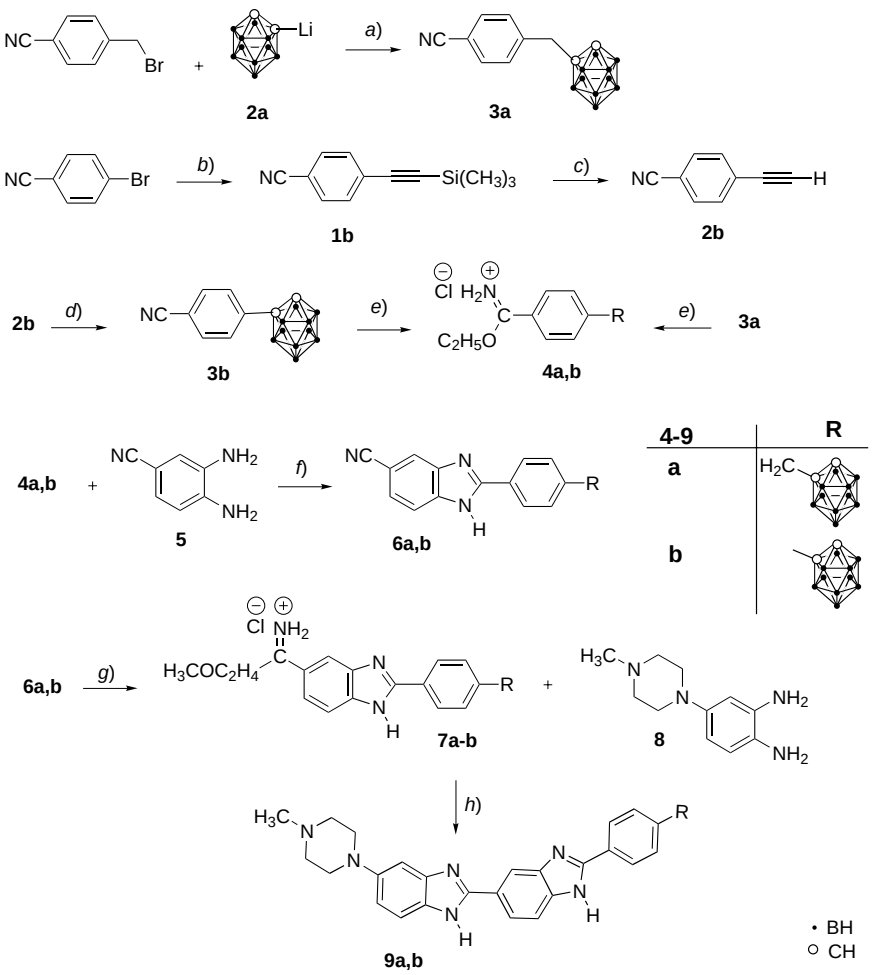
physiological properties of the carrier molecules are not substantially changed. Some of these elements have radioisotopes with the requisite physical properties to allow *in vivo* imaging of the B-containing compounds. For example, if the drug molecule contains an S-atom, this may be replaced by a Se-atom, which has the useful radioisotope ^{73}Se ($t_{1/2} = 7.1$ h, 65% positron yield). Thus, we were looking for Se-containing compounds that might carry the B-atoms into the tumor cell. In particular, our strategy was directed towards the replacement of the 4-methylpiperazin-1-yl group in **1** by a tetrahydro-2*H*-1,4-selenazin-4-yl (selenomorpholin-4-yl) group. The synthesis of such a compound would allow the introduction of the ^{73}Se radioisotope instead of inactive Se-atoms in natural abundance. However, the introduction of this short half-life radionuclide has to be carried out in the last step.

It should be mentioned that ^{73}Se can be produced in high yield by bombardment of arsenic, preferably in the form of a Cu_3As alloy, with 40 MeV protons in a cyclotron. Under these conditions, the production yield is 1.22 ± 0.12 GBq/μAh or 33 ± 3.3 mCi/μAh, the contaminations of ^{72}Se ($t_{1/2} = 8.5$ d) and of ^{75}Se ($t_{1/2} = 120$ d) being 0.34 and 0.026%, respectively [6].

Results and Discussion. – *1,2-Dicarbadodecaboranyl Derivatives* **9a**,**b** *of 4-{5-(4-Methylpiperazin-1-yl)[2,5′-bi-1*H*-benzimidazol]-2′-yl}phenol* (**1**). Compounds **9a**,**b** were synthesized by a convergent synthesis (*Scheme 1*). Thus, **3a** was obtained by the reaction of 1,2-dicarbadodecaboran(12)yllithium **2a** with 4-(bromomethyl)benzonitrile, and **3b** was prepared by the reaction of 4-ethynylbenzonitrile (**2b**; from silyl derivative **1b**) and the decaborane/bis-acetonitrile complex 6,9-$(MeCN)_2B_{10}H_{12}$. Transformation of compounds **3a**,**b** to the ethyl carboximidate hydrochlorides **4a**,**b** followed by their reaction with 3,4-diaminobenzonitrile (**5**) led to the formation of the 1*H*-benzimidazolecarbonitriles **6a**,**b**. In the same way, **7a**,**b** obtained from **6a**,**b** gave the 2,5′-bi-1*H*-benzimidazoles **9a**,**b** after reaction with compound **8**. Although the preparation of the ethyl carboximidate analogues of **7a**,**b** is easier and results in higher yields, the overall yields of the bi-1*H*-benzimidazoles are much higher with the 2-methoxyethyl carboximidates [7], perhaps due to stabilizing effects of the lone electron pairs of the O-atom of the MeO group.

Supposing the binding mechanism for compounds **9a**,**b** to DNA in the cell is the same as for compound **1** [8–10] (H-bridges of the NH groups of the bi-1*H*-benzimidazole moieties with adenine and thymine base pairs), these compounds should be useful for studying the influence of spacers like $(CH_2)_n$ ($n = 0, 1$) positioned between the bi-1*H*-benzimidazole group and the 1,2-dicarbadodecaborane(12) moiety in the derivatives **9a**,**b** of *Hoechst 33258*.

Scheme 1

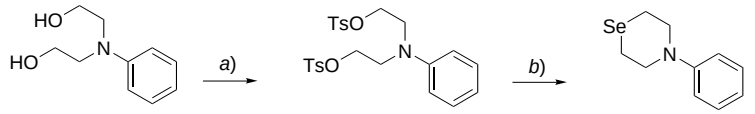


a) 1,2-Dicarbadodecaborane(12), BuLi, THF, 30 min at 0°, 12 h at 25°. *b*) Ethynyltrimethylsilane, Et_3N, Ar, CuI, $[PdCl_2(Ph_3P)_2]$. *c*) Aq. 1M K_2CO_3, MeOH. *d*) 6,9-$(MeCN)_2B_{10}H_{12}$, toluene, reflux. *e*) EtOH, dry HCl. *f*) AcOH, Ar, reflux. *g*) $MeOCH_2CH_2OH$, dry HCl. *h*) AcOH, Ar, reflux.

*Model Compounds for the Preparation of Selenomorpholinyl-1*H*-benzimidazoles.* To replace the 4-methylpiperazin-1-yl group in **9a**,**b** by a tetrahydro-2*H*-1,4-selenazin-4-yl (selenomorpholin-4-yl) group, the syntheses of some model compounds were necessary. The preparation of the selenomorpholine moiety (*Scheme 2*) was studied starting from the commercially available 2,2′-(phenylimino)bis[ethanol]. Bis-tosylation [11][12] (→ **10**) followed by nucleophilic reaction with lithium selenide [13–16] and ring closure gave 4-phenylselenomorpholine (**11**) in 40% yield.

Model compounds containing a 1*H*-benzimidazole such as **15** (from **12** *via* **13** and **14**; *Scheme 3*) and a 1*H*-benzimidazole/1,2-dicarbadodecaborane moiety such as **21**

Scheme 2

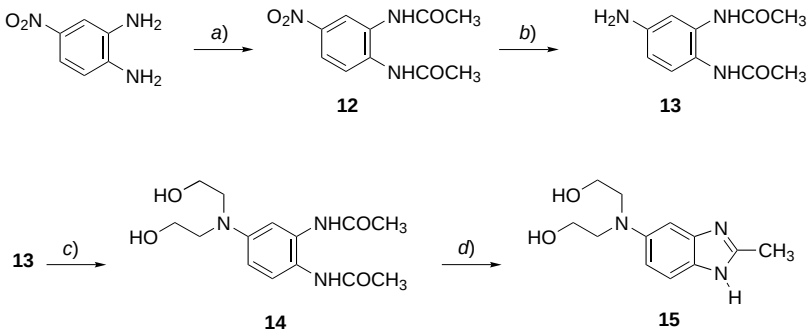


10 **11**

a) CH_2Cl_2, Et_3N, TsCl, 30 min at 0°, 12 h at 5–6°. *b*) Li_2Se, ^{t}BuOH, THF, N_2, reflux, 4 h.

(see below) were designed to study the compatibility of these compounds in tosylation and selenation. Thus, tosylation of **15** with 6 equiv. of TsCl (any quantity less than that produced many by-products) gave the two regioisomers **16a**,**b** (*Scheme 4*). Although they could not be separated, the ratio **16a**/**16b** 6:4 could be assigned by ^{1}H-NMR spectroscopy and comparison with similar compounds cited in [17].

Scheme 3



12 **13** **14** **15**

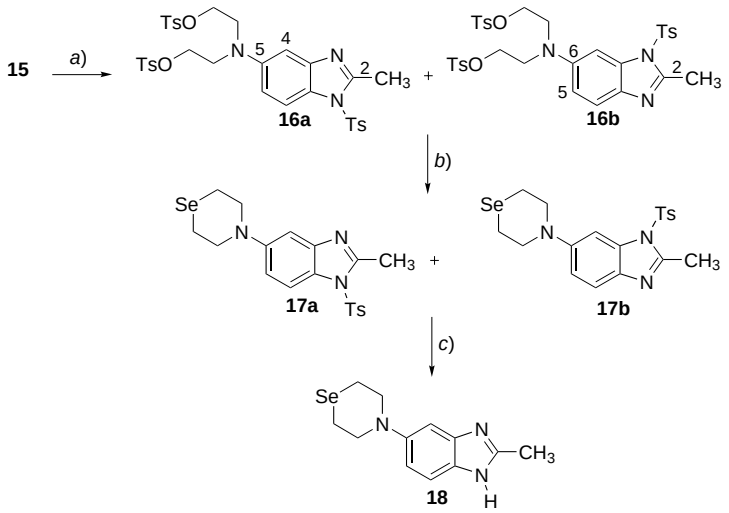
a) AcCl, reflux, 6 h. *b*) 5% Ru/C, $N_2H_4 \cdot H_2O$, EtOH, reflux, 5 h. *c*) Oxirane, 25% $AcOH/H_2O$, 2–3°, 5 h at 5°. *d*) 18% HCl/H_2O, reflux, 3 h.

In the ^{1}H-NMR spectrum (300 MHz, $CDCl_3$) of **16a**/**16b** 2*s* at 2.75 and 2.76 ppm in the ratio 6:4 were assigned to Me–C(2) of the 1*H*-benzimidazole ring. For the 6-ylimino regioisomer **16b**, the signal of H–C(7) is shifted to lower field (7.08 ppm) compared to the analogous signal of H–C(4) of **16a** (6.59 ppm), due to the *peri*-neighborhood of the tosyl group in **16b**. Integration of this signal also amounts to 40% of the total integral for H–C(4) and H–C(7) in the mixture.

The mixture **16a**/**16b** was selenated by two different methods. *Method A*, with NaHSe in EtOH, gave **17a**/**b** in a yield of 33% and *Method B*, with Li_2Se in THF, produced 35% of **17a**,**b**. *Method B* was finally preferred because **16a**/**b** are soluble in THF, but only slightly soluble in EtOH. Thus, in the case of automated processes with radioactive ^{73}Se, *Method B* would be applied. When 1 equiv. of Li_2Se was used, compound **18** was isolated in *ca.* 9% yield along with 35% of **17a**,**b**. An additional equiv. (in total 2 equiv.) of Li_2Se gave **18** in 53% yield[1]). In the present work, we did not deter-

[1]) The high yield of *N*-detosylated product **18** obtained by the treatment with 2 equiv. of Li_2Se suggests that the selenide anion acts as a strong electron donor ($Se + 2e^- \rightleftarrows Se^{2-} - 0.92$ V) for the reductive cleavage of the $N-SO_2Ar$ bond in our system. The introduction of electron-withdrawing substituents at the aromatic sulfonamide moiety instead of the Me group lower the reduction potential needed for the cleavage of the N–S bond and, as a consequence, increase the yield of the desulfonated product.

Scheme 4



a) Pyridine, 0°, TsCl, 72 h at 5°. *b*) *Method A:* NaHSe, EtOH, N_2, 6 h reflux, 15 h at r.t.; *Method B:* Li_2Se, ^{t}BuOH, THF, N_2, 12 h at r.t. *c*) Reductive cleavage by Li_2Se or electrochemical reduction (see text).

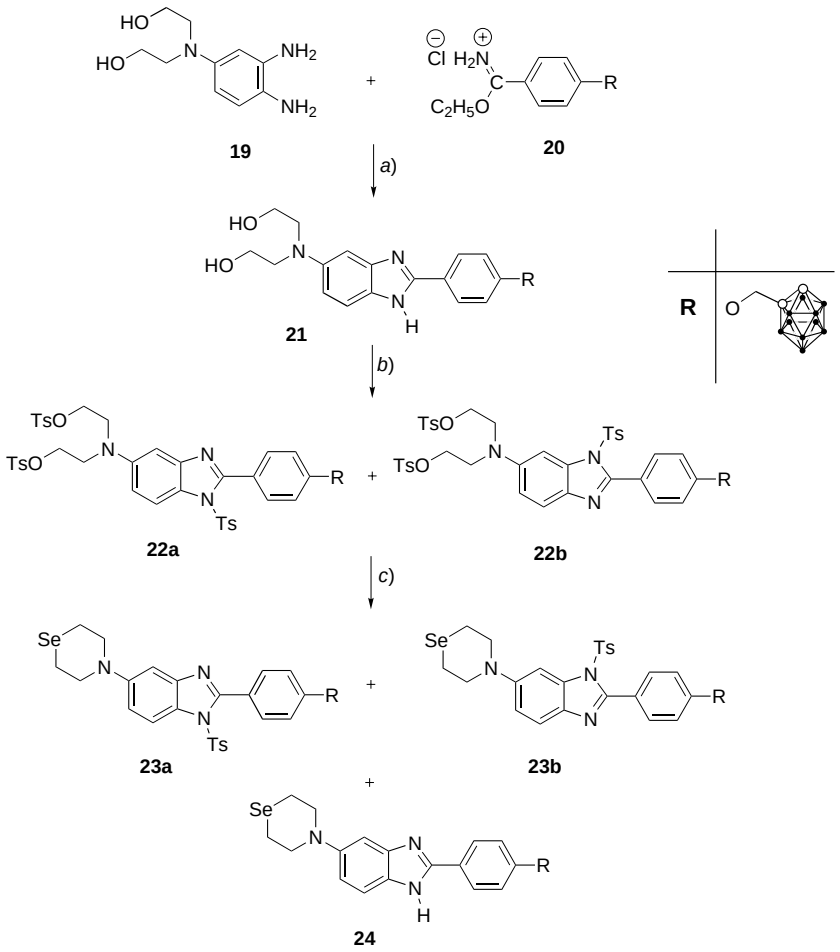
mine what excess of Li_2Se would be best to obtain the detosylated compound **18** in higher yield. Next, we studied the possibility to prepare **18** from the mixture **17a**/**17b** by electrochemical detosylation [18]. With this alternative method, **18** was obtained in 77% yield. Studies to cleave the *N*-tosyl group in presence of *O*-tosyl groups are under way.

To examine the influence of 1,2-dicarbadodecaborane moiety in this process, we synthesized the model compound **21** from **19** and **20** (*Scheme 5*). Tosylation of **21** with 6 equiv. of TsCl in pyridine gave the mixture **22a**/**22b** in 74% yield. Identification was possible only by MS (ESI). ^{1}H-NMR (300 MHz, (D_6)acetone) gave the correct number of 19 aromatic H-atoms after integration, but their signals were too superimposed to be assigned to the respective regioisomers. After selenation with 2 equiv. of Li_2Se, the detosylated compound **24** was obtained in 24% yield together with some **23a**,**b**.

*Bi-1*H*-benzimidazole Precursors for Selenation and Preparation of the 2′-{4-[1,2-Dicarba*-closo-*dodecaboran(12)-2-ylmethoxy]phenyl}-5-(selenomorpholin-4-yl)-2,5′-bi-1*H*-benzimidazole* (**29**). Finally, one of the analogues of the *Hoechst*-carbaboranyl derivatives **1a** or **9a**,**b** displaying a selenomorpholin-4-yl moiety instead of a 4-methylpiperazin-1-yl residue was synthesized. The precursors **26a**–**c** were obtained by the condensation of 2,2′-[(3,4-diaminophenyl)imino]bis[ethanol] (**19**) with the carboximidates **7a**,**b** or **25** [4] in 2-PrOH (*Scheme 6*). The same reaction in glacial acetic acid, however, did not lead to the desired compounds **26a**–**c**.

We then chose the synthesis of the selenomorpholinyl-carbaboranyl *Hoechst* analogue **29** of compound **1a**. Since 4 regioisomers are to be expected in the tosylation of precursor **26c**, a total of 32 equiv. of TsCl was applied to minimize side reactions, which furnished compounds **27a**–**d** in 51% yield (*Scheme 7*). The components of this

Scheme 5



a) ^{i}PrOH, N_2, reflux, 7 h. *b*) Pyridine, 0°, TsCl, 72 h at 5°. *c*) Li_2Se, ^{t}BuOH, THF, N_2, 2 h reflux and 12 h at r.t.

mixture could not be isolated, and an interpretation of the ^{1}H-NMR spectrum of the mixture was impossible on grounds of its complexity. However, identification was again achieved by MS (ESI). Selenation of the mixture **27a**–**d** with 4 equiv. of Li_2Se gave the final compound **29** in 42% yield.

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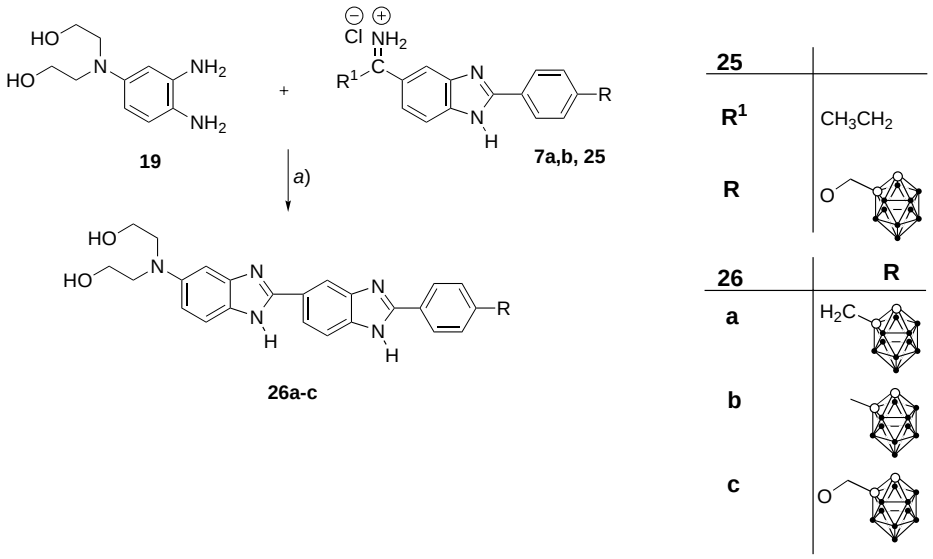
Scheme 6



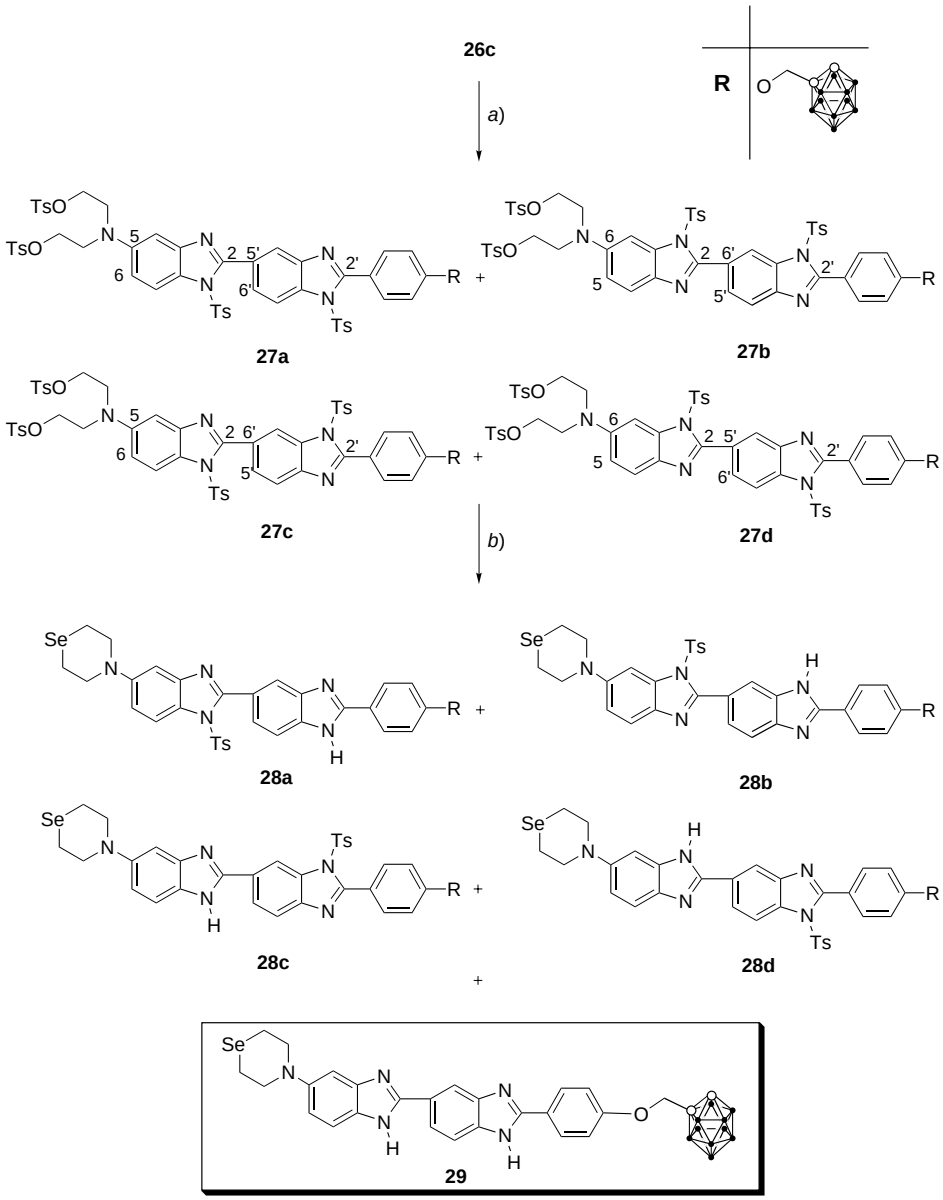
a) ^{i}PrOH, N_2, reflux, 7 h.

Experimental Part

General. If not otherwise stated, reagent-grade solvents were used without further purification (petroleum ether of b.p. 30 – 60° = p.e.). Decaborane and 1,2-dicarba-*closo*-dodecaborane(12) (*o*-carborane) were purchased from *Alfa*, a subsidiary of *Johnson Matthey Co*. Compounds **5**, **8**, **20**, and **25** have been reported previously [4], 2,2′-[(4-amino-3-nitrophenyl)imino]bis[ethanol] was a generous gift from *Wella Cosmital SA*, CH-1723 Marly, Switzerland. $LiSe_2$ and NaHSe were synthesized according to [13][14]. The polarographic measurements were carried out as described in [18]. Controlled-potential electrolysis was performed at 5° under Ar in a cylindrical three electrode divided cell with an electronic potentiostat; cathode: stirred Hg pool (area: 44 cm^2); anode: graphite rod; reference electrode: aq. sat. calomel; solvent supporting electrode: 0.1M Me_4NCl in 94% EtOH as catholyte and anolyte. TLC: *Merck* silica gel *60 F_{254}* plates (Al support, 0.2 mm thickness); detection of carbaborane compounds by $PdCl_2$ in HCl as described elsewhere [4]. FC = flash chromatography. M.p.: *Büchi 535* or *Mettler-FP5* and *-FP52* apparatus; uncorrected. IR Spectra: *Perkin-Elmer-FT-1600-IR* spectrophotometer; KBr pellets; in cm^{-1}. ^{1}H-NMR Spectra: *Bruker-AC-300* or *-ARX-300* or *Varian-Gemini-2000* spectrometer, all operating at 300 MHz; residual solvent peak ($CDCl_3$, (D_6)DMSO, CD_3OD or (D_6)acetone) as internal reference rel. to $SiMe_4$; δ in ppm and coupling constants *J* in Hz. MS: *Finnigan MAT 90* (CI, NH_3), *SSQ 700* (EI, 70 eV), *Fision VG TRIO 2000* (ESI, 40 eV), and *TSQ/SSQ 700* (ESI, NaI); *m*/*z* (rel. %). The Microanalytical Laboratory of the Institute of Organic Chemistry at the University of Zürich performed the elemental analyses.

Syntheses. 1. *4-[1,2-Dicarba*-closo-*dodecaboran(12)-2-ylmethyl]benzonitrile* (**3a**). To a deaerated soln. of 1,2-dicarba-*closo*-dodecaborane(12) (50 mmol, 7.2 g) in THF (160 ml), 2.7M BuLi in heptane (30 ml) was added dropwise under stirring at 0°. To this soln., 4-(bromomethyl)benzonitrile (50 mmol, 9.8 g) in THF (100 ml) was added dropwise. After stirring at r.t. under Ar for 12 h, the mixture was diluted with Et_2O (500 ml), the org. phase washed with H_2O (250 ml) and 10% NaCl soln. (2 × 250 ml), dried ($MgSO_4$), and evaporated, and the resulting light brown oil purified by FC (silica gel, CH_2Cl_2/hexane 1:1) to remove the non-reacted dicarbadodecaborane. A second FC (silica gel, AcOEt/p.e. 1:4) gave pure **3a** (5.36 g, 41%) [19]. M.p. 131.3 – 135.4°. R_f (CH_2Cl_2/hexane 1:1) 0.36; R_f (AcOEt/p.e. 1:4) 0.47; R_f (AcOEt/hexane 2:6) 0.51. IR: 2236, 2590. ^{1}H-NMR ($CDCl_3$): 3.30 (*s*, $CB_{10}H_{10}CH$); 3.57 (*s*, $CH_2CB_{10}H_{10}CH$); 7.30 – 7.70 (*AA′BB′*, 4 arom. H). CI-MS: 277

Scheme 7



a) Pyridine, 0°, TsCl, 72 h at 5°. *b*) Li_2Se, ^{t}BuOH, THF, N_2, 3 h at 70°, 12 h at r.t.

(100, $[M+NH_4]^+$), 260 (11 $[M+H]^+$), 259 (13). Anal. calc. for $C_9H_{14}B_{10}N$ (259.36): C 46.31, H 6.61, N 5.40; found: C 46.21, H 6.51, N 5.33.

2. *Ethyl 4-[1,2-Dicarba*-closo-*dodecaboran(12)-2-ylmethyl]benzenecarboximidate Hydrochloride* (**4a**). Dry HCl gas was bubbled through a soln. of **3a** (18.28 mmol, 4.71 g) and dry EtOH (50 ml), until saturation. The

mixture, protected against moisture, was stirred overnight. After evaporation, the residue was triturated with dry Et_2O, filtered, and dried *in vacuo:* 4.98 g (79.7%) of **4a**. White crystals. M.p. 161–163°. ^{1}H-NMR ((D_6)DMSO): 1.49 (*t*, *J* = 6.9, *Me*CH_2O); 3.78 (*s*, $CH_2CB_{10}H_{10}CH$); 4.64 (*q*, *J* = 6.9, $MeCH_2O$); 5.40 (*s*, $CB_{10}H_{10}CH$), 7.54 (*AA′XX′*, $J_A(J_X)$ = 8.4, 2 H_m; 8.14 (*AA′XX′*, $J_A(J_X)$ = 8.4, 2 H_o).

3. *2-{4-[1,2-Dicarba*-closo-*dodecaboran(12)-2-ylmethyl]phenyl}-1*H-*benzimidazole-5-carbonitrile* (**6a**). A soln. of **5** (23.39 mmol, 3.1 g) and **4a** (23.39 mmol, 8 g) in AcOH (300 ml) was refluxed for 7 h. Thereafter, the mixture was stirred overnight at r.t. The precipitate formed was filtered off and washed with Et_2O (3 × 250 ml). The combined Et_2O portions were dried (Na_2SO_4) evaporated and the residue purified by FC (silica gel, acetone/p.e. 1:2): 5.40 g (53%) of **6a**. Colorless crystalline solid. M.p. 283.3–284.8°. ^{1}H-NMR ($CDCl_3$): 3.30 (br. *s*, $CB_{10}H_{10}CH$); 3.60 (*s*, $CH_2CB_{10}H_{10}CH$); 7.32 (*AA′XX′*, $J_A(J_X)$ = 8.4, 2 H_m); 7.53 (*dd*, *J*(4,6) = 1.5, *J* (6,7 = 8.4, H–C(6)); 7.69 (*d*, *J*(4,7) = 0.6, *J*(6,7) = 8.4, H–C(7)); 7.96 (*d*, *J*(4,7) = 0.6, H–C(4)); 8.03 (*AA′XX′*, $J_X(J_A)$ = 8.4, 2 H_o). CI-MS: 376 (100, $[M+H]^+$), 375 (64). Anal. calc. for $C_{17}H_{21}B_{10}N_3 \cdot CH_3COOH$ (435.54): C 52.40, H 5.78, N 9.65; found: C 52.61, H 5.78, N 9.67.

4. *2-Methoxyethyl 2-{4-[1,2-Dicarba*-closo-*dodecaboran(12)-2-ylmethyl]phenyl}-1*H-*benzimidazole-5-carboximidate Hydrochloride* (**7a**). Dry HCl gas was bubbled through a soln. of **6a** (0.40 mmol, 0.173 g) in 2-methoxyethanol (30 ml) at 2–3°, until saturation. The mixture, protected against moisture, was stirred overnight. The white precipitate formed was filtered off, dried *in vacuo*, and used without further purification in the next step: 0.140 g (77%) of **7a**. ^{1}H-NMR ((D_6)DMSO): 3.35 (*s*, MeO); 3.72 (*m*, $MeOCH_2CH_2$); 3.79 (*s*, $CH_2CB_{10}H_{10}CH$); 4.47 (*m*, $MeOCH_2CH_2$); 5.39 (br. *s*, $CH_2CB_{10}H_{10}CH$); 7.59 (*AA′XX′*, $J_A(J_X)$ = 8.1, 2 H_m); 7.92 (*d*, *J*(6,7) = 8.6, H–C(7)); 8.08 (*dd*, *J*(6,7) = 8.6, H–C(6)); 8.35 (*d*, H–C(4)); 8.48 (*AA′XX′*, $J_X(J_A)$ = 8.1, 2 H_o).

5. *2′-{4-[1,2-Dicarba*-closo-*dodecaboran(12)-2-ylmethyl]phenyl}-5-(4-methylpiperazin-1-yl)-2,5′-bi-1*H-*benzimidazole* (**9a**). A mixture of **8** (0.55 mmol, 0.112 g) and **7a** (0.55 mmol, 0.250 g) in AcOH was refluxed for 7 h under Ar. The mixture was stirred overnight at r.t. The precipitate was filtered off, dissolved in MeOH, the soln. added slowly and dropwise to Et_2O, and this soln. kept in the refrigerator overnight. The precipitate formed was filtered off and dried *in vacuo:* 0.69 g (20%) of **9a**. Yellow crystals. ^{1}H-NMR (CD_3OD + drops of CF_3COOD): 3.02 (*s*, MeN); 3.24 (*t*, *J* = 12, 2 H, $MeNCH_2CH_2$); 3.38 (*t*, *J* = 12, 2 H, $MeNCH_2CH_2$); 3.70 (*d*, *J* = 13, 2 H, $MeNCH_2CH_2$); 3.78 (*s*, $CH_2CB_{10}H_{10}CH$); 3.99 (*d*, *J* = 13, 2 H, $MeNCH_2CH_2$); 4.60 (br. *s*, $CB_{10}H_{10}CH$); 7.37 (*d*, *J*(4,6) = 2, H–C(4)); 7.47 (*dd*, *J*(4,6) = 2, *J*(6,7) = 9, H–C(6)); 7.64 (*AA′XX′*, $J_X(J_A)$ = 8.4, 2 H_m); 7.78 (*d*, *J*(6,7) = 9, H–C(7)); 8.12 (*d*, *J*(6′,7′) = 9, H–C(7′)); 8.23 (*AA′XX′*, J_X (J_A) = 8.4, 2 H_o); 8.27 (*dd*, *J*(4′,6′) = 1.5, *J*(6′,7′) = 8.7, H–C(6′)); 8.63 (br. *s*, H–C(4′)). ESI-MS: 568 (54), 567 (97, $[M+1]^+$), 566 (100), 565 (59), 564 (25).

6. *4-[1,2-Dicarba*-closo-*dodecaboran(12)-2-yl]benzonitrile* (**3b**). 6.1. *4-(Trimethylsilylethynyl)benzonitrile* (**1b**). To a stirred mixture of 4-bromobenzonitrile (19.5 mmol, 3.54 g) and ethynyltrimethylsilane (23.4 mmol, 3.1 ml) in dry Et_3N (90 ml) under Ar, dichlorobis(triphenylphosphine)palladium(II) (0.71 mmol, 0.28 g) and CuI (0.1 mmol, 20 mg) were added. The mixture was allowed to stand for 7 h at r.t. and then filtered through a pad of *Celite* and Al_2O_3 (toluene/hexane 1:1 used for rinsing). Evaporation of the filtrate gave gold-brown crystals that were subjected to FC (silica gel, toluene/hexane 1:1) to yield an oil, which crystallized immediately: 2.12 g (57.7%) of **1b**. Colorless brilliant crystals. M.p. 100–101° ([20]: 111–112°). ^{1}H-NMR ($CDCl_3$): 0.26 (*s*, Me_3Si); 7.53 (*AA′BB′*, 2 arom. H); 7.59 (*AA′BB′*, 2 arom. H). CI-MS: 217 (100, $[M+NH_4]^+$), 199 (5). Anal. calc. for $C_{12}H_{13}NSi$ (199.33): C 72.31, H 6.57, N 7.03; found: C 72.31, H 6.32, N 7.01.

6.2. *4-Ethynylbenzonitrile* (**2b**). A mixture of **1b** (28.9 mmol, 5.75 g), MeOH (70 ml), and aq. 1M K_2CO_3 (10 ml) was stirred for 2 h at r.t. MeOH was evaporated and the crude product extracted from the aq. phase with Et_2O. The Et_2O phase was dried (Na_2SO_4) and evaporated and the residue subjected to FC (silica gel; toluene/p.e. 1:1): 3.15 (86%) of **2b**. White crystals. M.p. 156–158° ([20]: 156–157°; [21]: 154–155°). IR: 1456, 1498, 1601, 1798, 1926, 2103 (C≡C), 2228 (C=N, C≡C), 2853, 3089, 3236 (C≡CH), 3442. ^{1}H-NMR ($CDCl_3$): 3.30 (br. *s*, C≡CH); 7.58 (*AA′BB′*, 2 arom. H); 7.63 (*AA′BB′*, 2 arom. H). CI-MS: 145 (100, $[M+NH_4]^+$), 127 (5). Anal. calc. for C_9H_5N (127.14): C 85.02, H 3.96, N 11.02; found: C 84.44, H 3.97, N 10.98.

6.3. *Carbaboranylbenzonitrile* **3b**. A stirred mixture of the decaborane/bis(acetonitrile) complex 6,9-$(Me_3CN)_2B_{10}H_{10}$ (7.9 mmol, 1.45 g) and **2b** (7.9 mmol, 1.0 g) in toluene was refluxed for 6 h under N_2. The resulting mixture was filtered through a pad of *Celite* and the filtrate evaporated. The residue was purified by FC (silica gel, AcOEt/p.e. 1:9): 0.58 g (30%) of **3b** [22–23]. Colorless crystals. M.p. 194–196°. ^{1}H-NMR ($CDCl_3$): 3.99 (br. *s*, $CB_{10}H_{10}CH$); 7.60 (*m*, 2 arom. H); 7.66 (*m*, 2 arom. H). Anal. calc. for $C_9H_{15}B_{10}N$ (365.44): C 44.06, H 6.16, N 5.71; found: C 43.72, H 5.96, N 5.51.

7. *Ethyl 4-[1,2-Dicarba*-closo-*dodecaboran(12)-2-yl]benzenecarboximidate Hydrochloride* (**4b**). As described for **4a**, with **3b** (6.52 mmol, 1.61 g) and EtOH (20 ml): 1.5 g (70%) of **4b** [23]. Colorless crystals.

^{1}H-NMR ((D$_6$)DMSO): 1.45 (*t*, *J* = 6.9, *Me*CH$_2$O); 4.59 (*q*, *J* = 6.9, MeC*H*$_2$O); 6.0 (br. *s*, CB$_{10}$H$_{10}$C*H*); 7.84 (*AA′XX′*, $J_A(J_X)$ = 8.6, 2 H$_m$); 8.48 (*AA′XX′*, $J_X(J_A)$ = 8.6, 2 H$_o$).

8. *2-[4-[1,2-Dicarba*-closo-*dodecaboran(12)-2-yl]phenyl]-1*H-*benzimidazole-5-carbonitrile* (**6b**). As described for **6a**, with **5** (3.55 mmol, 0.473 g), **4b** (3.55 mmol, 1.17 g), and AcOH (40 ml) under N$_2$. Purification of the crude product by FC (silica gel, AcOEt/hexane 1:1) gave 0.38 g (30%) of pure **6b**. Light pink crystals. R_f (AcOEt/hexane 1:1) 0.5–0.52. ^{1}H-NMR ((D$_6$)acetone): 5.34 (br. *s*, CB$_{10}$H$_{10}$C*H*); 7.65 (*dd*, *J*(4,6) = 1.4, *J*(6,7) = 8.4, H–C(6)); 7.87 (*d*, *J*(6,7) = 8.4, H–C(7)); 7.89 (*AA′XX′*, $J_A(J_X)$ = 8.7, 2 H$_m$); 8.16 (*d*, *J*(4,7) = 0.6, H–C(4)); 8.31 (*AA′XX′*, $J_X(J_A)$ = 8.7, 2 H$_o$).

9. *2-Methoxyethyl 2-[4-[1,2-Dicarba*-closo-*dodecaboran(12)-2-yl]phenyl]-1*H-*benzimidazole-5-carboximidate Hydrochloride* (**7b**). As described for **7a**, with **6b** (1.7 mmol, 0.62 g) in 2-methoxyethanol (30 ml): 0.46 g (56.8%) of **7b**, which was used without further purification in the next step. ^{1}H-NMR ((D$_6$)DMSO): 3.38 (*s*, MeO); 3.85 (*m*, MeOC*H*$_2$CH$_2$); 4.77 (*m*, MeOCH$_2$C*H*$_2$); 5.96 (br. *s*, CB$_{10}$H$_{10}$C*H*); 7.85 (*AA′XX′*, $J_A(J_X)$ = 9, 2 H$_m$); 7.89 (*d*, *J* = 9, H–C(7)); 8.03 (*dd*, *J*(4,6) = 1.8, *J*(6,7) = 8.7, H–C(6)); 8.37 (*AA′XX′*, $J_A(J_X)$ = 8.7, 2 H$_o$); 8.53 (*s*, *J*(4,6) = 1.8, H–C(4)).

10. *2′-[4-[1,2-Dicarba*-closo-*dodecaboran(12)-2-yl]phenyl]5-(4-methylpiperazin-1-yl)-2,5′-bi-1*H-*benzimidazole* (**9b**). As described for **9a**, with **8** (0.62 mmol, 0.129 g), **7b** (0.62 mmol, 0.30 g), and AcOH (20 ml): 0.140 g (47.4%) of **9b**. Yellow crystals. ^{1}H-NMR (CD$_3$OD + drops of CF$_3$COOD): 2.98 (*s*, MeN); 3.24 (*t*, *J* = 12, 2 H, MeNC*H*$_2$CH$_2$); 3.33 (*t*, *J* = 12, 2 H, MeNC*H*$_2$CH$_2$); 3.67 (*d*, *J* = 11, 2 H, MeNCH$_2$C*H*$_2$); 3.95 (*d*, *J* = 12, 2 H, MeNCH$_2$C*H*$_2$); 5.15 (*s*, CB$_{10}$H$_{10}$C*H*), 7.35 (*d*, *J*(4,6) = 2.1, H–C(4)); 7.41 (*dd*, *J*(4,6) = 2.1, *J*(6,7) = 9, H–C(6)); 7.75 (*d*, *J*(6,7) = 9, H–C(7)); 7.94 (*AA′XX′*, $J_A(J_X)$ = 9, 2 H$_m$); 8.14 (*dd*, *J*(4′,7′) = 0.6, *J*(6′,7′) = 9, H–C(7′)); 8.23 (*AA′XX′*, $J_A(J_X)$ = 9, 2 H$_o$); 8.31 (*dd*, *J*(4′,6′) = 1.8, H–C(6′)); 8.67 (*dd*, *J*(4′,7′) = 0.6, *J*(4′,6′) = 1.8, H–C(4′)). ESI-MS: 554 (56), 553 (100, $[M+1]^+$), 552 (97), 551 (57), 550 (25).

11. *Tetrahydro-4-phenyl-*2H-*1,4-selenazine* (**11**). To a soln. of 2,2′-(phenylimino)bis[ethanol] (27.62 mmol, 5 g) in CH$_2$Cl$_2$ (80 ml) and dry Et$_3$N (3 equiv., 82.86 mmol, 11.41 ml) at 0°, TsCl (2.5 equiv., 69.05 mmol, 13.16 g) in CH$_2$Cl$_2$ (66 ml) was added over 30 min. The soln. was stirred at 5–6° overnight and then poured into vigorously stirred ice-water. The crude product, which crystallized within 15 min, was filtered off and dissolved in CH$_2$Cl$_2$. The soln. then was washed with H$_2$O, dried (MgSO$_4$), and evaporated and the residue subjected to FC (silica gel, CH$_2$Cl$_2$): 9.25 g (70%) of *2,2′-(phenylimino)bis[ethanol] bis(4-methylbenzenesulfonate)* (**10**). Fine colorless powder. M.p. 89–90°. ^{1}H-NMR (CDCl$_3$): 2.41 (*s*, 2 Me); 3.54 (*t*, *J* = 6.0, N(CH$_2$)$_2$); 4.08 (*t*, *J* = 6.0, 2 CH$_2$O); 6.42 (*d*, *J* = 8.2, H–C(2), and H–C(6) (Ph)); 6.69 (*t*, *J* = 7.3, H–C(4)(Ph)); 7.12 (*t*, *J* = 7.4, H–C(3), H–C(5)(Ph)); 7.27 (*AA′XX′*, $J_A(J_X)$ = 8.1, 4 H, H$_m$ (Ts)); 7.70 (*AA′XX′*, $J_A(J_X)$ = 8.3, 4 H, H$_o$ (Ts)).

A soln. of **10** (1.27 mmol, 0.63 g) and *t*BuOH (0.5 ml, 5.3 mmol) in THF (11 ml) was added dropwise to Li$_2$Se (1.27 mmol) suspended in THF (7 ml). This soln. was stirred and refluxed under N$_2$ for 4 h (TLC (silica gel, CHCl$_3$/hexane 1:2) monitoring: R_f 0.45). Et$_2$O/H$_2$O was added, the org. phase decanted, the aq. phase extracted twice with Et$_2$O, the combined Et$_2$O phase dried (MgSO$_4$) and evaporated, and the residue subjected to FC (silica gel, CHCl$_3$/hexane 1:2): 0.115 g (40%) of pure **11**. Light cream-colored solid. M.p. 49–51°. ^{1}H-NMR (CDCl$_3$): 2.71 (*AA′XX′*, $J_A(J_X)$ = 5.2, N(CH$_2$)$_2$); 3.78 (*AA′XX′*, $J_A(J_X)$ = 5.2, Se(CH$_2$)$_2$); 6.8 (*m*, H–C(2), H–C(4), H–C(6)); 7.24 (*m*, H–C(3), H–C(5)). CI-MS: 228 (100, $[M+H]^+$), 227 (16), 226 (49), 225 (21). Anal. calc. for C$_{10}$H$_{13}$NSe (226.18): C 53.10, H 5.79, N 6.19; found: C 52.87, H 6.10, N 6.33.

12. *2-Methyl-5-(tetrahydro-*2H-*1,4-selenazin-4-yl)-1*H-*benzimidazole* (**18**). 12.1. N,N′*-(4-Nitro-1,2-phenylene)bis[acetamide]* (**12**). A mixture of 4-nitrobenzene-1,2-diamine (32.65 mmol, 5 g) and AcCl (55 ml) was refluxed for 6 h. After cooling, the precipitate was filtered and dried under reduced pressure. The product was crystallized from AcOH: 7.27 g (94%) of **12**. Colorless needles. M.p. 249–251°. ^{1}H-NMR ((D$_6$)DMSO): 2.14 (*s*, *Ac*NH–C(1)); 2.16 (*s*, *Ac*NH–C(2)); 8.02 (*m*, H–C(3), H–C(6)); 8.50 (*m*, H–C(5)); 9.65 (*s*, AcN*H*–C(1)); 9.68 (*s*, AcN*H*–C(2)).

12.2. N,N′*-(4-Amino-1,2-phenylene)bis[acetamide]* (**13**). A mixture of **12** (4.64 mmol, 1.1 g), 5% Ru/C (0.44 g, 40%), and $N_2H_4 \cdot H_2O$ (99%, 2 ml) in EtOH (150 ml) was refluxed for 5 h. The mixture was filtered through a pad of *Celite* and the filtrate evaporated: 0.67 g (70%) of **13**, which was used without further purification in the next step. M.p. 209–210° ([7]: 204–205° (EtOH)). ^{1}H-NMR ((D$_6$)DMSO): 1.98 (*s*, *Ac*NH–C(2)); 2.02 (*s*, *Ac*NH–C(1)); 5.02 (*s*, NH$_2$); 6.31 (*dd*, *J*(3,5) = 2.4, *J*(5,6) = 8.5, H–C(5)); 6.88 (*d*, *J*(3,5) = 2.2, H–C(3)); 6.97 (*d*, *J*(5,6) = 8.5, H–C(6)); 8.98 (*s*, AcN*H*–C(2)); 9.03 (*s*, AcN*H*–C(1)).

12.3. N,N′*-[4-[Bis(2-hydroxyethyl)amino]-1,2-phenylene]bis[acetamide]* (**14**). Oxirane (10 ml) was added gradually to a soln. of **13** (20.3 mmol, 4.2 g) in 25% aq. AcOH soln. (30 ml) cooled to 2–3°. The mixture was stirred at 5° for 5 h. The excess oxirane was evaporated, the residue triturated in Et$_2$O, and the final compound purified by precipitation from MeOH/Et$_2$O 1:4: 4.80 g (80.3%) of **14**. M.p. 178–180° ([7]: 174–175° (EtOH)). ^{1}H-NMR ((D$_6$)DMSO): 1.97 (*s*, Ac), 2.01 (*s*, Ac); 3.34 (*m*, N(CH$_2$)$_2$); 3.50 (*m*, 2 CH$_2$O); 4.72

(t, J = 5, 2 OH); 6.43 (dd, J(5,6) = 9, J(3,5) = 2.7, H–C(5)); 6.85 (d, J(3,5) = 2.7, H–C(3)); 7.10 (d, J(5,6) = 9, H–C(6)); 8.95 (s, NH); 9.16 (s, NH).

12.4. *2,2′-[(2-Methyl-1*H*-benzimidazol-5-yl)imino]bis[ethanol]* (**15**). A soln. of **14** (10.17 mmol, 3 g) in 18% aq. HCl soln. (60 ml) was refluxed for 3 h. The mixture was cooled, neutralized with K_2CO_3, and extracted with AcOEt. Pure **15** was obtained by precipitation from MeOH/Et_2O 1:4: 0.72 g (30%). M.p. 151–153° ([7]: 149–151°). ^{1}H-NMR (CD_3OD): 2.49 (s, Me); 3.51 (t, J = 6, N(CH_2)$_2$); 3.72 (t, J = 6, 2 CH_2O); 6.78 (dd, J(4,6) = 2.4, J(6,7) = 8.8, H–C(6)); 6.83 (d, J(4,6) = 2.4, H–C(4)); 7.29 (dd, J(4,7) = 0.25, J(6,7) = 8.8, H–C(7)).

12.5. *2,2′-{[2-Methyl-1-[(4-methylphenyl)sulfonyl]-1*H*-benzimidazol-5-yl]imino}- and 2,2′-{[2-Methyl-1-[(4-methylphenyl)sulfonyl]-1*H*-benzimidazol-6-yl]imino}bis[ethanol] Bis(4-methylbenzenesulfonate)* (**16a** and **16b**, resp.). A soln. of **15** (5.45 mmol, 1.28 g) in pyridine (60 ml) was cooled to 0°, and solid TsCl (32.7 mmol, 6.25 g) was added portionwise. This soln. was stored at 5° for 72 h and then poured into stirred ice-water. The crude product, which crystallized within 15 min, was filtered off and washed with H_2O. The precipitate was dried *in vacuo:* 2.4 g (62%) of **16a**/**16b**. Cream-colored crystals. M.p. 127–128°. ^{1}H-NMR ($CDCl_3$): 2.36 (s, 6 H, Me (TsO)); 2.39 (s, 3 H, Me (TsN)); 2.75 (s, 1.8 H, Me–C(2) (**16a**)); 2.76 (s, 1.2 H, Me–C(2) (**16b**)); 3.59 (t, J = 5.7, 2.4 H, CH_2N); 3.60 (t, J = 5.7, 1.6 H, CH_2N); 4.10 (t, J = 5.7, 2.4 H, CH_2O); 4.13 (t, J = 5.7, 1.6 H, CH_2O); 6.40 (dd, J(6,7) = 8.9, J(4,6) = 2.5, 0.4 H, H–C(6) (**16a**)); 6.51 (dd, J(6,7) = 9, J(4,6) = 2.5, 0.6 H, H–C(5) (**16b**)); 6.59 (d, J(4,6) = 2.5, 0.6 H, H–C(4) (**16a**)); 7.08 (d, J(4,6) = 2.5, 0.4 H, H–C(7) (**16b**)); 7.19–7.34 (m, 7 H, arom. H (Ts), H–C(4) (**16b**)); 7.65–7.82 (m, 7 H, arom. H (Ts), H–C(7) (**16a**)). ESI-MS: 700 (23), 699 (40), 698 (100, $[M+1]^+$).

12.6. *2-Methyl-1-[(4-methylphenyl)sulfonyl]-5- and -6-(tetrahydro-2*H*-1,4-selenazin-4-yl)-1*H*-benzimidazole* (**17a** and **17b**, resp.). *Method A:* A soln. of NaHSe (1.13 mmol, 0.79 g) in EtOH (25 ml) was added slowly and dropwise to powdered **16a**/**16b** (1.13 mmol, 0.050 g). The resulting mixture was stirred and refluxed for 6 h under N_2, followed by another 15 h of stirring at r.t. EtOH was removed under reduced pressure and the residue suspended in H_2O (5 ml). The crude product was extracted with $CHCl_3$ (15 ml), then purified by FC (silica gel, gradient $CHCl_3$, $CHCl_3$/MeOH 95:5, $CHCl_3$/MeOH 80:20): 0.160 g (33%) of **17a**/**17b**.

Method B: A mixture **16a**/**16b** (1.27 mmol, 0.885 g) in THF (12 ml) and ^{t}BuOH (0.5 ml) was slowly and dropwise added to a suspension of Li_2Se (1.27 mmol, 0.118 g) in THF (4 ml). The resulting mixture was stirred overnight under N_2 at r.t. Workup as described in *Method A:* (0.190 g, 35%) of **17a**/**17b**. ^{1}H-NMR ($CDCl_3$): 2.38 (s, 6 H, Me (TsN) (**17a**/**17b**)); 2.74 (s, 3 H, Me–C(2) (**17a**)); 2.76 (s, 3 H, Me–C(2) (**17b**)); 2.79 ($AA'XX'$, 4 H, N(CH_2)$_2$); 3.77 (AA′XX′, 4 H, Se(CH_2)$_2$); 6.88 (d, J(4,6) = 2.1, 0.4 H, H–C(5) of **17b**); 6.92 (dd, J(6,7) = 8.8, J(4,6) = 2.1, 0.6 H, H–C(6) (**17a**)); 7.06 (d, J(4,6) = 2.1, 0.6 H, H–C(4) (**17a**)); 7.29 ($AA'XX'$, $J_A(J_X)$ = 8.8, 4 H, H_m (Ts)); 7.47 (d, J(6,7) = 8.7, 0.4 H, H–C(4) (**17b**), and 0.6 H, H–C(7) (**17b**)); 7.78 ($AA'XX'$, $J_A(J_X)$ = 8.3, 4 H, H_o (Ts)); 7.86 (d, J(6,7) = 9.0, 0.6 H, H–C(7) (**17a**)). EI-MS: 435 (68, $M^{+\bullet}$).

12.7. *(Tetrahydro-2*H*-1,4-selenazinyl)-1*H*-benzimidazole* **18**. A soln. of 0.1M Me_4NCl in 94% EtOH (300 ml), in the electrolysis cell at 5°, was flushed with a slow stream of Ar and electrolyzed at a potential of − 2.3 V. To this pre-electrolyzed soln., **17a**/**17b** (0.37 mmol, 0.160 g) in EtOH (5 ml) was added. After 90 min, at a potential of − 1.6 V, the current had dropped to 10 mA (TLC (silica gel, MeOH/CH_2Cl_2 1:9): no starting material left). The solvent was evaporated and the residue dissolved in H_2O. The pH of the aq. soln. was adjusted to 9–10 with 10% aq. K_2CO_3 soln. The crude product was extracted with CH_2Cl_2. FC (silica gel, MeOH/CH_2Cl_2 1:9) gave pure **18** (0.08 g, 77%). Product **18** was also isolated in 53% yield as a by-product in the synthesis of **17a**/**17b**, when 2 equiv. of Li_2Se for 1 equiv. of **16a**/**16b** were used. ^{1}H-NMR ($CDCl_3$): 2.58 (s, Me); 2.81 ($AA'XX'$, $J_A(J_X)$ = 5.1, N(CH_2)$_2$); 3.66 ($AA'XX'$, $J_A(J_X)$ = 5.1, Se(CH_2)$_2$); 6.87 (dd, J(6,7) = 8.7, J(4,6) = 2.0, H–C(6)); 7.00 (d, J(4,6) = 2, H–C(4)); 7.42 (d, J(6,7) = 8.7, H–C(7)). EI-MS: 281 (41, $M^{+\bullet}$).

13. *2,2′-[(3,4-Diaminophenyl)imino]bis[ethanol]* (**19**). A mixture of 2,2′-[(4-amino-3-nitrophenyl)imino]-bis[ethanol] [24] (1.51 mmol, 0.364 g), 5% Ru/C (0.073 g, 20%), $N_2H_4 \cdot H_2O$ (1 ml), and EtOH (30 ml) was refluxed for 1.5 h. The mixture was filtered through a pad of *Celite* and the solvent evaporated: 0.28 g (90%) of **19**, which was used without further purification in the next step. Cream-colored solid. ^{1}H-NMR (CD_3OD): 3.34 (t, J = 6.0, N(CH_2)$_2$); 3.64 (t, J = 6.0, 2 CH_2O); 6.15 (dd, J(3,5) = 2.7, J(5,6) = 8.4, H–C(5)); 6.31 (d, J(3,5) = 2.7, H–C(3)); 6.62 (d, J(5,6) = 8.4, H–C(6)).

14. *2-[4-[1,2-Dicarba*-closo-*dodecaboran(12)-2-ylmethoxy]phenyl]-5-(tetrahydro-2*H*-1,4-selenazin-4-yl)-1*H*-benzimidazole* (**24**). 14.1. *2,2′-{[2-[4-[1,2-Dicarba*-closo-*dodecaboran(12)-2-ylmethoxy]phenyl]-1*H*-benzimidazol-5-yl]imino}bis[ethanol]* (**21**). A mixture of **19** (2.75 mmol, 0.58 g) and **20** (2.75 mmol, 0.98 g) in ^{i}PrOH (30 ml) was stirred and refluxed for 7 h under N_2. The resulting soln. was stirred overnight under N_2 at r.t. The solvent was evaporated and the raw material subjected to FC (silica gel, MeOH/CH_2Cl_2 2:98, 5:95, and 10:90): 0.43 g (33%) of **24**. Golden crystals. M.p.: darkening at 269°, no melting up to 350°. R_f (MeOH/CH_2Cl_2 2:8)

0.79. ^{1}H-NMR (CD_3OD): 3.55 (t, J = 5.8, $N(CH_2)_2$); 3.76 (t, J = 5.8, $O(CH_2)_2$); 4.59 (s, $OCH_2CB_{10}H_{10}CH$); 4.79 (br. s, $CB_{10}H_{10}CH$); 6.84 (dd, J(4,6) = 2.3, J(6,7) = 8.9, H–C(6)); 6.88 (d, J(4,6) = 2.3, H–C(4)); 7.07 ($AA'XX'$, $J_A(J_X)$ = 8.9, 2 H_m); 7.42 (d, J(6,7) = 8.9, H–C(7)); 7.96 ($AA'XX'$, $J_A(J_X)$ = 8.9, 2 H_o). ESI-MS: 472 (55, $[M+1]^+$), 471 (98), 470 (100), 469 (75), 468 (33).

14.2. *2,2′-{[2-{4-[1,2-Dicarba*-closo-*dodecaboran(12)-2-ylmethoxy]phenyl}-1-[(4-methylphenyl)sulfonyl]-1*H-*benzimidazol-5-yl}imino}- and 2,2′-{[2-{4-[1,2-Dicarba*-closo-*dodecaboran(12)-2-ylmethoxy]phenyl}-1-[(4-methylphenyl)sulfonyl]-1*H-*benzimidazol-6-yl}imino}bis[ethanol] Bis(4-methylbenzenesulfonate)* (**22a** and **22b**, resp.). As described for **16a**/**16b**, with **21** (0.48 mmol, 0.23 g), pyridine (10 ml) and TsCl (2.88 mmol, 0.55 g, 6 equiv.): 0.33 g (74%) of **22a**/**22b**. ESI-MS: 935 (32), 934 (67, $[M+1]^+$), 933 (97), 932 (100), 931 (62), 930 (33).

14.3. *2-{4-[1,2-Dicarba*-closo-*dodecaboran(12)-2-ylmethoxy]phenyl}-1-[(4-methylphenyl)sulfonyl]-5- and -6-(tetrahydro-2*H-*1,4-selenazin-4-yl)-1*H-*benzimidazole* (**23a** and **23b**, resp.). A soln. of **22a**/**22b** (0.32 mmol, 0.3 g) in THF (5 ml) and ^{t}BuOH (0.5 ml) was added dropwise to Li_2Se (0.67 mmol, 0.053 g, 2 equiv.) suspended in THF (5 ml). The mixture was stirred and refluxed under N_2 for 2 h, then left overnight at r.t. Workup as described for **11**. The final product **23a**/**23b** was purified by FC (silica gel, acetone/hexane 4:6). R_f (acetone/hexane 5:5) 0.54. ESI-MS: 673 (30), 672 (63), 671 (92), 670 (100, $[M+1]^+$), 669 (95), 668 (78), 667 (55), 666 (33), 665 (20).

14.4. *[(Carbaboranylmethoxy)phenyl](tetrahydro-2*H-*1,4-selenazinyl)-1*H-*benzimidazole* **24** was obtained as a by-product in the synthesis of **23a**/**23b** as fine pale yellow crystals: 0.04 g (24%). M.p. 86° (dec.). R_f (acetone/hexane 5:5) 0.48. ^{1}H-NMR ((D_6)acetone): 2.77 ($AA'XX'$, $J_A(J_X)$ = 5.1, $N(CH_2)_2$); 3.68 ($AA'XX'$, $J_A(J_X)$ = 5.1, $Se(CH_2)_2$); 4.74 (s, $OCH_2CB_{10}H_{10}CH$); 4.98 (br. s, $CB_{10}H_{10}CH$); 6.91 (dd, J(4,6) = 2.3, J(6,7) = 8.8, H–C(6)); 7.01 (d, J(4,6) = 2.3, H–C(4)); 7.12 ($AA'XX'$, $J_A(J_X)$ = 9.0, 2 H_m); 7.44 (d, J(6,7) = 8.8, H–C(7)); 8.13 ($AA'XX'$, $J_A(J_X)$ = 9.0, 2 H_o). ESI-MS: 519 (19), 518 (50), 517 (86), 516 (100, $[M+1]^+$), 515 (94), 514 (77), 513 (56), 512 (33).

15. *2,2′-{[2′-{4-[1,2-Dicarba*-closo-*dodecaboran(12)-2-ylmethyl]phenyl}[2,5′-bi-1*H-*benzimidazol]-5-yl}imino}bis[ethanol]* (**26a**). A mixture of **19** (0.52 mmol, 0.11 g) and **7a** (0.52 mmol, 0.24 g) in ^{i}PrOH (20 ml) was stirred and refluxed for 7 h under N_2. The resulting soln. was stirred overnight under N_2 at r.t. The solvent was evaporated and the red residue subjected to FC (silica gel, $MeOH/CH_2Cl_2$ 1:9): 0.10 g (34%) of **26a**. Brilliant yellow crystals. M.p.: darkening at 203°, no melting up to 350°. R_f ($MeOH/CH_2Cl_2$ 1:9) 0.37. ^{1}H-NMR (CD_3OD): 3.58 (t, J = 5.8, $N(CH_2)_2$); 3.63 (s, $CH_2CB_{10}H_{10}CH$); 3.77 (t, J = 5.8, $O(CH_2)_2$); 4.48 (s, $CB_{10}H_{10}CH$); 6.88 (dd, J(4,6) = 2, J(6,7) = 8.8, H–C(6)); 6.92 (d, J(4,6) = 2, H–C(4)); 7.39 ($AA'XX'$, $J_A(J_X)$ = 8.3, 2 H_m); 7.45 (d, J(6,7) = 8.8, H–C(7)); 7.71 (d, J(6′,7′) = 8.5, H–C(7′)); 7.95 (dd, J(4′,6′) = 1.5, J(6′,7′) = 8.5, H–C(6′)); 8.09 ($AA'XX'$, $J_A(J_X)$ = 8.3, 2 H_o); 8.25 (d, J(4′,6′) = 1.5, H–C(4′)).

16. *2,2′-{[2′-{4-[1,2-Dicarba*-closo-*dodecaboran(12)-2-yl]phenyl}[2,5′-bi-1*H-*benzimidazol]-5-yl}imino}-bis[ethanol]* (**26b**). As described for **26a**, with **19** (0.33 mmol, 0.07 g), **7b** (0.33 mmol, 0.16 g) and ^{i}PrOH (20 ml). FC (silica gel, $MeOH/CH_2Cl_2$ 1:9) gave 0.08 g (44%) of **26b**. Brilliant yellow crystals. M.p.: darkening at 312°, no melting up to 350°. R_f ($MeOH/CH_2Cl_2$ 1:9) 0.33. ^{1}H-NMR (CD_3OD): 3.57 (t, J = 5.8, $N(CH_2)_2$); 3.78 (t, J = 5.8, $O(CH_2)_2$); 5.18 (s, $CB_{10}H_{10}CH$); 6.85 (dd, J(4,6) = 2, J(6,7) = 8.8, H–C(6)); 6.91 (d, J(4,6) = 2, H–C(4)); 7.45 (d, J(6,7) = 8.8, H–C(7)); 7.70 ($AA'XX'$, $J_A(J_X)$ = 8.5, 2 H_m); 7.72 (d, J(6′,7′) = 8.9, H–C(7′)); 7.95 (d, J(6′,7′) = 8.9, H–C(6′)); 8.09 ($AA'XX'$, $J_A(J_X)$ = 8.5, 2 H_o); 8.25 (s, H–C(4′)).

17. *2′-{4-[1,2-Dicarba*-closo-*dodecaboran(12)-2-ylmethoxy]phenyl}-5-(tetrahydro-2*H-*1,4-selenazin-4-yl)-2,5′-bi-1*H-*benzimidazole* (**29**). 17.1. *2,2′-{[2′-{4-[1,2-Dicarba*-closo-*dodecaboran(12)-2-ylmethoxy]phenyl}[2,5′-bi-1*H-*benzimidazol]-5-yl}imino}bis[ethanol]* (**26c**). As described for **26a**, with **19** (1.36 mmol, 0.29 g), **25** (1.36 mmol, 0.6 g), and ^{i}PrOH (40 ml). FC (silica gel, $MeOH/CH_2Cl_2$ 1:9) gave 0.34 g (43%) of **26c**. Brilliant yellow crystals. M.p.: darkening at 247°, no melting up to 350°. R_f ($MeOH/CH_2Cl_2$ 1:4) 0.6–0.7. ^{1}H-NMR (CD_3OD): 3.55 (t, J = 5.8, $N(CH_2)_2$); 3.77 (t, J = 5.8, $O(CH_2)_2$); 4.55 (s, $OCH_2CB_{10}H_{10}CH$); 4.75 (s, $CB_{10}H_{10}CH$); 6.85 (dd, J(4,6) = 2, J(6,7) = 8.8, H–C(6)); 6.88 (d, J(4,6) = 2, H–C(4)); 7.05 ($AA'XX'$, $J_A(J_X)$ = 8.9, 2 H_m); 7.42 (d, J(6,7) = 8.8, H–C(7)); 7.63 (d, J(6′,7′) = 8.5, H–C(7′)); 7.86 (dd, J(4′,6′) = 1.5, J(6′,7′) = 8.5, H–C(6′)); 8.00 ($AA'XX'$, $J_A(J_X)$ = 8.9, 2 H_o); 8.15 (d, J(4′,6′) = 1.5, H–C(4′)). ESI-MS: 588 (57, $[M+1]^+$), 587 (58), 586 (100), 585 (64), 584 (28).

17.2. *2,2′-{[2′-{4-[1,2-Dicarba*-closo-*dodecaboran(12)-2-ylmethoxy]phenyl}-1,1′-bis[(4-methylphenyl]sulfonyl][2,5′-bi-1*H-*benzimidazol]-5-yl}imino}-, -[2,6′-bi-1*H-*benzimidazol]-6-yl}imino}-, -[2,6′-1*H-*benzimidazol]-5-yl}imino}-, and -[2,5′-bi-1*H-*benzimidazol]-6-yl}imino}bis[ethanol] Bis(4-methylbenzenesulfonate)* (**27a**–**d**). A soln. of **26c** (0.31 mmol, 0.18 g) in pyridine (40 ml) was cooled to 0°, and solid TsCl (9.91 mmol, 32 equiv.) was added in portions. This soln. was left standing at 5° for 7 h. The mixture was poured into stirred ice-water. The crude product, which crystallized within 15 min, was filtered off and washed with H_2O. The

precipitate was dried *in vacuo:* 0.19 g (51%) of **27a**–**d**[2]). Cream-colored crystals. ESI-MS: 1205 (25), 1204 (45, $[M+1]^+$), 1203 (57), 1202 (41), 1201 (30).

17.3. *2′-[4-[1,2-Dicarba*-closo-*dodecaboran(12)-2-ylmethoxy]phenyl]-1-[(4-methylphenyl)sulfonyl]-5-(tetrahydro-2*H*-1,4-selenazin-4-yl)-2,5′-bi-1*H*-benzimidazole and -6-(tetrahydro-2*H*-1,4-selenazin-4-yl)-2,6′-bi-1*H*-benzimidazole, and 2′-[4-[1,2-Dicarba*-closo-*dodecaboran(12)-2-ylmethoxy]phenyl]-1-[(4-methylphenyl)sulfonyl]-5-(tetrahydro-2*H*-1,4-selenazin-4-yl)-2,6′-bi-1*H*-benzimidazole and -6-(tetrahydro-2*H*-1,4-selenazin-4-yl)-2,5′-bi-1*H*-benzimidazole* (**28a**–**d**). The mixture **27a**–**d** (0.15 mmol, 0.18 g) in THF (5 ml) and ^{t}BuOH (0.5 ml) was slowly and dropwise added to a stirred suspension of Li_2Se (0.6 mmol, 0.056 g, 4 equiv.) in THF (5 ml) under N_2. The soln. was stirred at 70° for 3 h and left at r.t. overnight. H_2O was added to the resulting mixture and the soln. extracted with Et_2O. The mixture was separated from by-products by FC (silica gel, acetone/hexane 1:1): 0.05 g (37%) of **28a**–**d**[2]). M.p. 271–273°. R_f ($MeOH/CH_2Cl_2$ 1:9) 0.90–0.94. ESI-MS: 788 (60), 787 (86), 786 (100, $[M+1]^+$), 785 (91), 784 (93), 783 (51).

17.4. *[(Carbaboranylmethoxy)phenyl](tetrahydro-2*H*-1,4-selenazin-4-yl)-2,5′-bi-1*H*-benzimidazole* **29** was obtained as a by-product in the synthesis of **28a**–**d**: 0.04 g (42%). M.p. 140° (dec.). R_f ($MeOH/CH_2Cl_2$ 1:9) 0.67. ^{1}H-NMR (CD_3OD): 2.79 (*AA′XX′*, $J_A(J_X) = 5.1$, $N(CH_2)_2$); 3.66 (*AA′XX′*, $J_A(J_X) = 5.1$, $Se(CH_2)_2$); 4.54 (*s*, $OCH_2CB_{10}H_{10}CH$); 4.74 (br. *s*, $CB_{10}H_{10}CH$); 6.95 (*dd*, *J*(4,6) = 2.2, *J*(6,7) = 8.8, H–C(6)); 7.04 (*AA′XX′*, $J_A(J_X) = 8.9$, 2 H_m); 7.06 (*d*, *J*(4,6) = 2.5, H–C(4)); 7.47 (*d*, *J*(6,7) = 8.9, H–C(7)); 7.64 (*d*, *J*(6′,7′) = 8.4, H–C(7′)); 7.89 (*dd*, *J*(4′,6′) = 1.5, *J*(6′,7′) = 8.5, H–C(6′)); 7.99 (*AA′XX′*, $J_A(J_X) = 8.8$, 2 H_o); 8.18 (*d*, H–C(4′)). ESI-MS: 634 (53), 633 (86), 632 (100, $[M+1]^+$), 631 (90), 630 (73), 629 (55), 628 (35).

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[2]) The ^{1}H-NMR spectrum ($CDCl_3$) of the product mixture was too complex for a full interpretation, especially with respect to the presence of the four isomers. Nevertheless, we conclude from our model reactions with **15** that all four isomers should have been formed.