Unexpected reactions and novel glycosylations with benzotriazole and nitrophenyl derivatives

Ungewöhnliche Reaktionen und neuartige Glycosylierungen mit Benzotriazol- und Nitrobenzolderivaten

DISSERTATION

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Index

Abbreviations

°	Degree (Angle)
α	Optical rotation
Å	Angstrom
Ac	Acetyl
Anal.	Analytical
Bn	Benzyl
br	Broad signal (NMR)
bs	Broad singlet (NMR)
Bz	Benzoyl
Calcd	Calculated
cc-pVDZ	Correlation consistent polarised valence double zeta (basis set)
cc-pVTZ	Correlation consistent polarised valence triple zeta (basis set)
CE	15-Crown-5 ether
COSY	Correlation spectroscopy (NMR)
δ	Chemical shift
d	Doublet (NMR)
D	Yellow sodium D line (589 nm)
dd	Doublet of doublet
DBU	1,8-Diazabyciclo[5.4.0]undec-7-ene
DCC	*N*,*N*-Dicyclohexylcarbodiimide
Dec.	Decomposition
DEPT	Distortionless enhancement by polarisation transfer (NMR)
DIAD	Diisopropyldiazacarboxylate
DIC	Diisopropylcarbodiimide
DMAE	Dimethylaminoethanol
DMF	*N*,*N*-Dimethylformamide
DMSO	Dimethylsulfoxide
EI	Electron impact (MS)
EWD	Electron withdrawing
FAB	Fast atom bombardment (MS)
Glyme	1,2-Dimethoxyethane
HOAt	7-Aza-1-hydroxybenzotriazole
HOBt	1-Hydroxybenzotriazole
HPLC	High performance liquid chromatography
HRMS	High resolution mass spectrometry
Hz	Herz
IDCP	Iodonium dicollidine perchlorate
IR	Infrared
J	Coupling constant
λ	Wavelength (UV/Vis, X-Ray)
LG	Leaving group
Lit.	Literature
m	Medium (IR)
m	Multiplet (NMR)
MALDI	Matrix assisted laser desorption ionization
Mes	Methanesulfonyl
Mesyl	Methanesulfonyl
mp	Melting point
MP2/	Moller-Plesset second order perturbation theory
MS	Mass spectrometry
ν	Wavelength (IR)
Nc	Naphthalocyanine
NBS	*N*-Bromosuccinimide
Nf	Nonafluorobutanesulfonyl
NIS	*N*-Iodosuccinimide
NMR	Nuclear magnetic resonance
Nonaflyl	Nonafluorobutanesulfonyl
Nos	*p*-Nitrobenzenesulfonyl
Nu	Nucleophile
Petroleum ether	Petroleum ether 65–90°C
Pc	Phthalocyanine
PDT	Photodynamic therapy
PhthN	Phthalimido
ppm	Part per million
PTSA	p-Toluenesulfonic acid
Pz	Porphyrazine
RT	Room temperature
s	Strong (IR)
t	Triplet (NMR)
t	Time
T	Temperature
TBDS	*tert*-Butyldimethylsilyl
THF	Tetrahydrofurane
Tf	Trifluoromethanesulfonyl
TfO	Trifluoromethanesulfonate
TLC	Thin layer chromatography
TMS	Trimethylsilyl
Tos	*p*-Toluenesulfonyl
Tosyl	*p*-Toluenesulfonyl
TOF	Time of flight
Triflyl	Trifluoromethanesulfonyl
UV	Ultraviolet
Vis	Visible
vs	Very strong (IR)
vw	Very weak (IR)
w	Weak (IR)

1 Introduction and Aim of the Work

Carbohydrate molecules have been nearly exclusively assigned as building blocks of protective cell wall constituents (for example cellulose and chitin) or as energy supply in cell metabolism. Biological information storage and transfer are commonly described to be based solely on nucleic acids and proteins. In contrast to nucleotides and amino acids, the most abundant type of biomolecules in nature, the carbohydrate molecules has been almost completely sidelined in this respect.[1]

Carbohydrates are unique regarding the complexity of their structures. In contrast to the other two major classes of biologically important biopolymers, proteins and nucleic acids, oligo- and polysaccharides are built from monomers, which have at least two functional groups participating in an oligorimerization reaction. In a sugar residue one or more of several different hydroxyl groups can be glycosylated, thus also allowing the formation of branched structures. Furthermore, the glycosidic linkage can occur in one of two different stereoisomers, the α- or the β-glycoside. Consequently, more configurational stereoisomers can be constructed from monosaccharides than amino acids or nucleotides.[2]

However, an important step in the development of carbohydrate research was the discovery of the biological importance of glycoconjugates containing a great variety of complex oligosaccharides. Carbohydrates habitually exist on cell surfaces as glycoprotein or glycolipid conjugates and are engaged in important functional and structural functions in various biological recognition processes like for instance, cancer metastasis, inflammatory response, innate and adaptive immunity, viral and bacterial infections and many other receptor-mediated signalling processes.[3,4] Moreover, a large number of natural products require glycosylation in order to show proper biological performance.[5,6,7] However, the effect of glycosylation on the structure and function of natural products is not well understood, mostly due to the lack of efficient synthesis methods to cover the structural diversity of glycoconjugates required for answering the distinct role of glycosylation in biological systems.

With this stimulant biological background, the O-glycosylation, which is a crucial organic synthetic pathway to attach a sugar to other sugar moieties or other molecules (aglyca), is again becoming more and more important. From a synthetic point of view, the efficiency of the O-glycosylation reaction generally involves high chemical yields as well as regio- and stereoselectivity. Among them, high regioselectivity is easily realised by the selective protection of the hydroxyl groups of the glycosyl acceptor. Although great achievements in the development of versatile and efficient glycosylation and building block strategies have been made during the last years,[8,9] there is still the need for more efficient procedures to prepare glycoconjugates.

The aim of this work is to develop two new efficient procedures to generate the O-glycosydic bond. In the first one, nonafluorobutanesulfonate is used as a leaving group for the formation of the glycosyl donor. In the second one, the generation of phenyl glycosides through nitro-substitution on aromatic compounds is investigated.

2 General Part

2.1 Overview on Glycosylation

2.1.1 Role of Carbohydrates in Nature

Oligosaccharides and glycoconjugates have intrigued biologist for decades as mediators of complex cellular events. With respect to structural diversity, they have capacities that far exceed proteins and nucleic acids. This structural variance allows them to encode information for many important biological processes: specific molecular recognition, to serve as determinants for protein folding and stability and influence the pharmacokinetics. It is demonstrated that glycosylation is one of the most ubiquitous forms of posttranslational modification.[10] Furthermore, the effects of altering glycosylation are highly variable and quite unpredictable.[3] Carbohydrates also constitute a very important group of molecules by themselves, they are major constituents of diverse natural products: secondary metabolites, nucleic acids, nucleotides, glycoproteins and glycolipids.[2]

2.1.2 O-Glycosylation Methods

Homogeneous and chemically defined glycoconjugates from biological sources for the investigation of the biological function are difficult to obtain. For this reason the synthesis of structurally defined oligosaccharides is a powerful tool in the study of glycobiology. Therefore chemical routes for the production of oligosaccharides and glycoconjugates are essential.

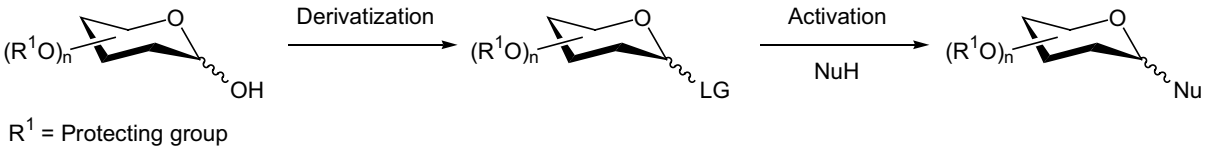
The chemical synthesis of natural glycoconjugates consists of the oligosaccharide synthesis, the aglycon synthesis and their glycosidic linkage to yield the target molecule. Commonly, the synthesis of glycoconjugates follows a convergent strategy. The two parts are synthesised separately, and the glycosidic linkage is formed in an advanced stage. Finally, the use of economic strategies due to the difficulty to ensemble monosaccharides has to be considered for the synthesis of the oligosaccharide. A convergent strategy makes it possible to reach the goal

with better yield than a linear strategy. The armed-disarmed[11] as well as the active-latent[12] concept can be utilised to facilitate the synthesis. The nonexistence of universal conditions for the synthesis of oligosaccharides, as Paulsen in 1982 stated, make that “each oligosaccharide synthesis remains an independent problem whose resolution requires considerable systematic research and a good deal of know-how”.[13]

Since the major historical Koenigs–Knorr method was reported in 1901,[14] considerable attention has been directed towards the efficiency of the O-glycosylation method.[8,9,13,15,16] From a synthetic point of view, the efficiency of the O-glycosylation reaction generally involves high chemical yields as well as regioselectivity and stereoselectivity. Among them, high regioselectivity is realised by the appropriate selective protection of the hydroxyl groups, adapted to the synthetic strategy of the glycosyl acceptor. Therefore, many methods have been developed focusing on the high chemical yield and the high stereoselectivity of this reaction.

One important consideration is the configuration of the anomeric center. In fact control of the stereochemical product of nucleophilic substitution (S_N1 or S_N2) at this position is one of the most difficult tasks faced by the synthetic chemist. Many factors can play an important role in α/β-stereoselectivity, namely nature of the solvent, protecting groups, neighboring group effect,[17] activation method and the anomeric effect.[18]

The most used strategy approach for glycosylation requires the derivatization of the anomeric substituent into a leaving group (LG, Scheme 1), whereby the intermediate or glycosyl donor can be isolated. In the next step the leaving group is activated with an appropriate promoter. The presence of a glycosyl acceptor (Nu) during the second step leads to the formation of the anomeric bond or glycoside product.[15,16] Many methods have been developed using this pathway. The most important ones are summarised in Table 1.

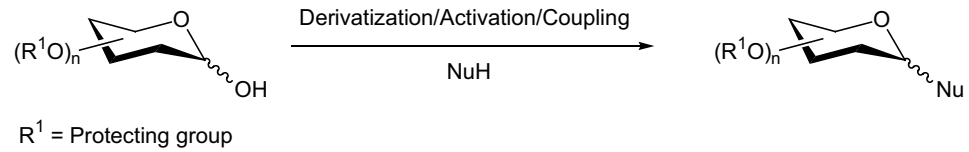


Scheme 1 Two step glycosylation strategy

Table 1 Promoter used for each leaving group in the two step glycosylation strategy

Leaving Group	Promoter	Comments
Halide Br or Cl	$Hg(CN)_2$,[19] Ag_2O,[20] $Sn(OTf)_2$[21]	unstable easy to hydrolyze high toxicity of metals
Halide F	$SnCl_2$-$AgOCl_4$,[22] SiF_4,[23] $BF_3{\cdot}OEt_2$,[24] TiF_4[25]	more stable than Br and Cl
SR'	IDCP,[26] NIS-TfOH,[27] NBS,[28] NIS[29]	very versatile
O-Acyl	$FeCl_3$,[30] $BF_3{\cdot}OEt_2$,[31] TMSOTf[32]	facile preparation
OC(NH)R'	$BF_3{\cdot}OEt_2$,[33] TMSOTf[33]	mild reaction conditions very versatile
$O(CH_2)_3CH{=}CH_2$	IDCP,[34] NIS-Et_3SiOTf[34]	versatile
$OP(OR')_2$	TMSOTf[35]	mild reaction conditions

Another concept for the formation of the glycosidic bond is the so called dehydrative glycosylation.[36] This consists in the derivatization, activation and coupling in one step (Scheme 2). The earliest reaction of this type was carried out by Fischer.[37] Since then significant advances have been made in this field, enlarging the methods useful for glycosylation. Dehydrative coupling needs mild conditions, a set of reagents that react rapidly and completely to form a highly reactive intermediate. The generation *in situ* of the glycosyl donor avoids the unnecessary isolation of the donor. A representative set of methods are summarised in Table 2.



Scheme 2 Direct dehydrative glycosylation[36]

Table 2 Methods used for the dehydrative glycosylation

Coupling via	Reagents	Comments
Protic acids	HCl[37]	only for simple glycosides
Lewis acids	$Yb(OTf)_3$-$MeOCH_2CO_2H$[38]	
	$Sn(OTf)_2$-TMS_2O[39]	
	$Ph_2Sn=S$, $AgClO_4$[40]	
Halides	$MeSO_3H$-$CoBr_2$-TBABr[41]	
Sulfonates	Tf_2O[42]	
	NosCl, AgOTf[43]	
Oxophosphonium	DIAD, PPh_3[44]	very versatile
	$Bu_3P=O$, Tf_2O[45]	facile procedure
Oxosulfonium	$Ph_2S=O$, Tf_2O[46]	very versatile
		facile procedure
Oxotitanium	[1,2-benzenediolato(2-)-*O*,*O*]-oxotitanium, Tf_2O[47]	useful for pyranose formation
Thio-tin	$Ph_2Sn=S$, Tf_2O[48]	useful for pyranose formation
Isourea	Cy-N=C=Ncy, Cucl[49]	useful for phenyl glycosides

There are still three chemical methods, which are very useful for the formation of the glycosidic bond, and can not be included in Scheme 1 or Scheme 2. These are the glycals, 1,2-anhydrosugar and orthoester methods summarised in Table 3.

Table 3 Promoter for glycosyl donors different from Scheme 1 or Scheme 2

Glycosyl donor	Promoter	Comments
Glycal	IDCP,[50] NIS[51]	useful for the synthesis 2-deoxy-sugars
1,2-Anhydrosugar	$ZnCl_2$[52]	useful for the synthesis trans 1,2-glycosides
Orthoester	AgOTf,[53] $TrClO_4$[54]	useful for the synthesis trans 1,2-glycosides

Solid-phase synthesis has revolutionised the synthesis of nucleotides and peptides, and strong progress has been made in oligosaccharide synthesis. Oligosaccharide solid-phase synthesis is more complicated due to the stereoselectivity and regioselectivity as well as the difficulty to synthesise branched structures. Solid-phase synthesis requires highly efficient reactions that give single products and near quantitative yield. For this reason there is still need for more efficient procedures to prepare glycoconjugates.[55]

An alternative to chemical synthesis to form the glycosidic bond is the enzyme method. Two kind of enzymes can be used: glycosyltransferases and glycosidases. Glycosidases give low yields, but the use of these for transglycosylation using fluoride or *p*-nitrophenyl glycosides as donors show very good results. On the other hand, glycosyltransferases produce glycosidic bonds using the same basic approach that has been developed by carbohydrate chemists. In general, enzymes do not need protecting groups, are specific and efficient, work under mild conditions and are environmentally friendly, but some disadvantages must be considered. They are difficult to obtain, are not useful for a big range of reactions due to the high specificity, and do not work without cofactors, precise pH and temperature.[56]

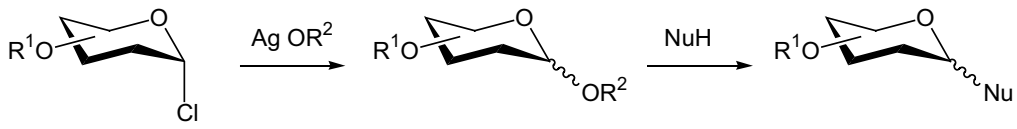
2.1.3 Sulfonates as Glycosyl Donors

Sulfones have great relevance in organic synthetic transformations[57,58] and additionally have a wide applicability in diverse fields including agrochemicals,[59] pharmaceuticals[60] and polymers.[61] Sulfones have been described as “chemical chameleons”[62] due to the ability of the sulfonyl group to serve as a temporary transformer of chemical reactivity. The RSO_2 group activates olefines for nucleophilic Michael additions,[63] is an excellent stabiliser of adjacent carbanions[64]and has been widely used for cross coupling reactions.[65,66] Although without proper asymmetry sulfones can also function as a stereoinducer.[67] The sulfonate function containing the RSO_2 group has been used in carbohydrate chemistry for the formation of glycosyl donors.

Glycosyl sulfonates were first reported in 1929 by Helferich et al. The toluenesulfonate was obtained by reacting glycosyl chloride with silver

toluenesulfonate (Scheme 3) and was described as white powder crystals, which were very unstable in solution.[68] Helferich and Gnuchtel synthesised later the mesyl glucopyranoside with the same procedure.[69]

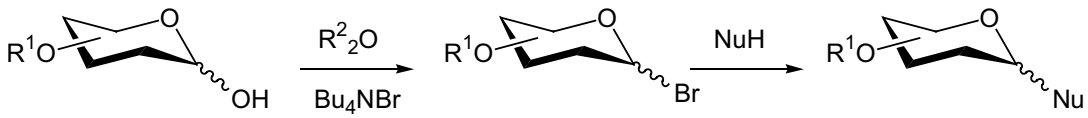
Schuerch and co-workers (Scheme 3) made some experiments with sulfonate donors, where a series of glucose, galactose and mannose were examined. Triflyl and tosyl glycosides were synthesised at –78 °C and at room temperature following the method from Helferich et al. The triflate derivative was reacted with MeOH in CH_2Cl_2 giving β-selectivity with 40% yield. On the other hand, using Et_2O as solvent, a 82% of α/β-mixture was obtained.[70] The same experiments with toluenesulfonate glycoside leads to α/β-mixtures.[71] Similar procedures were carried out with galactose, in which toluenesulfonate gives α-selectivity in contrast to glucose and good yields (60%–quant.) using different alcohols and solvents. In the case of triflate the α-selectivity and yield were reduced and depending on the solvent β-selectivity was obtained.[72] The β-selectivity could be explained by the effect of tight ion pairs.[72] From mannose, toluenesulfonate derivatives were synthesised. To maximise the strong anomeric effect, nonparticipating electron-withdrawing substituents as protecting group (mesyl) were inserted at the C-2 hydroxyl. These reactions were carried out in CH_3CN, obtaining β-selectivity in good yield (60–65%).[73] The authors claimed that the resulting strong opposite dipoles control the structure of the transition state allowing only pure S_N2 reaction leading to the substitution on the β-face.[73] Simultaneously Machami and Suami (Scheme 3) prepared selectively the α/β-mesyl derivatives from glucose. Reaction of the glycosyls donors with alcohols under S_N2 conditions lead to the β/α-products in good yields (70–95%).[74]



R^1 = Protecting group, R^2 = Tf, Tos, Mes

Scheme 3 Schuerch, Mashami and Suami method to synthesise glycosyl sulfonates

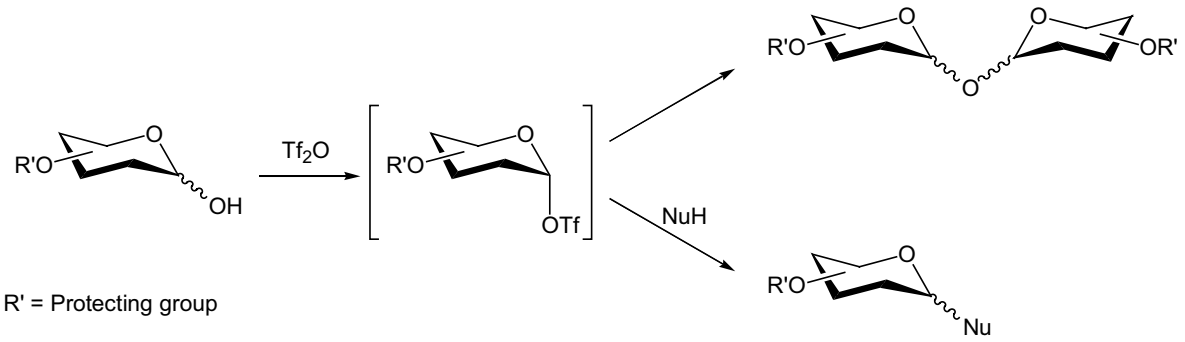
Leroux and Perlin (Scheme 4) investigated the formation of trifluoromethanesulfonates from glucose, also at low temperature and in CH_2Cl_2, but with unsatisfactory yields. They discovered that upon addition of Bu_4NBr in the reaction mixture the α-glucopyranosyl bromide could be formed in a few minutes. When the C-2 hydroxyl was protected with a participating group an orthoester was isolated. As in the previous case, adding Bu_4NBr gave the α-brominated glucosyl donor which was again isolated. Both products suggested the formation of a β-trifluoromethanesulfonyl donor. The same authors also examined the mesyl glycosides formed from Mes_2O, in which the reaction with MeOH gives an α/β-mixture in good yields (87%, 61% with addition of Bu_4NBr). They suggested that according to the α/β percentage, the α/β-mesylates existed in equilibrium and that the displacement of β occurs more rapidly to produce more α-glycoside.[75]



R^1 = Protecting group, R^2 = Mes, Tf

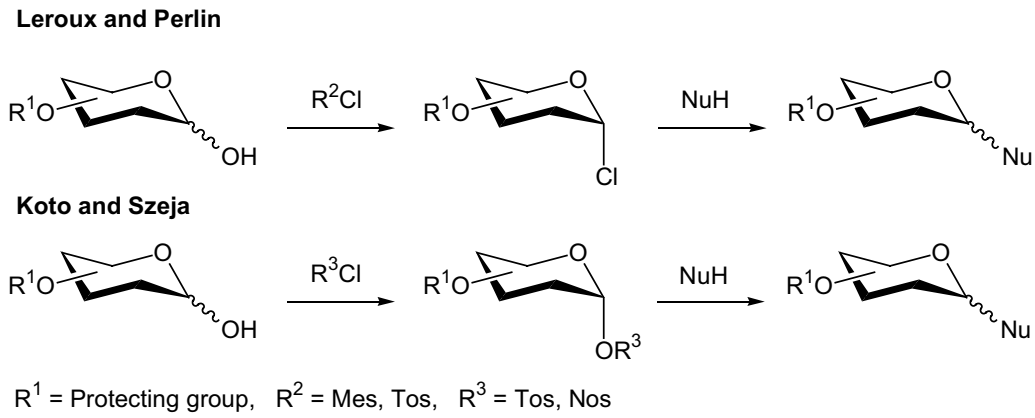
Scheme 4 Method of Leroux and Perlin

Similar studies with Tf_2O were carried out by Pavia and co-workers[76] (Scheme 5) but in the absence of base. They found that depending on the presence of the acceptor in the reaction mixture different products were formed. In the absence of the acceptor, trehalose derivatives were predominantly formed with α-α configuration and in a very good yield (>95%). This type of reaction with acceptors was also studied, giving good yields (55–90%) and α-selectivity.[77]



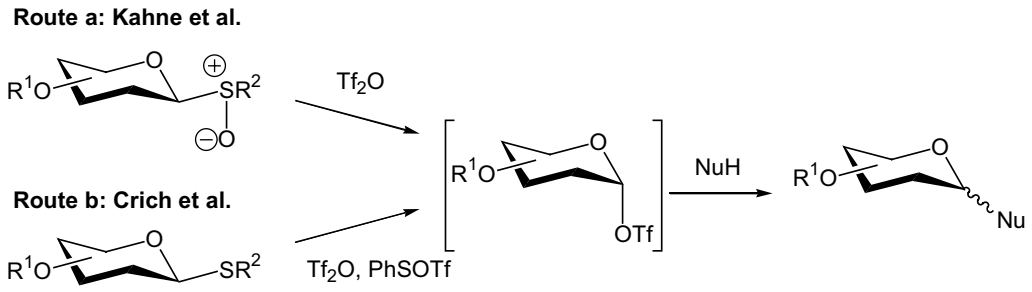
Scheme 5 Method of Pavia and co-workers

Leroux and Perlin (Scheme 6) studied the reaction of sugars with mesyl or tosyl chloride. In the reaction of 2,3,4,6,-tetra-*O*-benzyl-glucopyranose with mesyl or tosyl chloride in the presence of a base in CH_2Cl_2, the formation of the glucopyranosyl chloride could be observed, giving α/β mixtures after addition of the donor.[75] Szeja et al. (Scheme 6) obtained good results in the case of tosyl chloride, but the reaction was carried out under phase-transfer conditions.[78] As pointed out in Scheme 6, Koto et al.[79] investigated the reaction of *p*-nitrobenzenesulfonyl chloride (NosCl) and glycosyl donors in the presence of silver triflate and Et_3N. The selectivity was dependent on the absence or presence of *N*,*N*-dimethylacetamide, being β and α respectively. The formation of α-glycosides was associated with the formation of a *N*,*N*-dimethylacetamide β-intermediate, only allowing the nucleophilic substitution from the α face.[43]



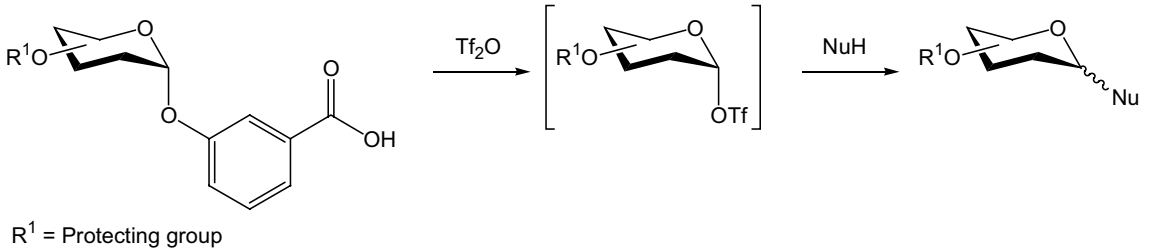
Scheme 6 Synthesis of glycoconjugates with sulfonyl chlorides

Crich and co-workers found out, through NMR studies,[80] that the reaction developed for Kahne et al. (Scheme 7) had a triflate glycoside as an intermediate. In this reaction, a thioglycoside was oxidised to give the glycosyl sulfoxide. Treatment of this sulfoxide with Tf_2O in the presence of one acceptor lead to the corresponding α/β-glycosides.[81] Finally, Crich and co-workers (Scheme 7) developed a method to generate the glycosidic bond in a one-pot reaction, starting from thioglycosides, using Tf_2O and benzenesulfenyl triflate. They also proved that the α-triflate glycoside was the intermediate.[80] More recently Wong et al. used *N*-(phenylthio)-ε-caprolactam in combination with Tf_2O to activate the phenylglycoside.[82] The selectivity depended on the used protective group and could be α[83] or β[80] selective in the case of mannose. The same protecting group effect was observed in the case of glucose, giving α-glucoside[84] or β-glucoside[85] selectively.



Scheme 7 Synthesis of glycoconjugates from thioglycosides and sulfoxides via glycosyl triflate

Kim et al. (Scheme 8) developed a new method for glycosylation based on the activation of 2-(hydroxycarbonyl)benzyl glycosides with Tf_2O in CH_2Cl_2 at low temperature. However they did not give any proof of the proposed mechanism.[86]

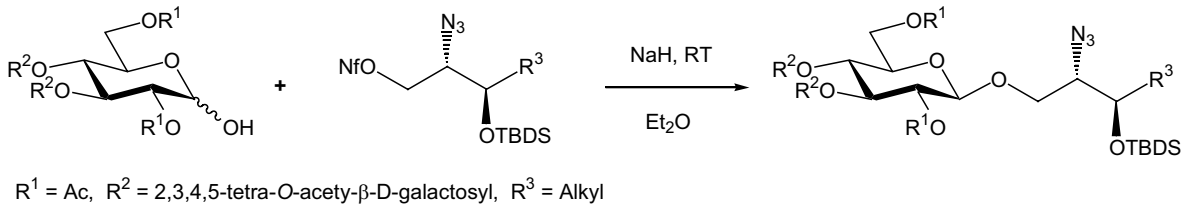


Scheme 8 Mechanism proposed by Kim et al. based on activation of 2-(hydroxycarbonyl)benzyl glycosides

2.1.4 Direct O-Alkylation and O-Arylation

Direct O-alkylation (Scheme 9) with 1-hydroxysugars was investigated for the first time by Purdier et al. in 1903.[87] This method turned to be important for the synthesis of a variety of glycosides.[88] Using this methodology for the synthesis of glycoconjugates, the stability of the anions, ring-chain tautomerism and reactivity of the three O-deprotected hydroxyls must be considered. The mainly used leaving groups for this reaction were sulfonates due to the low reactivity of the iodide.[89]

Even with high reactivity of the β-anion in comparison with the α-anion, high temperature is needed for the synthesis of β-conjugates in order to accelerate the α/β-anomerisation.[90] On the other hand, carrying out the reaction at low temperatures decelerates the anomerisation and the presence of bulky substituents at O-6 favor the α-selectivity.[90] Nevertheless, this methodology has limited general applicability to the synthesis of glycoconjugates.

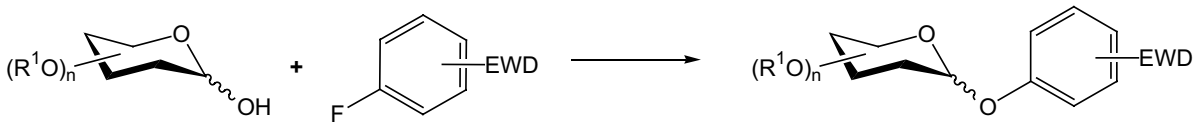


Scheme 9 Direct alkylation of 1-hydroxysugars and sulfonated aglycon[91]

Direct anomeric O-arylation (Scheme 10) of protected or unprotected sugars with electron-deficient aromatic compounds leading directly to aryl and

heteroaromatic compounds has been shown to be efficient.[92,93,94] The aromatic nucleophilic substitution take advantage of the excellent leaving group character of fluoride or chloride in halogenated heteroaromatic and substituted nitro- or dinitrobenzenes. Moreover, phenylglycosides containing a very electron-poor phenyl or heteroaromatic ring can be used as glycosyl donors.[92,93,95]

The selectivity of this aromatic nucleophilic substitution depends on many aspects. Solvent plays an important role. Reactions carried out in DMF or DMSO, in the presence of a base, give almost exclusively α-products, due to the anomerisation process that occurs after formation of the phenylglycosides, forming the thermodynamically most stable product.[96,97] The anomerisation effect could be suppressed using less polar solvents, namely CH_2Cl_2 or toluene.[92,93] In the case of toluene crown ethers are needed to solubilize the formed salts. The used base can also influence the selectivity. Huchel et al. found that β-product was obtained independent from the base used, with toluene or CH_2Cl_2 as solvents. This was explained due to the high nucleophilicity of the β-anion when comparing with the α-anion.[93] On the other hand, Petersen et al. observed that using a mixture of Li_2CO_3 and 4-(*N*,*N*-dimethylamino)pyridine or 1,4-dimethylpiperazine in CH_2Cl_2 α- and β-selectivity were respectively obtained. The explanation given by the authors for these results were the effect of different basicity of the used bases.[92]



R^1 = Protecting group

Scheme 10 Direct O-arylation of a carbohydrate

2.2 Glycosylation with Nonafluorobutanesulfonyl and Unexpected Reactions

2.2.1 Aim of this Work and Synthetic Strategies

Sulfonate characteristics as glycosyl donors for the effective synthesis of glycoconjugates presented in chapter 2.1.3 and the advantages of nonafluorobutanesulfonyl fluoride (NfF) when comparing with Tf_2O (chapter 2.2.2) encouraged to investigate the generation of glycosyl donors with NfF.

Three strategies were thought to be useful for the generation of the glycosylnonaflate, starting from:

1. commercially available NfF (**2a**),
2. nonafluorobutanesulfonyl-1*H*-1,2,3-benzotriazole (**6a**),
3. nonafluorobutanesulfonic acid 1*H*-1,2,3-benzotriazol-1-yl ester (**25a**).

The first methodology was envisaged in order to establish the synthetic possibilities for the glycosyl nonaflate. The use of reagents for sulfone transfer was very attractive, since commercially available fluorides are less reactive, need more basic conditions and nucleophiles that are sufficiently nucleophilic or not sterically encumbered. Numerous transfer reagents are described in the literature for the sulfonyl group, under mild conditions, starting from benzene derivatives or heterocycles, such as nitro- or dinitrophenyl triflates and nonaflates,[98,99] *N*-phenyltrifluoromethanesulfonamide,[100,101] *N*-(2-pyridyl)triflylimidate,[102] triflylimidazole,[103,104] 1-tosyl-1,4-dihydropyridine derivatives,[105,106] indole derivatives[107] and the more studied sulfonylbenzotriazoles, which are used for a wide variety of synthetic transformations, as accurately focused in chapter 2.2.4. For this reason, benzotriazoles were the heterocycles of choice for the nonaflyl group transfer.

Concerning the monosaccharide, a C1-OH unprotected carbohydrate was necessary to generate the glycosyl nonaflate. All other carbohydrate moiety hydroxyl groups had to be protected with a stable protecting group (PG). Moreover, in order to minimize the influence of the PG in the α/β-stereoselectivity, a non-participating C2-OH PG seemed to be appropriate. For these reasons benzyl was selected to be the glucose hydroxyls protecting group, in positions C-2, C-3, C-4 and C-6, which

allowed the reaction in a wide variety of conditions and with different bases. The resulting 2,3,4,6-tetra-*O*-benzyl-(α/β)-D-glucopyranose was the used carbohydrate for the optimisation reactions. The glycosyl acceptor selected for the optimisation was methanol due to the low steric effect and good accessibility.

2.2.2 Overview on the Uses of Nonafluorobutanesulfonyl Fluoride

The use of perfluoroalkyl sulfonates had considerably extended the possibility for new synthetic pathways.[108,109] Moreover, nonafluorobutanesulfonyl esters are very good leaving groups, being twice as fast as their trifluoromethane ester analogues in hydrolysis reactions.[110]

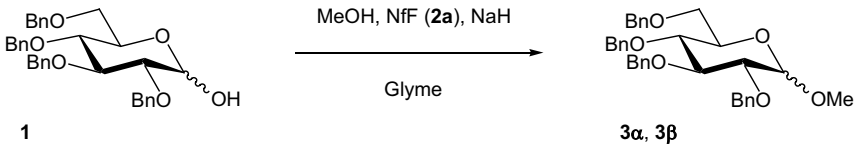
The strong electron-withdrawing effect of nonaflate has found many applications namely for alkylations,[91] fluorination,[111] dehydration of alcohols and phenols,[112] dienophiles for Diels-Alder reactions,[113] vinyl cation generation[114] and epoxy formation.[115] The main advantages of NfF when compared with Tf_2O are its stability when being exposed to air and moisture and no loss of half of the molecule during the reaction.

2.2.3 Nonafluorobutanesulfonyl Fluoride for Glycosylation

Initially, the formation of the glycosyl nonaflate was carried out using commercially available NfF (**2a**). Several reactions were conducted to optimise the glycosylation of 2,3,4,6-tetra-*O*-benzyl-(α/β)-D-glucopyranose[116] (**1**) with MeOH. The use of low pK_a bases, namely pyridine and Et_3N, did not lead to any product and strong bases like NaH were needed for the glycosyl nonaflate generation. Experiments carried out at –78°C, a temperature that was supposed to be optimal, were unsuccessful and therefore the experiments had to be performed at higher temperatures. DMF and 1,2-dimethoxyethane (glyme) were used as solvents when NaH was the base, however glyme showed to be the best solvent. The formation of the glycosyl nonaflate lead immediately to trehalose formation if a glycosyl acceptor was not present in the solution. On the other hand, in the presence of the glycosyl acceptor it was involved in the reaction with the glycosyl nonaflate. These results were comparable to the ones observed by Pavia et al. using Tf_2O.[76] Both reactions, the formation of trehalose and the glycosylation with methanol were optimised.

2.2.3.1 Methyl 2,3,4,6,-tetra-*O*-benzyl-(α/β)-D-glucopyranoside

The experiments summarised in Table 4 were performed adding the reagents in a different order, to find the optimal conditions for the reaction in Scheme 11.



1 **3α**, **3β**

Scheme 11 Glycosylation reaction with MeOH using NfF for the glycosyl donor formation

Since the experiments that were carried out at –78 °C (not indicated in Table 4) in order to form first the glycosyl nonaflate and then the glycoconjugate were unsuccessful, the reactions were performed at 0 °C, however without an improvement (entries 1,2 and 4-6). Only the formation of ββ-trehalose (**4c**; entry 3) or methyl-glucopyranosides **3α** and **3β** (entry 7) were observed when the order

changed in which the reagents were added. Despite the good results from entry 7, the large amount of needed glycosyl acceptor was not satisfactory and other conditions had to be investigated. Better results were observed at –20°C in the presence of 15-crown-5 ether (entries 8–14), in which the amount of glycosyl acceptor and NfF (**2a**) were progressively reduced (entries 8–14). Best results were obtained in the presence of a stoichiometric amount of 15-crown-5 and NaH based on glycosyl-donor and acceptor, 50% excess of glycosyl acceptor and **2a** at –20 °C (entry 14). **4** was observed at least as a shadow by TLC (entries 3, 7–14). After reaction optimisation at –20 °C other temperatures were tested with worse results (not indicated in Table 4), in which low reactivity or formation of by-products were observed at lower or higher temperatures, respectively.

Further investigations in this field were carried out in our working group.[117] This reaction was optimised in a bigger scale and with different glycosyl acceptors. Best conditions turned out to be the same as described in entry 15 giving in this case 72% yield, surprisingly with a different α/β-selectivity (α:β, 3:2). Under the same conditions and using MeCN as solvent a 79% yield (α:β, 3:2) was obtained. When 2,3,4,6-tetra-*O*-benzyl-α-D-glucopyranose (**1**) was added dropwise to the reaction mixture, in MeCN, β-selectivity (α:β = 1:10) was observed, in a 27% yield. Isopropyl- and *tert*-butyl alcohol were also used as glycosyl acceptors giving 56% (α:β , 3:2) and 37% (α:β, 3:2) yields, respectively.

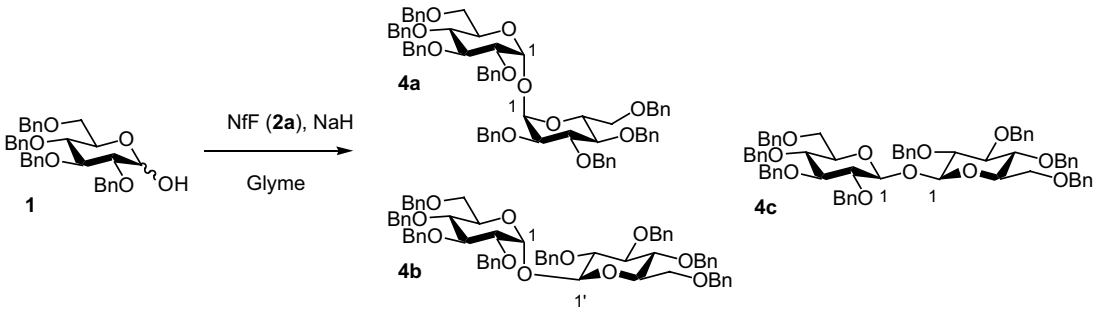
Table 4 Optimisation reactions carried out for the formation of methyl glucopyranosides **3α** and **3β**

	T[°C]	1st Comp.	2nd Comp.	3rd Comp	Results
1	0	2.8 eq NfF	**1**[a] and 2 eq NaH	12 eq MeOH	no reaction[b]
2	0	2.8 eq NfF and cat. NaBr	**1**[a] and 2 eq NaH	5 eq MeOH	no reaction[b]
3	0	2.8 eq NfF, 5 eq MeOH and cat. NaBr	**1**[a] and 2 eq NaH		**1** and traces of **4c**[b]
4	0	5 eq NaH and 3.7 eq NfF	**1**[a]	5 eq MeOH	no reaction[b]
5	0	2.8 eq NfF	**1**[a], 2 eq NaH and 2 eq CE	5 eq MeOH	no reaction[b]
6	0	1.5 eq NaH and 1.5 eq CE	**1**[a] and 3 eq NfF	5 eq MeOH	no reaction[b]
7	0	**1**, 5 eq NaH and 2 3 eq CE	5 eq MeOH	3.7 eq NfF	**3α** + **3β** (65%;1:2)
8	–20	**1**, 2 eq NaH and 2 eq CE	5 eq MeOH	2.8 eq NfF	as in entry 7[b]
9	–20	**1**, 3 eq NaH and 3 eq CE	2 eq MeOH	2.8 eq NfF	**4c** + **3α** + **3β** (46%; 4:7:12)
10	–20	**1**, 3 eq NaH and 1.5 eq CE	2 eq MeOH	2.8 eq NfF	**3α** + **3β** (~60–70%)[b]
11	–20	**1**, 3 eq NaH and 2 eq CE	2 eq MeOH	2.8 eq NfF	conversion of **1** was better when bigger amount of CE was used
12	–20	**1**, 2eq NaH and 2 eq CE	1 eq MeOH	2.8 eq NfF	**3α** + **3β** and **1** (~30%)[b]
13	–20	**1**, 2.5 eq NaH and 2.5 eq CE	1.5 eq MeOH	2 eq NfF	**3α** + **3β** and **1** (~40–50%)[b]
14	–20	**1**, 2.5 eq NaH and 2.5 eq CE	1.5 eq MeOH	1.5 eq NfF	**3α** + **3β** (70%;1:2)

Reactions were carried out overnight (otherwise stated) under argon; After base addition the subsequent components were added after 40 min; 100 mg of **1** were used; [a] **1** was dissolved in glyme; [b] Observed by TLC.

2.2.3.2 2,2',3,3',4,4',6,6'-Octa-*O*-benzyl-(αα/αβ/ββ)-trehalose

The experiments summarised in Table 5 were performed to optimise the reaction in Scheme 12. The reactions were conducted at room temperature, since low temperatures give less product yield (entry 8) or no reaction (entry 9). The presence of 15-crown-5 ether also had a very important role, since only in its presence the formation of the product could be observed (entries 3–8, 10, 11). Stoichiometric amounts were necessary to obtain trehalose **4** in moderate yields, in which a 50% excess of base and NfF were needed.



Scheme 12 Trehalose (**4**) formation using NfF for the glycosyl donor formation

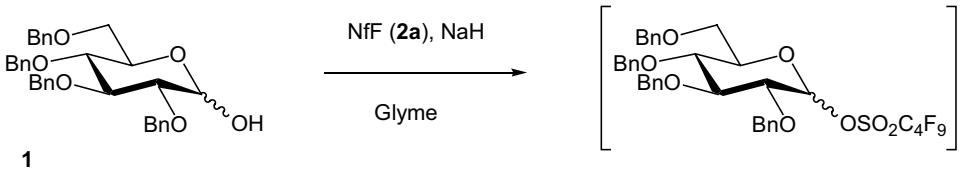
Table 5 Optimisation reactions carried out for the formation of trehaloses **4a**, **4b** and **4c**

	T°C	NaH	NfF	15-Crown-5	Results
1	RT	2 eq	1.5 eq	---	no reaction[a]
2	RT	1 eq	2 eq	---	no reaction[a]
3	RT	1.2 eq	2 eq	0.25 eq	**4**[b]
4	RT	1.2 eq	1.2 eq	0.5 eq	**4**[b]
5	RT	2 eq	0.5 eq	0.5 eq	**4**[b]
6	RT	2 eq	0.75 eq	0.5 eq	**4**[b]
7	RT	2.5 eq	2 eq	0.5 eq	**4a** + **4b** + **4c** (~20%)[a]
8	0	2.5 eq	2 eq	0.5 eq	**4**[b]
9	–20	2.5 eq	2 eq	0.5 eq	no reaction[a]
10	RT	1.2 eq	1.2 eq	1 eq	**4a** + **4b** + **4c** (~40%)[a]
11	RT	1.2 eq	1.5 eq	1 eq	**4a** + **4b** + **4c** (57%) (0.5:1:4)[c]

Reactions were carried out overnight under argon; All components were mixed and **2a** was added 40 minutes later drop wise; 100 mg of **1** were used; [a] Observed by TLC; [b] Observed as a shadow by TLC; [c] Isolated yield.

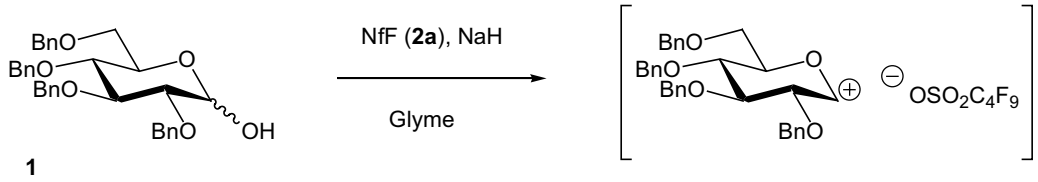
2.2.3.3 Reaction Mechanisms

When the reaction was carried out in a small scale either for the formation of **3** or **4** β-selectivity was observed. One proposed mechanism involves the formation of the α and β glycosyl nonaflate. This intermediate (Scheme 13) reacts under S_N2 conditions with sodium methoxide, giving an inversion of the anomeric center. This is a reasonable explanation for the presence of α-anomer majority in the initial reaction mixture, which is converted to β-anomer after S_N2 reaction.



Scheme 13 Intermediate under S_N2 conditions

Carrying out the same reaction in a big scale (realised in our working group[117]) gave an anomeric ratio in which the α-anomer was majoritary (α/β, 3:2). This means that the previously proposed mechanism could not be applied. Instead the proposed mechanism was S_N1 through an intermediate (Scheme 14) that was a glycosyl cation.



Scheme 14 Intermediate under S_N1 conditions

Another mechanism that could be proposed involves the formation of the nonafluorobutanesulfonic acid methyl ester, which reacts with the anomeric salt, giving the methylglycoside. With this mechanism it is also expected to obtain the α-methyl glucopyranoside, since low temperatures favour the reaction of the

α-anomeric-free hydroxyl. This reaction is competitive and can be observed by the formation of dimethyl ether gas during the reaction.

The formation of trehalose **4** can only be explained for the first two proposed mechanisms S_N1 or S_N2. For a S_N2 mechanism, two carbohydrate molecules are needed, the first reacting with **2a** to form the glycosyl nonaflate, starting from the α-form, and the second substituting the nonaflate, starting from the β-form. Since the probability that one carbohydrate reacts, starting from the α-form and the other from the β-form to give a ββ-major product is low, this mechanism was not considered. The most probable mechanism is a S_N1 reaction, in which the glycosyl cation intermediate is formed after nucleophilic attack of the α- or β-glucose to **2a**. This intermediate can now be substituted by another glucose, probably the most nucleophilic β-glucose, giving ββ- or αβ-anomers as major products. The fact that the ββ-product has majority could be explained by the presence of tight ions, in which the most probable stable tight ion of the nonaflate is proximate to the α-side.

2.2.4 Nonafluorobutanesulfonyl-1*H*-1,2,3-benzotriazole

Benzotriazole (Bt) has been widely utilised as a synthetic auxiliary in a multitude of reactions.[118,119,120,121,122,123,124] Benzotriazole is an inexpensive, stable, and biologically innocuous compound,[119] which can be easily introduced into organic molecules. After conferring its multiple activating influences for carrying out precise transformation reactions, it can be easily removed and can generally be recycled. The early results in the chemistry of benzotriazole have been described.[122]

N-Sulfonylbenzotriazoles are know for a long time, but only in the last years they have been used as starting material for many interesting reactions like, for instance, acyl group activation to preparare acid derivatives when the corresponding halides are not easy to synthesise,[125,126,127,128,129] preparation of thioacids and derivatives thereof with Grignard reagents,[130,131] as intermediates for the benzotriazolyl activation of aromatics[132] and heteroaromatics,[133] mild reagents for sulfonamides synthesis,[134,135] reagents for the formation of arylsulfonates,[134] dehydration of aldoximes and amides for nitrile synthesis,[136] formation of *N*-imidobenzotriazoles via a benzotriazole-mediated Beckmann rearrangement of oximes,[137] activation of alcohols to prepare alkyl benzotriazoles[133,138] and formation of C-sulfonyl bonds.[139]

The preparation of *N*-sulfonylbenzotriazoles derivatives was previously realised through diazotation of the corresponding *N*-(2-aminophenyl)-sulfonamides,[140] *N*-stannylation of the benzotriazole and subsequent destannylation with the corresponding sulfonyl chloride,[141] azide trapping of benzynes.[142] Actually, the synthesis of *N*-sulfonylbenzotriazoles generally involves the use of sulfonyl halides (normally chloride)[138,143] or anhydride[130] in the presence of a base.

2.2.4.1 Synthesis of 1-nonafluorobutanesulfonyl-1H-1,2,3-benzotriazole (6a)

Compound **6a** was tried to be synthesised under mild conditions starting from 1*H*-benzotriazole (**5a**) and nonafluorobutanesulfonyl fluoride (**2a**) but could only be obtained in a very low yield (Table 6). BuLi was found to be necessary to obtain **6a**

in a good yield, with THF as solvent. Better yield (89%) was obtained in a reaction carried out in glyme as solvent at reflux. Compound **6a** decomposes in the presence of light, therefore, it should be synthesised and cromatographed in the dark, as well as kept in a refrigerator. The compound was characterised by its spectral properties and elemental analyses (see experimental part).

Table 6 Optimisation reaction for the synthesis of **6a**

Solvent	Base	t [h]	T [°C]	Yield 6a [%]
CH_2Cl_2	pyridine	24	reflux	4
Et_2O	Et_3N	3	RT	5
Et_2O/THF 1:1	BuLi	72	reflux	73
THF	BuLi	4	RT	71
Glyme	BuLi	3	reflux	89

2.2.4.2 Reaction of 6a with Carbohydrates

The glycosidic bond formation with MeOH and 2,3,4,6-tetra-*O*-benzyl-α-D-glucopyranose (**1**) was carried out by activation of the C1-OH as a sulfonate, transferring the sulfonyl-group from **6a** to **1**. Different conditions, bases and solvents were used without success. Due to the difficulty of this two step-reaction in one-pot, it was thought that a primary investigation for the nonaflyl group transfer was necessary. Under these premises reactions with phenol (**7a**) were carried out, since phenyl sulfonates are stable products.

2.2.4.3 Reactions with Phenol (7a)

The reaction of **6a** with phenol (**7a**) was attempted in the presence of several bases and the results are summarised in Table 7. NaH and toluene was found to be the base and solvent of choice, respectively. Surprisingly, the major product isolated after aqueous work-up was an orange product which was shown by spectral and analytical analyses to be the azo compound **8a**. Although both *ortho*- and *para*-substituted azo compounds can be expected, the structure of the major product was

unambiguously assigned to be the *ortho*-substituted azo compound **8a**, as supported by its X-ray crystallographic analysis (see crystal data). Only a very small amount (ca. 5%) of the *para*-substituted derivative **8b** was isolated by column chromatography. Obviously, the triazole ring underwent an unexpected ring-opening reaction by nucleophilic attack of the phenoxide anion.

Table 7 Optimisation reaction of **6a** with phenol (**7a**) for the synthesis of **8a**

Base	**Solvent**	**t [h]**	**T [°C]**	**Yield [%]**
Et_3N	CH_2Cl_2	24	RT	no reaction
NaH	CH_2Cl_2	6	RT	74
NaH	Toluene	6	RT	76

Experiments conducted in other solvents, as summarised in Table 8 resulted in the *para*-substituted azo compound **8b**, the structure of which was proven by X-ray crystallographic analysis (see crystal data). Yield was moderate when conducting the reaction in DMF. This dipolar aprotic solvent probably blocks the *ortho* positions by coordinating the oxygen atom of the phenolate anion, thus directing the reaction to proceed virtually exclusively to the *para* product **8b**.

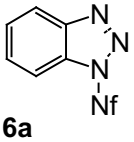
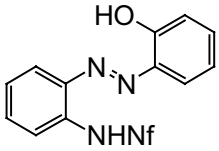
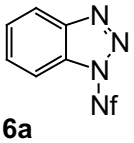
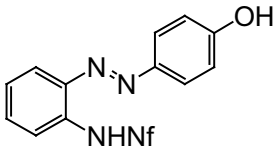
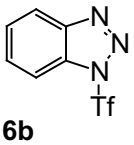
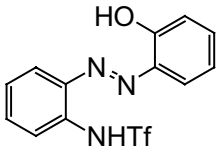
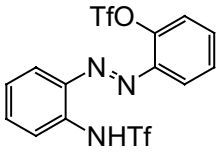
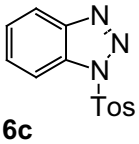
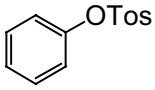
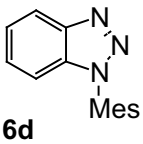
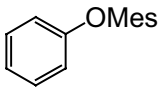
Table 8 Comparison of solvents and products

Solvent	**Base**	**T**	**8a [%]**	**8b [%]**
Toluene	NaH	RT	76	< 5
CH_2Cl_2	Na-phenolate	RT	44	6
THF	NaH	RT	31	18
DMF	NaH	RT	---	47
MeOH	NaOH	Reflux	---	10

Many reactions with different sulfonyl substituted benzotriazoles, results of which are summarised in Table 9, were carried out under the same reaction conditions as described for the synthesis of compound **8a** (Table 7, entry 3). The experiment with **6b**[130] was a mixture of the *ortho*-coupled azobenzenes **9a**

(Tf = SO_2CF_3) with a free phenolic group and its corresponding trifluoromethanesulfonate ester **9b** (OTf instead OH), the structure of which was proven by X-ray analysis (see crystal data). Pure **9a** could only be obtained after HPLC reverse phase separation of the mixture. On the other hand, the reaction with a double amount of **6b** lead to **9b** in an almost quantitative yield. The tosyl **6c**[138] and mesyl **6d**[143] substituted benzotriazoles gave the expected phenyl sulfone esters **10** and **11**.

Table 9 Reactions of phenol (**7a**) with different substituted benzotriazoles

Benzotriazole derivative	Product		Yield
 **6a**	 **8a**		76%
 **6a**	 **8b**		47%
 **6b**	 **9a**	 **9b**	75% 1:3[a] 95% 0:1[b]
 **6c**	 **10**		96%
 **6d**	 **11**		91%

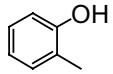
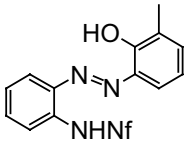
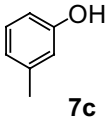
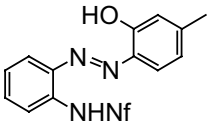
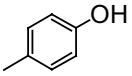
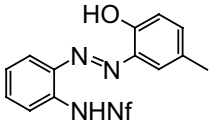
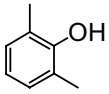
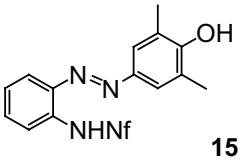
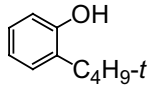
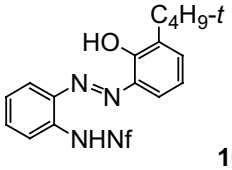
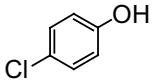
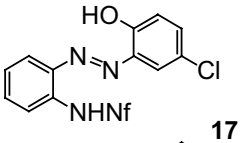
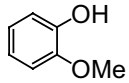
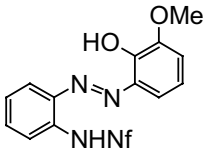
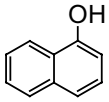
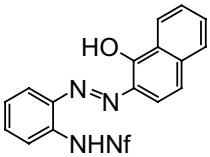
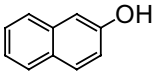
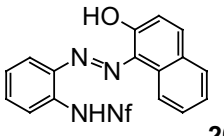
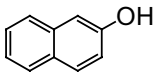
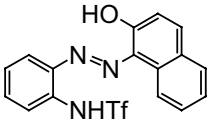
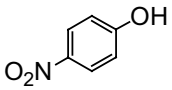
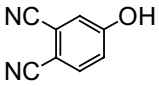
[a] Proportion **7a**:**6b** = 1.3 eq:1 eq; [b] Proportion **7a**:**6b** = 1 eq:2 eq

2.2.4.4 Reactions with Phenol Derivatives

Also a set of azobenzenes listed in Table 10 were prepared by this method using **6a** and different phenols. The authentication of the *ortho* coupling in the reaction of benzotriazole **6b** with phenols in toluene is proven by the formation of products **7b**, **7c**, **7f** and **7h** from 2-methyl-, 3-methyl-, 2-tert-butyl-, and 2-methoxyphenol, respectively. **7f** and **7h** gave more than 70% of the corresponding *ortho*-coupled products **16** and **18**, respectively, while 3-methylphenol quantitatively resulted in the *ortho* coupled azobenzene **13** (92%) and the other *ortho* regioisomer (8%; NMR). 2-Naphthol behaved in a typical way similar to a diazotization reaction and gave the *ortho*-product, whereas 1-naphthol showed opposite regioselectivity compared to that obtained in classical diazomethane reactions. 2,6-dimethylphenol (**7e**) having the *ortho* position blocked, reacts in *para* position giving **15** in 76% yield. In the presence of deactivating substituents like in *p*-nitrophenol (**7k**) and 3,4-dicyanophenol (**7l**) no reaction was observed.

The diazo compounds exhibit various colors depending upon the substituents (see UV-Vis in experimental part). The *ortho* structure of the coupled products can be easily detected by the chemical shift of the phenolic OH group, which appears in the downfield at δ = 11–16 ppm, as a result of a hydrogen-bonding interaction with the neighbouring nitrogen atom. In contrast, the phenolic OH group of the *para* product was found within the normal range of δ = 5–6 ppm. The neighbouring nitrogen effect also makes possible that the salt of **8a**, in a two phase system (EtOAc/$H_2$0 pH > 7), is more soluble in organic solvents than water when compared to the *para*-azophenol **8b** (Figure 1). This effect increased with the extension of the conjugation (compounds **19** and **20a**) and is independent of the substituents, as can be observed in **20d**.[144]

Table 10 Reaction of **6a** with a different phenols

Reagent	Product	Yield	Reagent	Product	Yield
 **7b**	 **12**	63%	 **7c**	 **13**	92%
 **7d**	 **14**	90%	 **7e**	 **15**	76%
 **7f**	 **16**	79%	 **7g**	 **17**	79%
 **7h**	 **18**	70%	 **7i**	 **19**	86%
 **7j**	 **20a**	94%	 **7j**	 **20b**	90%
 **7k**	No reaction		 **7l**	No reaction	

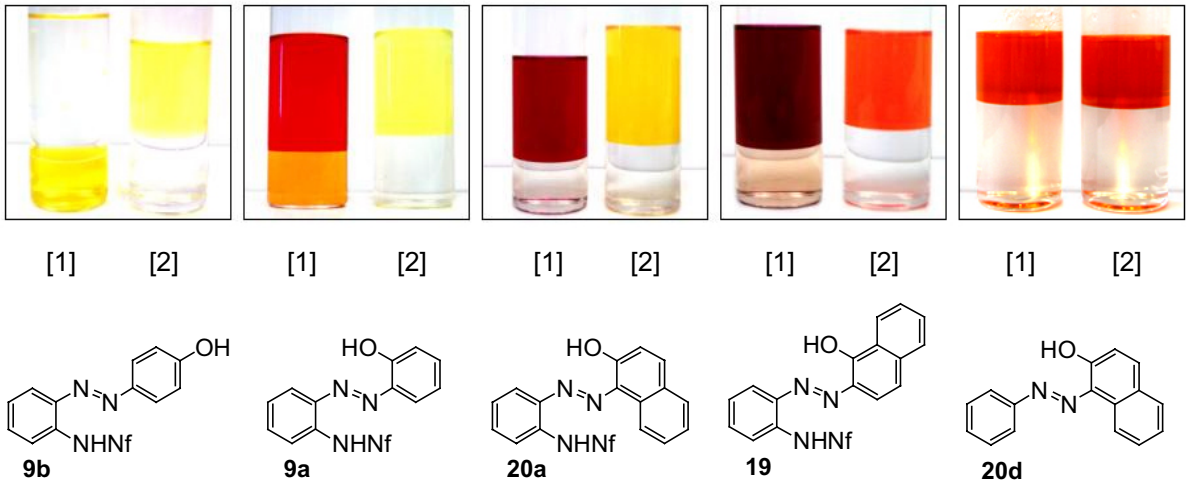


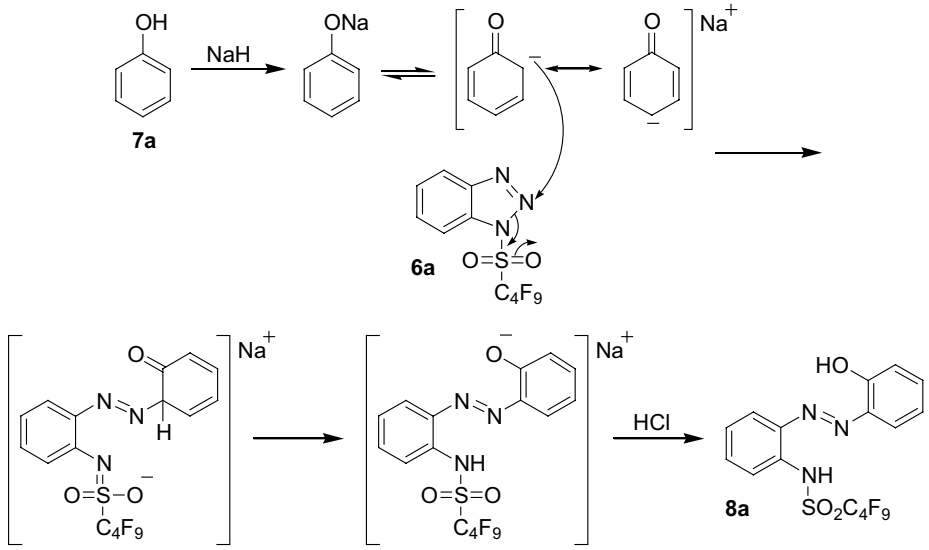
Figure 1 Solubility of *ortho* and *para* azo compounds in H_2O/EtOAc [1] pH = 14 and [2] pH = 1

2.2.4.5 Ring Opening Reaction Mechanism

The benzotriazole ring is extremely stable and only rarely ring cleavage takes place, giving raise to products of nitrogen extrusion. For example, Grignard reagents open and modify the triazole ring and give a variety of products.[145] Other methods for opening the benzotriazole ring are by thermolysis, photolysis and pyrolysis.[146,147] However, no actual ring opening of benzotriazole that has led to isolable azobenzenes has been reported so far.[122]

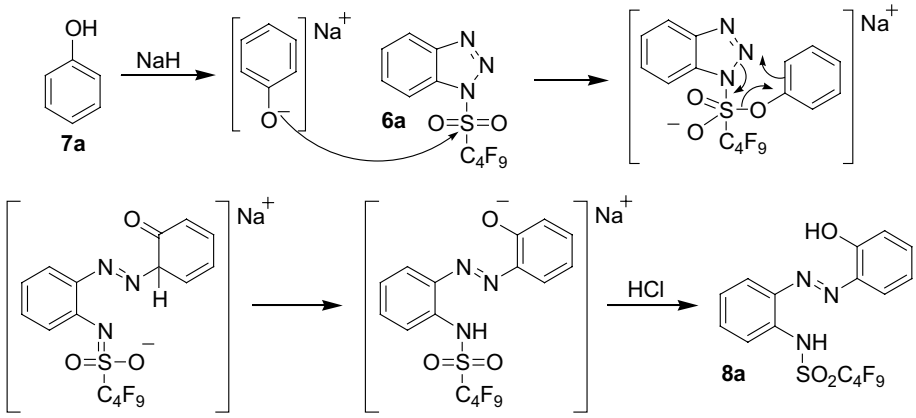
Although the presence of a strong electron-withdrawing substituent at N1 on benzotriazole has been shown to weaken the N1–N2 bond, thus leading to ring opening of the benzotriazole, they give products of nitrogen extrusion,[122] rearrangement[148,149] or undergo a Dimroth rearrangement when a 4-amino substituent is present.[150]

The mechanism for the azo compound formation is outlined in Scheme 15. The mesomeric anion formed by the reaction of NaH with phenol attacks at the N2 position of the benzotriazole moiety. The presence of the highly electron-withdrawing nonafluorobutanesulfone group then results in the opening of the ring, which leads to **8a** after protonic shift and acidic work-up. The formation of the *para* isomer can be considered to occur in a similar manner.

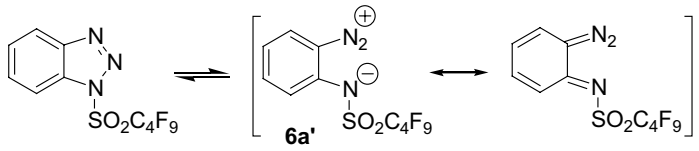


Scheme 15 Reaction mechanism through nucleophilic attack to **6a**

Another possibility for the formation of **8a** is a nucleophilic attack of the phenolate anion at the sulfur atom (Scheme 16),[151] thus resulting in ring opening of the triazole moiety by a rearrangement reaction. However, this will lead only to the *ortho*-substituted product **8a**. A mechanism involving a free diazonium intermediate existing in equilibrium with the benzotriazole **6a'** (Scheme 17) structure was also scrutinised.



Scheme 16 Reaction mechanism involving attack of the phenoxide anion at the sulfur atom



Scheme 17 Reaction mechanism involving a free diazonium intermediate

The existence of a free diazonium species in equilibrium with the 1,2,3-triazole ring is known in the parent 1,2,3-triazole substituted with a sulfonyl group at N1. This equilibrium was confirmed by ^{1}H NMR spectroscopic studies.[152,153,154] In the benzotriazole series two compounds can be conceived to be in equilibrium with the diazo structure. 1-Nitrobenzotriazole[155] was shown to react with amines; for example, piperidine gave an isolable piperidinium salt from the ring-opened benzotriazole. There was also a report[156] on the reversible thermochromic behaviour of 1-cyanobenzotriazole, which is yellow in the melt and colorless in the crystalline state. No chemical evidence was obtained to indicate that the colour might arise from ring opening to give the diazo-*N*-cyanoimine form, and no reactions of the cyano compound were reported. Experiments carried out with 1-nitrobenzotriazole by treating it with indolizine derivatives at room temperature were interpreted as an electron-transfer process and the same process is attributed to the reaction of amines with 1-nitrobenzotriazole.[157] Temperature-dependent NMR investigations were carried out to find out whether an equilibrium with a diazo structure does exist in the 1-nonafluorobutanesulfonyl-1*H*-benzotriazole **6a**. The signals in the aromatic region of the spectrum for molecule **6a** did not change when the sample was heated in DMF-d_6 up to a temperature of 100 °C. Spectra were recorded every 10 °C starting from ambient temperature. Above 100 °C the compound started to decompose to give a dark solution. No analysis of this sample could be carried out, as the sample completely decomposed. Coupling reactions were carried out at room temperature and on the basis of timedependent NMR data it could be concluded that no free diazonium intermediate participates in the reaction. Also, no vibration corresponding to the N=N group could be found in the IR spectrum of **6a**. It is considered that, as far as the mechanism is concerned, the one

shown in Scheme 15 is more probable, however, the other mechanism via the diazo structure cannot be completely ruled out at present.

Computer calculations were performed for a series of 1-substituted benzotriazoles to study the influence of the substituent to the azo-character of this molecule. For R = H, CH_3, NO_2, SO_2CH_3 (**6d**), SO_2CF_3 (**6b**), $SO_2C_4F_9$ (**6a**) a conformation search with *Spartan'02*[158] was performed using molecular mechanic calculations with MMFF (Merck Molecular Force Field). The structures were optimised using ab initio *QChem*[159] program and the values are summarised in Table 11 and Table 12.

Only the distances of these theoretical calculations that were thought to be important for the azo character are summarised. It represents the enlargement of the distance between N1 and N2 and the contraction of the N2 and N3 bond. It was found that 1-cyano-1*H*-benzotriazole has the largest azo character, followed by 1-triflyl- and 1-nonaflyl substituents. However, this theoretical outcoming was not proven in the laboratory. When comparing mesyl- and triflyl- or nonaflyl-benzotriazole, a 1.5 pm difference was observed for the N1−N2 distance. Moreover, this different azo-character was proven chemically. Despite the different reactivity observed for triflyl- and nonaflylbenzotriazole, no difference was observed in these theoretical calculations.

Table 11 Calculated energies [H] for the different 1-substituted-1*H*-benzotriazoles

R	**MP2/cc-pVDZ**[a]	**MP2/cc-pVTZ**[b]
H	–394.744788	–395.229771
CH_3	–433.929058	–434.469032
CN	–486.728547	–487.311957
NO_2	–598.738914	–599.446388
SO_2CH_3 (**6d**)	–981.610097	–982.462435
SO_2CF_3 (**6b**)	–1278.711991	–1279.882441
$SO_2C_4F_9$ (**6a**)	–1990.484117	---

[a] Calcd with *Spartan'02*; [b] Calcd with *Qchem*.

Table 12 Selected bond distances [pm] for the different 1-substituted-1*H*-benzotriazoles

R	MP2/cc-pVDZ[a]			MP2/cc-pVTZ[b]		
	R-N1	**N1-N2**	**N2-N3**	**R-N1**	**N1-N2**	**N2-N3**
H	101.51	135.77	131.91	100.45	134.67	130.90
CH_3	144.91	136.04	132.21	143.77	134.85	131.29
CN	135.55	139.14	130.40	133.88	137.97	129.36
NO_2	144.52	136.28	131.20	142.48	135.15	130.10
SO_2CH_3 (**6d**)	176.40	136.75	131.64	171.52	136.00	130.37
SO_2CF_3 (**6b**)	172.61	138.31	130.68	168.16	137.83	129.31
$SO_2C_4F_9$ (**6a**)	172.62	138.35	130.68	---	---	---

[a] Calcd with *Spartan'02*; [b] Calcd with *Qchem*.

The aromatic azo compounds behave differently[160,161] in many of their reactions compared to the aliphatic diazo compounds.[162,163] Aromatic azo compounds are the largest and most important group of dyes used in the dye industry.[160,164,165,166,167,168] They have also found use in diazo-type photocopying processes and diazosulfonates are beneficial as fungicides.[168] Although aromatic azo compounds are only represented to a marginal extent in pharmaceutical preparations,[169] azo groups have recently been included as substituents in some polycyclic compounds used as probes for chemical genetic studies.[170] Some other recent applications include their use for color marking of substrates in combinatorial chemistry[171] and in photosensitive nanocomposites.[172]

Aromatic azo compounds are still manufactured by the single most important synthetic route, that is, diazotization of aromatic amines followed by coupling with suitable acceptors.[160,164–168] In classical diazotization reactions, that is treating diazonium salt with an aromatic phenol or aniline derivative, the attack is usually at the position *para* to the activating OH group. If this position is hindered, coupling will sometimes take place in the *ortho* position, albeit at a much slower rate.[166]

The Wallach rearrangement of azoxybenzenes[173,174] affords predominantly *p*-hydroxyazobenzenes. The thermolysis of 1:1 complexes of azoxybenzenes with $SbCl_5$ was reported[173,174] to give *o*-azobenzenes, but only in two instances good

yields were obtained. The drawback of this reaction is that it requires the use of a harsh chemical ($SbCl_5$) and the prior preparation of azo compounds by a normal azo-coupling reaction and then oxidation to azoxybenzenes. Of the two reported patent procedures, one describes the formation of the *ortho*-substituted azo-coupled product of 1-naphthol in a heterogeneous H_2O-organic solvent mixture (for example, H_2O-CH_2Cl_2) in 26% yield[175] and the other leads to *ortho* products only under strong alkaline conditions.[176,177] In the latter case, the intermediate formation of the mesomeric *o*-benzoquinone diazide is probably responsible for the *ortho* coupling.[177]

These variations in the reaction conditions have been done only in the case of 1-naphthol to obtain various types of substituted azo dyes useful in the dye industry. Bearing in mind the above mentioned literature data, there exists no expedient direct method for the preparation of *ortho*-azobenzenes by a straight coupling reaction. Besides diazotization of aromatic amines, there are only a few methods, for example, diazotization of aryl hydrazines, transfer of an azo group by tosyl azides, known for the preparation of azobenzenes.[160,178,179]

2.2.5 Unsymmetrically Fused 1,2,3,-triazole-zincphthalocyanine

Phthalocyanines (Pcs), as well as their analogues, e.g. porphyrazines (Pzs) and naphthalocyanines (Ncs), attract much attention because of their electronic structure features, giving rise to a plethora of applications in materials science.[180,181,182] The properties of phthalocyanines can be widely modulated via changes in their chemical structure, introducing different coordinated elements into the cavity of the macrocycle or in the periphery when appropriate substituents are present, varying axial and peripheral ligands and substituents, changing the symmetry of the macrocycle, etc.

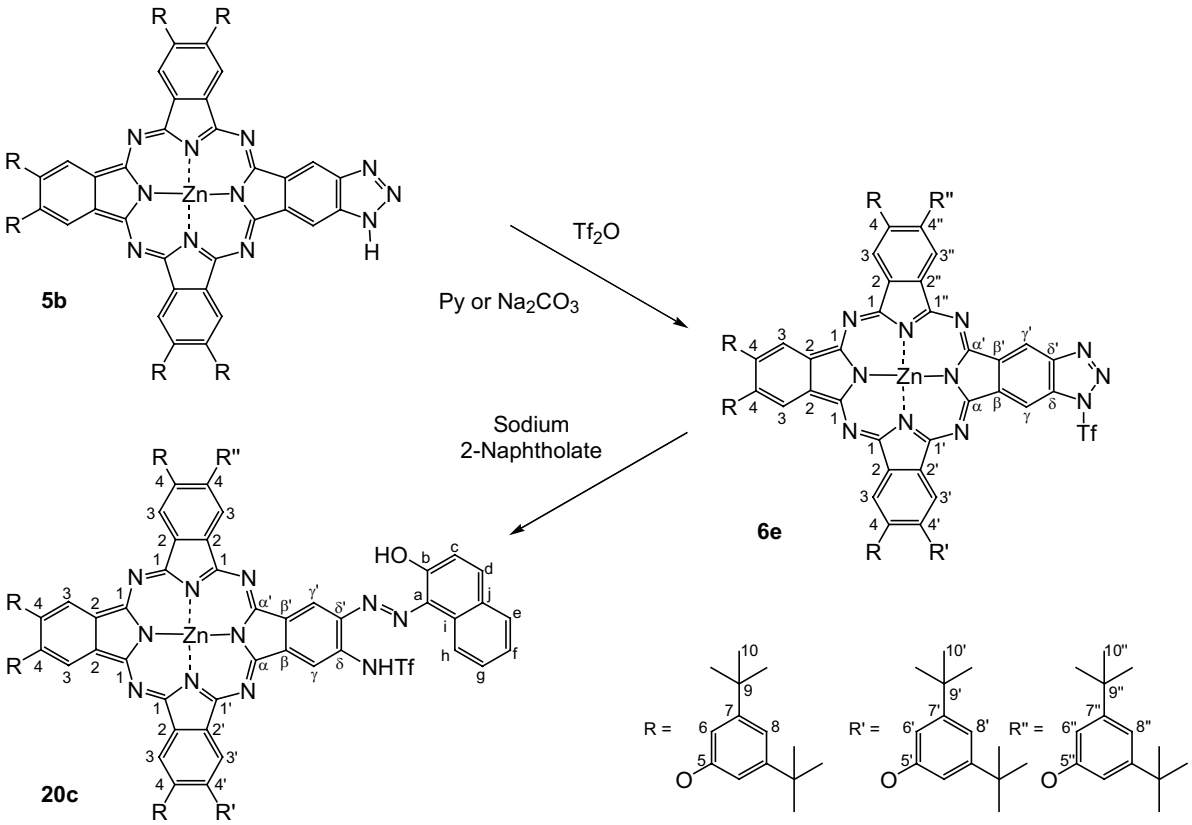
Unsymmetrical phthalocyanines, despite the comparatively complicated preparation methods, are gaining more consideration recently because of their high potential for modern applications,[183,184] e.g. in molecular electronics, mostly as self-assembled, highly-ordered thin films.[185,186,187] For these reasons, macrocyclic synthons useful for various unsymmetrical functionalizations of phthalocyanines are of special interest.

Based on sulfonated benzotriazole ring opening previously described (chapter 2.2.4), it was envisaged an application of this methodology in order to modify the previously reported unsymmetrical zincphthalocyanine with a fused 1,2,3-triazole.[188] Only one report on the synthesis of a modified phthalocyanine containing azo groups has been reported so far, namely the template tetramerization of 4-[4-(diethylamino)phenylazo]phthalonitrile.[189]

2.2.5.1 Synthesis of Naphthyl-azoconjugated Phthalocyanines

The zincphthalocyanine fused 1,2,3-triazole (**5b**)[188] was derivatised with a triflyl rest, since the synthetic conditions to introduce the nonaflyl rest (utilisation of BuLi under reflux) are not appropiate in phthalocyanine synthesis. The advantage of triflyl is the easy addition under mild conditions. On the other hand, only the most active 2-naphtol (**7i**), as provided in chapter 2.2.4.3 could be satisfactory used for the ring opening.

Addition of Tf_2O (**2b**) either to a mixture of **5b** and pyridin in CH_2Cl_2 or to **5b** and Na_2CO_3 in CH_2Cl_2 at 0 °C were efficient methods for the synthesis of the desired Pc **6e** in 88 and 93% yield respectively (Scheme 18). For the ring opening a small variation from the method described earlier was applied, since Pcs can not tolerate the use of strong bases for a long time. For this particular case, a big excess of 2-naphthol was previously stirred with NaH to form the naphtholate salt and then the phthalocyanine was added. With a very short reaction time, only 15 minutes, **20c** was obtained in a 86% yield after chromatographic separation.



Scheme 18 Synthesis of compounds **6e** and **20c**

Both compounds could be characterised unambiguously (see experimental part). The only weak point was the elemental analysis that showed 0% of sulfur, which can be associated to the possible formation of a sulfurzinc salt. Due to the fact that compound **20c** was a mixture of Pcs with different grades of protonation (from neutral, zwitter ion, once and twice protonated and deprotonated), the addition of

Et_3N to the deuterated solvent for ^{1}H- and ^{13}C-NMR measurements gave better resolved spectra. More details about the interesting spectroscopic properties that compound **20c** exhibits, indicating high acidity of the hydroxy group, especial behaviour in different solvents and photodecomposition mechanism of **20c** in chloroform and tetrahydrofuran are explained in the literature [190].

2.2.6 Phosphorus Ylides

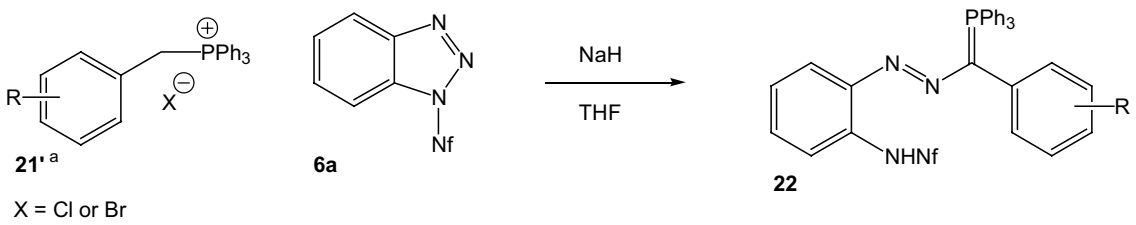
Phosphorus ylides have found use in a wide variety of interesting reactions in synthetic chemistry, especially in the preparation of naturally occurring products and compounds with biological and pharmacological activity.[191] These compounds have attained great significance as widely used reagents for linking synthetic building blocks with the formation of carbon–carbon double bonds.[192] Moreover, outstanding achievement in the development of phosphorus ylides chemistry demonstrate that they not only react with carbonyl compounds but also can be used in many nucleophilic reactions being comparable to Grignard reagents in regard to the variety of their possible reactions.[193]

Arylazomethylenetriphenylphosphoranes are stabilised phosphorus ylides that can be synthesised from alkyltriphenylphosphoranylidenes and arenediazonium salts[194] or from hydrazonoyl halides by reaction with triphenylphosphine and Et_3N via nitrile imine.[195] These kind of compounds are used for heterocyclic synthesis, namely indazolines,[196] oxycinnoline,[196] benzodiazepine,[197,198] pyrazoles[197] and tetrazolium salts.[199]

In order to exploit the arenediazonium salt character of the nonafluorobutanesulfonyl-1*H*-benzotriazole (**6a**) and using the same approach described above, the ring opening previously described in chapter 2.2.4.3 was appied using phosphorus ylide derivatives.

2.2.6.1 Synthesis with Benzyltriphenylphosphonium Salts

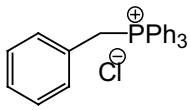
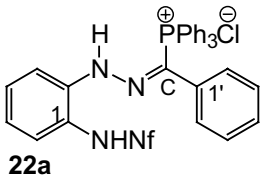
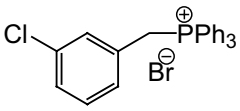
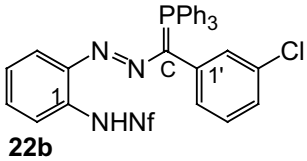
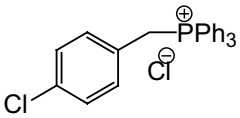
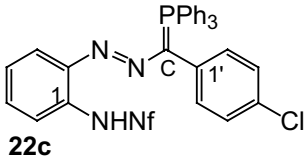
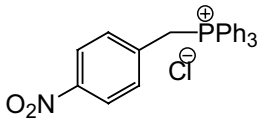
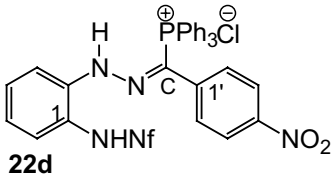
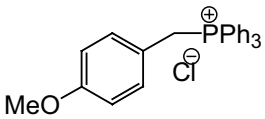
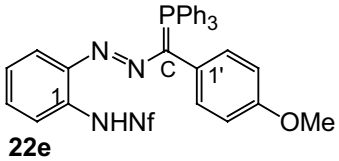
The synthesis was achieved by reacting **6a** with different substituted benzyltriphenylphosphoranylidene (Scheme 19).



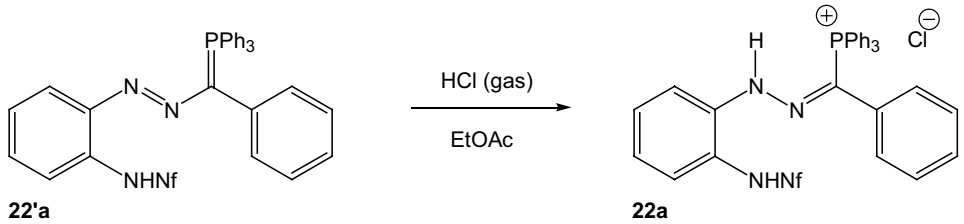
Scheme 19 Synthetic strategy for the synthesis of arylazomethylenephenylphosphoranes;
[a] Synthesised from **21** (see experimental part)

The synthesis and purification of the benzylphosphonium salts was carried out starting from the corresponding benzyl compounds **21** with the methods known from literature.[200,201] The compounds were dissolved in dry THF and NaH was added to form the benzylphosphorus ylidene. Addition of **6a** to the solution lead immediately to the arylazomethylenephosphoranylidenes, the results of which are summarised in Table 13. Purification was carried out by chromatography on silica gel with EtOAc as eluent. All compounds were yellow or orange coloured .

Table 13 Structure, numbering and yield form the synthesised arylazomethylenephenylphosphoranes

Phosphorus ylides	Phosphoranylidenes	Yield
 **21'a**	 **22a**	90%
 **21'b**	 **22b**	68%
 **21'c**	 **22c**	69%
 **21'd**	 **22d**	63%
 **21'e**	 **22e**	82%

Due to the fact that arylazomethylenephosphoranylidenes **22** can be protonated with HCl and isolated as colorless salts in their hydrazone form,[194] compounds **22'a** and **22'd** were dissolved in EtOAc and HCl gas was introduced (Scheme 20). Surprisingly, the hydrazone salts did not precipitate and only after evaporation of the solvent the white products precipitated as white solids. Moreover, NMR experiments could be carried out in deuterated chloroform without remarkable differences in comparing with other **22** products.

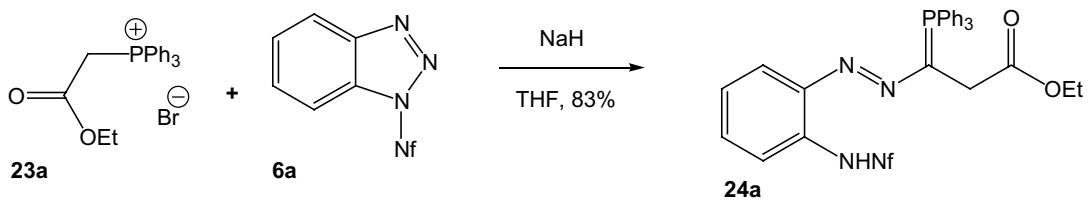


22'a **22a**

Scheme 20 Protonation of the arylazomethylenephosphoranylidenes **22'a**

2.2.6.2 Synthesis with Alkyl Triphenylphosphonium Salts

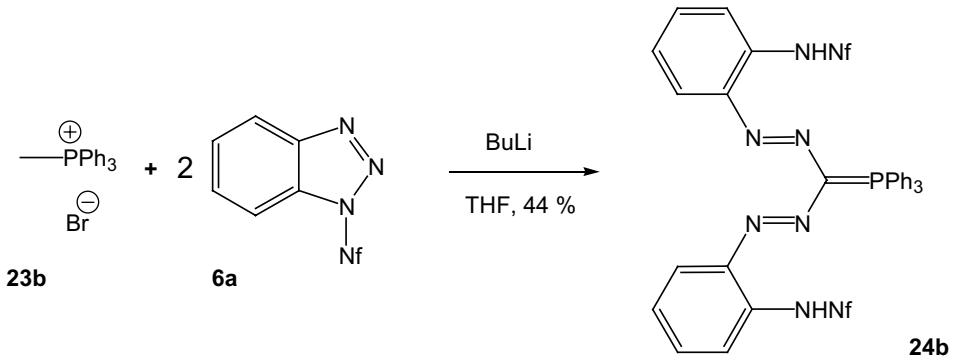
(Carbethoxymethyl)triphenylphosphonium bromide (**23a**) is described in the literature as a compound that can react with arenediazonium salts [194] and afterwards with acetylene derivatives to form pyrazoles.[197] For the synthetic interest that these compounds possess, the arylazomethylenephosphoranylidene derivative **24a** was synthesised. For the phosphorane formation, NaH was used and after 30 minutes the reaction was finished, obtaining the phosporanylidene derivative **24a** with a 83% yield (Scheme 21).



23a **6a** **24a**

Scheme 21 Synthesis of compound **24a**

Methyltriphenylphosphonium bromide (**23b**) needs BuLi as a base for the deprotonation and formation of methylenetriphenylphosphorane. The reactions of phosphorus ylidenes with arenediazonium salts described above are, according to the literature,[194-199] carried out in an alcohol solution or aqueous alcohol. These conditions do not allow the utilisation of strong bases, like BuLi. Due to the stabilised azo character of **6a**, the easy handling and the solubility in all organic solvents, some reactions can be carried out with the use of strong bases. Under these reaction conditions, **23b** can generate methylenetriphenylphosphorane as described in the literature,[202] starting from **23b** with BuLi in dry THF. **24b** was isolated and unambiguously characterised as a two times azosubstituted arylazomethyltriphenyl-phosphoranylidene (Scheme 22).



23b **6a** **24b**

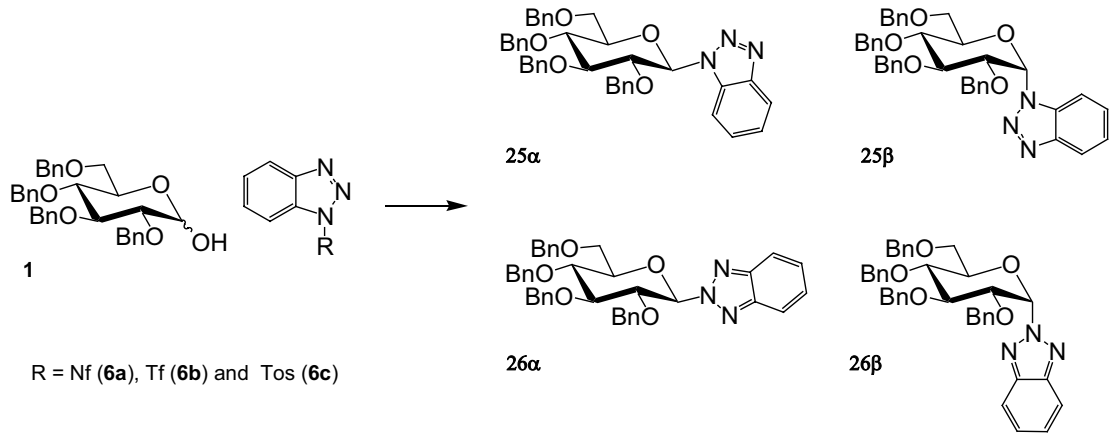
Scheme 22 Synthesis of compound **24b**

The same procedure was applied for ethyltriphenylphosphonium bromide (**23c**) and isopropyltriphenylphosphonium iodide[203] (**23d**), in order to obtain monosubstitution, but several by-products were observed by TLC and the workup of the reaction mixture was not carried out. No explanation was found for the differently observed reactivity with these three similar derivatives.

2.2.7 Synthesis of Glucosyl 1*H*- and 2*H*-benzotriazoles

Glucosyl-1*H*-, 2*H*-benzotriazoles and their derivatives have been described as unusual nucleosides for the treatment of the cancer.[204,205,206,207,208] They were previously synthesised by condensation of 1-TMS-benzotriazole with peracetylatedglucopyranoside in vacuum,[209] reaction of glycosyl bromide with mercury salts[210] or silver salts[206,211] of benzotriazole, activation of glycosyl halides with $Hg(CN)_2$ and benzotriazole,[206,212] glucosyl azide with benzines[208] and the trichloroacetimidate method.[213] In all cases β-selectivity was obtained and the products were 1*H*- and 2*H*-benzotriazoles. The regioselectivity of 1*H*- or 2*H*-benzotriazole depended on the method, being 1*H*-benzotriazole when 1*H*-benzotriazole salts or TMS-benzotriazole were used as well as glycosyl azides and benzines. On the other hand, the trichloroacetimidate method or activation of the glycosyl halide with $Hg(CN)_2$ and 1*H*-benzotriazole lead predominately to 2*H*-benzotriazole.

The synthesis of these kinds of compounds can be achieved with sulfonyl benzotriazoles. This is a literature known activation method for alcohols applied for tosylbenzotriazole, in absence of other nucleophiles.[133] Using this method, the alcoholate reacted with the sulfonyl-benzotriazole and lead to the sulfonate ester which was substituted for the 1*H*-benzotriazole giving the desired compound. Due to the different results obtained by the reaction of nonaflyl- (**6a**), triflyl- (**6b**) and tosyl-1*H*-benzotriazoles (**6c**) with phenols, it was anticipated that the optimisation reactions had to be carried out with **6c** and then applied for **6a** and **6b**.



Scheme 23 Synthesis of glycosyl 1*H*-and 2*H*-benzotriazoles with different sulfonylbenzotriazoles

The results of this optimisation process with **6c** are summarised in Table 14. As can be seen, no reaction was observed when weak bases were used (entries 1–4). The reaction can only be carried out with strong bases like NaH (entries 5–9). Comparing entries 4 and 5, best selectivity was obtained when the carbohydrate was added to the solution (entry 5) containing sulfonylbenzotriazole and NaH. The resulting products with β-configuration were a 1:1 mixture of 1*H*- or 2*H*-benzotriazoles. This selectivity might be due to the fact that **1** has mainly α-configuration. As a consequence the formed intermediate tosylglucopyranoside has α-configuration. The hypothetic substitution of the sulfonate under S_N2 conditions would lead to a β-anomer exclusively. Using **6b** as a reagent good yields were obtained but no α/β-selectivity was observed (entry 7). The most likely intermediate is a glycosyl cation. This could be due to the fact that glycosyltriflate is only stable at low temperatures. No selectivity was observed for 1*H*- or 2*H*-benzotriazole. Nonaflylbenzotriazole (**6a**) did not react at room temperature (entry 8). After heating the mixture to reflux the solution became dark because of decomposition of **6a**. β-Selectivity was exclusively observed when **6a** was used, which led to the assumption that higher temperatures, when compared to **6b**, allowed for the formation of the β-configuration through a glycosyl cation intermediate.

Table 14 Optimisation reaction of **1** and **6c** and results for **6a** and **6b**

	T [°C]	R	Base	Solvent	t [h]	Results
1	RT	Tos (**6c**)	Et_3N	THF	12	no reaction
2	70	Tos (**6c**)	Et_3N	THF	12	no reaction
3	RT	Tos (**6c**)	K_2CO_3	CH_2Cl_2	12	no reaction
4	45	Tos (**6c**)	K_2CO_3	CH_2Cl_2	12	no reaction
5	RT	Tos (**6c**)	NaH	THF	6	55% (**25**α, **26**α, **26**β; 5:1:10)
6[a]	RT	Tos (**6c**)	NaH	THF	6	74% (**25**α, **25**β, **26**β; 1:10:10)
7[a]	RT	Triflyl (**6b**)	NaH	THF	6	66% (**25**α, **26**α, **26**β; 3:1:3)
8	RT	Nonaflyl (**6a**)	NaH	THF	12	no reaction
9[b]	70	Nonaflyl (**6a**)	NaH	THF	0.5	21% (**25**β, **26**β; 3:2)

[a] **1** was added drop wise; [b] After 30 minutes at 70°C **6a** was completely decomposed.

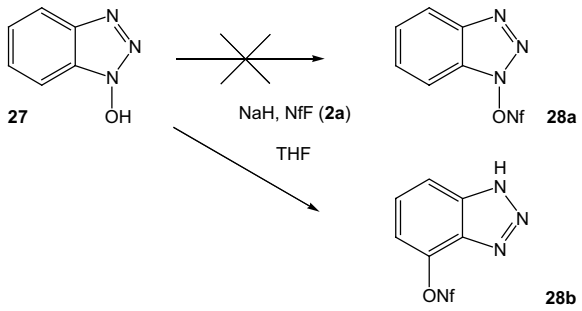
2.2.8 Nonafluorobutanesulfonic acid benzotriazol-1-yl ester

1-Hydroxybenzotriazole (HOBt, **27**) active esters are most frequently used for peptide bond formation.[214] The procedure is fast and can be applied for liquid-phase as well as solid-phase synthesis. HOBt can be used in combination of DCC or DIC, making the formation of almost all peptide bonds possible.[215] Modifications in the phenyl ring of benzotriazoles result in more effective and reactive reagents for bond formation.[216,217] Moreover, modifications in the hydroxy function of the hydroxy-benzotriazole results in phosphonium[218,219] and uronium salts,[220,221] which are very effective for the formation of active esters under mild conditions.

HOBt sulfonic acid esters and derivatives have also been investigated for peptide bond formation.[222,223,224,225] Some of them are comparable to phosphonium or uronium salts, with the advantage that sulfonic esters from HOBt are soluble in nonpolar solvents, thus increasing the range of conditions in which the activation can be carried out. Activation of acids to form other acid derivatives is also possible, namely esters[226] and thio esters[227]. The sulfonyl group transfer from HOBt to phosphodiester or to amines for the formation of triesters[228,229] or sulfonamides,[230,231] respectively, has already been investigated. No investigations were carried out for the alcohol activation through sulfones transferred from HOBt. For this reason the formation of the nonafluorobutanesulfonyl-HOBt has been envisaged as a new method for the activation of alcohols.

2.2.8.1 Synthesis of nonafluorobutanesulfonic acid benzotriazol-1-yl ester (28a)

The synthesis of **28a** was attempted starting from HOBt (**27**) and NfF (**2a**) with several bases, as summarised in Table 15. Only the use of strong bases lead to a major product, although in low yield. The isolated major product was **28b** (Scheme 24) and not the expected **28a**. This could be unambiguously characterised by spectral and analytical data.



Scheme 24 Formation of **28b** after possible rearrangement of **28a**

Table 15 Optimisation reactions carried out for the synthesis of **28b**

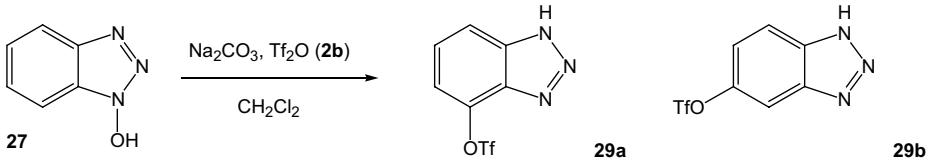
Solvent	Base	t [h]	T [°C]	Yield [%]
CH_2Cl_2	Et_3N	72	RT	---
CH_2Cl_2	lutidine	72	RT	---
CH_2Cl_2	collidine	72	RT	---
THF	NaH	24	reflux	17
THF	NaH	12	RT	26
THF	NaH	12	reflux	32

2.2.8.2 Reactions of HOBt Derivatives (31) with Tf_2O (2b)

The triflate homologue **29a** synthesis was carried out in CH_2Cl_2, using pyridine or Na_2CO_3 at room temperature obtaining a yield increase to 41 and 49%, respectively. Both compounds contain a 5% of **29b** that could be eliminated after crystallisation. The structure of **29a** could be proven by X-ray analysis (see crystal data).

In order to explore the new synthetic pathway of HOBt, 1-hydroxy-benzotriazole derivatives (**31**) were synthesised. The 1-hydroxybenzotriazole derivatives were synthesised in a similar way as described in the literature,[232,233,222,234] starting from the respective *o*-chloronitrobenzene (**30**). The formed products were protonated with HCl, filtered and recrystallised from a mixture of H_2O, EtOH and toluene.

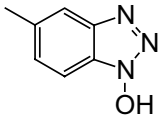
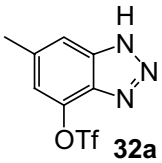
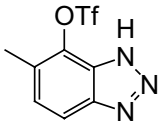
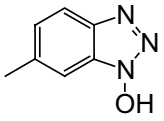
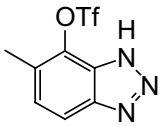
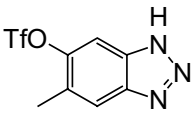
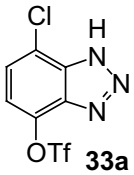
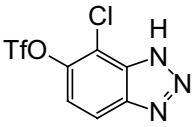
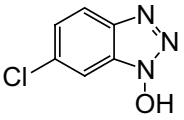
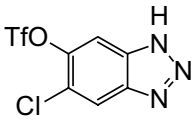
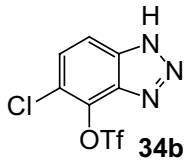
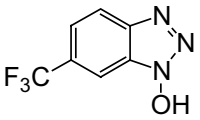
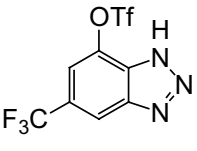
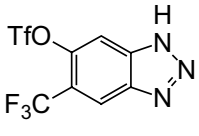
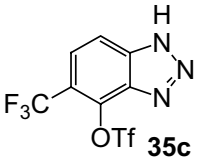
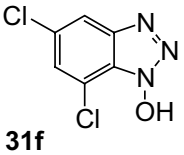
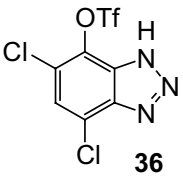
New experiments were carried out with Tf_2O (**2b**) at –78 °C, applying the method for the formation of the 1*H*-benzotriazole homologue (**6b**),[130] since reactions carried out with new compounds at room temperature were not successful and other by-products were visible by TLC. The active ester was formed at –78 °C. This was observed by TLC, but isolation of the active ester failed. When the reaction mixture was warmed up to room temperature, the active ester rearranged giving a mixture of two products (**29a** and **29b**) that were not possible to be separated (Scheme 25).



Scheme 25 Synthesis of **29a** and **29b** (93%, 66:33) after reaction of **27** with **2b**

The same procedure as used for the synthesis of **29a** and **29b** was applied to the new benzotriazoles, the results of which are summarised in Table 16. At –78 °C all reactions gave the active esters, which decomposed after warm up to RT. The time needed for the completion of the reaction can be used to estimate the stability of the active ester. The HOBt derivative **31e** and HOAt (**31g**) were the most stable of all HOBt derivatives. Their active esters were visible by TLC for at least 1 day and in case of **31g** no product could be isolated. All compounds isolated through column chromatography or HPLC were completely and unambiguously characterised. In the ^{13}C-NMR spectra only tertiary carbons, as broad signals, could be observed and in some cases the doublet or quadruplet from the CF_3. This phenomena is caused by proton delocalisation of the triazole.

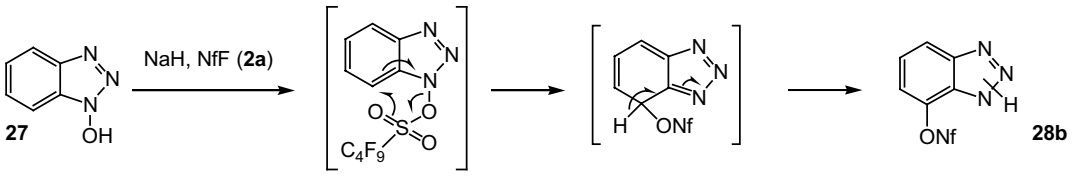
Table 16 Reactions of Tf_2O (**2b**) with different substituted 1-hydroxy-benzotriazoles (**31**)

HOBt derivatives	Product			Yield, Ratio
 **31a**	 **32a**	 **32b**		90%, 55:45[a]
 **31b**	 **32b**	 **32c**		88%, 70:30[a]
 **31c**	 **33a**	 **33b**		88%, 60:40
 **31d**	 **34a**	 **34b**		75%, 40:60
 **31e**	 **35a**	 **35b**	 **35c**	89%, 20:40:40[b]
 **31f**	 **36**			73%
 **31g**				0%

[a] Isolated as a mixture, the percentage was calcd in NMR; [b] Compounds separated in the HPLC, percentage calcd in HPLC.

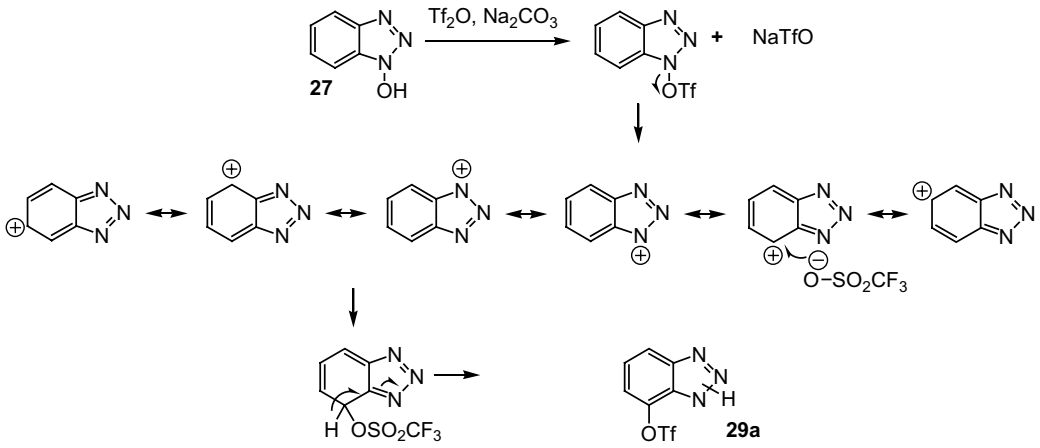
2.2.8.3 Reaction Mechanisms

The first mechanism proposed for the reaction of HOBt (**27**) with **2a** involved the formation of a sulfonyl active ester as intermediate that could not be isolated. The rearrangement of this intermediate gave **28b** (Scheme 26).



Scheme 26 Proposed rearrangement for the formation of **28b**

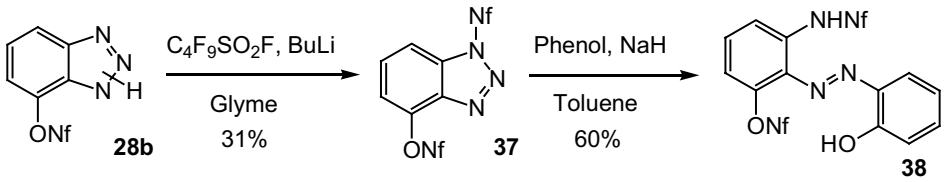
A second mechanism with a cation intermediate was proposed, since more products were isolated by using Tf_2O. The cation is generated by splitting up the triflate from the sulfonyl active ester (Scheme 27). Therefore, all positions in the benzene ring are activated for a subsequent triflate nucleophilic attack (Scheme 27). Rearomatisation and protonation of the triazole would lead to the desired product. When position 6 from HOBts was blocked with methyl (**31b**) or chlorine (**31d**) the sulfonated substitution took place at positions 5 and 7. Moreover, in case of 6-trifluoromethyl-HOBt (**31e**) also position 4 was substituted, due to the *meta* activation of trifluoromethyl. When 5-methyl-HOBt (**31a**) reacted, substitution in positions 4 and 7 took place. The products isolated from **31a** and **31e** indicate a strong activation of the triazole ring. 4-Chloro-HOBt (**31c**) reacted in position 5 and 7 while 4,6-dichloro-HOBt (**31f**) reacted exclusively at position 4, which has a lower steric effect. On the other hand no substitution was observed with HOAt (**31g**).



Scheme 27 Proposed ionic mechanism, only illustrated the formation of one isomer **29a**

2.2.8.4 Derivatisation of 28b

Compound **28b** was derivatised in the triazole ring using **2a** to prove which triazole regioisomer or regioisomers could be obtained. The nonaflated benzotriazole **37** was synthesised following the method used in chapter 2.2.4.1 (see experimental part). Only one of the two possible sulfonated products was obtained. To know which of the isomers was the synthesised the benzotriazole ring opening was carried out. It led to **38** in a 60% yield. This compound was unambiguously characterised as a sulfone ester with an azo function in *ortho* and a sulfonamide function in *meta* (see crystal data). This result permitted to assign the correct structure to **37**.



Scheme 28 Synthesis of compounds **37** and **38**

2.3 Aromatic Nitro Substitution

2.3.1 Introduction in Photodynamic Therapy

Photodynamic therapy (PDT) is a rapidly growing methodology to treat the age related macular degeneration, various skin disorders, and an increasing number of cancers that are accessible to irradiation with visible light.[235] In general terms, the PDT concept is that the therapeutic compound has low toxicity until it is activated by light, whereupon it becomes very reactive and toxic or it activates other indigenous molecules to become reactive and toxic.[236]

Porphyrin type compounds (e.g. porphyrins and/or phthalocyanines) photosensitise the formation of the highly reactive singlet oxygen via transfer of energy from the triplet excited state of the porphyrinoid to the triplet ground state of oxygen. Singlet oxygen is a potent oxidant that reacts with numerous biomolecules such as double bonds in lipids, bases of nucleic acids, aromatic amino acids, both phosphate backbone and subcellular organelles.[237]

Phthalocyanines (Pcs) are known for more than seven decades. These compounds have been extensively studied as advanced materials for various applications,[238,239] including photobiological and medical.[240] They own a higher efficiency to generate reactive oxygen species than porphyrins,[241] also possessing low dark toxicity.[242] Pcs are expected to exhibit strong photochemical and photodynamic activities appearing as a very promising kind of second generation photosensitisers for photodynamic therapy (PDT).[243]

Because the balance between hydrophobicity and hydrophilicity is acknowledged as a significant aspect for the design of new photosensitisers for PDT,[244] diverse research groups synthesised a variety of new porphyrinoid-carbohydrate conjugates,[245,246,247,248,249] assuming that the presence of the carbohydrate moiety could improve the membrane interaction, therefore increasing their tumour selectivity. Nonetheless, the related carbohydrate conjugates were not studied for their affinity to target a particular protein. Moreover, various types of glucose transporters are specific for different monosaccharides in cancer cells.[250,251]

Therefore it is reasonable to expect a cellular uptake enhancement of the complexes through glycoconjugation, which may increase the photodynamic activity.

Taking into account the significance of the premises referred above and the fact that, phthalocyanine-carbohydrate conjugates are quite uncommon, only the synthesis and characterisation of a phthalocyaninato zinc(II) complex peripherally substituted with four glucose moieties[252] and a phthalocyaninato silicone (IV) complex axially substituted with two galactose moieties have been reported so far.[253]

The aim of this particular work was the synthesis of dicyanophenyl carbohydrates linked via the anomeric carbon, which are precursors for the synthesis of phthalocyanines, as well as the synthesis of unprotected phthalocyanines.

2.3.2 Aromatic Nitro Substitution

For the synthesis of 3,4-dicyanophenyl-*O*-glucoside known methods for the preparation of the phenyl glycosides were applied, using 3,4-dicyanophenol (**7l**). These methods were: $BF_3{\cdot}OEt_2$[254] or PTSA[255] activation of penta-*O*-acetyl-glucose; TMSOTf[256] activation of 2,3,4,6-tetra-*O*-benzoyl-glucose trichloroacetimidate and reaction with 2,3,4,6-tetra-*O*-benzoyl-glucose (**30b**) under Mitsunobu[257] conditions. None of the above mentioned methods gave the desired arylated glycoside though.

The strategy that seemed to be more attractive was the substitution of the nitro group from the 4-nitrophthalonitrile (**40**). This method has already been widely used for the synthesis of oxoarylphthalonitriles.[258] The nucleophilic displacement of the nitro group from an activated aromatic substrate has been well investigated.[259] In general, nucleophilic displacement of a nitro group from an activated aromatic substrate can be effectively carried out with a variety of strong nucleophiles under dipolar aprotic solvent conditions. For example, alcoholates,[260,261,262] thiolates[260,263] and sulfinates[260] effectuate a synthetically practical displacement of a nitro group from carbonyl,[260,261,262,263,264] nitro,[260,264] cyano,[260,261,262,263,264] sulfone,[260] and aryl[263] activated substrates in DMF, DMSO, or HMPA at room temperature.

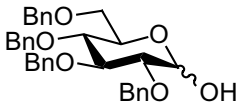
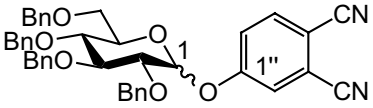
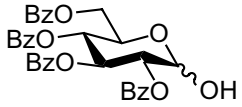
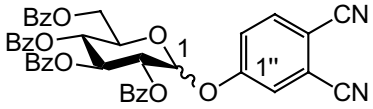
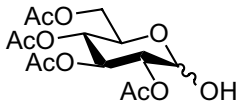
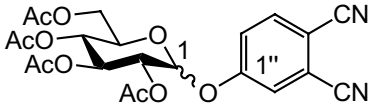
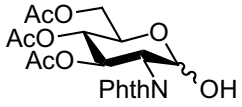
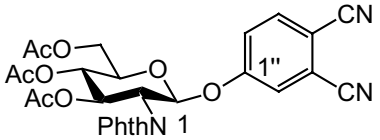
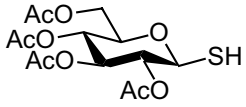
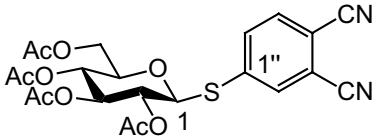
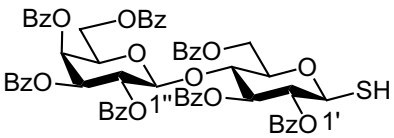
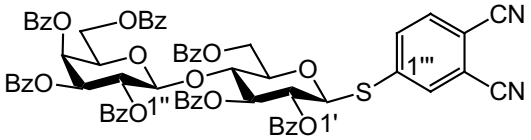
Furthermore, nitro groups are comparable to fluoro groups as leaving group in S_NAr reactions.[259]

2.3.2.1 Nitro Substitution with 4-nitrophthalonitrile (40)

The displacement of the nitro group from 4-nitrophthalonitrile (**40**) for the synthesis of oxoarylphthalonitrile derivatives is normally carried out with a high excess of K_2CO_3 in DMF.[258] For the synthesis of 3,4-dicyanophenyl carbohydrates it was expected that this reaction could take place under mild conditions due to the high nucleophilicity of the 1-OH of the sugar unit. The reaction between **40** and 2,3,4,6-tetra-*O*-benzyl-(α/β)-D-glucopyranose (**1**) was investigated. The stability of the benzyl groups was exploited and the reaction was carried out using NaH as base and DMF as a solvent. The reaction was completed in 1 h and the product obtained was 3,4-dicyanophenyl-2,3,4,6-tetra-*O*-benzyl-(α/β)-D-glucopyranose (**41**) in quantitative yield (Table 17). Initially, the obtained α/β ratio of 90:10 was surprising, but this could be explained by an anomerisation process that took place during the reaction using DMF[97] or DMSO[96] as a solvent. The mechanism given for the anomerisation involves the retro aromatic nucleophilic substitution at the phenyl moiety of **41** caused by the attack of a solvent molecule. The glucose moiety could anomerise and substitute again the solvent molecule, giving mainly the thermodynamically favoured α-anomer of **41**.[96] The nitro substitution was then carried out using THF as solvent, where theoretically the anomerisation can not take place. At room temperature no reaction was observed but after heating for 12 hours **41** was obtained also in quantitative yield and with α/β ratio 1:2.

The reaction conditions using DMF as a solvent, were repeated first using 2,3,4,6-tetra-*O*-benzoyl-(α/β)-D-glucopyranose (**39b**)[265] and then 2,3,4,6-tetra-*O*-acetyl-(α/β)-D-glucopyranose (**39c**)[266] and K_2CO_3 as base (Table 17). In both cases quantitative yields were obtained as well as high α-selectivity. The reaction in THF could not be repeated in these two particular cases due to the instability of the protecting groups under such conditions.

Table 17 Nitro substitution using **40**, DMF as solvent and K_2CO_3 as base.

Carbohydrate reagent	**3,4-dicyanophenyl product**	**Yield (%) Ratio (α:β)**
		99%, 90:10[a] 99%, 33:66[b]
1	**41α/41β**	
		99%, 91:9
39b	**42α/42β**	
		99%, 91:9
39c	**43α/43β**	
		50%, 0:100
39d	**44β**	
		99%, 0:100
39e	**45β**	
		99%, 0:100
39f	**46β**	

[a] NaH as base. [b] NaH as base and THF as solvent

A special example was 3,4,6-tri-*O*-acetyl-2-deoxy-2-phthalimido-(α/β)-D-glucopyranose[267,265b] (**39d**). Under the same conditions as for **39b** or **39c**, the reaction led only to the β-product (**44β**), probably due to the fact that, although **39d** is

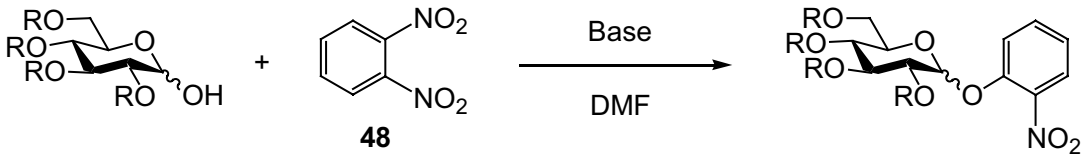
an O-nucleophile, it is sterically hindered by the presence of the phthalimido protecting group at position 2 which strongly promotes the formation of the found β-anomeric linkage.

Also the formation of thiophenyl-glycosides was thought to be interesting because no such thermodynamic equilibrium can take place in case of 1-thio sugars. 1-thioglucose[266a,268] **39e** and 1-thiolactose **39f** were tested obtaining as predicted quantitative yields with β-selectivity (Table 17).

Anomeric mixtures were separated by preparative HPLC for determining the anomeric ratio and all anomers were unambiguously assigned by NMR spectroscopy. The geminal coupling constants between H-1 and H-2 were calculated for the determination of α- or β-anomers (see experimental part).

2.3.2.2 Nitro Substitution with Monoactivated Nitrobenzenes

Additionally, monoactivated nitrobenzenes were tested for this efficient glycosylation method as well, namely *o*-dinitrobenzene (**48**) and *p*-nitrobenzonitrile (**49**). Due to the nucleophilicity of the carbohydrate moieties it was expected that the nitro substitution would also work well in the case of substituted phenyl compounds having only one additional electron withdrawing group. However, S_NAr reactions in DMF using K_2CO_3 or DBU as base failed completely. At room temperature, no reaction took place whereas at elevated temperatures decomposition of the starting materials occurred. Solely NaH as base gave the desired substitution products at room temperature (Scheme 29 and Table 18).



R = Benzyl (**1**), Benzoyl (**39b**) and Acetyl (**39c**)

Scheme 29 Optimisation reaction using **48** and different carbohydrates

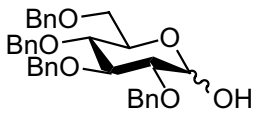
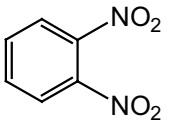
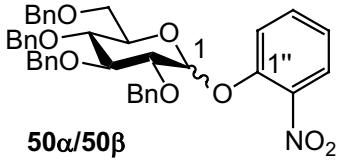
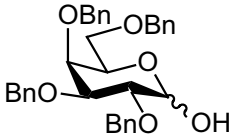
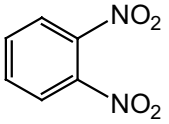
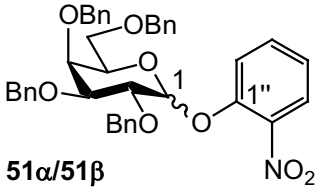
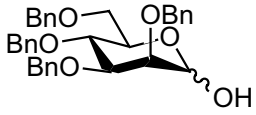
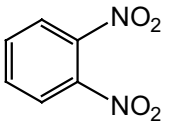
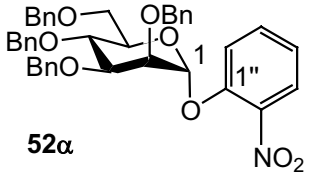
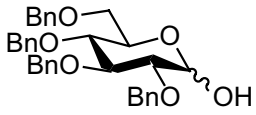
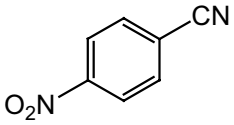
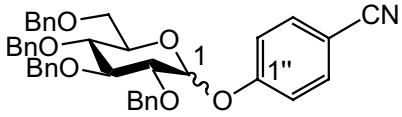
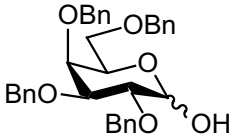
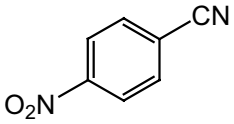
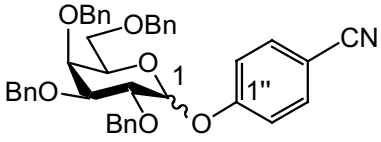
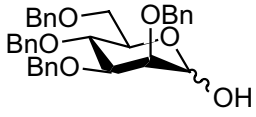
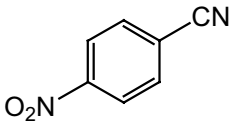
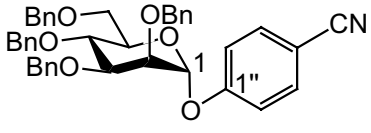
Table 18 Optimisation for the nitro substitution of **48** using DMF as solvent

	T [°C]	R	Base	Time	Results
1	RT	**39c**	4 eq K_2CO_3	over night	no reaction
2	100	**39c**	4 eq K_2CO_3	over night	no reaction
3	150	**39b**	1.2 eq K_2CO_3	over night	dec. of **1** (TLC)
4	RT	**39b**	1.2 eq DBU	over night	no reaction
5	100	**39b**	1.2 eq DBU	over night	dec. of **1** (TLC)
6	RT	**1**	1.2 eq NaH	15 min.	**50**, 92% [α:β, 3:1; (HPLC)]

A significantly lower anomeric selectivity for arylations in case of glucose **1** and galactose **47b**[269] with less activated nitro substituted benzenes (**48** and **49**) was observed (Table 19). This can be explained in terms of a slower or less possible retro nucleophilic substitution of the carbohydrate moiety caused by attack of a solvent molecule, when compared with phthalonitrile aglycon. In the case of mannose nucleophile **47c**,[270] only α-anomers **52α** and **55α** were found, due to the strong anomeric effect.

Anomeric mixtures were separated by preparative HPLC in the case of 2-nitrophenyl derivatives for determining the anomeric ratio and all anomers were unambiguously assigned by NMR spectroscopy (see experimental part). The α/β mixture from 4-cyanophenyl derivatives could not be separated. For this reason the α/β ratio was determinated by NMR and only representative ^{13}C-NMR signals are given.

Table 19 Nitro substitution using **48 and 49**

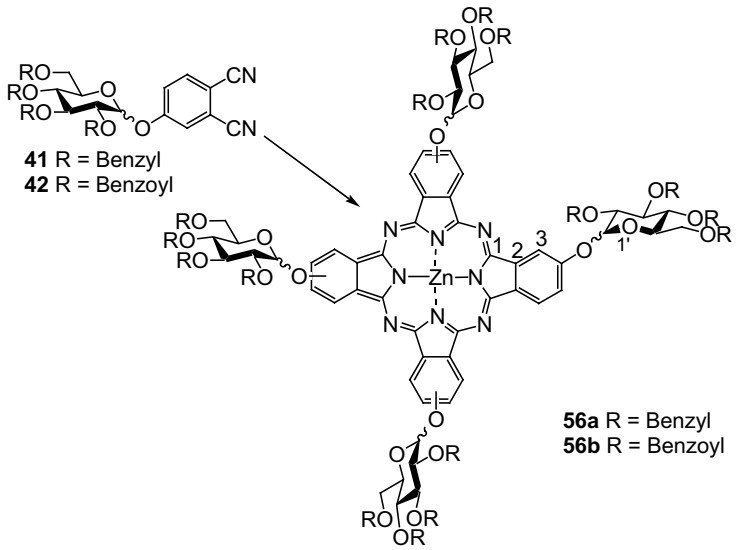
Carbohydrate reagent	nitrophenyl-derivative	phenyl-glycoside	yield (%) ratio (α/β)
 **1**	 **48**	 **50α/50β**	94%, 75:25
 **47b**	 **48**	 **51α/51β**	92%, 75:25
 **47c**	 **48**	 **52α**	89%, 100:0
 **1**	 **49**	 **53α/53β**	82%, 75:25
 **47b**	 **49**	 **54α/54β**	84%, 75:25
 **47c**	 **49**	 **55α**	84%, 100:0

DMF was used as solvent and NaH as base

2.3.3 Synthesis of Phthalocyanines

The synthesis of tetraglucose substituted zinc phthalocyanine (**56c**) was initially carried out using the classic phthalocyanine template reaction with protected dinitriles **41** and **42** (The Pc are synthesised starting from the α/β mixture), to obtain Pcs **56a** and **56b** respectively (Scheme 30) and subsequently deprotecting these compounds to obtain **56c**.

Tetra-*O*-benzyl-glucose PcZn **56a** was prepared in 58% yield, starting from **41**. Deprotection of the benzyl group however, turned out to be difficult, even by catalytic hydrogenation with Pd/C. Benzoyl as protecting group in **42** to form **56b** revealed to be less stable under the template conditions. The formation of the template was only possible at 160 °C, resulting in a lower yield and deprotection of some benzoyls, as observed by MALDI-TOF. Further deprotection of the carbohydrate moieties from **56b** was then tried under Zemplén conditions in order to obtain **56c**. This could only partially be accomplished since, as we confirmed by MALDI-TOF at least two or more benzoyl groups could not be removed completely, since the partially deprotected Pc precipitates in MeOH.



Scheme 30 Protected glucose PcsZn **56a** and **56b**; Reagents and conditions: a) n-pentanol, $Zn(Ac)_2 \cdot 2H_2O$,150 °C, 5 hours; b) DMAE, $Zn(Ac)_2 \cdot 2H_2O$, 160 °C, 5 hours

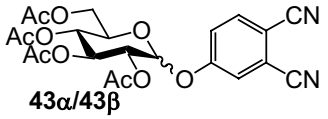
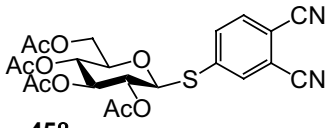
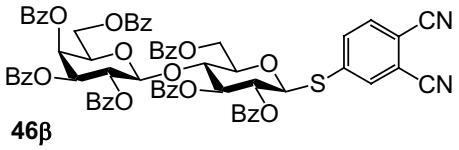
Another strategy was used for the synthesis of **56c** in order to obtain a better yield. Since Pcs are usually prepared in high boiling alcohols, such as pentanol, it was thought that the phthalocyanine template reaction could also be carried out starting from unprotected 3,4-dicyanophenyl carbohydrates. The deprotection of **39** was carried out under Zemplén conditions and the deprotected sugar were used directly without purification (see experimental part). By reacting unprotected 3,4-dicyanophenylglucopyranoside in butanol it led to the desired compound but in a low yield, since the dicyanophenyl derivative was not very soluble in butanol at 100 °C and the formed Pc precipitated immediately after formation, together with some unreacted starting material. A better solubility of the unprotected dicyanophenyl glycoside was observed when reacting it in DMAE at 100 °C, but the yield (12%) was not satisfactory as well. The optimum conditions were found to be using a mixture of butanol and DMAE (1:2). Under these conditions the dicyanophenylglycoside was soluble at 100 °C but the formed Pc could precipitate from the reaction mixture. In this conditions the yield increased to 51% (Table 20).

Also the Pcs from thioglucose and thiolactose derivatives were formed (Table 20). Both were synthesised using DMAE as solvent giving 15% and 10% yield respectively.

Pure Pcs **56c**, **56d** and **56e** were only possible to obtain after reverse phase HPLC. The classical physical purification methods proved to be insufficient. Spectroscopic data of Pc compounds **56** are in full agreement with common substituted phthalocyanines. Since **56** is a mixture of isomers,[271] their ^{1}H-NMR and ^{13}C-NMR (recorded in DMSO-d_6) showed typical chemical shifts for these kinds of compounds, with the difference that the phthalocyanine protons appear at higher ppm values (see experimental part), when compared with other oxo substituted Pcs.[271] This is due to the deshielding effect of the carbohydrate moieties. When comparing with compounds **6e** and **20c** the aggregation is higher, probably due to the nature of the used substituents in both cases. While in the cases of **56c**, **56d**, and **56e** the substituents are unprotected carbohydrates which tend to aggregate more, in the case of **6e** and **17c** (chapter 2.2.5.1) the substituent is di-*tert*-butylphenoxy, which is a much less aggregation-like substituent. The UV/Vis spectra of **56** are also characteristic for zinc substituted phthalocyanines, with a Q-band

maximum approximately at 680 nm. MALDI-TOF measurements confirmed unambiguously the molecular mass of compounds **56**.

Table 20 Synthesis of phthalocyanine-carbohydrate conjugates

3,4-dicyanophenyl-carbohydrate	Pc	yield (%)
 **43α/43β**	**56c**	12% 51%[a]
 **45β**	**56d**	15%
 **46β**	**56e**	10%

Reagents and conditions: 1. NaOMe, MeOH; 2. DMAE, $Zn(Ac)_2 \cdot 2H_2O$, 100 °C, 12 hours

[a] DMAE/n-butanol (2:1), $Zn(Ac)_2$, 100 °C, 24 hours

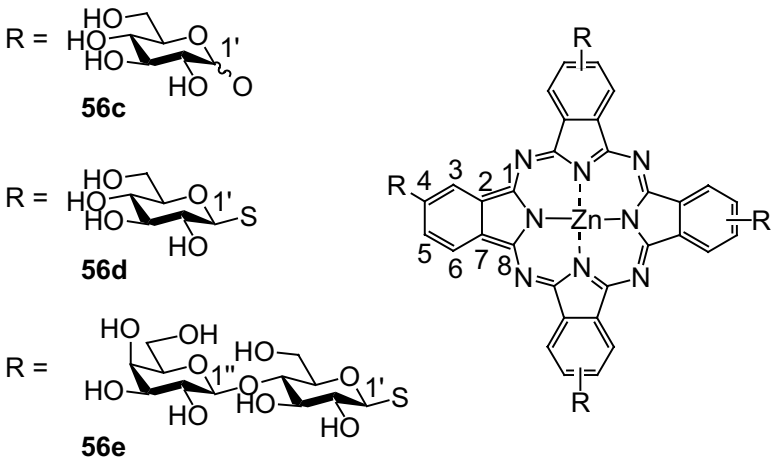


Figure 2 Structure of the Pcs synthesised without protecting groups

3 Summary

The thesis has been divided in two main sections. The first section deals with the generation of glucosyl nonafluorobutanesulfonate donors (cf. Scheme 13 and 14, p. 20). In the second section the direct 1-OH arylation via aromatic nitro displacement was described (cf. Scheme 29, p. 54).

In the first section three methods were investigated for the attainment of glycosyl nonaflate donors. First, the generation of donors were carried out using the commercially available nonafluorobutanesulfonyl fluoride (**2a**). Trehalose (**4**) was obtained when no other nucleophile was present in the reaction mixture (cf. Scheme 12, p. 19). On the other hand, addition of **2a** to a solution where other nucleophiles were present resulted in trehalose and the respective α/β-glycosides (**3**) formation (cf. Scheme 11 p. 16).

Second, nonafluorobutanesulfonyl-1*H*-benzotriazole (**6a**) was used for the transfer of nonaflyl group. **6a** was synthesised in 89% yield by treating lithium benzotriazolate with **2a** in glyme under reflux. No reaction was observed between carbohydrates and **6a** using different conditions. Reaction of **6a** with phenol (**7a**) in toluene led surprisingly to the azo compound **8a** (cf. Table 9, p. 25). However, carrying out the azo formation in DMF the ring opening proceeded almost exclusively to the *para*-product **8b** (cf. Table 8 and 9, p. 24). This methodology, when applied with other phenols, resulted in a new synthetic pathway for the formation of *ortho*-azoarenes through benzotriazole ring opening (cf. Table 10, p. 27). Reaction of triflylbenzotriazole (**6b**) with phenol in toluene led to a mixture of two *ortho*-coupled azobenzenes, with a free phenolic group and its corresponding trifluoromethane-sulfonate (OTf instead OH). Under the same reaction conditions tosyl- (**6d**) or mesyl-1*H*-benzotriazoles (**6c**) led to the corresponding phenyl sulfonic esters (cf. Table 9, p. 25). Some reaction mechanisms were proposed and computer calculations were realised in order to study the benzotriazole ring opening mechanism (cf. p. 29-32)

The ring opening of perfluoroalkanesulfonyl-1*H*-benzotriazole was exploited for the derivatisation of unsymmetrical phthalocyanine. An unsymmetrical phthalocyanine containing a benzotriazole moiety **5b** could be sulfonated with

trifluoromethane anhydride (cf. Scheme 18, p. 35). Subsequently, the ring opening was carried out with 2-naphthol in a good yield (86%).

Phosphorus ylides were also used as nucleophiles for the benzotriazole ring opening. Under similar conditions to the Wittig reaction, benzyl- and (carbethoxy-methyl)phosphoranylidenes **21'** and **23a** gave the corresponding methylazo-phosphranylidenes generally in good yields (63–90%) (cf. Table 13, p. 38; Scheme 21 p. 39). On the other hand, methylphosphoranylidenes (**23b**) led to the twice substituted methylazophophoranylidene **24b** (cf. Scheme 22, p. 40).

The synthesis of 1*H*- and 2*H*-benzotriazole glucopyranosides could be achieved using sulfonyl-benzotriazoles. Reactions between tosyl- (**6c**), trylflyl- (**6b**) or nonaflylbenzotriazoles (**6a**) and 2,3,4,6-tetra-*O*-benzyl-α/β-D-glucopyranose (**1**) led to 1*H*- and 2*H*-benzotriazole glycosides **25** and **26**. Despite the low reactivity and decomposition from **6a**, when compared to **6b** and **6c**, high β-selectivity was observed (cf. Table 14, p. 43).

The third reagent studied for the transfer of nonaflyl was the nonafluoro-butanesulfonic acid 1-benzotriazole-1-yl ester (**25a**). By reacting hydroxy-benzotriazole (**27**) with **2a** for the formation of the active ester **25a** an interesting rearrangement occurred leading to **28b** formation, an aryl benzotriazolesulfonic ester (cf. Scheme 24, p. 45). Similar phenomena occurred when the reaction was carried out with Tf_2O (**2b**), with the difference that two aryl sulfonates were isolated (cf. Scheme 24, p. 45). The new synthetic pathway was applied to a set of HOBts (cf. Table 16, p. 47). A cationic mechanism was proposed instead of the initial rearrangement. **29b** was derivatised with **2a** in order to obtain the sulfonylbenzotriazole **37** and subsequently proceeding to the ring opening (cf. Scheme 27, p. 49).

In the second topic of the thesis, the synthesis of deprotected carbohydrates linked to phthalocyanines, with are attached via the anomeric carbon, was carried out. For this purpose the carbohydrate dicyanophenyl phthalocyanine precursors were synthesised by an aromatic nitro displacement. This allowed the formation of *O*- and *S*-phenylglucosides from 4-nitrophthalonitrile (**40**) (cf. Table 17, p. 53). The nitro aromatic substitution was conducted in DMF under very mild conditions and

good yields. The reactions with *O*-glycosides occurred generally with a high α-selectivity. The preparation of the benzyl protected sugar zinc(II) phthalocyanines **56a** was carried out under classical template conditions (cf. Scheme 30, p. 57). Special synthetic conditions were needed for the synthesis of phthalocyanines linked to deprotected carbohydrate moieties, instead (cf. Table 20 and Figure 2, p. 59). Furthermore, the nitro substitution was also applied to monoactivated *p*-nitrobenzonitrile (**48**) and *o*-dinotrobenzene (**49**). Although the α-selectivity was lower, the yield was still high (cf. Table 19, p. 56).

4 Experimental Part

4.1 General Comments

Commercially available reagents were used as acquired. Additional purification proceedings are described in the respective synthetic procedures. All solvents were purified and/or dried according to literature methods. The following equipment was used for the analysis and characterization of the compounds:

Melting Point

Büchi B-540. The melting points are uncorrected.

Optical Rotations

Perkin-Elmer Polarimeter 341. The optical rotations were recorded at 20 °C as solutions in $CHCl_3$ (unless otherwise stated) using a 1 dm quartz cell.

IR Spectroscopy

Bruker Tensor 27: solid substances were grounded with KBr and pressed to pellets, liquid compounds were measured directly.

UV/Vis Spectroscopy

Shimadzu UV 2102 PC: The absorption spectra of the compound were recorded as solutions in CH_3CN (unless otherwise stated) using a 1 cm quartz cell.

NMR Spectroscopy

^1H NMR Spectra were recorded on Bruker AC 250 (250 MHz), Bruker Avance 400 (400 MHz) and Bruker AMX 600 (600 MHz). ^{13}C NMR Spectra were recorded on Bruker AC 250 (62.9 MHz), Bruker Avance 400 (100 MHz) and Bruker AMX 600

(151 MHz). The deuterated solvent was used as an internal standard. Chemical shifts are reported in part per million (ppm) relative to the internal standard. The correlation between the signals was made by using increments, comparison with known related compounds, DEPT-spectra and two dimensional correlation experiments $^{1}H^{1}H$-COSY and $^{1}H\,^{13}C$-COSY . Coupling constants are given in Hertz.

Mass Spectrometry

EI: Finnigan MAT TSQ 70 with direct inlet, temperature of ion source 200 °C, electron energy 70 eV; FAB: Finnigan MAT TSQ 70 using xenon atoms for the ionisation and 3-nitrobenzyl alcohol as the matrix; FD: Finnigan MAT 711 A; HRMS: Finnigan MAT 711 A; MALDI-TOFF: Bruker Autoflex, the spectra were measured with α-cyano-*m*-hydroxycinnamic acid as matrix for phthalocyanines and 2′-(4-hydroxyphenylazo)benzoic acid for other compounds.

Elemental Analysis

Elemental analysis was performed on HEKAtech GmbH Euro EA 3000 analyzer.

Crystallographic Structure

Crystallographic structures were determined on Enraf-Nonius CAD 4 diffractometer (Cu-Kα-radiation, λ = 154.184 pm) and Stoe IPDS diffractometer (Mo-Kα-radiation graphite monochromated, λ = 71.073 pm). SHELXS-97[272] and SHELXL-97[273] were used for the solution and refinement of the crystal structures. PLATON[274] and DIAMOND[275] were used for the molecular graphics of the crystal structures.

Thin Layer Chromatography (TLC)

POLYGRAM® SIL G/UV_{254} plates from Macherey & Nagel. The detection was conducted with the UV-lamp and/or carbonisation after spraying with a solution of 5% H_2SO_4 in EtOH.

Preparative Column Chromatography

The column size was selected depending on the amount of compound and was carried out with silica gel (0.032–0.063 mm) from Macherey & Nagel. The eluents are given in each reaction procedure.

High Performance Liquid Chromatography (HPLC)

Preparative HPLC was performed on Sykam system using an Grom Saphir Si; 5 μm; 250 × 20 mm. Analytical HPLC were performed on Sykam system using an Grom Saphir Si; 5 μm; 250 × 6 mm. The eluents used were *n*-heptane and EtOAc. Reverse phase HPLC were performed on waters system using a GROM SIL 120 ODS-4HE; 10 μm; 250 × 20 mm.

Chemicals

1-Bromo-2,2-dimethylpropane (Aldrich), 1-hydroxy-7-azabenzotriazole (Aldrich), 1-hydroxybenzotriazole (Aldrich), 15-crown-5 (Fluka), 1,2-dinitrobenzene (Aldrich), 1,3,5-trichloro-2-nitrobenzene (Fluka), 2-acetamido-2-deoxy-D-glucose (Glycon), 2,3-dichloronitrobenzene (Aldrich), 2,5-dichloronitrobenzene (Aldrich), 2,6-dimethylphenol (Acros), 3-chloro-4-nitrotoluene (Acros), 3-chlorobenzyl bromide (Aldrich), 4-chlorobenzyl chloride (Aldrich), 4-chloro-3-nitro-benzotrifluoride (Aldrich), 4-chloro-3-nitrotoluene (Aldrich), 4-chlorophenol (Aldrich), 4-methoxybenzyl chloride (Aldrich), 4-nitrobenzonitrile (Aldrich), 4-nitrobenzyl chloride (Aldrich), 4-nitrophenol (Riedel de Haen), 4-nitrophthalonitrile (Fluka), 2-*tert*.-butylphenol (Aldrich), butyllithium solution in hexane (Aldrich), benzotriazole (Aldrich), benzyl chloride (Fluka), (carbethoxymethyl)triphenylphosphonium bromide (Aldrich), Dowex 50WX8 400 ion-exchange resin (Acros), (ethyl)triphenylphosphonium bromide (Aldrich), D-(+)-glucose (Fluka), lactose-monohydrate (Merk), methanesulfonyl chloride (Aldrich), methyl-α-D-glucopyranose (Fluka), nonafluorobutanesulfonyl fluroride (Aldrich), *p*-toluenesulfonyl chloride (Acros), sodium hydride (Fluka), triethyl phosphonoacetate (Aldrich), trifluoromethane sulfonic anhydride (Aldrich).

4.2 Experimental Procedures

4.2.1 Related to Chapter 2.2.3

Synthesis of methyl 2,3,4,6-tetra-*O*-benzyl-(α/β)-D-glucopyranoside (3α/3β)

2,3,4,6-Tetra-*O*-benzyl-α-D-glucopyranose (**1**;[116] 100 mg, 0.19 mmol), NaH (22 mg, 0.5 mmol, 60% suspension in oil) and 15-Crown-5 (91 µl, 0.5 mmol) were dissolved at –20° in dry glyme. After 40 minutes MeOH (12 µl, 0.3 mmol) was added and the reaction mixture was stirred for another 10 minutes Nonafluorobutanesulfonyl fluoride (**2a**; 50µl, 0.3 mmol) was added drop wise and the reaction mixture was stirred overnight. At the end of this period, the reaction was poured into H_2O (10 ml) and CH_2Cl_2 (5 ml). The aqueous layer was extracted with CH_2Cl_2 (3 × 5 ml). The combined organic layers were washed with H_2O (3 × 5 ml). After drying (Na_2SO_4), filtration and removal of the solvent, the crude product was purified by chromatography on silica gel [eluent: toluene/EtOAc, 10:3] to give 23 mg **3α** + 49 mg **3β**; yield: 72 mg [70%; α/β, (1:2)].

Methyl 2,3,4,6-tetra-*O*-benzyl-α-D-glucopyranoside (3α)[276]

White powder; $[\alpha]_D^{20°}$ +18.4° (*c* = 0.3, $CHCl_3$), (Lit.[276] $[\alpha]_D^{20°}$ 17.8°, (*c* = 1, $CHCl_3$)).

^{1}H NMR (250 MHz, $CDCl_3$): δ = 3.36 (s, 3 H, H-CH_3), 3.50–3.56 (dd, 1 H, $J_{2\text{-}1}$ = 3.7, $J_{2\text{-}3}$ = 9.6 Hz, H-2), 3.60–3.76 (m, 4 H, H-4, H-5, H-6), 3.91–4.00 (s, 1 H, $J_{3\text{-}4}$ = 8.8, $J_{3\text{-}4}$ = 9.6 Hz, H-3), 4.45 (d, 1 H, *J* = 11.8 Hz, H-CH_2), 4.54–4.66 (m, 3 H, H-1, H-CH_2), 4.74–4.83 (m, 2 H, H-CH_2), 4.95 (d, 1 H, *J* = 11.1 Hz, H-CH_2), 7.09–7.13 (m, 2 H, H-2Ar), 7.23–7.34 (m, 18 H, H-2Ar, H-3Ar, H-4Ar).

^{13}C NMR (62.9 MHz, $CDCl_3$): δ = 55.1 (C-CH_3), 68.5 (C-6), 70.1 (C-5), 73.4, 73.5, 75.0, 75.7 [C-CH_2], 77.7 (C-4), 79.9 (C-2), 82.1 (C-3), 98.2 (C-1), 127.5, 127.6, 127.7, 127.82, 127.87, 127.9, 128.1, 128.34, 128.36, 128.4 [C-2Ar, C-3Ar, C-4Ar] 137.9, 138.2, 138.3, 128.8 [C-1Ar].

FAB-MS: *m*/*z* = 577.1 $[M + Na]^+$.

Methyl 2,3,4,6-tetra-*O*-benzyl-β-D-glucopyranoside (3β)[276]

Colorless oil; $[\alpha]_D^{20°}$ +12.1° (*c* = 0.3, $CHCl_3$), (Lit.[276] $[\alpha]_D^{20°}$ 11.4°, (*c* = 1, $CHCl_3$)).

^{1}H NMR (250 MHz, $CDCl_3$): δ = 3.40–3.79 (m, 9 H, H-2, H-3, H-4, H-5, H-6, H-CH_3), 4.31 (d, 1 H, $J_{1\text{-}2}$ = 7.9 Hz, H-1), 4.50–4.64 (m, 3 H, H-CH_2), 4.70 (d, 1 H, *J* = 11.1 Hz, H-CH_2), 4.78 (d, 1 H, *J* = 11.1 Hz, H-CH_2), 4.81 (d, 1 H, *J* = 10.8 Hz, H-CH_2), 4.89–4.94 (m, 2 H, H-CH_2), 7.13–7.17 (m, 2 H, H-2Ar), 7.23–7.37 (m, 18 H, H-2Ar, H-3Ar, H-4Ar).

^{13}C NMR (62.9 MHz, $CDCl_3$): δ = 57.1 (C-CH_3), 68.9 (C-6), 73.5, 74.7 [C-CH_2], 74.9 (C-5), 75.0, 75.7 [C-CH_2], 77.9 (C-4), 82.3 (C-2), 84.7 (C-3), 104.7 (C-1), 127.60, 127.62, 127.7, 127.8, 127.9, 127.0, 128.1, 128.3, 128.4 [C-2Ar, C-3Ar, C-4Ar], 138.1, 138.2, 138.5, 138.6 [C-1Ar].

FAB-MS: *m*/*z* = 577.1 $[M + Na]^+$.

Synthesis of 2,2',3,3',4,4'6,6'-octa-*O*-benzyl-(αα/αβ/ββ)-trehalose (4a/4b/4c)

2,3,4,6-Tetra-*O*-benzyl-α-D-glucopyranose (**1**;[116] 100 mg, 0.18 mmol), NaH (9 mg, 0.24 mmol, 60% suspension in oil) and 15-Crown-5 (35 µl, 0.2 mol) were dissolved in dry glyme. After 40 minutes nonafluorobutanesulfonyl fluoride (**2a**; 55 µl, 0.3 mmol) was added drop wise. The reaction mixture was stierred overnight. At the end of this period, the reaction was poured into H_2O (10 ml) and CH_2Cl_2 (5 ml). The aqueous layer was extracted with CH_2Cl_2 (3 × 5 ml). The combined organic layers were washed with H_2O (3 × 5 ml). After drying (Na_2SO_4), filtration and removal of the solvent, the crude product was purified by chromatography on silica gel [eluent: toluene/EtOAc, 10:3] to give 38 mg **4c** + 20 mg **4b** + 9 mg **4a**; yield 54 mg [57%; ββ/βα/αα (4:1:0.5)].

2,2',3,3',4,4',6,6'-Octa-*O*-benzyl-αα-trehalose (4a)[277]

Colorless oil; $[\alpha]_D^{20°}$ +81.0° (*c* = 0.5, $CHCl_3$), (Lit.[277] $[\alpha]_D^{20°}$ + 82°, (*c* = 0.7, $CHCl_3$)).

^{1}H NMR (400 MHz, $CDCl_3$): δ = 3.47–3.55 (m, 4 H, H-2, H-5), 3.66–3.78 (m, 8 H, H-3, H-4, H-6), 4.52 (d, 2 H, *J* = 12.1 Hz, H-CH_2), 3.57–3.61 (m, 4 H, H-CH_2), 4.52

(d, 2 H, J = 11.1 Hz, H-CH_2), 4.79 (d, 2 H, J = 10.8 Hz, H-CH_2), 4.82 (d, 2 H, J = 10.9 Hz, H-CH_2), 4.89 (d, 2 H, $J_{1\text{-}2}$ = 7.8 Hz, H-1), 4.94 (d, 2 H, J = 10.8 Hz, H-CH_2), 4.01(d, 2 H, J = 10.8 Hz, H-CH_2), 7.18–7.37 (m, 40 H, H-2Ar, H-3Ar, H-4Ar).

^{13}C NMR (100 MHz, $CDCl_3$): δ = 68.9 (C-6), 73.4, 74.6 [C-CH_2], 75.0 (C-5, C-CH_2), 75.6 (C-CH_2), 77.7 (C-4), 82.2 (C-2), 84.6 (C-3), 99.3 (C-1), 127.50, 127.55, 127.6, 127.7, 127.8, 127.9, 128.2, 128.3, 128.4 [C-2Ar, C-3Ar, C-4Ar], 138.2, 138.3, 138.5, 138.6 [C-1Ar].

FAB-MS: m/z = 1085.3 $[M + Na]^+$.

2,2',3,3',4,4',6,6'-Octa-*O*-benzyl-αβ-trehalose (4b)[277]

Colorless oil; $[\alpha]_D^{20°}$ +47° (c = 0.3, $CHCl_3$), (Lit.[277] $[\alpha]_D^{20°}$ + 46°, (c = 1.9, $CHCl_3$)).

^{1}H NMR (250 MHz, $CDCl_3$): δ = 3.40–3.77 (m, 10 H, H-2, H-4, H-6, H-2', H-3', H-4', H-5', H-6'), 4.02–4.16 (m, 10 H, H-3, H-5), 4.27 (d, 1 H, J = 12.1 Hz, H-CH_2), 4.44–4.58 (m, 6 H, H-1', H-CH_2), 4.62–4.66 (m, 2 H, H-CH_2), 4.71–4.91 (m, 7 H, H-CH_2), 5.09 (d, 1 H, J = 11.3 Hz, H-CH_2), 5.14 (d, 2 H, $J_{1\text{-}2}$ = 3.2 Hz, H-1), 7.10–7.35 (m, 40 H, H-2Ar, H-3Ar, H-4Ar).

^{13}C NMR (62.9 MHz, $CDCl_3$): δ = 68.0 (C-6), 68.9, 71.2 (C-5), 73.1, 73.3, 73.4, 74.5, 74.9 [C-CH_2], 75.0 (C-5', C-CH_2), 75.5, 75.6 [C-CH_2], 77.6 (C-4'), 77.7 (C-4), 79.7 (C-2), 81.7 (C-2'), 82.0 (C-3), 84.7 (C-3'), 99.5 (C-1), 104.2 (C-1'), 127.3, 127.50, 127.57, 127.63, 127.69, 127.7, 127.81, 127.85, 127.88, 127.9, 128.0, 128.1, 128.27, 128.29, 128.32, 128.34, 128.36 [C-2Ar, C-3Ar, C-4Ar], 138.0, 138.1, 138.2, 138.5, 138.6, 138.7, 138.8 [C-1Ar].

FAB-MS: m/z = 1085.3 $[M + Na]^+$.

2,2',3,3',4,4',6,6'-Octa-*O*-benzyl-ββ-trehalose (4c)[277]

Colorless oil; $[\alpha]_D^{20°}$ +81.3° (c = 0.5, $CHCl_3$), (Lit.[277] $[\alpha]_D^{20°}$ + 82°, (c = 0.7, $CHCl_3$)).

^{1}H NMR (250 MHz, $CDCl_3$): δ = 3.44–3.50 (dd, 2 H, $J_{6a\text{-}6b}$ = 1.2, $J_{6a\text{-}6b}$ = 10.7 Hz, H-6a), 3.57–3.63 (dd, 2 H, $J_{6b\text{-}6a}$ = 3.0, $J_{6b\text{-}6a}$ = 10.7 Hz, H-6b), 3.64–3.71 (dd, 2 H, $J_{2\text{-}1}$ = 3.6, $J_{2\text{-}3}$ = 9.5 Hz, H-2), 3.72–3.81 (t, 2 H, $J_{4\text{-}3/4\text{-}5}$ = 9.5 Hz, H-4), 4.08–4.16 (t,

2 H, $J_{3\text{-}2/3\text{-}4}$ = 9.5 Hz, H-3), 4.21–4.45 (m, 2 H, H-5), 4.45 (d, 2 H, *J* = 12.1 Hz, H-CH_2), 4.54 (d, 2 H, *J* = 10.8 Hz, H-CH_2), 4.59–4.65 (m, 4 H, H-CH_2), 4.76 (s, 4 H, H-CH_2), 4.86–4.96 (m, 4 H, H-CH_2), 5.07 (d, 2 H, *J* = 11.1 Hz, H-CH_2), 5.32 (d, 2 H, $J_{1\text{-}2}$ = 3.6 Hz, H-1), 7.18–7.24 (m, 4 H, H-2Ar), 7.27–7.44 (m, 36 H, H-2Ar, H-3Ar, H-4Ar).

^{13}C NMR (62.9 MHz, $CDCl_3$): δ = 68.3 (C-6), 70.8 (C-5), 72.8, 73.6, 75.1, 75.7 [C-CH_2], 77.8 (C-4), 79.5 (C-2), 81.9 (C-3), 94.5 (C-1), 127.5, 127.6, 127.7, 127.9, 128.0, 128.1 [C-2Ar, C-3Ar, C-4Ar], 138.0, 138.3, 138.5, 139.0 [C-1Ar].

FAB-MS: *m*/*z* = 1085.3 $[M + Na]^+$.

4.2.2 Related to Chapter 2.2.4

1-Nonafluorobutanesulfonyl-1*H*-1,2,3-benzotriazole (6a)

A 1.6 M solution of BuLi in *n*-hexane (9.4 ml, 15 mmol) was added slowly to a stirred solution of 1*H*-benzotriazole (**5a**; 1.8 g, 15 mmol) in anhydrous dimethoxymethane (50 ml) at 0 °C under argon. After 1 h, nonafluorobutanesulfonyl fluoride (**2a**; 4.75 ml, 22.4 mmol) was added dropwise. The reaction mixture was stirred under reflux for ca. 3 h, while the progress of the reaction monitored by TLC. After completion of the reaction, the mixture was cooled to room temperature, and diluted with Et_2O (100 ml). The organic layer was washed with aq sat. NH_4Cl solution (2 × 50 ml), and H_2O (1 × 50 ml). After drying (Na_2SO_4), filtration and removal of the solvent, the crude product was purified by chromatography on silica gel under protection from light [eluent: petroleum ether/EtOAc, 4:1] to give **6a**; yellow solid; yield: 5.33 g (89%); mp 46.1–46.8 °C (petroleum ether/EtOAc).

IR (KBr): ν = 1356, 1193 (SO_2), 1271, 1138, 1028 cm^{-1} (CF).

UV/Vis (MeCN): λ (ε $mol^{-1}dm^3cm^{-1}$) = 211 (10700), 253 (5480), 293 (1480), 409 nm (352).

^1H NMR (250 MHz, $CDCl_3$): δ = 7.55–7.64 (t, 1 H, $J_{4\text{-}5/5\text{-}6}$ = 8.2, Hz, H-5), 7.75–7.85 (t, 1 H, $J_{4\text{-}5/6\text{-}7}$ = 8.12 Hz, H-6), 7.98 (d, 1 H, $J_{4\text{-}5}$ = 8.2 Hz, H-4), 8.23 (d, 1 H, $J_{6\text{-}7}$ = 8.2 Hz, H-7).

^{13}C NMR (62.9 MHz, $CDCl_3$): δ = 111.8 (C-4), 121.4 (C-7), 127.2 (C-5), 131.9 (C-6), 132.1 (C-8), 145.3 (C-9).

EI-MS: *m*/*z* = 400.9 $[M]^+$, 182.0 $[M - C_4F_9]^+$.

Anal. calcd for $C_{10}H_4F_9N_3O_2S$: C, 29.94; H, 1.00; N, 10.47, S, 7.99. Found: C, 30.06; H, 0.93; N, 10.36; S, 8.16.

4-Hydroxyphthalonitrile (7l) [278]

K_2CO_3 (41.00 g, 300 mmol) was added to a solution of benzyl alcohol (6.20 ml, 60 mmol) and 4-nitrophthalonitrile (**31**; 7.00 g, 40 mmol) in DMF (100 ml). The mixture was heated and stirred at 80 °C for 6 h. At the end of this period, the mixture

was cooled down to room temperature and poured into ice water (1 l). The product was filtered and recrystallised from EtOH. A solution of 4-benzyloxyphthalonitrile (8.9 g, 38 mmol) in EtOAc (200 ml) was added to a suspension of 10% Pd/C (300 mg) in EtOAc (100 ml). The solution was stirred under H_2 for 6 h. The catalyst was removed from the solution by filtration over Celite. The EtOAc was evaporated and the product was dissolved in a 5% aq solution of NaOH, filtered and the filtrate was neutralised with concentrated HCl to give yield **7l**. Brownish powder; 4.6 g (85%); mp 211.5–213 °C (H_2O); Lit: [278] 208– 210 °C.

^{1}H NMR (250 MHz, DMSO-d_6): δ = 7.16–7.22 (dd, 1 H, $J_{5\text{-}3}$ = 2.5, $J_{5\text{-}6}$ = 8.6 Hz, H-5), 7.37 (d, 1 H, $J_{3\text{-}5}$ = 2.5 Hz, H-3), 7.89 (d, 1 H, $J_{6\text{-}5}$ = 8.6 Hz, H-6).

^{13}C NMR (62.9 MHz, MeOH-d_4): δ = 107.74 (C-4), 118.17 (C-6), 118.82 (C-3, C-5), 119.64 (C-2), 123.38 (C-1CN), 128.11 (C-2CN), 164.57 (C-1).

EI-MS: m/z = 143.9 $[M]^+$.

Reaction of 3 with Phenols in the Presence of NaH; General Procedure

NaH (0.12 g, 3 mmol, 60% suspension in oil) was added to a stirred solution of the appropriate phenol (3 mmol) and 1-[(nonafluorobutane)sulfonyl]-1*H*-1,2,3-benzotriazole (**6a**; 1 g, 2.5 mmol) in anhydrous toluene (50 ml) at room temperature under argon. The mixture was stirred for the given time (see below) while controlling the progress of the reaction by TLC. At the end of this period, EtOAc (100 ml) and H_2O (25 ml) were added and the suspension was treated with conc. HCl, till the colour of the organic phase changed from red to orange-red. The aqueous phase must remain colourless during this time. The organic phase was separated, dried (Na_2SO_4), filtered, and the solvent was evaporated. The crude product was purified by chromatography over silica gel [eluent: petroleum ether/EtOAc (30:1) containing 1% AcOH].

Nonafluoro-*N*-{2-[(*E*)-2-(2-hydroxyphenyl)diazenyl]phenyl}-1-butane-sulfonamide (8a)

Prepared from phenol **7a**. Reaction time: 7 h. Yellow solid; yield: 0.94 g (76%); mp 134.2–135.1 °C (petroleum ether).

IR (KBr): ν = 3441 (NH, OH), 1349, 1184 (SO_2), 1285, 1252, 1135 cm^{-1} (CF).

UV/Vis (MeCN): λ (ε $mol^{-1}dm^3cm^{-1}$) = 250 (11700), 321 (12000), 395 nm (8320).

^{1}H NMR (600 MHz, $CDCl_3$): δ = 7.06 (d, 1 H, $J_{5'-6'}$ = 8.6 Hz, H-6'), 7.08−7.12 (dd, 1 H, *J* = 7.3, 7.9 Hz, H-5'), 7.37–7.44 (m, 2 H, H-4, H-4'), 7.44–7.50 (m, 1 H, H-5), 7.75 (d, 1 H, $J_{3'-4'}$ = 7.9 Hz, H-3'), 7.82–7.87 (m, 2 H, H-3, H-6), 11.86 (s, 1 H, N-H), 12.00 (s, 1 H, OH).

^{13}C NMR (151 MHz, $CDCl_3$): δ = 118.7 (C-6'), 120.4 (C-3), 120.8 (C-5'), 126.1 (C-4), 129.8 (C-1), 130.3 (C-6), 131.4 (C-4'), 132.4 (C-5), 134.8 (C-3'), 135.9 (C-1'), 137.3 (C-2), 153.1 (C-2').

EI-MS: *m*/*z* = 494.9 $[M]^+$, 212.1 $[M - C_4F_9O_2S]^+$.

Anal. calcd for $C_{16}H_{10}F_9N_3O_3S$: C, 38.80; H, 2.03; N, 8.48; S 6.47. Found: C, 38.62; H, 1.99; N, 8.33; S, 6.52.

Nonafluoro-*N*-{2-[(*E*)-2-(4-hydroxyphenyl)diazenyl]phenyl}-1-butane-sulfonamide (8b)

Synthesised from phenol **7a**. This reaction was carried out in DMF and the crude was chromatographed with petroleum ether/EtOAc (10:1) as eluent. Reaction time: 12 h. Orange solid; yield: 0.58 g (47%); mp 129.5–130 °C (petroleum ether/toluene).

IR (KBr): ν = 3500 (NH, OH), 1352, 1199 (SO_2), 1281, 1233, 1134 cm^{-1} (CF).

UV/Vis (CH_3CN): λ (ε $mol^{-1}dm^3cm^{-1}$) 250 (11300), 358 nm (19000).

^{1}H NMR (400 MHz, $CDCl_3$): δ = 5.56 (s, 1 H, OH), 6.94–6.99 (m, 2 H, H-2', H-6'), 7.29–7.35 (ddd, 1H, J_{4-6} = 1.4, J_{4-3} = 7.6, J_{4-5} = 8.7 Hz, H-4), 7.40–7.46 (ddd, 1H, J_{5-2} = 1.6, J_{5-6} = 7.9, J_{5-4} = 8.7 Hz, H-5), 7.77–7.85 (m, 3H, H-3, H-3', H-5'), 7.88–7.93 (dd, 1H, J_{6-4} = 1.4, J_{5-6} = 7.9 Hz, H-6), 11.20 (s, 1 H, N-H).

^{13}C NMR (100.6 MHz, $CDCl_3$): δ = 116.2 (C-3', C-5'), 119.2 (C-6), 125.0 (C-2', C-6'), 125.6 (C-5), 125.7 (C-3), 131.3 (C-2), 131.9 (C-4), 139.1 (C-1), 145.7 (C-1'), 159.4 (C-4').

EI-MS: *m/z* = 495.0 $[M]^+$, 212.1 $[M - C_4F_9O_2S]^+$.

Anal. calcd for $C_{16}H_{10}F_9N_30_3S$: C, 38.80; H, 2.03; N, 8.48; S, 6.47. Found: C, 38.94; H, 1.97; N, 8.40; S, 6.53.

Trifluoro-*N*-{2-[(*E*)-2-(2-hydroxyphenyl)diazenyl]phenyl}-1-methanesulfonamide (9a)

The title compound was isolated as a by-product being **9a** the major product; Yellow solid; yield: 0.35 g (58%); mp 132–133.4 °C

9b; Synthesised from phenol (**7a**) and 1-trifluoromethanesulfonyl-1*H*-benzotriazole (**6b**;[130] 0.63 g, 2.5 mmol). Reaction time: 12 h. The crude product was purified by chromatography over silica gel [eluent: petroleum ether/EtOAc (10:1)]. Orange solid; yield: 0.15 g (19%); mp 111.2–112 °C (petroleum ether/EtOAc). For analytical purposes the title compound was separated by preparative reverse phase HPLC.

IR (KBr): ν = 3451 (NH, OH), 1384, 1209 (SO_2), 1289, 1228, 1139 cm^{-1} (CF).

UV/Vis (CH_3CN): λ (ε $mol^{-1}dm^3cm^{-1}$) = 243 (10900), 321 (12500), 387 nm (7900).

^{1}H NMR (250 MHz, $CDCl_3$): δ = 6.92–7.12 (m, 2 H, H-5', H-6'), 7.27–7.49 (m, 3 H, H-4, H-5, H-4'), 7.64–7.84 (m, 3 H, H-3, H-6, H-3'), 12.08 (s, 1 H, N-H,O-H).

^{13}C NMR (62.9 MHz, $CDCl_3$): δ = 118.7 (C-6'), 120.7 (C-5', C-3), 122.3 (C-1), 125.9 (C-4), 129.7 (C-6), 131.4 (C-3'), 132.3 (C-4'), 134.7 (C-5), 136.0 (C-1'), 137.6 (C-2), 153.2 (C-2').

EI-MS: *m/z* = 345.0 $[M]^+$, 212.1 $[M - CF_3O_2S]^+$.

Anal. calcd for $C_{13}H_{10}F_3N_3S{\cdot}CF_3COOH$: C, 39.22; H, 2.41; N, 9.15; S, 6.98. Found: C, 39.29; H, 2.39, N, 9.25; S, 6.89.

Trifluoromethanesulfonic Acid *2*-[(2-Trifluoromethanesufonylaminophenyl)-diazenyl]phenyl Ester (9b)

NaH (0.08 g, 2.0 mmol, 60% suspension in oil) was added to a stirred solution of phenol (**7a**; 0.2 g, 2.0 mmol) and 1-trifluoromethanesulfonyl-1*H*-benzotriazole (**6b**;[130] 1 g, 4 mmol) in anhydrous toluene (50 ml) at room temperature under argon. The mixture was allowed to stir for 12 h while controlling the progress of the reaction by TLC. At the end of this period, EtOAc (100 ml) and H_2O (25 ml) were added and the suspension was treated with conc. HCl, till the colour of the organic phase changed from red to orange. The aqueous phase must remain colourless during this time. The organic phase was separated, dried (Na_2SO_4), filtered, and the solvent was evaporated. The crude product was purified by chromatography over silica gel [eluent: petroleum ether/EtOAc (10:1)]. Yellow solid; yield 0.90 g (95%); mp 132.7–133.4 °C (petroleum ether/EtOAc).

IR (KBr): ν = 3422 (OH), 3277 (NH), 1365, 1200 (SO_2), 1285, 1229, 1139 cm^{-1} (CF).

UV/Vis (CH_3CN): λ (ε $mol^{-1}dm^3cm^{-1}$) = 203 (23400), 233 (11400), 326 nm (16700).

^1H NMR (250 MHz, $CDCl_3$): δ = 7.31–7.39 (m, 1 H, H-5'), 7.45 (dd, 1 H, $J_{3\text{-}5}$ = 1.5, $J_{3\text{-}4}$ = 8.2 Hz, H-3), 7.48–7.65 (m, 3 H, H-4, H-5, H-4'), 7.72–7.82 (m, 2 H, H-6, H-6'), 7.96 (d, 1 H, $J_{3'\text{-}4'}$ = 8.1 Hz, H-3'), 9.00 (s, 0.9 H, N-H).

^{13}C NMR (62.9 MHz, $CDCl_3$): δ =117.6 (C-6), 119.5 (C-3'), 120.7 (C-6'), 122.8 (C-3), 126.5 (C-5'), 129.1 (C-4), 133.5 (C-5), 134.1 (C-2'), 134.2 (C-4'), 141.3 (C-1'), 143.8 (C-2), 147.9 (C-1).

EI-MS: *m/z* = 476.9 $[M]^+$, 344.1 $[M^+ - CF_3O_2S]$, 211.1 $[M - C2F_6O_4S_2]^+$.

Anal. calcd for $C_{14}H_9F_6N_3O_5S_2$: C, 35.22; H, 1.90; N, 8.80; S, 13.43. Found: C, 35.17; H, 2.01; N, 8.69; S, 13.04.

Toluone-4-sulfonic acid phenyl ester (10)[279]

NaH (0.12 g, 3 mmol, 60% suspension in oil) was added to a stirred solution of phenol (**7a**; 0.28 g, 3 mmol) and 1-(toluene-4-sulfonyl)-1*H*-benzotriazole (**6c**;[138] 0.68 g, 2.5 mmol) in anhydrous toluene (50 ml) at room temperature under argon. The mixture was allowed to stir for 12 h while controlling the progress of the reaction by

TLC. At the end of this period, EtOAc (100 ml) and H_2O (25 ml) were added. The organic phase was washed with H_2O (2 x 25 ml), separated, dried (Na_2SO_4), filtered, and the solvent was evaporated. The crude product was recrystallised from *n*-hexane. White solid; yield: 0.59 g (96%); mp 94.6–95.3 °C (*n*-hexane). (Lit.[279] 95.8–97.5 °C (EtOH)).

^{1}H NMR (250 MHz, $CDCl_3$): δ = 3.42 (s, 3 H, H-CH_3), 6.97 (d, 2 H, $J_{2'\text{-}3',6'\text{-}5'}$ = 8.6 Hz, H-2', H-6'), 7.18–7.32 (m, 5 H, H-2, H-3, H-4, H-5, H-6), 7.69 (d, 2 H, $J_{3'\text{-}2',5'\text{-}6'}$ = 8.6 Hz, H-3', H-5').

^{13}C NMR (62.9 MHz, $CDCl_3$): δ = 21.7 (C-CH_3), 122.4 (C-2, C-6), 127.0 (C-4), 128.5 (C-3, C-5), 129.6 (C-3', C-5'), 129.35 (C-2', C-6'), 132.5 (C-1'), 145.3 (C-4'), 149.7 (C-1).

Methanesulfonic acid phenyl ester (11)[280]

NaH (0.12 g, 3 mmol, 60% suspension in oil) was added to a stirred solution of phenol (**7a**; 0.28 g, 3 mmol) and 1-methanesulfonyl-1*H*-benzotriazole (**6d**;[143] 0.49 g, 2.5 mmol) in anhydrous toluene (50 ml) at room temperature under argon. The mixture was allowed to stir for 12 h while controlling the progress of the reaction by TLC. At the end of this period, EtOAc (100 ml) and H_2O (25 ml) At the end of this period, EtOAc (100 ml) and H_2O (25 ml) were added. The organic phase was washed with H_2O (2 x 25 ml), separated, dried (Na_2SO_4), filtered, and the solvent was evaporated. The crude product was recrystallised from *n*-hexane. White solid; yield: 0.42 g (91%); mp 60.5–61 °C (*n*-hexane) (Lit.[280] 61–62°C (EtOH)).

^{1}H NMR (250 MHz, $CDCl_3$): δ = 3.11 (s, 3 H, H-CH_3), 7.23–7.45 (m, 5 H, Ar-H).

^{13}C NMR (62.9 MHz, $CDCl_3$): δ = 37.3 (C-CH_3), 121.9 (C-2, C-6), 127.4 (C-4), 130.0 (C-3, C-5), 149.3 (C-1).

Nonafluoro-*N*-{2-[(*E*)-2-(2-hydroxy-3-methylphenyl)diazenyl]phenyl}-1-butane-sulfonamide (12)

Synthesised from 2-methylphenol (**7b**). Reaction time: 3 h. Orange solid; yield: 0.8 g (63%); mp 96.3–98.4 °C (pentane/toluene).

IR (KBr): ν = 3459 (OH), 3284 (NH), 1355, 1185 (SO_2), 1264, 1228, 1144 cm^{-1} (CF).
UV/Vis (CH_3CN): λ (ε $mol^{-1}dm^3cm^{-1}$) = 219 (15600), 245 (10200), 325 (9900), 411 nm (7500).
^1H NMR (250 MHz; $CDCl_3$): δ = 2.98 (s, 3 H, H-CH_3), 7.05–6.97 (t, 1 H, $J_{5'-6'/5'-4'}$ = 7.6 Hz, H-5'), 7.31 (d, 1 H, $J_{4'-5'}$ = 7.4 Hz, H-4'), 7.43–7.35 (ddd, 1 H, J_{4-6} = 1.5, J_{4-3} = 7.5, J_{4-5} = 9.1 Hz, H-4), 7.50–7.43 (ddd, 1 H, J_{5-3} = 1.7, J_{5-6} = 7.5, J_{5-4} = 9.1 Hz, H-5), 7.56–7.63 (dd, 1 H, $J_{6'-4'}$ = 1.3, $J_{6'-5'}$ = 7.9 Hz, H-6'), 7.80–7.90 (m, 2 H, H-6, H-3), 12.15 (s, 0.7 H, OH), 12.19 (s, 0,9 H, NH).
^{13}C NMR (62.9 MHz; $CDCl_3$): δ = 15.3 (C-CH_3), 120.2 (C-3), 120.3 (C-4'), 126.1 (C-4), 128.0 (C-3'), 129.2 (C-6'), 129.9 (C-1), 130.6 (C-6), 132.3 (C-5), 135.6 (C-1'), 135.9 (C-4'), 137.1 (C-2), 151.6 (C-2').
EI-MS: *m*/*z* = 509 $[M]^+$, 226.2 $[M - C_4F_9O_2S]^+$.
Anal. calcd for $C_{17}H_{12}F_9N_3O_3S$: C, 40.09; H, 2.37; N, 8.25; S, 6.30. Found: C, 40.12; H, 2.41; N, 8.24; S, 6.28.

Nonafluoro-*N*-{2-[(*E*)-2-(2-hydroxy-4-methylphenyl)diazenyl]phenyl}-1-butanesulfonamide (13)

Synthesised from 3-methylphenol (**7c**). Reaction time: 3 h. This product was recrystallyzed from pentane/toluene (4:1) without previous chromatography. Yellow solid; yield: 1.17 g (92%); mp 132.7−133.0 °C (pentane/toluene).
IR (KBr): ν = 3419 (NH, OH), 1351, 1183 (SO_2), 1282, 1228, 1137 cm^{-1} (CF).
UV/Vis (CH_3CN): λ (ε $mol^{-1}dm^3cm^{-1}$) = 255 (22800), 325 (19300), 412 nm (18700).
^1H NMR (250 MHz, $CDCl_3$): δ = 2.41 (s, 3 H, H-CH_3), 6.85−6.97 (m, 2 H, H-3', H-5'), 7.34−7.50 (m, 2 H, H-4, H-5), 7.59−7.65 (d, 1 H, $J_{6'-5'}$ = 8.1 Hz, H-6'), 7.77–7.90 (m, 2 H, H-6, H-3), 11.97 (s, 1 H, NH), 12.13 (s, 1 H, OH).
^{13}C NMR (62.9 MHz, $CDCl_3$): δ = 22.2 (C-CH_3), 118.9 (C-3'), 120.3 (C-3), 122.3 (C-5'), 126.1 (C-4), 129.2 (C-4'), 130.6 (C-6), 131.5 (C-6'), 132.0 (C-5), 134.4 (C-1), 137.2 (C-1'), 146.9 (C-2), 153.2 (C-2').
EI-MS: *m/z* = 509 $[M]^+$, 226.1 $[M - C_4F_9O_2S]^+$.
HRMS: *m*/*z* calcd for $C_{17}H_{12}F_9N_3O_3S$: M = 509.04551; Found: 509.05092.

Nonafluoro-*N*-{2-[(*E*)-2-(2-hydroxy-5-methylphenyl)diazenyl]phenyl}-1-butane-sulfonamide (14)

Synthesised from 4-methylphenol (**7d**). Reaction time: 3 h. Orange solid; yield: 1.15 g (90%); mp 126.7–127.1 °C (petroleum ether/toluene).

IR (KBr): ν = 3456 (NH, OH), 1353, 1182 (SO_2), 1281, 1246, 1135 cm^{-1} (CF).

UV/Vis (CH_3CN): λ (ε $mol^{-1}dm^3cm^{-1}$) = 208 (30500), 257 (24700), 319 (15000), 419 (12500).

^1H NMR (400 MHz, $CDCl_3$): δ = 2.39 (s, 3 H, H-CH_3), 6.97 (d, 1 H, $J_{3'-4'}$ = 8.9 Hz, H-3'), 7.22–7.26 (dd, 1 H, $J_{4'-6'}$ = 2.2, $J_{4'-3'}$ = 8.9 Hz, H-4'), 7.37–7.42 (ddd, 1 H, J_{4-6} = 1.8, J_{4-5} = 7.7, J_{4-3} = 9.3 Hz, H-4), 7.44–7.50 (ddd, 1 H, J_{5-3} = 1.8, J_{5-4} = 7.7, J_{5-6} = 8.4 Hz, H-5), 7.52 (d, 1H, $J_{6'-4'}$ = 1.8 Hz, H-6'), 7.83–7.88 (m, 2 H, H-6, H-3), 11.75 (s, 1 H, N-H), 12.11 (s, 0.9 H, OH).

^{13}C NMR (100.6 MHz, $CDCl_3$): δ = 20.3 (C-CH_3), 118.4 (C-3'), 120.1 (C-3), 125.9 (C-4), 129.6 (C-1), 130.3 (C-5'), 130.5 (C-6), 130.9 (C-6'), 132.2 (C-5), 135.6 (C-1'), 135.9 (C-4'), 137.1 (C-2), 150.9 (C-2').

EI-MS: *m/z* = 509 $[M]^+$, 226.1 $[M - C_4F_9O_2S]^+$.

Anal. calcd for $C_{17}H_{12}F_9N_3O_3S$: C, 40.09; H, 2.37; N, 8.25; S, 6.30. Found: C, 40.25; H, 2.39; N, 8.23; S, 6.29.

Nonafluoro-*N*-{2-[(*E*)-2-(4-hydroxy-3,5-dimethylphenyl)diazenyl]phenyl}-1-butanesulfonamide (15)

from 2,6-dimethylphenol (**7e**). Reaction time: 12 h. The crude was chromatographied with petroleum ether/EtOAc (4:1). Yellow solid; yield: 1 g (76%); mp 133.5–133.9 °C (petroleum ether/toluene).

IR (KBr): ν = 3568 (OH), 3280 (NH), 1358, 1187 (SO_2), 1293, 1230, 1143 cm^{-1} (CF).

UV/Vis (CH_3CN): λ (ε $mol^{-1}dm^3cm^{-1}$) = 251 (11800), 370 nm (17400).

^1H NMR (400 MHz, $CDCl_3$): δ = 2.33 (s, 6 H, H-CH_3), 5.17 (s, 1 H, OH), 7.28–7.34 (ddd, 1 H, J_{3-6} = 1.3, J_{4-5} = 8.2, J_{4-3} = 9.3 Hz, H-4), 7.37–7.43 (ddd, 1 H, J_{5-3} = 1.6, J_{5-6} = 7.7, J_{5-4} = 8.2 Hz, H-5), 7.55 (s, 2H, H-2', H-6'), 7.77–8.82 (dd, 1 H, J_{3-5} = 1.6,

$J_{3\text{-}4}$ = 8.4 Hz, H-3), 7.87–7.92 (dd, 1 H, $J_{6\text{-}4}$ = 1.3, $J_{6\text{-}5}$ = 7.7 Hz, H-6), 11.56 (s, 1 H, N-H).

^{13}C NMR (100.6 MHz, $CDCl_3$): δ = 15.9 (C-CH_3), 119.2 (C-3), 123.7 (C-2', C-6'), 124.1 (C-3',C-5'), 125.6 (C-4), 126.4 (C-6), 130.9 (C-1), 131.6 (C-5), 139.1 (C-2), 144.8 (C-1'), 156.3 (C-4').

EI-MS: *m/z* = 523 $[M]^+$, 240.2 $[M - C_4F_9O_2S]^+$.

Anal. calcd for $C_{18}H_{14}F_9N_3O_3S$: C, 41.31; H, 2.70; N, 8.03; S, 6.13. Found: C, 41.31; H, 2.69; N, 7.94; S, 6.10.

Nonafluoro-*N*-{2-[(*E*)-2-(3-*tert*-butyl-2-hydroxyphenyl)diazenyl]phenyl}-1-butanesulfonamide (16)

Synthesised from 2-*tert*-butylphenol (**7f**). Reaction time: 2 h. Orange solid; yield: 1.09 g (79%); mp 88.7–91.3 °C (pentane/toluene).

IR (KBr): ν = 3441 (OH, NH), 1352, 1190 (SO_2), 1262, 1237, 1140 cm^{-1} (CF).

UV/Vis (CH_3CN): λ (ε $mol^{-1}dm^3cm^{-1}$) = 245 (11300), 326 (11600), 411 nm (8990).

^{1}H NMR (250 MHz, $CDCl_3$): δ = 1.47 (s, 9 H, CH_3), 6.99–7.07 (m, 1 H, H-5), 7.34–7.42 (ddd, 1H, $J_{4\text{-}6}$ = 1.7, $J_{4\text{-}3}$ = 7.9, $J_{4\text{-}5}$ = 9.4 Hz, H-4), 7.43–7.52 (m, 2 H, H-4', H-5), 7.57–7.63 (dd, 1 H, $J_{6'\text{-}4'}$ = 1.7, $J_{6'\text{-}5'}$ = 7.9 Hz, H-6'), 7.83–7.91 (m, 2 H, H-6, H-3), 12.01 (s, 1 H, OH), 12.62 (s, 1 H, NH).

^{13}C NMR (62.9 MHz, $CDCl_3$): δ = 29.5 (C-CH_3), 35.32 (C-*tert*), 120.1 (C-5'), 120.2 (C-3), 126.1 (C-4), 128.9 (C-6'), 129.7 (C-6), 130.2 (C-1), 132.2 (C-4'), 132.4 (C-5), 136.2 (C-3'), 137.1 (C-1'), 139.4 (C-2), 153.3 (C-2').

EI-MS: *m/z* = 551.1 $[M]^+$, 268.1 $[M - C_4F_9O_2S]^+$.

HRMS: *m*/*z* calcd for $C_{20}H_{18}F_9N_3O_3S$: M = 551.09246; found: 551.09654.

Nonafluoro-*N*-{2-[(*E*)-2-(5-chloro-2-hydroxyphenyl)diazenyl]phenyl}-1-butanesulfonamide (17)

Synthesised from 4-chlorophenol (**7g**). Reaction time: 3 h. Yellow solid; yield: 1.04 g (79%); mp 145.4–145.8 °C (petroleum ether/toluene).

IR (KBr):ν = 1354, 1182 (SO_2), 1286, 1242, 1135 cm^{-1} (CF).

UV/Vis (CH_3CN): λ (ε $mol^{-1}dm^3cm^{-1}$) = 203 (19800), 251 (9550), 322 (11900), 400 nm (8320).

^1H NMR (400 MHz, $CDCl_3$): δ = 7.04 (d, 1 H, $J_{3'-4'}$ = 8.8 Hz, H-3'), 7.37 (dd, 1 H, $J_{4'-6'}$ = 2.6, $J_{4'-3'}$ = 8.8 Hz, H-4'), 7.40–7.45 (ddd, 1 H, J_{4-3} = 1.3, J_{4-5} = 7.7, J_{4-3} = 9.3 Hz, H-4), 7.44–7.50 (ddd, 1 H, J_{5-3} = 1.8, J_{5-4} = 7.7, J_{5-6} = 8.4 Hz, H-5), 7.52 (d, 1 H, $J_{6'-4'}$ = 2.6 Hz, H-6'), 7.82–7.88 (m, 2 H, H-6, H-3), 11.36 (s, 1 H, OH), 11.61 (s, 1 H, N-H).

^{13}C NMR (100.6 MHz, $CDCl_3$): δ = 120.0 (C-3'), 120.7 (C-3), 125.5 (C-5'), 126.3 (C-4), 129.5 (C-6'), 129.6 (C-6), 130.1 (C-1), 133.1 (C-5), 134.4 (C-4'), 136.2 (C-1'), 137.6 (C-2), 151.7 (C-2').

EI-MS: *m/z* = 529 $[M]^+$, 246.0 $[M - C_4F_9O_2S]^+$.

Anal. calcd for $C_{16}H_9ClF_9N_3O_3S$: C, 36.27; H, 1.71; N, 7.93; S, 6,05. Found: C, 36.37; H, 1.70; N, 8.05; S, 5.99.

Nonafluoro-*N*-{2-[(*E*)-2-(2-hydroxy-3-methoxyphenyl)diazenyl]phenyl}-1-butanesulfonamide (18)

Synthesised from 2-methoxyphenol (**7h**). Reaction time: 3 h. Yellowish brown solid; yield 0.8 g (70%); mp 134−135 °C (pentane/toluene).

IR (KBr): ν = 3442 (OH), 3239 (NH), 1352, 1187 (SO_2), 1259, 1236, 1138 cm^{-1} (CF).

UV/Vis (CH_3CN): λ (ε $mol^{-1}dm^3cm^{-1}$) = 222 (23500), 333 (13400), 407 nm (8400).

^1H NMR (250 MHz, $CDCl_3$): δ = 3.94 (s, 3 H, H-CH_3), 6.99–7.06 (m, 2 H, H-4', H-6'), 7.34–7.42 (m, 2 H, H-4, H-5'), 7.43-7.52 (ddd, 1 H, J_{5-3} = 1.7, J_{5-4} = 7.4, J_{5-6} = 9.1 Hz, H-5), 7.84–7.92 (m, 2 H, H-6, H-3), 11.06 (s, 1 H, NH), 11.96 (s, 0.9 H, OH).

^{13}C NMR (62.9 MHz, $CDCl_3$): δ = 56.6 (C-CH_3), 115.7 (C-6'), 119.9 (C-4'), 120.2 (C-3, C-5'), 126.1 (C-4), 130.1 (C-1), 130.4 (C-6), 132.6 (C-5), 136.3 (C-1'), 137.7 (C-2), 143.9 (C-3'), 149.0 (C-2').

EI-MS: *m/z* = 525 $[M]^+$, 242.1 $[M - C_4F_9O_2S]^+$.

Anal. calcd for $C_{17}H_{12}F_9N_30_3S$: C, 38.87; H, 2.30; N, 8.00; S, 6.10. Found: C, 38.95; H, 2.33; N, 7.92; S, 6.07.

Nonafluoro-*N*-{2-[(*E*)-2-(1-hydroxy-2-naphthyl)diazenyl]phenyl}-1-butane-sulfonamide (19)

Synthesised from 1-naphthol (**7i**). Reaction time: 4 h. Dark red solid; yield 1.18 g (86%); mp 161.6−161.9 °C (petroleum ether/toluene).

IR (KBr): ν = 3441 (NH, OH), 1354, 1186 (SO_2), 1236, 1135 cm^{-1} (CF).

UV/Vis (CH_3CN): λ (ε $mol^{-1}dm^3cm^{-1}$) = 205 (40400), 245 (29900), 293 (20200), 524 nm (26800).

^1H NMR (600 MHz, acetone-d_6): δ =7.04 (d, 1 H, $J_{3'-4'}$ = 9.3 Hz, H-3'), 7.22–7.27 (m, 2 H, H-5, H-4'), 7.32–7,39 (m, 2 H, H-4, H-6'), 7.44 (d, 1 H, J_{3-4} = 7.9 Hz, H-3), 7.52–8.53 (ddd, 1 H, $J_{7'-5'}$ = 1.0, $J_{7'-6'}$ = 6.9, $J_{7'-8'}$ = 7.9 Hz, H-7'), 7.55 (d, 1 H, $J_{5'-6'}$ = 6.7 Hz, H-5'), 7.84 (dd, 1 H, J_{6-4} = 1.5, J_{6-5} = 8.4 Hz, H-6), 8.20 (d, 1 H, $J_{8'-7'}$ = 7.9 Hz, H-8'), 10.56 (s, 1 H, NH), 14.54 (s, 1 H, OH).

^{13}C NMR (62.9 MHz, aceton-d_6): δ = 118.2 (C-6), 122.7 (C-3'), 126.4 (C-4'), 126.8 (C-8'), 127.0 (C-1), 127.5 (C-6'), 128.8 (C-5), 128.8 (C-5'), 129.5 (C-3), 129.6 (C-10'), 130.6 (C-4), 132.9 (C-7'), 134.7 (C-2'), 137.9 (C-9'), 143.2 (C-2), 169.5 (C-1').

EI-MS: *m/z* = 545 $[M]^+$, 262.1 $[M - C_4F_9O_2S]^+$.

HRMS calcd for $C_{20}H_{12}F_9N_30_3S$: M = 545.04551. Found: *m/z* 545. 05190.

Nonafluoro-*N*-{2-[(*E*)-2-(2-hydroxy-1-naphthyl)diazenyl]phenyl}-1-butane-sulfonamide (20a)

Synthesised from 2-naphthol (**7j**). Reaction time: 2 h. This product was recrystallyzed from petroleum ether/toluene (5:1) without previous chromatography. Red solid; yield: 1.28 g (94%); mp 174.0–174.7 °C (petroleum ether/toluene).

IR (KBr): ν = 3417 (NH, OH), 1354, 1192 (SO_2), 1297, 1235,1142 cm^{-1} (CF).

UV/Vis (CH_3CN): λ (ε $mol^{-1}dm^3cm^{-1}$) = 212 (22600), 226 (21400), 235 (14600), 250 (8200), 277 (11100), 321 (3700), 518 nm (19000).

^1H NMR (600 MHz, acetone-d_6): δ = 6.94 (d, 1 H, $J_{3'-4'}$ = 9.3 Hz, H-3'), 7.44–7,51 (m, 2 H, H-5, H-6'), 7.59–7.66 (m, 3 H, H-3, H-4, H-7'), 7.77 (d, 1 H, $J_{5'-6'}$ = 7.8 Hz, H-5'),

7.95 (d, 1 H, $J_{4'-3'}$ = 9.3 Hz, H-4'), 8.18 (dd, 1 H, J_{6-4} = 1.1, J_{6-5} = 8.2 Hz, H-6), 8.63 (d, 1 H, $J_{8'-7'}$ = 8.2 Hz, H-8'), 10.78 (s, 1 H, NH), 15.58 (s, 1 H, OH).

^{13}C NMR (151 MHz, aceton-d_6): δ = 118.7 (C-6), 122.6 (C-8'), 124.2 (C-3'), 126.9 (C-6'), 127.1 (C-1), 129.1 (C-5), 129.4 (C-9'), 129.7 (C-5'), 129.9 (C-7'), 129.9 (C-4), 130.9 (C-3), 131.4 (C-10'), 134.1 (C-1'), 140.9 (C-4'), 144.4 (C-2), 168.1 (C-2').

EI-MS: *m/z* = 545 $[M]^+$, 262.1 $[M - C_4F_9O_2S]^+$.

Anal. calcd for $C_{20}H_{12}F_9N_3O_3S$: C, 44.0; H, 2.22; N, 7.70; S, 5.88. Found: C, 43.86; H, 2.19; N, 7.60; S, 5.89.

Trifluoro-*N*-{2-[(*E*)-2-(2-hydroxy-1-naphthyl)diazenyl]phenyl}-1-methanesulfonamide (20b)

Synthesised from 2-naphthol (**7j**) and 1-trifluoromethanesulfonyl-1*H*-benzotriazole (**6b**;[130] 0.63 g, 2.5 mmol). Reaction time: 2 h. This product was recrystallised from toluene and not chromatographied. Red solid; yield: 0.95 g (90%); mp 209.4–210.1 °C (toluene).

IR (KBr): ν = 3422 (NH, OH), 1373, 1207 (SO_2), 1294, 1233, 1151 cm^{-1} (CF).

UV/Vis (CH_3CN): λ (ε $mol^{-1}dm^3cm^{-1}$) = 227 (31700), 312 (6600), 486 nm (13100).

^{1}H NMR (250 MHz, DMSO-d_6): δ = 6.88 (d, 1 H, $J_{3'-4'}$ = 9.6, H-3'), 7.27–7.49 (m, 4 H, H-3, H-4, H-5, H-6'), 7.53–7.62 (m, 1 H, H-7'), 7.74 (d, 1 H, $J_{4'-3'}$ = 7.6 Hz, H-5'), 7.93 (d, 1 H, $J_{5'-6'}$ = 9.6 Hz, H-4'), 8.05 (d, 1 H, J_{6-5} = 7.4 Hz, H-6), 8.5 (d, 1 H, $J_{8'-7'}$ = 8.1 Hz, H-8'), 12.39 (s, 1.5 H, NH, OH).

^{13}C NMR (62.9 MHz, DMSO-d_6): δ = 171.2 (C-2'), 141.5 (C-2), 141.2 (C-4'), 133.2 (C-1'), 130.4 (C-10'), 129.7 (C-7'), 129.4 (C-5'), 129.3 (C-3), 128.6 (C-4), 128.4 (C-1), 128.4 (C-7'), 128.2 (C-5), 126.6 (C-6'), 124.88 (C-3'), 121.92 (C-8') 117.2 (C-6).

EI-MS: *m/z* = 395.1 $[M]^+$, 262.1 $[M - CF_3O_2S]^+$.

Anal. calcd for $C_{17}H_{12}F_3N_3O_3S$: C, 51.64; H, 3.06; N, 10.64; S, 8.11. Found: C, 51.35; H, 3.07; N, 10.47; S, 8.10.

4.2.3 Related to Chapter 2.2.5

9,10,16,17,23,24-[Hexakis-3,5-bis(*tert*-butylphenoxy)]-2,3-[*d*]{1-[(trifluoro-methane)sulfonyl]-1*H*-1,2,3-triazole}phthalocyaninato zinc (6e)

Method 1

To a stirred solution of (**5b**;[188] 100 mg, 54 µmol) in anhydrous CH_2Cl_2 (3 ml) was added pyridine (20 µL, 240 µmol). The reaction mixture was cooled to 0 °C. After 15 minutes, trifluoromethanesulfonic anhydride (20 µL, 240 µmol) was added dropwise. The reaction mixture was stirred at room temperature for ca. 2 h, while the progress of the reaction was monitored by TLC. After removal of the solvent, the crude product was purified by chromatography on silica gel under protection from light [eluent: $CHCl_3$] to give **6e**; green solid; yield: 102 mg (88%). Product·2Py = 2135.07 g/mol.

Method 2

To a stirred solution of (**5b**;[188] 50 mg, 27 µmol) in anhydrous CH_2Cl_2 (2 mL) was added K_2CO_3 (41 mg, 30 µmol). The reaction mixture was cooled to 0 °C. After 15 minutes, trifluoromethanesulfonic anhydride (20 µL, 240 µmol) was added dropwise. The reaction mixture was stirred at room temperature for ca. 2 h, while the progress of the reaction was monitored by TLC. After removal of the solvent, the crude product was purified by chromatography on silica gel under protection from light [eluent: $CHCl_3$] to give **6e**; green solid; yield: 50 mg (93%).

IR (KBr): 539 vw, 580 w, 617 m, 691 vw, 707m, 720 w, 748 m, 807 vw, 824 vw, 842vw, 878 m, 902 m, 961 s, 1003 w, 1035 m, 1049 w, 1088 s, 1120 m, 1134 m, 1200 s, 1229 m, 1244 m, 1269 s, 1297 vs, 1317 m, 1364 m, 1402 vs, 1422 vs, 1440 s, 1586 vs, 1608 m, 2360 vw, 2869 m, 2906 m, 2964 vs, 3072 cm^{-1} w.

UV/Vis (CH_2Cl_2): ($c = 4.77 \cdot 10^{-6}$) λ [log (ε $mol^{-1}dm^3cm^{-1}$)] = 291 (4.68), 352 (4.88), 620 (4.57), 683 (5.23), 697 nm (5.23).

^1H NMR (250 MHz, THF-d_8): δ = 1.36 s, 1.37 s (72 H, H-10), 1.41 (s, 18 H, H-10''), 1.44 (s, 18 H, H-10'), 7.18–7.31 (m, 16 H, H-6, H-6', H-6'', H-8),

7.39 (t, 1 H, $J_{8''\text{-}6''}$ = 1.8 Hz, H-8''), 7.44 (t, 1 H, $J_{8'\text{-}6'}$ = 1.8 Hz, H-8'), 9.00 s, 9.02 s, 9.03 s (6 H, H-3), 9.43 (s, 1 H, H-γ'), 9.86 (s, 1 H, H-γ).

^{13}C NMR (62.9 MHz, THF-d_8): δ = 31.9 [C-10], 35.7, 35.8, [C-9], 104.9 (C-γ'), 113.1, 113.2, 113.4,113.9, 114.4 [C-6] 114.1, 114.25, 115.28, 115.3, 115.5 [C-3], 115.8 (C-γ), 117.7, 117.8, 117.9, 118.3, 118.6 [C-8], 123.2 (C-δ'), 124.6 (C-py), 133.1 (C-β'), 134.9, 135.2, 135.6, 135.75, 135.76, 135.8 [C-2], 137.6 (C-py), 138.0 (C-β), 141.4 (C-α'), 147.4 (C-α), 147.6 (C-Py), 150.5 (C-δ), 150.3, 150.9, 151.4, 151.5, 152.0, 152.3 [C-4] 153.29, 153.30, 153.33, 153.35, 153.5, 153.7 [C-7], 153.2, 153.7, 154.6, 154.7, 154.8, 155.0 [C-1], 157.5, 158.1, 158.5, 158.6, 158.7 [C-5].

MS MALDI-TOF: *m*/*z* = 2136 [M + 2Py + H]$^+$, 1970 [M + 2Py – N_2 + H]$^+$, 1879 [M + 2Py – N_2 – CF_3 + H]$^+$,1843 [M + 2Py – SO_2CF_3 + H]$^+$.

Anal. calcd for $C_{117}H_{134}F_3N_{11}O_8SZn$: C, 71.09; H, 6.83; N, 7.79; S, 1.62. Found: C, 70.88; H, 6.77; N, 7.47; S, 0.00.

9,10,16,17,23,24-[Hexakis-3,5-bis(*tert*-butylphenoxy)]-2-(trifluormethane-sulfonamide)-3-(2 hydroxynaphthalin-1-ylazo)phthalocyaninato zinc (20c)

NaH (3 mg, 75 µmol, 60 % suspension in oil) was added to a stirred solution of 2–Naphthol (**7j**; 11 mg, 75 µmol) in anhydrous toluene (3 mL) at room temperature. After 15 minutes compound **6e** was added and the mixture was stirred for 10 minutes while controlling the progress of the reaction by TLC. At the end of this period AcOH (0.5 mL) was added. The organic phase was evaporated, and the crude product was purified by chromatography over silica gel [eluent: $CHCl_3$ containing 1% AcOH] to afford **20c**; green solid; yield: 46 mg (86 %).

IR (KBr): 459 vw, 507 vw, 597 w, 706 m, 719 w, 748 m, 866 m, 902 m, 961 s, 1002 vw, 1037 s, 1087 s, 1119 m, 1139 m, 1198 vs, 1226 m, 1247 m, 1269 s, 2361 vw, 1297 vs, 1364 m, 1402 vs, 1422 vs, 1450 vs, 1479 vs, 1586 s, 1608 s, 2868 m, 2906 m, 2963 vs, 3071 cm^{-1} vw.

UV/Vis (THF): (c = 2.70·10^{-6}) λ [log (ε mol^{-1}dm^{3}cm^{-1})] = 287 (4.72), 356 (4.94), 569 (4.44), 628 (4.67), 691 (5.27), 711 nm (5.13).

UV/Vis (CH_2Cl_2): (c = 5.82·10^{-6}) λ [log (ε mol^{-1}dm^{3}cm^{-1})] = 290 (4.59), 352 (4.77), 520 (4.16), 565 (4.09), 689 (4.89), 728 nm (4.78).

^{1}H NMR (250 MHz, THF-d_8): δ = 1.34 s,1.35 s, 1.36 s, 1.40 s (90 H, H 10), 1.45 (s, 18 H, H-10'), 6.77 (d, 1 H, $J_{c\text{-}d}$ = 9.6 Hz, H-c), 7.17–7.30 (m, 17 H, H-6, H-6', H-8), 7.46 (t, 1 H, $J_{8'\text{-}6'}$ = 1.8 Hz, H-8'), 7.53 (dd, 1 H, $J_{f\text{-}g}$ = 6.9, $J_{f\text{-}e}$ = 7.7 Hz, H-f), 7.67 (dd, 1 H, $J_{g\text{-}f}$ = 6.9, $J_{g\text{-}h}$= 7.7 Hz, H-g), 7.73 (d, 1 H, $J_{e\text{-}f}$ = 7.7 Hz, H-e), 7.96 (d, 1 H, J = 9.55 Hz, H-d), 8.94 (d, 1 H, $J_{h\text{-}g}$ = 7.7 Hz, H-h), 9.10 (s, 5 H, H-3), 9.31 (s, 1 H, H-3'), 9.48 (s, 1 H, H-γ'), 9.92 (s, 1 H, H-γ), 16.98 (s, 1.4 H, OH, NH).

^{1}H NMR (250 MHz, THF-d_8 + Et_3N): δ = 1.34 s, 1.35 s, 1.36 s, 1.37 s (90 H, H 10), 1.45 (s, 18 H, H-10'), 7.05 (d, 1 H, $J_{c\text{-}d}$ = 9.6 Hz, H-c,), 7.17–7.30 (m, 17 H, H-6, H-6', H-8), 7.35 (t, 1 H, $J_{8'\text{-}6'}$ = 1.2 Hz, H-8'), 7.44 (dd, 1 H, $J_{h\text{-}g}$ = 7.8 Hz, $J_{h\text{-}f}$ = 7.2 Hz, H-f), 7.61 (m, 1 H, H-d, H-g), 7.79 (d, 1 H, $J_{e\text{-}f}$ = 9.6 Hz, H-e), 8.87 (d, 1 H, $J_{h\text{-}g}$ = 7.8 Hz, H-h), 9.08s, 9.11s, 9.14s (5 H, H-3), 9.34 (s, 1 H, H-3'), 9.57 (s, 1 H, H-γ'), 9.87 (s, 1 H, H-γ), 16.98 (s, 1 H, NH).

^{13}C NMR (62.9 MHz, THF-d_8 + Et_3N): δ = 31.7, 31.9, 31.9 [C-10], 35.73, 35.78, [C-9], 109.7 (C-γ), 113.05, 113.08, 113.1, 113.2, 113.5 [C-6], 114.1,114.2, 114.7, 114.9, 115.0 [C-3], 115.4 (C-3'), 117.4, 117.6, 117.7 [C-8], 118.1 (C-γ', C-8), 123.1 (C-h), 123.2 (q, CF_3 , J = *327* Hz), 127.7 (C-c), 129.1 (C-i), 129.6 (C-d), 130.2 (C-g), 131.8 (C-j), 134.1 (C-β'), 135.2 (C-a), 135.8, 135.83, 135.85, 135.9, 136.2, [C-4], 138.2 (C-β),139.4 (C-δ'), 141.3 (C-δ), 141.6 (C-e), 150.5, 150.6, 150.9, 151.0, 151.1, 151.27 [C-4], 153.3, 153.4, [C-7], 153.50, 153.55, 154.3, 154.4 [C 1], 156.0 (C-α'), 156.2 (C-α), 158.2, 158.5, 158.61, 158.67, 158,72, 158.74 [C-5], 178.7 (C-b).

MS-MALDI-TOF: m/z = 2121 [M]$^+$, 1964 [M – $C_{10}H_7N_2O$]$^+$.

Anal. calcd for $C_{127}H_{142}F_3N_{11}O_9SZn^{2+}$: C, 71.92; H, 6.75; N, 7.26; S 0.00. Found: C, 72.17; H, 6.81; N, 6.97; S, 0.03.

4.2.4 Related to Chapter 2.2.6

Preparation of Phosphonium Salts

The phosphonium salts (**21'**) were prepared according to the literature,[200,201] heating a toluene solution of Ph_3P and the corresponding equivalent amounts of benzyl halides (**21**) overnight at reflux. The precipitated phosphonium salts were collected by filtration washed repeatedly with Et_2O and used subsequently without further purification.

General Method for the Synthesis of Triphenylphosphoranylidenes

NaH (0.12 g, 60% suspension in oil) was added to a stirred solution of phosphonium salt (2.3 mmol) in anhydrous THF (10 ml) at room temperature under argon. The mixture was stirred for 4 h. At the end of this period, 1-nonafluorobutanesulfonyl-1*H*-benzotriazole (**6a**; 1.00 g, 2.5 mmol) was added and stirred for 30 minutes. EtOAc (50 ml) and H_2O (50 ml) were added and the aqueous phase was extracted with EtOAc (2 × 25 ml). The organic phase was dried (Na_2SO_4), filtered, and the solvent was evaporated. The crude product was purified by chromatography over silica gel (eluent: EtOAc).

{[2-(2-{[Nonafluorobutanesulfonyl]amino}phenyl)diazenyl](phenyl)methyl}-(triphenyl)phosphonium chloride (22a)

Synthesised from benzyl chloride (**21a**) according to literature procedure;[200] The product was dissolved in EtOAc (10 ml) and HCl gas was introduced. The solvent was evaporated to give **22a**; white solid; yield: 1.64 g (90%); mp 213.4−214.7 °C (dec.; EtOAc).

IR (KBr): ν = 3437 (NH), 1349, 1192 (SO_2), 1439 (CP), 1266, 1033 cm^{-1} (CF).

UV/Vis (CH_3CN): λ (ε $mol^{-1}dm^3cm^{-1}$) = 328 nm (8540).

^1H NMR (250 MHz, $CDCl_3$): δ = 6.86−6.97 (m, 2 H, H-4, H-6), 7.00−7.07 (m, 1 H, H-5), 7.12−7.16 (m, 2 H, H-3', H-5'), 7.29 (dd, 1 H, J_{3-4} = 1.5, J_{3-5} = 7.6 Hz, H-3),

7.33−7.42 (m, 3 H, H-2', H-4', H-6'), 7.47−7.65 (m, 12 H, H-2'', H-3'', H-5'', H-6''), 7.76−7.84 (m, 3 H, H-4''), 10.72 (s, 1 H, NH).

^{13}C NMR (62.9 MHz, $CDCl_3$): δ = 116.5 (C-6), 118.7 (d, $J_{1''\text{-P}}$ = 89.6 Hz, C-1''), 122.9 (C-1), 124.0 (C-4), 125.7 (d, $J_{\text{CP-P}}$ = 130 Hz, C-CP), 127.4 (d, $J_{1'\text{-P}}$ = 20.3 Hz, C-1'), 128.3 (C-5), 129.9 (C-4'), 130.1 (C-3', C-5'), 130.1 (d, $J_{2''\text{-P/6''-P}}$ = 12.2 Hz, C-2'', C-6''), 130.2 (C-3), 131.4 (d, $J_{2'\text{-P/6'-P}}$ = 1.74 Hz, C-2', C-6'), 134.4 (d, $J_{3''\text{-P/5''-P}}$ = 9.6 Hz, C-3'', C-5''), 135.1 (d, $J_{4''\text{-P}}$ = 3.5 Hz, C-4''), 138.5 (C-2).

FAB-MS: *m/z* = 754.14 $[M + H]^+$.

FAB(–)-MS: *m/z* = 752 $[M - H]^-$, 788 $[M + Cl]^-$.

Anal. calcd for $C_{35}H_{26}ClF_9N_3O_2PS$: C, 53.21; H, 3.32; N, 5.32; S, 4.06. Found: C, 53.10; H 3.29; N, 5.45; S, 3.98.

Nonafluorobutane-*N*-{2-[2-[(3-chlorophenyl)(triphenylphosphoranylidene)-methyl]diazenyl]phenyl}-1-sulfonamide (22b)

Synthesised from 3-chlorobenzyl bromide (**21b**) according to literature procedure;[200] yellow solid; yield: 1.23 g (68%); mp 199.2−200.3 °C (dec.; EtOAc).

IR (KBr): ν = 3425 (NH), 1350, 1192 (SO_2), 1439 (CP), 1265, 1130, 1030 cm^{-1} (CF).

UV/Vis (CH_3CN): λ (ε $mol^{-1}dm^3cm^{-1}$) = 379 nm (5410).

^{1}H NMR (250 MHz, $CDCl_3$): δ = 6.63−6.68 (m, 1 H, H-5), 6.75−6.89 (m, 3 H, H-4, H-6, H-2'), 7.09−7.11 (m, 1 H, H-6'), 7.35−7.37 (m, 2 H, H-4', H-5'), 7.48−7.67 (m, 13 H, H-3, H-1'', H-2'', H-3'', H-4''), 7.78−7.84 (m, 3H, H-4''), 10.6 (s, 1 H, NH).

^{13}C NMR (62.9 MHz, $CDCl_3$): δ = 112.4 (C-6), 117.5 (d, $J_{\text{CP-P}}$ = 137 Hz, C-CP), 119.1 (d, $J_{1''\text{-P}}$ = 90.5 Hz, C-1''), 120.5 (C 5), 123.7 (C-3), 124.6 (C-4), 127.9 (d, $J_{6'\text{-P}}$ = 4.2 Hz, C-6'), 129.3 (d, $J_{1''\text{-P}}$ = 21.7 Hz, C-1'), 129.6 (d, $J_{2'\text{-P}}$ = 2.8 Hz, C-2'), 130.1 (d, $J_{2''\text{-P/6''-P}}$ = 12.9 Hz, C-2'', C-6''), 131.2 (d, $J_{5'\text{-P}}$ = 1.4 Hz, C-5'), 131.8 (C-4'), 133.8 (C-1), 134.25 (d, $J_{3''\text{-P/5''-P}}$ = 10.2 Hz, C-3'', C-5''), 135.1 (d, $J_{4''\text{-P/}}$ = 3.2 Hz, C-4''), 136.0 (C-3'), 136.2 (d, $J_{2'\text{-P}}$ = 1 Hz, C-2).

FAB-MS: *m/z* = 788.0 $[M + H]^+$.

Anal. calcd for $C_{35}H_{24}ClF_9N_3O_2PS$: C, 53.34; H, 3.07; N, 5.33; S, 4.07. Found: C, 53.57; H, 3.19; N, 5.29 S, 3.87.

Nonafluorobutane-*N*-{2-[2-((4-chlorophenyl)(triphenylphosphoranylidene)-methyl)diazenyl]phenyl}-1-sulfonamide (22c)

Synthesised from 4-chlorobebzyl (**21c**) chloride according to literature procedure;[200] yellow solid; yield: 1.25 g (69%); mp 200.3−203.5 °C (dec.; EtOAc).

IR (KBr): ν = 3442 (NH), 1350, 1190 (SO_2), 1439 (CP), 1267, 1029 cm^{-1} (CF).

UV/Vis (CH_3CN): λ (ε $mol^{-1}dm^3cm^{-1}$) = 379 nm (5480).

^1H NMR (250 MHz, $CDCl_3$): δ = 6.62−6.69 (m, 1 H, H-5), 6.77−6.88 (m, 2 H, H-4, H-6), 6.95 (d, 2 H, $J_{2'\text{-}3'/6'\text{-}5'}$ = 8.3 Hz, H-2', H-6'), 7.30 (d, 2 H, $J_{3'\text{-}2'/5'\text{-}6'}$ = 8.3 Hz, H-3', H-5'), 7.45−7.66 (m, 13 H, H-3, H-2'', H-3'', H-4'', H-6''), 7.77−7.84 (m, 3 H, H-4''), 10.49 (s, 1 H, NH).

^{13}C NMR (62.9 MHz, $CDCl_3$): δ = 112.5 (C-6), 118.1 (d, $J_{CP\text{-}P}$ = 137 Hz, C-CP), 119.2 (d, $J_{1''\text{-}P}$ = 89.8 Hz, C-1''), 120.6 (C-5), 123.9 (C-3), 124.4 (C-4), 126.0 (d, $J_{1'\text{-}P}$ = 21.7 Hz, C-1'), 130.1 (d, $J_{2''\text{-}P/6''\text{-}P}$ = 12.9 Hz, C-2'', C-6''), 130.7 (C-3', C-5'), 130.9 (d, $J_{2'\text{-}P/6'\text{-}P}$ = 3.7 Hz, C-2', C-6',), 133.9 (C-1), 134.3 (d, $J_{3''\text{-}P/5''\text{-}P}$ = 10.2 Hz, C-3'', C-5''), 135.1 (d, $J_{4''\text{-}P}$ = 2.8 Hz, C-4''), 135.8 (C-4'), 137.3 (d, $J_{2'\text{-}P/}$ = 1.9 Hz, C-2').

FAB-MS: *m/z* = 788.0 $[M + H]^+$.

Anal. calcd for $C_{35}H_{24}ClF_9N_3O_2PS$: C, 53.34; H, 3.07; N, 5.33; S, 4.07. Found: C, 53.20; H, 3.07; N, 5.16; S, 3.93.

{(4-Nitrophenyl)[2-(2-{[nonafluorobutanesulfonyl]amino}phenyl)diazenyl]-methyl}(triphenyl)phosphonium chloride (22d)

Synthesised from 4-nitrobenzyl chloride (**21d**) according to literature procedure;[200] The product was dissolved in EtOAc (10 ml) and HCl gas was introduced. The solvent was evaporated to give **22d**; orange solid; yield: 1.21 g (63%); mp 205.9−207.6 °C (dec.; EtOAc).

IR (KBr): ν = 3425 (NH), 1192 (SO_2), 1439 (CP), 1348 (NO_2), 1268, 1131, 1032 cm^{-1} (CF).

UV/Vis (CH_3CN): λ (ε $mol^{-1}dm^3cm^{-1}$) = 317 nm (16100).

^1H NMR (250 MHz, $CDCl_3$): δ = 6.64−6.71 (m, 1 H, H-5), 6.80−6.87 (m, 2 H, H-4, H-6), 7.20−7.24 (m, 2 H, H-2', H-6'), 7.38−7.42 (m, 1 H, H-3), 7.51−7.68 (m, 12 H,

H-2'', H-3'', H-5'', H-6''), 7.77−7.85 (m, 3 H, H-4''), 8.09−8.12 (m, 2 H, H-3', H-5'), 10.62 (s, 1 H, NH).

^{13}C NMR (62.9 MHz, $CDCl_3$): δ = 112.7 (C-6), 116.9 (d, J_{CP-P} = 137.6 Hz, C-CP), 118.8 (d, $J_{1''-P}$ = 90.5 Hz, C-1''), 120.9 (C-5), 123.9 (C-3), 124.9 (C-4), 125.3 (C-3', C-5'), 130.3 (d, $J_{2''-P/6''-P}$ = 12.9 Hz, C-2'', C-6''), 130.9 (d, $J_{2'-P/6'-P}$ = 3.2 Hz, C-2', C-6'), 133.7 (C-1), 134.3 (d, $J_{3''-P/5''-P}$ = 9.7 Hz, C-3'', C-5''), 134.4 (d, $J_{1'-P}$ = 21.7 Hz, C-1'), 135.3 (d, $J_{4''-P}$ = 3.23 Hz, C-4''), 135.9 (C-2).

FAB-MS: *m/z* = 799.1 $[M + H]^+$.

Anal. calcd for $C_{35}H_{25}F_9N_4OP_4S$: C, 50.34; H, 3.02; N, 6.71; S, 3.84. Found: C, 50.44; H, 3.00; N, 6.78; S, 3.52.

Nonafluorobutane-*N*-{2-[2-((4-methoxyphenyl)(triphenylphosphoranylidene)-methyl)diazenyl]phenyl}-1-sulfonamide (22e)

Synthesised from 4-methoxybenzyl chloride (**21e**) according to literature procedure;[201] yellow solid; yield: 1.48 g (82%); mp 208.2−209.0 °C (dec.; EtOAc).

IR (KBr): ν = 3445 (NH), 1192 (SO_2), 1440 (CP), 2843 (OMe), 1264, 1133, 1033 cm^{-1} (CF).

UV/Vis (CH_3CN): λ (ε $mol^{-1}dm^3cm^{-1}$) = 374 nm (7690).

^{1}H NMR (250 MHz, $CDCl_3$): δ = 3.74 (s, 3 H, H-CH_3), 6.61−6.68 (m, 1 H, H-5), 6.77−6.94 (m, 6 H, H-4, H-6, H-2', H-3', H-5', H-6'), 7.45−7.64 (m, 13 H, H-3, H-2'', H-3'', H-5'', H-6''), 7.74−7.82 (m, 3 H, H-4''), 12.45 (s, 1 H, NH).

^{13}C NMR (62.9 MHz, $CDCl_3$): δ = 55.3 (C-CH_3), 112.4 (C-6), 115.9 (C-3', C-5'), 119.2 (d, $J_{1'-P}$ = 21.7 Hz, C-1'), 119.5 (d, $J_{1''-P}$ = 89.6 Hz, C-1''), 119.9 (d, J_{CP-P} = 134 Hz, C-CP), 123.8 (C-3), 123.9 (C-4), 130.0 (d, $J_{2''-P/6''-P}$ = 12.5 Hz, C-2'', C-6''), 131.1 (d, *J* = 3.7 Hz, C-2', C-6'), 134.3 (d, $J_{3''-P/5''-P}$ = 9.7 Hz, C-3'', C-5''), 134.3 (C-1), 134.9 (d, $J_{4''-P}$ = 2.8 Hz, C-4''), 135.3 (C-2), 161.4 (C-4').

FAB-MS: *m/z* = 784.0 $[M + H]^+$.

Anal. calcd for $C_{36}H_{27}FN_3O_3PS$: C, 5.18; H, 3.47; N, 5.36; S, 4.09. Found: C, 54.23; H, 3.50; N, 5.42; S, 3.93.

Ethyl 2-{(*E*)-2-[2-({nonafluorobutanesulfonyl}amino)phenyl]diazenyl}-2-(triphenylphosphoranylidene)acetate (24a)

Synthesised from (carbethoxymethyl)triphenylphosphonium bromide (**23a**; 0.99 g, 2.3 mmol); yellow solid; yield: 1.46 g (83%); mp 193.5−196.5 °C (dec.; EtOAc).

IR (KBr): ν = 3442 (NH), 1349, 1191 (SO_2), 1688 (CO), 1440 (CP), 1264, 1130, 1029 cm^{-1} (CF).

UV/Vis (CH_3CN): λ (ε $mol^{-1}dm^3cm^{-1}$) = 410 nm (13400).

^1H NMR(250 MHz, $CDCl_3$): δ = 1.09 (t, 3 H, $J_{1''\text{-}2''}$ = 7.1 Hz, H-CH_3), 4.29 (q, 2 H, $J_{2''\text{-}1''}$ = 7.1 Hz, H-CH_2) 6.55−6.58 (m, 2 H, H-3, H-4), 6.92−6.99 (m, 1 H, H-5), 6.55−6.58 (m, 2 H, H-3, H-4), 7.58−7.70 (m, 13 H, H-6, H-2', H-3', H-5', H-6'), 7.76−7.84 (m, 3 H, H-4'), 13.89 (s, 1H, NH).

^{13}C NMR(62.9 MHz, $CDCl_3$): δ = 13.9 (C2''-CH_3), 62.9 (C1''-CH_2), 104.5 (d, $J_{CP\text{-}P}$ = 145 Hz, C-CP), 113.4 (C-3), 119.7 (d, $J_{1'\text{-}P}$ = 93.26, C-1'), 120.0 (C-4), 122.7 (C-6), 127.5 (C-5), 129.8 (d, $J_{2'\text{-}P/6'\text{-}P}$ = 12.9 Hz, C-2', C-6'), 133.0 (C-2), 134.1 (d, $J_{3'\text{-}P/5'\text{-}P}$ = 10.2 Hz, C-3', C-5'), 134.6 (d, $J_{4'\text{-}P}$ = 2.8 Hz, C-4'), 138.7 (C-1), 161.6 (d, $J_{CO\text{-}P}$ = 27.2 Hz, C-CO).

FAB-MS: *m/z* = 749.9 $[M + H]^+$.

Anal. calcd for $C_{32}N_{25}F_9N_3O_4PS$: C, 51.27; H, 3.36; N, 5.61; S, 4.28. Found: C, 51.27; H, 3.55; N, 5.62; S, 4.13.

Nonafluoro-*N*-{2-[2-({2-[2-({nonafluorobutanesulfonyl}amino)phenyl]diazenyl}-(triphenylphosphoranylidene)methyl)diazenyl]phenyl}-1-butanesulfonamide (24b)

BuLi in *n*-hexane (0.50 ml, 1.35 mmol) was added to a stirred solution of methyltriphenylphosphonium bromide (**23b**; 0.45 g, 1.26 mmol) in anhydrous THF (10 ml) at room temperature under argon. The mixture was stirred for 4 h. At the end of this period, 1-nonafluorobutanesulfonyl-1*H*-benzotriazole (**6a**; 1.00 g, 2.5 mmol) was added and stirred for 30 minutes EtOAc (50 ml) and H_2O (50 ml) were added and the aqueous phase was extracted with EtOAc (2 × 25 ml). The organic phase was dried (Na_2SO_4), filtered, and the solvent was evaporated. The crude product

was purified by chromatography over silica gel [eluent: petroleum ether/EtOAc (1:3)]; brown solid; yield: 0.58 g (44%); mp 189.7−192.5 °C (petroleum ether/EtOAc).

IR (KBr): ν = 3442 (NH, OH), 1350, 1191 (SO_2), 1440 (CP), 1134, 1035 cm^{-1} (CF).

UV/Vis (CH_3CN): λ (ε $mol^{-1}dm^3cm^{-1}$) = 534 nm (12800).

^1H NMR (250 MHz, $CDCl_3$): δ = 6.89−6.95 (m, 2 H, H-4, H-4'), 7.02−7.06 (m, 2 H, H-3, H-3'), 7.09−7.16 (m, 2 H, H-5, H-5'), 7.45−7.48 (m, 2H, H-6, H-6'), 7.59−7.67 (m, 12 H, H-2'', H-3'', H-5'', H-6''), 7.71−7.81 (m, 3 H, H-4''), 16.5 (s, 2H, NH).

^{13}C NMR (62.9 MHz, $CDCl_3$): δ = 115.8 (C-3, C-3'), 119.1 (d, $J_{1''\text{-P}}$ = 92.3 Hz, C-1''), 125.1 (C-4, C-4'), 126.6 (C-6, C-6'), 128.0 (d, $J_{\text{CP-P}}$ = 174 Hz, C-CP), 130.0 (d, $J_{2''\text{-P/6''-P}}$ = 12.9 Hz, C-2'', C-6''), 130.5 (C-5, C-5'), 134.2 (d, $J_{3''\text{-P/5''-P}}$ = 10.2 Hz, C-3'', C-5''), 134.9 (C-2, C-2'), 135.1 (d, $J_{4''\text{-P}}$ = 3.2 Hz, C-4''), 140.8 (C-1, C-1').

FAB-MS: *m/z* = 1078.9 $[M + H]^+$.

Anal. calcd for $C_{39}H_{25}F_{18}N_6O_4PS_2$: C, 43.42; H, 2.34; N, 7.79; S, 5.95. Found: C, 44.09; H, 2.46; N, 7.85; S, 5.47.

4.2.5 Related to Chapter 2.2.7

Reactions with 1-(Toluene-4-sulfonyl)-1*H*-1,2,3-benzotriazole (6c)

Method 1

NaH (80 mg, 2 mmol, 60% suspension in oil) was added to a stirred solution of 2,3,4,6-tetra-*O*-benzyl-α-D-glucopyranose (**1**;[116] 1 g, 1.9 mmol), and 1-(toluene-4-sulfonyl)-1*H*-1,2,3-benzotriazole (**6c**;[138] 0.57 g, 2 mmol) in dry THF (10 ml) at room temperature under argon. The mixture was stirred 6 hours. At the end of this period, the mixture was poured into brine (100 ml) and Et_2O (20 ml). The aqueous layer was extracted with Et_2O (3 × 20 ml). The organic layer was washed with H_2O (3 × 20 ml). After drying (Na_2SO_4), filtration and removal of the solvent, the crude product was purified by chromatography on silica gel [eluent: toluene/acetone, 30:1]; yield: 41 mg **26**α + 419 **26**β + 215 mg **25**α [55%; **25**α:**26**α:**26**β:, (5:1:10)].

Method 2

2,3,4,6-Tetra-*O*-benzyl-α-D-glucopyranose (**1;**[116]1 g, 1.9 mmol) in dry THF (10 ml) was added dropwise to a stirred solution of NaH (80 mg, 2 mmol, 60% suspension in oil) and 1-(toluene-4-sulfonyl)-1*H*-1,2,3-benzotriazole (**6c**;[138] 0.57 g, 2 mmol) in dry THF (10 ml) at room temperature under argon. The mixture was stirred 6 hours. At the end of this period, the mixture was poured into brine (100 ml) and Et_2O (20 ml). The aqueous layer was extracted with Et_2O (3 × 20 ml). The organic layer was washed with H_2O (3 × 20 ml). After drying (Na_2SO_4), filtration and removal of the solvent, the crude product was purified by chromatography on silica gel [eluent: toluene/acetone, 30:1]; yield: 420 mg **25**β + 410 **26**β + 39 mg **25**α [74%; **25**α:**25**β:**26**β, (1:10:10)].

Reaction with 1-trifluoromethanesulfonyl-1*H*-1,2,3-benzotriazole (6b)

Synthesised from 1-trifluoromethanesulfonyl-1*H*-benzotriazole (**6b**;[130] 0.50 g, 2 mmol) as in method 2; yield: 90 mg **26**α + 350 mg **26**β+ 350 mg **25**α [66%; **25**α:**26**α:**26**β, (3:1:3)].

Reaction with 1-nonafluorobutanesulfonyl-1*H*-1,2,3-benzotriazole (6a)

Synthesised from 1-nonafluorobutanesulfonyl-1*H*-benzotriazole (**6a**; 0.80 g, 2 mmol) as in method 1 at 70°; yield: 110 mg **26**β + 155 mg **25**β [21%; **25**β:**26**β, (3:2)]

1*H*-1,2,3-Benzotriazole-2,3,4,6-tetra-*O*-benzyl-α-D-glucopyranoside (25α)

White solid; mp 117–118 °C (*n*-heptane/EtOAc); $[\alpha]_D^{20°}$ +21.7° (c = 1, $CHCl_3$)

^{1}H NMR (250 MHz, $CDCl_3$): δ = 3.40–3.44 (dd, 1 H, $J_{6a\text{-}5}$ = 1.5, $J_{6a\text{-}6b}$ = 10.8 Hz, H-6a), 3.65–3.70 (dd, 1 H, $J_{6b\text{-}5}$ = 2.7, $J_{6b\text{-}6a}$ = 10.8 Hz, H-6b), 3.85–3.95 (m, 2 H, H-4, H-5), 4.15–4.21 (dd, 1 H, $J_{2\text{-}1}$ = 5.9, $J_{2\text{-}3}$ = 9.3 Hz, H-6), 4.36 (d, 1 H, *J* = 12 Hz, H-CH_2), 4.45–4.52 (m, 2 H, H-CH_2), 4.57 (d, 1 H, *J* = 11 Hz, H-CH_2), 4.75 (d, 1 H, *J* = 12.3 Hz, H-CH_2), 4.89–5.13 (m, 4 H, H-3, H-CH_2), 6.05 (d, 1 H, $J_{1\text{-}2}$ = 5.9 Hz, H-1), 6.97–7.01 (m, 2 H, H-2Ar), 7.10–7.40 (m, 21 H, H-4', H-5', H-6', H-2Ar, H-3Ar, H-4Ar), 8.12 (d, 1 H, $J_{7'\text{-}6'}$ = 8.4, H-7').

^{13}C NMR (62.9 MHz, $CDCl_3$): δ = 68.0 (C-6), 73.2 (C-5), 73.5, 74.3, 74.9, 75.8 [C-CH_2], 77.5 (C-4), 79.2 (C-2), 81.3 (C-1), 82.7 (C-3), 109.5 (C-4'), 120.1 (C-7'), 124.2 (C-5'), 127,60, 127.65, 127.70, 127.75, 127.9, 128.0, 128.1, 128.3, 128.4, 128.5 [C-6', C-2Ar, C-3Ar, C-4Ar], 134.0 (C-7'a), 137.6, 137.8, 138.4, 138.8 [C-1Ar], 142.2 (C-3'a).

MS-MALDI-TOF: *m*/*z* = 664.0 $[M + Na]^+$.

Anal. calcd for $C_{40}H_{39}N_3O_5$: C, 74.86; H, 6.13; N, 6.55. Found: C, 74.81; H, 6.29; N, 6.63.

1*H*-1,2,3-Benzotriazole-2,3,4,6-tetra-*O*-benzyl-β-D-glucopyranoside (25β)[213]

Colourless oil; $[\alpha]_D^{20°}$ –21.8° (c = 0.5, $CHCl_3$), (Lit.[213] $[\alpha]_D^{20°}$ –22.8°, (*c* = 1, $CHCl_3$)).

^{1}H NMR (400 MHz, $CDCl_3$): δ = 3.73–3.98 (m, 6 H, H-3, H-4, H-5, H-6, H-CH_2), 4.29–4.34 (m, 2 H, H-2, H-CH_2), 4.47 (d, 1 H, *J* = 12.1 Hz, H-CH_2), 4.54 (d, 1 H, *J* = 12.1 Hz, H-CH_2), 4.67 (d, 1 H, *J* = 10.6 Hz, H-CH_2), 4.89–4.97 (m, 2 H, H-CH_2), 5.96 (d, 1 H, $J_{1\text{-}2}$ = 9.1 Hz, H-1), 6.74 (d, 2 H, *J* = 7.3 Hz, H-2Ar), 7.01–7.07 (m, 3 H,

H-3Ar, H-4Ar), 7.21–7.44 (m, 17 H, H-5', H-6', H-2Ar, H-3Ar, H-4Ar), 7.61 (d, 1 H, *J* = 8.1 Hz, H-4'), 8.07 (d, 1 H, *J* = 7.8 Hz, H-7').

^{13}C NMR (100 MHz, $CDCl_3$): δ = 68.3 (C-6), 73.4, 74.7, 75.2, 75.8 [C-CH_2], 77.2 (C-5), 77.9 (C-4), 79.4 (C-2), 85.5 (C-3), 87.2 (C-1), 110.7 (C-4'), 120.2 (C-7'), 124.3 (C-5'), 127.56, 127.59, 127.69, 127.74, 127.91, 127.97, 127.99, 128.1, 128.3, 128.6 [C-6', C-2Ar,C-3Ar, C-4Ar], 132.3 (C-7'a), 136.6, 137.7, 137.9, 138.1 [C-1Ar], 146.3 (C-3'a).

FAB-MS: *m*/*z* = 642.1 $[M + H]^+$.

2*H*-1,2,3-Benzotriazole-2,3,4,6-tetra-*O*-benzyl-α-D-glucopyranoside (26α)[213]

Colourless oil; $[\alpha]_D^{20°}$ +92.4° (c = 0.5, $CHCl_3$), (Lit.[213] $[\alpha]_D^{20°}$ +93°, (*c* = 0.5, $CHCl_3$)).

^{1}H NMR (250 MHz, $CDCl_3$): δ = 3.52–8.58 (dd, 1 H, $J_{6a\text{-}5}$ = 1.9, $J_{6a\text{-}6b}$ = 11 Hz, H-6a), 3.72–3.78 (dd, 1 H, $J_{6b\text{-}5}$ = 2.9, $J_{6b\text{-}6a}$ = 11 Hz, H-6b), 3.87–3.95 (dd, 1 H, $J_{4\text{-}3}$ = 9.4, $J_{4\text{-}5}$ = 9.8 Hz, H-4), 4.09–4.16 (dd, 1 H, $J_{2\text{-}1}$ = 6.0, $J_{2\text{-}3}$ = 9.6 Hz, H-2), 4.41–4.66 (m, 6 H, H-5, H-CH_2), 4.90–5.07 (m, 4 H, H-3, H-CH_2), 6.58 (d, 1 H, $J_{1\text{-}2}$ = 6.0 Hz, H-1), 7.11–7.45 (m, 22 H, H-5', H-6', H-2Ar, H-3Ar, H-4Ar), 7.88–7.93 (dd, 2 H, $J_{4'\text{-}6'/7'\text{-}5'}$ = 2.9, $J_{4'\text{-}5'/7'\text{-}6'}$ = 6.6 Hz, H-4', H-7').

^{13}C NMR (62.9 MHz, $CDCl_3$): δ = 68.1 (C-6), 73.4, 73.6 [C-CH_2], 74.3 (C-5), 75.4, 75.6 [C-CH_2], 77.4 (C-4), 78.4 (C-2), 81.5 (C-3), 88.8 (C-1), 118.7 (C-4', C-7'), 126.8 (C-5', C-6'), 127.6 , 127.7, 127.82, 127.89, 127.9, 128.0, 128.1, 128.4, 128.4 [C-2Ar, C-3Ar, C-4Ar], 137.2, 137.8, 138.2, 138.8 [C-1Ar], 144.2 (C-3'a, C-7'a).

FAB-MS: *m*/*z* = 642.1 $[M + H]^+$.

2*H*-1,2,3-Benzotriazole-2,3,4,6-tetra-*O*-benzyl-β-D-glucopyranoside (26β)[213]

White solid; $[\alpha]_D^{20°}$ –33.8° (c = 0.5, $CHCl_3$), (Lit.[213] $[\alpha]_D^{20°}$ –34.6°, (*c* = 1, $CHCl_3$)).

^{1}H NMR (250 MHz, $CDCl_3$): δ = 3.74–3.95 (m, 5 H, H-3, H-4, H-5, H-6), 4.06 (d, 1 H, *J* = 10.8 Hz, H-CH_2), 4.44–4.57 (m, 4 H, H-2, H-CH_2), 4.63 (d, 1 H, *J* = 10.8, H-CH_2), 4.86–5.00 (m, 3 H, H-CH_2), 5.93 (d, 1 H, $J_{1\text{-}2}$ = 9.1 Hz, H-1), 6.73–6.77 (m, 2 H, H-2Ar), 6.97–7.09 (m, 3 H, H-3Ar, H-4Ar), 7.16–7.34 (m, 15 H, H-2Ar, H-3Ar, H-4Ar),

7.38–7.43 (dd, 2 H, $J_{5'\text{-}7'/6'\text{-}4'}$ = 2.9, $J_{5'\text{-}4'/6'\text{-}7'}$ = 6.6 Hz, H-5', H-6'), 7.87–7.91 (dd, 2 H, $J_{4'\text{-}6'/7'\text{-}5'}$ = 2.9, $J_{4'\text{-}5'/7'\text{-}6'}$ = 6.6 Hz, H-4', H-7').

^{13}C NMR (62.9 MHz, $CDCl_3$): δ = 68.6 (C-6), 73.5, 74.8, 75.2, 75.7 [C-CH_2], 77.4 (C-5), 78.3 (C-4), 80.9 (C-2), 85.7 (C-3), 92.2 (C-1), 118.7 (C-4', C-7'), 127.2 (C-5', C-6'), 127.6, 127.7, 127.9, 128.0, 128.3, 128.4 [C-2Ar, C-3Ar, C-4Ar], 137.3, 137.8, 137.9, 138.2 [C-4Ar], 144.5 (C-3'a, C-7'a).

FAB-MS: m/z = 642.1 $[M + H]^+$.

4.2.6 Related to Chapter 2.2.8

Nonafluorobutane1-sulfone acid 1*H*-1,2,3-benzotriazol-4-yl ester (28b)

A 1.6 M solution of BuLi in *n*-hexane (6.25 ml, 10 mmol) was added slowly to a stirred solution of 1-hydroxy-1*H*-1,2,3-benzotriazole (**27**; 1.35 g, 10 mmol) in anhydrous THF (50 ml) at 0 °C under argon. After 1 h, nonafluorobutanesulfonyl fluoride (2.15 ml, 12 mmol) was added dropwise. The reaction mixture was stirred under reflux for ca. 12 h, while the progress of the reaction monitored by TLC. After completion of the reaction, the mixture was cooled to room temperature, and diluted with Et_2O (100 ml). The organic layer was washed with aq sat. NH_4Cl solution (2 × 50 ml), and H_2O (1 × 50 ml). After drying (Na_2SO_4), filtration and removal of the solvent, the crude product was purified by chromatography on silica gel [eluent: petroleum ether/EtOAc, 1:1] and recrystallised from toluene to give **28b**; colourless needles; yield 1.40 g (33%); mp 202.5–203.5 °C (toluene).

IR (KBr): 521 w, 571 w, 585 w, 635 w, 652 w, 738 m, 752 m, 788 m, 806 m, 836 w, 890 m, 992 w, 1006 s, 1035 m, 1061 m, 1128 m, 1145 s, 1195 vs, 1241 s, 1295 w, 1356 m, 1406 m, 1426 vs, 1448 w, 1592 w, 1637 w, 2898 w, 2960 w, 3020 w, 3106 m, 3442 cm^{-1} w.

UV/Vis (THF): λ (ε $mol^{-1}dm^3cm^{-1}$) = 211 (10900), 254 (6800), 272 nm (5100).

^1H NMR (250 MHz, DMSO-d_6): δ = 7.51 (d, 1 H, $J_{5\text{-}6}$ = 7.9 Hz, H-5), 7.60–7.68 (dd, 1 H, $J_{6\text{-}5}$ = 7.9, $J_{6\text{-}7}$ = 8.1 Hz, H-6), 7.98 (d, 1 H, $J_{7\text{-}6}$ = 8.1 Hz, H-7), 16.35 (s, 1 H, H-1)

^{13}C NMR (62.9 MHz, DMSO-d_6): δ = 113 (bs, C-7), 115.6 (bs, C-5), 127.4 (bs, C-6).

MS-EI: *m*/*z* = 416.9 $[M]^+$, 389.0 $[M - N_2]^+$, 134.0 $[M - C_4F_9O_2S]^+$, 106.1 $[M - C_4F_9N_2O_2S]^+$.

Anal. calcd for $C_{10}H_4F_9N_3O_3S$: C, 28,79; H, 0,97; N, 10,07; S, 7,69. Found: C, 28.95; H, 0.92; N, 10.03; S, 7.70.

Trifluoromethane-1-sulfone acid 1*H*-1,2,3-benzotriazol-4-yl ester (29a)

Method 1

Pyridine (0.35 ml, 4.3 mmol) was added to a stirred solution of 1-Hydroxy-1*H*-1,2,3-benzotriazole (**27**; 0.5 g, 3.7 mmol) in anhydrous CH_2Cl_2 (20 ml) at 0 °C under argon. After 30 minutes trifluoromethanesulfonyl anhydride (**2b**; 0.93 ml, 4.3 mmol) was added dropwise. The reaction mixture was stirred at 0°C for ca. 30 minutes, while the progress of the reaction monitored by TLC. After completion of the reaction, the mixture was diluted with CH_2Cl_2 (100 ml). The organic layer was washed with H_2O (2 × 50 ml). After drying (Na_2SO_4), filtration and removal of the solvent, the crude product was purified by chromatography on silica gel [eluent: petroleum ether/EtOAc, 1:1] and recrystallised from petroleum ether/EtOAc to give **29a**; yield 0.41 g (41%).

Method 2

Na_2CO_3 (0.41 ml, 3.8 mmol) was added to a stirred solution of 1-Hydroxy-1*H*-1,2,3-benzotriazole (**27**; 0.5 g, 3.7 mmol) in anhydrous CH_2Cl_2 (20 ml) at 0 °C under argon. After 30 minutes trifluoromethanesulfonyl anhydride (**2b**; 0.93 ml, 4.3 mmol) was added dropwise. The reaction mixture was stirred at 0°C for ca. 30 minutes, while the progress of the reaction monitored by TLC. After completion of the reaction, the mixture was diluted with CH_2Cl_2 (100 ml). The organic layer was washed with H_2O (2 × 50 ml). After drying (Na_2SO_4), filtration and removal of the solvent, the crude product was purified by chromatography on silica gel [eluent: petroleum ether/EtOAc, 1:1] and recrystallised from petroleum ether/EtOAc to give **29a**; yield 0.49 g (49%).

Colourless needles; mp 200.5–201.5 °C (Dec.; petroleum ether/EtOAc).
IR (KBr): 520 vw, 561 vw, 590 w, 691 vw, 755 w, 766 , 804 w, 825 s, 883 m, 906 vw, 992 w, 1006 w, 1041 vw, 1062 w, 1140 vs, 1205 vs, 1272 w, 1311 vw, 1384 w, 1404 w, 1426 vs, 1448 w, 1592 w, 1635 w, 1360 vw, 1843 w, 2896 w, 2959 w, 3017w , 3105 m, 3423 cm^{-1} w.
UV/Vis (THF): λ (ε $mol^{-1}dm^3cm^{-1}$) = 210 (8800), 254 (6200), 272 nm (4400).

^{1}H NMR (400 MHz, DMSO-d_6): δ = 7.48 (d, 1 H, $J_{5\text{-}6}$ = 7.8 Hz, H-5), 7.60–7.68 (dd, 1 H, $J_{6\text{-}5}$ = 7.8, $J_{6\text{-}7}$ = 8.0 Hz, H-6), 7.94 (d, 1 H, $J_{7\text{-}6}$ = 8.0 Hz, H-7), 15.09 (s, 0.7 H, H-1).

^{13}C NMR (62.9 MHz, DMSO-d_6): δ = 112.0 (bs, C-7), 116.0 (bs, C-5), 118.8 (d, $J_{C\text{-}F}$ = 320 Hz, CF_3), 128.0 (bs, C-6).

MS-EI: m/z = 267.1 $[M]^+$, 239.1 $[M - N_2]^+$, 134.2 $[M - CF_3O_2S]^+$, 106.2 $[M - CF_3N_2O_2S]^+$.

Anal. calcd for $C_7H_4F_3N_3O_3S$: C, 31,47; H, 1,51; N, 15,73 ; S, 12,00. Found: C, 31.34; H, 1.43; N, 15.65; S, 11.84.

General procedure for the synthesis of 1-hydroxy-1*H*-benzotriazoles

A *o*-chloronitrobenzene derivative (0.1 mol) and hydrazine hydrate (15 g, 0.3 mol) were dissolved in 50 ml EtOH. The reaction mixture was stirred under reflux for 24 h. After completion of the reaction, the mixture was cooled to room temperature, and diluted with H_20 (200 ml). Concentrated HCl was then added until pH 1. The formed solid was filtered and recrystallised with EtOH/H_2O (1:1) Containging 5% of toluene to give the corresponding 1-hydroxy-1*H*-benzotriazole.

1-Hydroxy-5-methyl-1*H*-1,2,3-benzotriazole (31a)[232]

Prepared from 3-chloro-4-nitrotoluene (**30a**, 5 ml, 30 mmol). Colourless needles; yield: 3.56 g (82%); mp 183–184 °C (dec.; EtOH/H_2O/toluene); (Lit.[232] mp 191 °C, (EtOH)).

IR (KBr): 620 m, 635 m, 699 s, 768 vs, 793 vs, 825 s, 871 vw, 929 s, 1037 m, 1098 s, 1144 vs, 1171 s, 1219 m, 1279 s, 1347 vs, 1377 vs, 1455 m, 1621 s, 1850 s, 2493 s, 2924 w, 2956 w, 3068 w, 3103 w, 3434 cm^{-1} vw.

UV/Vis (THF): λ (ε $mol^{-1}dm^3cm^{-1}$) = 211 (19500), 259 (5500), 292 nm (4100).

^{1}H NMR (250 MHz, MeOD-d_4): δ = 2.38 (s, 3 H, H-CH_3), 7.28 (d, 1 H, $J_{6\text{-}7}$ = 6.9 Hz, H-6), 7.36 (s, 1 H, H-4), 7.45 (d, 1 H, $J_{7\text{-}6}$ = 6.9 Hz, H-7).

^{13}C NMR (62.9 MHz, MeOD-d_4): δ = 21.6 (C-CH_3), 126.7 (C-7a), 127.1 (C-7), 130.5 (C-5), 132.3 (C-4), 132.9 (C-6), 141.6 (C-3a).

MS-EI: m/z = 149.1 $[M]^+$.

Anal. calcd for $C_7H_7N_3O$: C, 56.37; H, 4.73; N, 28.17. Found: C, 56.51; H, 4.72; N, 28.05.

1-Hydroxy-6-methyl-1*H*-1,2,3-benzotriazole (31b)[233]

Prepared from 4-chloro-3-nitrotoluene (**30b**). Colourless needles; yield: 11.7 g (79%); mp 181–182 °C (dec.; EtOH/H_2O/toluene); (Lit.[233] mp 188–189 °C, (H_2O)).

IR (KBr): 623 vw, 710 w, 782 m, 809 vs, 936 s, 995 w, 1039 w, 1092 s, 1140 w, 1174 s, 1229 w, 1241 m, 1267 s, 1347 m, 1388 s, 1457 m, 1618 s, 2598 s, 2925 w, 3071 w, 3415 cm^{-1} s.

UV/Vis (THF): λ (ε $mol^{-1}dm^3cm^{-1}$) = 212 (18500), 268 nm (5800).

^1H NMR (400 MHz, DMSO-d_6): δ = 2.39 (s, 3 H, H-CH_3), 7.14 (d, 1 H, $J_{5\text{-}6}$ = 8.3 Hz, H-5), 7.40 (s, 1 H, H-7), 7.45 (d, 1 H, $J_{4\text{-}5}$ = 8.3 Hz, H-4)

^{13}C NMR (100 MHz, DMSO-d_6): δ = 22.2 (C-CH_3), 109.2 (C-7), 119.6 (C-5), 127.7 (C-4), 129.1 (C-7a), 138.6 (C-6), 142.4 (C-3a)

MS-EI: m/z = 149.1 $[M]^+$.

Anal. calcd for $C_7H_7N_3O$: C, 56.37; H, 4.73; N, 28.17. Found: C, 56.19; H, 4.76; N, 28.15.

4-Chloro-1-hydroxy-1*H*-1,2,3-benzotriazole (31c)[222]

Prepared from 2,3-dichloronitrobenzene (**30c**). Colourless needles; yield: 15.5 g (92%); mp 171–172 °C (dec.; EtOH/H_2O/toluene), (Lit.[222] mp 170–172 °C, (EtOH)).

IR (KBr): 556 w, 735 s, 769 s, 786 s, 864 s, 894 vw, 926 w, 965 w, 1140 w, 1158 m, 1169 m, 1201 m, 1230 w, 1255 vw, 1288 s, 1365 vs, 1390 vs, 1434 m, 1476 w, 1492 w, 1522 w, 1605 w, 1617 w, 1871m, 2434 m, 2693 m, 3093 m, 3314 cm^{-1} s.

UV/Vis (THF): λ (ε $mol^{-1}dm^3cm^{-1}$) = 211 (18100), 262 (5500), 270 (4600), 288 nm (4600).

^1H NMR (400 MHz, DMSO-d_6): δ = 7.36–7.42 (m, 1 H, H-5, H-6), 7.54–7.60 (dd, 1 H, $J_{7\text{-}5}$ = 3.6, $J_{7\text{-}6}$ = 5.6 Hz, H-7), 13.92 (s, 1 H, OH).

^{13}C NMR (100 MHz, DMSO-d_6): δ = 109.4 (C-7), 123.8 (C-4), 124.6 (C-6), 128.6 (C-5), 129.8 (C-7a), 140.6 (C-3a).

MS-EI: m/z = 169.1 $[M]^+$.

Anal. calcd for $C_6H_4ClN_3O$: C, 42.50; H, 2.38; N, 24.78. Found: C, 42.62; H, 2.51; N, 25.23.

6-Chloro-1-hydroxy-1*H*-1,2,3-benzotriazole (31d)[234]

Prepared from 2,5-dichloronitrobenzene (**30d**). Colourless needles; Yield: 14.4 g (86%); mp 197–198 °C (dec.; EtOH/H_2O/toluene); (Lit.[234] mp 195 °C, (H_2O/EtOH)).

IR (KBr): 604 w, 639 w, 670 m, 753 vs, 775 m, 813 vs, 856 m, 912 vs, 961 vw, 1038 m, 1134 w, 1152 w, 1177 s, 1211 vs, 1241 m, 1295 vs, 1346 vs, 1388 vs, 1437 vs, 1475 s, 1609 m, 1710 s, 2515 s, 3104 m, 3158 vw, 3418 cm^{-1} w.

UV/Vis (THF): λ (ε $mol^{-1}dm^3cm^{-1}$) = 214 (26300), 271 nm (6300).

^{1}H NMR (250 MHz, DMSO-d_6): δ = 7.37–7.41 (dd, 1 H, $J_{5\text{-}7}$ = 1.9, $J_{5\text{-}4}$ = 8.8 Hz, H-5), 7.82–7.85 (dd, 1 H, $J_{7\text{-}4}$ = 1, $J_{7\text{-}5}$ = 1.9 Hz, H-7), 7.97–8.02 (dd, 1 H, $J_{7\text{-}5}$ = 1, $J_{7\text{-}6}$ = 8.8 Hz, H-4), 13.76 (s, 1 H, OH)

^{13}C NMR (62.9 MHz, DMSO-d_6): δ = 109.6 (C-7), 121.4 (C-4), 125.8 (C-5), 128.8 (C-6), 132.9 (C-7a), 142.0 (C-3a)

MS-EI: m/z = 169.1 $[M]^+$.

Anal. calcd for $C_6H_4ClN_3O$: C, 42.50; H, 2.38; N, 24.78. Found: C, 42.95; H, 2.47; N, 24.65.

1-Hydroxy-6-trifluoromethyl-1*H*-1,2,3-benzotriazole (31e)[232]

Prepared from 4-chloro-3-nitro-benzotrifluoride (**30e**). Colourless needles; Yield: 17.87 g (88%); mp 145–146 °C (dec.; toluene); (Lit.[232] mp 148–149 °C, (H_2O)).

IR (KBr): 547 w, 596 w, 617 w, 645 vw, 670 vw, 736 s, 765 s, 806 m, 822 m, 895 s, 921 s, 1036 m, 1145 vs, 1166 vs, 1218 m, 1250 s, 1316 vs, 1361 vs, 1406 m, 1445 m, 1631 m, 1780 w, 2362 m, 2547 m, 3106 w, 3432 cm^{-1} vw.

UV/Vis (THF): λ (ε $mol^{-1}dm^3cm^{-1}$) = 211 (22100), 243 (6100), 292 nm (3800).

^{1}H NMR (400 MHz, DMSO-d_6): δ = 7.62 (d, 1 H, $J_{5\text{-}4}$ = 8.9 Hz, H-5), 8.12 (s, 1 H, H-7), 8.17 (d, 1 H, $J_{4\text{-}5}$ = 8.9 Hz, H-4), 13.69 (s, 0.5 H, OH)

^{13}C NMR (62.9 MHz, DMSO-d_6): δ = 108.8 (q, $J_{7\text{-}F}$ = 4.4 Hz, C-7), 121.1 (q, $J_{5\text{-}F}$ = 3.5 Hz, C-5), 121.4 (C-4), 124.4 (q, $J_{7\text{-}F}$ = 272 Hz, C-CF_3), 127.5 (C-7a), 128.2 (q, $J_{6\text{-}F}$ = 32 Hz, C-6), 144.5 (C-3a).

MS-EI: m/z = 203.1 $[M]^+$.

Anal. calcd for $C_7H_4F_3N_3O$: C, 41.39; H, 1.98; N, 20.69. Found: C, 41.39; H, 1.90; N, 20.41.

5,7-Dichloro-1-hydroxy-1*H*-1,2,3-benzotriazole (31f)

Prepared from 1,3,5-trichloro-2-nitrobenzene (**30f**, 2.25 g, 0.01 mmol) in MeOH. Colourless needles; Yield: 1.31 g (64%); mp 184–185 °C (dec.; toluene).

IR (KBr): 641 vw, 685 w, 746 w, 805 w, 831 m, 849 vs, 867 w, 877 m, 1003 s, 1076 m, 1120 vs, 1167 vs, 1210 w, 1226 m, 1262 w, 1273 vw, 1353 vs, 1379 m, 1402 vs, 1475 m, 1521 m, 1588 s, 2342 m, 2361 vw, 3081 vw, 3094 , 3453 cm^{-1} m.

UV/Vis (THF): λ (ε $mol^{-1}dm^3cm^{-1}$) = 217 (28200), 262 (5300), 271 (4600), 303 nm (4300).

^{1}H NMR (250 MHz, DMSO-d_6): δ = 7.73 (s, 1 H, H-6), 8.13 (s, 1 H, H-4), 14.09 (s, 1 H, OH)

^{13}C NMR (62.9 MHz, DMSO-d_6): δ = 116.6 (C-7), 118.5 (C-4), 124.5 (C-5), 128.5 (C-6), 129.6 (C-7a), 145.0 (C-3a)

MS-EI: m/z = 203.0 $[M]^+$.

Anal. calcd for $C_6H_3Cl_2N_3O$: C, 35.32; H, 1.48; N, 20.60. Found: C, 35.54; H, 1.46; N, 20.54.

General procedure for the synthesis of substituted 1*H*-1,2,3-benzotriazoles

Na_2CO_3 (1 mmol) was added to a stirred solution of a 1-Hydroxy-1*H*-1,2,3-benzotriazole derivative (1 mmol) in anhydrous CH_2Cl_2 (20 ml) at –78 °C under argon. Trifluoromethanesulfonyl anhydride (1.2 mmol) was added dropwise. The reaction mixture was heated till room temterature and stirred for the given time

(see below), while the progress of the reaction monitored by TLC. Without workup the crude product was purified by chromatography on silica gel [eluent: petroleum ether/EtOAc, 1:1] and recrystallised from petroleum ether/EtOAc.

Reaction with 1-Hydroxy-1*H*-1,2,3-benzotriazole (27)

Amount: 500 mg (3.7 mmol) of **27**. Reaction time: 12 h. 2 Products isolated as a mixture. White solid; Yield: 920 mg [93%; **29a/29b**, 66:33 (NMR)]

Trifluoromethane-1-sulfone acid 1*H*-1,2,3-benzotriazol-6-yl ester (29b)

^{1}H NMR (250 MHz, DMSO-d_6): δ = 7.58 (dd, 1 H, $J_{6\text{-}4}$ = 2.2, $J_{6\text{-}7}$ = 9.0 Hz, H-6), 7.60–7.68 (m, 2 H, H-4, H-7).

^{13}C NMR (62.9 MHz, DMSO-d_6): δ = 108.6 (bs, C-4), 116.6 (bs, C-7), 118.6 (d, $J_{C\text{-}F}$ = 320 Hz, CF_3), 119.7 (bs, C-6).

MS-EI: m/z = 267.1 $[M]^+$, 239.1 $[M - N_2]^+$, 134.2 $[M - CF_3O_2S]^+$, 106.2 $[M - CF_3N_2O_2S]^+$.

Reaction with 1-Hydroxy-5-methyl-1*H*-1,2,3-benzotriazole (29a)

Amount: 100 mg (0.67 mmol) of **31a**.[232] Reaction time: 12 h. 2 Products isolated as a mixture. White solid; Yield: 170 mg [90%; **31a**/**32b**, 55:45 (NMR)].

Trifluoromethane-1-sulfone acid 6-methyl-1*H*-1,2,3-benzotriazol-4-yl ester (32a)

^{1}H NMR (250 MHz, Acetone-d_6): δ = 2.56 (s, 3 H, CH_3), 7.31 (s, 1 H, H-5), 7.69 (s, 1 H, H-7), 14.93 (bs, 0.5 H, H-1).

^{13}C NMR (62.9 MHz, Acetone-d_6): δ = 20.7 (C-CH_3), 110.8 (bs, C-7), 117.8 (bs, C-5), 118.8 (d, $J_{C\text{-}F}$ = 320 Hz, CF_3).

MS-FAB: m/z = 281.9 $[M + H]^+$.

Trifluoromethane-1-sulfone acid 5-methyl-1*H*-1,2,3-benzotriazol-4-yl ester (32b)

^{1}H NMR (250 MHz, Acetone-d_6): δ = 2.53 (s, 3 H, H-CH_3), 7.58 (d, 1 H, $J_{6\text{-}7}$ = 8.5 Hz, H-6), 7.90 (d, 1 H, $J_{7\text{-}6}$ = 8.5 Hz, H-7), 14.98 (bs, 0.75 H, H-1).

^{13}C NMR (62.9 MHz, Acetone-d_6): δ = 14.9 (C-CH_3), 111.2 (bs, C-7), 118.7 (d, $J_{C\text{-}F}$ = 320 Hz, CF_3), 131.1 (bs, C-6).

MS-FAB: m/z = 281.9 $[M + H]^+$.

Reaction with 1-Hydroxy-6-methyl-1*H*-1,2,3-benzotriazole (32b)

Amount: 500 mg (3.3 mmol) of **31b**.[233] Reaction time: 12 h. 2 Products isolated as a mixture. White solid; Yield: 820 mg [88%; **32b**/**32c**, 70:30 (NMR)].

Trifluoromethane-1-sulfone acid 5-methyl-1*H*-1,2,3-benzotriazol-6-yl ester (32c)

^{1}H NMR (600 MHz, Acetone-d_6): δ =2.53 (s, 3 H, CH_3), 8.01 (s, 1 H, H-4), 7.90 (s, 1 H, H-7).

^{13}C NMR (62.9 MHz, Acetone-d_6): δ = 16.4 (C-CH_3), 108.8 (bs, C-7), 116.1 (bs, C-4), 118.7 (d, $J_{C\text{-}F}$ = 320 Hz, CF_3).

MS-FAB: m/z = 281.9 $[M + H]^+$.

Reaction with 4-chloro-1-Hydroxy-1*H*-1,2,3-benzotriazole (31c)

Amount: 500 mg (2.95 mmol) of **31c**.[222] Reaction time: 24 h. 2 Products. Yield: 470 mg **33a** + 310 mg **33b** [88%; **33a**:**33b**, 60:40].

1.Fraction

Trifluoromethane-1-sulfone acid 7-chloro-1*H*-1,2,3-benzotriazol-4-yl ester (33a)

Colourless solid; mp 94.5–96 °C (petroleum ether/EtOAc).

IR (KBr): 573 m, 593 s, 630 s, 666 m, 707 m, 770 m, 828 vs, 847 vs, 951 m, 970 m, 1013 s, 1057 s, 1090 m, 1135 vs, 1216 vs, 1251 vs, 1286 s, 1381 m, 1433 vs, 1514 vs, 1580 vw, 1630 w, 2847 s, 2935 s, 2997 s, 3088 s, 3416 cm^{-1} m.

UV/Vis (THF): λ (ε $mol^{-1}dm^3cm^{-1}$) = 211 (23500), 257 (8300), 264 (8100), 282 nm (8200).

^{1}H NMR (250 MHz, Acetone-d_6): δ = 7.57 (d, 1 H, $J_{6\text{-}7}$ 8.2 Hz, H-6), 7.70 (d, 1 H, $J_{7\text{-}6}$ = 8.2 Hz, H-7).

^{13}C NMR (62.9 MHz, Acetone-d_6): δ = 118.2 (bs, C-7), 118.8 (q, $J_{C\text{-}F}$ = 320 Hz, C-CF_3), 126.6 (bs, C-7).

MS-FAB: m/z = 301.9 $[M + H]^+$.

Anal. calcd for $C_7H_3ClF_3N_3O_3S$: C, 27,87; H, 1,00; N, 13,93; S, 10,63. Found: C, 28.01; H, 1.03; N, 13.67; S, 10.60.

2.Fraction

Trifluoromethane-1-sulfone acid 7-chloro-1*H*-1,2,3-benzotriazol-6-yl ester (33b)

Colourless solid; mp 173–174 °C (dec.; petroleum ether/EtOAc).

IR (KBr): 547 vw, 576 vw, 605 s, 632 m, 658 vw, 679 w, 739 m, 768 vw, 815 m, 846 s, 952 s, 1005 m, 1035 w, 1099 w, 1131 vs, 1211 vs, 1307 vw, 1372 vw, 1390 w, 1424 vs, 1460 w, 1508 vw, 1592 vw, 1618 w, 2803 m, 2936 w, 2987 w, 3030 w, 3074 w, 3416 cm^{-1} w.

UV/Vis (THF): λ (ε $mol^{-1}dm^3cm^{-1}$) = 212 (25700), 255 (8200), 261 (7600), 282 nm (5500).

^{1}H NMR (250 MHz, Acetone-d_6): δ = 7.66 (d, 1 H, $J_{5\text{-}4}$ = 9.0 Hz, H-5), 8.06 (d, 1 H, $J_{4\text{-}5}$ = 9.0 Hz, H-4), 15.38 (bs, 0.2 H, H-1).

^{13}C NMR (62.9 MHz, Acetone-d_6): δ = 118.7 (d, $J_{C\text{-}F}$ = 320 Hz, C-CF_3), 121.3 (bs, C-4, C-5).

MS-FAB: m/z = 301.9 $[M + H]^+$.

Anal. calcd for $C_7H_3ClF_3N_3O_3S$: C, 27,87; H, 1,00; N, 13,93; S, 10,63. Found: C, 28.15; H, 0.98; N, 13.68; S, 10.64.

Reaction with 6-chloro-1-Hydroxy-1*H*-1,2,3-benzotriazole (31d)

Amount: 500 mg (2.95 mmol) of **31d**.[234] Reaction time: 24 h. 2 Products. Yield: 310 mg **34a** + 470 mg **34b** [75%; **34a**:**34b**, 40:60].

1. Fraction

Trifluoromethane-1-sulfone acid 5-chloro-1*H*-1,2,3-benzotriazol-6-yl ester (34a)

Colourless solid; mp 194–195.5 °C (dec.; petroleum ether/EtOAc).

IR (KBr): 518 w, 568 w, 583 m, 613 vs, 667 m, 708 w, 747 s, 776 w, 812 m, 893 vs, 983 m, 1007 vs, 1100 m, 1134 vs, 1210 vs, 1248 vs, 1272 m, 1299 s, 1361 w, 1404 s, 1429 vs, 1455 m, 1493 w, 1586 vw, 1629 w, 1737 vw, 2784 s, 2850 s, 2941 s, 3023 m, 3104 s, 3423 cm^{-1} w.

UV/Vis (THF): λ (ε $mol^{-1}dm^3cm^{-1}$) = 212 (38100), 251 (8100), 285 nm (6200).

^1H NMR (250 MHz, Acetone-d_6): δ = 8.25 (s, 1 H, H-4), 8.31 (s, 1 H, H-7).

^{13}C NMR (62.9 MHz, Acetone-d_6): δ = 110.6 (bs, C-7), 116.7 (bs, C-4), 118.7 (d, $J_{C\text{-}F}$ = 320 Hz, CF_3).

MS-FAB: m/z = 301.9 $[M + H]^+$.

Anal. calcd for $C_7H_3ClF_3N_3O_3S$: C, 27,87; H, 1,00; N, 13,93; S, 10,63. Found: C, 28.30; H, 0.94; N, 13.82; S, 10.64.

2.Fraction

Trifluoromethane-1-sulfone acid 5-chloro-1*H*-1,2,3-benzotriazol-4-yl ester (34b)

Colourless solid; mp 215.1– 215.4 °C (dec.; petroleum ether/EtOAc).

IR (KBr): 514 vw, 530 vw, 568 w, 603 m, 641 s, 686 vw, 728 w, 765 vw, 824 m, 840 vs, 916 s, 1010 m, 1071 m, 1138 vs, 1211 vs, 1237 s, 1268 vw, 1310 vw, 1372 m, 1387 m, 1428 vs, 1445 m, 1499 vw, 1586 w, 1619 w, 2940 w, 3109 m, 3416 cm^{-1} m.

UV/Vis (THF): λ (ε $mol^{-1}dm^3cm^{-1}$) = 211 (24300), 254 (6700), 285 nm (4600).

^1H NMR (250 MHz, Acetone-d_6): δ = 7.74 (d, 1 H, $J_{6\text{-}7}$ = 8.9 Hz, H-6), 8.01 (d, 1 H, $J_{7\text{-}6}$ = 8.9 Hz, H-7).

^{13}C NMR (62.9 MHz, Acetone-d_6): δ = 114.2 (C-7), 118.7 (d, $J_{C\text{-}F}$ = 320 Hz, C-CF_3), 128.8 (C-7).

MS-FAB: m/z = 301.9 $[M + H]^+$.

Anal. calcd for $C_7H_3ClF_3N_3O_3S$: C, 27,87; H, 1,00; N, 13,93; S, 10,63. Found: C, 28.28; H, 1.15; N, 13.67; S, 10.58.

Reaction with 1-Hydroxy-6-trifluoromethyl-1*H*-1,2,3-benzotriazole (31e)

Amount: 500 mg (2.17 mmol) of **31e**.[233] Reaction time: 36 h. 3 Products isolated as a mixture. Yield: 650 mg [89%; **35a**/**35b**/**35c** (20:40:40); (HPLC)]. For analytical purpose 100 mg were separated by preparative HPLC.

1. Fraction

Trifluoromethane-1-sulfone acid 5-trifluromethyl-1*H*-1,2,3-benzotriazol-7-yl ester (35a)

Colourless solid; mp 164–165 °C (dec.; petroleum ether/EtOAc).

IR (KBr): 508 vw, 543 vw, 570 vw, 588 w, 606 w, 648 vw,663 vw, 681 vw, 703 w, 764 w, 794 w, 820 m, 888 m, 927 m, 985, w, 1005 w, 1067 w, 1092 m, 1122 m, 1132 s, 1147 vs, 1193 m, 1221 vs, 1248 vs, 1352 s, 1386 w, 1420 s, 1443 s, 1524w, 1600 vw, 1646 vw, 3095 w, 3454 cm^{-1} m.

UV/Vis (THF): λ (ε $mol^{-1}dm^3cm^{-1}$) = 211 (22200), 242 (8100), 277 nm (4300).

^1H NMR (250 MHz, Acetone-d_6): δ = 7.87 (s, 1 H, H-6), 8.49 (s, 1 H, H-4).

^{13}C NMR (62.9 MHz, Acetone-d_6): δ = 113.0 (bs, C-4), 114.0 (bs, C-6), 118.8 (q, $J_{C\text{-}F}$ = 320 Hz, C-CF_3).

MS-FAB: m/z = 335.9 $[M + H]^+$.

Anal. calcd for $C_8H_3F_6N_3O_3S$: C, 28,67; H, 0,90; N, 12,54; S, 9,57. Found: C, 29.13; H, 0.80; N, 11.76; S, 9.02.

2. Fraction

Trifluoromethane-1-sulfone acid 5-trifluromethyl-1*H*-1,2,3-benzotriazol-6-yl ester (35b)

Colourless solid; mp 167–168.5 °C (dec.; petroleum ether /EtOAc).

IR (KBr): 518 vw, 571 vw, 587 vw, 645 m, 664 vw, 724 w, 748 vw, 769 w, 817 w, 871 s, 884 s, 915 m, 1008 m, 1133 vs, 1169 s, 1213 vs, 1241 vs, 1259 s, 1288 w, 1336 m, 1379 w, 1408 vs, 1497 w, 1605 w, 1641 w, 2798 w, 2857 w, 2957 w, 3073 w, 3417 cm^{-1} w.

UV/Vis (THF): λ (ε $mol^{-1}dm^3cm^{-1}$) = 211 (28700), 246 (7100), 275 nm (4600).

^{1}H NMR (250 MHz, Acetone-d_6): δ = 8.27 (s, 1 H, H-7), 8.62 (s, 1 H, H-4).

^{13}C NMR (62.9 MHz, Acetone-d_6): δ = 109.2 (C-7), 117.8 (bs, C-4), 118.5 (d, $J_{C\text{-}F}$ = 320 Hz, C-CF_3), 122.6 (d, $J_{C\text{-}F}$ = 272 Hz, C-CF_3).

MS-FAB: m/z = 335.9 $[M + H]^+$.

Anal. calcd for $C_8H_3F_6N_3O_3S$: C, 28,67; H, 0,90; N, 12,54; S, 9,57. Found: C, 28.66; H, 0.82; N, 11.87; S, 9.13.

3.Fraction

Trifluoromethane-1-sulfone acid 5-trifluromethyl-1*H*-1,2,3-benzotriazol-4-yl ester (35c)

Colourless solid; mp 168–169.5 °C (dec.; petroleum ether /EtOAc)

IR (KBr): 520 vw, 579 w, 633 m, 651 vw, 685 w, 694 w, 760 m, 832 s, 916 s, 989 vw, 1008 w, 1072 m, 1090 w, 1113 m, 1132 s, 1148 s, 1177 m, 1190 s, 1212 vs, 1235 s, 1332 vs, 1375 m, 1416 s, 1430 s, 1514 w, 1569 vw, 1594 w, 1638 m, 3133 m, 3415 cm^{-1} w.

UV/Vis (THF): λ (ε $mol^{-1}dm^3cm^{-1}$) = 211 (24400), 245 nm (8100).

^{1}H NMR (250 MHz, Acetone-d_6): δ = 7.92 (d, 1 H, $J_{6\text{-}7}$ = 8.6 Hz, H-6), 8.62 (s, 1 H, $J_{7\text{-}6}$ = 8.6 Hz, H-7).

^{13}C NMR (62.9 MHz, Acetone-d_6): δ = 113.6 (C-7), 118.7 (d, $J_{C\text{-}F}$ = 318 Hz, C-CF_3), 124.5 (bs, C-4).

MS-FAB: m/z = 335.9 $[M + H]^+$.

Anal. calcd for $C_8H_3F_6N_3O_3S$: C, 28,67; H, 0,90; N, 12,54; S, 9,57. Found: C, 29.13; H, 0.98; N, 12.29; S, 9.06.

Reaction with 5,7-dichloro-1-hydroxy-1*H*-1,2,3-benzotriazole (31f)

Amount: 500 mg (2.45 mmol) of **31f**. Reaction time: 12 h. Yield: 620 mg (73%).

Trifluoromethane-1-sulfone acid 4,6-dichloro-1*H*-1,2,3-benzotriazol-7-yl ester (36)

Colourless solid; mp 75–76 °C (petroleum ether/EtOAc).

IR (KBr): 509 w, 540 vw, 568 vw, 603 s, 627 m, 650 m, 706 w, 768 w, 810 m, 835 vs, 881 vw, 973 m, 1011 m, 1078 m, 1135 s, 1213 vs, 1293 w, 1368 vw, 1433 vs, 1499 s, 1587 w, 1618 w, 1637 w, 2857 m, 2924 m, 3089 m, 3415 m, 3476 m, 3551 cm^{-1} w.

UV/Vis (THF): λ (ε $mol^{-1}dm^3cm^{-1}$) = 212 (32900), 260 (7800), 269 (7700), 290 nm (6300).

^1H NMR (250 MHz, Acetone-d_6): δ = 7.88 (s, 1 H, H-5).

^{13}C NMR (62.9 MHz, Acetone -d_6): δ = 118.6 (q, $J_{C\text{-}F}$ = 320 Hz, C-CF_3), 127.7 (bs, C-5).

MS-FAB: *m*/*z* = 335.8 $[M + H]^+$.

Anal. calcd for $C_7H_2Cl_2F_3N_3O_3S$: C, 25,02; H, 0,60; N, 12,50; S, 9,54. Found: C, 25.52; H, 0.65; N, 12.26; S, 9.45.

Reaction with 1-Hydroxy-7-aza-1*H*-1,2,3-benzotriazole

Amount: 100 mg (0.73 mmol) of **31g**. Reaction time: 48 h. The isolation of the active ester was not possible.

Nonafluorobutane-1-sulfonic acid 1-(nonafluorobutane-1-sulfonyl)-1*H*-1,2,3-benzotriazol-4-yl ester (37)

A 2.5 M solution of BuLi in *n*-hexane (0.5 ml, 1.3 mmol) was added slowly to a stirred solution of nonafluorobutane-1-sufonic acid-1*H*-1,2,3-benzotriazol-4-yl ester (**28b**; 1.8 g, 15 mmol) in anhydrous dimethoxymethane (10 ml) at 0 °C under argon. After 1 h, nonafluorobutanesulfonyl fluoride (**2a**; 0.4 ml, 2.2 mmol) was added dropwise. The reaction mixture was stirred under reflux for ca. 3 h, while the progress of the reaction monitored by TLC. After completion of the reaction, the mixture was cooled to room temperature, and diluted with Et_2O (20 ml). The organic layer was washed with aq sat. NH_4Cl solution (2 × 10 ml), and H_2O (1 × 10 ml). After drying (Na_2SO_4),

filtration and removal of the solvent, the crude product was purified by chromatography on silica gel under protection from light [eluent: petroleum ether/EtOAc, 4:1] to give **37**; yelowish solid; yield: 0.26 g (31%); mp 83–84 °C (petroleum ether/EtOAc).

IR (KBr): 515 w, 532 vw, 550 vw, 586 w, 622 w, 653 w, 663 m, 678 vw, 741 w, 754 vw, 789 w, 804 m, 835 vw, 895 vw, 915 vw, 948 vw, 1009 m, 1037 w, 1112 w, 1142 vs, 1202 vs, 1231 s, 1261 m, 1300 w, 1329 w, 1355 m, 1415 vs, 1445 s, 1495 w, 1593 vw, 1620 vw, 2924 m, 3418 m.

^{1}H NMR (250 MHz, CDCl3): δ = 7.48 (d, 1 H, $J_{5\text{-}6}$ = 7.9 Hz, H-5), 7.72–7.80 (dd, 1 H, $J_{6\text{-}5}$ = 7.9, $J_{6\text{-}7}$ = 8.4 Hz, H-6), 7.91 (d, 1 H, $J_{7\text{-}6}$ = 8.4 Hz, H-7).

^{13}C NMR (62.9 MHz, CDCl3): δ = 111.3 (C-7),119.0 (C-5), 132.1 (C-6), 133.6 (C-7a), 137.5 (C-4), 139.6 (C-3a).

MS-EI: *m*/*z* = 698.8 $[M]^+$, 479.9 $[M - C_4F_9]^+$.

Nonafluoro-butane-1-sulfonic acid 2-(2-hydroxy-phenylazo)-3-(nonafluoro-butane-1-sulfonylamino)-phenyl ester (38)

NaH (20 mg, 60% suspension in oil) was added to a stirred solution of phenol (**7a**, 45 mg, 0.48 mmol) and nonafluorobutane-1-sulfonic acid 1-(nonafluorobutane-1-sulfonyl)-1*H*-1,2,3-benzotriazol-4-yl ester (**37**; 150 mg, 0.21 mmol) in anhydrous toluene (10 ml) at room temperature under argon. The mixture was stirred for 7 h. while controlling the progress of the reaction by TLC. At the end of this period, EtOAc (20 ml) and H_2O (10 ml) were added and the suspension was treated with conc. HCl, till the colour of the organic phase changed from red to orange-red. The aqueous phase must remain colourless during this time. The organic phase was separated, dried (Na_2SO_4), filtered, and the solvent was evaporated. The crude product was purified by chromatography over silica gel [eluent: petroleum ether/EtOAc (30:1) containing 1% AcOH] to give **38**; orange solid; yield: 0.1 g (60%); mp 118–120 °C (petroleum ether/EtOAc).

IR (KBr): 507 w, 532 vw , 548 vw, 571 w, 585 m, 616 vw, 652 vw, 696 m, 730 m, 771 m, 799 m, 839 vw, 858 vw, 847 vw, 916 vw, 936 w, 1037 s, 1125 m, 1148 vs,

1200 vs, 1238 vs, 1353 s, 1428 vs, 1469 vs, 1572 m, 1617 m, 1958 vw, 2360 vw, 2854 vw, 2925 vw, 2963 vw, 3443 cm^{-1} w.

UV/Vis (): λ (ε $mol^{-1}dm^3cm^{-1}$) = 247 (10200), 327 (11200), 398 nm (8400).

^1H NMR (250 MHz, CDCl3): δ = 710–7.20 (m, 2 H, H-3', H-5'), 7.35 (d, 1 H, $J_{4\text{-}5}$ = 8.6 Hz, H-4), 7.45–7.59 (m, 2 H, H-5, H-4'), 7.74–780 (dd, 1 H, $J_{6'\text{-}4'}$ = 1.7, $J_{6'\text{-}5'}$ = 8.6 Hz, H-6'), 7.92 (d, 1 H, $J_{4\text{-}5}$ = 8.6 Hz, H-6), 11.21 (bs, 1 H, H-NH), 12.86 (s, 1 H, OH).)

^{13}C NMR (62.9 MHz, CDCl3): δ = 118.8 (C-4), 119.5 (C-3'), 119.8 (C-6), 121.4 (C-5'), 130.1 (C-3), 131.4 (C-1'), 132.5 (C-6'), 132.9 (C-5), 136.4 (C-2), 136.5 (C-4'), 147.2 (C-1), 153.0 (C-2').

MS-EI: *m*/*z* = 793.0 $[M]^+$, 510.1 $[M - SO_2C_4F_9]^+$, 227.2 $[M - S_2O_4C_8F_{18}]^+$.

HRMS: calcd for $C_{20}H_9F_{18}N_3O_6S_2$: M = 792.96769. Found: *m/z* = 792.96443.

4.2.7 Related to Chapter 2.3.2

3,4-Dicyanophenyl-2,3,4,6-tetra-*O*-benzyl-α/β-D-glucopyranoside (38α/38β)

Method 1

NaH (280 mg, 7 mmol, 60% suspension in oil) was added to a stirred solution of 2,3,4,6-tetra-*O*-benzyl-α/β-D-glucopyranose (**1**;[116] 3.80 g, 7.0 mmol) and 4-nitrophthalonitrile (**40**; 1.33 g, 7.7 mmol) in dry DMF (25 ml) under argon. The mixture was stirred for 2 h. At the end of this period, the reaction was poured into H_2O (200 ml) and CH_2Cl_2 (100 ml). The aqueous layer was extracted with CH_2Cl_2 (3 × 50 ml). The combined organic layers were washed with H_2O (3 × 50 ml). After drying (Na_2SO_4), filtration and removal of the solvent, the crude product was purified by chromatography on silica gel [eluent: toluene/acetone, 10:1] to give (**38α/38β**); yield: 4.63 g [99%; α/β, 95:5 (HPLC)].

Method 2

NaH (9 mg, 0.22 mmol, 60% suspension in oil) was added to a stirred solution of 2,3,4,6-tetra-*O*-benzyl-α/β-D-glucopyranose (**1**;[116] 100 mg, 0.18 mmol) and 4-nitrophthalonitrile (**40**; 38 mg, 0.22 mmol) in dry THF (5 ml) under argon. The mixture was stirred for 2 h. At the end of this period, the reaction was poured into H_2O (15 ml) and Et_2O (25 ml). The mixture was cooled to room temperature, and diluted with Et_2O (25 ml). The organic layer was washed with aq sat. NH_4Cl solution (2 × 15 ml), and H_2O (1 × 15 ml). After drying (Na_2SO_4), filtration and removal of the solvent, the crude product was purified by chromatography on silica gel [eluent: toluene/acetone, 10:1] to give (**41α/41β**); yield: 117 g [98%; α/β, 1:2 (HPLC)].

α-Isomer (**41α**)

Colorless oil; $[\alpha]_D^{20^\circ}$ +132.7 (*c* = 1.0, $CHCl_3$).

^{1}H NMR (250 MHz, $CDCl_3$): δ = 3.51–3.59 (m, 1 H, H-6a), 3.64–3.83 (m, 5 H, H-2, H-3, H-4, H-5, H-6b), 4.08–4.18 (dd,1 H, $J_{3\text{-}4}$ = 8.6, $J_{3\text{-}2}$ = 9.4 Hz, H-3), 4.38–4.65 (m, 4 H, H-CH_2), 4.81–4.93 (m, 3 H, H-CH_2), 5.03 (d, 1 H, *J* = 10.8 Hz, H-CH_2), 5.37 (d,

1 H, $J_{1\text{-}2}$ = 3.4 Hz, H-1), 7.11–7.17 (m, 2 H, H-Ar), 7.23–7.44 (m, 20 H, H-Ar, H-2', H-6'), 7.66 (d, 1 H, $J_{5'\text{-}6'}$ = 8.6 Hz, H-5').

^{13}C NMR (62.9 MHz, $CDCl_3$): δ = 67.9 (C-6), 71.9 (C-5), 73.5, 74.0, 75.3, 75.9 [C-CH_2], 76.9 (C-2), 79.5 (C-4), 81.6 (C-3), 96.3 (C-1), 108.9 (C-4'), 115.0 (C-3'CN), 115.4 (C-4'CN), 117.5 (C-3'), 121.4 (C-2', C-6'), 127.81, 127.87, 127.91, 127.95, 128.0, 128.2, 128.46, 128.48, 128.5, 128.6 [C-2Ar, C-3Ar, C-4Ar], 135.2 (C-5'), 137.5, 137.7, 137.8, 138.5 [C-1Ar], 159.7 (C-1').

MS-MALDI-TOF: *m*/*z* = 689.4 $[M + Na]^+$.

Anal. calcd for $C_{42}H_{38}N_2O_6$: C, 75.66; H, 5.74; N, 4.20. Found: C, 75.95; H, 5.76; N, 4.30.

β-Isomer (**41β**)

^{1}H NMR (250 MHz, $CDCl_3$): δ = 3.58–3.78 (m, 6 H, H-2, H-3, H-4, H-5, H-6), 4.42–4.59 (m, 3 H, H-CH_2), 3.78–4.95 (m, 5 H, H-CH_2), 5.01 (d, 1 H, $J_{1\text{-}2}$ = 7.8 Hz, H-1), 7.13–7.43 (m, 22 H, H-Ar, H-2', H 6'), 7.59 (d, 1 H, $J_{5'\text{-}6'}$ = 8.6 Hz, H-5').

^{13}C NMR (62.9 MHz, $CDCl_3$): δ = 68.4 (C-6), 73.5, 75.1, 75.3 [C-CH_2], 75.5 (C-5), 75.8 (C-CH_2), 77.3 (C-2), 81.7 (C-4), 84.5 (C-3), 100.7 (C-1), 109.1 (C-4'), 115.0 (C-3'CN), 115.4 (C-4'CN), 117.4 (C-3'), 121.1 (C-2'), 121.7 (C-6'), 127.5, 127.7, 127.8, 127.9, 128.0, 128.44, 128.47, 128.5, 128.8, 128.9 [C-2Ar, C-3Ar, C-4Ar], 135.2 (C-5'), 137.7, 137.8, 138.1 [C-1Ar], 159.9 (C-1').

MS-MALDI-TOF: *m*/*z* = 689.4 $[M + Na]^+$.

General method for the synthesis of substituted dicyanophenyl compounds:

K_2CO_3 (6 mmol) was added to a stirred solution of 1-OH/1-SH unprotected carbohydrate (1 mmol) and 4-nitrophthalonitrile (**40**; 1.2 mmol) in dry DMF (10 ml). The mixture was stirred overnight. At the end of this period, the mixture was poured into H_2O (100 ml) and CH_2Cl_2 (20 ml). The aqueous layer was extracted with CH_2Cl_2 (3 × 20 ml). The organic layer was washed with H_2O (3 × 20 ml). After drying (Na_2SO_4), filtration and removal of the solvent, the crude product was purified by chromatography on silica gel [eluent: toluene/acetone, 10:1]. For analytical purposes the α/β-mixtures were separated by preparative HPLC.

3,4-Dicyano-phenyl-2,3,4,6-tetra-*O*-benzoyl-α/β-D-glucopyranoside (42α/42β)

Synthesised from 2,3,4,6-tetra-*O*-benzoyl-α/β-D-glucopyranose (**36b**;[265] 4.00 g, 6.7 mmol); yield: 4.80 g [99%; α/β, 95:5 (HPLC)].

α-Isomer (**42α**)

Amorphous white solid; $[\alpha]_D^{20^\circ}$ +98.4 (*c* = 1.0, $CHCl_3$).

^{1}H NMR (250 MHz, $CDCl_3$): δ = 7.38–4.58 (m, 3 H, H-5, H-6), 5.44–5.52 (d, 2 H, $J_{2\text{-}1}$ = 3.7, $J_{2\text{-}3}$ = 10.1 Hz, H-2), 5.71–5.76 (dd,1 H, $J_{4\text{-}5}$ = 9.6, $J_{4\text{-}3}$ = 9.9 Hz, H-4), 6.14 (d, 1 H, $J_{1\text{-}2}$ = 3.4 Hz, H-1), 6.27–6.39 (dd, 1 H, $J_{3\text{-}4}$ = 9.9, $J_{3\text{-}2}$ = 10.1 Hz, H-3), 7.27–7.65 (m, 15 H, H-2Ar H-4Ar, H-2', H-5', H-6'), 7.83–7.98 (m, 8 H, H-3Ar).

^{13}C NMR (62.9 MHz, $CDCl_3$): δ = 62.6 (C-6), 68.9 (C-4), 69.7 (C-5), 69.72 (C-3), 71.1 (C-2), 94.4 (C-1), 109.7 (C-4'), 114.6 (C-3'CN), 115.0 (C-4'CN), 117.7 (C-3'), 120.9 (C-2'), 121.7 (C-6'), 128.2, 128.3, 128.4, 128.54, 128.59, 128.6, 128.7, 129.1 [C-1Ar, C-3Ar], 129.5, 129.7, 129.9 [C-2Ar], 133.5, 133.7, 133.8, 133.9 [C-4Ar], 135.3 (C-5'), 158.6 (C-1'), 165.3, 165.6, 165.75, 165.76 [C-CO].

FAB-MS: *m*/*z* = 723.1 $[M + H]^+$.

Anal. calcd for $C_{42}H_{30}N_2O_{10}$: C, 69.80; H, 4.18; N, 3.88. Found: C, 69.90; H, 4.20; N, 3.79.

β-Isomer (**42β**)

^{1}H NMR (250 MHz, $CDCl_3$): δ = 4.39–4.57 (m, 2 H, H-5, H-6a), 4.64–4.71 (dd, 1 H, $J_{6b\text{-}5}$ = 2.5, $J_{6b\text{-}6a}$ = 11.8 Hz, H-6b), 5.56 (d, 1 H, $J_{1\text{-}2}$ = 7.2 Hz, H-1), 5.69–5.82 (m, 2 H, H-2, H-4), 5.94–6.03 (t, 1 H, $J_{3\text{-}2/3\text{-}4}$ = 9.1 Hz, H-3), 7.20–7.64 (m, 15 H, H-2', H-5', H-6', H-3Ar, H-4Ar), 8.82–8.99 (m, 8 H, H-2Ar).

^{13}C NMR (62.9 MHz, $CDCl_3$): δ = 62.7 (C-6), 68.9 (C-4), 71.3 (C-2), 72.2 (C-3), 73.3 (C-5), 98.2(C-1), 109.9 (C-4'), 114.7 (C-3'CN), 115.1 (C-4'CN), 117.6 (C-3'), 121.2 (C-2'), 121.6 (C-6'), 128.4, 128.6, 128.7 [C-3Ar], 129.1 (C-1Ar), 129.6, 129.7, 129.8, 129.9 [C-2Ar], 133.5, 133.6, 133.8 [C-4Ar], 135.1 (C-5'), 159.1 (C-1'), 164.9, 165.2, 165.6, 165.8 [C-CO].

FAB-MS: *m*/*z* = 723.1 $[M + 1]^+$.

3,4-Dicyanophenyl-2,3,4,6-tetra-*O*-acetyl-α/β-D-glucopyranosid (43α/43β)

Synthesised from 2,3,4,6-tetra-O-acetyl-α/β-D-glucopyranose (**39c**;[266] 6 g, 17 mmol). Yield: 8.06 g [Quantitative; α/β, 95:5 (HPLC)]

α-Isomer (**43α**)

Amorphous white solid; $[\alpha]_D^{20°}$ +202.0° (c = 1, $CHCl_3$).

^{1}H NMR (250 MHz, $CDCl_3$): δ = 2.01 s, 2.02 s, 2.03 s, 2.04 s [12 H, H-CH_3], 3.91–4.06 (m, 2 H, H-5, H-6a), 4.15–4.24 (dd, 1 H, J_{6b-5} = 4.9, J_{6b-6a} = 12.3 Hz, H-6b), 5.02–5.07 (dd, 1 H, J_{2-1} = 3.5, J_{2-3} = 10.1 Hz, H-2), 5.08–5.18 (dd, 1 H, J_{4-3} = 9.6, J_{4-5} = 10.1 Hz, H-4), 5.57–5.67 (dd, 1 H, J_{3-4} = 9.6, J_{3-2} = 10.1 Hz, H-3), 5.81 (d, 1 H, J_{1-2} = 3.5 Hz, H-1), 7.38–7.45 (dd, 1 H, $J_{6'-2'}$ = 2.5, $J_{6'-5'}$ = 8.6 Hz, H-6'), 7.53 (d, 1 H, $J_{2'-6'}$ = 2.5 Hz, H-2'), 7.75 (d, 1 H, $J_{5'-6'}$ = 2.5 8.6 Hz, H-5').

^{13}C NMR (62.9 MHz, $CDCl_3$): δ = 20.4 (C-CH_3), 61.4 (C-6), 67.8 (C-4), 69.1 (C-5), 69.4 (C-3), 69.9 (C-2), 94.6 (C-1), 109.9 (C-4'), 114.7 (C-3'CN), 115.1 (C-4'CN), 117.8 (C-3'), 121.1 (C-6'), 121.5 (C-2'), 135.4 (C-5'), 158.9 (C-1'), 169.4, 169.9, 170.0, 170.3 [C-CO].

MS-MALDI-TOF: m/z = 497.23 $[M + Na]^+$.

Anal. calcd for $C_{22}H_{22}N_2O_{10}$: C, 55.70; H, 4.67; N 5.90. Found: C, 55.50; H, 4.63; N, 5.57.

β-Isomer (**43β**)

^{1}H NMR (250 MHz, $CDCl_3$): δ = 2.02 s, 2.05 s, 2.09 s (12 H, H-CH_3), 3.89–3.97 (m, 1 H, H-5), 2.17–2.24 (m, 2 H, H-6), 5.02–5.31 (m, 4 H, H-1, H-2, H-3, H-4), 7.25–7.30 (dd, 1 H, $J_{6'-2'}$ = 2.5, $J_{6'-5'}$ = 8.6 Hz, H-6'), 7.38 (d, 1 H, $J_{2'-6'}$ = 2.5 Hz, H-2'), 7.72 (d, 1 H, $J_{5'-6'}$ = 8.6 Hz, H-5').

^{13}C NMR (62.9 MHz, $CDCl_3$): δ = 20.52 (C-CH_3), 61.87 (C-6), 67.90 (C-2), 70.79 (C-4), 72.25 (C-3), 72.76 (C-5), 97.98 (C-1), 110.08 (C-4'), 114.90 (C-3'CN), 115.06 (C-4'CN), 117.70 (C-3'), 121.09 (C-2'), 121.77 (C-6'), 135.21 (C-5'), 159.26 (C-1'), 169.06, 169.31, 170.03, 170.37 [C-CO].

MS-MALDI-TOF: m/z = 497.23 $[M + Na]^+$.

3,4-Dicyanophenyl-3,4,6-tri-*O*-acetyl-2-desoxy-2-phthalimido-β-D-gluco-pyranoside (44β)

Synthesised from 3,4,6-tri-O-acetyl-2-desoxy-2-phthalimido-α/β-D-glucopyranose (**39d**;[265b,267] 6.50 g, 15 mmol); amorphous white pouder; yield: 4.25 g (50%); $[\alpha]_D^{20°}$ +74.9 (c = 1, $CHCl_3$).

^{1}H NMR (250 MHz, $CDCl_3$): δ = 1.87 s, 2.05 s, 2.12 s [H-CH_3], 4.03–4.15 (m, 1 H, H-5), 2.16–4.31 (m, 2 H, H-6), 4.56–4.65 (dd, 1 H, $J_{2\text{-}1}$ = 8.8, $J_{2\text{-}3}$ = 10.6 Hz, H-2), 5.15–5.25 (dd, 1 H, $J_{4\text{-}3}$ = 9.1, $J_{4\text{-}5}$ = 10.1 Hz, H-4), 5.78–5.88 (dd, 1 H, $J_{3\text{-}4}$ = 9.1, $J_{3\text{-}2}$ = 10.6 Hz, H-3), 6.11 (d, 1 H, $J_{1\text{-}2}$ = 8.8 Hz, H-1), 4.18–4.24 (dd, 1 H, $J_{6'\text{-}2'}$ = 2, $J_{6'\text{-}5'}$ = 8.8 Hz, H-6'), 7.33 (d, 1 H, $J_{2'\text{-}6'}$ = 2 Hz, H-2'), 7.65 (d, 1 H, $J_{5'\text{-}6'}$ = 8.8 Hz, H-5'), 7.72–7.79 (m, 2 H, H-3Ar, H-4Ar), 7.80–7.88 (m, 2 H, H-2Ar, H-6Ar).

^{13}C NMR (62.9 MHz, $CDCl_3$): δ = 20.3, 20.6, 20.7 [C-CH_3], 54.1 (C-2), 61.9 (C-6), 68.4 (C-4), 70.3 (C-3), 72.8 (C-5), 95.3 (C-1), 110.0 (C-4'), 114.9 (C-3'CN), 115.1 (C-4'CN), 117.6 (C-3'), 121.4 (C-2'), 121.7 (C-6'), 123.9 (C-2Ar, C-5Ar), 131.1 (C-1Ar, C-6Ar), 134.7 (C-3Ar, C-4Ar), 135.1 (C-5'), 159.1 (C-1'), 169.37, 170.02, 170.43 [C-CO].

MS-MALDI-TOF: m/z = 584.32 $[M + Na]^+$.

Anal. calcd for $C_{28}H_{23}N_3O_{10}$: C, 59.89; H, 4.13; N 7.48. Found: C, 59.95; H, 4.18; N, 7.28.

3,4-Dicyanophenyl-2,3,4,6-tetra-*O*-acetyl-1-thio-β-D-glucopyranoside (45β)

Synthesised from 2,3,4,6-Tetra-*O*-acetyl-1-thio-β-D-glucopyranose (**39e**;[266a,268] 4.00 g, 11 mmol); amorphous white pouder; yield: 5.48 g (Quantitative); $[\alpha]_D^{20°}$ –51.0 (c = 0.5, $CHCl_3$).

^{1}H NMR (250 MHz, $CDCl_3$): δ = 1.98 s, 2.02 s, 2.06 s, 2.12 s [12 H, H-CH_3], 3.78–3.86 (m, 1 H, H-5), 4.18–4.23 (m, 2 H, H-6), 4.82 (d, 1 H, $J_{1\text{-}2}$ = 10 Hz, H-1), 4.92–5.08 (m, 2 H, H-2, H-4), 5.20–5.30 (dd, 1 H, $J_{3\text{-}4}$ = 9.1, $J_{3\text{-}4}$ = 9.3 Hz, H-3), 7.67–7.71 (dd, 1 H, $J_{5'\text{-}2'}$ = 1, $J_{5'\text{-}6'}$ = 8.4 Hz, H-5'), 7.71–7.76 (dd, 1 H, $J_{6'\text{-}2'}$ = 2, $J_{6'\text{-}5'}$ = 8.4 Hz, H-6'), 7.86–7.88 (dd, 1 H, $J_{2'\text{-}5'}$ = 1, $J_{2'\text{-}6'}$ = 2 Hz, H-2').

^{13}C NMR (62.9 MHz, $CDCl_3$): δ = 20.5, 20.7, 20.8 [C-CH_3], 61.9 (C-6), 67. 8 (C-4), 69.4 (C-2), 73.4 (C-3), 76.4 (C-5), 83.9 (C-1), 114.3 (C-4'), 114.9 (C-3'CN), 115.0 (C-4'CN), 116.5 (C-3'), 133.3 (C-5'), 134.9 (C-2'), 135.0 (C-6'), 140.88 (C-1'),169.1, 169.3, 169.9, 170.5 [C-CO].

MS-MALDI-TOF: m/z = 513.24 $[M + Na]^+$.

Anal. calcd for $C_{22}H_{22}N_2O_9S$: C, 53.87; H, 4.52; N, 5.71; S, 6.54. Found: C, 53.86; H, 4.73; N, 5.33; S, 6.24.

2,3,6,2',3',4',6'-Hepta-*O*-benzoyl-1-thio-β-lactose (36f)

Lactose (6.50 g, 19 mmol) in Pyridin (60 ml) was heated at 80 °C for 30 minutes and on cooling benzoyl chloride (30 ml, 258 mmol) was added dropwise. The reaction mixture was heated for 2 h at 0 °C. To the cooled solution was added H_2O (10 ml) and after 10 minutes the mixture was poured into ice water (500 ml). The aqueous phase was extracted with CH_2Cl_2 (3 × 100 ml). The organic phase was washed with 2M HCl (3 × 50 ml), sat. solution of $NaHCO_3$ (1 × 50 ml) and H_2O (1 × 50 ml), dried (Na_2SO_4), filtrated and the solvent was removed *in vacuo*. The product was not isolated and used immediately.

A solution of 1,2,3,6,2',3',4',6'-octa-*O*-benzoyl-α/β-lactose (19 mmol) in CH_2Cl_2 (50 ml) was treated with 33% HBr in AcOH (20 ml) at r.t. for 2 h. The solution was cooled in an ice-bath, diluted with CH_2Cl_2 (100 ml), washed sequentially with ice-cold H_2O (50 ml), ice-cold, sat. solution of $NaHCO_3$ (2 × 50 ml) and ice cold H_2O (50 ml), dried (Na_2SO_4), and filtrated and the solvent was removed *in vacuo*. The product was not isolated and used immediately.

A solution of 2,3,6,2',3',4',6'-hepta-*O*-benzoyl-α-lactosyl bromide and thiourea (1.90 g, 25 mmol) in anhydrous acetone (200 ml) was boiled under reflux for 7 h, cooled and aceton was evaporated *in vacuo*. The residue was stierred with CH_2Cl_2 (100 ml) and one aqueous solution of $K_2S_20_7$ (5.60 g, 25 mmol) at reflux over night. After cooling, the organic layer was separeted and washed with water (25 ml). After drying (Na_2SO_4), filtration and removal of the solvent, the crude product was purified

by chromatography on silica gel [eluent: toluene/acetone, 10:1] to give **36f**; amorphous white solid; yield: 12.47 g (60 %); $[\alpha]_D^{20°}$ –69.8 (c = 0.5, $CHCl_3$).

^{1}H NMR (250 MHz, $CDCl_3$): δ = 3.68–3.76 (m, 2 H, H-6'), 3.80–3.91 (m, 2 H, H-5, H-5'), 4.20–4.30 (dd, 1 H, $J_{4\text{-}3}$ = 9.4, $J_{4\text{-}5}$ = 9.8 Hz, H-4), 4.47–4.60 (m, 2 H, H-6), 4.68–4.77 (dd, 1 H, $J_{1\text{-}2}$ = 9.6, $J_{1\text{-SH}}$ = 9.8 Hz, H-1), 4.86 (d, 1 H, $J_{1\text{-}2}$ = 7.9 Hz, H-1'), 5.31–5.45 (m, 2 H, H-2, H-3'), 5.65–5.81 (m, 3 H, H-3, H-2', H-4'), 7.09–7.60 (m, 21 H, H-3Ar, H-4Ar), 7.84–8.02 (m, 14 H, H-2Ar).

^{13}C NMR (62.9 MHz, $CDCl_3$): δ = 61.0 (C-6'), 62.5 (C-6), 67.5 (C-4'), 69.9 (C-2'), 71.4 (C-5'), 71.8 (C-3'), 73.7 (C-3), 74.1 (C-2), 75.7 (C-4), 77.5 (C-5), 78.9 (C-1), 100.9 (C-1'), 128.2, 128.4, 128.51, 128.55, 128.6 [C-3Ar], 129.5, 129.64,129.67, 129.7, 129.9, 129.9 [C-1Ar, C-2Ar], 133.2, 133.4, 133.5 [C-4Ar], 164.8, 165.2, 165.3, 165.5, 165.9 [C-CO].

MALDI-TOF: m/z = 1109.65 $[M + Na]^+$.

Anal. calcd for $C_{61}H_{50}O_{17}S$: C, 67.39; H, 4.64; S, 3.65. Found: C, 68.05; H, 4.29; S, 2.55.

3,4-Dicyanophenyl-2,3,6,2',3',4',6'-hepta-*O*-benzoyl-1-thio-β-lactoside (46β)

Synthesised from 2,3,6,2',3',4',6'-Hepta-*O*-benzoyl-1-thio-β-lactose (**39f**; 10.00 g, 9.2 mmol); amorphous white solid; yield: 11.00 g (Quantitative); $[\alpha]_D^{20°}$ +20.6 (c = 0.5, $CHCl_3$).

^{1}H NMR (250 MHz, $CDCl_3$): δ = 3.64–3.84 (m, 2 H, H-6'), 3.92–4.03 (m, 2 H, H-5, H-5'), 4.12–4.21 (dd, 1 H, $J_{4\text{-}3}$ = 9.4, $J_{4\text{-}5}$ = 9.6 Hz, H-4), 4.45–4.54 (dd, 1 H, $J_{6a\text{-}5}$ = 4.9, $J_{6a\text{-}6b}$ = 12.3 Hz, H-6a), 4.63–4.71 (dd, 1 H, $J_{6b\text{-}5}$ = 1.7, $J_{6b\text{-}6a}$ = 12.3 Hz, H-6b), 4.90 (d, 1 H, $J_{1'\text{-}2'}$ = 7.9 Hz, H-1'), 4.99 (d, 1 H, $J_{1\text{-}2}$ = 9.9 Hz, H-1), 4.34–4.45 (m, 2 H, H-2, H-3'), 4.67–4.76 (m, 2 H, H-2', H-4'), 4.80–4.89 (t, 1 H, $J_{\text{H-2/H-5}}$ = 9.4 Hz, H-3), 7.09–7.60 (m, 24 H, H-3Ar, H-4Ar, H-2'', H-5'', H-6''), 7.84–8.02 (m, 14 H, H-2Ar).

^{13}C NMR (62.9 MHz, $CDCl_3$): δ = 60.9 (C-6'), 62.1 (C-6), 67.5 (C-4'), 69.9 (C-2'), 70.0 (C-2), 71.5 (C-5'), 71.7 (C-3'), 73.5 (C-3), 75. 8 (C-4), 77.6 (C-5), 83.9 (C-1), 101.1 (C-1'), 114.2 (C-4''), 114.6 (C-3''CN), 114.9 (C-4''CN), 116.2 (C-3''), 128.3, 128.4, 128.5, 128.6, 128.7 [C-3Ar], 128.8, 129.2, 129.4 [C-1Ar], 128.5, 129.6, 129.7,

129.92, 129.98 [C-2Ar], 133.2, 133.3, 133.4, 133.5, 133.6, 133.7, 133.8 [C-5'', C-4Ar], 135.3 (C-6''), 135.4 (C-2''), 140.4 (C-1''), 164.8, 165.1, 165.19, 165.22, 165.4, 165.6 [C-CO].

MS-MALDI-TOF: m/z = 1235.92 $[M + Na]^+$.

Anal. calcd for $C_{69}H_{52}N_2O_{17}S$: C, 68.31; H, 4.32; N 2.31; S, 2.64. Found: C, 68.02; H, 4.29; N, 2.23; S, 2.56.

General method for the synthesis of monosubstituted phenyl glycosides:

NaH (88 mg, 2.2 mmol, 60% suspension in oil) was added to a stirred solution of 2,3,4,6-tetra-*O*-benzyl-α/β-D-glucopyranose (**1**;[116] 1 g, 1.85 mmol) and nitrobenzene derivatives (2.2 mmol) in dry DMF (10 ml) at room temperature under argon. The mixture was stirred 15 minutes At the end of this period, the mixture was poured into H_2O (100 ml) and CH_2Cl_2 (20 ml). The aqueous layer was extracted with CH_2Cl_2 (3 × 20 ml). The organic layer was washed with H_2O (3 × 20 ml). After drying (Na_2SO_4), filtration and removal of the solvent, the crude product was purified by chromatography on silica gel [eluent: toluene/acetone, 20:1]. For analytical purposes the α/β-mixtures were separated, when possible, by preparative HPLC.

2-Nitrophenyl-2,3,4,6-tetra-*O*-benzyl-α/β-D-glucopyranoside (50α/50β)

Synthesised from 2,3,4,6-tetra-*O*-benzyl-α/β-D-glucopyranose (**1**)[116] and *o*-dinitrobenzene (**48**); yield: 1.22 g [94%; α/β, 3:1 (HPLC)].

α-Isomer (**50α**)

Colourless oil; $[\alpha]_D^{20°}$ +120.1° (c = 1, $CHCl_3$).

^{1}H NMR (250 MHz, $CDCl_3$): δ = 3.52–3.58 (dd, 1 H, $J_{6a\text{-}5}$ = 2, $J_{6a\text{-}6b}$ = 11 Hz, H-6a), 3.67–3.78 (m, 3 H, H-2, H-4, H-6b), 3.89–3.95 (m, 1 H, H-5), 4.17–4.27 (dd, 1H, $J_{3\text{-}2}$ = 9.1, $J_{3\text{-}4}$ = 9.3 Hz, H-3), 4.4 (d, 1 H, J = 12 Hz, H-CH_2), 4.47–4.64 (m, 3 H, H-CH_2), 4.77–4.91 (m, 3 H, H-CH_2), 5.00 (d, 1 H, J = 11 Hz, H-CH_2), 5.46 (d, 1 H, $J_{1\text{-}2}$ = 3.5 Hz, H-1), 7.02–7.11 (ddd, 1 H, $J_{4'\text{-}6'}$ = 1.2, $J_{4'\text{-}5'}$ = 7.4, $J_{4'\text{-}3'}$ = 8.4 Hz, H-4'),

7.13–7.37 (m, 21 H, H-6', H-2Ar, H-3Ar, H-4Ar), 7.38–7.45 (ddd, 1 H, $J_{5'-3'}$ = 1.7, $J_{5'-4'}$ = 7.4, $J_{5'-6'}$ = 9.1 Hz, H-5'), 7.80–7.84 (dd, 1 H, $J_{3'-5'}$ = 1.7, $J_{3'-4'}$ = 8.4 Hz, H-3').
^{13}C NMR (62.9 MHz, $CDCl_3$): δ = 68.2 (C-6), 71.9 (C-5), 73.4, 73.5, 74.9, 75.9 [C-CH_2], 77.1 (C-4), 79.8 (C-2), 81.5 (C-3), 96.9 (C-1), 117.1 (C-6'), 121.8 (C-4'), 125.4 (C-3'), 127.6, 127.7, 127.8, 128.9, 128.1, 128.3, 128.4, 128.5 [C-2Ar, C-3Ar, C-4Ar], 133.8 (C-5'), 137.7, 138.2, 138.3, 138.7 [C-1Ar], 140.8 (C-2'), 149.9 (C-1').
MS-MALDI-TOF: m/z = 684.6 $[M + Na]^+$.
Anal. calcd for $C_{40}H_{39}NO_8$: C, 72.60; H, 5.94; N, 2.12. Found: C, 72.98; H, 5.84; N, 2.09.

β-Isomer (**50β**)
^{1}H NMR (250 MHz, $CDCl_3$): δ = 3.55–3.87 (m, 6 H, H-2, H-3, H-4, H-5, H-6), 4.45–4.58 (m, 3 H, H-CH_2), 4.77–4.85 (m, 3 H, H-CH_2), 4.97 (d, 1H, J = 11 Hz, H-CH_2), 5.04 (d, 1H, J = 11 Hz, H-CH_2), 5.11 (d, 1 H, J_{1-2} = 7 Hz, H-1), 7.15–7.50 (m, 23 H, H-4', H-5', H-6', H-2 Ar, H-3 Ar, H-4Ar), 7.83 (d, 1 H, $J_{3'-4'}$ = 7.9 Hz, H-3').
^{13}C NMR (62.9 MHz, $CDCl_3$): δ = 68.9 (C-6), 73.5 (C-5), 75.1, 75.2, 75.5, 75.8 [C-CH_2], 77.5 (C-2), 81.6 (C-4), 84.6 (C-3), 100.9 (C-1), 117.1 (C-6'), 122.0 (C-4'), 125.4 (C-3'), 127.7, 127.8, 127.9, 128.0, 128.3, 128.4, 128.5 [C-2Ar, C-3 Ar, C-4 Ar], 133.9, 137.8, 137.9, 138.4 [C-1Ar], 140.5 (C-2'), 150.1 (C-1').
MS-MALDI-TOF: m/z = 684.6 $[M + Na]^+$.

2-Nitrophenyl-2,3,4,6-tetra-*O*-benzyl-α/β-D-galactopyranoside (51α/51β)

Synthesised from 2,3,4,6-tetra-*O*-benzyl-α/β-D-galactopyranose (**47b**;[269] 0.5 g, 0.92 mmol) and *o*-dinitrobenzene (**48**); yield: 0.55 g [92%; α/β, 3:1 (HPLC)].

α-Isomer (**51α**)
Colourless oil; $[\alpha]_D^{20°}$ +129° (c = 0.75, $CHCl_3$).
^{1}H NMR (250 MHz, $CDCl_3$): δ = 3.42–3.54 (m, 2 H, H-6), 3.99 (bs, 1 H, H-4), 4.07–4.15 (dd, 1 H, J_{5-6a} = 6.4, J_{5-6b} = 6.9 Hz, H-5), 4.17–4.25 (m, 2 H, H-2, H-3), 4.27–4.39 (m, 2 H, H-CH_2), 4.30 (d, 1 H, J = 11.6 Hz, H-CH_2), 4.37 (d, 1 H, J = 11.8 Hz,

H-CH_2), 4.56 (d, 1 H, J = 11.3 Hz, H-CH_2), 4.63 (d, 1 H, J = 12.3 Hz, H-CH_2), 4.78 (d, 1 H, J = 11.6 Hz, H-CH_2), 4.82–4.92 (m, 2 H, H-CH_2), 4.96 (d, 1 H, J = 11.3 Hz, H-CH_2), 5.56 (d, 1 H, $J_{1\text{-}2}$ = 2.2 Hz, H-1), 7.00–7.07 (ddd, 1 H, $J_{4'\text{-}6'}$ = 0.9, $J_{4'\text{-}5'}$ = 7.2, $J_{4'\text{-}3'}$ = 8.1 Hz, H-4'), 7.12–7.43 (m, 22 H, H-2Ar, H-3Ar, H-4Ar), 7.78–7.84 (dd, 1 H, $J_{3'\text{-}5'}$ = 1.7, $J_{3'\text{-}4'}$ = 8.1 Hz, H-3').

^{13}C NMR (62.9 MHz, $CDCl_3$): δ = 68.6 (C-6), 71.2 (C-5), 73.2, 73.5, 73.6, 74.9 [C-CH_2], 75.2 (C-4), 76.1 (C-2), 78.6 (C-3), 97.2 (C-1), 117.0 (C-6'), 121.5 (C-4'), 125.4 (C-3'), 127.55, 127.58, 127.61, 127.63, 127.73, 127.74, 128.21, 128.26, 128.29, 128.31, 128.39 [C-2Ar, C-3Ar, C-4Ar], 133.8 (C-5'), 137.8, 138.51, 138.54, 138.6 [C-1Ar], 140.7 (C-2'), 150.1 (C-1').

MS-MALDI-TOF: m/z = 684.0 $[M + Na]^+$.

Anal. calcd for $C_{40}H_{39}NO_8$: C, 72.60; H, 5.94; N, 2.12. Found: C, 73.05; H, 5.97; N, 2.10.

β-Isomer (**51β**)

^{1}H NMR (250 MHz, $CDCl_3$): δ = 3.53–3.70 (m, 2 H, H-6), 3.76–3.78 (m, 1 H, H-5), 4.10–4.15 (dd, 1 H, $J_{3\text{-}4}$ = 3.9, $J_{3\text{-}2}$ = 7.6 Hz, H-3), 4.29–4.61 (m, 9 H, H-2, H-2, H-CH_2), 4.69 (d, 1 H, J = 11.8 Hz, H-CH_2), 5.66 (1 H, $J_{1\text{-}2}$ = 1.2 Hz, H-1), 7.04–7.11 (ddd, 1 H, $J_{4'\text{-}6'}$ = 1, $J_{4'\text{-}5'}$ = 7.1, $J_{4'\text{-}3'}$ = 8.1 Hz, H-4'), 7.12–7.43 (m, 22 H, H-2Ar, H-3Ar, H-4Ar), 7.78–7.82 (dd, 1 H, $J_{3'\text{-}5'}$ = 1.7, $J_{3'\text{-}4'}$ = 8.1 Hz, H-3').

^{13}C NMR (62.9 MHz, $CDCl_3$): δ = 70.5 (C-6), 72.2, 72.5, 73.4, 75.5 (x2) [C-CH_2] (C-5), 82.1 (C-4), 82.3 (C-3), 88.5 (C-2), 106.4 (C-1), 119.4 (C-6'), 122.2 (C-4'), 125.5 (C-3'), 127.5, 127.6, 127.7, 127.8, 127.9, 128.0, 128.1, 128.33, 128.37, 128.36, 128.39, 128.4 [C-2Ar, C-3Ar, C-4Ar], 133.7 (C-5'), 137.3, 137.6, 138.1, 138.2 [C-1Ar], 141.3 (C-2'), 149.8 (C-1').

MS-MALDI-TOF: m/z = 684.0 $[M + Na]^+$.

2-Nitrophenyl -2,3,4,6-tetra-*O*-benzyl-α-D-manopyranoside (52α)

Synthesised from 2,3,4,6-tetra-*O*-benzyl-α/β-D-manopyranose (**47c**;[270] 0.5 g, 0.92 mmol) and *o*-dinitrobenzene (**48**); colourless oil; yield: 0.53 g (89%); $[\alpha]_D^{20°}$ +59.7° (c = 1, $CHCl_3$).

^{1}H NMR (250 MHz, $CDCl_3$): δ = 3.66–3.71 (dd, 1 H, J_{6a-5} = 2.2, J_{6a-5} = 10.8 Hz, H-6a), 3.73–3.80 (dd, 1 H, J_{6b-5} = 4.9, J_{6b-5} = 11.1 Hz, H-6b), 3.89–4.13 (m, 4 H, H-2, H-3, H-4, H-5), 4.46 (d, 1 H, *J* = 11.8 Hz, H-CH_2), 4.52 (d, 1 H, *J* = 11.1 Hz, H-CH_2), 4.60 (d, 1 H, *J* = 11.8 Hz, H-CH_2), 3.67–4.75 (m, 3 H, H-CH_2), 4.81 (d, 1 H, *J* = 12.1 Hz, H-CH_2), 4.89 (d, 1 H, *J* = 11.1 Hz, H-CH_2), 5.57 (d, 1 H, J_{1-2} = 2.0 Hz, H-1), 7.04–7.12 (ddd, 1 H, $J_{4'-6'}$ = 1.7, $J_{4'-5'}$ = 6.7, $J_{4'-3'}$ = 8.1 Hz, H-4'), 7.16–7.45 (m, 22 H, H-2Ar, H-3Ar, H-4Ar), 7.78–7.83 (dd, 1 H, $J_{3'-5'}$ = 1.4, $J_{3'-4'}$ = 8.1 Hz, H-3').

^{13}C NMR (62.9 MHz, $CDCl_3$): δ = 69.1 (C-6), 72.7, 73.2 [C-CH_2], 73.3 (C-5, C-CH_2), 74.4 (C-4), 74.8 (C-2), 75.0 (C-CH_2), 79.6 (C-3), 98.3 (C-1), 118.7 (C-6'), 122.3 (C-4'), 125.4 (C-3'), 127.5, 127.6, 127.7, 127.8, 127.9, 128.1, 128.2, 128.3, 128.4, 128.5 [C-2Ar, C-3Ar, C-4Ar], 134.1 (C-5'), 138.1, 138.2 (x 2), 138.4 [C-1Ar], 140.7 (C-2'), 149.7 (C-1').

MS-MALDI-TOF: *m*/*z* = 684.0 $[M + Na]^+$.

Anal. calcd for $C_{40}H_{39}NO_8$: C, 72.60; H, 5.94; N, 2.12. Found: C, 73.02; H, 5.96; N, 2.11.

4-Cyanophenyl-2,3,4,6-tetra-*O*-benzyl-α/β-D-glucopyranoside (53α/53β)

Synthesised from 2,3,4,6-tetra-*O*-benzyl-α/β-D-glucopyranose (**1**)[116] and *p*-nitrobenzonitrile (**49**); slighly yellow oil; yield: 0.95 g [82%; α/β, 3:1 (NMR)].

Representativ signals in ^{13}C NMR for α and β isomers.

α-Isomer (**53α**)

^{13}C NMR (62.9 MHz, $CDCl_3$): δ = 68.1 (C-6), 71.3 (C-5), 77.1 (C-4), 79.6 (C-2), 81.8 (C-3), 95.4 (C-1), 105.6 (C-4'), 117.2 (C-2', C-6'), 133.9 (C-3', C-5'), 159.9 (C-1').

β-Isomer (**53β**)

^{13}C NMR (62.9 MHz, $CDCl_3$): δ = 68.7 (C-6), 75.3 (C-5), 77.5 (C-2), 81.8 (C-4), 84.6 (C-3), 100.7 (C-1), 105.9 (C-4'), 117.2 (C-2', C-6'), 133.9 (C-3', C-5'), 160.3 (C-1').
MS-MALDI-TOF: *m*/*z* = 663.9 $[M + Na]^+$.

4-Cyanophenyl-2,3,4,6-tetra-*O*-benzyl-α/β-D-galactopyranoside (54α/54β)

Synthesised from 2,3,4,6-tetra-*O*-benzyl-α/β-D-galactopyranose[269] (**47b**) and *p*-nitrobenzonitrile (**49**); slighly yellow oil; yield: 0.97 g [84 %; α/β, 6:1 (NMR)].
Representativ signals in ^{13}C NMR for α and β isomers

α-Isomer (**54β**)

^{13}C NMR (62.9 MHz, $CDCl_3$): δ = 68.6 (C-6), 70.6 (C-5), 74.7 (C-4), 76.0 (C-2), 78.7 (C-3), 96.4 (C-1), 105.5 (C-4'), 117.4 (C-2', C-6'), 133.8 (C-3', C-5'), 160.3 (C-1').

β-Isomer (**54β**)

^{13}C NMR (62.9 MHz, $CDCl_3$): δ = 70.3 (C-6), 75.9 (C-5), 82.3 (C-4), 82.4 (C-3), 88.5 (C-2), 104.3 (C-1), 105.5 (C-4'), 117.4 (C-2', C-6'), 133.8 (C-3', C-5'), 160.3 (C-1').
MS-MALDI-TOF: *m*/*z* = 663.9 $[M^+ + Na]$.

4-Cyanophenyl-2,3,4,6-tetra-*O*-benzyl-α-D-manopyranoside (55α)

Synthesised from 2,3,4,6-tetra-*O*-benzyl-α/β-D-manopyranose (**47c**;[270] 0.5 g, 0.92 mmol) and *p*-nitrobenzonitrile (**49**); slighly yellow oil; yield: 0.49 g (84%); $[\alpha]_D^{20°}$ +80.8 (c = 0.75, $CHCl_3$).
^{1}H NMR (250 MHz, $CDCl_3$): δ = 3.59–3.66 (dd, 1 H, $J_{6a\text{-}5}$ = 3.9, $J_{6a\text{-}5}$ = 12.5 Hz, H-6a), 3.70–3.80 (m, 2 H, H-5, H-6b), 3.91–3.95 (t, 1 H, $J_{2\text{-}1/2\text{-}3}$ = 3.9 Hz, H-2) 4.01–4.13 (m, 2 H, H-3, H-4), 4.43 (d, 1 H, *J* = 11.8 Hz, H-CH_2), 4.51 (d, 1 H, *J* = 10.5 Hz, H-CH_2), 4.59 (d, 1 H, *J* = 11.8 Hz, H-CH_2), 3.67–4.90 (m, 5 H, H-CH_2), 5.58 (d, 1 H, $J_{1\text{-}2}$ = 2.0 Hz, H-1), 7.05 (d, 2 H, $J_{2'\text{-}3'/6'\text{-}5'}$ = 8.9 Hz, H-2', H-6'), 7.13–7.40 (m, 20 H, H-2Ar, H-3Ar, H-4Ar), 7.52 (d, 2 H, $J_{3'\text{-}4'/5'\text{-}6'}$ = 8.9 Hz, H-3', H-5').

^{13}C NMR (62.9 MHz, $CDCl_3$): δ = 68.8 (C-6), 72.6 (C-CH_2), 72.9 (C-5), 73.1, 73.3 [C-CH_2], 74.4 (C-4), 74.5 (C-2), 75.1 (C-CH_2), 79.6 (C-3), 96.5 (C-1), 105.6 (C-4'), 117.1 (C-2', C-6'), 127.5, 127.6, 127.71, 127.75, 127.83, 127.87, 127.9, 128.3, 128.4, 128.5 [C-2Ar, C-3Ar, C-4Ar], 133.9 (C-3', C-5'), 137.9, 138.1, 138.2 (x 2) [C-1Ar], 159.3 (C-1').

MS-MALDI-TOF: *m*/*z* = 663.9 [M^+ + Na].

Anal. calcd for $C_{41}H_{39}NO_6$: C, 76.73; H, 6.13; N, 2.18. Found: C, 76.81; H, 6.14; N, 2.18.

4.2.8 Related to Chapter 2.3.3

Tetrakis-2(3),9(10),16(17),23(24)-(2,3,4,6-tetrabenzyl-α/β-D-glucopyranosyl)-phthalocyaninato zinc (56a)

A mixture of 3,4-Dicyanophenyl-2,3,4,6-tetra-*O*-benzyl-α/β-D-glucopyranoside (**41α/41β**, 3.5 g, 5.2 mmol) and zinc acetate dihydrate (0.57 g, 2.6 mmol) in pentanol (10 ml) was stirred 5 h at 150 °C. After cooling, the mixture was poured into MeOH (100 ml) and the solid was filtered. The crude product was purified by chromatography over silica gel [eluent: CH_2Cl_2] to give **56a**; green solid; yield 1.9 g (58%).

UV-Vis (DMSO): λ (In. Rel. %) = 354 (42, B-band), 612 (19, sh), 680 nm (100, Q-band).

^{1}H NMR (250 MHz, DMSO-d_6): δ = 3.75–5.37 (m, 24 H, H-2', H-3', H-4', H-5', H-6'), 6.29 (br, 1 H, H-1'), 7.03–7.55 (br, 80 H, H-Bn), 7.98 (br, 4 H, H-5), 9.25 (s, 4 H, H-3), 9.39 (bd, 4 H, H-6).

^{13}C NMR (62.9 MHz, DMSO-d_6): δ = 69.9 (C-6'α), 73.1 (C-5'α), 73.7, 74.0, 74.2, 75.7, 76.3, 76.5 [C-CH_2Bnα/β], 78.8 (C-4'α), 81.4(C-2'α), 83.2 (C-3'α), 83.5 (C-4'β), 85.9 (C-3'β), 96.9, 97.2 [C-1'α], 102.7 (C-1'β), 110.5 (C-3), 119.0 (C-5), 124.7 (C-6), 127–129 [C-Bn], 134.0 (C-7), 139–140 [C-Bn], 141.5 (C-2), 154.0 (C-1, C-8), 160 (C-4).

MS MALDI-TOF: *m*/*z* = 2730 $[M + H]^+$.

Anal. calcd for $C_{168}H_{152}N_8O_{24}Zn$: C, 73.85; H, 5.61; N, 4.10. Found: C, 73.09; H, 5.65; N, 4.10.

Tetra-2(3),9(10),16(17),23(24)-α/β-D-glucopyranosyl-phthalocyaninato zinc (56c)

Method 1

A mixture of 3,4-Dicyanophenyl-2,3,4,6-tetra-*O*-benzoyl-α/β-D-glucopyranoside (**42α/42β**, 2 g, 2.7 mmol) and zinc acetate dihydrate (1.1 g, 5.4 mmol) in DMAE (2 ml) was stirred 5 h at 170 °C. After cooling, the mixture was poured into MeOH (100 ml) and the solid was filtered. The crude product was purified by

chromatography over silica gel [eluent: CH_2Cl_2] to give **56b**. The resulting mixture of phthalocyanines was dissolved in dry MeOH containing 20% of dry THF. NaOMe (100 µl) was added and the solution was stirred for 1 h. Dowex 50WX8-400 Ion exchanger was added to neutralise the solution and then was filtered off. The solvent was evaporated and the solid washed with *n*-hexane to give **56c** as a mixture of 110 mg from phthalocyanines with different grade of deprotection.

Method 2

A mixture of 3,4-dicyanophenyl-2,3,4,6-tetra-*O*-acetyl-α/β-D-glucopyranoside (**43α/43β**; 1 g, 2 mmol) was suspended in dry MeOH (25 ml). NaOMe (100 µl) was added and the solution was stirred for 1 h. Dowex 50WX8-400 ion exchanger was added to neutralise the solution. The ion exchanger was then filtered off and the solvent evaporated.

To the deprotected dinitrile dissolved in a mixture of DMAE (1 ml) zinc acetate dihydrate (231 mg, 1 mmol) was added. The reaction mixture was stirred under Argon for 8 h at 100°C. After cooling it was dissolved in a minimal amount of water and acetone was added. The solid was filtered, dissolved again in a minimal amount of water, reprecipitated adding acetone and collected after filtration. The crude product was purified by preparative reverse phase HPLC chromatography [eluent: H_2O/CH_3CN] to give **56c**; green solid; yield 82 mg (12%).

Method 3

A mixture of 3,4-dicyanophenyl-2,3,4,6-tetra-*O*-acetyl-α/β-D-glucopyranoside (**43α/43β**; 1 g, 2 mmol) was suspended in dry MeOH (25 ml). NaOMe (100 µl) was added and the solution was stirred for 1 h. Dowex 50WX8-400 ion exchanger was added to neutralise the solution. The ion exchanger was then filtered off and the solvent evaporated.

To the deprotected dinitrile dissolved in a mixture of DMAE (1 ml) and butanol (0.5 ml), zinc acetate (183 mg, 1 mmol) was added. The reaction mixture was stirred under Argon for 24 h at 100°C. After cooling it was dissolved in a minimal amount of water and acetone was added. The solid was filtered, dissolved again in a minimal

amount of water, reprecipitated adding acetone and collected after filtration. The crude product was purified by preparative reverse phase HPLC chromatography [eluent: H_2O/CH_3CN] to give **56c**; green solid; yield 320 mg (51%).

UV-Vis (DMSO): λ (In. Rel. %) = 354 (41, B-band), 613 (17, sh), 681 nm (100, Q-band).

^{1}H NMR (250 MHz, DMSO-d_6): δ = 6.05 (br, 4 H, H-1'), 7.95 (br, 4 H, H-6), 9.08 (br, 4 H, H-3), 9.35 (s, 4 H, H-5).

^{13}C NMR (62.9 MHz, DMSO-d_6): δ = 61.3 (C-6'), 70.5 (C-5'), 72.3 (C-4'), 73.8 (C-2'), 74.8 (C-3'), 98.9 (C-1'), 109.8 (C-3), 120.2 (C-5), 124.2 (C-6), 132.5 (C-7), 140.1 (C-2), 153 (C-1, C-8), 159 (C-4).

MS-MALDI-TOF: Anal. calcd for $C_{56}H_{57}N_8O_{24}Zn$ $[M + H]^+$ *m*/*z* = 1289.2777. Found: *m*/*z* = 1289.2690.

Tetra-2(3),9(10),16(17),23(24)-(1-thio-β-D-glucopyranosyl)-phthalocyaninato zinc (56d)

A mixture of 3,4-dicyanophenyl-2,3,4,6-tetra-O-acetyl-1-thio-β-D-glucopyranoside (**45β**; 1.5 g, 3.1 mmol) was suspended in dry MeOH (25 ml). NaOMe (100 μl) was added and the solution was stirred for 1 h. Dowex 50WX8-400 ion exchanger was added to neutralise the solution. The ion exchanger was then filtered off and the solvent evaporated.

To the deprotected dinitrile dissolved in a mixture of DMAE (1 ml) zinc acetate dihydrate (335 mg, 1.53 mmol) was added. The reaction mixture was stirred under Argon for 12 h at 100°C. After cooling it was dissolved in a minimal amount of water and acetone was added. The solid was filtered, dissolved again in a minimal amount of water, reprecipitated adding acetone and collected after filtration. The crude product was purified by preparative reverse phase HPLC chromatography [eluent: H_2O/CH_3CN] to give **56d**; green solid; yield 95 mg (15%).

UV-Vis (DMSO): λ (In. Rel. %) = 362 (33, B-band), 622 (16, sh), 691 nm (100, Q-band).

^{1}H NMR (250 MHz, DMSO-d_6): δ = 8.3 (br, 4 H, H-6), 9.3 (br, 4 H, H-5), 9.5 (br, 4 H, H-3).

^{13}C NMR (62.9 MHz, DMSO-d_6): δ = 61.6 (C-6'), 70.3 (C-4'), 73.1 (C-2'), 78.8 (C-5'), 81.7 (C-3'), 88.0 (C-1'), 123.0 (C-3), 123.6 (C-6), 130.9 (C-4), 136.5 (C-7), 137.8 (C-2), 139 (C-4), 153 (C-1, C-8).

MS-MALDI-TOF: Anal. calcd for $C_{56}H_{57}N_8O_{20}S_4Zn$ $[M + H]^+$ m/z = 1353.18634. Found: m/z = 1353.14486.

Tetra-2(3),9(10),16(17),23(24)-(1-thio-β-D-lactosyl) phthalocyaninato zinc (56e)

A mixture of 3,4-dicyanophenyl-2,3,4,6-tetra-O-benzoyl-1-thio-β-D-lactoside (**46β**, 3.0 g, 2.5 mmol) was suspended in dry MeOH (200 ml). NaOMe (100 μl) was added and the solution was stirred for 3 h. Dowex 50WX8-400 ion exchanger was added to neutralise the solution. The ion exchanger was then filtered off and the solvent evaporated.

To the deprotected dinitrile dissolved in a mixture of DMAE (1 ml) zinc acetate dihydrate (271 mg, 1.25 mmol) was added. The reaction mixture was stirred under Argon for 12 h at 100°C. After cooling it was dissolved in a minimal amount of water and acetone was added. The solid was filtered, dissolved again in a minimal amount of water, reprecipitated adding acetone and collected after filtration. The crude product was purified by preparative reverse phase HPLC chromatography [eluent: H_2O/CH_3CN] to give **56e**: Yield 125 mg (10%).

UV-Vis (DMSO): λ (In. Rel. %) = 363 (55, B-band), 622 (22, sh), 689 nm (100, Q-band).

^{1}H NMR (250 MHz, DMSO-d_6): δ = 8.3 (br, 4 H, H-6), 9.5 (br, 4 H, H-5), 9.3 (br, 4 H, H-3).

^{13}C NMR (62.9 MHz, DMSO-d_6): δ = 60.9 (C-6', C-6''), 68.6 (C-4''), 71.0 (C-2''), 73.2 (C-2'), 73.7 (C-5'), 76.0 (C-3'), 76.9 (C-3''), 79.6 (C-5''), 80.6 (C-4'), 87.6 (C-1'), 104.3 (C-1'').

MS-MALDI-TOF: Anal. calcd for $C_{80}H_{96}N_8O_{40}S_4Zn+Na$ $[M]^+$ m/z = 2013.37958. Found: m/z =2023.378.

5 Crystal Data

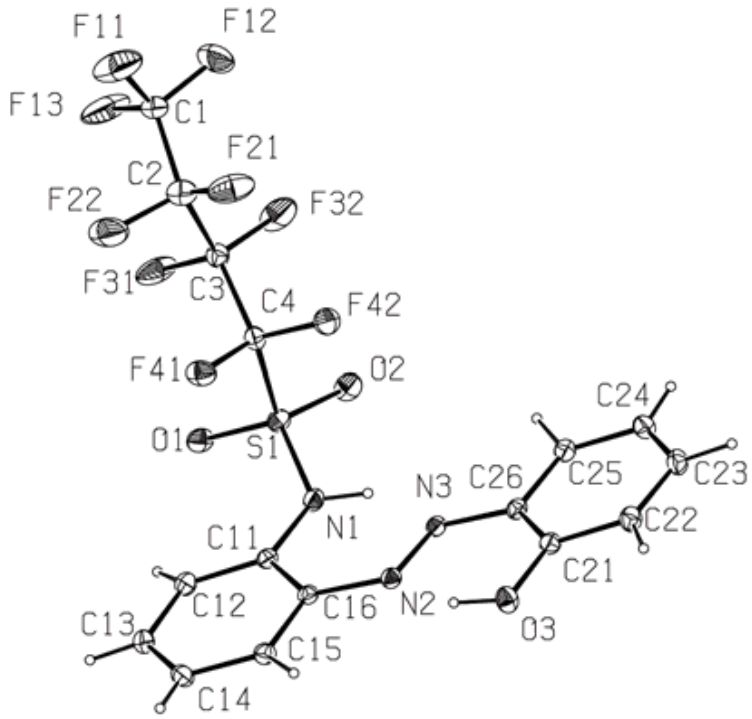


Figure 3 Molecular structure and atom numbers of compound **8a**

Table 21 Crystal data of compound **8a**

Crystal description			orange needle
Crystal size [mm]		a	0.75
		b	0.15
		c	0.15
Temperature [K]			213(2)
Unit cell dimensions	[Å]	a	5.6549(3)
		b	12.2550(9)
		c	27.170(6)
	[°]	α	90
		β	90.446(8)
		γ	90

Table 21 cont. Crystal data of compound **8a**

Volume [Å^3]	1882.9(5)
Crystal system	monoclinic
Space group	$P2_1/c$
Z	4
Calculated density [g/cm^3]	1.747
Independent reflexions	3075
$2\Theta_{max}$ [°]	129.9
Reflections observed	2735
Refined parameter	329
R_1	0.0881
wR_2	0.2521

Table 22 Atomic coordinates [Å] and isotropic displacement parameter [Å^2] for compound **8a**

Atom	X	Y	Z	U (eq)
C (1)	–0.1490 (2)	0.5696 (6)	0.5696 (6)	0.083 (2)
C (2)	–0.2543 (2)	0.5049 (7)	0.5049 (7)	0.100 (2)
C (3)	–0.0820 (1)	0.4394 (4)	0.4394 (4)	0.058 (1)
C (4)	–0.1952 (9)	0.3632 (4)	0.3632 (4)	0.053 (1)
C (11)	–0.3124 (8)	0.2696 (4)	0.2696 (4)	0.044 (1)
C (12)	–0.2734 (1)	0.3617 (4)	0.3617 (4)	0.055 (1)
C (13)	–0.4322 (1)	0.3923 (4)	0.3923 (4)	0.056 (1)
C (14)	–0.6318 (1)	0.3313 (4)	0.3313 (4)	0.055 (1)
C (15)	–0.6711 (9)	0.2372 (4)	0.2372 (4)	0.049 (1)
C (16)	–0.5146 (8)	0.2053 (3)	0.2053 (3)	0.043 (1)
C (21)	–0.7440 (9)	–0.0772 (4)	–0.0772 (4)	0.049 (1)
C (22)	–0.7995 (1)	–0.1683 (4)	–0.1683 (4)	0.057 (1)
C (23)	–0.6516 (1)	–0.2051 (4)	–0.2051 (4)	0.059 (1)
C (24)	–0.4399 (1)	–0.1506 (5)	–0.1506 (5)	0.061 (1)
C (25)	–0.3810 (9)	–0.0605 (4)	–0.0605 (4)	0.052 (1)

Table 22 cont. Atomic coordinates [Å] and isotropic displacement parameter [Å^2] for compound **8a**

C (26)	–0.5293 (8)	–0.0226 (4)	–0.0226 (4)	0.045 (1)
F (11)	–0.3196 (1)	0.6289 (7)	0.6289 (7)	0.185 (3)
F (12)	–0.0894 (1)	0.5115 (5)	0.5115 (5)	0.148 (2)
F (13)	0.0142 (2)	0.6305 (6)	0.6305 (6)	0.216 (5)
F (21)	–0.4249 (8)	0.4449 (6)	0.4449 (6)	0.132 (2)
F (22)	–0.3501 (2)	0.5810 (6)	0.5810 (6)	0.198 (4)
F (31)	0.0546 (1)	0.5106 (5)	0.5106 (5)	0.146 (3)
F (32)	0.0464 (1)	0.3795 (4)	0.3795 (4)	0.153 (3)
F (41)	–0.3634 (6)	0.4169 (3)	0.4169 (3)	0.076 (1)
F (42)	–0.2985 (7)	0.2798 (3)	0.2798 (3)	0.079 (1)
N (1)	–0.1531 (8)	0.2336 (3)	0.2336 (3)	0.052 (1)
N (2)	–0.5844 (7)	0.1081 (3)	0.1081 (3)	0.044 (1)
N (3)	–0.4498 (7)	0.0716 (3)	0.0716 (3)	0.043 (1)
O (1)	0.1050 (7)	0.3965 (3)	0.3965 (3)	0.068 (1)
O (2)	0.1576 (7)	0.2326 (3)	0.2326 (3)	0.073 (1)
O (3)	–0.8946 (6)	–0.0445 (3)	–0.0445 (3)	0.060 (1)
S (1)	0.0117 (2)	0.3058 (1)	0.3058 (1)	0.051 (1)

Table 23 Hydrogen coordinates [Å] and isotropic displacement parameter [Å^2] for compound **8a**

Atom	**X**	**Y**	**Z**	***U* (eq)**
H (1)	–0.4000 (1)	0.4520 (5)	–0.0600 (2)	0.066 (2)
H (2)	–0.8330 (1)	0.1940 (4)	–0.0261 (2)	0.057 (1)
H (3)	–0.6940 (1)	–0.2660 (5)	0.1700 (2)	0.061 (2)
H (4)	–0.1300 (1)	0.4020 (5)	–0.0040 (2)	0.063 (2)
H (5)	–0.2260 (1)	–0.0140 (6)	0.1440 (2)	0.083 (2)
H (6)	–0.8670 (1)	0.0210 (6)	0.0400 (2)	0.074 (2)
H (7)	–0.3640 (9)	–0.1690 (4)	0.1860 (2)	0.048 (1)
H (8)	–0.9230 (1)	–0.1950 (5)	0.1020 (2)	0.070 (2)
H (9)	–0.1800 (1)	0.1690 (5)	0.0740 (2)	0.056 (2)
H (10)	–0.7210 (1)	0.3470 (5)	–0.0690 (2)	0.070 (2)

Table 24 Bond lengths [Å] for compound **8a**

Atom	Length	Atom	Length
O(3)–C(21)	1.346 (6)	N(1)–S(1)	1.605 (4)
C(21)–C(22)	1.385 (7)	C(1)–F(13)	1.231 (9)
C(21)–C(26)	1.410 (7)	C(1)–F(12)	1.257 (8)
C(22)–C(23)	1.372 (8)	C(1)–F(11)	1.331 (10)
C(23)–C(24)	1.397 (8)	C(1)–C(2)	1.494 (10)
C(24)–C(25)	1.368 (8)	C(2)–F(21)	1.283 (10)
C(25)–C(26)	1.400 (7)	C(2)–F(22)	1.385 (9)
C(26)–N(3)	1.404 (6)	C(2)–C(3)	1.543 (10)
N(2)–N(3)	1.269 (5)	C(3)–F(31)	1.300 (7)
N(2)–C(16)	1.416 (6)	C(3)–F(32)	1.319 (7)
C(11)–C(12)	1.382 (7)	C(3)–C(4)	1.532 (7)
C(11)–C(16)	1.413 (6)	C(4)–F(42)	1.334 (6)
C(11)–N(1)	1.422 (6)	C(4)–F(41)	1.337 (6)
C(12)–C(13)	1.377 (8)	C(4)–S(1)	1.847 (5)
C(13)–C(14)	1.375 (8)	S(1)–O(1)	1.413 (4)
C(14)–C(15)	1.376 (7)	S(1)–O(2)	1.422 (4)
C(15)–C(16)	1.392 (7)		

Table 25 Angles [°] for compound **8a**

Atom	Angle	Atom	Angle
O(3)–C(21)–C(22)	119.1 (5)	F(12)–C(1)–C(2)	112.9 (7)
O(3)–C(21)–C(26)	122.4 (4)	F(11)–C(1)–C(2)	108.4 (8)
C(22)–C(21)–C(26)	118.5 (5)	F(21)–C(2)–F(22)	105.7 (9)
C(23)–C(22)–C(21)	121.3 (5)	F(21)–C(2)–C(1)	113.0 (7)
C(22)–C(23)–C(24)	120.4 (5)	F(22)–C(2)–C(1)	105.6 (7)
C(25)–C(24)–C(23)	119.3 (5)	F(21)–C(2)–C(3)	110.6 (6)
C(24)–C(25)–C(26)	121.0 (5)	F(22)–C(2)–C(3)	103.7 (6)
C(25)–C(26)–N(3)	115.1 (4)	C(1)–C(2)–C(3)	117.0 (8)

Table 25 cont. Angles [°] for compound **8a**

C(25)–C(26)–C(21)	119.5 (4)	F(31)–C(3)–F(32)	108.8 (6)
N(3)–C(26)–C(21)	125.3 (4)	F(31)–C(3)–C(4)	111.0 (4)
N(3)–N(2)–C(16)	117.5 (4)	F(32)–C(3)–C(4)	108.1 (5)
N(2)–N(3)–C(26)	115.9 (4)	F(31)–C(3)–C(2)	106.3 (6)
C(12)–C(11)–C(16)	118.7 (4)	F(32)–C(3)–C(2)	106.2 (5)
C(12)–C(11)–N(1)	123.0 (4)	C(4)–C(3)–C(2)	116.1 (5)
C(16)–C(11)–N(1)	118.2 (4)	F(42)–C(4)–F(41)	107.5 (4)
C(13)–C(12)–C(11)	120.7 (5)	F(42)–C(4)–C(3)	109.5 (4)
C(14)–C(13)–C(12)	120.7 (5)	F(41)–C(4)–C(3)	109.6 (4)
C(13)–C(14)–C(15)	119.8 (5)	F(42)–C(4)–S(1)	107.6 (3)
C(14)–C(15)–C(16)	120.5 (5)	F(41)–C(4)–S(1)	107.5 (3)
C(15)–C(16)–C(11)	119.5 (4)	C(3)–C(4)–S(1)	114.9 (4)
C(15)–C(16)–N(2)	113.1 (4)	O(1)–S(1)–O(2)	122.2 (3)
C(11)–C(16)–N(2)	127.4 (4)	O(1)–S(1)–N(1)	110.9 (2)
C(11)–N(1)–S(1)	128.4 (3)	O(2)–S(1)–N(1)	107.3 (2)
F(13)–C(1)–F(12)	110.5 (9)	O(1)–S(1)–C(4)	105.6 (2)
F(13)–C(1)–F(11)	108.9 (8)	O(2)–S(1)–C(4)	105.1 (2)
F(12)–C(1)–F(11)	100.1 (7)	N(1)–S(1)–C(4)	104.2 (2)
F(13)–C(1)–C(2)	114.9 (6)		

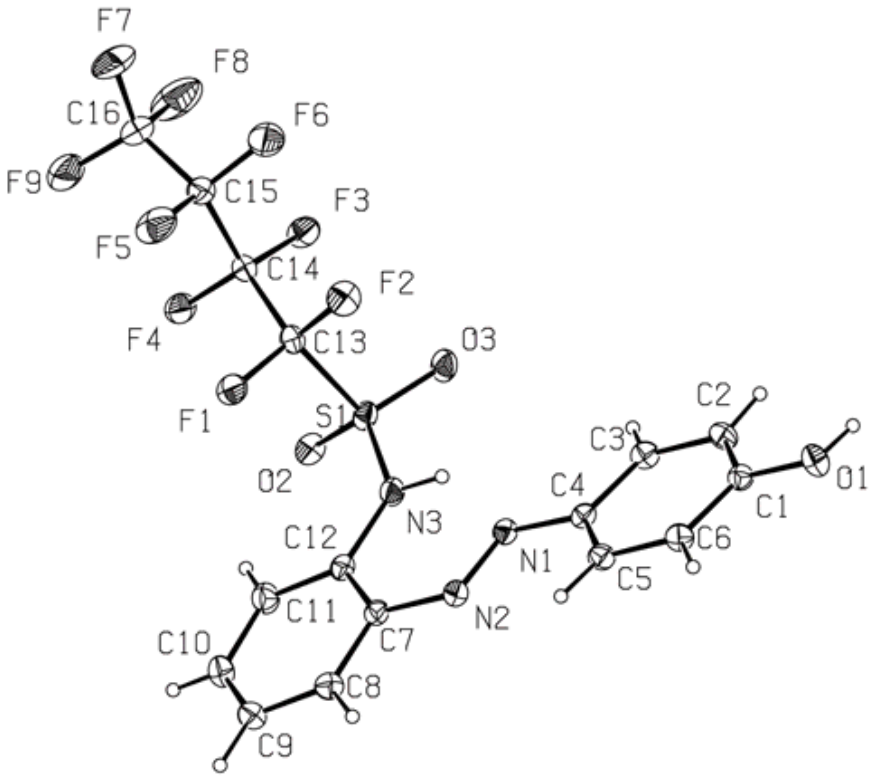


Figure 4 Molecular structure and atom numbers of compound **8b**

Table 26 Crystal data of compound **8b**

Crystal description			red needle
Crystal size [mm]		a	0.25
		b	0.10
		c	0.05
Temperature [K]			213(2)
Unit cell dimensions	[Å]	a	5.4635(2)
		b	10.2660(1)
		c	17.6448(2)
	[°]	α	105.731(6)
		β	93.187(5)
		γ	97.036(7)

Table 26 cont. Crystal data of compound **8b**

Volume [Å^3]	941.33(2)
Crystal system	triclinic
Space group	P–1
Z	2
Calculated density [g/cm^3]	1.748
Independent reflexions	3196
$2\Theta_{max}$ [°]	129.86
Reflections observed	2421
Refined parameter	329
R_1	0.0707
wR_2	0.1337

Table 27 Atomic coordinates [Å] and isotropic displacement parameter [Å^2] for compound **8b**

Atom	X	Y	Z	*U* (eq)
C (1)	1.4851 (5)	0.7945 (3)	–0.0725 (2)	0.035 (1)
C (2)	1.2909 (6)	0.8661 (3)	–0.0493 (2)	0.041 (1)
C (3)	1.1499 (5)	0.8350 (3)	0.0074 (2)	0.039 (1)
C (4)	1.1996 (5)	0.7322 (3)	0.0411 (2)	0.034 (1)
C (5)	1.3954 (5)	0.6608 (3)	0.0174 (2)	0.038 (1)
C (6)	1.5370 (6)	0.6924 (3)	–0.0390 (2)	0.040 (1)
C (7)	0.9265 (5)	0.5735 (3)	0.1789 (2)	0.036 (1)
C (8)	0.9642 (6)	0.4531 (3)	0.1970 (2)	0.045 (1)
C (9)	0.8275 (7)	0.4058 (3)	0.2498 (2)	0.049 (1)
C (10)	0.6505 (7)	0.4796 (4)	0.2852 (2)	0.052 (1)
C (11)	0.6102 (7)	0.5995 (4)	0.2696 (2)	0.049 (1)
C (12)	0.7483 (5)	0.6486 (3)	0.2175 (2)	0.038 (1)
C (13)	0.7902 (5)	0.9941 (3)	0.3274 (2)	0.039 (1)
C (14)	0.6765 (6)	1.1047 (3)	0.3864 (2)	0.040 (1)
C (15)	0.8654 (7)	1.2107 (3)	0.4487 (2)	0.051 (1)

Table 27 cont. Atomic coordinates [Å] and isotropic displacement parameter [Å^2] for compound **8b**

C (16)	0.7538 (1)	1.3022 (4)	0.5174 (3)	0.072 (1)
F (1)	0.8669 (4)	0.9063 (2)	0.3639 (1)	0.056 (1)
F (2)	0.9861 (3)	1.0532 (2)	0.3005 (1)	0.057 (1)
F (3)	0.5508 (3)	1.1729 (2)	0.3460 (1)	0.053 (1)
F (4)	0.5162 (4)	1.0436 (2)	0.4247 (1)	0.063 (1)
F (5)	1.0245 (5)	1.1447 (2)	0.4782 (1)	0.086 (1)
F (6)	0.9937 (5)	1.2906 (2)	0.4120 (1)	0.078 (1)
F (7)	0.9274 (6)	1.3975 (3)	0.5605 (2)	0.108 (1)
F (8)	0.5875 (7)	1.3635 (3)	0.4913 (2)	0.123 (1)
F (9)	0.6590 (8)	1.2348 (3)	0.5626 (2)	0.140 (1)
N (1)	1.0437 (4)	0.7068 (2)	0.0986 (1)	0.036 (1)
N (2)	1.0786 (4)	0.6044 (2)	0.1218 (1)	0.037 (1)
N (3)	0.7161 (5)	0.7726 (3)	0.1983 (2)	0.042 (1)
O (1)	1.6355 (4)	0.8213 (2)	–0.1269 (1)	0.047 (1)
O (2)	0.3579 (4)	0.8475 (2)	0.2725 (1)	0.047 (1)
O (3)	0.5675 (4)	0.9807 (2)	0.1903 (1)	0.052 (1)
S (1)	0.5742 (1)	0.8942 (1)	0.2407 (1)	0.038 (1)

Table 28 Hydrogen coordinates [Å] and isotropic displacement parameter [Å^2] for compound **8b**

Atom	**X**	**Y**	**Z**	***U* (eq)**
H (1)	0.8550 (6)	0.3240 (4)	0.2620 (2)	0.049 (9)
H (2)	1.4350 (6)	0.5940 (3)	0.0400 (2)	0.046 (9)
H (3)	1.0200 (6)	0.8820 (3)	0.0234 (2)	0.042 (9)
H (4)	0.5630 (7)	0.4500 (4)	0.3180 (2)	0.067 (1)
H (5)	0.4860 (6)	0.6500 (3)	0.2930 (2)	0.045 (9)
H (6)	1.0940 (7)	0.4020 (4)	0.1710 (2)	0.061 (1)
H (7)	1.2590 (6)	0.9370 (4)	–0.0680 (2)	0.058 (1)
H (8)	1.6640 (6)	0.6420 (3)	–0.0570 (2)	0.041 (8)
H (9)	1.5830 (7)	0.8820 (4)	–0.1480 (3)	0.074 (1)
H (10)	0.8220 (7)	0.7960 (4)	0.1640 (2)	0.071 (1)

Table 29 Bond lengths [Å] for compound **8b**

Atom	Length	Atom	Length
S(1)–O(3)	1.419 (2)	N(3)–C(12)	1.432 (4)
S(1)–O(2)	1.421 (2)	C(1)–C(2)	1.382 (4)
S(1)–N(3)	1.586 (3)	C(1)–C(6)	1.386 (4)
S(1)–C(13)	1.854 (3)	C(2)–C(3)	1.376 (4)
F(1)–C(13)	1.333 (3)	C(3)–C(4)	1.391 (4)
F(2)–C(13)	1.339 (3)	C(4)–C(5)	1.391 (4)
F(3)–C(14)	1.342 (3)	C(5)–C(6)	1.375 (4)
F(4)–C(14)	1.334 (3)	C(7)–C(8)	1.393 (4)
F(5)–C(15)	1.331 (4)	C(7)–C(12)	1.406 (4)
F(6)–C(15)	1.334 (4)	C(8)–C(9)	1.376 (5)
F(7)–C(16)	1.313 (5)	C(9)–C(10)	1.374 (5)
F(8)–C(16)	1.298 (5)	C(10)–C(11)	1.372 (5)
F(9)–C(16)	1.281 (5)	C(11)–C(12)	1.379 (4)
O(1)–C(1)	1.358 (3)	C(13)–C(14)	1.537 (4)
N(1)–N(2)	1.258 (3)	C(14)–C(15)	1.552 (5)
N(1)–C(4)	1.416 (4)	C(15)–C(16)	1.526 (5)
N(2)–C(7)	1.418 (4)		

Table 30 Angles [°] for compound **8b**

Atom	Angle	Atom	Angle
O(3)–S(1)–O(2)	121.79 (14)	C(11)–C(12)–N(3)	123.2 (3)
O(3)–S(1)–N(3)	106.62 (14)	C(7)–C(12)–N(3)	117.0 (3)
O(2)–S(1)–N(3)	112.21 (14)	F(1)–C(13)–F(2)	108.5 (2)
O(3)–S(1)–C(13)	104.93 (14)	F(1)–C(13)–C(14)	109.6 (2)
O(2)–S(1)–C(13)	105.54 (14)	F(2)–C(13)–C(14)	109.2 (2)
N(3)–S(1)–C(13)	104.14 (14)	F(1)–C(13)–S(1)	107.6 (2)
N(2)–N(1)–C(4)	114.9 (2)	F(2)–C(13)–S(1)	107.8 (2)
N(1)–N(2)–C(7)	117.3 (2)	C(14)–C(13)–S(1)	114.0 (2)

Table 30 cont. Angles [°] for compound **8b**

C(12)–N(3)–S(1)	130.3 (2)	F(4)–C(14)–F(3)	108.1 (3)
O(1)–C(1)–C(2)	122.7 (3)	F(4)–C(14)–C(13)	108.6 (2)
O(1)–C(1)–C(6)	117.0 (3)	F(3)–C(14)–C(13)	108.8 (2)
C(2)–C(1)–C(6)	120.2 (3)	F(4)–C(14)–C(15)	108.1 (3)
C(3)–C(2)–C(1)	119.4 (3)	F(3)–C(14)–C(15)	107.9 (2)
C(2)–C(3)–C(4)	120.9 (3)	C(13)–C(14)–C(15)	115.1 (3)
C(5)–C(4)–C(3)	119.3 (3)	F(5)–C(15)–F(6)	107.6 (3)
C(5)–C(4)–N(1)	123.8 (3)	F(5)–C(15)–C(16)	108.3 (3)
C(3)–C(4)–N(1)	116.9 (2)	F(6)–C(15)–C(16)	108.2 (3)
C(6)–C(5)–C(4)	119.8 (3)	F(5)–C(15)–C(14)	108.8 (3)
C(5)–C(6)–C(1)	120.4 (3)	F(6)–C(15)–C(14)	108.3 (3)
C(8)–C(7)–C(12)	118.4 (3)	C(16)–C(15)–C(14)	115.5 (3)
C(8)–C(7)–N(2)	113.7 (3)	F(9)–C(16)–F(8)	109.8 (5)
C(12)–C(7)–N(2)	127.9 (3)	F(9)–C(16)–F(7)	107.6 (4)
C(9)–C(8)–C(7)	121.4 (3)	F(8)–C(16)–F(7)	107.2 (4)
C(10)–C(9)–C(8)	118.9 (3)	F(9)–C(16)–C(15)	111.8 (3)
C(11)–C(10)–C(9)	121.3 (3)	F(8)–C(16)–C(15)	110.5 (4)
C(10)–C(11)–C(12)	120.1 (3)	F(7)–C(16)–C(15)	109.7 (4)
C(11)–C(12)–C(7)	119.8 (3)		

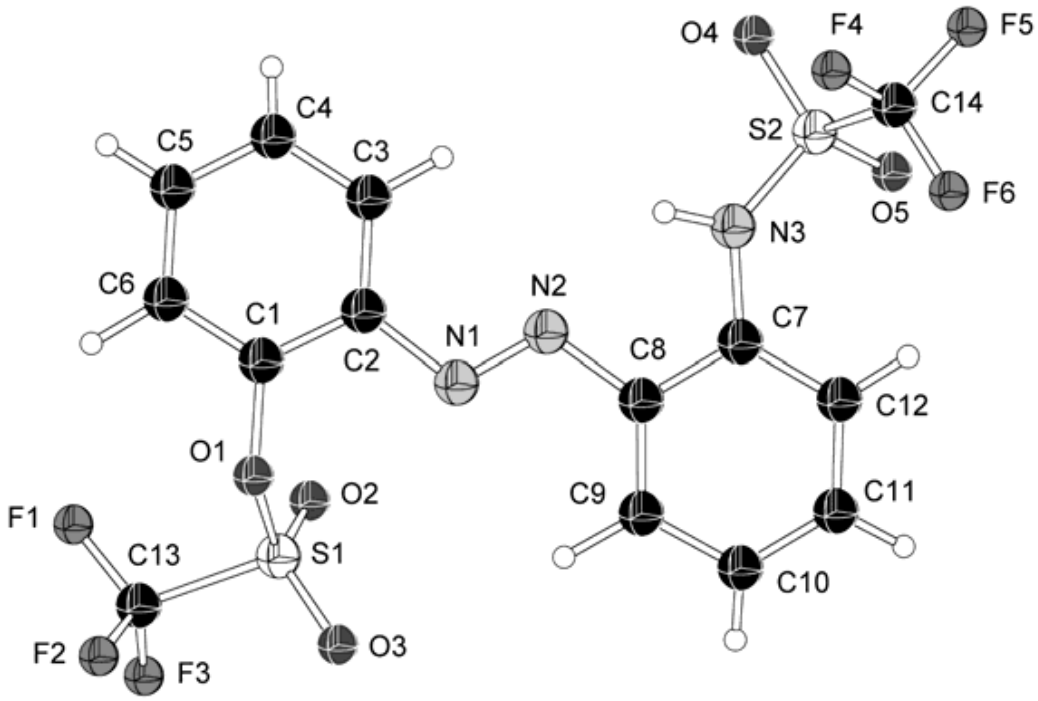


Figure 5 Molecular structure and atom numbers of compound **9b**

Table 31 Crystal data of compound **9b**

Crystal description			orange needle
Crystal size [mm]		a	0.5
		b	0.06
		c	0.01
Temperature [K]			220
Unit cell dimensions	[Å]	a	5.235(1)
		b	10.503(3)
		c	17.330(3)
	[°]	α	79.93(3)
		β	87.13(2)
		γ	78.96(3)
Volume [Å^3]			920.6
Crystal system			triclinic

Table 31 cont. Crystal data of compound **9b**

Space group	P-1
Z	2
Calculated density [g/cm^3]	1.722
Independent reflexions	4090
$2\Theta_{max}$ [°]	2.50–28.15
Refined parameter	307
R_1	0.0751
wR_2	0.1580

Table 32 Atomic coordinates [Å] and isotropic displacement parameter [Å^2] for compound **9b**

Atom	X	Y	Z	*U* (eq)
S (1)	1.6912 (3)	0.2162 (2)	0.1320 (1)	0.063 (1)
S (2)	0.6664 (2)	0.7071 (1)	0.3863 (1)	0.057 (1)
O (1)	1.8653 (6)	0.2806 (3)	0.1777 (2)	0.056 (1)
O (2)	1.5042 (7)	0.1617 (4)	0.1809 (2)	0.070 (1)
O (3)	1.6273 (9)	0.2985 (5)	0.0606 (2)	0.096 (2)
O (4)	0.7673 (7)	0.6452 (4)	0.4605 (2)	0.070 (1)
O (5)	0.4118 (6)	0.7027 (4)	0.3632 (2)	0.070 (1)
N (1)	1.4248 (8)	0.4288 (4)	0.2320 (2)	0.054 (1)
N (2)	1.2445 (8)	0.5042 (4)	0.2613 (2)	0.054 (1)
N (3)	0.8776 (9)	0.6677 (5)	0.3214 (3)	0.062 (1)
C (1)	1.8304 (9)	0.2782 (5)	0.2597 (3)	0.050 (1)
C (2)	1.6156 (9)	0.3577 (5)	0.2880 (3)	0.050 (1)
C (3)	1.5990 (1)	0.3622 (6)	0.3676 (3)	0.056 (1)
C (4)	1.7980 (1)	0.2904 (6)	0.4162 (3)	0.062 (2)
C (5)	2.0110 (1)	0.2140 (6)	0.3865 (3)	0.061 (2)
C (6)	2.0290 (1)	0.2069 (5)	0.3079 (3)	0.056 (1)
C (7)	0.8483 (9)	0.6596 (5)	0.2418 (3)	0.052 (1)
C (8)	1.0460 (1)	0.5744 (5)	0.2082 (3)	0.053 (1)

Table 32 cont. Atomic coordinates [Å] and isotropic displacement parameter [Å^2] for compound **9b**

C (9)	1.0360 (1)	0.5643 (6)	0.1299 (3)	0.061 (1)
C (10)	0.8230 (1)	0.6349 (7)	0.0865 (4)	0.072 (2)
C (11)	0.6320 (1)	0.7159 (6)	0.1195 (3)	0.065 (2)
C (12)	0.6380 (1)	0.7310 (6)	0.1962 (3)	0.063 (2)
C (13)	1.9370 (1)	0.0763 (7)	0.1106 (4)	0.076 (2)
C (14)	0.6710 (1)	0.8813 (6)	0.3838 (4)	0.074 (2)
F (1)	2.0330 (8)	0.0027 (4)	0.1750 (3)	0.101 (1)
F (2)	2.1309 (7)	0.1174 (4)	0.0666 (2)	0.094 (1)
F (3)	1.8197 (9)	0.0077 (5)	0.0714 (3)	0.116 (2)
F (4)	0.8977 (7)	0.8980 (4)	0.4024 (3)	0.105 (1)
F (5)	0.4971 (9)	0.9258 (4)	0.4362 (3)	0.104 (1)
F (6)	0.6010 (9)	0.9500 (4)	0.3158 (2)	0.105 (1)

Table 33 Hydrogen coordinates [Å] and isotropic displacement parameter [Å^2] for compound **9b**

Atom	**X**	**Y**	**Z**	***U* (eq)**
H (1)	1.040 (1)	0.630 (7)	0.333 (4)	0.110 (20)
H (2)	1.450 (1)	0.421 (5)	0.391 (3)	0.064 (15)
H (3)	1.798 (8)	0.290 (4)	0.465 (3)	0.038 (12)
H (4)	2.152 (9)	0.167 (4)	0.419 (3)	0.045 (12)
H (5)	2.193 (9)	0.153 (4)	0.281 (3)	0.041 (11)
H (6)	1.200 (1)	0.507 (6)	0.103 (3)	0.079 (17)
H (7)	0.830 (9)	0.626 (5)	0.037 (3)	0.053 (14)
H (8)	0.480 (1)	0.762 (5)	0.091 (3)	0.059 (13)
H (9)	0.500 (1)	0.791 (6)	0.221 (3)	0.071 (17)

Table 34 Bond lengths [Å] for compound **9b**

Atom	Length	Atom	Length
S(2)–O(4)	1.414 (3)	C(3)–C(4)	1.388 (7)
S(2)–O(5)	1.421 (3)	F(3)–C(13)	1.319 (7)
S(2)–N(3)	1.588 (5)	N(3)–C(7)	1.414 (6)
S(2)–C(14)	1.828 (7)	F(5)–C(14)	1.332 (8)
S(1)–O(3)	1.395 (4)	C(8)–C(9)	1.384 (7)
S(1)–O(2)	1.402 (4)	C(8)–C(7)	1.405 (8)
S(1)–O(1)	1.553 (4)	C(7)–C(12)	1.402 (6)
S(1)–C(13)	1.836 (8)	C(4)–C(5)	1.378 (8)
O(1)–C(1)	1.420 (6)	C(11)–C(10)	1.357 (9)
N(2)–N(1)	1.257 (6)	C(11)–C(12)	1.367 (8)
N(2)–C(8)	1.427 (5)	F(4)–C(14)	1.296 (7)
N(1)–C(2)	1.433 (5)	C(6)–C(5)	1.374 (7)
C(1)–C(6)	1.382 (6)	F(6)–C(14)	1.299 (6)
C(1)–C(2)	1.389 (7)	C(13)–F(1)	1.305 (7)
F(2)–C(13)	1.332 (7)	C(10)–C(9)	1.388 (7)
C(3)–C(2)	1.387 (7)		

Table 35 Angles [°] for compound **9b**

Atom	Angle	Atom	Angle
O(4)–S(2)–O(5)	122.8 (3)	C(12)–C(7)–N(3)	123.8 (5)
O(4)–S(2)–N(3)	108.1 (2)	C(8)–C(7)–N(3)	116.5 (4)
O(5)–S(2)–N(3)	111.2 (2)	C(5)–C(4)–C(3)	121.0 (5)
O(4)–S(2)–C(14)	104.2 (3)	C(10)–C(11)–C(12)	122.2 (5)
O(5)–S(2)–C(14)	105.4 (3)	C(3)–C(2)–C(1)	118.4 (4)
N(3)–S(2)–C(14)	103.0 (3)	C(3)–C(2)–N(1)	124.6 (5)
O(3)–S(1)–O(2)	122.2 (3)	C(1)–C(2)–N(1)	117.0 (4)
O(3)–S(1)–O(1)	108.5 (3)	C(5)–C(6)–C(1)	118.8 (5)
O(2)–S(1)–O(1)	111.9 (2)	C(11)–C(12)–C(7)	118.5 (6)

Table 35 cont. Angles [°] for compound **9b**

O(3)–S(1)–C(13)	106.9 (3)	F(1)–C(13)–F(3)	110.0 (6)
O(2)–S(1)–C(13)	106.0 (3)	F(1)–C(13)–F(2)	108.8 (5)
O(1)–S(1)–C(13)	98.4 (2)	F(3)–C(13)–F(2)	109.0 (5)
C(1)–O(1)–S(1)	121.0 (3)	F(1)–C(13)–S(1)	111.1 (4)
N(1)–N(2)–C(8)	115.2 (4)	F(3)–C(13)–S(1)	106.9 (5)
N(2)–N(1)–C(2)	113.1 (4)	F(2)–C(13)–S(1)	111.0 (5)
C(6)–C(1)–C(2)	122.1 (4)	C(11)–C(10)–C(9)	120.7 (5)
C(6)–C(1)–O(1)	117.8 (4)	F(4)–C(14)–F(6)	111.2 (6)
C(2)–C(1)–O(1)	119.7 (4)	F(4)–C(14)–F(5)	108.1 (6)
C(2)–C(3)–C(4)	119.5 (6)	F(6)–C(14)–F(5)	106.9 (5)
C(7)–N(3)–S(2)	130.5 (4)	F(4)–C(14)–S(2)	111.1 (4)
C(9)–C(8)–C(7)	120.1 (4)	F(6)–C(14)–S(2)	111.1 (5)
C(9)–C(8)–N(2)	125.7 (5)	F(5)–C(14)–S(2)	108.4 (5)
C(7)–C(8)–N(2)	114.2 (4)	C(6)–C(5)–C(4)	120.1 (5)
C(12)–C(7)–C(8)	119.6 (5)	C(8)–C(9)–C(10)	118.9 (6)

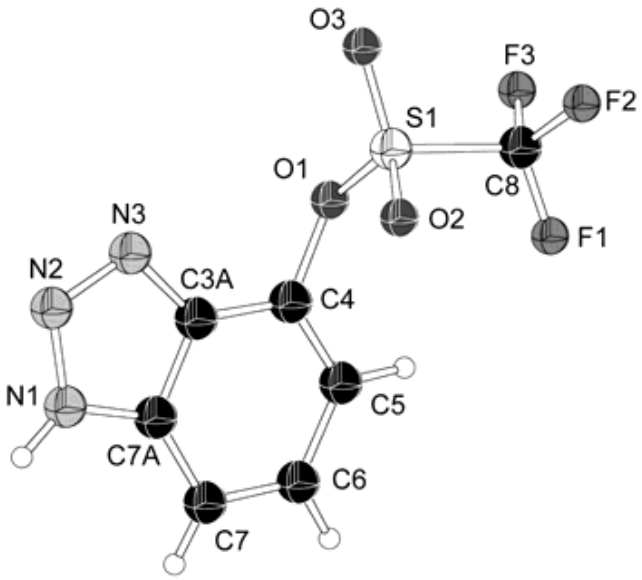


Figure 6 Molecular structure and atom numbers of compound **29a**

Table 36 Crystal data of compound **29a**

Crystal description			white needle
Crystal size [mm]		a	0.30
		b	0.10
		c	0.04
Temperature [K]			220
Unit cell dimensions	[Å]	a	9.246(1)
		b	9.358(1)
		c	2.3631(3)
	[°]	α	90
		β	90
		γ	90
Volume [$Å^3$]			204.46(4)
Crystal system			orthorhombic
Space group			P b c a (No. 61)
Z			8
Calculated density [g/cm^3]			1.736

Table 36 cont. Crystal data of compound **29a**

Independent reflexions	2005
$2\Theta_{max}$ [°]	2.80–25.99
Refined parameter	170
R_1	0.0580
wR_2	0.1309

Table 37 Atomic coordinates [Å] and isotropic displacement parameter [$Å^2$] for compound **29a**

Atom	X	Y	Z	*U* (eq)
C (3A)	0.7879 (3)	0.0767 (4)	0.0575 (1)	0.039 (1)
C (4)	0.8180 (3)	–0.0290 (4)	0.0973 (1)	0.043 (1)
C (5)	0.7069 (4)	–0.0932 (4)	0.1258 (2)	0.048 (1)
C (6)	0.5643 (4)	–0.0508 (4)	0.1153 (2)	0.053 (1)
C (7)	0.5286 (4)	0.0513 (4)	0.0762 (2)	0.048 (1)
C (7A)	0.6453 (3)	0.1140 (4)	0.0477 (1)	0.040 (1)
C (8)	1.0824 (7)	–0.1251 (8)	0.2018 (2)	0.102 (2)
F (1)	0.9632 (5)	–0.1463 (7)	0.2241 (2)	0.171 (2)
F (2)	1.1728 (5)	–0.0691 (7)	0.2383 (2)	0.173 (2)
F (3)	1.1384 (6)	–0.2398 (5)	0.1825 (2)	0.176 (2)
N (1)	0.6541 (3)	0.2161 (3)	0.0072 (1)	0.047 (1)
N (2)	0.7927 (3)	0.2422 (4)	–0.0064 (1)	0.050 (1)
N (3)	0.8759 (3)	0.1576 (3)	0.0236 (1)	0.046 (1)
O (1)	0.9624 (2)	–0.0770 (3)	0.1051 (1)	0.050 (1)
O (2)	0.9990 (5)	0.1277 (4)	0.1677 (2)	0.121 (2)
O (3)	1.2028 (4)	0.0059 (7)	0.1183 (2)	0.137 (2)
S (1)	1.0683 (1)	0.0073 (1)	0.1440 (1)	0.065 (1)

Table 38 Hydrogen coordinates [Å] and isotropic displacement parameter [Å^2] for compound **29a**

Atom	X	Y	Z	*U* (eq)
H (1)	0.581 (5)	0.269 (5)	–0.007 (2)	0.070 (13)
H (5)	0.732 (4)	–0.168 (4)	0.152 (2)	0.049 (10)
H (6)	0.484 (5)	–0.101 (4)	0.132 (2)	0.061 (11)
H (7)	0.438 (4)	0.075 (3)	0.067 (1)	0.029 (8)

Table 39 Bond lengths [Å] for compound **29a**

Atom	Length	Atom	Length
S(1)–O(3)	1.383 (4)	C(3A)–C(7A)	1.384 (5)
S(1)–O(2)	1.412 (4)	C(3A)–C(4)	1.392 (5)
S(1)–O(1)	1.557 (3)	C(4)–C(5)	1.367 (5)
S(1)–C(8)	1.849 (7)	C(7A)–C(7)	1.400 (5)
O(1)–C(4)	1.421 (4)	C(5)–C(6)	1.399 (5)
N(3)–N(2)	1.312 (4)	C(6)–C(7)	1.370 (5)
N(1)–N(2)	1.344 (4)	F(1)–C(8)	1.237 (7)
N(3)–C(3A)	1.370 (4)	F(2)–C(8)	1.311 (7)
N(1)–C(7A)	1.353 (4)	C(8)–F(3)	1.276 (7)

Table 40 Angles [°] for compound **29a**

Atom	Angle	Atom	Angle
O(3)–S(1)–O(2)	126.1 (3)	C(5)–C(4)–O(1)	120.2 (3)
O(3)–S(1)–O(1)	107.6 (2)	C(3A)–C(4)–O(1)	120.0 (3)
O(2)–S(1)–O(1)	110.66 (18)	N(1)–C(7A)–C(3A)	103.9 (3)
O(3)–S(1)–C(8)	104.7 (3)	N(1)–C(7A)–C(7)	133.0 (3)
O(2)–S(1)–C(8)	105.8 (3)	C(3A)–C(7A)–C(7)	123.2 (3)
O(1)–S(1)–C(8)	98.1 (2)	C(4)–C(5)–C(6)	119.7 (4)
C(4)–O(1)–S(1)	120.5 (2)	C(7)–C(6)–C(5)	123.0 (4)
N(2)–N(3)–C(3A)	107.6 (3)	C(6)–C(7)–C(7A)	115.5 (3)

Table 40 cont. Angles [°] for compound **29a**

N(3)–C(3A)–C(7A)	109.1 (3)	F(1)–C(8)–F(3)	112.3 (8)
N(3)–C(3A)–C(4)	132.0 (3)	F(1)–C(8)–F(2)	110.6 (6)
C(7A)–C(3A)–C(4)	118.9 (3)	F(3)–C(8)–F(2)	108.2 (5)
N(2)–N(1)–C(7A)	110.8 (3)	F(1)–C(8)–S(1)	111.1 (4)
N(3)–N(2)–N(1)	108.6 (3)	F(3)–C(8)–S(1)	109.1 (5)
C(5)–C(4)–C(3A)	119.6 (3)	F(2)–C(8)–S(1)	105.3 (6)

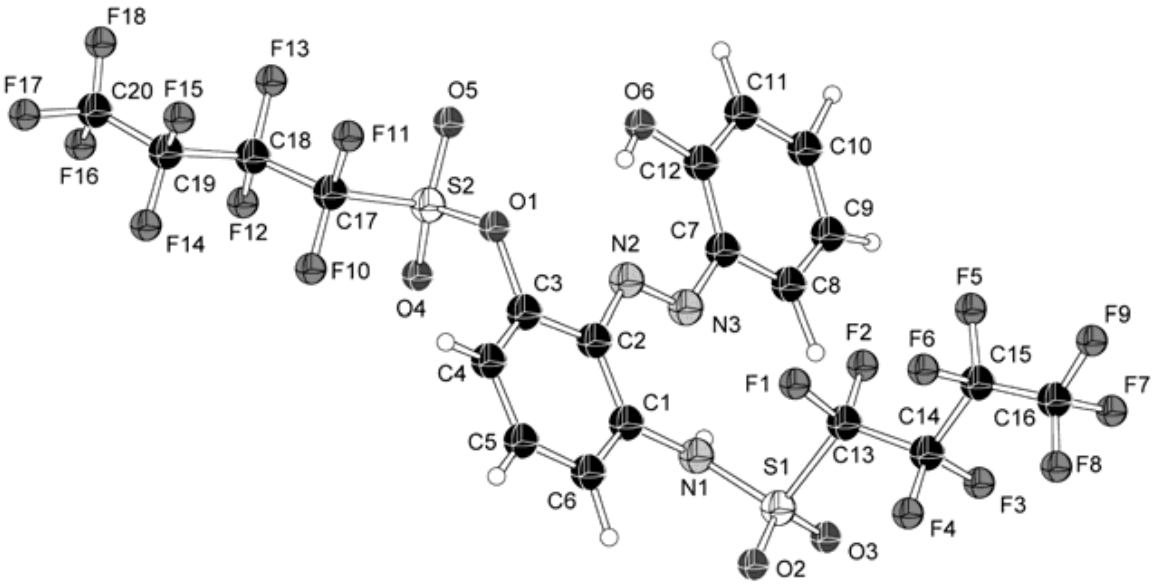


Figure 7 Molecular structure and atom numbers of compound **38**

Table 41 Crystal data of compound **38**

Crystal description		red needle
Crystal size [mm]	a	0.5
	b	0.35
	c	0.15
Temperature [K]		220
Unit cell dimensions [Å]	a	5.9812(11)
	b	16.572(3)
	c	17.656(3)
[°]	α	91.22(2)
	β	99.38(2)
	γ	92.89(2)
Volume [Å^3]		1723.7(5)
Crystal system		triclinic
Space group		P–1

Table 41 cont. Crystal data of compound **38**

Z	2
Calculated density [g/cm^3]	1.529
Independent reflexions	6282
$2\Theta_{max}$ [°]	2.34–25.96
Refined parameter	478
R_1	0.1175
wR_2	0.3093

Table 42 Atomic coordinates [Å] and isotropic displacement parameter [Å^2] for compound **38**

Atom	X	Y	Z	*U* (eq)
C (1)	–0.7031 (9)	0.3329 (3)	–0.0049 (3)	0.050 (1)
C (2)	–0.5210 (9)	0.2940 (3)	–0.0282 (3)	0.048 (1)
C (3)	–0.4052 (9)	0.3358 (4)	–0.0795 (3)	0.052 (1)
C (4)	–0.4590 (11)	0.4113 (4)	–0.1054 (4)	0.062 (2)
C (5)	–0.6391 (12)	0.4460 (4)	–0.0820 (4)	0.063 (2)
C (6)	–0.7609 (11)	0.4076 (4)	–0.0334 (4)	0.058 (2)
C (7)	–0.4627 (9)	0.1084 (3)	0.0680 (3)	0.048 (1)
C (8)	–0.5968 (10)	0.0669 (4)	0.1145 (4)	0.062 (2)
C (9)	–0.5340 (12)	–0.0059 (4)	0.1446 (4)	0.068 (2)
C (10)	–0.3326 (11)	–0.0368 (4)	0.1309 (4)	0.060 (2)
C (11)	–0.1965 (10)	0.0025 (4)	0.0866 (4)	0.056 (2)
C (12)	–0.2581 (9)	0.0764 (3)	0.0558 (3)	0.052 (1)
C (13)	–0.6648 (11)	0.3450 (4)	0.1910 (4)	0.063 (2)
C (14)	–0.6944 (16)	0.3858 (5)	0.2673 (5)	0.085 (2)
C (15)	–0.4740 (30)	0.4032 (8)	0.3251 (6)	0.131 (4)
C (16)	–0.4700 (50)	0.4413 (13)	0.3977 (10)	0.177 (7)
C (17)	–0.1370 (14)	0.2984 (5)	–0.2407 (4)	0.077 (2)
C (18)	–0.1009 (15)	0.2483 (7)	–0.3132 (5)	0.090 (3)
C (19)	–0.0410 (30)	0.2995 (12)	–0.3810 (7)	0.148 (5)
C (20)	0.0210 (30)	0.2583 (14)	–0.4456 (10)	0.157 (6)

Table 42 cont. Atomic coordinates [Å] and isotropic displacement parameter [Å^2] for compound **38**

F	(1)	–0.5125 (7)	0.3895 (3)	0.1600 (2)	0.088 (1)
F	(2)	–0.5843 (7)	0.2719 (3)	0.2032 (3)	0.085 (1)
F	(3)	–0.8268 (13)	0.3356 (5)	0.3007 (3)	0.159 (3)
F	(4)	–0.7874 (15)	0.4549 (4)	0.2530 (3)	0.153 (3)
F	(5)	–0.3232 (14)	0.3564 (8)	0.3216 (5)	0.187 (4)
F	(6)	–0.3670 (30)	0.4721 (11)	0.2903 (6)	0.316 (10)
F	(7)	–0.5560 (30)	0.3855 (15)	0.4371 (7)	0.342 (12)
F	(8)	–0.6020 (40)	0.4902 (14)	0.3976 (6)	0.440 (20)
F	(9)	–0.2900 (30)	0.4519 (8)	0.4409 (6)	0.246 (7)
F	(10)	–0.2936 (12)	0.3503 (3)	–0.2608 (3)	0.121 (2)
F	(11)	0.0609 (12)	0.3339 (4)	–0.2111 (3)	0.142 (3)
F	(12)	–0.2792 (15)	0.2042 (6)	–0.3363 (4)	0.171 (3)
F	(13)	0.0571 (15)	0.1992 (6)	–0.2945 (4)	0.179 (4)
F	(14)	–0.2020 (40)	0.3402 (13)	–0.4029 (9)	0.415 (17)
F	(15)	0.1140 (40)	0.3521 (13)	–0.3558 (7)	0.438 (19)
F	(16)	–0.1250 (40)	0.2138 (15)	–0.4707 (9)	0.366 (15)
F	(17)	0.0510 (30)	0.3044 (10)	–0.5010 (6)	0.279 (7)
F	(18)	0.1820 (40)	0.2335 (19)	–0.4347 (9)	0.370 (16)
N	(1)	–0.8308 (9)	0.2933 (4)	0.0458 (3)	0.057 (1)
N	(2)	–0.4341 (7)	0.2202 (3)	–0.0034 (3)	0.050 (1)
N	(3)	–0.5478 (7)	0.1792 (3)	0.0384 (3)	0.052 (1)
O	(1)	–0.2096 (6)	0.3015 (3)	–0.0995 (2)	0.060 (1)
O	(2)	–0.9946 (9)	0.4110 (3)	0.1011 (3)	0.084 (2)
O	(3)	–1.0648 (8)	0.2728 (3)	0.1461 (3)	0.080 (1)
O	(4)	–0.4554 (9)	0.2093 (3)	–0.1905 (3)	0.083 (2)
O	(5)	–0.0585 (11)	0.1813 (4)	–0.1454 (4)	0.105 (2)
O	(6)	–0.1174 (8)	0.1143 (3)	0.0134 (3)	0.069 (1)
S	(1)	–0.9235 (3)	0.3322 (1)	0.1178 (1)	0.062 (1)
S	(2)	–0.2308 (3)	0.2356 (1)	–0.1667 (1)	0.065 (1)

Table 43 Hydrogen coordinates [Å] and isotropic displacement parameter [Å^2] for compound **38**

Atom	X	Y	Z	*U* (eq)
H (1)	–0.3500 (200)	0.4680 (70)	–0.1310 (60)	0.160 (40)
H (2)	–0.6940 (120)	0.4880 (50)	–0.1020 (40)	0.070 (20)
H (3)	–0.9190 (110)	0.4270 (40)	–0.0210 (30)	0.064 (17)
H (4)	–0.8250 (180)	0.2550 (60)	0.0490 (60)	0.110 (40)
H (5)	–0.7520 (100)	0.0930 (30)	0.1330 (30)	0.051 (14)
H (6)	–0.6200 (200)	–0.0680 (70)	0.1710 (70)	0.160 (40)
H (7)	–0.2490 (110)	–0.0980 (40)	0.1520 (40)	0.071 (19)
H (8)	–0.0640 (140)	–0.0310 (50)	0.0710 (40)	0.090 (20)
H (9)	–0.1740 (110)	0.1510 (40)	0.0010 (40)	0.054 (19)

Table 44 Bond lengths [Å] for compound **38**

Atom	Length	Atom	Length
S(1)–O(2)	141.5 (5)	F(18)–C(20)	106.1 (18)
S(1)–O(3)	141.7 (5)	O(1)–C(3)	141.7 (7)
S(1)–N(1)	160.2 (6)	O(6)–C(12)	135.5 (7)
S(1)–C(13)	184.8 (7)	N(1)–C(1)	141.9 (8)
S(2)–O(4)	138.6 (5)	N(2)–N(3)	126.8 (6)
S(2)–O(5)	141.2 (5)	N(2)–C(2)	140.4 (7)
S(2)–O(1)	158.0 (5)	N(3)–C(7)	138.2 (7)
S(2)–C(17)	182.9 (7)	C(1)–C(6)	138.5 (8)
F(1)–C(13)	133.6 (7)	C(1)–C(2)	140.6 (8)
F(2)–C(13)	133.5 (8)	C(2)–C(3)	140.1 (7)
F(3)–C(14)	133.2 (10)	C(3)–C(4)	137.6 (8)
F(4)–C(14)	130.9 (10)	C(4)–C(5)	136.3 (10)
F(5)–C(15)	122.8 (15)	C(5)–C(6)	136.1 (9)
F(6)–C(15)	147.5 (17)	C(7)–C(12)	140.3 (8)
F(7)–C(16)	130.0 (2)	C(7)–C(8)	140.5 (8)
F(8)–C(16)	116.0 (2)	C(8)–C(9)	137.4 (9)

Table 44 cont. Bond lengths [Å] for compound **38**

F(9)–C(16)	122.0 (2)	C(9)–C(10)	138.7 (9)
F(10)–C(17)	131.4 (9)	C(10)–C(11)	136.8 (8)
F(11)–C(17)	131.8 (9)	C(11)–C(12)	139.4 (8)
F(12)–C(18)	126.6 (11)	C(13)–C(14)	153.4 (11)
F(13)–C(18)	128.6 (10)	C(14)–C(15)	153.9 (17)
F(14)–C(19)	122.3 (19)	C(15)–C(16)	141.0 (2)
F(15)–C(19)	125.7 (18)	C(17)–C(18)	156.1 (13)
F(16)–C(20)	114.0 (2)	C(18)–C(19)	156.0 (15)
F(17)–C(20)	128.5 (18)	C(19)–C(20)	143.0 (2)

Table 45 Angles [°] for compound **38**

Atom	Angle	Atom	Angle
O(2)–S(1)–O(3)	122.1 (3)	C(14)–C(13)–S(1)	115.8 (5)
O(2)–S(1)–N(1)	110.2 (3)	F(4)–C(14)–F(3)	111.3 (8)
O(3)–S(1)–N(1)	108.2 (3)	F(4)–C(14)–C(13)	108.8 (6)
O(2)–S(1)–C(13)	106.2 (3)	F(3)–C(14)–C(13)	107.1 (7)
O(3)–S(1)–C(13)	105.6 (3)	F(4)–C(14)–C(15)	107.5 (8)
N(1)–S(1)–C(13)	102.7 (3)	F(3)–C(14)–C(15)	106.9 (8)
O(4)–S(2)–O(5)	122.1 (4)	C(13)–C(14)–C(15)	115.3 (8)
O(4)–S(2)–O(1)	110.9 (3)	F(5)–C(15)–C(16)	115.3 (14)
O(5)–S(2)–O(1)	107.0 (3)	F(5)–C(15)–F(6)	96.5 (16)
O(4)–S(2)–C(17)	109.0 (4)	C(16)–C(15)–F(6)	96.3 (13)
O(5)–S(2)–C(17)	106.3 (4)	F(5)–C(15)–C(14)	115.8 (10)
O(1)–S(2)–C(17)	99.1 (3)	C(16)–C(15)–C(14)	122.7 (16)
C(3)–O(1)–S(2)	120.8 (4)	F(6)–C(15)–C(14)	101.9 (9)
C(1)–N(1)–S(1)	127.7 (5)	F(8)–C(16)–F(9)	118.0 (2)
N(3)–N(2)–C(2)	116.3 (4)	F(8)–C(16)–F(7)	101.0 (3)
N(2)–N(3)–C(7)	118.5 (4)	F(9)–C(16)–F(7)	96.4 (13)
C(6)–C(1)–C(2)	120.1 (5)	F(8)–C(16)–C(15)	113.7 (16)
C(6)–C(1)–N(1)	120.8 (5)	F(9)–C(16)–C(15)	119.0 (2)

Table 45 cont. Angles [°] for compound **38**

C(2)–C(1)–N(1)	119.1 (5)	F(7)–C(16)–C(15)	103.6 (19)
C(3)–C(2)–N(2)	116.0 (5)	F(10)–C(17)–F(11)	112.8 (8)
C(3)–C(2)–C(1)	116.1 (5)	F(10)–C(17)–C(18)	109.2 (6)
N(2)–C(2)–C(1)	127.8 (5)	F(11)–C(17)–C(18)	107.1 (7)
C(4)–C(3)–C(2)	123.3 (6)	F(10)–C(17)–S(2)	107.5 (5)
C(4)–C(3)–O(1)	118.7 (5)	F(11)–C(17)–S(2)	107.4 (5)
C(2)–C(3)–O(1)	117.7 (5)	C(18)–C(17)–S(2)	112.9 (6)
C(5)–C(4)–C(3)	118.3 (6)	F(12)–C(18)–F(13)	105.6 (11)
C(6)–C(5)–C(4)	121.0 (6)	F(12)–C(18)–C(19)	109.3 (9)
C(5)–C(6)–C(1)	121.0 (6)	F(13)–C(18)–C(19)	108.4 (9)
N(3)–C(7)–C(12)	125.8 (5)	F(12)–C(18)–C(17)	108.4 (7)
N(3)–C(7)–C(8)	115.2 (5)	F(13)–C(18)–C(17)	109.7 (7)
C(12)–C(7)–C(8)	119.1 (5)	C(19)–C(18)–C(17)	115.0 (10)
C(9)–C(8)–C(7)	120.4 (6)	F(14)–C(19)–F(15)	103.0 (2)
C(8)–C(9)–C(10)	119.4 (6)	F(14)–C(19)–C(20)	108.9 (14)
C(11)–C(10)–C(9)	121.7 (5)	F(15)–C(19)–C(20)	108.7 (16)
C(10)–C(11)–C(12)	119.4 (6)	F(14)–C(19)–C(18)	107.5 (12)
O(6)–C(12)–C(11)	117.9 (5)	F(15)–C(19)–C(18)	109.5 (11)
O(6)–C(12)–C(7)	122.2 (5)	C(20)–C(19)–C(18)	118.3 (16)
C(11)–C(12)–C(7)	119.9 (5)	F(18)–C(20)–F(16)	115.0 (3)
F(2)–C(13)–F(1)	107.6 (5)	F(18)–C(20)–F(17)	99.3 (19)
F(2)–C(13)–C(14)	110.3 (5)	F(16)–C(20)–F(17)	105.2 (19)
F(1)–C(13)–C(14)	108.6 (6)	F(18)–C(20)–C(19)	114.0 (2)
F(2)–C(13)–S(1)	107.2 (5)	F(16)–C(20)–C(19)	108.6 (18)
F(1)–C(13)–S(1)	106.9 (4)	F(17)–C(20)–C(19)	114.1 (19)

6 Compound Numbers

1 2,3,4,6-Tetra-*O*-benzyl-(α/β)-D-glucopyranose

2a Nonafluorobutanesulfonyl fluoride

2b Trifluoromethanesulfonyl anhydride

3α Methyl 2,3,4,6-tetra-*O*-benzyl-α-D-glucopyranoside

3β Methyl 2,3,4,6-tetra-*O*-benzyl-β-D-glucopyranoside

4a 2,2',3,3',4,4',6,6'-Octa-*O*-benzyl-αα-trehalose

4b 2,2',3,3',4,4',6,6'-Octa-*O*-benzyl-αβ-trehalose

4c 2,2',3,3',4,4',6,6'-Octa-*O*-benzyl-ββ-trehalose

5a 1*H*-1,2,3-benzotriazole

5b 9,10,16,17,23,24-[Hexakis-3,5-bis(*tert*-butylphenoxy)]-2,3-[*d*]{1*H*-1,2,3-triazole}phthalocyaninato zinc

6a 1-Nonafluorobutanesulfonyl-1*H*-1,2,3-benzotriazole

6b 1-Trifluoromethanesulfonyl-1*H*-1,2,3-benzotriazole

6c 1-(*p*-Toluenesulfonyl)-1*H*-1,2,3-benzotriazole

6d 1-Methanesulfonyl-1*H*-1,2,3-benzotriazole

6e 9,10,16,17,23,24-[Hexakis-3,5-bis(*tert*-butylphenoxy)]-2,3-[*d*]{1-[(trifluoromethane)sulfonyl]-1*H*-1,2,3-triazole}phthalocyaninato zinc

7a Phenol

7b 2-Methylphenol

7c 3-Methylphenol

7d 4-Methylphenol

7e 2,6-Dimethylphenol

7f 2-*tert*-Butylphenol

7g 4-Chlorophenol

7h 2-Methoxyphenol

7i 1-Naphthol

7j 2-Naphthol

7k 4-Nitrophenol

7l 3,4-Dicianophenol

8a Nonafluoro-*N*-{2-[(*E*)-2-(2-hydroxyphenyl)diazenyl]phenyl}-1-butane-sulfonamide

8a Nonafluoro-*N*-{2-[(*E*)-2-(4-hydroxyphenyl)diazenyl]phenyl}-1-butane-sulfonamide

9a Trifluoro-*N*-{2-[(*E*)-2-(2-hydroxyphenyl)diazenyl]phenyl}-1-methane-sulfonamide

9b Trifluoromethanesulfonic acid *2*-[(2-trifluoromethanesufonylaminophenyl)-diazenyl]phenyl ester

10 Toluone-4-sulfonic acid phenyl ester

11 Methanesulfonic acid phenyl ester

12 Nonafluoro-*N*-{2-[(*E*)-2-(2-hydroxy-3-methylphenyl)diazenyl]phenyl}-1-butane-sulfonamide

13 Nonafluoro-*N*-{2-[(*E*)-2-(2-hydroxy-4-methylphenyl)diazenyl]phenyl}-1-butanesulfonamide

14 Nonafluoro-*N*-{2-[(*E*)-2-(2-hydroxy-5-methylphenyl)diazenyl]phenyl}-1-butane-sulfonamide

15 Nonafluoro-*N*-{2-[(*E*)-2-(4-hydroxy-3,5-dimethylphenyl)diazenyl]phenyl}-1-butanesulfonamide

16 Nonafluoro-*N*-{2-[(*E*)-2-(3-*tert*-butyl-2-hydroxyphenyl)diazenyl]phenyl}-1-butanesulfonamide

17 Nonafluoro-*N*-{2-[(*E*)-2-(5-chloro-2-hydroxyphenyl)diazenyl]phenyl}-1-butanesulfonamide

18 Nonafluoro-*N*-{2-[(*E*)-2-(2-hydroxy-3-methoxyphenyl)diazenyl]phenyl}-1-butanesulfonamide

19 Nonafluoro-*N*-{2-[(*E*)-2-(1-hydroxy-2-naphthyl)diazenyl]phenyl}-1-butane-sulfonamide

20a Nonafluoro-*N*-{2-[(*E*)-2-(2-hydroxy-1-naphthyl)diazenyl]phenyl}-1-butane-sulfonamide

20b Trifluoro-*N*-{2-[(*E*)-2-(2-hydroxy-1-naphthyl)diazenyl]phenyl}-1-methane-sulfonamide

20c 9,10,16,17,23,24-[Hexakis-(3,5-bis(tert-butylphenoxy)]-2-[(trifluormethane)-sulfonamide]-3-(2 hydroxynaphthalin-1-ylazo)phthalocyaninato zinc

20d 1-Phenylazo-naphthalen-2-ol

21a Benzyl chloride

21b 3-Chlorobenzyl bromide

21c 4-Chlorobenzyl chloride

21d 4-Nitrobenzyl chloride

21e 4-Methoxybenzyl chloride

21'a Benzyltriphenylphosphonium chloride

21'b 3-Chlorobenzylphosphonium bromide

21'c 4-Chlorobenzylphosphonium chloride

21'd 4-Nitrobenzylphosphonium chloride

21'e 4-Methoxybenzylphosphonium chloride

22a {[2-(2-{[Nonafluorobutanesulfonyl]amino}phenyl)diazenyl](phenyl)methyl}(triphenyl)phosphonium chloride

22'a Nonafluorobutane-*N*-{2-[2-[(phenyl)(triphenylphosphoranylidene)methyl]-diazenyl]phenyl}-1-sulfonamide

22b Nonafluorobutane-*N*-{2-[2-[(3-chlorophenyl)(triphenylphosphoranylidene)-methyl]diazenyl]phenyl}-1-sulfonamide

22c Nonafluorobutane-*N*-{2-[2-((4-chlorophenyl)(triphenylphosphoranylidene)-methyl)diazenyl]phenyl}-1-sulfonamide

22d {(4-Nitrophenyl)[2-(2-{[nonafluorobutanesulfonyl]amino}phenyl)diazenyl]-methyl}(triphenyl)phosphonium chloride

22'd Nonafluorobutane-*N*-{2-[2-[(4-Nitrophenyl)(triphenylphosphoranylidene)-methyl]diazenyl]phenyl}-1-sulfonamide

22e Nonafluorobutane-*N*-{2-[2-((4-methoxyphenyl)(triphenylphosphoranylidene)-methyl)diazenyl]phenyl}-1-sulfonamide

23a (Carbethoxymethyl)triphenylphosphonium bromide

23b Methyltriphenylphosphonium bromide

23c Ethyltriphenylphosphonium bromide

23d Isopropyltriphenylphosphonium iodide

24a Ethyl 2-{(E)-2-[2-({nonafluorobutanesulfonyl}amino)phenyl]diazenyl}-2-(triphenylphosphoranylidene)acetate

24b Nonafluoro-*N*-{2-[2-({2-[2-({nonafluorobutanesulfonyl}amino)phenyl]diazenyl}-(triphenylphosphoranylidene)methyl)diazenyl]phenyl}-1-butanesulfonamide

25α 1*H*-1,2,3-Benzotriazole-2,3,4,6-tetra-*O*-benzyl-α-D-glucopyranoside

25β 1*H*-1,2,3-Benzotriazole-2,3,4,6-tetra-*O*-benzyl-β-D-glucopyranoside

26α 2*H*-1,2,3-Benzotriazole-2,3,4,6-tetra-*O*-benzyl-α-D-glucopyranoside

26β 2*H*-1,2,3-Benzotriazole-2,3,4,6-tetra-*O*-benzyl-β-D-glucopyranoside

27 1-Hydroxy-1*H*-1,2,3-benzotriazole

28a Nonafluorobutane-1-sulfone acid-1*H*-1,2,3-benzotriazol-1-yl ester

28b Nonafluorobutane-1-sulfone acid-1*H*-1,2,3-benzotriazol-4-yl ester

29a Trifluoromethane-1-sulfone acid-1*H*-1,2,3-benzotriazol-4-yl ester

29b Trifluoromethane-1-sulfone acid-1*H*-1,2,3-benzotriazol-5-yl ester

30a 3-chloro-4-nitrotoluene

30b 4-chloro-3-nitrotoluene

30c 2,3-Dichloronitrobenzene

30d 2,5-Dichloronitrobenzene

30e 4-Chloro-3-nitro-benzotrifluoride

30f 1,3,5-Trichloro-2-nitrobenzene

31a 1-Hydroxy-5-methyl-1*H*-1,2,3-benzotriazole

31b 1-Hydroxy-6-methyl-1*H*-1,2,3-benzotriazole

31c 4-Chloro-1-hydroxy-1*H*-1,2,3-benzotriazole

31d 6-Chloro-1-hydroxy-1*H*-1,2,3-benzotriazole

31e 1-Hydroxy-6-trifluoromethyl-1*H*-1,2,3-benzotriazole

31f 5,7-Dichloro-1-hydroxy-1*H*-1,2,3-benzotriazole

32a Trifluoromethane-1-sulfone acid 6-methyl-1*H*-1,2,3-benzotriazol-4-yl ester

32b Trifluoromethane-1-sulfone acid 5-methyl-1*H*-1,2,3-benzotriazol-4-yl ester

32c Trifluoromethane-1-sulfone acid 5-methyl-1*H*-1,2,3-benzotriazol-6-yl ester

33a Trifluoromethane-1-sulfone acid 7-chloro-1*H*-1,2,3-benzotriazol-4-yl ester

33b Trifluoromethane-1-sulfone acid 7-chloro-1*H*-1,2,3-benzotriazol-6-yl ester

34a Trifluoromethane-1-sulfone acid 5-chloro-1*H*-1,2,3-benzotriazol-6-yl ester

34b Trifluoromethane-1-sulfone acid 5-chloro-1*H*-1,2,3-benzotriazol-4-yl ester

35a Trifluoromethane-1-sulfone acid 5-trifluromethyl-1*H*-1,2,3-benzotriazol-7-yl ester

35b Trifluoromethane-1-sulfone acid 5-trifluromethyl-1*H*-1,2,3-benzotriazol-6-yl ester

35c Trifluoromethane-1-sulfone acid 5-trifluromethyl-1*H*-1,2,3-benzotriazol-4-yl ester

36 Trifluoromethane-1-sulfone acid 4,6-dichloro-1*H*-1,2,3-benzotriazol-7-yl ester

37 Nonafluorobutane-1-sulfonic acid 1-(nonafluorobutane-1-sulfonyl)-1*H*-1,2,3-benzotriazol-4-yl ester

38 Nonafluorobutane-1-sulfonic acid 2-(2-hydroxy-phenylazo)-3-(nonafluorobutane-1-sulfonylamino)-phenyl ester

39b 2,3,4,6-Tetra-*O*-benzoyl-α/β-D-glucopyranose

39c 2,3,4,6-Tetra-*O*-acetyl-α/β-D-glucopyranose

39d 3,4,6-Tri-*O*-acetyl-2-desoxy-2-phthalimido-α/β-D-glucopyranose

39e 2,3,4,6-Tetra-*O*-acetyl-1-thio-β-D-glucopyranose

39f 2,3,6,2',3',4',6'-Hepta-*O*-benzoyl-1-thio-β-lactose

40 4-Nitrophthalonitrile

41α 3,4-Dicyanophenyl-2,3,4,6-tetra-*O*-benzyl-α-D-glucopyranoside

41β 3,4-Dicyanophenyl-2,3,4,6-tetra-*O*-benzyl-β-D-glucopyranoside

42α 3,4-Dicyanophenyl-2,3,4,6-tetra-*O*-benzoyl-α-D-glucopyranoside

42β 3,4-Dicyanophenyl-2,3,4,6-tetra-*O*-benzoyl-β-D-glucopyranoside

43α 3,4-Dicyanophenyl-2,3,4,6-tetra-*O*-acetyl-α-D-glucopyranoside

43β 3,4-Dicyanophenyl-2,3,4,6-tetra-*O*-acetyl-β-D-glucopyranoside

44β 3,4-Dicyanophenyl-3,4,6-tri-*O*-acetyl-2-desoxy-2-phthalimido-β-D-glucopyranoside

45β 3,4-Dicyanophenyl-2,3,4,6-tetra-*O*-acetyl-1-thio-β-D-glucopyranoside

46β 3,4-Dicyanophenyl-2,3,6,2',3',4',6'-hepta-*O*-benzoyl-1-thio-β-lactoside

47b 2,3,4,6-tetra-*O*-benzyl-α/β-D-galactopyranose

47c 2,3,4,6-tetra-*O*-benzyl-α/β-D-manopyranose

48 1,2-dinitrobenzene

49 4-nitrobenzonitrile

50α 2-Nitrophenyl-2,3,4,6-tetra-*O*-benzyl-α-D-glucopyranoside

50β 2-Nitrophenyl-2,3,4,6-tetra-*O*-benzyl-β-D-glucopyranoside

51α 2-Nitrophenyl-2,3,4,6-tetra-*O*-benzyl-α-D-galactopyranoside

51β 2-Nitrophenyl-2,3,4,6-tetra-*O*-benzyl-β-D-galactopyranoside

52α 2-Nitrophenyl-2,3,4,6-tetra-*O*-benzyl-α-D-manopyranoside

53α 4-Cyanophenyl-2,3,4,6-tetra-*O*-benzyl-α-D-glucopyranoside

53β 4-Cyanophenyl-2,3,4,6-tetra-*O*-benzyl-β-D-glucopyranoside

54α 4-Cyanophenyl-2,3,4,6-tetra-*O*-benzyl-α-D-galactopyranoside

54β 4-Cyanophenyl-2,3,4,6-tetra-*O*-benzyl-β-D-galactopyranoside

55α 4-Cyanophenyl-2,3,4,6-tetra-*O*-benzyl-α-D-manopyranoside

56a Tetrakis-2(3),9(10),16(17),23(24)-(2,3,4,6-tetrabenzyl-α/β-D-glucopyranosyl)-phthalocyaninato zinc

56b Tetrakis-2(3),9(10),16(17),23(24)-(2,3,4,6-tetrabenzoyl-α/β-D-glucopyranosyl)-phthalocyaninato zinc

56c Tetra-2(3),9(10),16(17),23(24)-α/β-D-glucopyranosyl-phthalocyaninato zinc

56d Tetra-2(3),9(10),16(17),23(24)-(1-thio-β-D-glucopyranosyl)-phthalocyaninato zinc

56e Tetra-2(3),9(10),16(17),23(24)-(1-thio-β-D-lactosyl)-phthalocyaninato zinc

7 Literature

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Abstract

1. Glycosyl sulfonates have been somewhat neglected in recent years, despite of their considerable potential in stereoselective glycosylation. For this reason, the generation of glycosyl donors with nonafluorobutanesulfonyl derivatives has been studied.
Using the commercially available nonafluorobutane sulfonyl fluoride, it was found that either trehalose or the glycosylated product could be formed depending on the order in which the reagents were added.
The use of 1*H*-benzotriazole for the transfer of the nonafluorobutane sulfonyl group to glucose and the generation of the glycosyl donor was studied. By studying how to cleave the nonafluorobutane sulfonyl group from thebenzotriazole moiety with phenol, the heterocyclic ring was opened between positions N1 and N2, resulting in a new methodology for the formation of azobenzenes. This reaction was exploited in phthalocyanine chemistry in case of benzotriazole-substituted phthalocyanines. The sulphonated benzotriazole ring could also be opened with phosphor ylides, giving new phosphoranylidenes. When mesyl and tosyl benzotriazoles were used, these groups were transferred to phenol giving the corresponding esters. Triflyl benzotriazole gave first the azo compound and then formed ester. When sugars were used as nucleophiles, 1*H* and 2*H*-benzotriazole substituted sugars were obtained, in the case of tosyl and tryflyl and nonaflyl 1*H*-benzotriazoles.
1-hydroxybenzotriazole was also used for this purpose. In theses cases substraction of the sulphonate group occurred, giving a sulphonate substituted 1*H*-1,2,3-benzotriazoles that could not further be used for glycosilation.
The mechanisms of all new reactions were investigated.

2. Carbohydrates attached to porphyrin-like compounds have been previously considered for the treatment of cancer with visible light (photodynamic therapy). Since phthalocyanines are effective substances in photodynamic therapy, as well, the attachment of one carbohydrate to the phthalocyanine ring at the anomeric carbon was considered. The tested glycosilation reactions were not successful when 3,4-dicyanophenol was the substrate. But the substitution of the nitro group in 4-Nitrophthalonitrile was successful. Mainly α−linked phenyl glucosides were obtained in good yields. More compounds were synthesised with this method and several phthalocyanines were formed. This reaction was also studied with dinitro or nitrocyano phenyls that need particular conditions for the formation of phenyl glycosides.

Kurzzusammenfassung

1. Glycosylsulfonate haben, trotz ihres Potentials für die stereoselektive Synthese, in den letzten Jahren wenig Beachtung gefunden. Aus diesem Grunde wurde die Synthese von Glycosyldonoren mit Nonafluorbutansulfonyl-Derivaten untersucht.
Dabei wurde gefunden, dass man unter Verwendung des handelsüblichen Nonafluorbutansulfonsäurefluorids entweder Trehalose oder aber das glykosylierte Produkt erhalten konnte, abhängig von der Reihenfolge, in der die Reagenzien zugegeben wurden.
Die Verwendung von 1*H*-Benzotriazol als Überträger der Nonafluorbutansulfonyl-Gruppe auf Glucose wurde untersucht. Während der Untersuchungen zur Abspaltung der Nonafluorbutansulfonyl-Gruppe vom Benzotriazolrest mittels Phenol, wurde der Heterozyklus zwischen den Positionen N1 und N2 geöffnet, woraus sich eine neue Synthesemethode für Azobenzole ergab. Diese Methode wurde in der Phthalocyaninchemie speziell für die Synthese von Benzotriazol-substituierten Phthalocyaninen angewandt. Der Nonafluorbutansulfonyl-substituierte Benzotriazolring konnte ebenfalls mit Phosphoryliden geöffnet werden, wobei neue Phosphoranylide entstanden. Verwendete man Mesyl- oder Tosyl-Gruppen, wurden diese Gruppen auf Phenol übertragen und bildeten die korrespondierenden Ester. Triflylbenzotriazole bildeten zuerst die Azokomponente und anschließend die Ester. Wenn Zuckerderivate als Nukleophile eingesetzt wurden, erhielt man im Fall von Tosyl-, Triflyl- und Nonaflylbenzotriazolen die 1*H*- und 2*H*-Benzotriazol-substituierten Zuckerderivate.
Zum gleichen Zweck wurde 1-Hydroxybenzotriazol eingesetzt. Dabei fand eine Abspaltung des Sulfonates und das entstandene Sufonat-substituierte 1*H*-Benzotriazol konnte nicht weiter zur Glykosylierung verwendet werden.
Die Mechanismen aller neuen Reaktionen wurden untersucht.

2. An porphyrinähnliche Substanzen gekoppelte Kohlenhydrate wurden schon früher für die Krebstherapie mit sichtbarem Licht (Photodynamiktherapie) in Betracht gezogen. Da Phthalocyanine ebenfalls als effektive Wirkstoffe in der Photodynamiktherapie eingesetzt werden, wurde geplant, ein Kohlenhydrat mit dem anomeren Zentrum an einen Phthalocyaninring anzubinden. Direkte Glykosylierungsreaktionen waren nicht erfolgreich, wenn 3,4-Dicyanophenol als Gykosylakzeptor verwendet wurde. Allerdings verlief die Substitution der Nitrogruppe in 4-Nitrophthalonitril erfolgreich. Als Hauptprodukt wurden α–substituierte Glycoside in sehr guter Ausbeute erhalten. Mehrere ähnliche Substanzen wurden mit dieser Methode synthetisiert und einige Phthalocyanine gebildet. Diese Reaktion wurde auch mit 1,2-Dinitrobenzol und 4-Nitrobenzoesäurenitril untersucht, die spezielle Bedingungen für die Bildung von Phenylglykosiden benötigen.

Ich versichere, dass ich die mir vorgelegte Dissertation selbständig angefertigt, die benutzten Quellen und Hilfsmittel vollständig angegeben und die Stellen der Arbeit – einschließlich Tabellen, Karten und Abbildungen –, die anderen Werken im Wortlaut oder dem Sinn nach entnommen sind, in jedem Einzelfall als Entlehnung kenntlich gemacht habe; dass diese Dissertation noch keiner anderen Fakultät oder Universität zur Prüfung vorgelegen hat; dass sie – abgesehen von unten angegebenen Teilpublikationen – noch nicht veröffentlicht worden ist sowie, dass ich eine solche Veröffentlichung vor Abschluss des Promotionsverfahrens nicht vornehmen werde.
Die Bestimmungen dieser Promotionsordnung sind mir bekannt. Die von mir vorgelegte Dissertation ist von **Prof. Dr. Thomas Ziegler** betreut worden.

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