Alkyl Glycosides as Stable Glycosyl Donors for Oligosaccharide Synthesis

Mr. SRINIVASA RAO VIDADALA

Dr. Srinivas Hotha

(RESEARCH SUPERVISOR)

DIVISION OF ORGANIC CHEMISTRY

NATIONAL CHEMICAL LABORATORY

PUNE – 411008 (INDIA)

[July 2011]

Alkyl Glycosides as Stable Glycosyl Donors for Oligosaccharide Synthesis

A THESIS
SUBMITTED TO
UNIVERSITY OF PUNE
FOR THE DEGREE OF
DOCTOR OF PHILOSOPHY
(IN CHEMISTRY)

BY

Mr. SRINIVASA RAO VIDADALA

DIVISION OF ORGANIC CHEMISTRY
NATIONAL CHEMICAL LABORATORY
PUNE – 411008 (INDIA)

July 2011

Dedicated
To

My Parents, Sister and Brother-in-law

CERTIFICATE

This is to certify that the research work presented in thesis entitled "***Alkyl Glycosides as Stable Glycosyl Donors for Oligosaccharide Synthesis***" has been carried out under my supervision at National Chemical Laboratory, Pune and is a bonafide work of **Mr. Srinivasa Rao Vidadala.** This work is original and has not been submitted for any other degree or diploma of this or any other University.

Pune-411008 **(Dr. Srinivas Hotha)**

July 2011 **Research Supervisor**

DECLARATION

I hereby declare that the research work presented in this thesis was carried out by me at National Chemical Laboratory, Pune under the supervision of **Dr. Srinivas Hotha**, Organic Chemistry Division, National Chemical Laboratory, Pune - 411 008. This work is original and has not been submitted in part or full, for any degree or diploma of this or any other university.

Organic Chemistry Division (**Srinivasa Rao Vidadala**)
National Chemical Laboratory
Pune-411008
July 2011

Acknowledgements

Science shines forth in all its value as a good capable of motivating our existence, as a great experience of freedom for truth, as a fundamental work of service. Through research each scientist grows as a human being and helps others to do likewise. It is a pleasant feeling for me to have this opportunity to express my gratitude for all of them who have been accompanied and supported throughout the time I spent working for my doctoral studies.

It gives me immense pleasure to express my deep sense of gratitude to my supervisor and mentor ***Dr. Srinivas Hotha*** *for his excellent guidance, continuous encouragement, and generous support in achieving this entire endeavor. I am very much grateful to him for motivating me in carbohydrate (The Sweet Molecules of Life) chemistry and appreciate his able guidance, wholeheartedly. Working with him was really a great pleasure and fetched me a lot of learning experience. I do sincerely acknowledge the freedom rendered by him in the laboratory for the independent thinking, planning and execution of research. Although this eulogy is insufficient, I preserve an everlasting gratitude for him. Without his encouragement and constant guidance, I could not have finished my doctoral degree. I sincerely thank fruitful collaboration with* ***Prof. Torsten Linker****, University of Potsdam, Germany.*

I sincerely thank Dr. H. V. Thulasiram, Dr. Sayam Sen Gupta, Dr. B. L. V. Prasad, Dr. C. V. Ramana, Dr. M J Kulkarni and Mr. I. Shivakumar who were always ready for their help, guidance and moral support.

I wholeheartedly thank and give acknowledgements to the entire NMR and Elemental analysis group especially Dr. Rajmohan, Mr. Sathe and Mrs. Phalgune from NMR facility. I also thank Mrs. Shantakumari for their timely help in mass spectroscopic analysis.

During the course of this work in NCL, I learnt that a journey is easier when we travel together. I would like to thank my labmates, Susheel, Sudhir, Ashish, Girish, Suresh, Asif, Abhijeet, Shivaji, Venki, Suneel, Sandesh and Ram for their kind help and support, invaluable discussions which we shared and for maintaining a lively environment in the laboratory during every walk of life in the laboratory to achieve this goal.

I wholeheartedly thank my friends Ramesh, Arup, Ankush, sutar, Bharat, Kishore, Prasanna, Kannan, Ramanujan, Mishra, Ganya, Abhijeet, Kamendra, Nishant , Abhilash, Malli, Umesh, Ramesh, Sujit, Debashish, rahul, pitamber, abasaheb, saikat, Ashish, somesh, mandeep, NCL sports community, GP Lab, KNG lab, Ramana lab, PKT lab, Pedireddi lab, Chavan lab,

Argade lab, Sanjayan lab, OCD division ... for their unconditional support and continuous encouragement during my stay in NCL.

I woud like toexpress my sincere gratitude to my telugu friends Sridhar, rajendra, swaroop, Raaman, Satyannarayana, bhargava, Srinivas, Siva, raghupathi, Srinivas B, nageswar, Kiran, Rambabu, Sudhakar, Ramesh, Govind, Srinivas(gula), kitappa, Koti, Santosh, Yadagiri, Vilas, narasimha reddy, Bhogesh, Kanna, Chaitanya, venu, ajay, manoj, Suneel, Chandrababu, Durga, Sivakumar, Bala, ramireddy, vijay, raju, rambabu, janakiram .... for their cheerful company and making my life in NCL very lively and enjoyable. I wish to extend my sincere thanks to Tamil friends (Nagaraj, edvin, lenin, palani, Dharmaraj, senthil, vijay, Mohan), Kerala friends (Rajesh, Eldo, Suresh, Alson), Marathi friends and Bengali friends.... for their cheerful and enjoyable company. Also, I express my sincere thanks to all hostelites who are residing in the Golden Jubilee Hostel for the enjoyable and colourful atmosphere.

I would like to express my deep and sincere gratitude to my M.Sc. teachers, Prof. Suryaprakash Rao, Prof. Sambasiva Rao, Dr. B.B.Das, Dr.Vekatesan, Dr.Vasuki, Dr. Dastagiri reddy, and my M. Sc. colleagues Ramesh, Johny, Gupta, Gopi, vijay, krishnareddy, narayana, Srinivas, Prakash, muthu pandey, Sharmil, Sobharani, jagadesh, Girish, sudhakar, and whole chemistry dept. ... for their understanding, encouraging and guidance during my Post graduation in Pondicherry University, Pondicherry. I would like to thank my ever inspirational teacher Raghavulu sir for guiding me to this position and all my B.Sc teachers and Friends for their valuable suggestion.

I am grateful to Council of Scientific and Industrial Research, Government of India, for awarding the junior and senior research fellowships and Dr. S. Sivaram, Ex-Director, Dr. Sourav Pal, Director, National Chemical Laboratory to carry out my research works, extending all infrastructure facilities.

Last, but not least, I dedicate this achievement to my family who walked along with me, sharing every ups and downs. It has been a difficult task to capture and express my feelings for my family members. What I am and intend to be in the future is because of the good will and unstinted support of my grandparents (bhagyamma garu, Venkateswarlu garu), parents(Nagendramma garu, Rangaiah garu), elder sister (Edukondalu), without knowing much what I am doing exactly, just wishing me all the time with no expectations. No words are enough to acknowledge them for their patience and sacrifice which were always remain a source of inspiration and will remain throughout my life. My success now and always will be dedicated to them.

Srinivasa Rao Vidadala

Contents

Page Number

General Remarks

- ^{1}H NMR spectra were recorded on AV-200 MHz, AV-400 MHz, and DRX-500 MHz spectrometer using tetramethylsilane (TMS) as an internal standard. Chemical shifts have been expressed in ppm units downfield from TMS.
- ^{13}C NMR spectra were recorded on AV-50 MHz, AV-100 MHz, and DRX-125 MHz spectrometer.
- Mass spectra were recorded on Applied Biosystems API QSTAR Pulsar Mass Spectrometer (Electro spray ionization, direct infusion method, solvents used acetonitrile/methanol). EI Mass spectra were recorded on Finngan MAT-1020 spectrometer at 70 *eV* using a direct inlet system. Mass spectra were recorded on Waters LCMS-UPLC systems.
- Elemental analysis was carried out on Thermo Finnigan Flash EA 1112 series analyzer.
- Infrared spectra were scanned on Shimadzu IR 470 and Perkin-Elmer 683 or 1310 spectrometers with sodium chloride optics and are measured in cm^{-1}.
- Optical rotations were measured with a JASCO DIP 370 digital polarimeter.
- All reactions are monitored by Thin Layer chromatography (TLC) carried out on 0.25 mm E-Merck silica gel plates (60F-254) with UV light, I_2, and anisaldehyde in ethanol as developing agents.
- All reactions were carried out under nitrogen or argon atmosphere with dry, freshly distilled solvents under anhydrous conditions unless otherwise specified. Yields refer to chromatographically and spectroscopically homogeneous materials unless otherwise stated.
- All evaporations were carried out under reduced pressure on Büchi rotary evaporator below 45 °C unless otherwise specified.
- Silica gel (60–120), (100-200), and (230-400) mesh were used for column chromatography.
- Scheme, Figure and Compound numbers in abstract and individual chapters are different.

Abbreviations

Ac	Acetyl/Acetate
Ac_2O	Acetic anhydride
CAN	Acetonitrile
All	Allyl
Ar	Aryl
Boc	*tert*-butoxycarbonyl
Bn	Benzyl
Bz	Benzoyl
CAN	Ceric ammonium nitrite
DCM	Dichloromethane
DDQ	2,3-dichloro-5,6-dicynao *p*-benzoquinone
DIPEA	*N*,*N*-diisopropylethylamine
DMAP	4-(dimethylamino)pyridine
DMDO	2,2 Dimetyhldioxirane
DMF	*N*,*N*-dimethylformamide
DMSO	Dimethyl sulfoxide
Fmoc	9-Flourenylmethoxy Carbonyl
g	Gram
HMDS	Hexamethyl disilazane
Hz	Hertz
IDCP	Iodonium-dicollidine perchlorate
DMTST	Dimethyl(methylthio)sulfonium trifluoromethanesulfonate
J	Coupling constant
M	Molar
mL	Milliliter
mol	Mole
mmol (mM)	Millimole
m.p.	Melting point
MsCl	Methanesulphonyl chloride
Na-Asc.	Sodium ascorbate
NIS	*N*-iodosuccinimide
NMO	*N*-morphiline oxide
-OMe	Methoxy
PTSA	*p*-toluene sulfonic acid
Ph	Phenyl
Phth	Phthalimido
Py	Pyridine
TBAF	Tetrabutylammonium fluoride
TBDPS	*tert*-butyldiphenylsilyl
TBS	*tert*-butyldimethylsilyl
TCP	tatra chloro phthaloyl
TfOH	Triflic acid
TFA	Trifluoroacetic acid
THF	Tetrahydrofuran
TLC	Thin layer chromatography
TMS	Trimethylsilyl
TMSCl	Trimethylsilyl chloride
$TMSN_3$	Trimethylsilyl azide
TEA	Triethyl amine
TsOH	*p*-toluene sulfonic acid

Abstract

Abstract

Thesis Organization : The thesis entitled *Alkyl Glycosides as Stable Glycosyl Donors for Oligosaccharide Synthesis* is organized into three chapters.

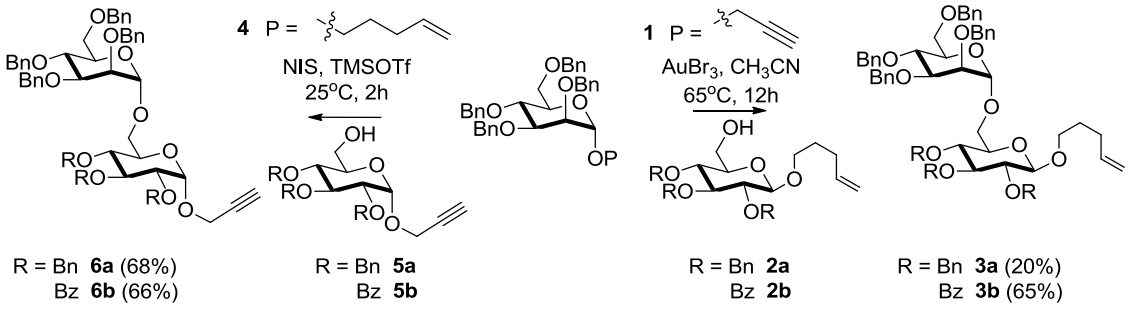
The first chapter highlights the utility of orthogonal activation strategy with respect to propargyl and pentenyl glycosides for the synthesis of oligosaccharides, whereas the second chapter describes the development of stable glycosyl donors, alkyl glycosides as novel glycosyl donors using catalytic $AuBr_3$ for the synthesis of glycosides, disaccharides, oligosaccharides and glycoconjugates. The third chapter enables the exploitation of methyl glycosides for the synthesis of *C*-2 functionalized glycosides, di-saccharides and interesting bi-cyclic lactones.

Chapter 1: Oligosaccharide synthesis using orthogonal activation strategy of propargyl and *n*-pentenyl glycosides

Glycoconjugates and oligosaccharides are the most functionally and structurally diverse molecules in nature and it is now well established that membrane bound saccharides play essential roles in many biological processes namely fertilization, embryogenesis, neuronal development, hormone activities, the proliferation of cells and their organization into specific tissues etc impacting eukaryotic biology and disease. The major drawbacks in the study of glycoconjugates are the low availability of pure samples from nature, low concentrations and in micro heterogeneous forms, which complicates their isolation and characterization. Therefore, the chemical synthesis of oligosaccharides of biological importance is essential.

In our laboratory, propargyl glycosides as well as propargyl 1, 2-orthoesters were identified as novel and stable glycosyl donors in the presence of catalytic $AuBr_3$ for the glycoconjugate synthesis. By considering biological significance of oligosaccharides we got interested in synthesizing them using orthogonal activation strategy as propargyl and *n*-pentenyl glycosides can be activated independently and the strategy needs less number of steps to synthesize.

Scheme 1 *Orthogonal Activation of Propargyl and n-Pentenyl Glycosides*



Accordingly, propargyl glycosyl donor **1** was reacted with *n*-pentenyl glucoside as an aglycone **2a** in the presence of 10 mol% of $AuBr_3$ in acetonitrile at 65^{o}C for 12h to obtain 20% yield of the disaccharide **3a** (Scheme 1) and the yield could be improved to 65% by switching the protecting groups of the aglycone from armed benzyl ethers to disarmed benzoyl esters as in **2b** to get the corresponding disaccharide **3b**.

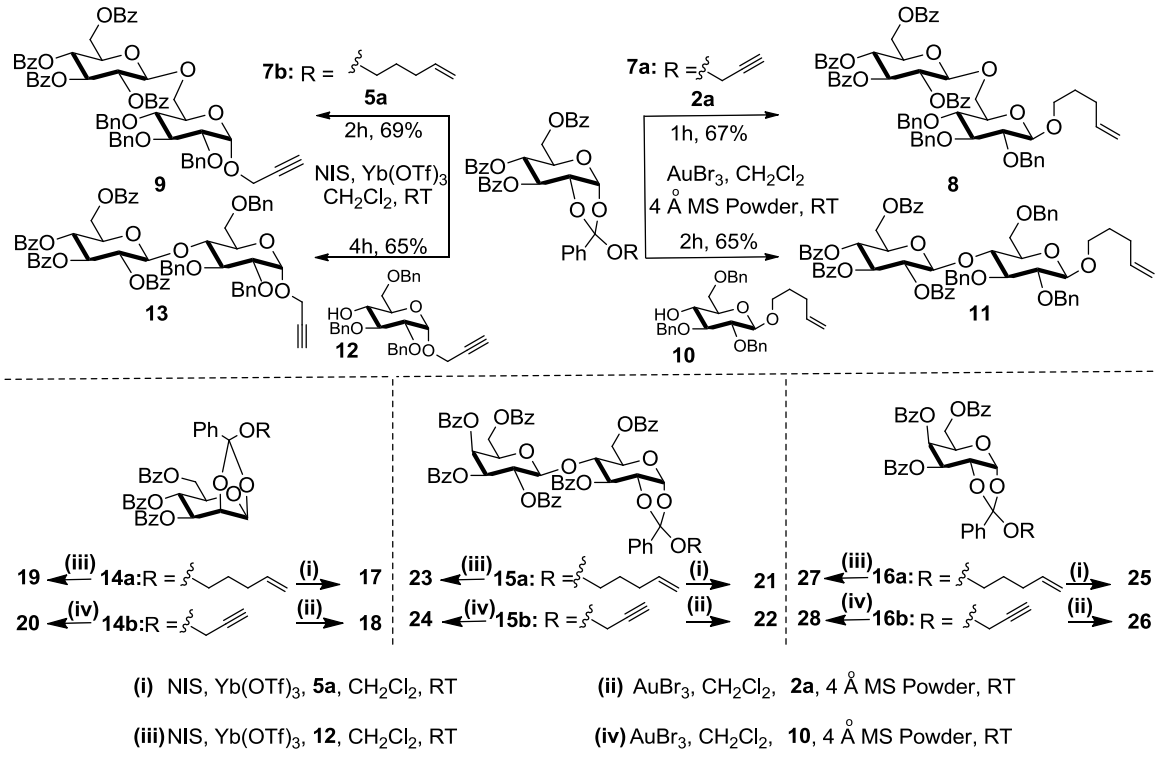
Similarly, the *n*-pentenyl mannosyl donor **4** was reacted with propargyl containing aglycones **5a** and **5b** to get the disaccharides **6a** and **6b** in 68 and 66% yield respectively. The poor yield in the case of **1**+**2a** to give **3a** can be attributed to our recent observations that $AuBr_3$ also activates *n*-pentenyl glycosides at higher temperature.

Thus we studied the utility of orthogonal activation strategy using propargyl 1, 2-orthoesters as glycosyl donors and *n*-pentenyl glycosides as aglycones since propargyl 1,2-ortho esters would act as glycosyl donors at the room temperature. Accordingly, a gold catalyzed glycosylation reaction between propargyl orthoester **7a** and aglycone **2a** was successfully carried out at room temperature in CH_2Cl_2 to obtain the disaccharide **8** as an *n*-pentenyl glycoside (Scheme 2).

In other way, the reaction between *n*-pentenyl orthoester **7b** and the propargyl glucoside **5a** in the presence of NIS/$Yb(OTf)_3$ in CH_2Cl_2 showed the orthogonality to result in the isolation of disaccharide **9** as a propargyl glycoside in 69% yield. The

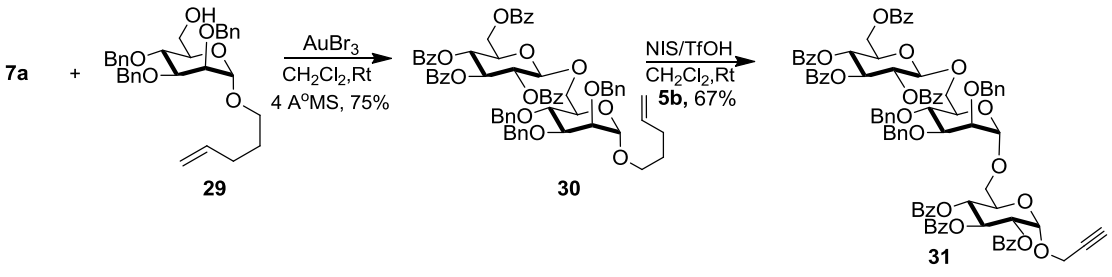
protocol was then extended to various other aglycones (**10, 12**) and glycosyl donors (**14, 15, 16**) to get corresponding propargyl and pentenyl oligosaccharides (**17**-**28**) (Scheme 2).

Scheme 2 *Activation of Propargyl Orthoesters in the Presence of n-PentenylGlycosides and Vice versa*



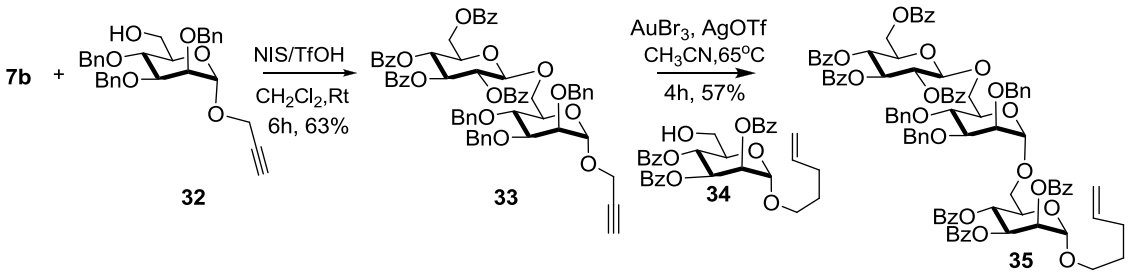
Then we studied the utility of orthogonal activation strategy for the synthesis of higher oligosaccharides. Propargyl orthoester **7a** was allowed to react with aglycone **29** to give disaccharide **30** with pentenyl group at the reducing end, which was activated in the presence of propargyl glucoside **5b** to give trisaccharide **31** (Scheme 3).

Scheme 3 *Synthesis of Propargyl Tri-saccharide: general applicability*



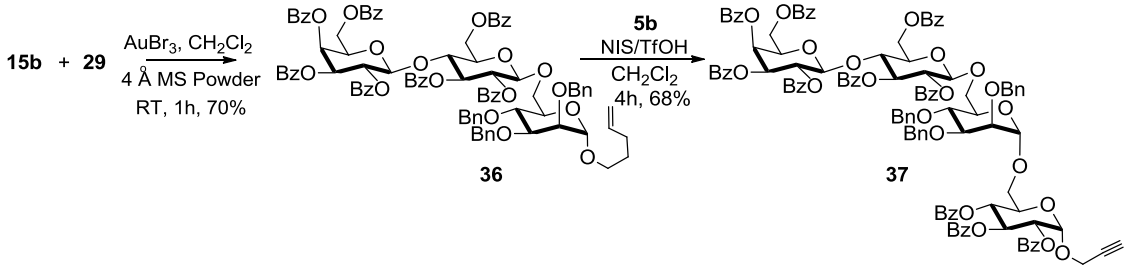
Similarly, pentenyl orthoester **7b** was allowed to react with aglycone **32** to give disaccharide **33** with Propargyl group at the reducing end, which was activated in the presence of pentenyl glycoside **34** to give tri saccharide **35** with pentenyl group at the reducing end (Scheme 4).

Scheme 4 *Synthesis of Pentenyl Tri-saccharide: general applicability*



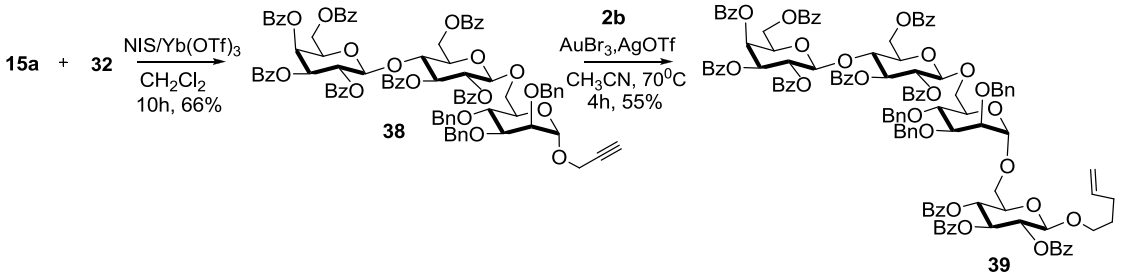
Using the same orthogonal strategy, we synthesized tetra saccharides with propargyl and pentenyl groups at the reducing end. The reaction between lactose propargyl orthoester **15a** and aglycone **29** resulted in the formation of trisaccharide **36** with pentenyl group at the reducing end which was further activated in the presence of acceptor **5b** to give propargyl tetra saccharide **37** (Scheme 5).

Scheme 5 *Synthesis of Propargyl Tetra-saccharide: general applicability*



In contrast, the reaction between lactose pentenyl orthoester **15a** and aglycone **32** resulted in the formation of tri- saccharide **38** with propargyl group at the reducing end which was further activated in the presence of acceptor **2b** to give pentenyl tetra saccharide **39** (Scheme 6).

Scheme 6 *Synthesis of Pentenyl Tetra-saccharide: general applicability*



In conclusion, we studied the orthogonal activation strategy using propargyl and *n*-pentenyl glycosides. We observed that *n*-pentenyl glycosides can be activated to become glycosyl donors in the presence of propargyl glycosides as aglycones. In addition, propargyl 1,2-orthoesters were found to behave as glycosyl donors with *n*-pentenyl glycosides as aglycones and *vice versa*. Synthesis of tetra saccharides containing propargyl and *n*-pentenyl groups at the reducing end were achieved in good yields.

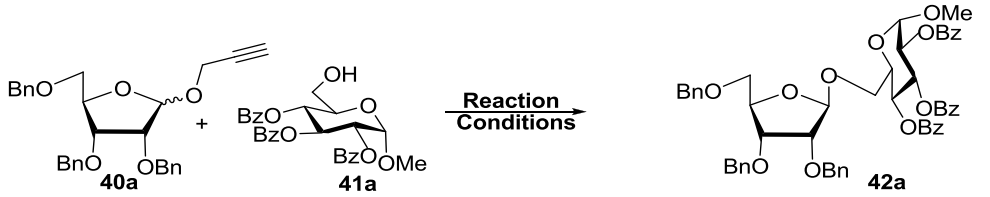
Chapter 2: Alkyl glycosides as stable glycosyl donors for oligosaccharide synthesis.

The development of stable, efficient and stereoselective glycosylation methodologies has attracted a great deal of attention in recent years due to the biological significance of many complex oligosaccharides and glycoconjugates. To date, many innovative glycosylation methodologies have been developed. However, most of these address the preparation of pyranose glycosides. In contrast, studies on stereoselective furanosylation have been more limited. So, there is a need for methods that enable the preparation of furanosides in a stereoselective manner, given the critical role that glycoconjugates containing these residues play in the life cycle of a number of microorganisms.

As propargyl pyranosides were exploited for the synthesis of various glyco-conjugates using catalytic gold salts in our laboratory, we target utilization of the method for the synthesis of furanosyl glycosides which are xenobiotic in nature to humans. To begin our investigation, propargyl 2,3,5-tri-*O*-benzyl-(α/β)-riboside (**40a)** and methyl 2,

3, 4-Tri-*O*-benzoyl- α-D-glucopyranoside (**41a)** were treated with $AuCl_3$ in acetonitrile under argon to result the formation of 1,2- *trans* stereoselective disaccharide **42a** (Table 1). But the reaction was not completed even after 48h. We screened various catalysts as well as their combinations and the best results for the trans glycosylation was observed with the combination of $AuBr_3$ and AgOTf. Latter we explored methodology by $AuBr_3$, AgOTf and RT as standard conditions with different aglycones (**41a-41e**) to get 1, 2-*trans* glycosides as well as disaccharides (**42a-42e**) in a stereo selective manner.

Table 1 *Optimization of catalyst*

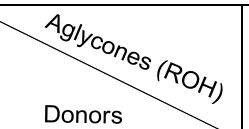
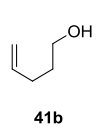
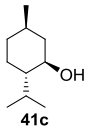
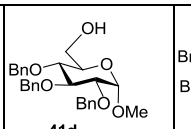
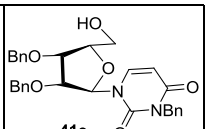
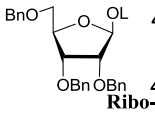
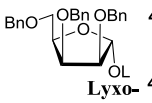
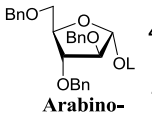
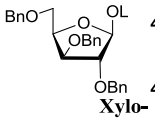


Entries	Reagents	Temparature(°c)	Time(h)	% Yield
1	15 mol% $AuCl_3$,CH_3CN	RT	48	41
2	15 mol% $AuBr_3$,CH_3CN	RT	48	55
3	15 mol% $AuCl_3$,$AgBF_4$,CH_3CN	RT	24	54
4	15 mol% $AuCl_3$,AgOTf,CH_3CN	RT	2	60
5	15 mol% $AuBr_3$,AgOTf,CH_3CN	RT	2	72
6	15 mol% $AuBr_3$,AgOTf,CH_3CN	60	12	72

We extended the scope of the method to Lyxo- (**40c)**, Arabino- (**40e)**, Xylo- (**40g)**, and furanosides to get corresponding glycosides(**43b-45b**, **43c-45c)** and disaccharides(**43a-45a, 43d-45d, 443e**) (Scheme 7). Interestingly, we observed single 1, 2-*trans* selectivity in case of *lyxo*- (**40c)** furanosides also, whereas (α/β) mixture in case of *xylo*- (**40g)** and *arabino*- (**40e)** furanosides.

During the course of the synthesis of lyxo- furanosides, the serendipitous observation of cleavage of methyl glycosides, followed by the attack of aglycone results the formation of di-saccharide was observed, which is a ground breaking result because of their quite stability and never acts as glycosyl donor before.

Scheme 7 *Synthesis of furanosyl glycosides & Di-saccharides*

Donors \ Aglycones (ROH)	 **41a**	 **41b**	 **41c**	 **41d**	 **41e**
 **Ribo-** **40a** :L = Prop	**24h, 72%, 42a, β only**	**12h, 77% 42b,β only**	**16h, 73% 42c, β only**	**48h, 60% 42d, β only**	**24h, 68% 42e, β only**
40b :L = Me	**24h, 69%**	**12h, 90%**	**16h, 68%**		
 **Lyxo-** **40c** :L = Prop	**24h, 69 % 43a, α only**	**12h, 85 % 43b, α only**	**12h, 75 % 43c, α only**	**24h, 61 % 43d, α only**	**24h, 62 % 43e, α only**
40d :L = Me	**24h, 60 %**	**12h, 89%**	**12h, 66 %**		
 **Arabino-** **40e** :L = Prop	**24h, 66 % 44a, 1:0.1(α:β)**	**12h, 86% 44b, 1:0.2(α:β)**	**12h, 72% 44c, 1:0.1(α:β)**	24h, 65% **44d, α only**	———
40f :L = Me	**24h, 60 %**	**12h, 85%**	**12h, 71%**		
 **Xylo-** **40g** :L = Prop	**24h, 67% 45a, 0.2:1(α:β)**	**12h, 90 % 45b, 0.2:1(α:β)**	**18h, 75 % 45c, 0.1:1(α:β)**	**24h, 68 % 45d, 0.6:1(α:β)**	———
40h :L = Me	**24h, 65 %**	**12h, 91 %**	**18h, 75 %**		

So we explored methyl furanosides as glycosyl donors for the synthesis of various glycosides and di-saccharides. Methyl ribo-(**40b**), Lyxo-(**40d**), Arabinao-(**40f**) and Xylo-(**40h**) furanosides were treated with various glycosyl acceptors(**41a-41e**) to get corresponding glycosides(**42b-45b, 42c-45c,)** and disaccharides(**42a-45a, 42d-45d, 42e, 43e**) (Scheme 7).

Scheme 8 *Synthesis of disaccharide***:** *way to novel glycosyl donor*

1 **46a** R_1 = Bn; **41a** R_1 = Bz

47a R_1 = Bn (60%); **47b** R_1 = Bz (78%)

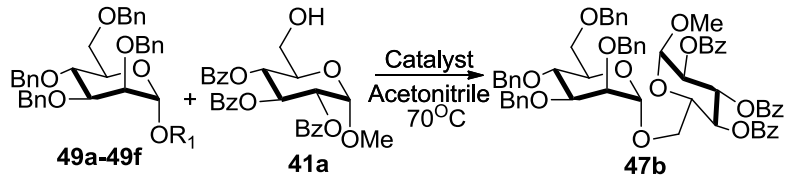
48a R_1 = Bn (20%); **48b** R_1 = Bz (0%)

Similar kind of cleavage of methyl glycosides were observed with pyranosides as well. While glycoconjugate syntheses, we contemplated upon utilizing propargyl mannopyranoside (**1**) as glycosyl donor and aglycone **46a** to synthesize a disaccharide **47a** in the presence of 5 mol% of $AuCl_3$ in acetonitrile at 70^{o}C.Gratifyingly, we observed

the formation of disaccharide **47a** along with 20% of 1,6-anhydro sugar derivative **48a** (Scheme 8). Interestingly, 1,6-anhydro derivative **48a** was not observed when the Au-mediated reactions were conducted at 25^{o}C indicating the strong temperature dependence. Formation of **48a** could be prevented by changing the protecting group from more reactive benzyls to less reactive benzoates **41a** to afford disaccharide **47b** (Scheme 8). which indicates activation of methyl glucoside of **46a** leading to the oxocarbenium ion which could have been trapped by the primary hydroxyl group in an intramolecular fashion.

Thus methyl per-*O*-benzyl-α-D-mannopyranoside (**49a**) was allowed to react with aglycone **41a** in the presence of $AuCl_3$ in acetonitrile at 70^{o}C for 24h to afford the disaccharide **47b** in 47% yield (Entry 1, Table 2).

Table 2 *Optimization of catalyst & alkyl glycosides*



Entry	*R_1*	*Catalyst*	*Glycosyl Donor*	*% Yield*	*Entry*	*R_1*	*Catalyst*	*Glycosyl Donor*	*% Yield*
1.	$-CH_3$	$AuCl_3$	**49a**	47	8.	$-CH_3$	$BF_3.Et_2O$	**49a**	47
2.	$-CH_3$	$AuBr_3$	**49a**	65	9.	$-CH_3$	$Sc(OTf)_3$	**49a**	46
3.	$-CH_3$	AuCl	**49a**	32	10.	$-CH_2CH_3$	$AuBr_3$	**49b**	31
4.	$-CH_3$	Au_2O_3	**49a**	0	11.	$-CH(CH_3)_2$	$AuBr_3$	**49c**	45
5.	$-CH_3$	$Au(PPh_3)Cl$	**49a**	0	12.	$-CH_2Ph$	$AuBr_3$	**49d**	10
6.	$-CH_3$	$HAuCl_4$	**49a**	55	13.	-Cholesteryl	$AuBr_3$	**49e**	5
7.	$-CH_3$	$AuBr_3,Et_3N$	**49a**	0	14.	-Allyl	$AuBr_3$	**49f**	15

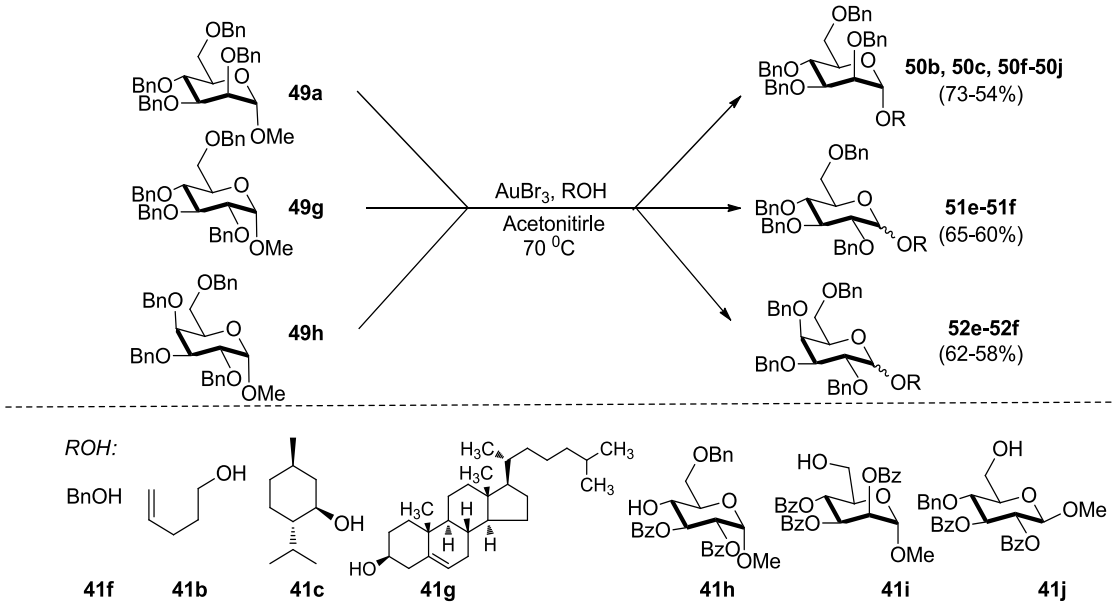
Changing the catalyst to $AuBr_3$ increased the yield to 65%, AuCl resulted in 32% of the disaccharide **47b** whereas Au_2O_3 and $AuPPh_3Cl$ did not show any disaccharide **47b** even after 36h (Entries 2-5). $HAuCl_4$ promoted the glycosylation affording **47b** in 55% yield along with 15% of the unwanted lactol (Entry 6). Addition of organic bases such as triethylamine was detrimental to the progress of the reaction (Entry 7). The efficacy of

the reaction was also checked with other Lewis acids [$BF_3.Et_2O$ and $Sc(OTf)_3$] and found to give low yields (Entries 8,9).

The effect of $AuBr_3$ in acetonitrile on selected panel of alkyl glycosides (**49b**-**49f**) was then investigated. Interestingly, ethyl- (**49b**), isopropyl- (**49c**) mannosides gave disaccharide **47b** in average yields whereas benzyl- (**49d**), cholesteryl- (**49e**) and allyl- (**49f**) glycosides resulted in poor yields of **47b** (Entries 10-14).

Furthermore, the scope of the reaction was gauged by a panel of aglycones comprising benzyl alcohol (**41f**), 4-penten-1-ol (**41b**), menthol (**41c**), cholesterol (**41g**), and sugar aglycones (**41h-41j**) and found that the methyl mannoside (**49a**) behaves as a glycosyl donor giving good yields of corresponding glycosides (**50b, 50c, 50f**) and disaccharides (**50h-50j**) except with **41g** which can be attributed to the poor solubility of cholesterol **d** in acetonitrile(Scheme 9).

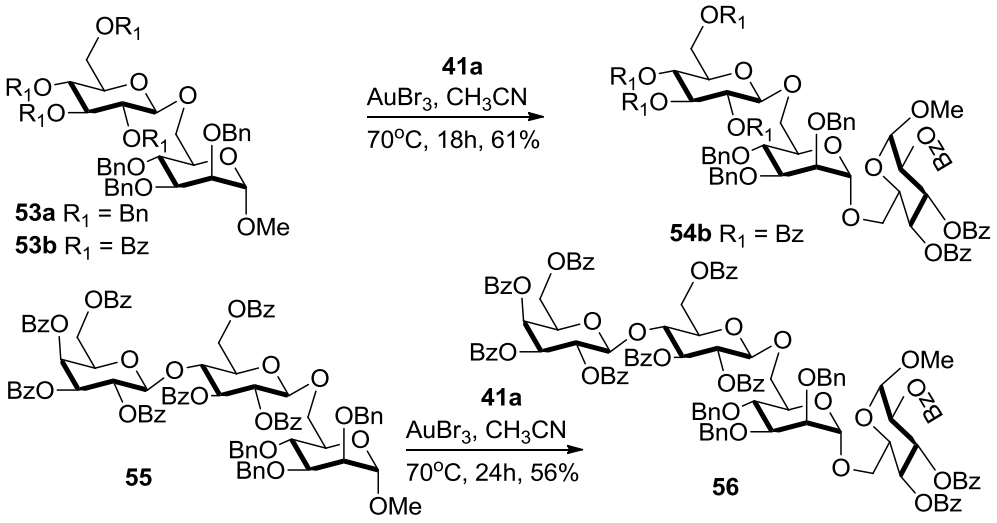
Scheme 9 *Synthesis of glycoconjugates from methyl glycosides*



It is pertinent to declare that the current strategy has been successfully extended to the methyl per-*O*-benzylated glucoside (**49g**) and galactoside (**49h**) to obtain disaccharides (**51h-51j**, **53h-53j**) as α, β-mixtures (Scheme 9). In addition, we

synthesized tri- and tetra saccharides (**54b**, **56**) using the similar protocol from the corresponding di- and tri saccharides (**53**, **55**) (Scheme 10).

Scheme 10 *Synthesis of tri- and tetra- saccharides using methyl glycosides*



In conclusion, propargyl as well as methyl furanosides were developed as glycosyl donors for the synthesis of glycosides and disaccharides. Methyl glycosides were identified as novel and stable glycosyl donors. A diverse range of aglycones are shown to react with methyl glycosides, resulting in the formation of corresponding glycosides and disaccharides in good yields. Interesting to note that tri- and tetra- saccharides were synthesized from respective di- and tri- saccharides exploiting salient features of this novel glycosylation protocol.

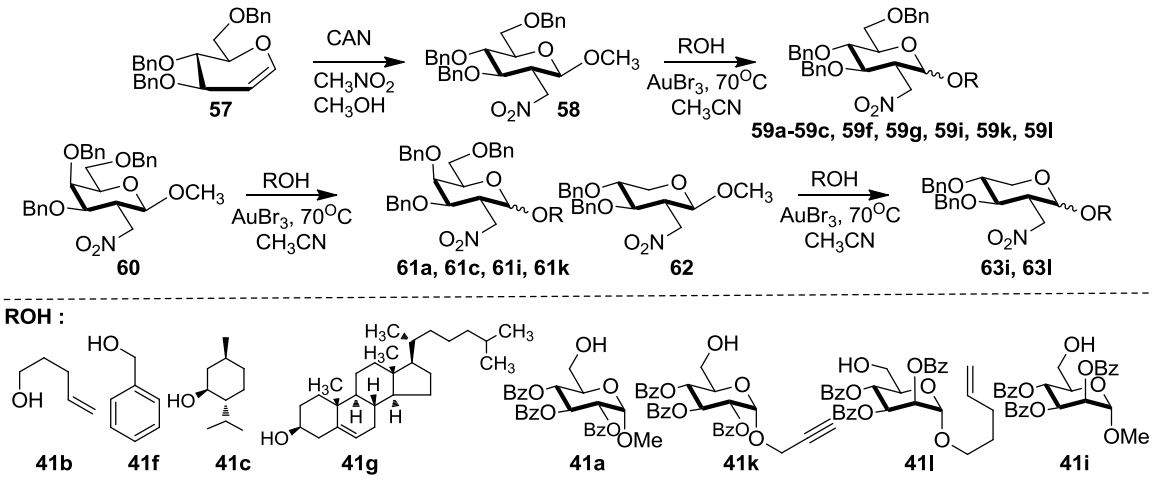
Chapter 3: Synthesis of C-2 functionalized glycosides exploiting methyl glycosides

Synthesis of C-2 functionalized glycosides has got its importance because of their promising biological activities. Glycosamine containing glycopeptides and glycolipids play pivotal roles in a variety of cellular processes such as cell-cell adhesion, cell growth, fertilization and infection. Artificial and unnatural *N*-functionalized glucosamines were studied as substrates for the inhibition of *N*-acetylglucosaminyl transferases.

Additionally, glycosamine homologs are interesting as they modulate the cellular molecular recognition events.

Since we identified the methyl glycosides acts as stable glycosyl donors and can be activated by catalytic gold, we thought of using the methodology for the synthesis of 2-*C*-nitromethyl glycosides as well as disaccharides. Radical addition of nitromethane to the tri-*O*-Bn Glucal(**57**) using ceric ammonium nitrate generalized by Prof. Torsten Linker led to the formation of 2-*C*-nitromethyl glucoside (**58**), which upon reaction with various aglycones (**41a-41c, 41f, 41g, 41i, 41k, 41l**) using catalytic amount gold salts resulted to corresponding glycosides (**59b,59c, 59f, 59g**) and disaccharides (**59a, 59i, 59k, 59l**) (Scheme 11). Interestingly, in case of less hindered aglycones (**41a, 41f**) resulting glycosides were α/β mixtures where as sterically hindered acceptors resulted only as α isomer. These results were extended to galacto-(**60**) as well as xylo-(**62**) pyranosides

Scheme 11 *Synthesis of various 2-C-nitromethyl branched glycosides and disaccharides*



to give corresponding glycosides (**61c**) and disaccharides (**61a, 61i, 61k**, **62h**, **63i, 63l**). More interestingly, in all reactions 10-15% of the anomerized product was observed which was confirmed by 2D NMR. This mechanistic rationale is in accordance to our observed α/β-selectivities. Thus, intermediate **B** is only formed if R is small (e.g. Me), explaining why only methyl glycosides serve as donors in gold-catalyzed reactions

(Figure 1). For other simple primary alcohols (**41b**, **41f)** the transglycosidation is still possible to some extent, and α/β-mixtures result. On the other hand, secondary alcohols and disaccharides are sterically too demanding and only intermediate **C** can be formed (Figure 1). Therefore, the exocyclic C-O bond cannot be cleaved anymore, then the anomerization took place. The percentage of anomerization was minimized by using 3

Figure 1 *Mechanism of glycoside activation with $AuBr_3$*

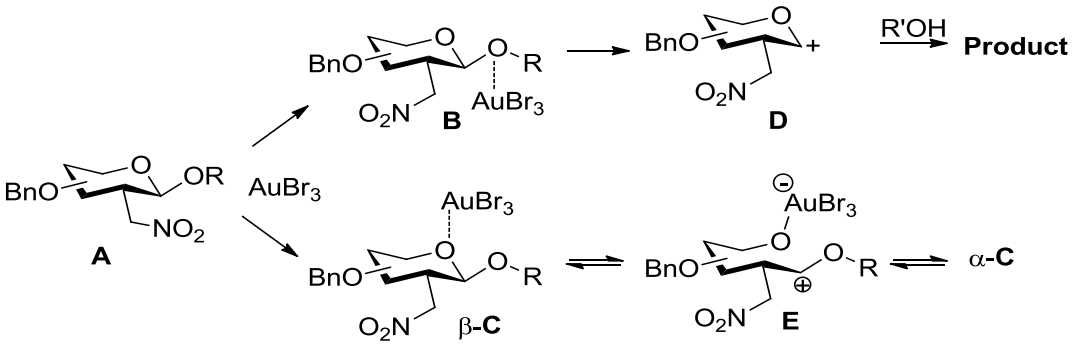
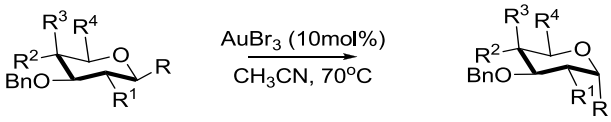
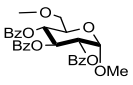


Table 3 *Gold-catalyzed anomerizations of various β-glycosides*



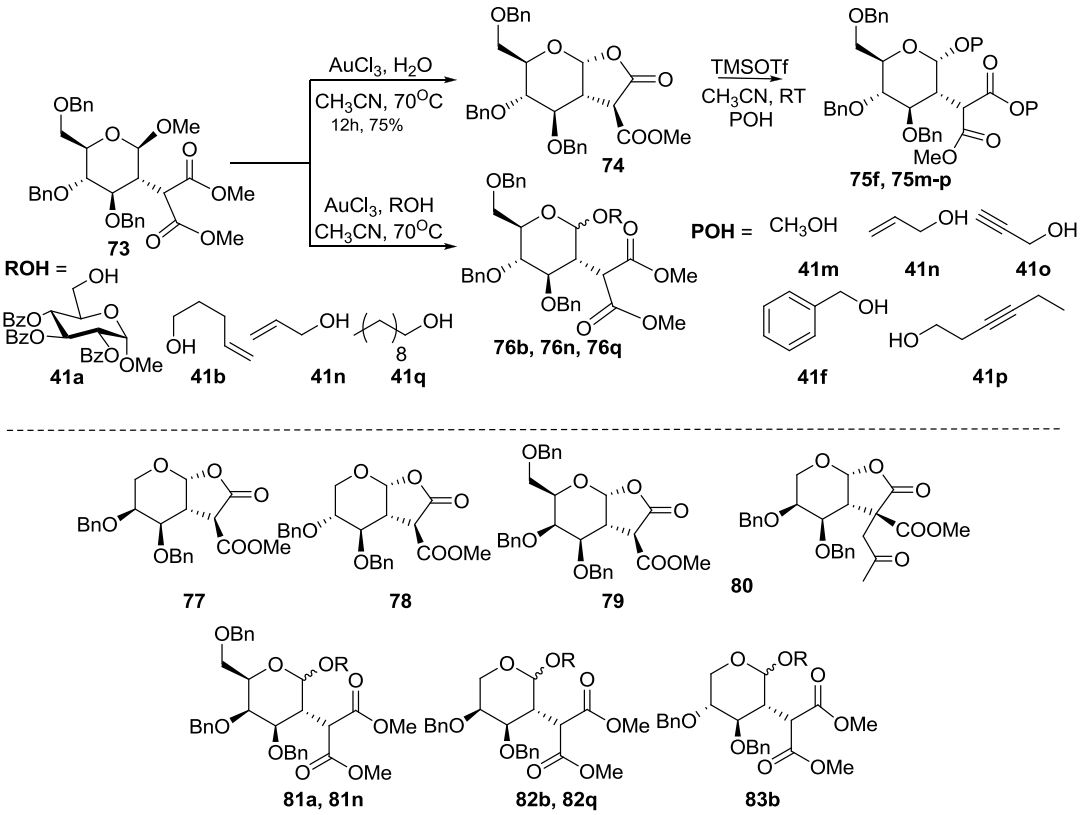
1,2-*trans or* β 1,2-*cis or* α

Entry	Substrate	R^1	R^2	R^3	R^4	R	Product	Time Yield (%)[a]
1	**58**	$-CH_2NO_2$	-OBn	H	$-CH_2OBn$	$-OCH_3$	**64**	2h 86%
2	**60**	$-CH_2NO_2$	H	-OBn	$-CH_2OBn$	$-OCH_3$	**65**	1h 80%
3	**62**	$-CH_2NO_2$	-OBn	H	H	$-OCH_3$	**66**	2h 71%
4	**67**	-OBn	-OBn	H	$-CH_2OBn$	$-OCH_3$	**49g**	12h 55%
5	**68**	-OBn	H	-OBn	$-CH_2OBn$	$-OCH_3$	**49h**	8h 70%
6	**69**	-OBn	-OBn	H	$-CH_2OBn$		**70**	12h 51%
7	**71**	-OBn	-OBn	H	$-CH_2OBn$		**72**	12h 41%

equivalents of acceptor. In continuation we treated 2-*C*-nitromethyl glucoside **58** alone in acetonitrile with catalytic gold to result the anomerized product **64** in good yield. Similar results were obtained with 2-C-nitromethyl galacto- (**60**) and xylo-(**62**) glycosides to get α glycosides (**65**, **66**). Later, we checked the anomerization of different alkyl glycosides (**67, 68, 69**) to get corresponding α-glycosides (**49g, 49h, 70**) (Table 3). More interestingly, the interglycosidic bond having β-linkage of the disaccharide (**71**) also underwent anomerization to get α–linked disaccharide (**72**) in moderate yield (Table 3).

Lactones represent an important class of organic compounds, are industrial intermediates, and can be synthesized by various methods. γ -Lactones, in particular, are widespread in nature and possess promising pharmacological properties as enzyme inhibitors, due to their common ring opening by nucleophiles. Interestingly, linking of carbohydrates to the reactive heterocycle increases water solubility, which is advantageous for the bioavailability.

Scheme 12 *Synthesis of bi-cyclic lactones & C-2 functionalized glycosides*



We visualized that 2-*C*-branched monosaccharide **73** as a precursor for the synthesis of bicyclic lactone. Accordingly, Radical addition of dimethyl melonate to the tri-*O*-Bn glucal (**57**) using ceric ammonium nitrate led to the formation of 2-C-melonate addition product **73**, which upon treatment with $AuCl_3$, H_2O, at $70^{O}C$ for 12h, resulted in the formation of lactol and subsequent cyclization *in situ* resulting bi-cyclic lactone **74** (Scheme 12). Similar protocol was used for the synthesis of various carbohydrate γ-bicyclic lactones (**77-80**).

Later, we exploited the bi-cyclic lactone for the synthesis of various *O*-glycosides (**75f, 75m-75p**) using TMSOTf at RT. On the other hand, we activated methyl glycosides with $AuCl_3$ in the presence of various alcohols to get different *C*-2 Functionalized *O*-glycosides(**76b, 76n, 76q, 81a, 81n, 82b, 82q, 83b**) as well (Scheme 12).

In summary, gold-catalyzed transglycosidations were applied to 2-*C*-branched methyl glycosides for the synthesis of various glycosides and disaccharides to obtain functionalized carbohydrates. During the gold-catalysis we observed an interesting anomerization and synthesis of various carbohydrate γ-bicylic lactones implicating the diversity of methyl glycosides under gold catalysis.

****

Note: Compound numbers in abstract are different from those in the thesis

Chapter 1

Oligosaccharide synthesis using orthogonal activation strategy of propargyl and *n*-pentenyl glycosides

Chapter 1: Introduction

Carbohydrates are the important biomolecules and are main source of energy, provide the ideal fuel (glucose) for our body to function optimally, as well as many essential vitamins and minerals. They are also the only form of energy used by the brain. In addition to their well respected roles in supporting structural matrices, in energy storage; and as biosynthetic starting materials, carbohydrates are cast in a variety of interesting settings as glycoconjugates, for example as antibiotics, antitumor agents and catiotonic glycosides. Cell surface carbohydrates are involved in various molecular recognitions with virus, toxins, lectins, bacteria, harmones and antibodies, thereby impacting the development of carbohydrate based vaccines, therapeutics.[1]

However, the accesses of biologically important carbohydrates are limited because of their low availability, low concentrations and their existence as micro-heterogeneous forms. Hence chemical synthesis is the only alternative for accessing complex carbohydrates. The majority of biologically important and therapeutically active carbohydrates exist as polysaccharides or as complex glycoconjugates in which oligosaccharides are connected to peptides, proteins, or fatty acids. The template-driven nature of protein and nucleic acid biosynthesis and the redundancy of the linkages within these linear polymers have facilitated the development of genetic and chemical methods, now largely automated[2]. Whereas in case of oligosaccharides, automated synthesis is rendered because of their staggering diversity of linkages. So the chemical synthesis of even moderate complexity still represents a significant challenge (Figure 1).

The first attempts to address the challenge of oligosaccharide synthesis emerged in the mid-1980s and 1990s, and resulted in development of a number of revolutionary approaches. Nicolaou's selective activation,[3] Fraser-Reid's armed-disarmed approach,[4] Danishefsky's glycal assembly,[5] Ogawa's orthogonal technique,[6] Boon's active-latent concept,[7] Wong's and Ley's programmable strategies[8] are few examples. These excellent innovations allowed to synthesize complex oligosaccharides and glycoconjugates. For example, the total synthesis of tumor antigens of Globo-H by Danishefsky[9], Schmidt[10],

Boons[11], Wong[12], and Seeberger[13] have become modern classics of synthetic carbohydrate chemistry.

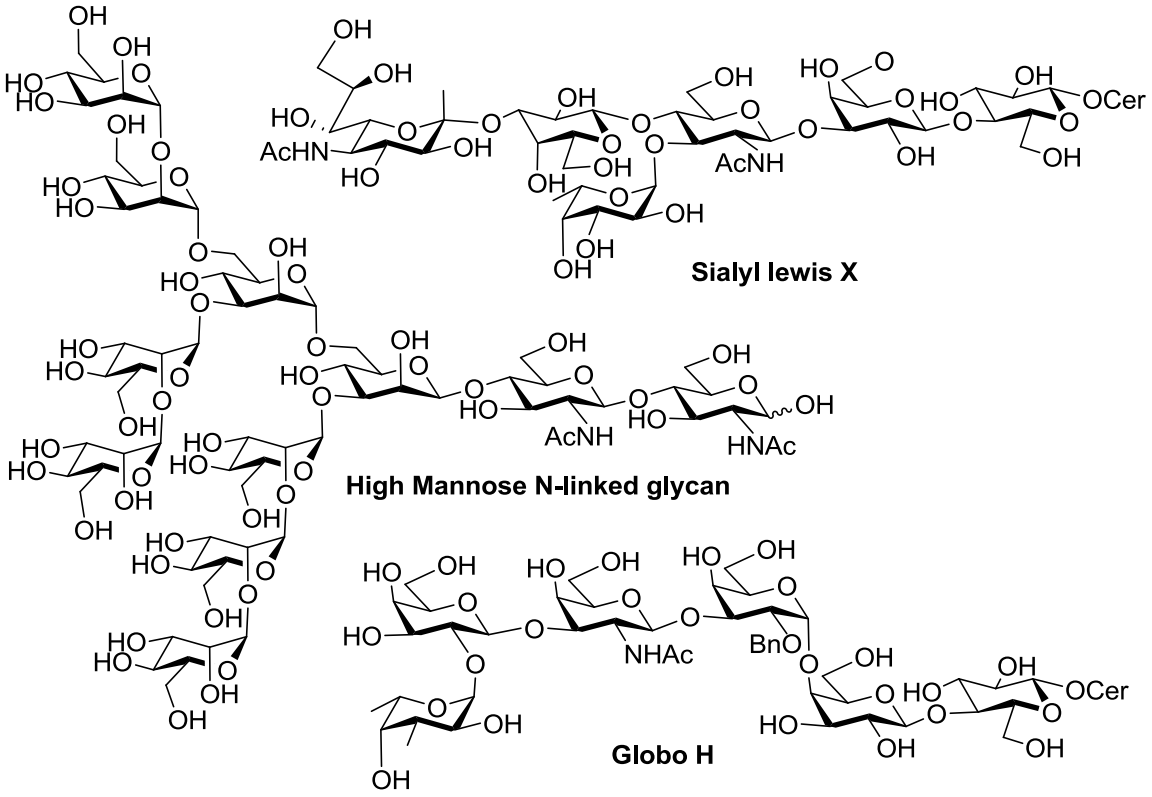


Figure 1

In spite of significant progress in the glycoside syntheses, the necessity of forming either a 1,2-*cis* or a 1,2-*trans*-glycosidic bond with high stereoselectivity and good yield remains the main reason that chemical *O*-glycosylation is ranked among the most challenging problems in modern synthetic carbohydrate chemistry. The achievement of high yield and stereo control is difficult, because of the complexity of glycosylation process, which often proceeds together with variety of side reactions.

Principles of chemical glycosylation

Chemical glycosylation is the nucleophillic displacement of a leaving group on glycosyl donor by hydroxyl moiety of the glycosyl acceptor. The remaining hydroxyl groups of the both components are temporarily masked with protecting groups. Although, full detailed mechanism of the glycosylation reaction not yet known, the commonly accepted prototype mechanism of glycosylation is explained. First, promoter assisted

departure of the leaving group, leads to the formation of flattened oxacarbenium ion followed by the attack of nucleophile from the possible both sides results into two products (1,2-*cis* and 1,2-*trans*).

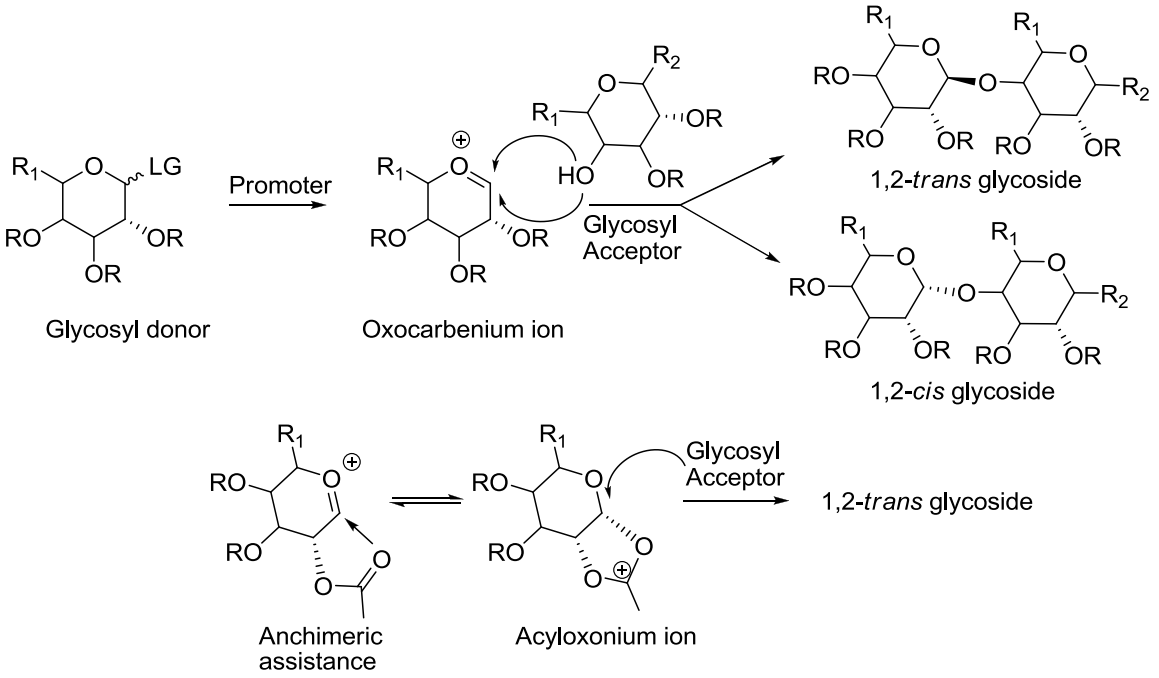


Figure 2

Various factors such as temperature, pressure, structure, conformation, solvent, promoter, steric hindrance, or leaving group can affect the stereoselectivity of glycosylation. Some of these factors influence the stereoselectivity dramatically, others only to some extent. Neighbouring substituent at *C*-2 is one of the major factors that influence the selectivity. 1,2-*trans* Glycosides can be prepared by the use of ester protecting group at *C*-2 due neighbouring group participation.[14]

The development of efficient coupling reactions is largely responsible for the progress that has been made in the area of oligosaccharide synthesis. Hence a number of synthetic strategies that allow the convenient assembly of complex oligosaccharides from properly protected building block units involving minimum number of steps are developed which are described below.

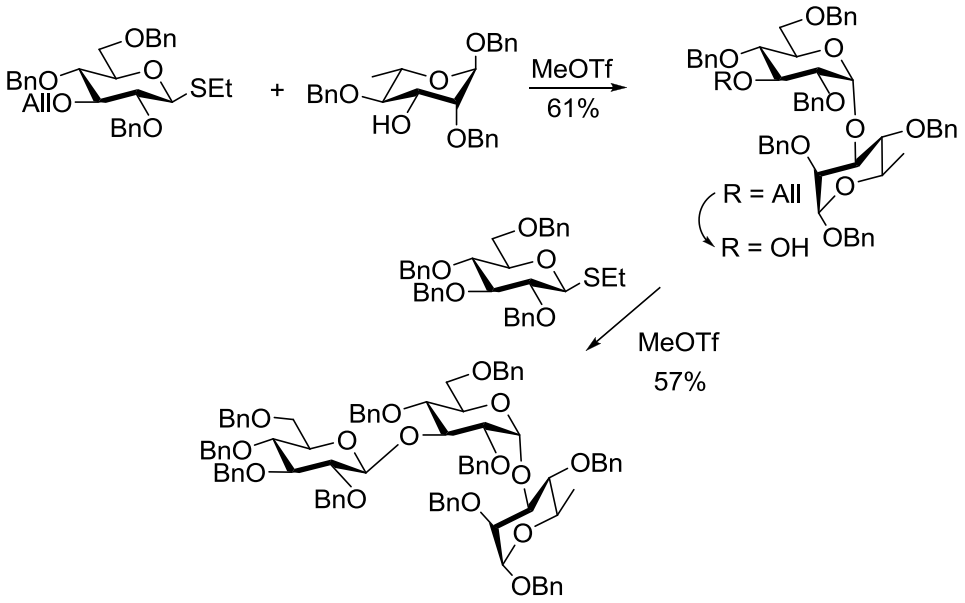
Synthetic strategies for the oligosaccharide synthesis

1) Linear glycosylation strategy:[15] A linear oligosaccharide synthesis consists of the glycosylation of monosaccharide donor and monosaccharide acceptor, in the presence of

promoter, to give the desired disaccharide. Then the resulting disaccharide can be converted into either glycosyl donor or glycosyl acceptor by protecting group manipulations, followed by the addition of one more glycosyl unit to obtain a trisaccharide and can be iterated until the required oligosaccharide of interest.

For example, thio- glycosyl donor was found to react with the rhamnose acceptor in the presence of methyl triflate (MeOTf) to form the disaccharide in 61% yield. The resulting disaccharide was then deallylated over two steps to give glycosyl acceptor which was glycosylated with galactosyl donor in the presence of MeOTf to give trisaccharide (Scheme 1).[16]

Scheme 1



In this strategy, each step requires manipulation of protecting and leaving groups which increases the number of reaction steps considerably. This fact, together with its low convergence, makes this strategy the least efficient for the synthesis of complex oligosaccharides.

2) Convergent block synthesis:[17] The challenges associated with linear glycosylation strategy were overcome through convergent block approach, developed by Zen, Paulsen, and Ogawa. In this strategy, oligosaccharide building blocks are obtained separately and then coupled together (converged) by means of glycosylation reactions. As shown in figure 3, first two disaccharides are constructed individually, the first disaccharide is then

converted into glycosyl donor whereas second disaccharide is deprotected to get free -OH group as glycosyl acceptor, followed by coupling of the two by glycosylation to get the corresponding tetrasaccharide.

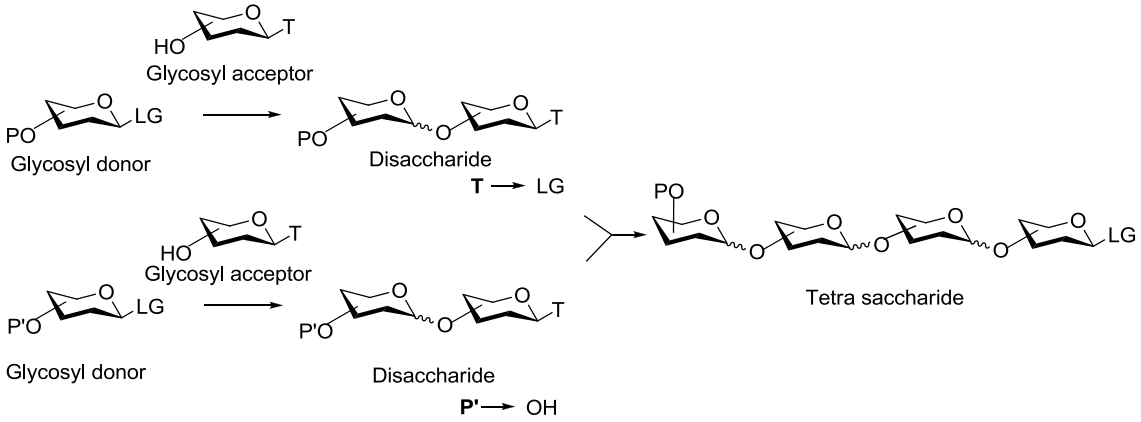
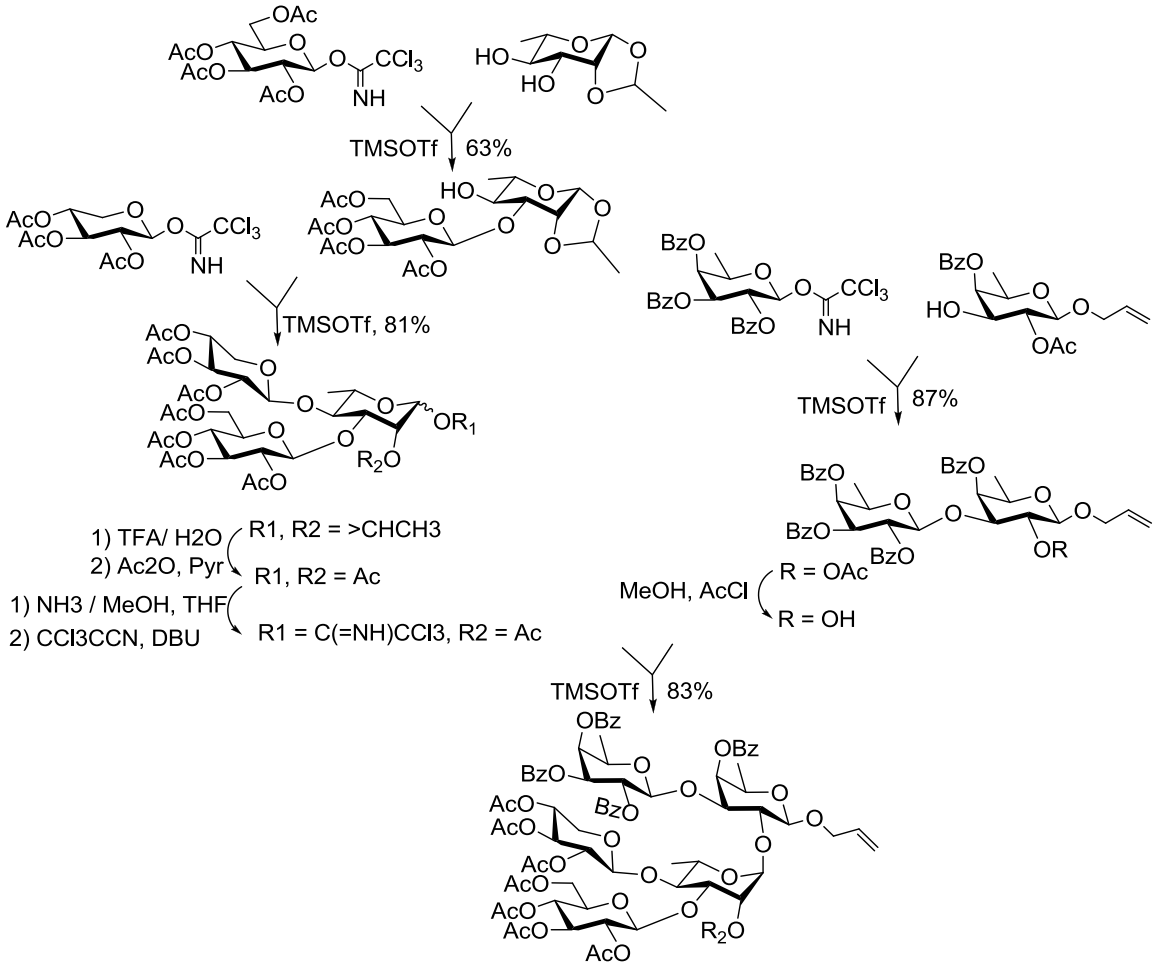


Figure 3

Scheme 2



Glycosylation of trichloroacetimidate donor and rhamnosyl diol resulted in a disaccharide, which serves as glycosyl acceptor for the reaction with xylosyl donor to give trisaccharide. The trisaccharide was further converted into glycosyl donor by protecting group manipulations followed by the glycosylation reaction with disaccharide-acceptor to get the corresponding pentasaccharide of *Spergularia ramnose*[18] (scheme 2).

3) Selective and Two-Stage Activation:[19,20] Though the convergent block synthesis is advantageous, the conversion of common building blocks into a glycosyl donors often require several manipulations at the anomeric center. The selective and two stage activation strategy solves this problem in an elegant manner. The schematic outline shown in figure 4.

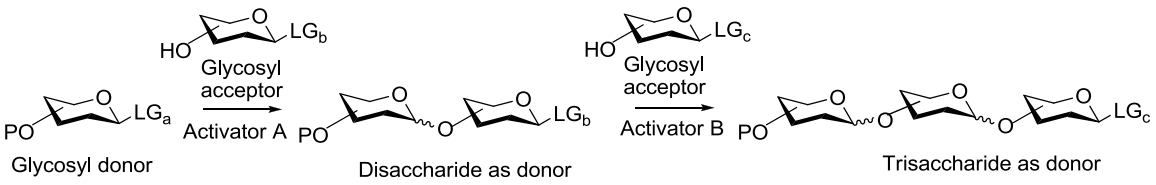
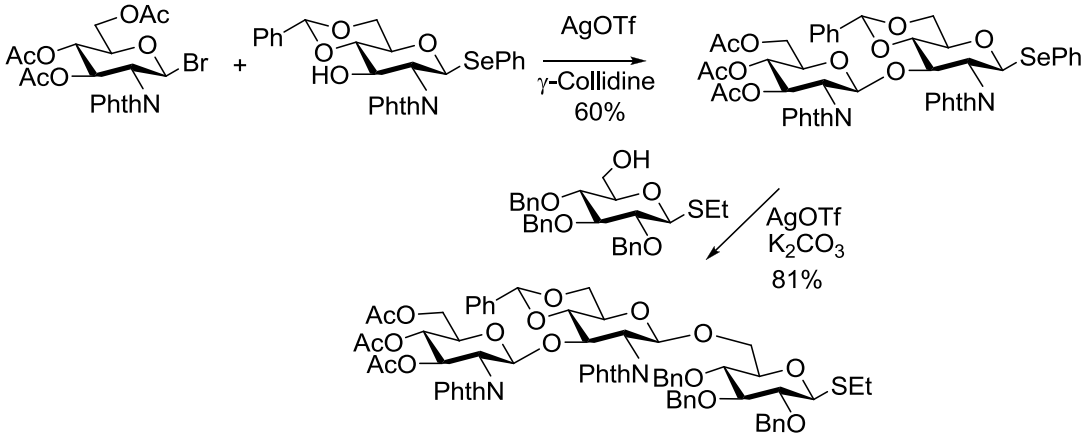


Figure 4

Glycosyl donor bearing a reactive leaving group (LG_a) is coupled with glycosyl acceptor, bearing a relatively stable LG_b to get disaccharide. The activation sequence can be continued provided there is an LG_c that would withstand reaction conditions for the LG_b activation (Scheme 3 & figure 4).

Scheme 3



In two stage activation strategy, two types of anomeric leaving groups one obtained from the other, and one type of activation is used as shown in figure 4. First the

potential glycosyl donor (LG_a) converted into an LG_b, which then selectively activated over LG_a of the glycosyl acceptor to get disaccharide and so on to get higher saccharides.

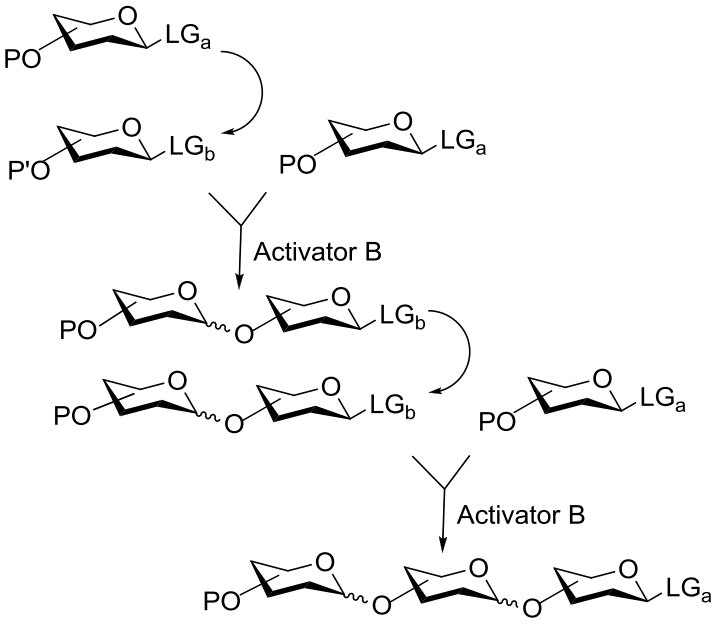
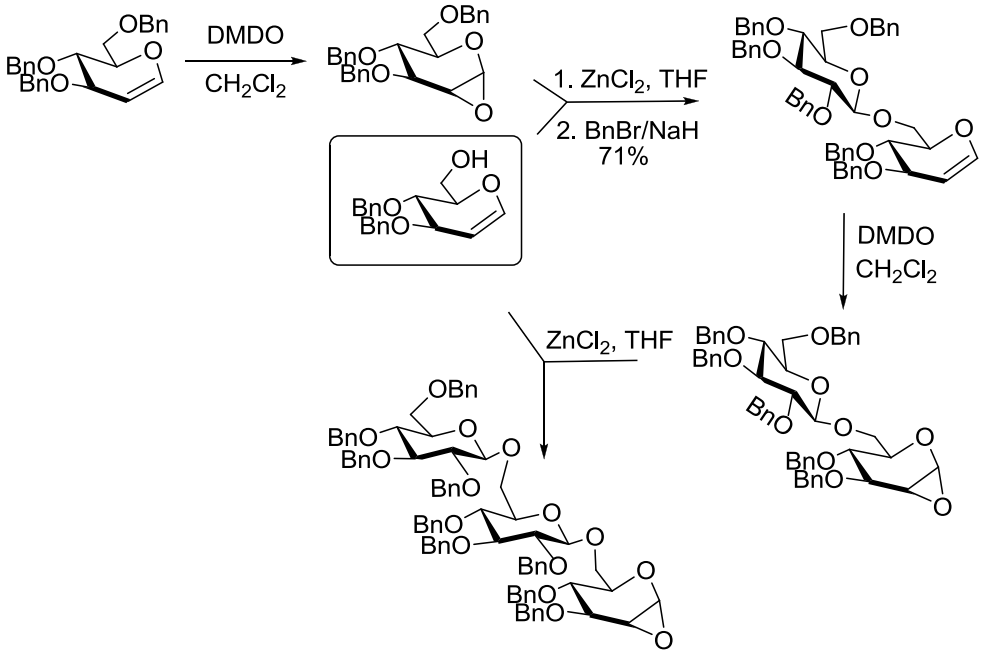


Figure 5

Scheme 4



This concept was discovered by Zen for *S*-ethyl (LG_a) and bromo- (LG_b) groups and further developed by Nicolaou for *S*-phenyl (LG_a) and fluoro (LG_b) groups[21]. This strategy utilizes the epoxidation of glucal using DMDO to get the 1,2-anhydro

derivatives, which was employed as glycosyl donor to get 1,2-*trans* disaccharide. Similar sequence of steps such as epoxidation and glycosylation led to the formation of required trisaccharides (Scheme 4).[22]

4) Orthogonal activation strategy:[23] The combination of two chemically distinct glycosylation reactions, in which one of the leaving groups is activated while the other remains intact, and *vice versa*, led to the discovery of orthogonal activation strategy for oligosaccharide synthesis.

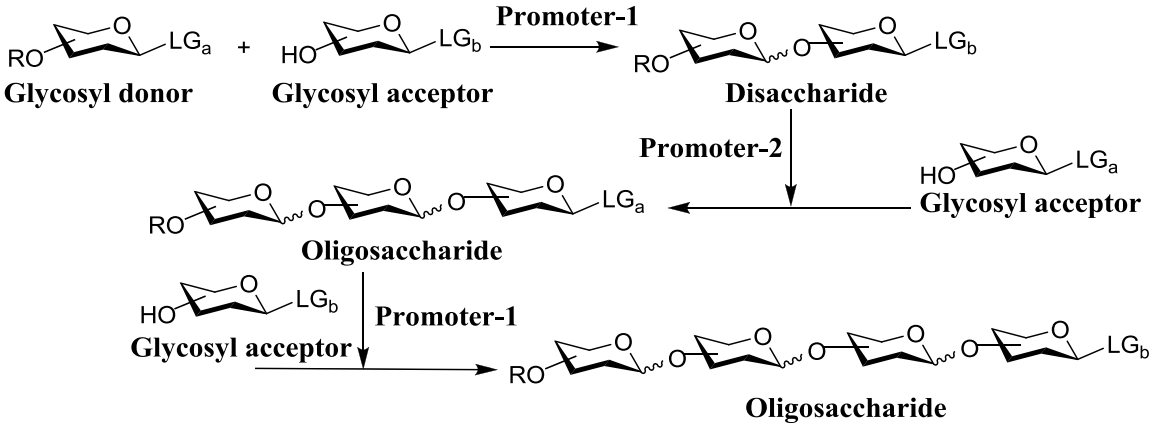
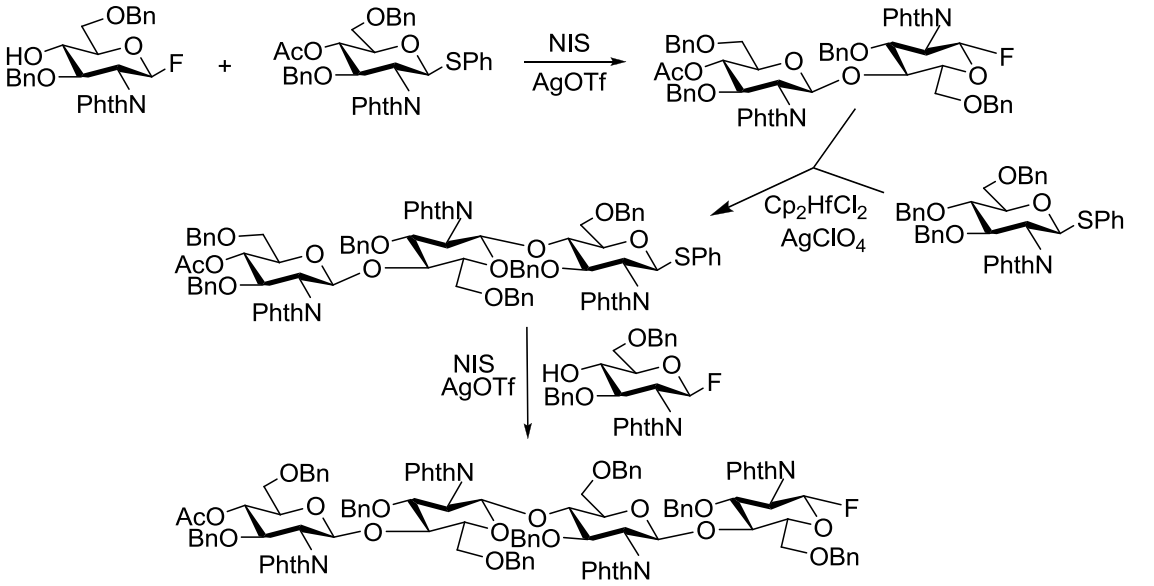


Figure 6

Scheme 5



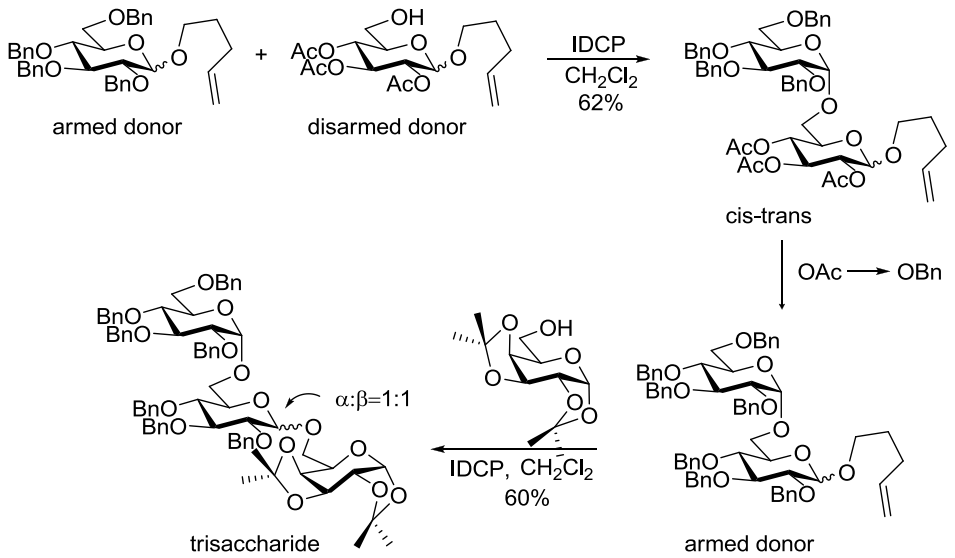
This is one of the most conceptually attractive technique for oligosaccharide synthesis, requires two orthogonal classes of glycosyl donors. In 1994, Ogawa and co-workers

proposed this strategy that reduces the manipulation at the oligosaccharide stage. Schematic representation of orthogonal activation strategy had shown in figure 6 wherein glycosyl donor LG_a is activated over the glycosyl acceptor bearing LG_b to get a disaccharide. Then, LG_b of disaccharide is selectively activated over LG_a to get trisaccharide and can be elaborated further to get required oligosaccharide.

Ogawa *et al* showed that the phenyl thioglycoside can be selectively activated in the presence of glycosyl fluoride using NIS/AgOTf to afford disaccharide. The fluoro- group at the reducing end of disaccharide can be activated over -SPh to afford trisaccharide.[24]

5) Armed-Disarmed chemoselective glycosylation[25]: When two glycosyl building blocks possess different reactivities at the anomeric centre due to the substituents present in *C*-2, the more reactive building block enhances glycosylation in the presence of promoter as compared to a less reactive building block as shown in scheme 7. The more reactive building block is known as an armed donor and the less reactive one is a disarmed donor.

Scheme 6

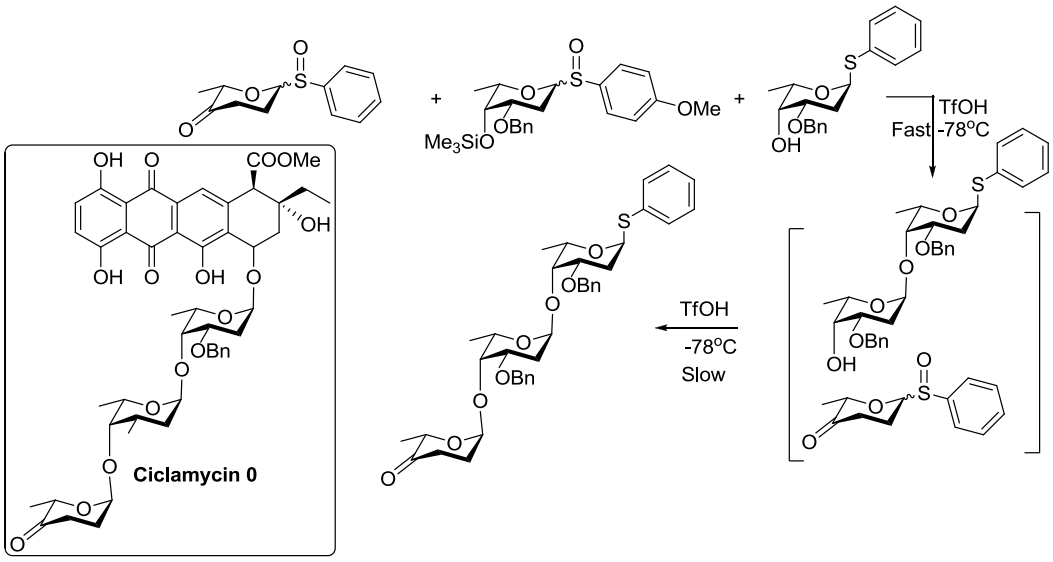


Fraser-Reid *et al*. demonstrated the utility of armed-disarmed effect[26] for the synthesis of trisaccharide in which *n*-pentenyl glucoside containing benzyl ether substituents is activated chemoselectively with iodinium dicollidine perchlorate (IDCP) in the presence of *n*-pentenyl glucoside containing acetate substituents. The resulting

disaccharide is converted into an armed substrate in a two step process which in turn is activated in the presence of acceptor derived from galactose with IDCP (Scheme 8). Similarly, thioglycosides, glycal, selenoglycosides based glycosyl donors are utilized for the synthesis of oligosaccharides *via* an armed-disarmed strategy.

6) One-pot multistep synthesis:[27] One-pot synthesis of oligosaccharide is often referred as a reactivity-based one pot method in which glycosyl donors with decreasing anomeric reactivities are allowed to react sequentially in the same flask.

Scheme 7



Although, this procedure is highly convenient because it reduces the number of steps considerably; however, it has the inconvenience of finding correct reactivities for all the partners and thus has to be carefully tuned which implies extensive protecting group manipulations.

Synthesis of Ciclamycin trisaccharide in a stereoselective manner from the monosaccharide components represents one-pot synthesis (Scheme 7).[28] Glycosylation takes place in a sequential manner, *para*-methoxy phenyl sulfoxide is activated faster than phenyl sulfoxide reacts preferentially with thiophenyl glycoside to give required trisaccharide in a single step.

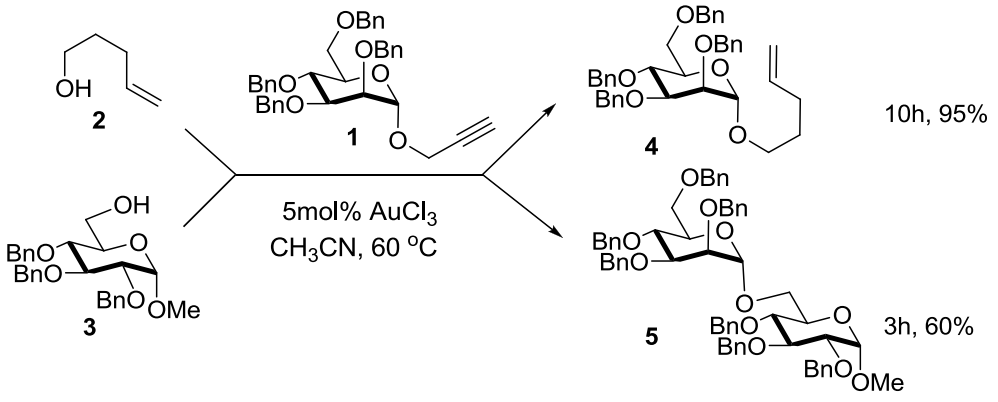
****

Chapter 1: Present Work

Glycoconjugates and oligosaccharides play significant roles in various extracellular and intracellular molecular recognition events. Lack of sufficient quantity of the glycoconjugates is one of the drawbacks in unraveling the importance of these glycoconjugates in the cellular context. Chemical or enzymatic synthesis of oligosaccharides either in solution or on solid phase is a popular method to access sufficient quantity of glycoconjugates as material amplification techniques such as Polymerase Chain Reaction (PCR) are not yet available for oligosaccharides.[29] Glycoconjugates are often present as oligosaccharides coupled to an aglycone (lipid, protein, steroid etc.) and the process of oligosaccharide synthesis breaks down to the systematic addition of sugar residues either in a convergent or a linear fashion by means of glycosylation reactions. In this context, several glycosyl donors that were developed over the past century can be classified into stable (e.g. *n*-pentenyl,[30a] thio-,[30b-d] vinyl-,[30e] 2-carboxybenzyl-,[30f] etc.) and unstable (e.g. imidate-,[30g] halo-[30h-j] etc.) glycosyl donors depending on the shelf life of the actual glycosyl donor.

In our laboratory, serendipitous observation of the deprotection of propargyl ether in the presence of catalytic amount of gold(III) chloride in acetonitrile while performing diversity oriented synthesis (DOS) of natural product-like and oxygen-rich small molecule libraries, led to the development of propargyl glycosides as novel and stable glycosyl donors.[31] Propargyl glycosides are found to act as glycosyl donors with catalytic gold(III) chloride to result in various glycosides and disaccharides (Scheme 8).[32]

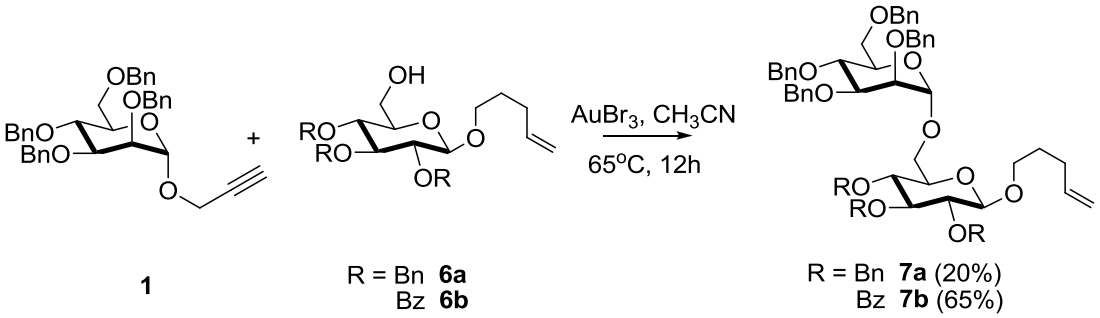
Scheme 8



Propargyl 2,3,4,6 tetra-*O*-benzyl-β-D-mannopyranoside (**1**) was treated with *n*-pentenol (**2**) and methyl 2,3,4 tri-*O*-benzyl-α-D-glucopyanoside (**3**) in the presence of 5 mol% of $AuCl_3$ in acetonitrile at 60^oC to get corresponding *n*-pentenyl mannoside (**4**) and disaccharide (**5**) in good yields. These stable propargyl glycosides are advantageous as they serve the dual role of a robust protecting group initially and later become a glycosyl donor upon activation by $AuCl_3$. In continuation to this programme on the development of glycoconjugate synthesis, we have chosen the orthogonal activation strategy as it provides required oligosaccharide in less number of steps. Since propargyl glycosides were transglycosylated into *n*-pentenyl glycosides and also *n*-pentenyl glycosides were used extensively for the synthesis of complex oligosaccharides, we thought of selective activation of propargyl glycosides in the presence of *n*-pentenyl glycosides and vice-versa to facilitate oligosaccharide synthesis in an easier way.

For an initial attempt to study the orthogonal activation, propargyl 2,3,4,6-tetra-*O*-benzyl mannopyranoside (**1**) and *n*-pentenyl 2,3,4,6-tetra-*O*-benzyl mannopyranoside (**4**) were chosen as glycosyl donors mainly because of the possibility of expected 1,2-*trans* stereoselectivity in the products. Accordingly, propargyl mannopyranosyl donor (**1**) was reacted with *n*-pentenyl glucoside as the glycosyl acceptor (**6a**) in the presence of 5 mol% of $AuBr_3$ in acetonitrile at 65 ^oC for 12 h to obtain 20% yield of the disaccharide **7a** and the yield could be improved to 65% by switching the protecting groups of the aglycon from armed benzyl ethers to disarmed benzoyl esters as in **6b** to obtain the corresponding disaccharide **7b** (Scheme 9).

Scheme 9

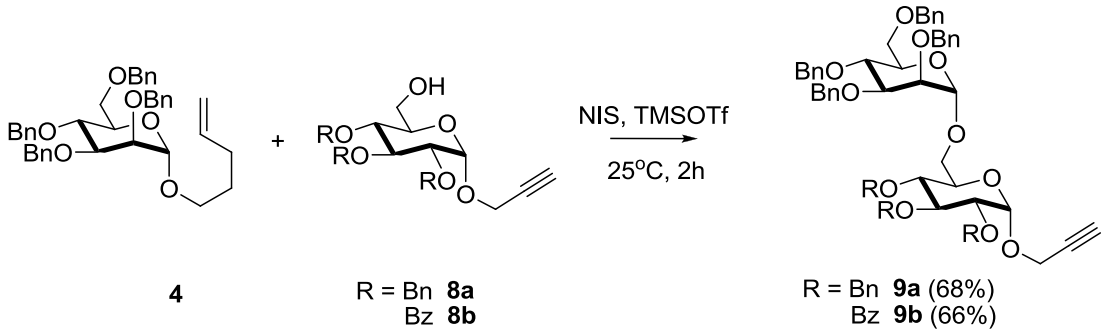


The structure of *n*-Pentenyl disaccharide **7a** was confirmed thoroughly using various spectroscopic techniques. In the ^1H NMR spectrum of compound **7a**, resonances

at δ 1.72, 2.75, and 5.81 ppm as multiplets corresponding to *n*-pentenyl group and in the ^{13}C NMR spectrum, characteristic signals due to α- and β- anomeric carbons at δ 98.2 and 103.6 ppm, *n*-Pentenyl terminal olefin (=CH_2) at δ 115.0 ppm confirmed the assigned structure **7a**. Further DEPT NMR spectrum showed thirteen negatively phased resonances for the presence of 13 –CH_2s in the assigned disaccharide **7a**, and the HRMS (MALDI-ToF) showed a molecular weight peak at 1063.4981 calculated for $C_{66}H_{72}O_{11}Na$.

Similarly, the *n*-pentenyl mannosyl donor **4** was reacted with propargyl-containing aglycons **8a** and **8b** to obtain the disaccharides **6a** and **6b** in 68% and 66% yield, respectively. The structure of propargyl disaccharide **9a** was confirmed from the spectroscopic experiments and mass spectral analysis.

Scheme 10



4

R = Bn **8a**
Bz **8b**

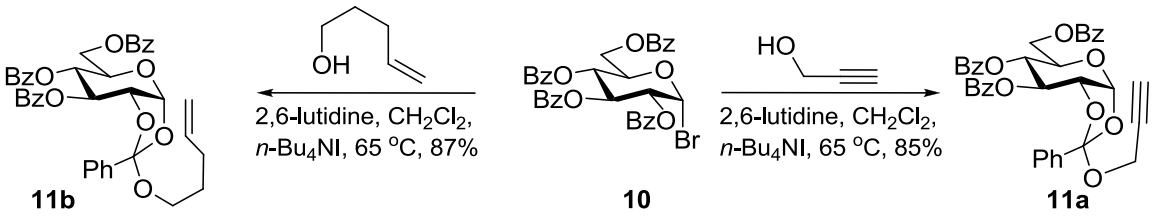
R = Bn **9a** (68%)
Bz **9b** (66%)

In the ^{1}H NMR spectrum of compound **9a**, resonances at δ 2.43 ppm as triplet were attributed to the methine proton and in the ^{13}C NMR spectrum, characteristic signals due to two α-anomeric carbons at δ 94.7 and 98.2 ppm were noticed; in addition, DEPT NMR spectrum showed the presence of ten methylene groups further confirming the disaccharide **9a**. HRMS (MALDI-ToF) showed a molecular weight peak at 1033.4430 calculated for $C_{64}H_{66}O_{11}Na$. The poor yield in the case of **1** + **6a** to give **7a** can be attributed to our recent observations that $AuBr_3$ also activates *n*-pentenyl glycosides at higher temperature (explained later).[33]

So we thought that bringing reaction temperature to rt would improve the yield as well as the overall elegancy. Moreover, the glycosylation reactions (other than man*p*-) with glu*p*- , gal*p*-, and lactosyl- donors result in the transglycosylated products as α/β mixtures which would further complicate their further synthesis. Owing to the above reasons, we changed our strategy from propargyl glycosides to propargyl 1,2-orthoesters,

which were also found to act as glycosyl donors in the presence of catalytic amount of $AuBr_3$ at room temperature to get 1,2-*trans* glycosides in stereoselective fashion.

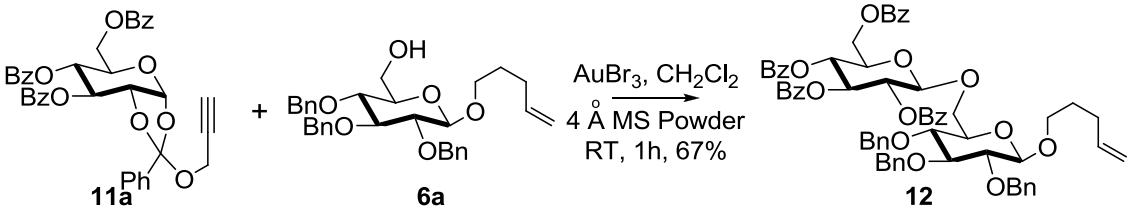
Scheme 11



To commence our investigation, 3,4,6-tri-*O*-benzoyl-α-D-glucopyranose-1,2-(propargyl orthobenzoate) **11a** was chosen as a model substrate that can be prepared from glucose *via* the treatment of glucose penta-*O*-benzoate with HBr in AcOH to form 2,3,4,6-tetra-*O*-benzoyl-α-D-glucopyranosyl bromide **10** which reacted with a propargyl alcohol, 2,6-lutidine in dichloromethane at 65 ^{o}C for 2 days to give propargyl 1,2-orthoester **11a** (Scheme 11). Under similar conditions, use of *n*-pentenyl alcohol instead of propargyl alcohol resulted in the corresponding *n*-pentenyl orthoester (**11b**).

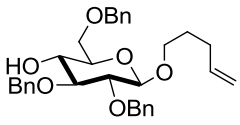
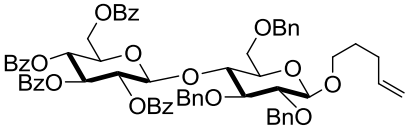
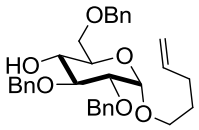
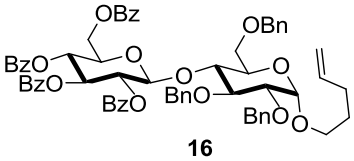
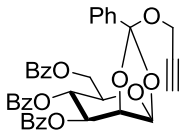
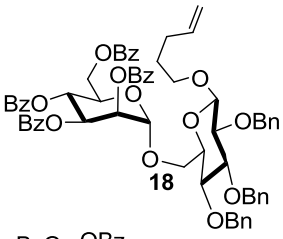
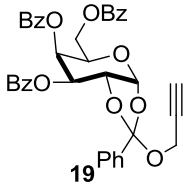
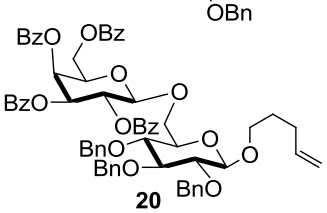
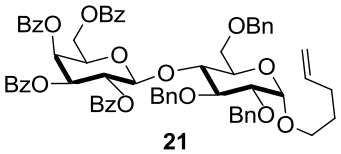
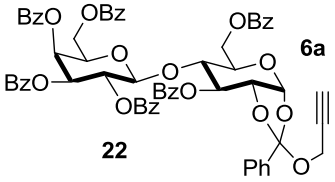
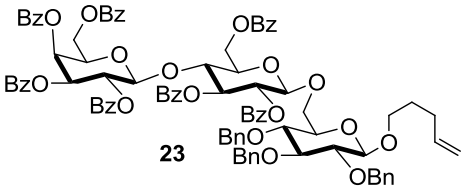
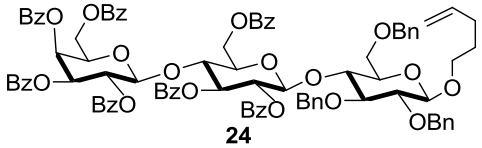
Having prepared both glycosyl donors **11a** and **11b**, the utility of orthogonal activation strategy using propargyl 1,2-orthoesters as glycosyl donors and *n*-pentenyl glycosides as aglycons was studied.[34] Accordingly, a gold-catalyzed glycosylation reaction between propargyl orthoester **11a** and aglycon **6a** was successfully carried out at room temperature in CH_2Cl_2 to obtain the disaccharide **12** as an *n*-pentenyl glycoside (Scheme 12). The structure of *n*-pentenyl disaccharide **12** was confirmed by means of

Scheme 12



various spectroscopic techniques. For example, in the ^{1}H NMR spectrum of compound **12**, characteristic resonances at δ 1.63, 2.08 ppm as quartets, and δ 5.81 ppm as a multiplet for the pentenyl group were found; further, the ^{13}C NMR spectrum pointed out characteristic signals due to two β-anomeric carbons at δ 101.3 and 103.5 ppm, olefin

Table1

Donor	Acceptor	Product	Time (h)	%Yield
11a	 **13**	 **14**	2	65
	 **15**	 **16**	2	66
 **17**	**6a**	 **18**	4	68
 **19**	**6a**	 **20**	1	65
	15	 **21**	2	60
 **22**	**6a**	 **23**	2	70
	13	 **24**	3	64

***Reagents & Conditions : 10mol% $AuBr_3/CH_2Cl_2$/rt/4Å M.S.powder**

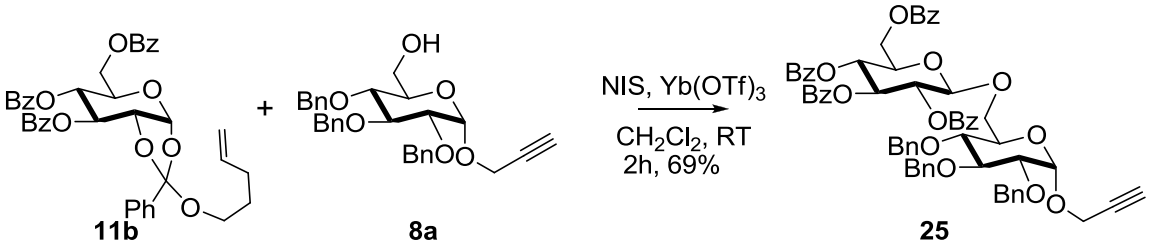
carbon at δ 115.0 ppm thereby confirming the assigned structure **12**. DEPT NMR spectrum specified nine methylene groups as in the assigned disaccharide **12**, and the

HRMS (MALDI-ToF) showed a molecular weight peak at 1119.4146 calculated for $C_{66}H_{64}O_{15}Na$.

The protocol was then extended to various other aglycons (**13**, **15**) and glycosyl donors such as mannose (**17**), galactose (**19**), and lactose (**22**) propargyl orthoester as well. Disaccharides (**14** and **16**) with an *n*-pentenyl group at the reducing end were obtained in good yields (Table 1).[35] Similarly, propargyl orthoesters **17**, **19**, and **22** also resulted in the formation of corresponding *n*-pentenyl disaccharides (**18**, **20**, **21**) and trisaccharides (**23**, **24**) respectively (Table 1).

In continuation, activation of *n*-pentenyl 1,2-orthoesters in the presence of propargyl group containing aglycons was studied.[35] Accordingly, the reaction between *n*-pentenyl orthoester **11b** and the propargyl glucoside **8a** in the presence of NIS/$Yb(OTf)_3$ in CH_2Cl_2 showed the orthogonality to result in the isolation of disaccharide **25** as a propargyl glycoside in 69% yield (Scheme 13).

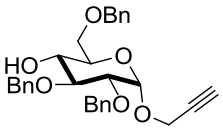
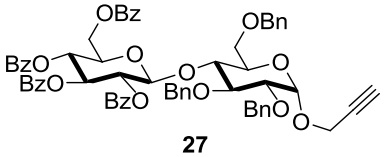
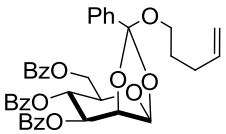
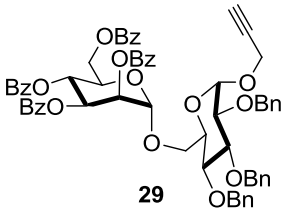
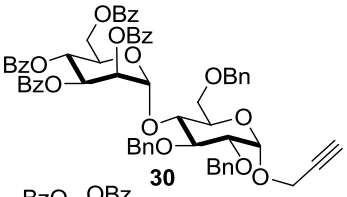
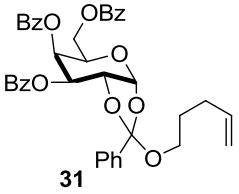
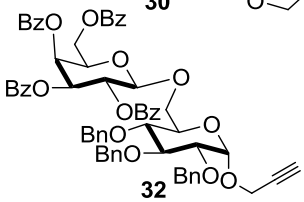
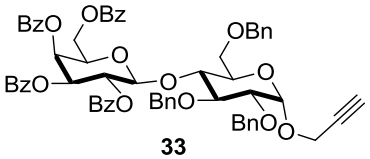
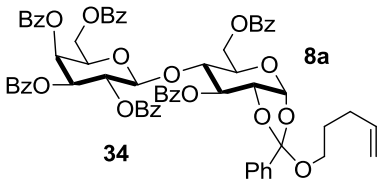
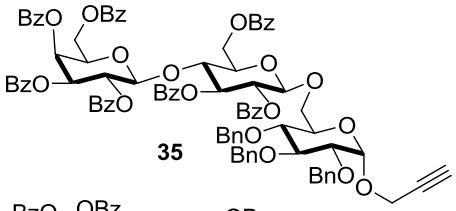
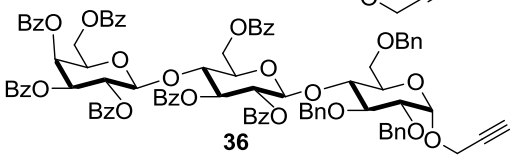
Scheme 13



In the ^1H NMR spectrum of compound **25**, resonances due to the propargylic methine were noticed at δ 2.38 ppm as triplet, the ^{13}C NMR spectrum revealed two anomeric carbons with 1,2-*cis* and 1,2-*trans* linkages at δ 95.0 and 101.3 ppm respectively; DEPT NMR spectrum indicated the presence of six methylene groups of disaccharide **25**, and the and the HRMS (MALDI-ToF) showed a molecular weight peak at 1089.3605 calculated for $C_{64}H_{58}O_{15}Na$.

Subsequently, the orthogonal activation condition was tested with other mannose (**28)**, galactose (**31)**, lactose (**34)** orthoesters and aglycons (**8a**, **26**). Glycosyl orthoesters (**12**, **28**, **31**, **34**) reacted with propargyl glycosides **8a** and **26** to give corresponding 1, 2-*trans* disaccharides (**27**, **29**, **30**, **32**, **33**) and trisaccharides (**35**, **36**) as propargyl glycosides (Table 2).[35]

Table 2

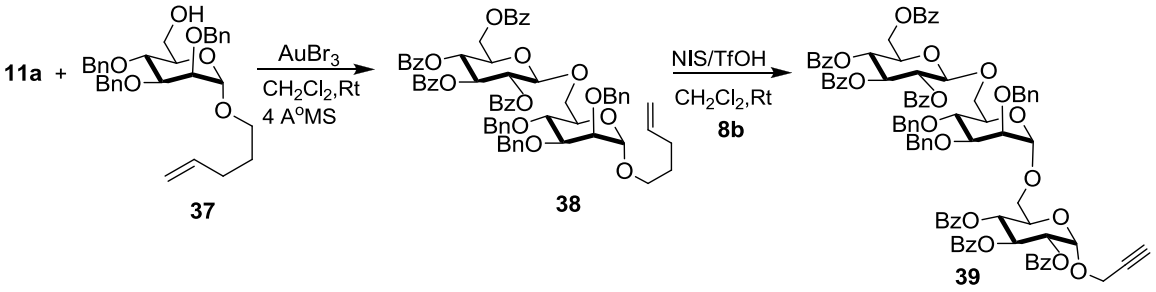
Donor	Acceptor	Product	Time (h)	%Yield
11b	 **26**	 **27**	4	65
 **28**	**8a**	 **29**	2.5	70
	26	 **30**	4	67
 **31**	**8a**	 **32**	4	59
	26	 **33**	6	55
 **34**	**8a**	 **35**	4	67
	26	 **36**	12	65

***Reagents & Conditions : NIS/Yb(OTf)$_3$/CH$_2$Cl$_2$/rt/4Å M.S.powder**

All the products were characterized thoroughly by ^{1}H, ^{13}C, DEPT NMR and mass spectral analysis. Then we studied the utility of orthogonal activation strategy using

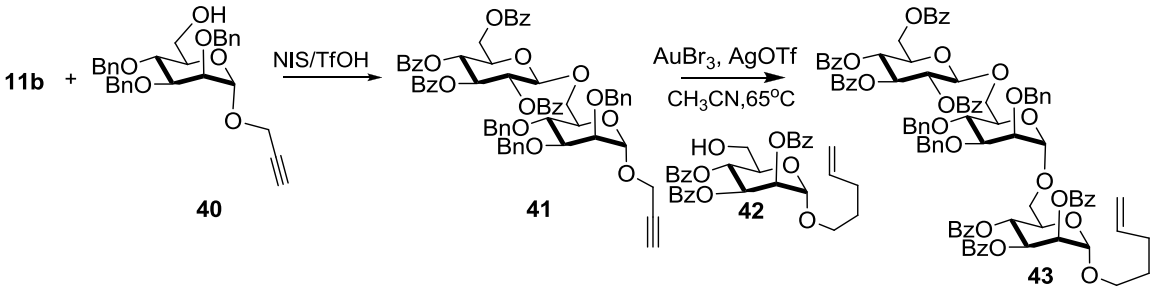
propargyl 1,2-orthoesters as glycosyl donors and *n*-pentenyl glycosides as aglycons vice versa for the synthesis of higher oligosaccharides. Glucose propargyl orthoester (**11a**) was allowed to react with aglycone (**37**) under 10mol% $AuBr_3/CH_2Cl_2$/rt/4Å MS powder under argon atmosphere to give disaccharide (**38**) with *n*-pentenyl group at the reducing end, which was activated in the presence of propargyl glycoside (**8b**) using NIS/TfOH/ CH_2Cl_2/rt to give trisaccharide (**39**) in good yield (Scheme 14).

Scheme 14



In the ^{1}H NMR spectrum of propargyl trisaccharide **39,** resonances due to the methine proton of propargyl group noticed at δ 2.60 ppm (t, 1H, *J* = 2.3Hz). Further, the ^{13}C NMR spectrum showed three anomeric carbons (two α and one β) at δ 96.3, 98.0 and 101.5 ppm with rest of the spectral values in agreement with the assigned structure trisaccharide **39**. The structure was further confirmed from the DEPT NMR spectrum wherein seven CH_2-s (δ 55.3, 63.3, 65.9, 69.1, 71.8, 72.5 and 74.7 ppm) of trisaccharide and the LC-MS showed a molecular weight peak at 1564.43 calculated for $C_{91}H_{80}O_{23}Na$.

Scheme 15

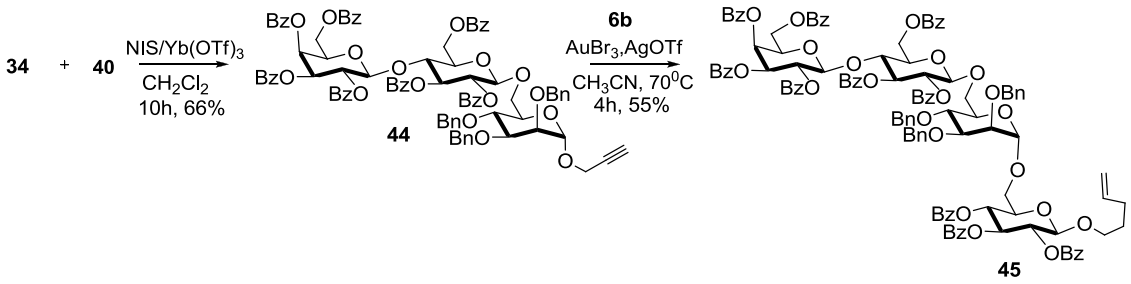


In other way, *n*-pentenyl orthoester (**11b**) was allowed to react with aglycone (**40**) under NIS/$Yb(OTf)_3/CH_2Cl_2$/rt to give disaccharide (**41**) with propargyl group at the reducing end, which was activated in the presence of *n*-pentenyl glycoside (**42**) using $AuBr_3$/AgOTf/CH_3CN/55^{o}C to give trisaccharide (**43**) in good yield (Scheme 15).

Addition of AgOTf to the reaction facilitated the formation of required trisaccharide under low reaction temperature. The structure of the pentenyl trisaccharides (**43**) was confirmed by ^{1}H, ^{13}C, DEPT NMR and mass spectral analysis.

Using the same orthogonal strategy tetrasaccharides were synthesized with propargyl and *n*-pentenyl groups at the reducing end. The glycosylation reaction between lactose *n*-pentenyl orthoester (**34**) and aglycone **40** under $NIS/Yb(OTf)_3/CH_2Cl_2$/rt resulted in the propargyl trisaccharide (44) which was further activated in the presence of pentenyl mannoside using $AuBr_3/AgOTf/CH_3CN/55^oC$ to give tetrasaccharide (**45**) in good yield (Scheme 16). The ^{1}H NMR spectrum of tetrasaccharide **45** revealed the presence of *n*-pentenyl moiety by showing multiplets at δ 1.60 and 1.97 ppm whereas the ^{13}C NMR spectrum pointed

Scheme 16

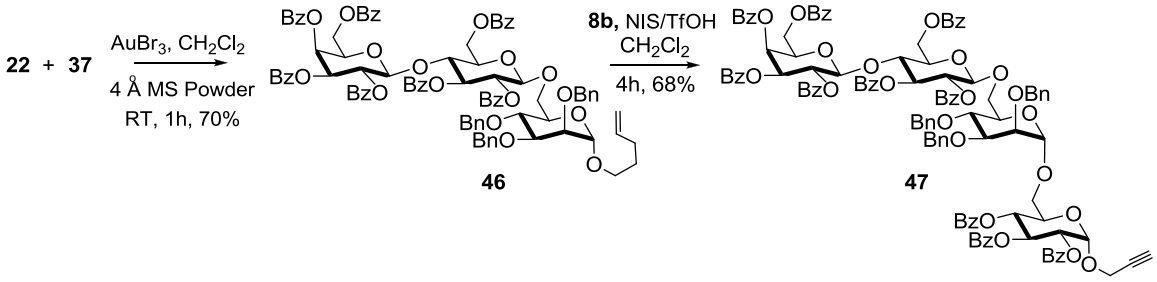


out the characteristic signals due to four anomeric carbons (two α and two β) at δ 98.0, 101.0, 101.2, and 101.5 ppm, olefin ($=CH_2$) at δ 115.0 ppm with the rest of the spectrum in agreement with the assigned structure **45**. Further in the DEPT NMR spectrum, eleven negatively phased resonances were observed at δ 28.6, 29.9, 61.2, 62.4, 65.4, 68.9, 69.4, 72.0, 72.4, 74.8 and 115.0 ppm signals for eleven methylene groups of the tetrasaccharide **45**, and the LC-MS showed a molecular ion peak at 2069.12 calculated for $C_{120}H_{108}O_{31}Na$.

Similarly, the glycosylation reaction between lactose propargyl orthoester (**22**) and aglycone **37** under 10mol% $AuBr_3/CH_2Cl_2$/rt/4Å M.S.powder resulted in the formation of trisaccharide (**46**) with *n*-pentenyl group at the reducing end which was further activated in the presence of acceptor **8b** using $NIS/TfOH/CH_2Cl_2$/rt to give propargyl tetrasaccharide (**47**) (Scheme 17). In the ^{1}H NMR spectrum of propargyl tetrasaccharide **47,** resonances due to methine were noticed at δ 2.56 ppm (t, 1H, *J* =

2.3Hz). Further, the ^{13}C NMR spectrum showed four peaks (two α and two β) corresponding to four anomeric carbons at δ 96.3, 98.0, 101.0 and 101.5 ppm and rest of the spectrum in complete agreement with the assigned structure **47**. The structure was further confirmed from the DEPT NMR spectrum wherein the resonances at δ 55.3, 61.1, 62.4, 66.0, 69.0, 71.7, 72.4 and 74.8 ppm were of negative intensity for the eight methylene groups of tetrasaccharide and the LC-MS showed a molecular ion peak at 2039.12 calculated for $C_{118}H_{102}O_{31}Na$.

Scheme 17



In conclusion, the orthogonal activation strategy using propargyl and *n*-pentenyl glycosides was studied. It has been noticed that *n*-Pentenyl glycosides can be activated to become glycosyl donors in the presence of propargyl glycosides as aglycons. In addition, propargyl 1,2-orthoesters were found to behave as glycosyl donors with *n*-pentenyl glycosides as aglycons. Similarly, *n*-pentenyl 1, 2-orthoesters behaved as glycosyl donors with propargyl glycosides as aglycons. Furthermore, tri- and tetra- saccharides containing propargyl and *n*-pentenyl groups at the reducing end were synthesized using the strategy which can be used further for chemical ligation by click chemistry or for the synthesis of higher oligosaccharides.

****

Note: Characterization data and full spectral charts for all compounds can also be found in ***J. Org. Chem.*** **2009*, 74,*** 9233-9236**.**

Chapter 1: Experimental section

General Procedure for Glycosylations using Propargyl Glycosides as Glycosyl Donor: To a solution of glycosyl donor (0.1 mmol) and aglycone (0.12 mmol) in anhydrous acetonitrile (5 ml) was added a solution of 5 mol% of $AuBr_3$ in anhydrous acetonitrile (2 ml) under argon atmosphere at room temperature. The resulting mixture was heated to 65 ^oC and stirred till the completion of the reaction as judged by TLC analysis. The reaction mixture was concentrated *in vacuo* to obtain a crude residue which was purified by conventional silica gel column chromatography using ethyl acetate-petroleum ether as mobile phase.

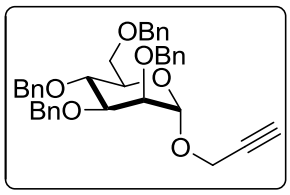
General Procedure for Glycosylations using n-Pentenyl Glycosides as Glycosyl Donor: To a solution of glycosyl acceptor (0.1mmol) in CH_2Cl_2 (5mL), NIS (0.13mmol) and TMSOTf (0.03mmol) were added under Argon atmosphere. The glycosyl donor (0.13mmol) in 5mL of CH_2Cl_2 was added at 0^oC and brought to room temperature, stirred under argon atmosphere for specified time. The reaction mixture was diluted with 15mL of CH_2Cl_2 and washed with 10% aqueous sodium thiosulfate solution and saturated $NaHCO_3$. The Organic layer was washed with brine solution and dried over anhydrous sodium sulphate. Dried CH_2Cl_2 solution was concentrated *in vacuo* and purified by silica gel column chromatography using ethyl acetate-petroleum ether as mobile phase.

General Procedure for Glycosylations using n-Pentenyl 1,2-Orthoesters as Glycosyl Donor: To a CH_2Cl_2 solution of glycosyl donor (0.3mmol) and glycosyl acceptor (0.1mmol) at 0^oC was added *N*-iodosuccinimide (0.4mmol) under argon atmosphere. After 5 minutes of stirring at 0^oC, catalytic amount of $Yb(OTf)_3$ (0.033mmol) was added and stirred at room temperature for specified time. The reaction was quenched with 10% aqueous sodium thiosuphate and saturated aqueous sodium bicarbonate, extracted with CH_2Cl_2, and purified by silica gel column chromatography using ethyl acetate-petroleum ether as mobile phase.

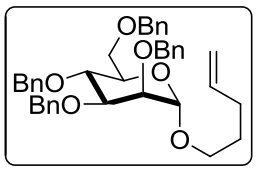
General Procedure for Glycosylations using Propargyl 1,2-Orthoesters as Glycosyl Donor: To a solution of glycosyl donor (0.1 mmol), glycosyl acceptor (0.11 mmol) and 4Å molecular sieves powder (50 mg) in anhydrous CH_2Cl_2 (5 mL) was added $AuBr_3$ (10 mol%) under argon atmosphere at room temperature. The reaction mixture was stirred at

room temperature for the specified time and the reaction mixture was filtered and the filtrate was concentrated *in vacuo*. The resulting residue was purified by silica gel column chromatography using ethyl acetate-petroleum ether as the mobile phase.

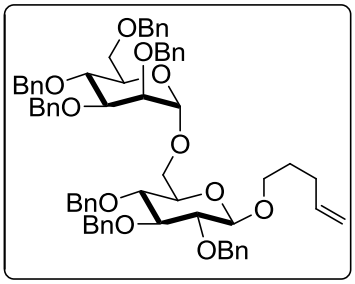
Prop-2-ynyl 2,3,4,6-tetra-*O*-benzyl-α-D-mannopyranoside (1) : $[\alpha]_D$ ($CHCl_3$, *c* 1.02) = +29.1; ^{1}H NMR (200.13 MHz, $CDCl_3$): δ 2.39 (t, 1H, *J* = 2.4Hz), 3.70-3.88 (m, 4H), 3.95-4.04 (m, 2H), 4.19 (d, 2H, *J* = 2.5Hz), 4.60 (bs, 2H), 4.61 (ABq, 2H, *J* = 12.2Hz), 4.69(ABq, 2H, *J* = 10.8Hz), 4.74 (bs, 2H), 5.08 (d, 1H, *J* = 1.8Hz), 7.10-7.42 (m, 20H); ^{13}C NMR (50.32 MHz, $CDCl_3$): δ 54.2, 69.2, 72.1, 72.3, 72.7, 73.5, 74.4, 74.7, 74.8, 75.2, 78.9, 80.1, 96.5, 127.5-128.4, 138.2, 138.4, 138.5, 138.6; HRMS(MALDI-TOF) calculated for $C_{37}H_{38}O_6Na$: 601.2566, Found: 601.2539.



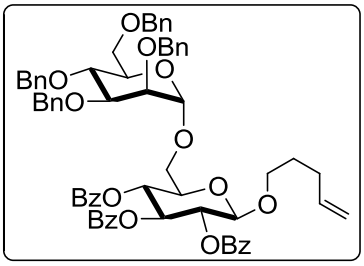
Pent-4-enyl 2,3,4,6-tetra-*O*-benzyl-α-D-mannopyranoside (4) : $[\alpha]_D$ ($CHCl_3$, *c* 1.00) = +26.49; ^{1}H NMR (200.13 MHz, $CDCl_3$): δ 1.63((q, 2H, *J* = 6.6, 14.1Hz), 2.06(q, 2H, *J* = 7.1, 14.3Hz), 3.35(dt, 1H, *J* = 6.4, 12.9Hz), 3.58-3.84(m, 5H), 3.85-4.08(m, 2H), 4.61(ABq, 2H, *J* = 12.2Hz), 4.63(bs, 2H), 4.69(ABq, 2H, *J* = 10.8Hz), 4.73(bs, 2H), 4.85(bs, 1H), 4.90-5.04(m, 2H), 5.75(m, 1H), 7.08-7.42(m, 20H); ^{13}C NMR (50.32 MHz, $CDCl_3$): δ 28.7, 30.4, 67.0, 69.4, 71.9, 72.3, 72.7, 73.4, 74.9, 75.1, 75.2, 80.4, 98.0, 115.0, 127.4-128.4, 138.1, 138.5, 138.5, 138.6, 138.7; HRMS(MALDI-TOF) calculated for $C_{39}H_{44}O_6Na$: 631.3036, Found: 631.3034.



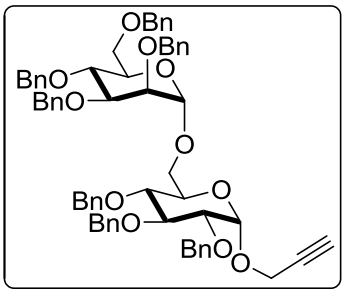
Pent-4-enyl 2,3,4-tri-*O*-benzyl-6-*O*-(2,3,4,6-tetra-*O*-benzyl-α-D-mannopyranosyl)-β-D-glucopyranoside (7a) : $[\alpha]_D$ ($CHCl_3$, *c* 1.45) = +14.4; ^{1}H NMR (400.13 MHz, $CDCl_3$): δ 1.72(m, 2H), 2.15(q, 2H, *J* = 7.3, 14.4Hz), 3.35-3.56(m, 4H), 3.65-4.06(m, 10H), 4.39(d, 1H, *J* = 8.1Hz), 4.45-4.86(m, 11H), 4.90-5.12(m, 6H), 5.81(m, 1H), 7.12-7.50(m, 35H); ^{13}C NMR (100.61 MHz, $CDCl_3$): δ 29.0, 30.2, 65.7, 69.1, 69.4, 71.7, 71.8, 72.1, 73.3, 74.0, 74.4, 74.8, 74.9, 75.0, 75.1, 75.8, 77.6, 79.5, 82.3, 84.7, 98.2, 103.6, 115.0, 127.3-129.8, 137.9, 138.0, 138.3, 138.4, 138.4, 138.4, 138.5, 138.7, ; HRMS(MALDI-TOF) calculated for $C_{66}H_{72}O_{11}Na$: 1063.4972, Found: 1063.4981.



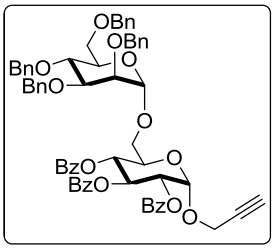
Pent-4-enyl 2,3,4-tri-*O*-benzoyl-6-*O*-(2,3,4,6-tetra-*O*-benzyl-α-D-mannopyranosyl)-β-D-glucopyranoside (7b) : $[\alpha]_D$ ($CHCl_3$, *c* 1.85) = +17.8; ^{1}H NMR (200.13 MHz, $CDCl_3$): δ 1.55(q, 2H, *J* = 6.4, 13.2Hz), 1.93(q, 2H, *J* = 6.4, 13.6Hz), 3.36-3.98(m, 10H), 4.35-4.96(m, 7H), 4.39(bs, 2H), 4.51(ABq, 2H, *J* = 12.0Hz), 4.67(bs, 2H), 5.53(m, 3H), 5.84(t, 1H, *J* = 9.7Hz), 7.08-7.53(m, 29H), 7.75-8.03(m, 6H); ^{13}C NMR (50.32 MHz, $CDCl_3$): δ 28.5, 29.8, 66.5, 69.1, 69.4, 70.3, 71.8, 72.0, 72.1, 72.5, 72.9, 73.0, 73.3, 74.4, 74.7, 75.0, 80.0, 98.2, 101.2, 114.9, 127.4-130.0, 133.2, 133.2, 133.2, 133.3, 137.8, 138.4, 138.6, 138.7, 165.1, 165.2, 165.9; HRMS(MALDI-TOF) calculated for $C_{66}H_{66}O_{14}Na$: 1105.4350, Found: 1105.4356.



Prop-2-ynyl 2,3,4-tri-*O*-benzyl-6-*O*-(2,3,4,6-tetra-*O*-benzyl-α-D-mannopyranosyl)-α-D-glucopyranoside (9a) $[\alpha]_D$ ($CHCl_3$, *c* 1.00) = +48.0; ^{1}H NMR (500.13 MHz, $CDCl_3$): δ 2.43(t, 1H, *J* = 2.3Hz), 3.41(t, 1H, *J* = 9.8Hz), 3.49(dd, 1H, *J* =4.0, 9.6Hz), 3.51(t, 1H, *J* = 9.0Hz), 3.60(d, 1H, *J* = 9.4Hz), 3.60-3.74(m, 3H), 3.77(t, 1H, *J* = 2.3Hz), 3.81-3.89(m, 2H), 3.98(dd, 2H, *J* = 9.3, 18.7Hz), 4.20(t, 2H, *J* = 2.8Hz), 4.42-4.55(m, 4H), 4.55-5.05(m, 12H), 7.10-7.44(m, 35H); ^{13}C NMR (125.76 MHz, $CDCl_3$): δ 54.3, 65.5, 69.0, 70.4, 71.8, 72.0, 72.4, 72.8, 73.2, 74.5, 74.8, 74.9, 75.0, 75.0, 75.8, 77.3, 78.8, 79.4, 79.5, 81.9, 94.7, 98.2, 127.2-128.5, 137.9, 138.1, 138.3, 138.3, 138.4, 138.6, 138.6; HRMS(MALDI-TOF) calculated for $C_{64}H_{66}O_{11}Na$: 1033.4503, Found: 1033.4430.

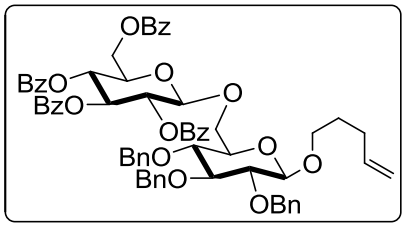


Prop-2-ynyl 2,3,4-tri-*O*-benzoyl-6-*O*-(2,3,4,6-tetra-*O*-benzyl-α-D-mannopyranosyl)-α-D-glucopyranoside (9b) : $[\alpha]_D$ ($CHCl_3$, *c* 1.00) = 68.6; ^{1}H NMR (200.13 MHz, $CDCl_3$): δ 2.36(t, 1H, *J* = 2.3Hz), 3.50-3.78(m, 4H), 3.82-3.90(m, 3H), 4.27(d, 2H, *J* = 2.3Hz), 4.32-4.95(m, 11H), 5.28(dd, 1H, *J* = 3.8, 10.2Hz), 5.48(d, 1H, *J* = 3.6Hz), 5.60(t, 1H, *J* = 9.8Hz), 6.12(t, 1H, *J* = 9.8Hz), 7.12-7.58(m,29H), 7.82-8.02(m, 6H); ^{13}C NMR (125.76 MHz, $CDCl_3$): δ 55.5, 65.9, 68.7, 68.9, 69.6, 70.3, 71.6, 71.8, 72.1, 72.5, 73.1, 74.7, 74.7, 74.9, 75.4, 78.2, 79.8, 94.9, 98.2,

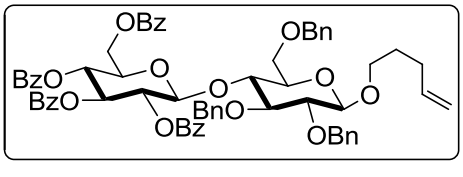


127.3-129.9, 133.1, 133.2, 133.3, 138.3, 138.4, 138.5, 138.6, 165.0, 165.7, 165.8; HRMS(MALDI-TOF) calculated for $C_{64}H_{60}O_{14}Na$: 1075.3881, Found: 1075.3817.

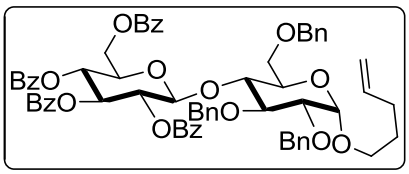
Pent-4-enyl 2,3,4-tri-*O*-benzyl-6-*O*-(2,3,4,6-tetra-*O*-benzoyl-β-D-glucopyranosyl)-β-D-glucopyranoside (12) : $[\alpha]_D$ ($CHCl_3$, *c* 0.9) = +9.5; ^{1}H NMR (200.13 MHz, $CDCl_3$): δ 1.63(q, 2H, *J* = 6.9, 14.5Hz), 2.08(q, 2H, *J* = 6.9, 14.5Hz), 3.34(m, 4H), 3.53(dd, 1H, *J* = 8.9, 17.3Hz), 3.64-3.88(m, 2H), 4.03-4.33(m, 3H), 4.35-4.75(m, 6H), 4.76-5.10(m, 5H), 5.46-5.96(m, 4H), 7.10-7.58(m, 27H), 7.75-8.08(m, 8H); ^{13}C NMR (50.32 MHz, $CDCl_3$): δ 28.9, 30.3, 63.2, 68.5, 69.2, 69.7, 71.9, 72.2, 73.0, 74.6, 74.9, 74.9, 75.6, 77.8, 82.1, 84.6, 101.3, 103.5, 115.0, 127.6-129.9, 133.2, 133.2, 133.3, 133.5, 137.9, 138.2, 138.5, 138.6, 165.1, 165.2, 165.9, 166.2; HRMS(MALDI-TOF) calculated for $C_{66}H_{64}O_{15}Na$: 1119.4143, Found: 1119.4149.



Pent-4-enyl 2,3,6-tri-*O*-benzyl-4-*O*-(2,3,4,6-tetra-*O*-benzoyl-β-D-glucopyranosyl)-β-D-glucopyranoside (14) : $[\alpha]_D$ ($CHCl_3$, *c*1.9) = -1.8; ^{1}H NMR (200.13 MHz, $CDCl_3$): δ 1.71(m, 2H), 2.11(m, 2H), 3.21(d, 1H, *J* = 9.1Hz), 3.31-3.78(m, 6H), 3.88(dt, 1H, *J* = 6.5, 12.7Hz), 4.03(t, 1H, *J* = 9.3Hz), 4.15-4.44(m, 4H), 4.68(dd, 2H, *J* = 10.6, 12.0Hz), 4.82(t, 2H, *J* = 10.9Hz), 4.89-5.10(m, 4H), 5.41-5.90(m, 4H), 7.10-7.56(m, 27H), 7.76-7.99(m, 8H); ^{13}C NMR (50.32 MHz, $CDCl_3$): δ 28.9, 30.2, 63.1, 67.9, 69.3, 69.7, 72.0, 72.3, 73.2, 73.5, 74.3, 74.9, 75.3, 77.4, 81.7, 82.6, 100.4, 103.5, 115.0, 127.2-129.9, 133.1, 133.3, 133.4, 133.4, 138.1, 138.2, 138.5, 139.1, 164.9, 165.1, 165.8, 166.1; HRMS(MALDI-TOF) calculated for $C_{66}H_{64}O_{15}Na$: 1119.4143, Found: 1119.4146.

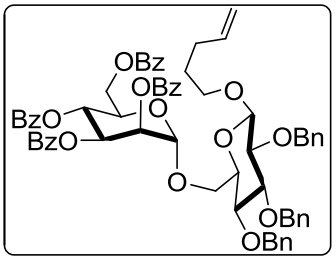


Pent-4-enyl 2,3,6-tri-*O*-benzyl-4-*O*-(2,3,4,6-tetra-*O*-benzoyl-β-D-glucopyranosyl)-α-D-glucopyranoside (16) : $[\alpha]_D$ ($CHCl_3$, *c* 1.7) = +7.9; ^{1}H NMR (200.13 MHz, $CDCl_3$): δ 1.65(m, 2H), 2.01(m, 2H), 3.29-3,55(m, 5H), 3.68(dd, 2H, *J* = 2.4, 10.2Hz), 3.92(quintet, 2H, *J* = 8.8, 17.9Hz), 4.32(ddd, 2H, *J* = 3.6, 12.0, 17.3Hz), 4.68(ABq, 2H, *J* = 12.4Hz), 4.69(dd, 2H, *J* = 3.7,

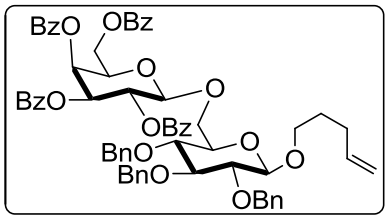


10.6Hz), 4.71(s, 1H), 4.77(s, 1H), 4.82-4.95(m, 2H), 4.91(ABq, 2H, *J* = 11.0Hz), 5.40-5.82(m, 4H), 7.05-7.63(m, 27H), 7.73-8.05(m, 8H); ^{13}C NMR (50.32 MHz, $CDCl_3$): δ 28.3, 30.1, 63.1, 67.4, 67.6, 69.5, 69.8, 71.8, 72.2, 73.1, 73.3, 73.5, 75.2, 77.3, 79.1, 79.9, 97.1, 100.4, 114.8, 127.0-129.7, 132.9, 133.1, 133.2, 133.3, 137.9, 137.9, 138.5, 139.3, 164.8, 165.0, 165.7, 166.0; HRMS(MALDI-TOF) calculated for $C_{66}H_{64}O_{15}Na$: 1119.4143, Found: 1119.4146.

Pent-4-enyl 2,3,4-tri-*O*-benzyl-6-*O*-(2,3,4,6-tetra-*O*-benzoyl-α-D-mannopyranosyl)-β-D-glucopyranoside (18) : $[\alpha]_D$ ($CHCl_3$, *c* 1.3) = -14.7; ^{1}H NMR (200.13 MHz, $CDCl_3$): δ 1.73(m, 2H), 2.12(m, 2H), 3.38-3.95(m, 7H), 3.95-4.09(m, 1H), 4.30-4.58(m, 3H), 4.59-5.05(m, 9H), 5.13(d, 1H, *J* = 1.5Hz), 5.76(dd, 2H, *J* = 1.8, 3.0Hz), 5.91(dd, 1H, *J* = 3.3, 10.0Hz), 6.11(t, 1H, *J* = 10.0Hz), 7.15-7.68(m, 27H), 7.78-8.18(m, 8H); ^{13}C NMR (50.32 MHz, $CDCl_3$): δ 29.0, 30.1, 62.5, 66.7, 66.9, 68.8, 69.3, 70.0, 70.2, 73.9, 74.9, 75.0, 75.7, 77.9, 82.2, 84.7, 97.5, 103.5, 114.9, 127.6-129.9, 133.0, 133.1, 133.4, 133.4, 137.8, 137.9, 138.3, 138.5, 165.2, 165.4, 165.4, 166.1 ; HRMS(MALDI-TOF) calculated for $C_{66}H_{64}O_{15}Na$: 1119.4341, Found: 1119.4171.

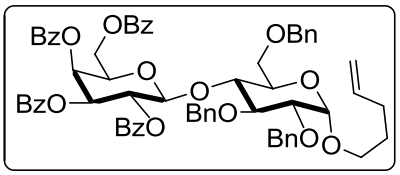


Pent-4-enyl 2,3,4-tri-*O*-benzyl-6-*O*-(2,3,4,6-tetra-*O*-benzoyl-β-D-galactopyranosyl)-β-D-glucopyranoside (20) : $[\alpha]_D$ ($CHCl_3$, *c* 1.6) = +46.6; ^{1}H NMR (200.13 MHz, $CDCl_3$): δ 1.61(m, 2H), 2.07(q, 2H, *J* = 6.9Hz), 3.26-3.43(m, 3H), 3.44-3.63(m, 2H), 3.65-3.85(m, 2H), 4.15-4.50(m, 5H), 4.58-4.78(m, 4H), 4.80-5.06(m, 5H), 5.59(dd, 1H, *J* = 3.4, 10.4Hz), 5.65-5.90(m, 2H), 5.99(d, 1H, *J* = 3.0Hz), 7.10-7.68(m, 27H), 7.73-8.15(m, 8H); ^{13}C NMR (50.32 MHz, $CDCl_3$): δ 28.8, 30.1, 61.9, 68.0, 68.4, 69.1, 69.7, 71.2, 71.6, 74.5, 74.8, 74.8, 75.6, 77.7, 82.0, 84.5, 101.5, 103.4, 114.9, 127.5-130.0, 133.1, 133.2, 133.2, 133.5, 137.8, 138.0, 138.3, 138.4, 165.1, 165.5, 165.5, 166.0; HRMS(MALDI-TOF) calculated for $C_{66}H_{64}O_{15}Na$: 1119.4143, Found: 1119.4142.

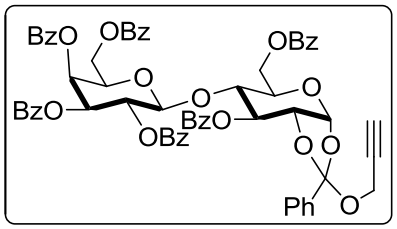


Pent-4-enyl 2,3,6-tri-*O*-benzyl-4-*O*-(2,3,4,6-tetra-*O*-benzoyl-β-D-galactopyranosyl)-α-D-glucopyranoside (21) : $[\alpha]_D$ ($CHCl_3$, *c* 1.2) = +24.8; ^{1}H NMR (200.13 MHz,

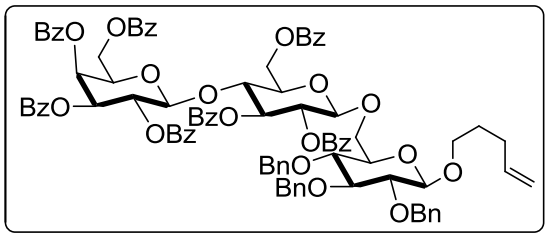
$CDCl_3$): δ 1.65(m, 2H), 2.04(q, 2H, *J* = 9.9Hz), 3.28-3.62(m, 5H), 3.68(dd, 1H, *J* = 2.7, 10.7Hz), 3.80-4.09(m, 3H), 4.10-4.52(m, 3H), 4.55-5.05(m, 7H), 5.04(ABq, 2H, *J* = 11.0Hz), 5.28(dd, 1H, *J* = 3.4, 10.4Hz), 5.60-5.88(m, 3H), 7.10-7.64(m, 27H), 7.70-8.05(m, 8H); ^{13}C NMR (50.32 MHz, $CDCl_3$): δ 28.3, 30.1, 61.3, 67.3, 67.5, 67.8, 69.5, 70.3, 70.9, 71.8, 73.3, 73.6, 75.2, 76.8, 78.9, 79.8, 97.1, 100.4, 114.8, 127.1-129.9, 133.1, 133.2, 133.3, 133.4, 137.8, 137.9, 138.4, 139.4, 164.9, 165.4, 165.4, 165.8, .; HRMS(MALDI-TOF) calculated for $C_{66}H_{64}O_{15}Na$: 1119.4143, Found: 1119.4136.



3,6-di-*O*-benzoyl-4-*O*-(2,3,4,6-tetra-*O*-benzoyl-β-D-galactopyranosyl)-α-D-gluco-pyranose-1,2-(prop-2-ynyl orthoacetate) (22) : $[\alpha]_D$ ($CHCl_3$, *c* 1.3) = +79.6; ^{1}H NMR (200.13 MHz, $CDCl_3$): δ 2.40(t, 1H, *J* = 2.4Hz), 3.84(dt, 1H, *J* = 2.6, 5.1Hz), 3.99(ddd, 2H, *J* = 2.5, 15.4, 17.8, Hz), 4.10-4.20(m, 3H), 4.43-4.55(m, 2H), 4.65-4.78(m, 2H), 5.19(d, 1H, *J* = 8.0Hz), 5.66(dd, 1H, *J* = 5.7, 10.6Hz), 5.95(dd, 1H, *J* = 8.2, 10.1Hz), 6.02(d, 1H, *J* = 5.6Hz), 6.05(d, 1H, *J* = 3.3Hz), 6.11(d, 1H, *J* = 2.4Hz), 7.05-7.65(m, 23H), 7.68-8.19(m, 12H); ^{13}C NMR (50.32 MHz, $CDCl_3$): δ 52.4, 62.1, 63.0, 67.5, 68.1, 69.5, 69.5, 71.6, 71.6, 71.8, 73.9, 76.8, 79.2, 97.8, 103.0, 121.2, 126.7, 128.0-130.0, 132.8, 132.9, 133.2, 133.3, 133.5, 133.5, 133.6, 164.6, 165.0, 165.4, 165.5, 165.5, 165.7; HRMS(MALDI-TOF) calculated for $C_{64}H_{52}O_{18}Na$: 1131.3051, Found: 1131.3036.

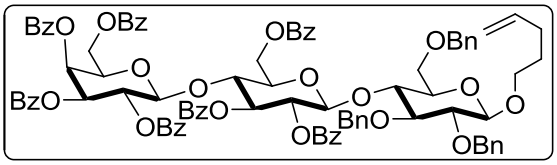


Pent-4-enyl 2,3,4-tri-*O*-benzyl-6-*O*-(2,3,6-tri-*O*-benzoyl)-4-*O*-(2,3,4,6-tetra-*O*-benzoyl-β-D-galactopyranosyl)-β-D-glucopyranosyl)-β-glucopyranoside (23) : $[\alpha]_D$ ($CHCl_3$, *c* 1.7) = +35.3; ^{1}H NMR (500.13 MHz, $CDCl_3$): δ 1.58(m, 2H), 2.07(m, 2H), 3.30(m, 2H), 3.39(ddd, 1H, *J* = 1.1, 4.9, 5.9Hz), 3.52(t, 1H, *J* = 8.9Hz), 3.60-3.80(m, 4H), 3.88(t, 1H, *J* = 6.3Hz), 4.08(dd, 1H, *J* = 1.3, 11.0Hz), 4.21(d, 1H, *J* = 7.8Hz), 4.27(dd, 1H, *J* = 9.4, 18.6Hz), 4.36(d, 1H, *J* = 11.0Hz), 4.45-4.73(m, 5H), 4.75-4.90(m, 4H), 4.93-5.05(m, 2H), 5.32-5.40(m, 1H), 5.53(m, 1H), 5.68-5.83(m, 4H), 7.05-7.78(m, 36H), 7.85-8.10(m, 14H); ^{13}C

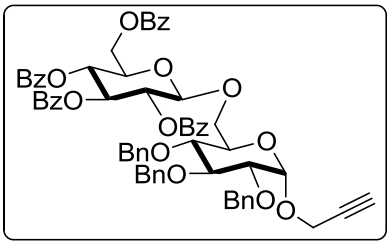


NMR (125.76 MHz, $CDCl_3$): δ 28.8, 30.1, 61.0, 62.3, 67.5, 68.3, 69.1, 69.8, 71.3, 71.7, 71.7, 72.8, 72.9, 74.5, 74.7, 74.8, 75.5, 75.9, 77.7, 82.0, 84.4, 101.0, 101.1, 102.3, 114.9, 127.5-130.0, 133.1, 133.1, 133.2, 133.3, 133.4, 133.5, 137.8, 138.0, 138.0, 138.3, 138.4, 164.7, 165.0, 165.2, 165.4, 165.4, 165.5, 165.8; HRMS(MALDI-TOF) calculated for $C_{93}H_{86}O_{23}Na$: 1594.5491, Found: 1594.5469.

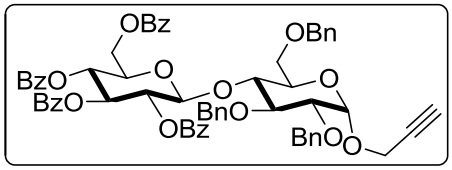
Pent-4-enyl 2,3,6-tri-*O*-benzyl-4-*O*-(2,3,6-tri-*O*-benzoyl)-4-*O*-(2,3,4,6-tetra-*O*-benzoyl-β-D-galactopyranosyl)-β-D-glucopyranosyl)-β-glucopyranoside (24) : $[\alpha]_D$ ($CHCl_3$, *c* 1.5) = +20.0; ^{1}H NMR (500.13 MHz, $CDCl_3$): δ 1.72(m, 2H), 2.14(m, 2H), 3.25(dq, 2H, *J* = 1.7, 3.5, 9.8Hz), 3.36(dd, 1H, *J* = 8.0, 9.0Hz), 3.43-3.75(m, 6H), 3.80(t, 1H, *J* = 6.7Hz), 3.85-3.98(m, 3H), 1.48(t, 1H, *J* = 9.7Hz), 4.23-4.38(m, 4H), 4.60-4.86(m, 6H), 4.95-5.05(m, 2H), 5.32(dd, 1H, *J* = 3.4, 10.4z), 5.45(dd, 1H, *J* = 8.1, 9.9Hz), 5.59(t, 1H, *J* = 9.4Hz), 5.70-5.85(m, 3H), 7.01-7.65(m, 36H), 7.91-8.12(m, 14H); ^{13}C NMR (125.76 MHz, $CDCl_3$): δ 28.8, 30.1, 60.9, 62.4, 67.4, 67.8, 69.2, 69.7, 71.2, 71.8, 72.2, 72.6, 72.9, 73.3, 74.1, 74.7, 74.8, 75.4, 77.3, 81.5, 83.5, 100.1, 100.7, 103.4, 114.8, 126.9-129.4, 133.0, 133.2, 133.3, 133.4, 133.5, 133.5, 137.9, 138.0, 138.0, 138,.4, 138.9, 164.7, 164.9, 165.2, 165.3, 165.3, 165.5, 165.7; HRMS(MALDI-TOF) calculated for Mol. Wt. calculated for $C_{93}H_{86}O_{23}Na$: 1594.5491, Found: 1594.5412.



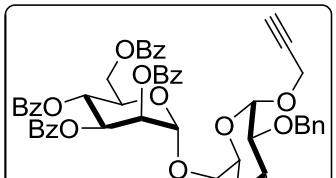
Prop-2-ynyl 2,3,4-tri-*O*-benzyl-6-*O*-(2,3,4,6-tetra-*O*-benzoyl-β-D-glucopyranosyl)-α-D-glucopyranoside (25) : $[\alpha]_D$ ($CHCl_3$, *c* 1.0) = +30.5; ^{1}H NMR (200.13 MHz, $CDCl_3$): δ 2.38 (t, 1 H, *J* = 2.3 Hz), 3.21-3.52 (m, 2 H), 3.89 (t, 1 H, *J* = 9.2 Hz), 3.72-3.92 (m, 2 H), 4.10-4.32 (m, 5 H), 4.45-5.02 (m, 9 H), 5.58 (dd, 1 H, *J* = 8.0, 9.6 Hz), 5.67 (t, 1 H, *J* = 9.6 Hz), 5.90 (t, 1 H, *J* = 9.5 Hz), 7.00-7.57 (m, 27 H), 7.78-8.02 (m, 8 H); ^{13}C NMR (100.61 MHz, $CDCl_3$): δ 54.3, 63.2, 68.1, 69.8, 70.1, 71.8, 72.2, 72.9, 72.9, 74.6, 74.7, 75.5, 77.2, 79.0, 79.3, 81.7, 95.0, 101.3, 127.4-129.7, 133.1, 133.1, 133.2, 133.4, 138.0, 138.2, 138.8, 165.0, 165.1, 165.2, 165.8; HRMS(MALDI-TOF) calculated for $C_{64}H_{58}O_{15}Na$: 1089.3673, Found: 1089.3605.



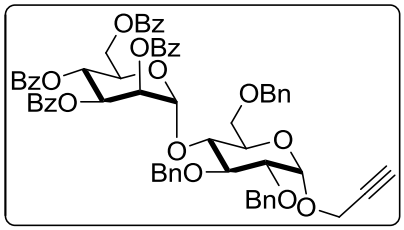
Prop-2-ynyl 2,3,6-tri-*O*-benzyl-4-*O*-(2,3,4,6-tetra-*O*-benzoyl-β-D-glucopyranosyl)-α-D-glucopyranoside (27) : $[\alpha]_D$ ($CHCl_3$, *c* 1.0) = +15.36; ^{1}H NMR (200.13 MHz, $CDCl_3$): δ 2.27 (t, 1 H, *J* = 2.2 Hz), 3.41 (dd, 1 H, *J* = 1.5, 10.8 Hz), 3.50 (dd, 1 H, *J* = 3.7, 9.3 Hz), 3.56 (d, 1 H, *J* = 9.8 Hz), 3.62-3.78 (m, 2 H), 3.93 (d, 1 H, *J* = 2.5 Hz), 3.94 (ABq, 1 H, *J* = 8.8 Hz), 4.15 (d, 2 H, *J* = 2.2 Hz), 4.21-4.46 (m, 3 H), 4.55-5.10 (m, 7 H), 5.40-5.68 (m, 3 H), 7.12-7.58 (m, 27 H), 7.75-8.05 (m, 8 H); ^{13}C NMR (100.61 MHz, $CDCl_3$): δ 54.7, 63.1, 67.3, 69.8, 70.1, 71.8, 72.2, 73.0, 73.2, 73.6, 74.7, 75.3, 77.1, 78.3, 78.8, 79.7, 95.6, 100.3, 127.1-129.7, 132.9, 133.1, 133.2, 133.3, 137.8, 138.2, 139.2, 164.7, 165.0, 165.7, 166.0; HRMS(MALDI-TOF) calculated for $C_{64}H_{58}O_{15}Na$: 1089.3673, Found: 1089.3686.



Prop-2-ynyl 2,3,4-tri-*O*-benzyl-6-*O*-(2,3,4,6-tetra-*O*-benzoyl-α-D-mannopyranosyl)-α-D-glucopyranoside (29) : $[\alpha]_D$ ($CHCl_3$, *c* 1.0) = +18.5; ^{1}H NMR (200.13 MHz, $CDCl_3$): δ 2.47(t, 1H, *J* = 2.3Hz), 3.55(t, 1H, *J* = 9.1Hz), 3.63(dd, 1H, *J* = 3.7, 9.7Hz), 3.75-3.95(m, 3H), 4.05(t, 1H, *J* = 9.2Hz), 4.25-4.51(m, 2H), 4.38(s, 2H), 4.58-4.89(m, 3H), 4.75(s, 2H), 4.95-5.16(m, 4H), 5.73(dd, 1H, *J* = 1.7, 3.1Hz), 5.87(dd, 1H, *J* = 3.1, 10.0Hz), 6.09(t, 1H, *J* = 10.0Hz), 7.20-7.65(m, 27H), 7.76-8.15(m, 8H); ^{13}C NMR (50.32 MHz, $CDCl_3$): δ 54.6, 62.6, 66.6, 66.7, 68.8, 69.9, 70.1, 70.5, 73.0, 75.0, 75.0, 75.7, 77.5, 78.8, 79.6, 81.9, 94.9, 97.7, 127.6-129.8, 133.0, 133.1, 133.4, 133.4, 137.9, 138.1, 138.6, 165.2, 165.4, 165.4, 166.1; HRMS(MALDI-TOF) calculated for $C_{64}H_{58}O_{15}Na$: 1089.3673, Found: 1089.3613.

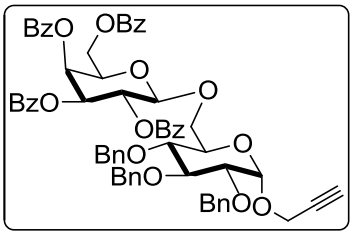


Prop-2-ynyl 2,3,6-tri-*O*-benzyl-4-*O*-(2,3,4,6-tetra-*O*-benzoyl-α-D-mannopyranosyl)-α-D-glucopyranoside (30) : $[\alpha]_D$ ($CHCl_3$, *c* 1.0) = -15.2; ^{1}H NMR (200.13 MHz, $CDCl_3$): δ 2.49(t, 1H, *J* = 2.3Hz), 3.63(dd, 1H, *J* = 3.6, 9.2Hz), 3.74-4.03(m, 4H), 4.09(dd, 1H, *J* = 7.3, 15.5Hz), 4.24(dd, 1H, *J* = 3.2, 12.1Hz), 4.34(d, 2H, *J* = 2.3Hz), 4.47(td, 2H, *J* = 2.3, 12.0Hz), 4.58-4.75(m, 4H), 4.99(ABq, 2H, *J* = 10.8Hz), 5.09(d, 1H, *J* = 3.2Hz), 5.61-5.78(m, 2H), 5.89(dd, 1H, *J* = 3.1, 10.0Hz), 6.07(t, 1H, *J* = 10.0Hz), 6.91-7.65(m, 27H),

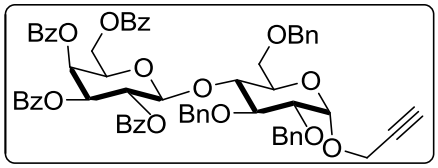


7.78-8.13(m, 8H); ^{13}C NMR (50.32 MHz, $CDCl_3$): δ 54.5, 62.5, 66.5, 68.8, 69.5, 69.8, 70.1, 70.3, 72.8, 73.4, 75.0, 75.3, 75.7, 78.7, 79.5, 81.1, 94.8, 98.8, 127.1-129.8, 132.9, 133.0, 133.2, 133.3, 137.5, 137.6, 138.0, 164.8, 165.2, 165.4, 165.9 ; HRMS(MALDI-TOF) calculated for $C_{64}H_{58}O_{15}Na$: 1089.3673, Found: 1089.3609.

Prop-2-ynyl 2,3,4-tri-*O*-benzyl-6-*O*-(2,3,4,6-tetra-*O*-benzoyl-β-D-galactopyranosyl)-α-D-glucopyranoside (32) : $[\alpha]_D$ ($CHCl_3$, *c* 1.0) = +84.4; ^{1}H NMR (200.13 MHz, $CDCl_3$): δ 2.30 (t, 1 H, *J* = 2.1 Hz), 3.35 (d, 1 H, *J* = 10.3 Hz), 3.45 (dd, 1 H, *J* = 3.6, 9.9 Hz), 3.67-3.98 (m, 3 H) 4.09-5.03 (m, 14 H), 5.61 (dd, 1 H, *J* = 3.32, 10.4 Hz), 5.84 (dd, 1 H, *J* = 8.1, 10.4 Hz), 5.97 (d, 1 H, *J* = 2.5 Hz), 7.05-7.68 (m, 27 H), 7.72-8.18 (m, 8 H); ^{13}C NMR (125.76 MHz, $CDCl_3$): δ 54.3, 61.9, 68.0, 68.3, 69.7, 70.2, 71.3, 71.5, 72.9, 74.7, 74.7, 75.5, 77.2, 78.9, 79.3, 81.7, 94.9, 101.9, 127.4-130.0, 133.1, 133.3, 133.3, 133.6, 137.9, 138.1, 138.7, 165.1, 165.5, 165.6, 166.0; HRMS(MALDI-TOF) calculated for $C_{64}H_{58}O_{15}Na$: 1089.3673, Found: 1089.3645.

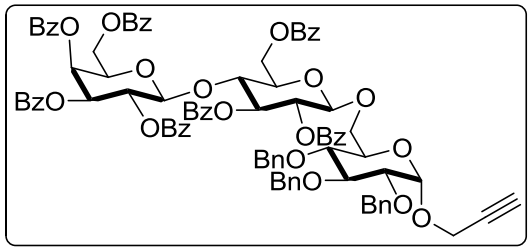


Prop-2-ynyl 2,3,6-tri-*O*-benzyl-4-*O*-(2,3,4,6-tetra-*O*-benzoyl-β-D-galactopyranosyl)-α-D-glucopyranoside (33) : $[\alpha]_D$ ($CHCl_3$, *c* 1.0) = +33.3; ^{1}H NMR (200.13 MHz, $CDCl_3$): δ 2.30 (t, 1 H, *J* = 2.3 Hz), 3.51 (ABq, 2 H, *J* = 10.6 Hz), 3.55 (dd, 1 H, *J* = 3.9, 9.5 Hz), 3.69 (dd, 1 H, *J* = 2.7, 10.4 Hz), 3.85-4.10 (m, 3 H), 4.17 (d, 2 H, *J* = 2.3 Hz), 4.23-4.48 (m, 3 H), 4.61-4.84 (m, 4 H), 4.98 (ABq, 2 H, *J* = 11.2 Hz), 5.01 (d, 1 H, *J* = 3.6 Hz), 5.30 (dd, 1 H, *J* = 3.4, 10.4 Hz), 5.69 (dd, 1 H, *J* = 8.0, 10.4 Hz), 5.85 (d, 1 H, *J* = 3.0 Hz), 7.12-7.61 (m, 27 H), 7.70-8.08 (m, 8 H); ^{13}C NMR (50.32 MHz, $CDCl_3$): δ 54.7, 61.3, 67.3, 67.7, 70.1, 70.2, 70.9, 71.8, 73.2, 73.6, 74.7, 75.3, 76.5, 78.2, 78.8, 79.6, 95.7, 100.4, 127.1-129.8, 133.1, 133.2, 133.3, 133.4, 137.7, 138.1, 139.3, 164.8, 165.3, 165.3, 165.8; HRMS(MALDI-TOF) calculated for $C_{64}H_{58}O_{15}Na$: 1089.3673, Found: 1089.3626.

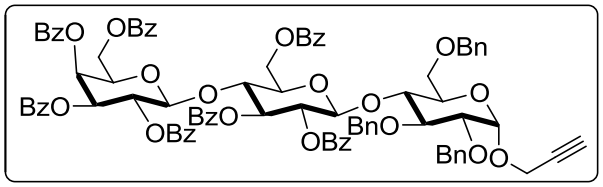


Prop-2-ynyl 2,3,4-tri-*O*-benzyl-6-*O*-(2,3,6-tri-*O*-benzoyl)-4-*O*-(2,3,4,6-tetra-*O*-benzoyl-β-D-galactopyranosyl)-β-D-glucopyranosyl)-α-glucopyranoside (35) : $[\alpha]_D$ ($CHCl_3$, *c* 1.0) = +35.7; ^{1}H NMR (200.13 MHz, $CDCl_3$): δ 2.35(t, 1H, *J* = 2.3Hz), 3.25-

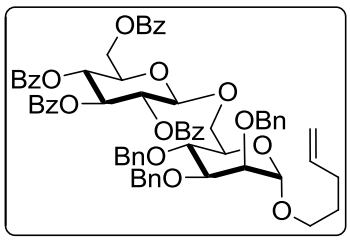
3.46(m, 2H), 3.60-3.91(m, 6H), 4.01-4.32(m, 5H), 4.36-4.76(m, 8H), 4.81-4.98(m, 3H), 5.37(dd, 1H, *J* = 3.4, 10.4Hz), 5.53(dd, 1H, *J* = 8.1, 9.8Hz), 5.67-5.85(m, 3H), 6.98-7.68(m, 36H), 7.87-8.03(m, 14H); ^{13}C NMR (125.76 MHz, $CDCl_3$): δ 54.2, 61.1, 62.3, 67.5, 68.0, 70.0, 70.1, 71.3, 71.5, 71.7, 72.8, 72.9, 73.0, 74.7, 74.7, 75.5, 75.9, 77.1, 78.8, 79.2, 81.6, 94.8, 100.9, 101.2, 127.4-130.0, 133.1, 133.2, 133.2, 133.3, 133.4, 133.4, 133.5, 137.8, 138.0, 138.7, 164.7, 165.0, 165.1, 165.4, 165.4, 165.5, 165.8; HRMS(MALDI-TOF) calculated for $C_{91}H_{80}O_{23}Na$: 1564.5022, Found: 1564.5029.



Prop-2-ynyl 2,3,6-tri-*O*-benzyl-4-*O*-(2,3,6-tri-*O*-benzoyl)-4-*O*-(2,3,4,6-tetra-*O*-benzoyl-β-D-galactopyranosyl)-β-D-glucopyranosyl)-α-glucopyranoside (36) : $[\alpha]_D$ ($CHCl_3$, *c* 1.0) = +45.5; ^{1}H NMR (200.13 MHz, $CDCl_3$): δ 2.25(t, 1H, *J* = 2.3Hz), 3.15-3.90(m,10H), 4.05-4.36(m,6H), 4.45-4.78(m, 6H), 4.95(t, 1H, *J* = 3.8Hz), 5.02(t,1H, *J* = 5.8Hz), 5.29(dd, 1H, *J* = 3.2, 10.2Hz), 5.44(quintet, 2H, *J* = 8.1,10.0Hz), 5.70(m, 2H), 6.90-7.68(m, 36H), 7.70-8.11(m, 14H); ^{13}C NMR (125.76 MHz, $CDCl_3$): δ 54.6, 60.9, 62.4, 67.2, 67.4, 69.7, 70.0, 71.2, 71.7, 72.0, 72.5, 72.9, 73.1, 73.5, 74.6, 75.1, 75.3, 77.0, 78.1, 78.7, 79.7, 95.6, 100.2, 100.6, 126.8-130.0, 133.0, 133.2, 133.2, 133.3, 133.4, 133.5, 133.5, 137.5, 138.0, 139.0, 164.8, 164.8, 165.2, 165.3, 165.3, 165.5, 165.7; HRMS(MALDI-TOF) calculated for $C_{91}H_{80}O_{23}Na$: 1564.5022, Found: 1564.5021.

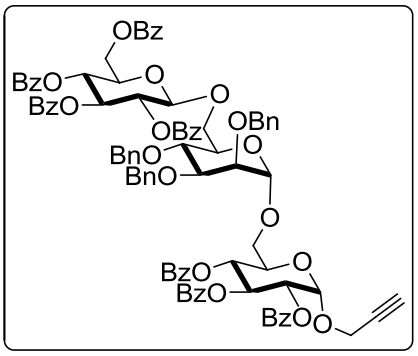


Pent-4-enyl 2,3,4-tri-*O*-benzyl-6-*O*-(2,3,4,6-tetra-*O*-benzoyl-β-D-glucopyranosyl)-α-D-mannopyranoside (38) : $[\alpha]_D$ ($CHCl_3$, *c* 3.0) = +27.3; ^{1}H NMR (200.13 MHz, $CDCl_3$): δ 1.32(m, 2H), 1.89(m, 2H), 2.95(m, 1H), 3.38(m, 1H), 3.52-3.80(m, 5H), 4.10-4.28(m, 2H), 4.35-4.78(m, 9H), 4.84-5.00(m, 3H), 5.50-5.98(m, 4H), 7.12-7.58(m, 27H), 7.75-8.09(m, 8H); ^{13}C NMR (50.32 MHz, $CDCl_3$): δ 28.3, 30.2, 63.1, 66.4, 69.4, 69.7, 71.1, 71.8, 72.0, 72.0,

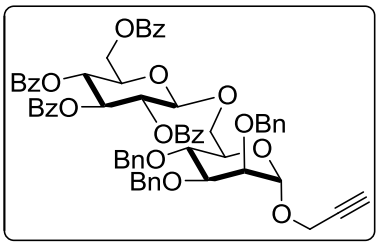


72.5, 72.9, 74.4, 74.9, 75.0, 80.2, 97.5, 101.6, 114.6, 127.4-129.8, 132.9, 133.0, 133.1, 133.3, 138.1, 138.2, 138.3, 138.4, 164.9, 165.1, 165.8, 166.1; HRMS(MALDI-TOF) calculated for $C_{66}H_{64}O_{15}Na$: 1119.4143, Found: 1119.4164.

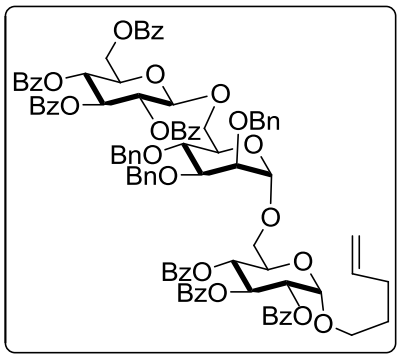
Prop-2-ynyl 2,3,4-tri-*O*-benzoyl-6-*O*-(2,3,4-tri-*O*-benzyl)-6-*O*-(2,3,4,6-tetra-*O*-benzoyl-β-D-glucopyranosyl)-α-D-mannopyranosyl)-α-glucopyranoside (39) : $[\alpha]_D$ ($CHCl_3$, *c* 1.7) = -11.0; ^1H NMR (200.13 MHz, $CDCl_3$): δ 2.60(t, 1H, *J* = 2.3Hz), 3.33(dd, J=3.3,11.0Hz, 1H),3.57-3.73(m, 4H), 3.76(dd, J=3.2, 11.1Hz, 1H), 3.83(dd, J=2.4, 8.5Hz, 1H), 4.06-4.12(m, 3H), 4.31-4.41(m, 5H), 4.51(dd, J= 5.2, 12.7Hz, 1H), 4.59(s, 2H), 4.61(dd(, J= 3.4, 12.7Hz, 1H), 4.67(d, J= 10.9Hz, 1H), 4.76(s, 1H), 4.84(d, J = 7.7, 1H), 5.26(s, 1H), 5.47(dd, J= 7.8, 9.8Hz, 1H), 5.66(t, J= 9.2Hz, 1H), 5.70(d, J= 3.4Hz, 1H), 5.83(dd, J= 3.4, 10.1Hz, 1H), 5.89(t, J= 9.6Hz, 1H), 6.00(t, J = 10.2Hz, 1H), 7.19-7.54(m, 36H), 7.86-8.14(m, 14H); ^{13}C NMR (55.32 MHz, $CDCl_3$): δ 55.2, 63.3, 65.9, 67.2, 69.1, 69.7, 69.8, 70.0, 70.5, 71.2, 71.8, 71.9, 72.0, 72.5, 73.0, 74.7, 74.7, 74.7, 75.8, 78.3, 80.3, 96.3, 98.0, 101.5, 127.5-130.0, 133.1, 133.1, 133.1, 133.3, 133.3, 133.5, 133.6, 138.4, 138.5, 138.5, 165.0, 165.2, 165.3, 165.4, 165.5, 165.9, 166.2; Mol. Wt. calculated for $C_{91}H_{80}O_{23}Na$: 1564.5022, Found: 1564.43 (M^++23 for Na).



Prop-2-ynyl 2,3,4-tri-*O*-benzyl-6-*O*-(2,3,4,6-tetra-*O*-benzoyl-β-D-glucopyranosyl)-α-D-mannopyranoside (41) : $[\alpha]_D$ ($CHCl_3$, *c* 1.0) = +32.5; ^1H NMR (200.13 MHz, $CDCl_3$): δ 2.33(t, 1H, *J* = 2.4Hz), 3.76(m, 4H), 3.91(d, 2H, *J* = 2.3Hz), 4.20(m, 2H), 4.50(s, 2H), 4.58(m, 2H), 4.67(s, 2H), 4.73(ABq, 2H, *J* = 11.1Hz), 4.90(s, 1H), 4.96(d, 1H, *J* = 7.7Hz), 5.60(d, 1H, *J* = 9.6Hz), 5.68(dd, 2H, *J* = 10.0, 19.4Hz), 5.94(t, 1H, *J* = 9.6Hz), 7.12-7.52(m, 27H), 7.80-8.05(m, 8H); ^{13}C NMR (50.32 MHz, $CDCl_3$): δ 53.6, 63.0, 69.2, 69.6, 71.7, 71.8, 71.8, 72.0, 72.5, 72.8, 74.0, 74.6, 74.6, 74.8, 78.7, 79.8, 95.8, 101.5, 127.3-129.7, 133.0, 133.0, 133.1, 133.3, 137.9, 138.1, 138.2, 164.9, 165.0, 165.7, 166.0; HRMS(MALDI-TOF) calculated for $C_{64}H_{58}O_{15}Na$: 1089.3673, Found: 1089.3613.

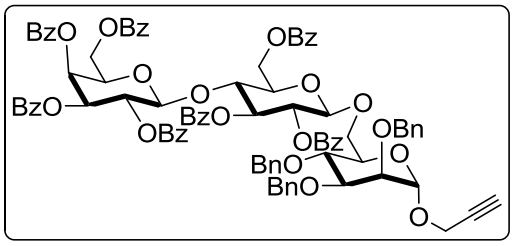


Pent-4-enyl 2,3,4-tri-*O*-benzoyl-6-*O*-(2,3,4-tri-*O*-benzyl)-6-*O*-(2,3,4,6-tetra-*O*-benzoyl-β-D-glucopyranosyl)-α-D-mannopyranosyl)-α-glucopyranoside (43) :



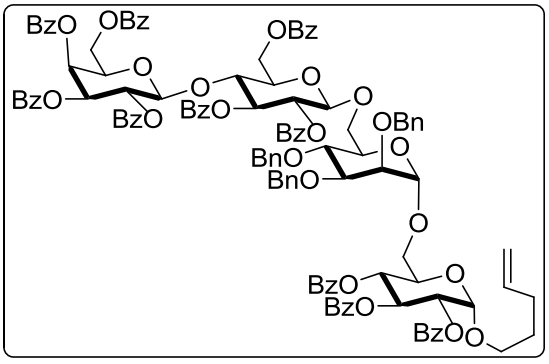
$[\alpha]_D$ ($CHCl_3$, *c* 1.6) = -13.5; ^{1}H NMR (200.13 MHz, $CDCl_3$): δ 1.80(m, 2H), 2.21(m, 2H), 3.28(dd, J = 3.3, 11.0Hz, 1H), 3.32(dd, J= 3.0, 6.4 Hz, 1H), 3.56 (d, J = 6.6, 1H), 3.64-3.81(m, 6H), 4.01-4.09(m, 3H), 4.28(s, 1H), 4.32(d, J = 5.3Hz, 1H), 4.47-4.63(m, 5H), 4.72(d, J = 1.4Hz,2H), 4.76(d, J = 7.8Hz, 1H), 5.00(d, J = 0.8Hz, 1H), 5.04(dd, J = 1.4, 3.1 Hz, 1H), 5.13(q, J = 1.6, 3.4, 1H), 5.41(dd, J = 7.7, 9.6Hz, 1H), 5.58(t, J = 9.7Hz, 1H), 5.61(dd, J = 1.7, 3.4Hz, 1H), 5.76-6.00(m, 4H), 7.12-7.54(m, 36H), 7.80-8.10(m, 14H); ^{13}C NMR (100.61 MHz, $CDCl_3$): δ 28.5, 30.2, 63.2, 66.1, 67.4, 68.0, 69.0, 69.1, 69.8, 70.2, 70.8, 71.0, 71.7, 71.8, 71.9, 72.4, 72.9, 74.5, 74.6, 74.6, 77.2, 80.3, 97.4, 98.0, 101.5, 115.2, 127.3-130.0, 132.9, 133.0, 133.0, 133.2, 133.2, 133.4, 133.4, 137.8, 138.4, 138.5, 164.8, 165.2, 165.3, 165.5, 165.5, 165.8, 166.1; Mol. Wt. calculated for $C_{91}H_{80}O_{23}Na$: 1594.5491, Found: 1594.54 (M^++23 for Na).

Prop-2-ynyl 2,3,4-tri-*O*-benzyl-6-*O*-(2,3,6-tri-*O*-benzoyl)-4-*O*-(2,3,4,6-tetra-*O*-benzoyl-β-D-galactopyranosyl)-β-D-glucopyranosyl)-α-mannopyranoside (44) :

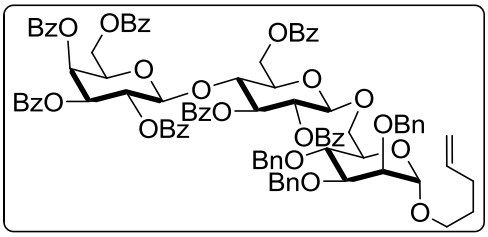


$[\alpha]_D$ ($CHCl_3$, *c* 1.0) = +51.1; ^{1}H NMR (200.13 MHz, $CDCl_3$): δ 2.35(t, 1H, *J* = 2.3Hz), 3.60-3.98(m, 10H), 4.10-4.52(m, 7H), 4.53-4.78(m, 4H), 4.80-4.97(m, 3H), 5.43(dd, 1H, *J* = 3.2, 10.3Hz), 5.59(dd, 1H, *J* = 7.9, 10.0Hz), 5.70-5.95(m, 3H), 7.01-7.65(m, 36H), 7.70-8.04(m, 14H); ^{13}C NMR (50.32 MHz, $CDCl_3$): δ 53.5, 60.9, 62.2, 67.3, 69.0, 69.7, 71.2, 71.6, 71.6, 71.6, 72.4, 72.7, 72.7, 73.8, 74.5, 74.6, 74.6, 74.7, 75.8, 78.5, 79.7, 95.6, 100.7, 101.3, 127.1-129.8, 132.8, 132.9, 133.1, 133.1, 133.2, 133.2, 133.3, 137.8, 138.0, 138.1, 164.6, 164.9, 165.0, 165.2, 165.2, 165.3, 165.6; HRMS(MALDI-TOF) calculated for $C_{91}H_{80}O_{23}Na$: 1564.5022, Found: 1564.5022.

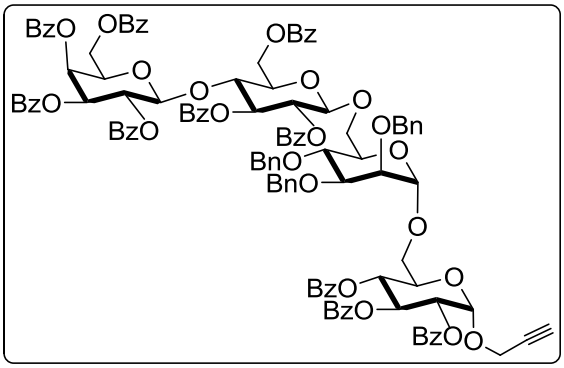
Pent-4-enyl 2,3,4-tri-*O*-benzoyl-6-*O*-(2,3,4-tri-*O*-benzyl)-6-*O*-(2,3,6-tetra-*O*-benzoyl)-4-O-(2,3,4,6-tetra-O-benzoyl-β-D-galactopyranosyl)-β-D-glucopyranosyl)-α-manno-pyranosyl)-α-glucopyranoside (45) : $[\alpha]_D$ ($CHCl_3$, *c* 1.6) = +38.6; ^1H NMR (200.13 MHz, $CDCl_3$): δ 1.60(m, 2H), 1.97(m, 2H), 3.26(dd, 1H, J = 2.5, 11.5Hz), 3.35-3.60(m, 6H), 3.63-3.75(m, 4H), 3.85-3.90(m, 3H), 4.22(d, 2H, J = 10.0Hz), 4.36(ABq, 2H, J = 11.5Hz), 4.47(dd, 1H, J = 4.0, 12.3Hz), 4.54-4.62(m, 6H), 4.70(d, 2H, J = 8.6Hz), 4.80(dd, 1H, J = 1.5, 15.3Hz), 4.84(t, 1H, J = 8.0Hz), 5.35-5.51(m, 5H), 5.58-5.80(m, 5H), 7.06-7.63(m, 45H), 7.72-8.02(m, 20H); ^{13}C NMR (100.61 MHz, $CDCl_3$): δ 28.5, 29.8, 61.1, 62.4, 65.3, 67.5, 68.8, 69.3, 69.4, 69.9, 71.4, 71.8, 71.8, 71.9, 72.0, 72.4, 72.7, 72.8, 73.0, 73.2, 74.2, 74.6, 74.8, 76.0, 77.3, 80.0, 98.0, 101.0, 101.2, 101.5, 115.0, 127.5-130.0, 133.1, 133.2, 133.2, 133.2, 133.2, 133.3, 133.5, 133.5, 133.5, 133.6, 138.0, 138.4, 138.5, 138.6, 164.9, 164.9, 165.0, 165.2, 165.3, 165.5, 165.5, 165.6, 165.9, 165.9; Mol. Wt. calculated for $C_{118}H_{102}O_{31}Na$: 2069.1127, Found: 2069.12(M^++23 for Na).



Pent-4-enyl 2,3,4-tri-*O*-benzyl-6-*O*-(2,3,6-tri-*O*-benzoyl)-4-*O*-(2,3,4,6-tetra-*O*-benzoyl-β-D-galactopyranosyl)-β-D-glucopyranosyl)-α-mannopyranoside (46) : $[\alpha]_D$ ($CHCl_3$, *c* 2.5) = +42.2; ^1H NMR (200.13 MHz, $CDCl_3$): δ 1.29(m, 2H), 1.89(m, 2H), 2.94(m, 1H), 3.32(m, 1H), 3.55-3.93(m, 9H), 4.05-4.42(m, 3H), 4.45-4.75(m, 8H), 4.78-4.99(m, 4H), 5.30-5.88(m, 6H), 7.05-7.83(m, 36H), 7.81-8.15(m, 14H); ^{13}C NMR (50.32 MHz, $CDCl_3$): δ 28.2, 30.2, 61.0, 62.3, 66.3, 67.5, 69.2, 69.8, 71.2, 71.3, 71.7, 71.9, 71.9, 72.4, 72.8, 72.9, 74.3, 74.9, 75.9, 77.2, 80.1, 97.4, 100.9, 101.4, 114.6, 127.3-129.9, 132.9, 133.0, 133.2, 133.3, 133.4, 133.5, 133.5, 138.1, 138.2, 138.2, 138.3, 164.7, 165.0, 165.1, 165.3, 165.4, 165.5, 165.8; HRMS(MALDI-TOF) calculated for $C_{93}H_{86}O_{23}Na$: 1594.5491, Found: 1594.5451.



Prop-2-ynyl 2,3,4-tri-*O*-benzoyl-6-*O*-(2,3,4-tri-*O*-benzyl)-6-*O*-(2,3,6-tetra-*O*-benzoyl)-4-O-(2,3,4,6-tetra-O-benzoyl-β-D-galactopyranosyl)-β-D-glucopyranosyl)-α-manno-pyranosyl)-α-glucopyranoside (47) : $[\alpha]_D$ ($CHCl_3$, *c* 1.6) = +10.3; ^1H NMR (200.13 MHz, $CDCl_3$): δ 2.56(t, J = 2.3Hz, 1H), 3.34(dd, J = 3.6, 10.9Hz, 1H), 3.49-3.57(m, 2H), 3.61(t, J = 9.3Hz, 2H), 3.65-3.75(m, 5H), 3.87(t, J = 6.5Hz, 1H), 3.93(d, J = 9.1, 1H), 3.98(dd, J = 3.6, 13.3Hz, 1H), 4.21-4.32(m, 6H), 4.45(dd, J = 3.7, 12.0Hz, 1H), 4.51(d, J = 2.0Hz, 2H), 4.56(d, J = 11.0Hz, 2H), 4.66(d, J = 7.7Hz, 1H), 4.74(d, J = 1.2Hz, 1H), 4.84(d, J = 8.0Hz, 1H), 5.19(d, J = 1.4Hz, 1H), 5.35(dd, J = 3.3, 10.3Hz, 1H), 5.45(dd, J = 8.0, 9.9, 1H), 5.63(dd, J = 1.7, 3.1Hz, 1H), 5.70-5.75(m, 2H), 5.76(dd, J = 2.9, 10.2Hz, 2H), 5.92(t, J = 10.2, 1H), 7.08-7.64(m, 45H), 7.72-8.07(m, 20H); ^{13}C NMR (100.61 MHz, $CDCl_3$): δ55.3, 61.1, 62.4, 66.0, 67.3, 67.5, 69.0, 69.7, 69.9, 70.0, 70.5, 71.2, 71.4, 71.7, 71.8, 72.4, 72.9, 73.0, 74.5, 74.6, 74.8, 76.0, 76.0, 78.3, 80.1, 96.3, 98.0, 101.0, 101.5, 127.4-130.0, 133.0, 133.2, 133.2, 133.2, 133.3, 133.4, 133.5, 133.5, 133.6, 133.6, 138.5, 138.5, 138.5, 164.9, 165.0, 165.2, 165.3, 165.4, 165.5, 165.5, 165.5, 165.6, 165.9; Mol. Wt. calculated for $C_{118}H_{102}O_{31}Na$: 2039.0436, Found: 2039.12 (M^++23 for Na).

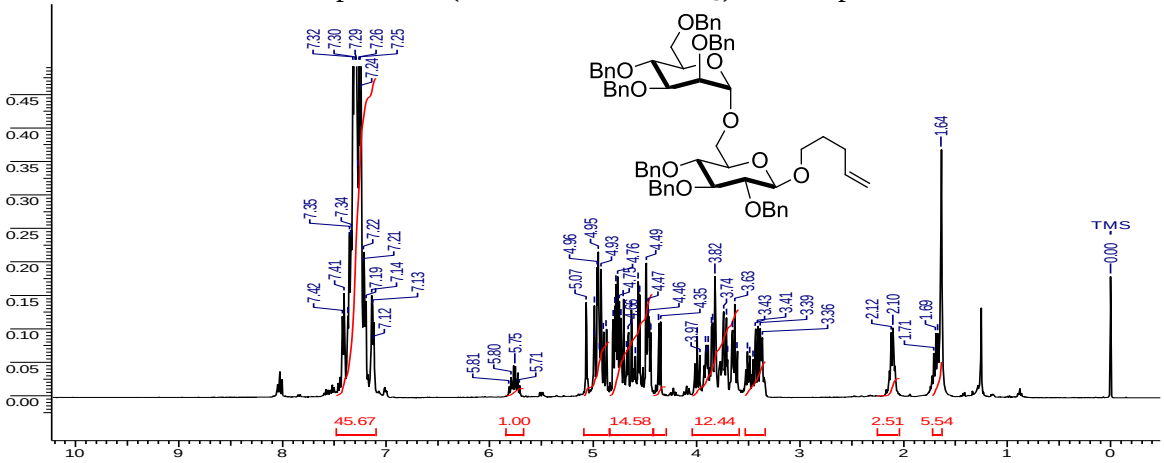


****

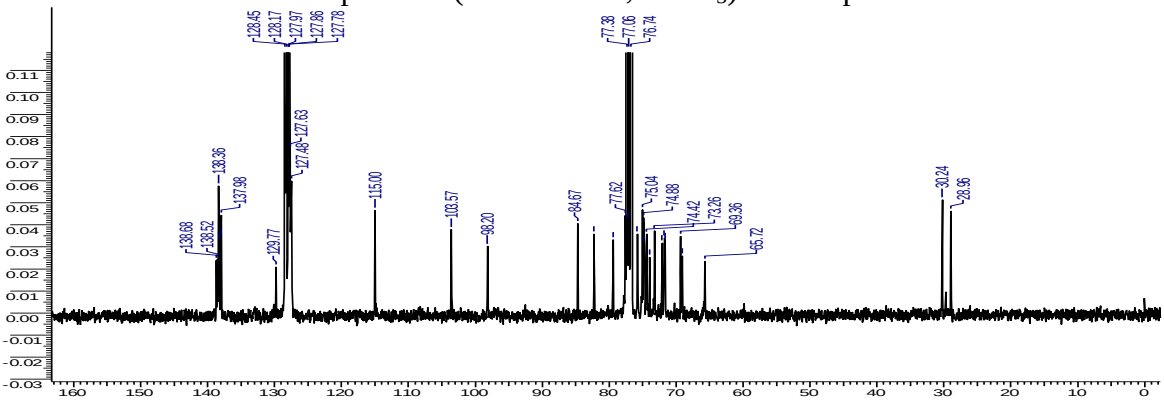
Chapter 1: Spectral charts

(For full characterization data and spectral charts, see reference: ***J. Org. Chem***. **2009**, 9233-9236)

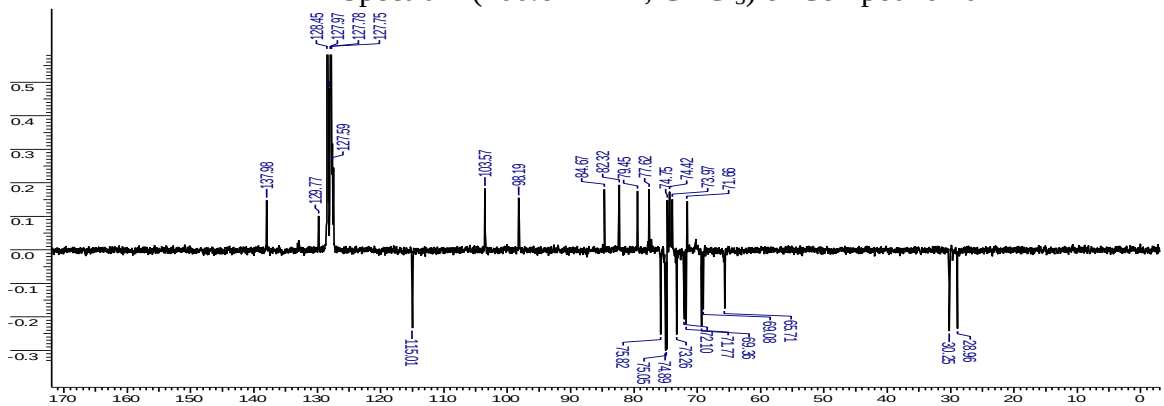
^{1}H NMR Spectrum (400.13 MHz, $CDCl_3$) of Compound **7a**



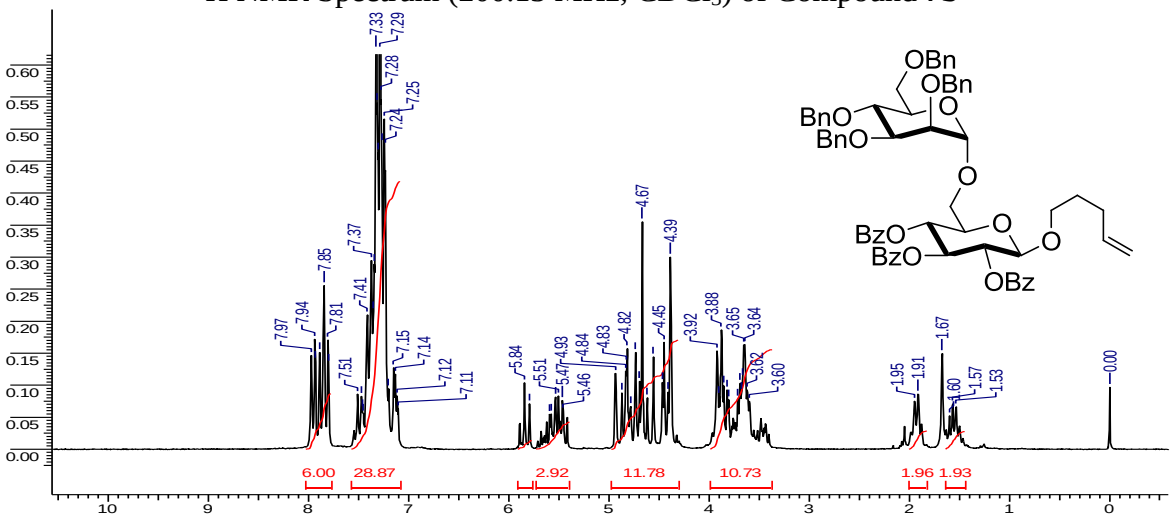
^{13}C NMR Spectrum (100.61 MHz, $CDCl_3$) of Compound **7a**



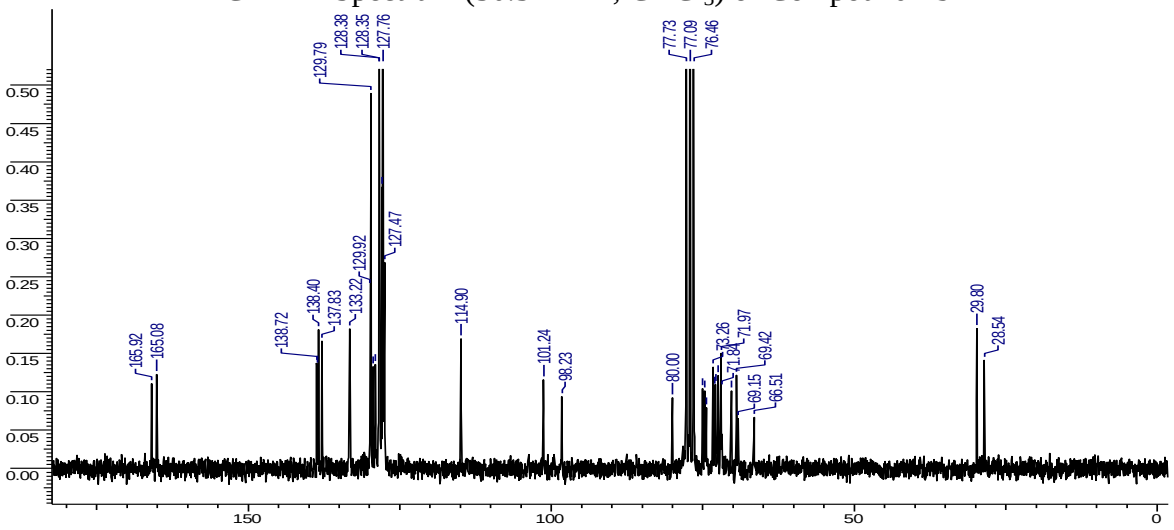
DEPT NMR Spectrum (100.61 MHz, $CDCl_3$) of Compound **7a**



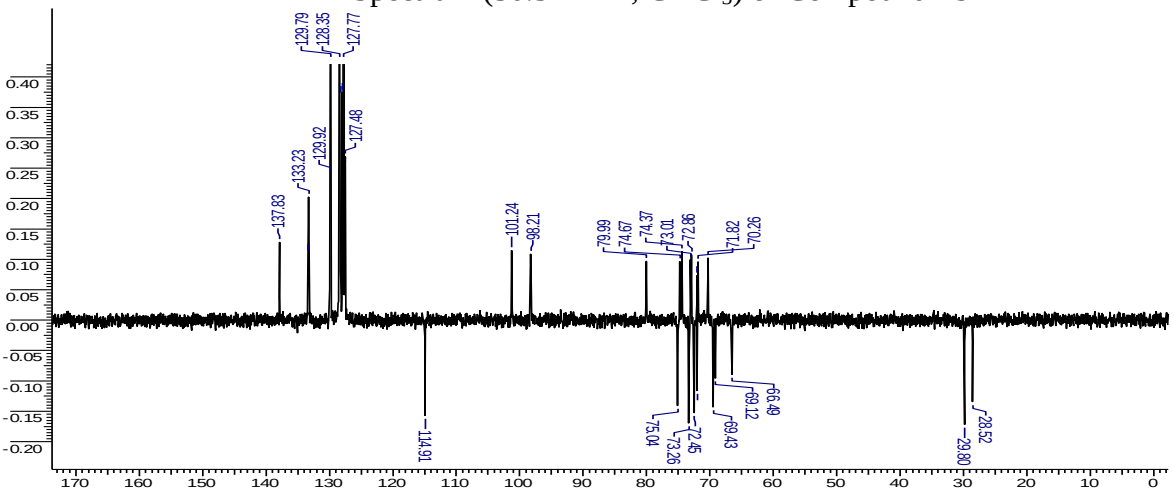
^{1}H NMR Spectrum (200.13 MHz, $CDCl_3$) of Compound **7b**



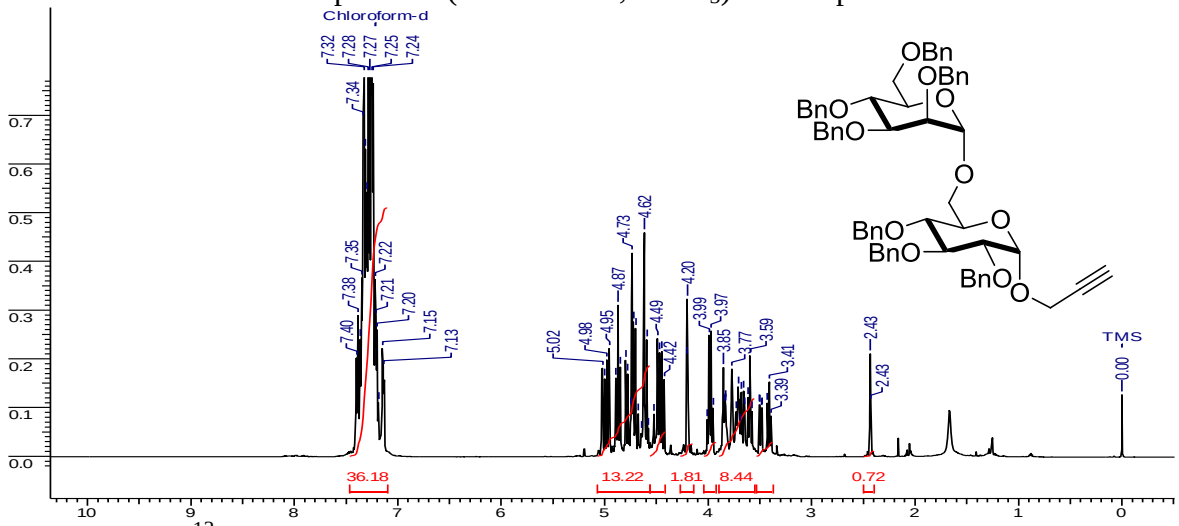
^{13}C NMR Spectrum (50.32MHz, $CDCl_3$) of Compound **7b**



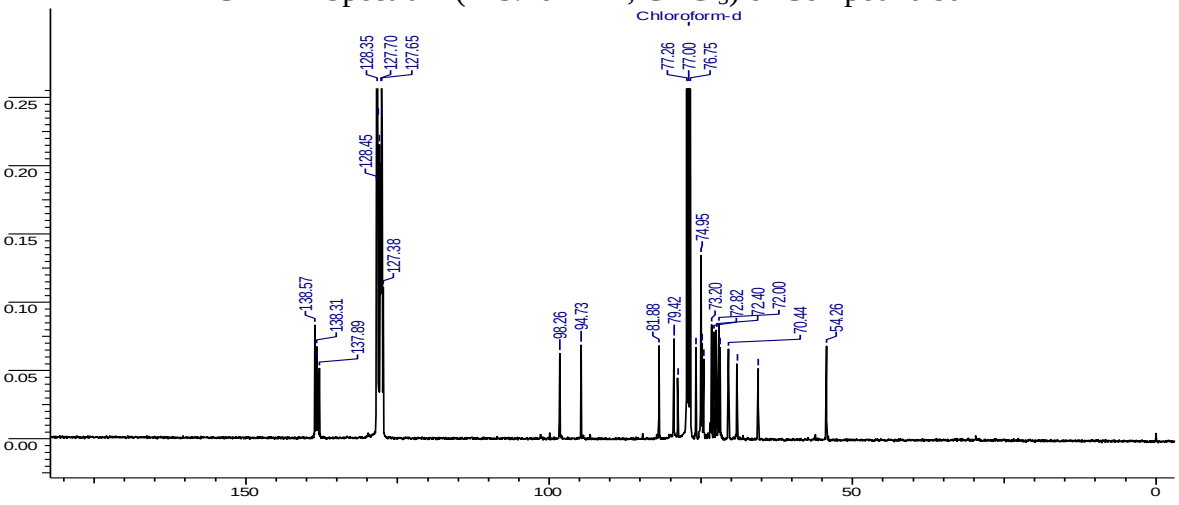
DEPT NMR Spectrum (50.32MHz, $CDCl_3$) of Compound **7b**



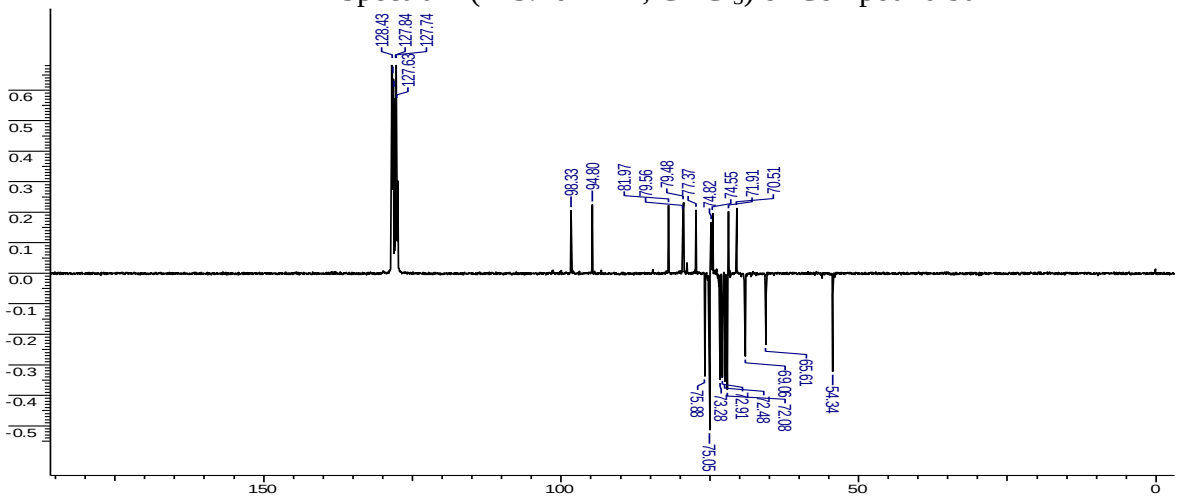
^{1}H NMR Spectrum (500.13 MHz, $CDCl_3$) of Compound **9a**



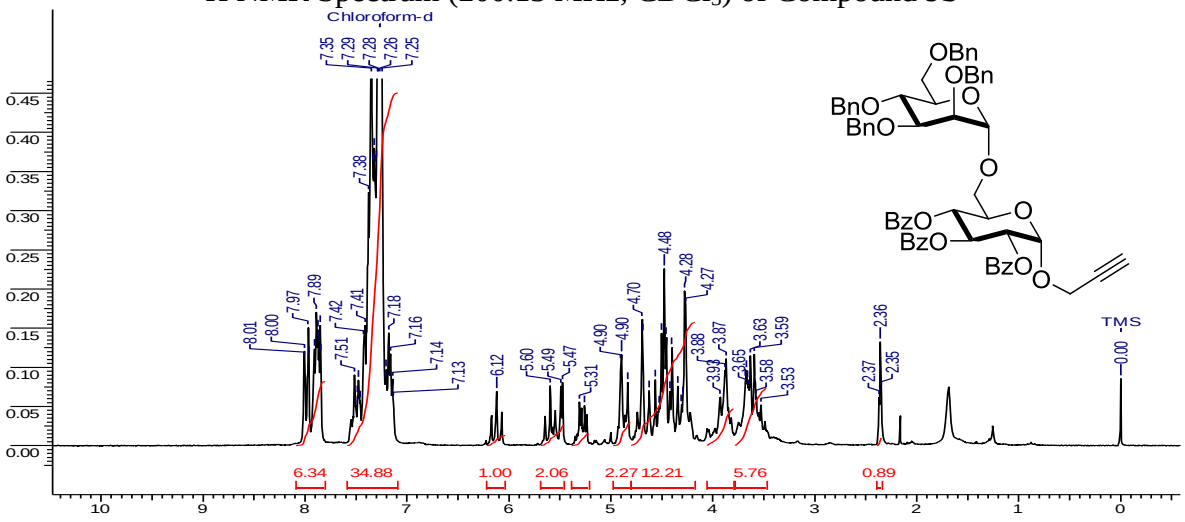
^{13}C NMR Spectrum (125.76 MHz, $CDCl_3$) of Compound **9a**



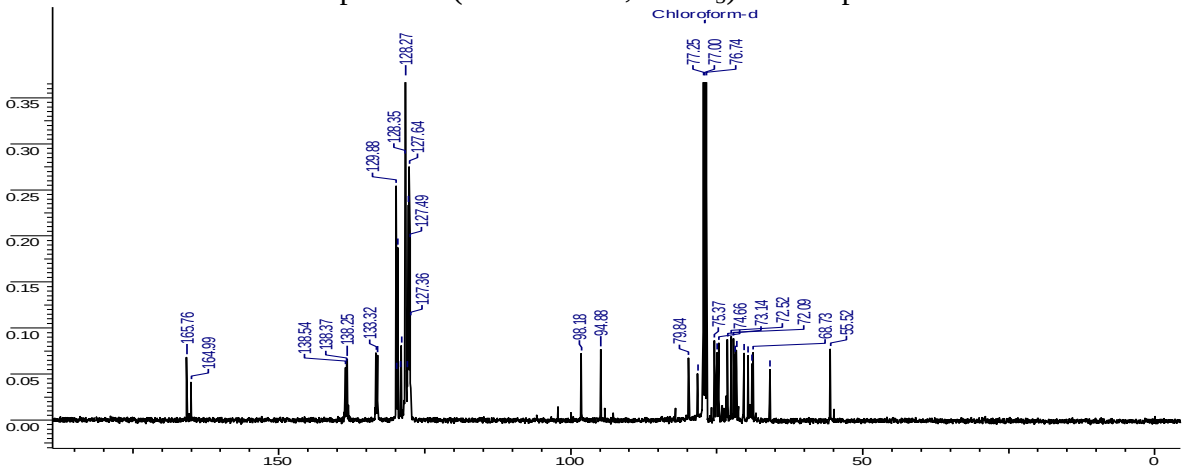
DEPT NMR Spectrum (125.76 MHz, $CDCl_3$) of Compound **9a**



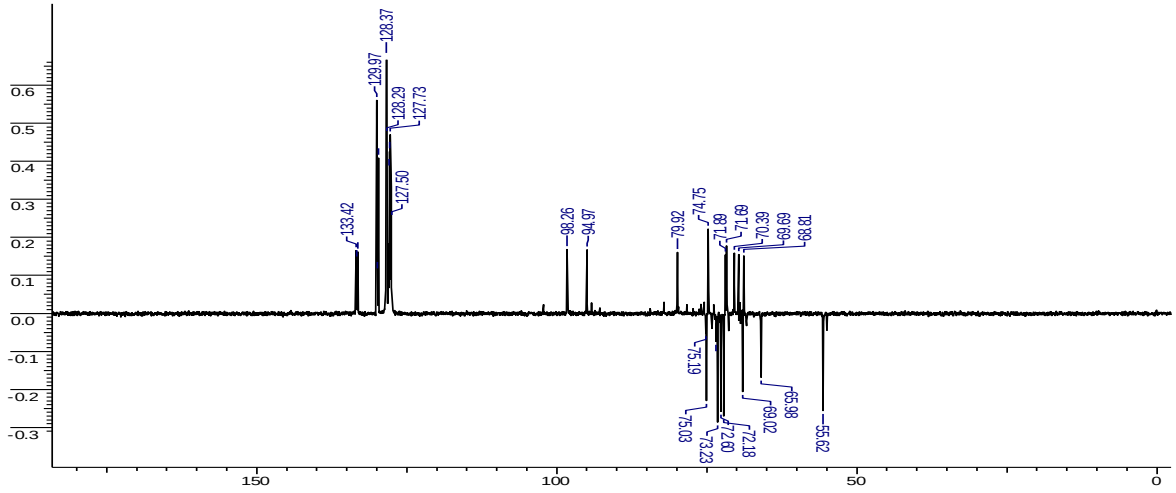
^{1}H NMR Spectrum (200.13 MHz, $CDCl_3$) of Compound **9b**



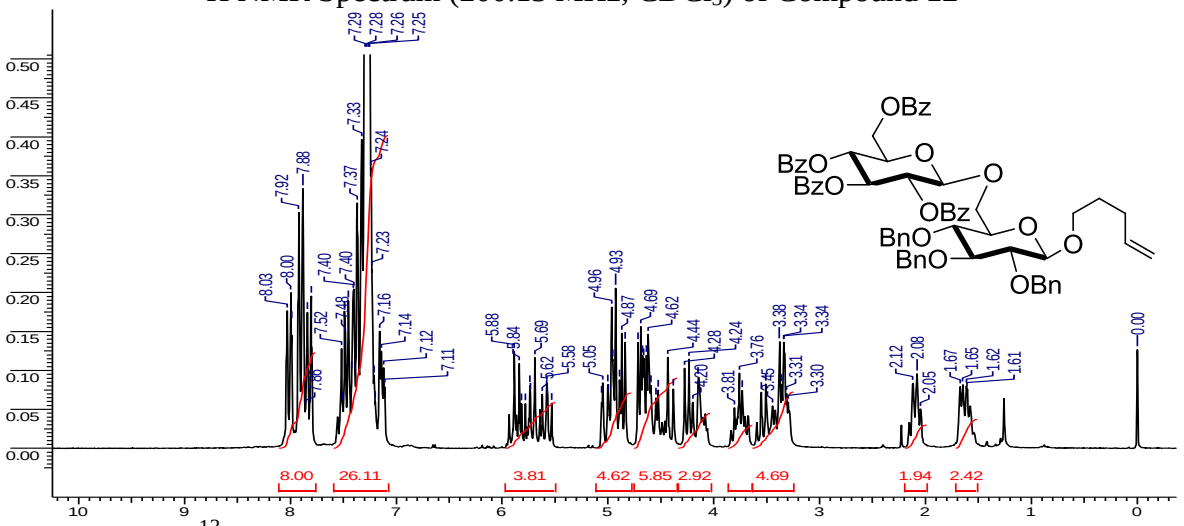
^{13}C NMR Spectrum (125.76 MHz, $CDCl_3$) of Compound **9b**



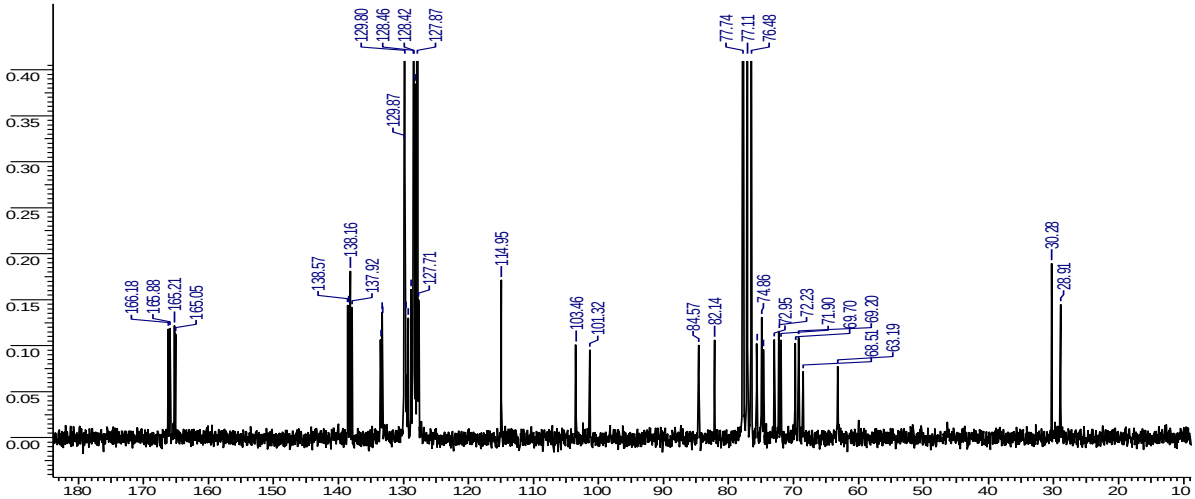
DEPT NMR Spectrum (125.76 MHz, $CDCl_3$) of Compound **9b**



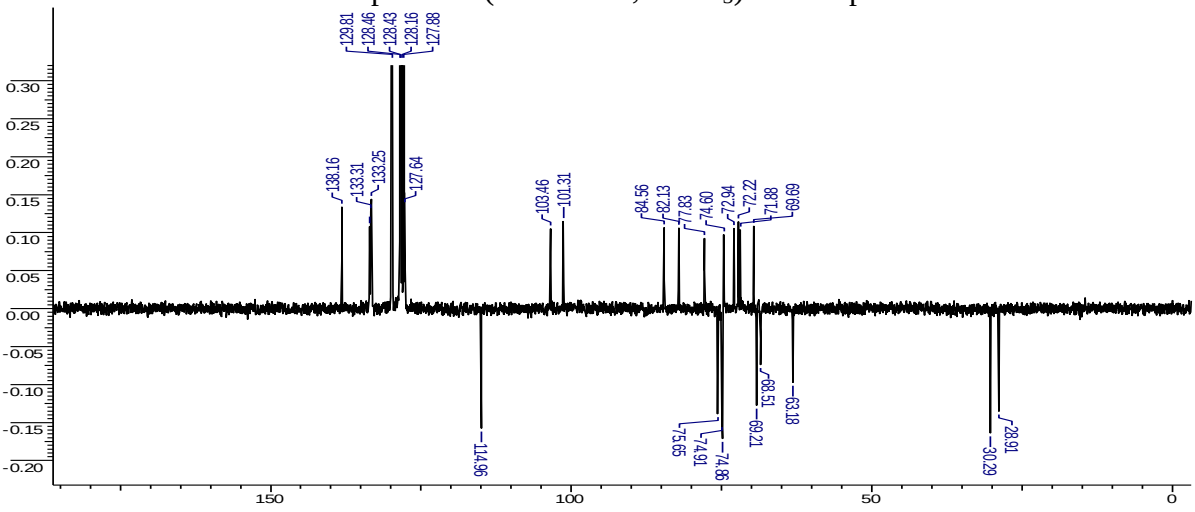
^{1}H NMR Spectrum (200.13 MHz, $CDCl_3$) of Compound **12**



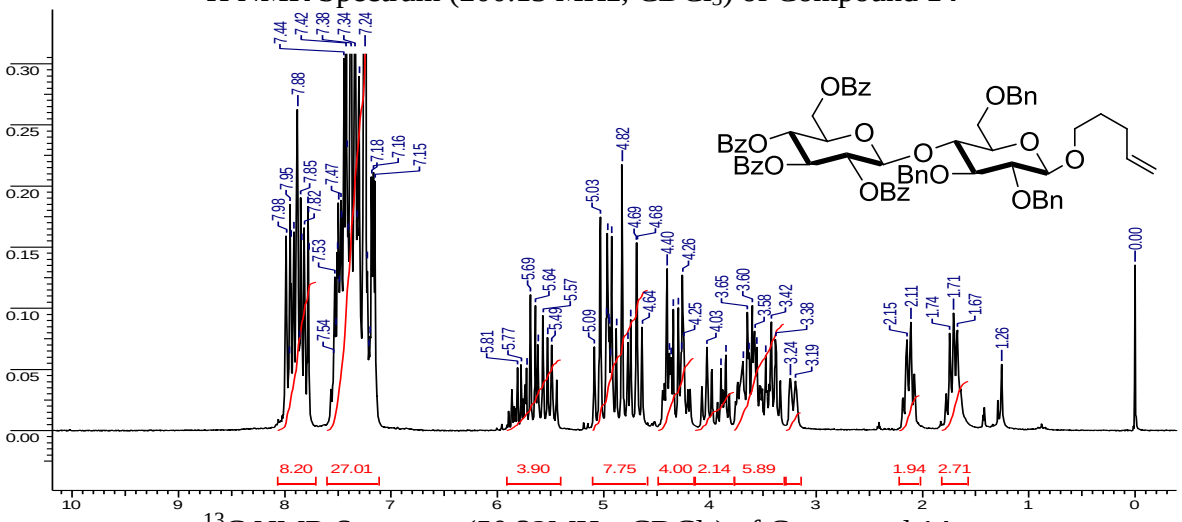
^{13}C NMR Spectrum (50.32 MHz, $CDCl_3$) of Compound **12**



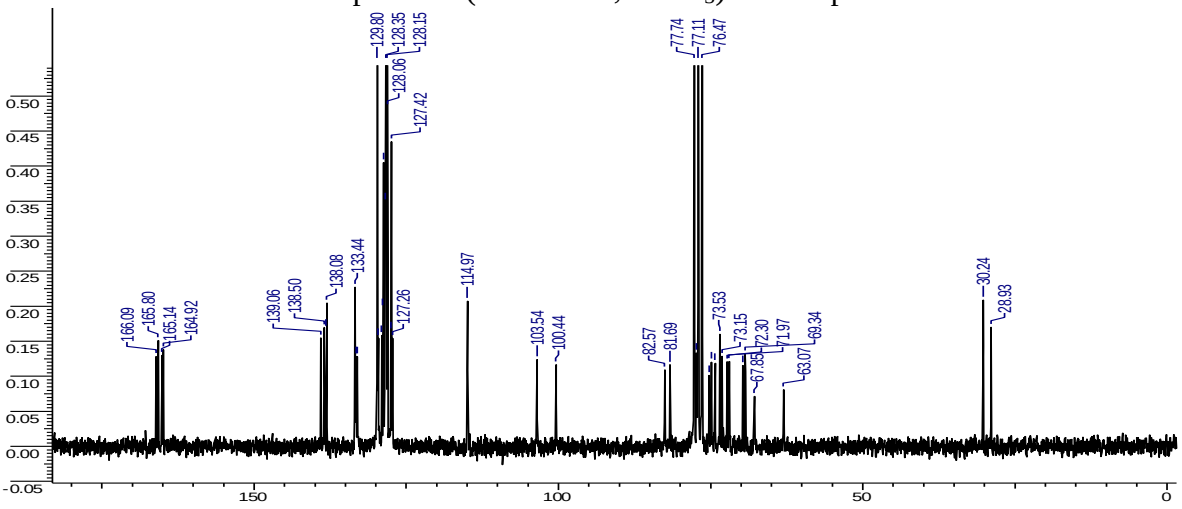
DEPT NMR Spectrum (50.32MHz, $CDCl_3$) of Compound **12**



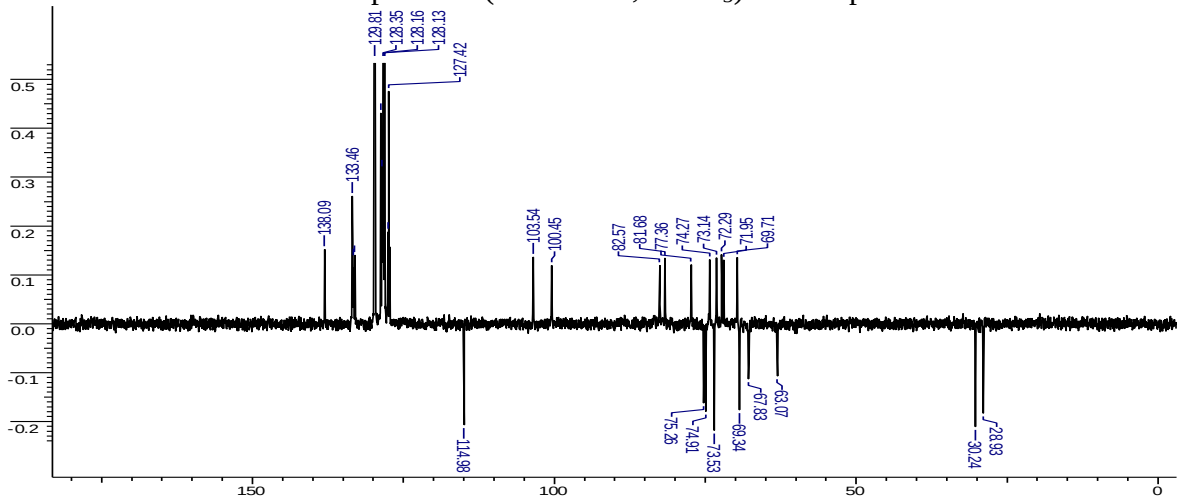
^{1}H NMR Spectrum (200.13 MHz, $CDCl_3$) of Compound **14**



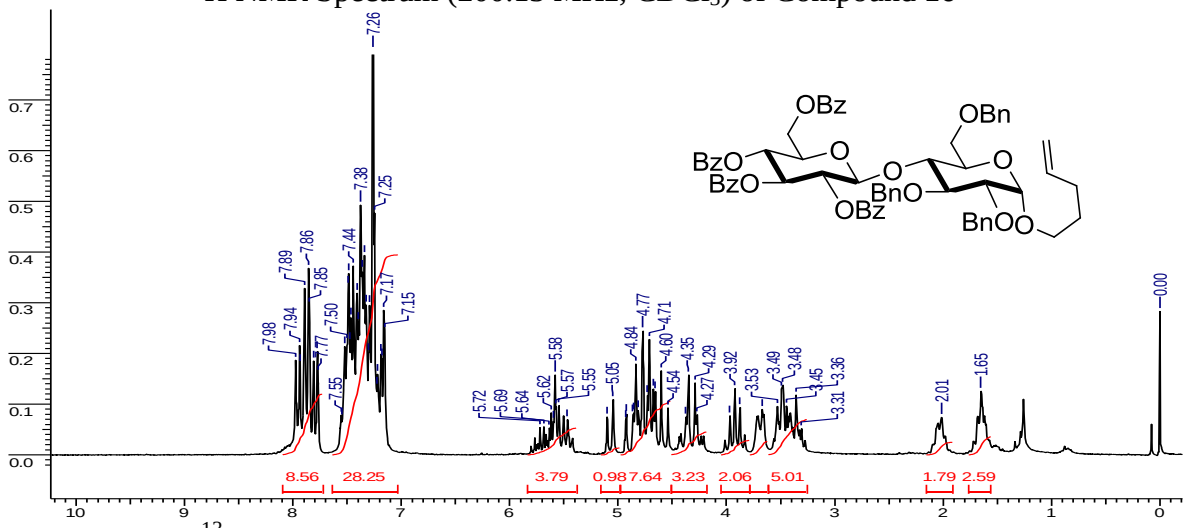
^{13}C NMR Spectrum (50.32MHz, $CDCl_3$) of Compound **14**



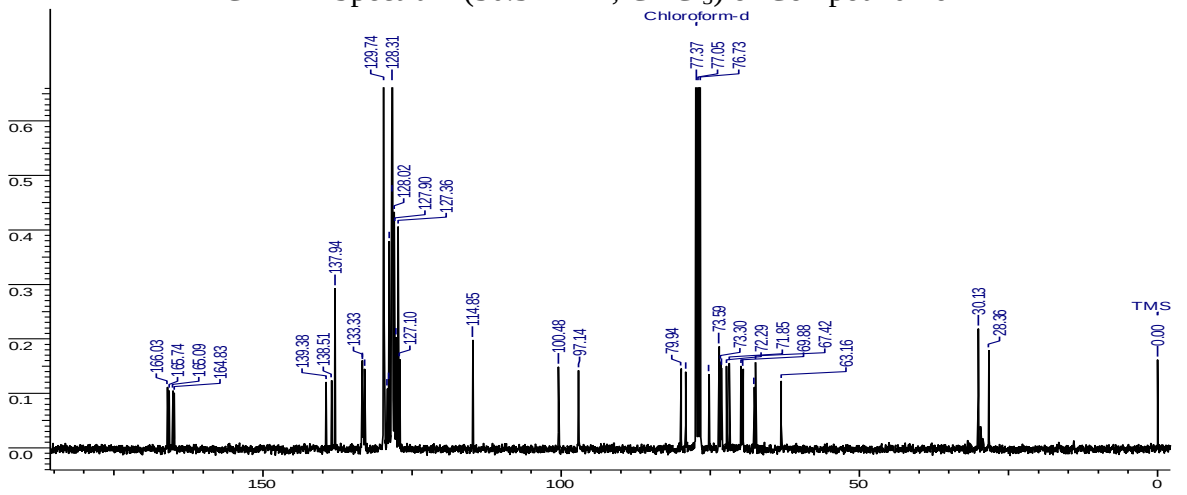
DEPT NMR Spectrum (50.32MHz, $CDCl_3$) of Compound **14**



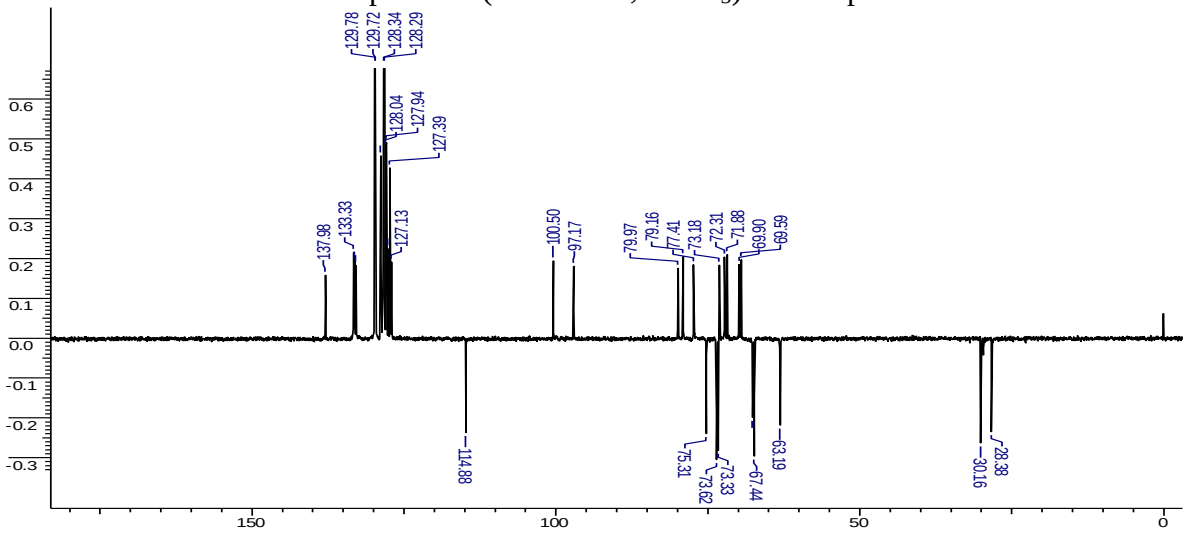
^{1}H NMR Spectrum (200.13 MHz, $CDCl_3$) of Compound **16**



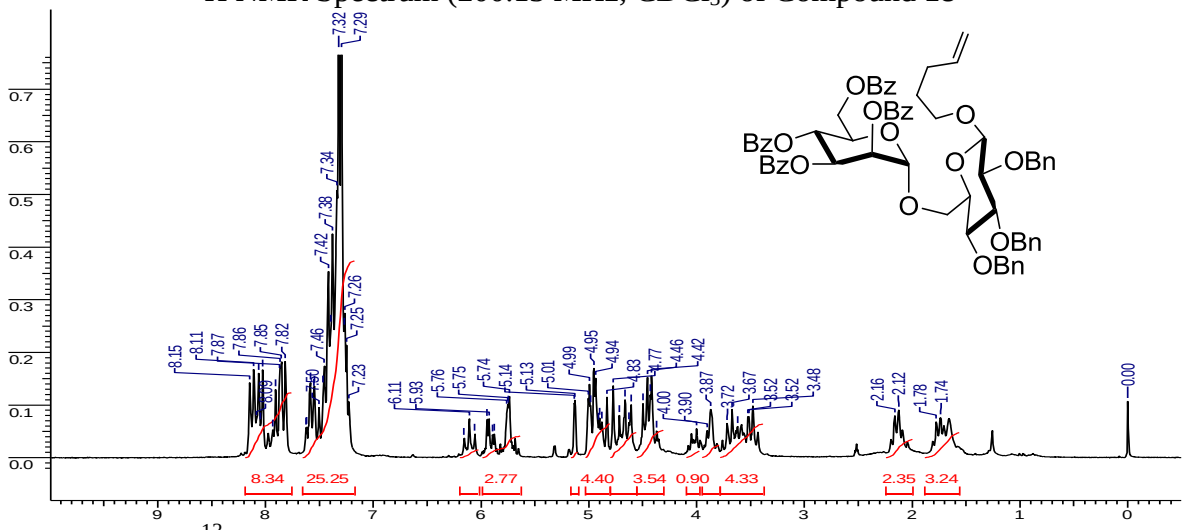
^{13}C NMR Spectrum (50.32MHz, $CDCl_3$) of Compound **16**



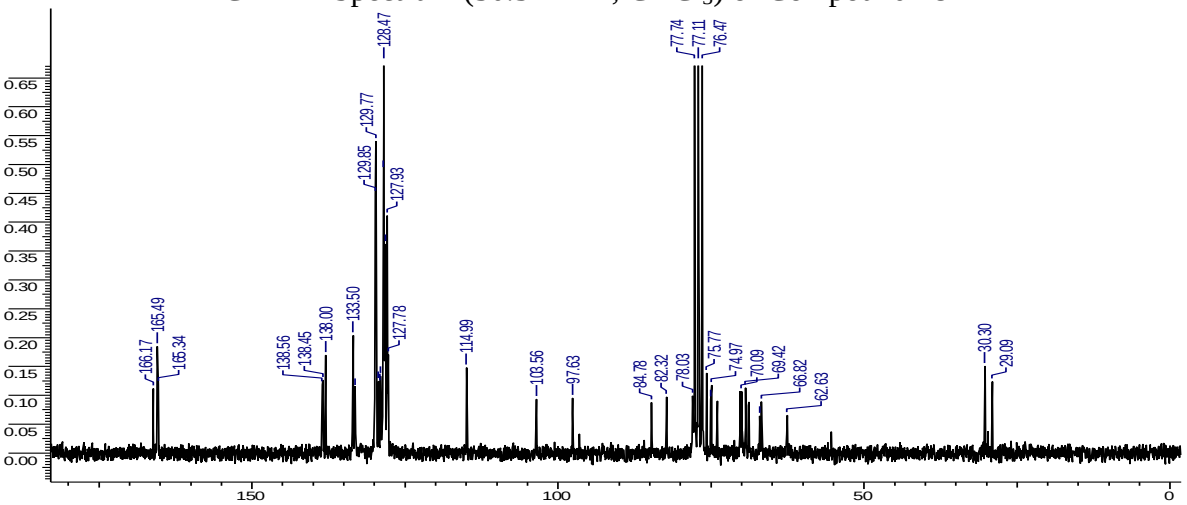
DEPT NMR Spectrum (50.32MHz, $CDCl_3$) of Compound **16**



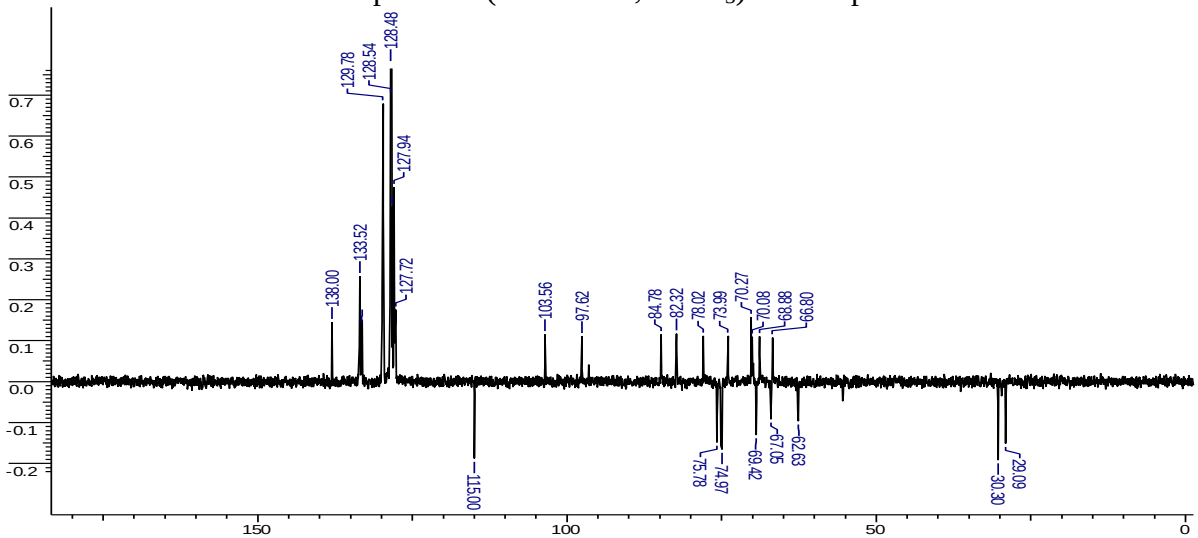
^{1}H NMR Spectrum (200.13 MHz, $CDCl_3$) of Compound **18**



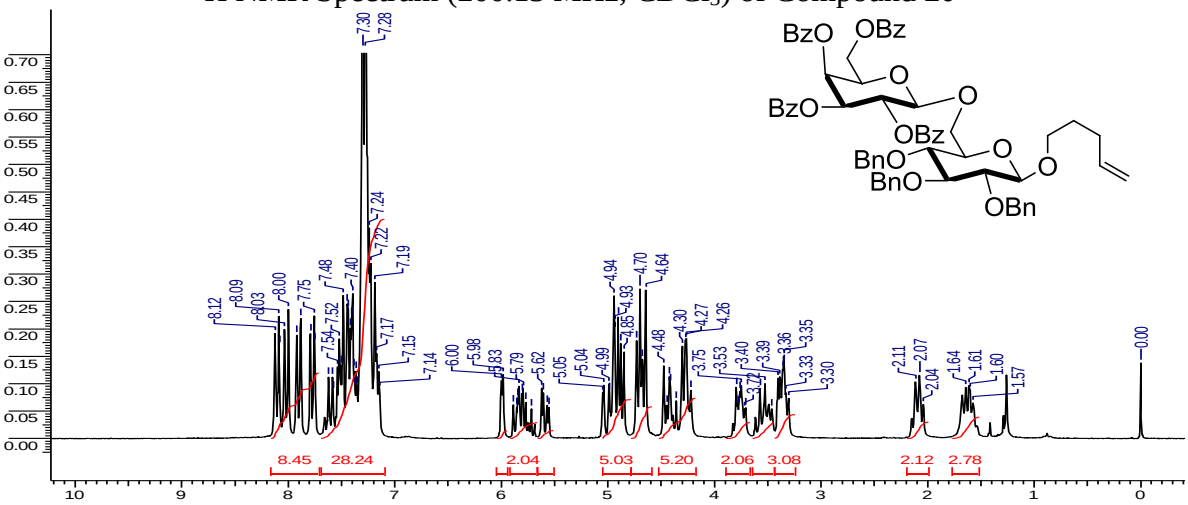
^{13}C NMR Spectrum (50.32MHz, $CDCl_3$) of Compound **18**



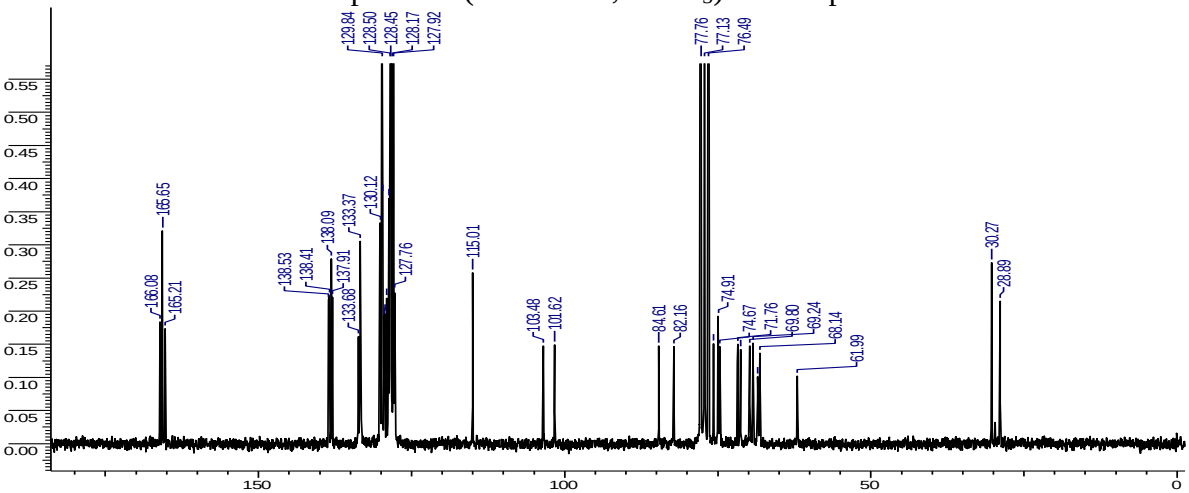
DEPT NMR Spectrum (50.32MHz, $CDCl_3$) of Compound **18**



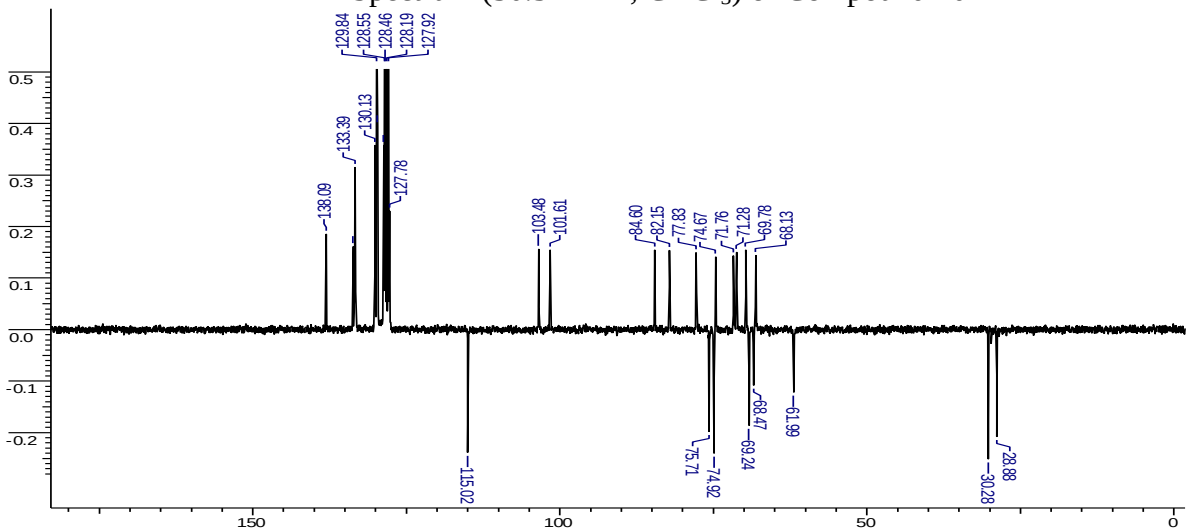
^{1}H NMR Spectrum (200.13 MHz, $CDCl_3$) of Compound **20**



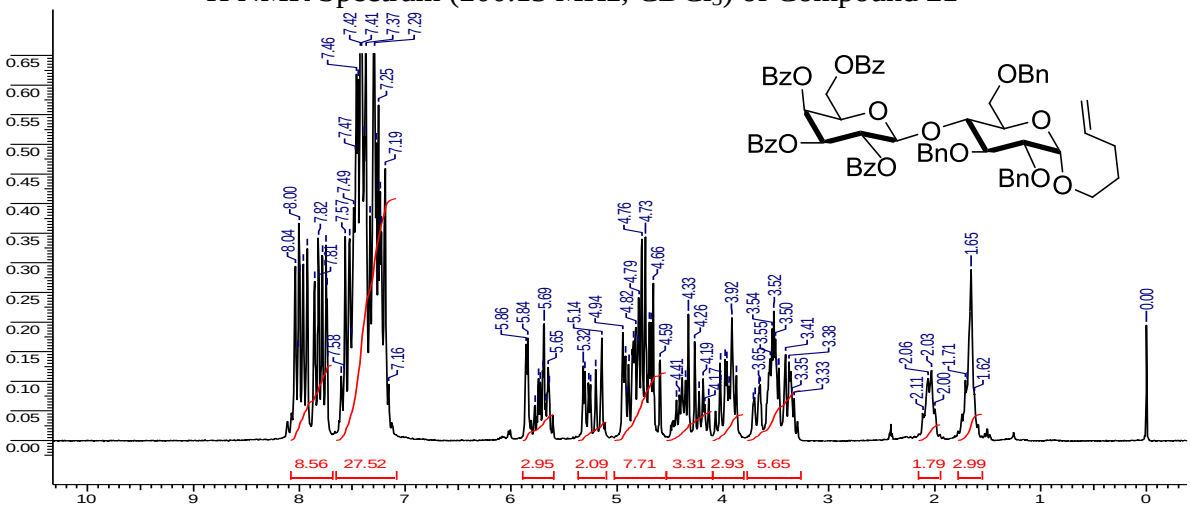
^{13}C NMR Spectrum (50.32MHz, $CDCl_3$) of Compound **20**



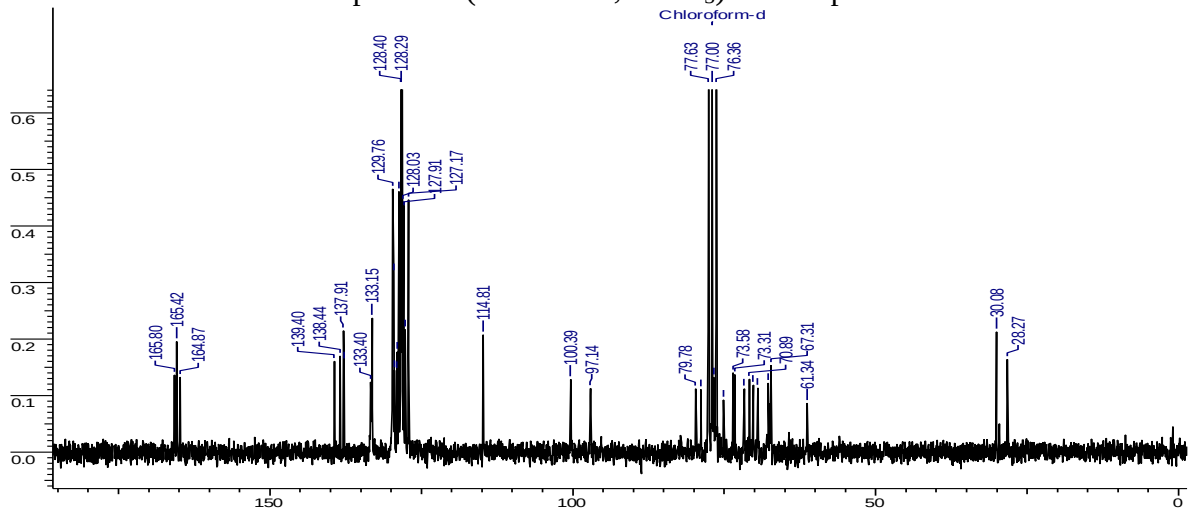
DEPT NMR Spectrum (50.32MHz, $CDCl_3$) of Compound **20**



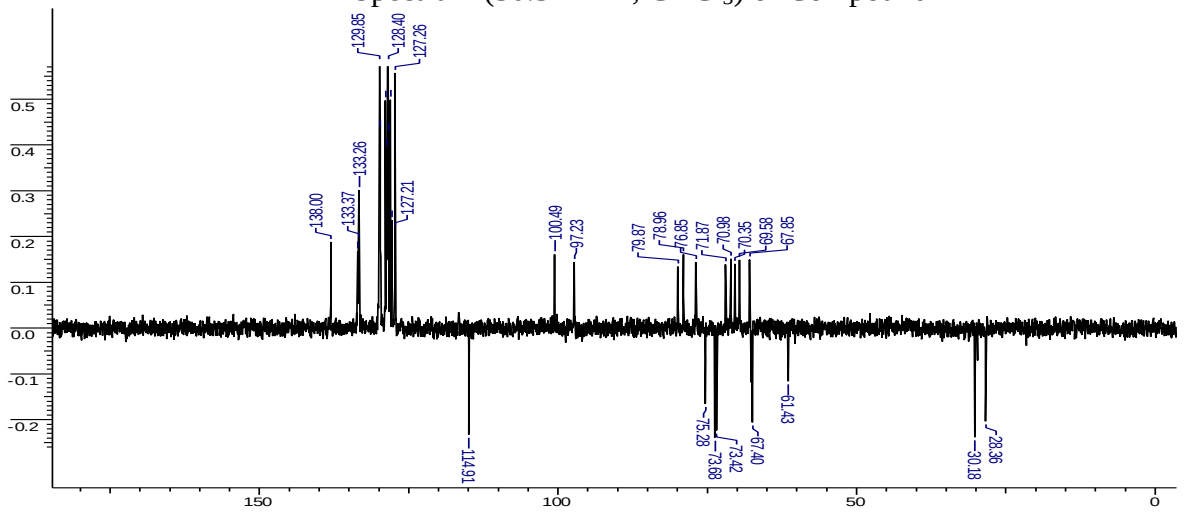
^{1}H NMR Spectrum (200.13 MHz, $CDCl_3$) of Compound **21**



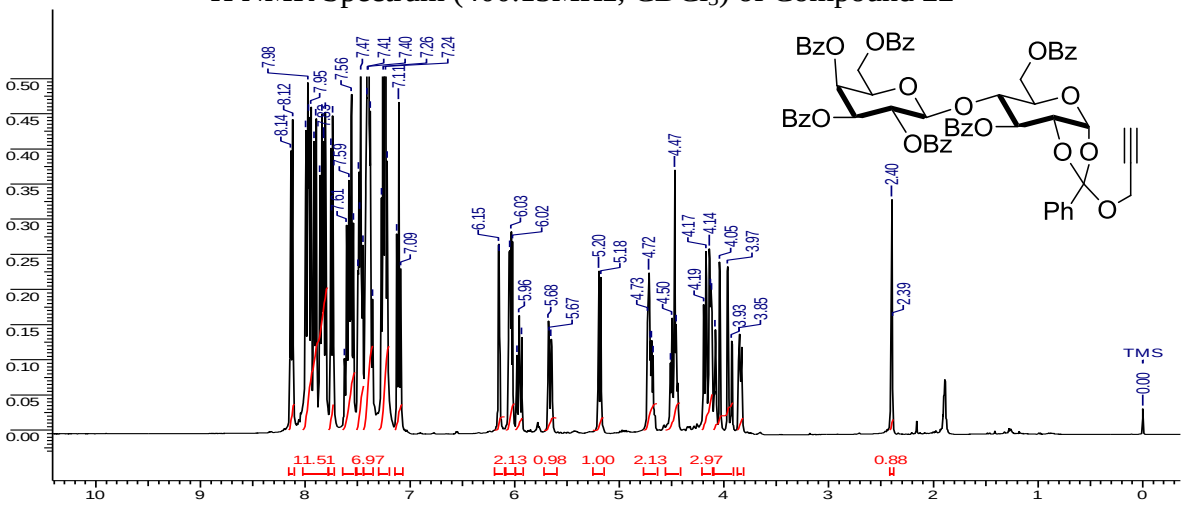
^{13}C NMR Spectrum (50.32MHz, $CDCl_3$) of Compound **21**



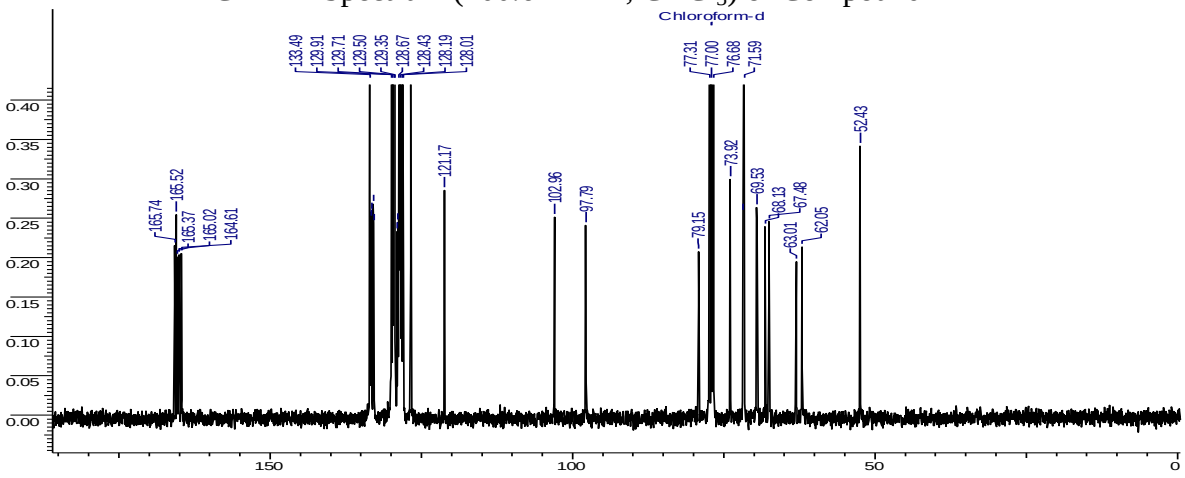
DEPT NMR Spectrum (50.32MHz, $CDCl_3$) of Compound **21**



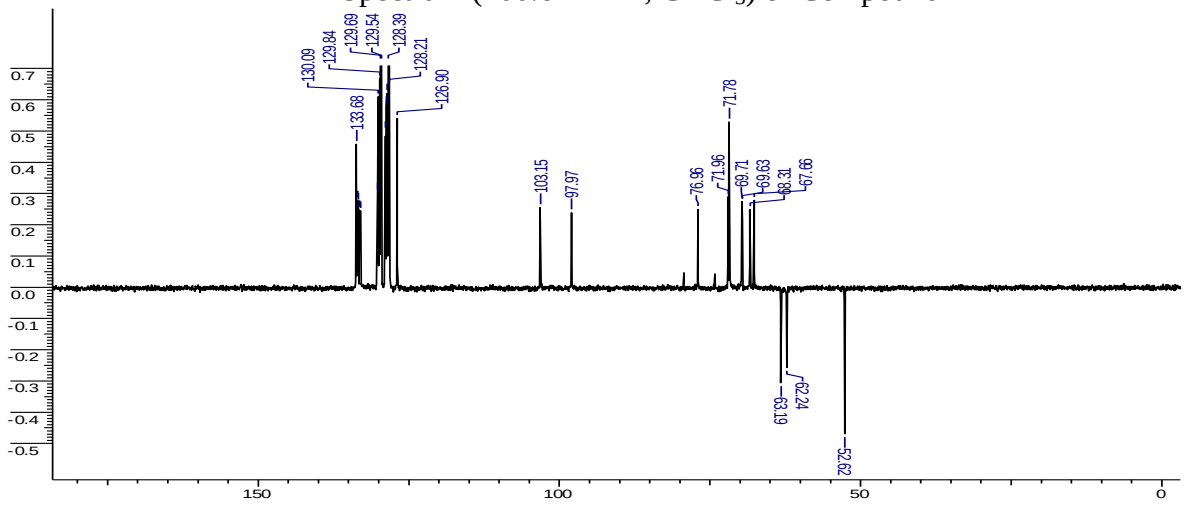
^{1}H NMR Spectrum (400.13MHz, $CDCl_3$) of Compound **22**



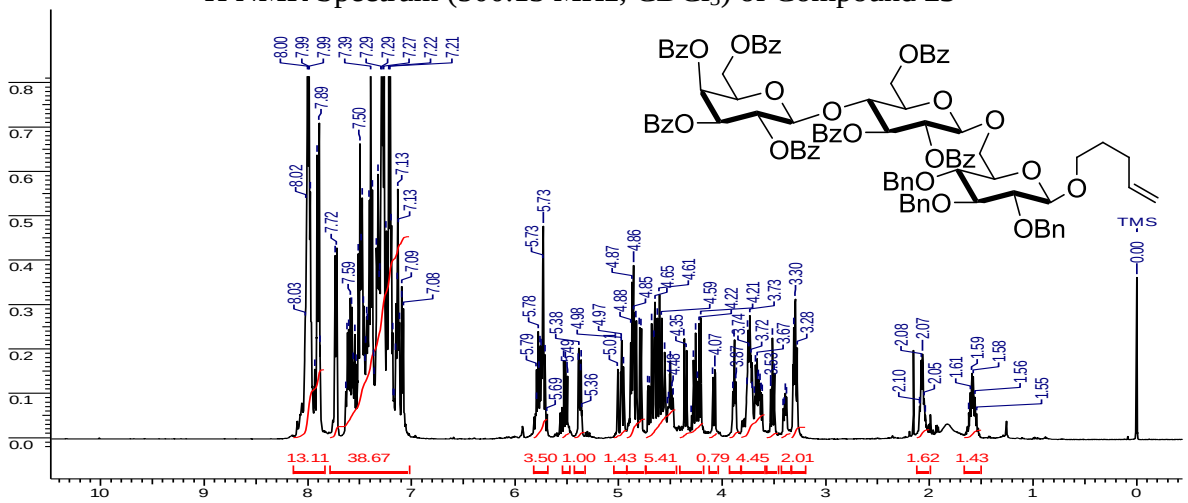
^{13}C NMR Spectrum (100.61 MHz, $CDCl_3$) of Compound **22**



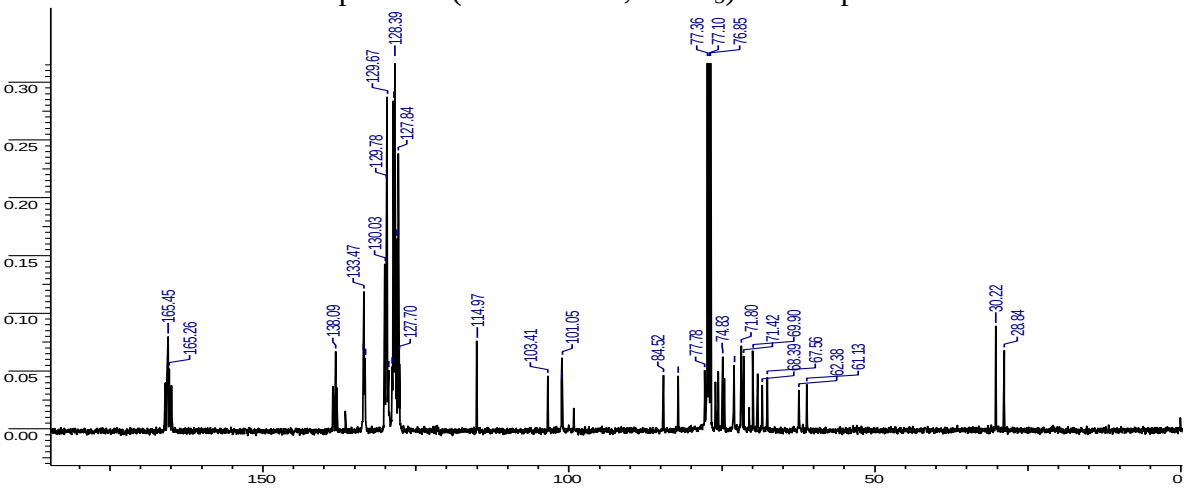
DEPT NMR Spectrum (100.61 MHz, $CDCl_3$) of Compound **22**



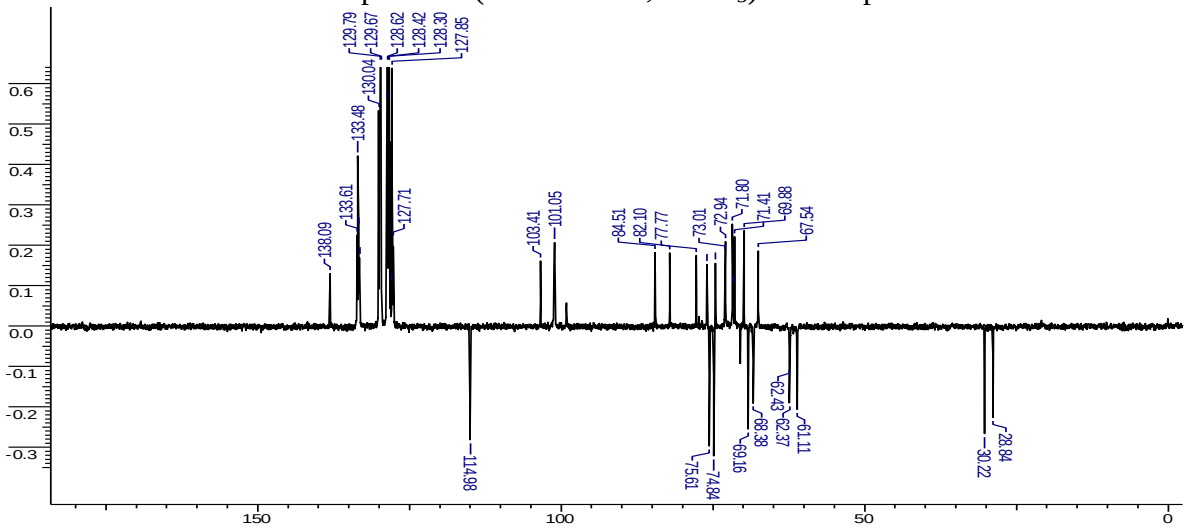
^{1}H NMR Spectrum (500.13 MHz, $CDCl_3$) of Compound **23**



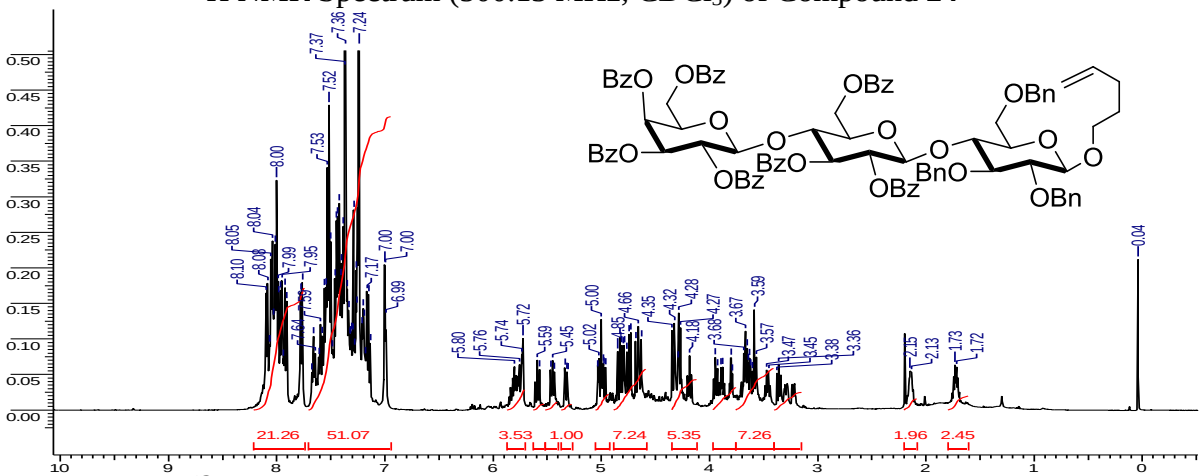
^{13}C NMR Spectrum (125.76 MHz, $CDCl_3$) of Compound **23**



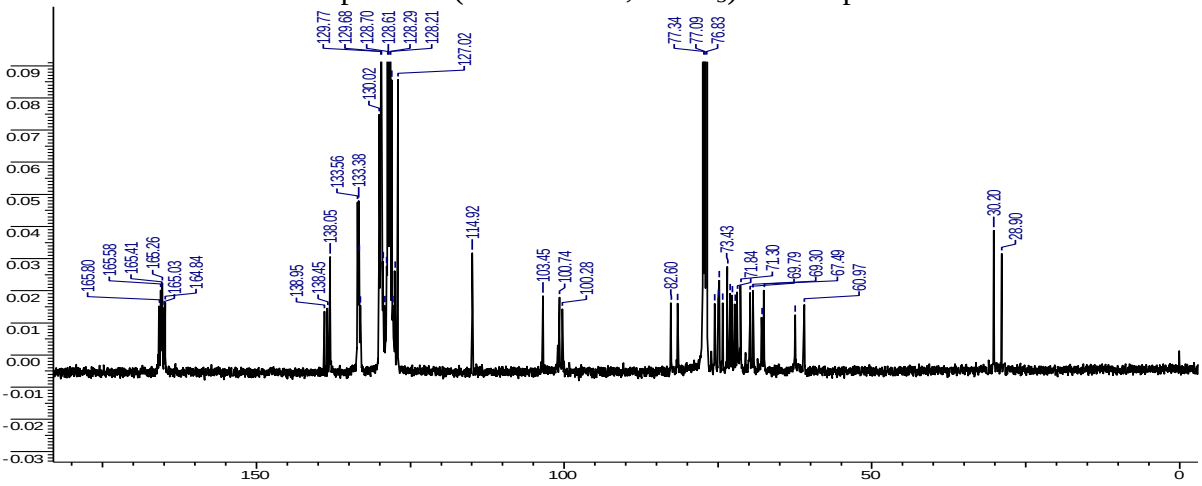
DEPT NMR Spectrum (125.76 MHz, $CDCl_3$) of Compound **23**



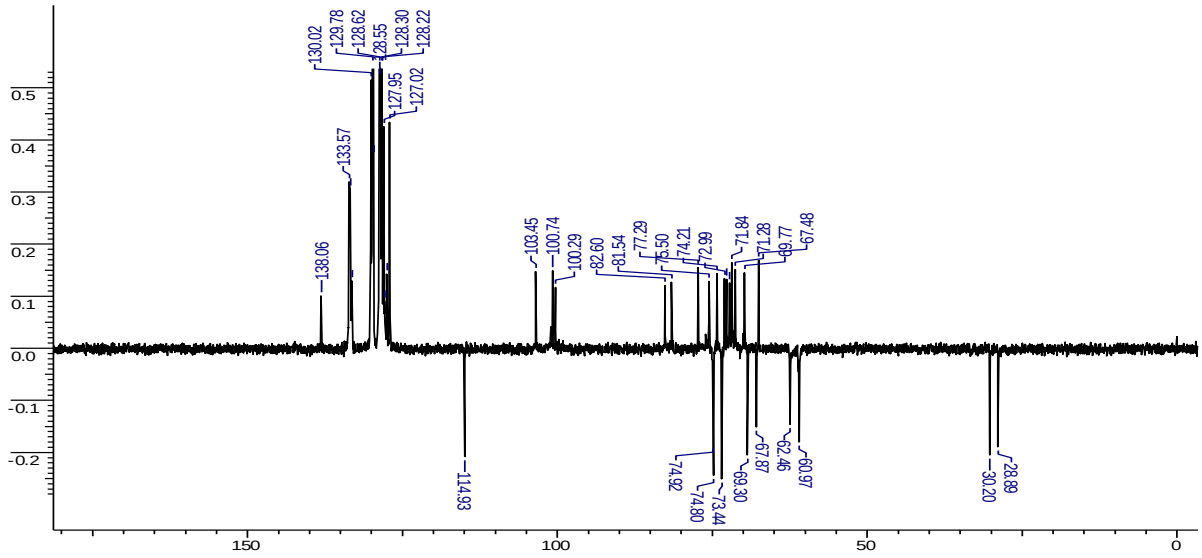
^{1}H NMR Spectrum (500.13 MHz, $CDCl_3$) of Compound **24**



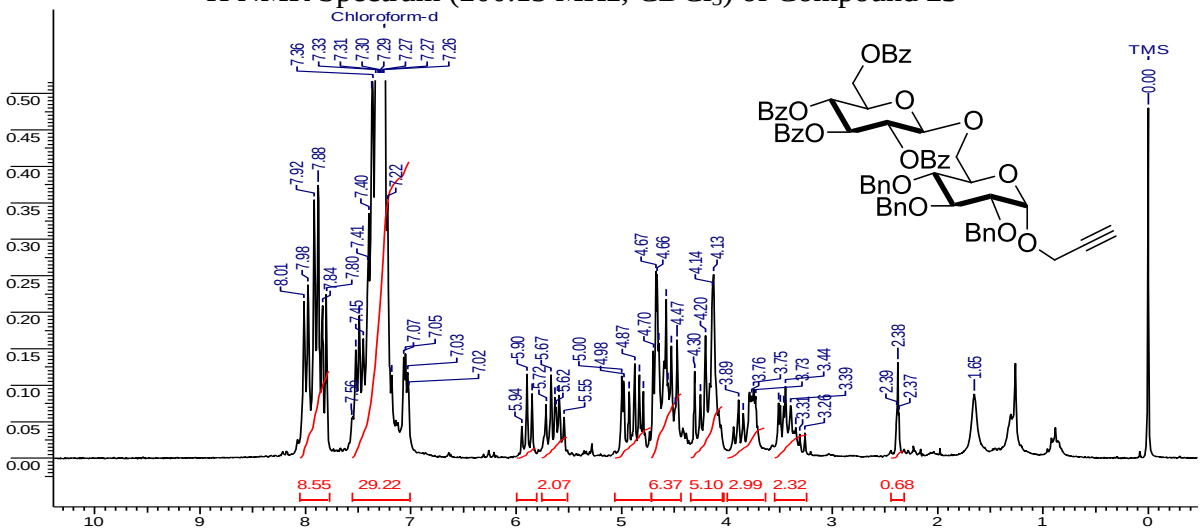
^{13}C NMR Spectrum (125.76 MHz, $CDCl_3$) of Compound **24**



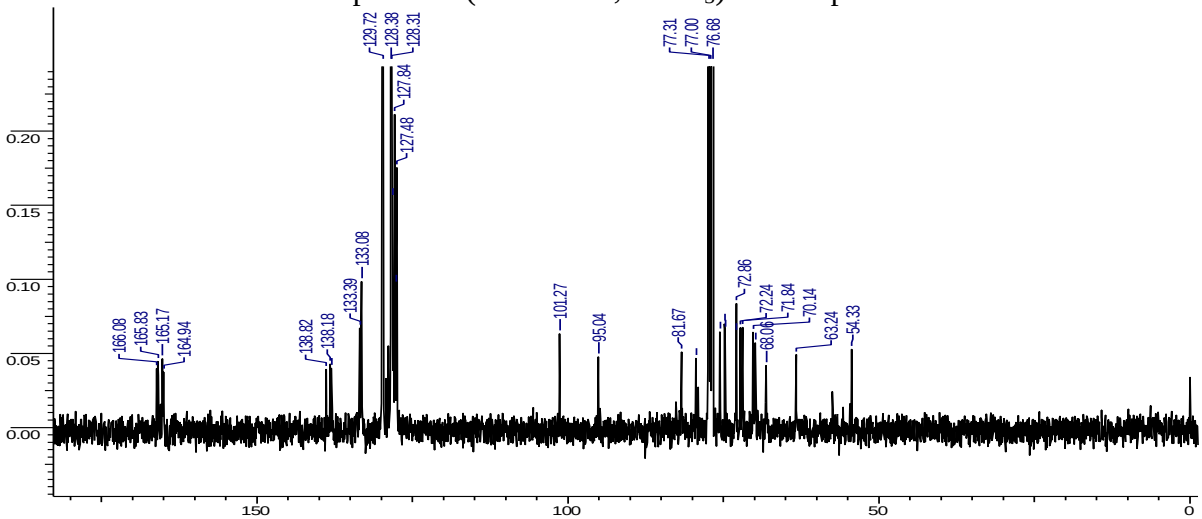
DEPT NMR Spectrum (125.76 MHz, $CDCl_3$) of Compound **24**



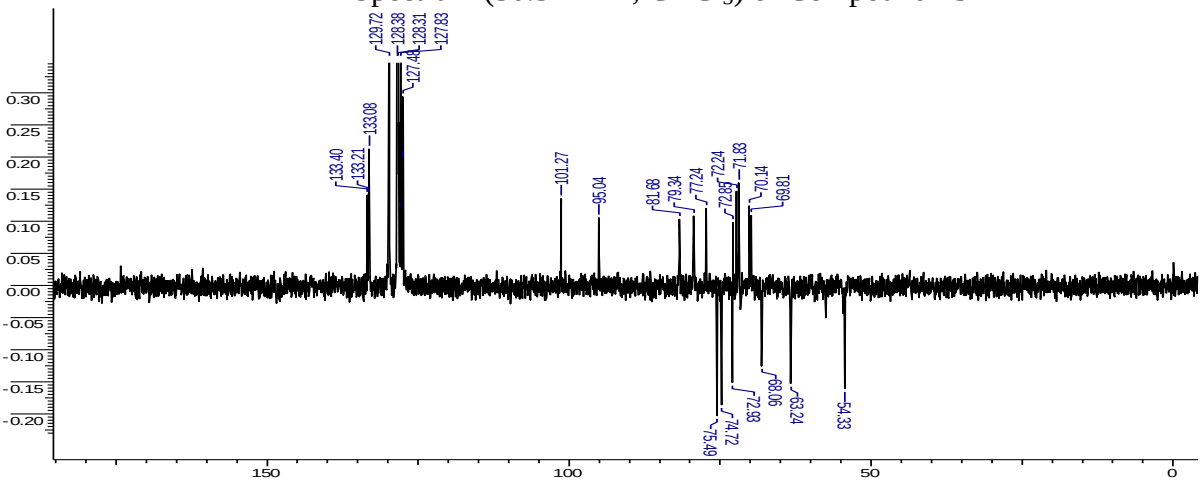
^{1}H NMR Spectrum (200.13 MHz, $CDCl_3$) of Compound **25**



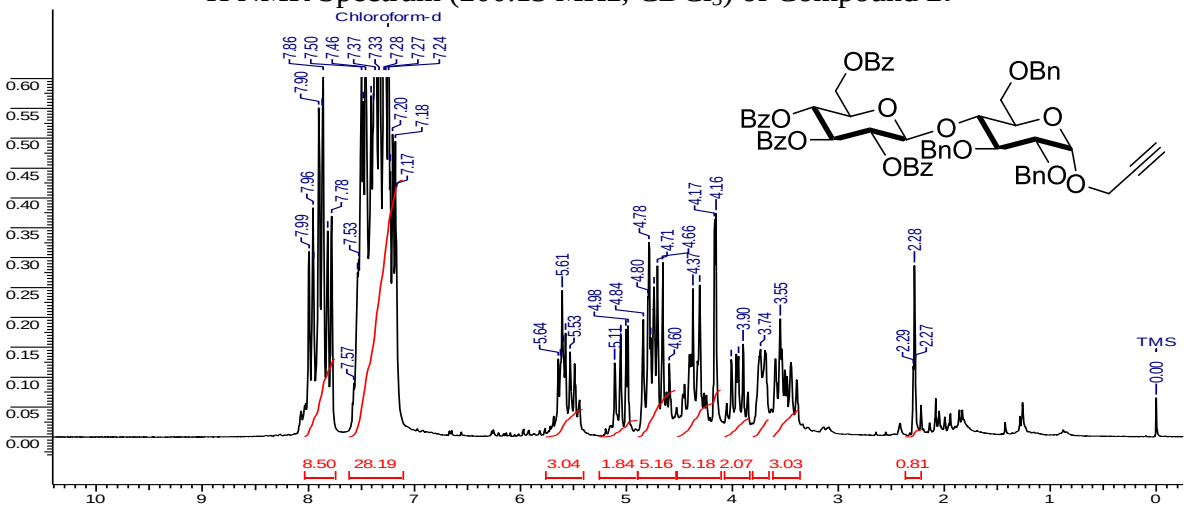
^{13}C NMR Spectrum (50.32MHz, $CDCl_3$) of Compound **25**



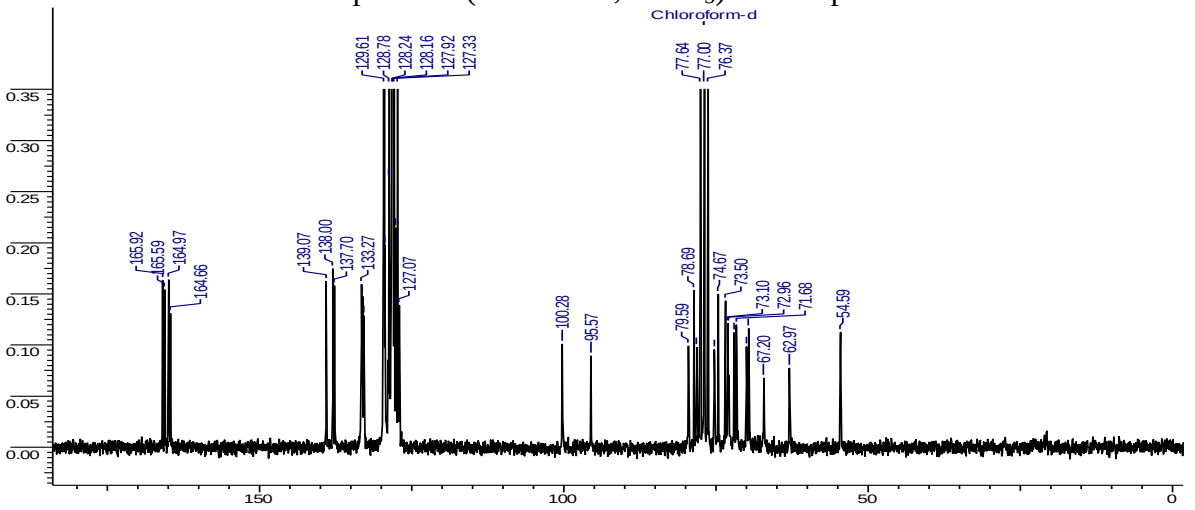
DEPT NMR Spectrum (50.32MHz, $CDCl_3$) of Compound **25**



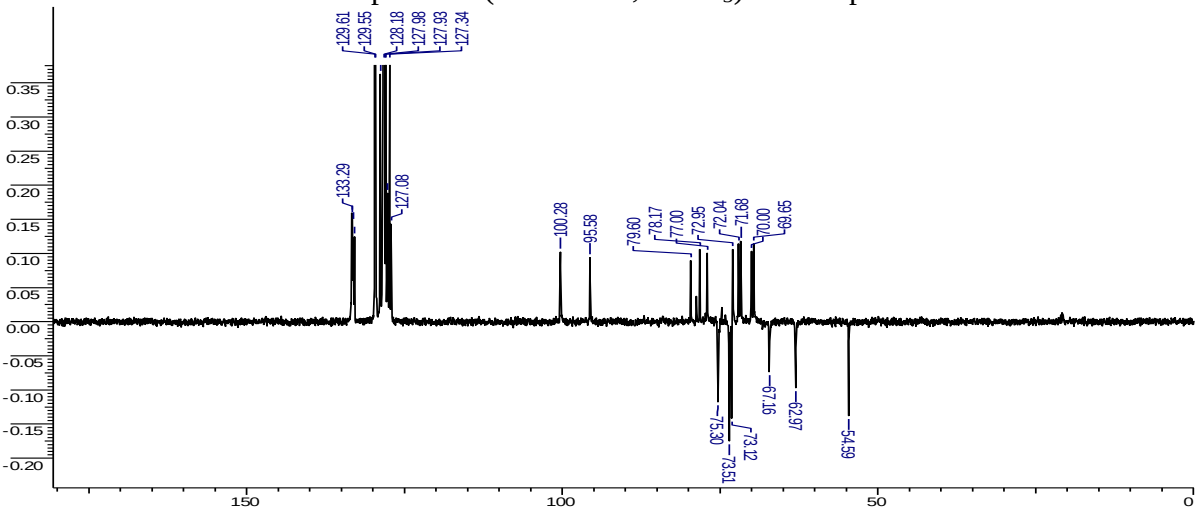
^{1}H NMR Spectrum (200.13 MHz, $CDCl_3$) of Compound **27**



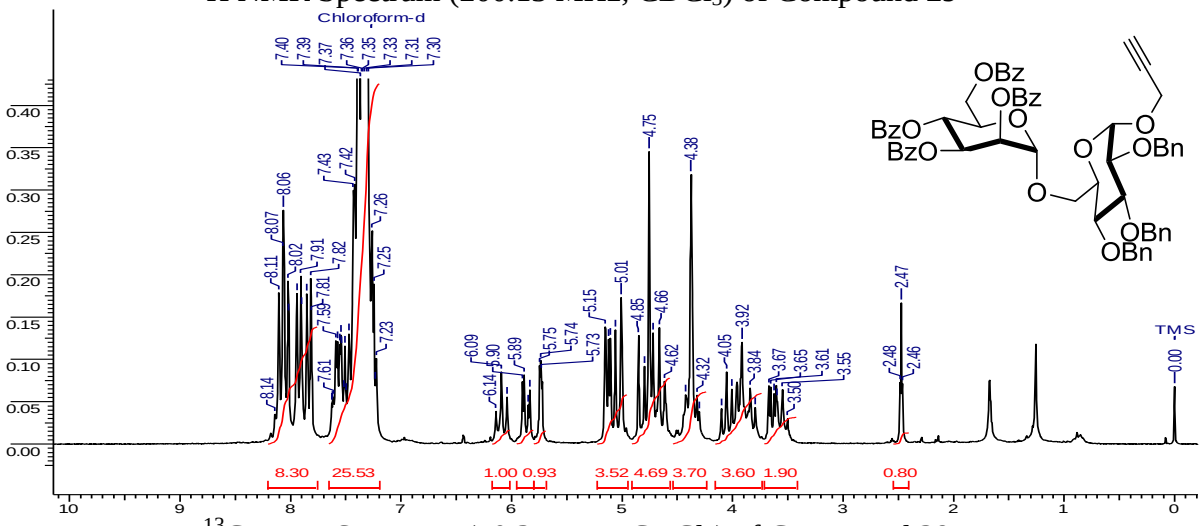
^{13}C NMR Spectrum (50.32MHz, $CDCl_3$) of Compound **27**



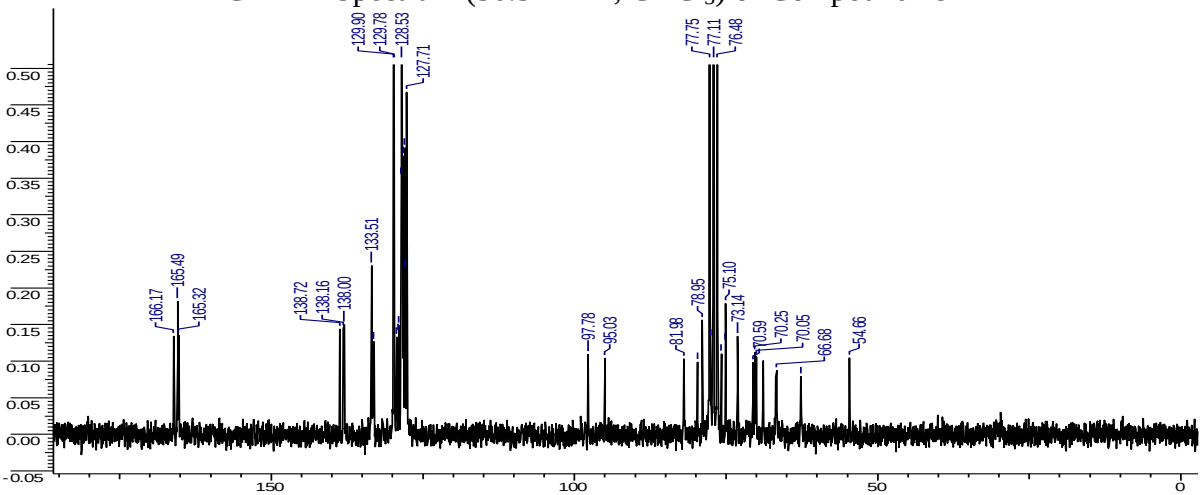
DEPT NMR Spectrum (50.32MHz, $CDCl_3$) of Compound **27**



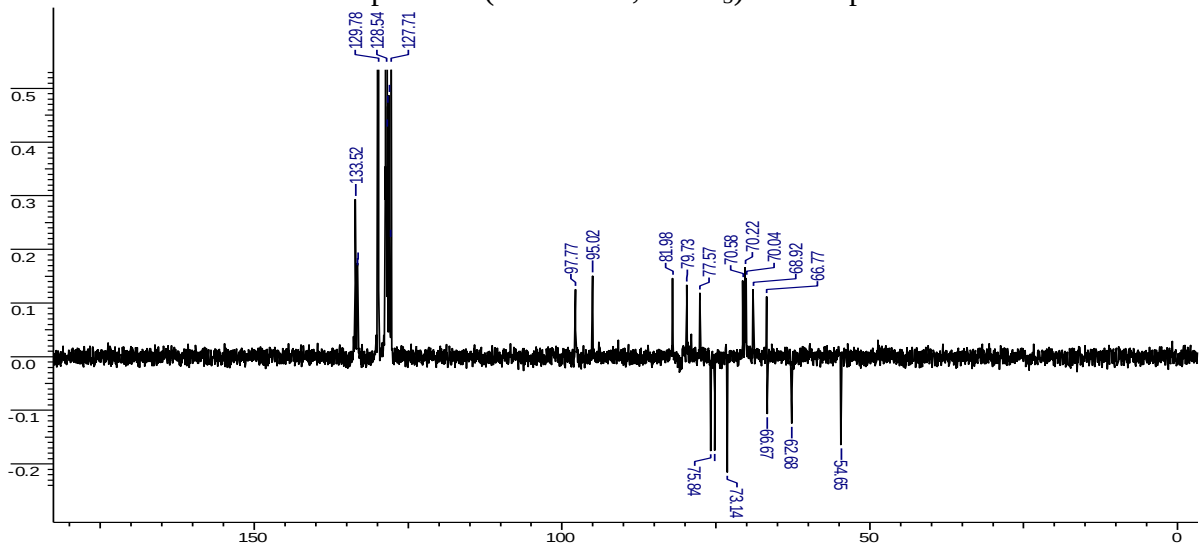
^{1}H NMR Spectrum (200.13 MHz, $CDCl_3$) of Compound **29**



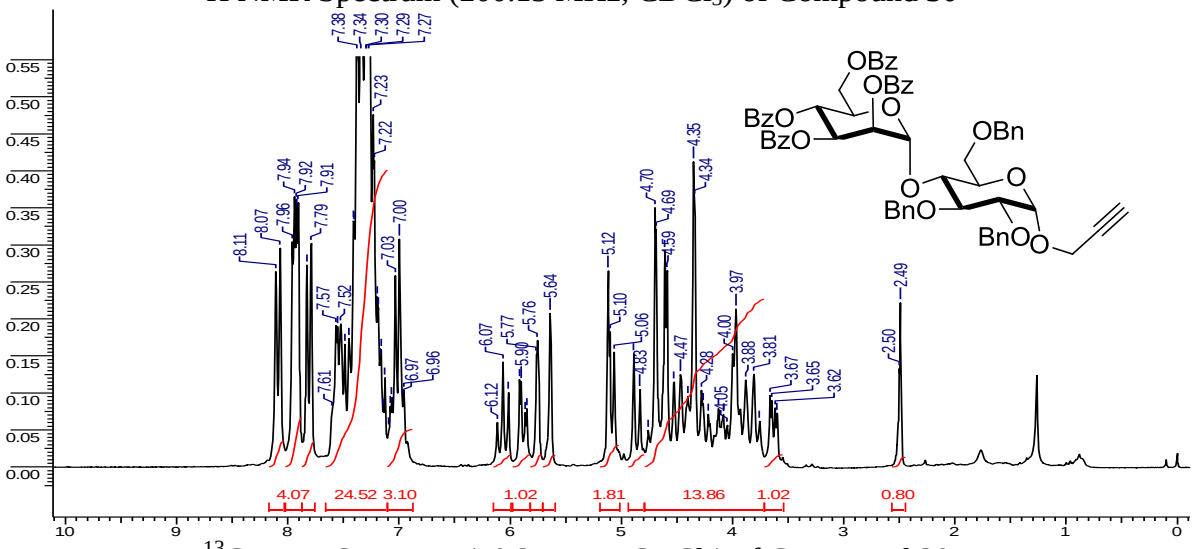
^{13}C NMR Spectrum (50.32MHz, $CDCl_3$) of Compound **29**



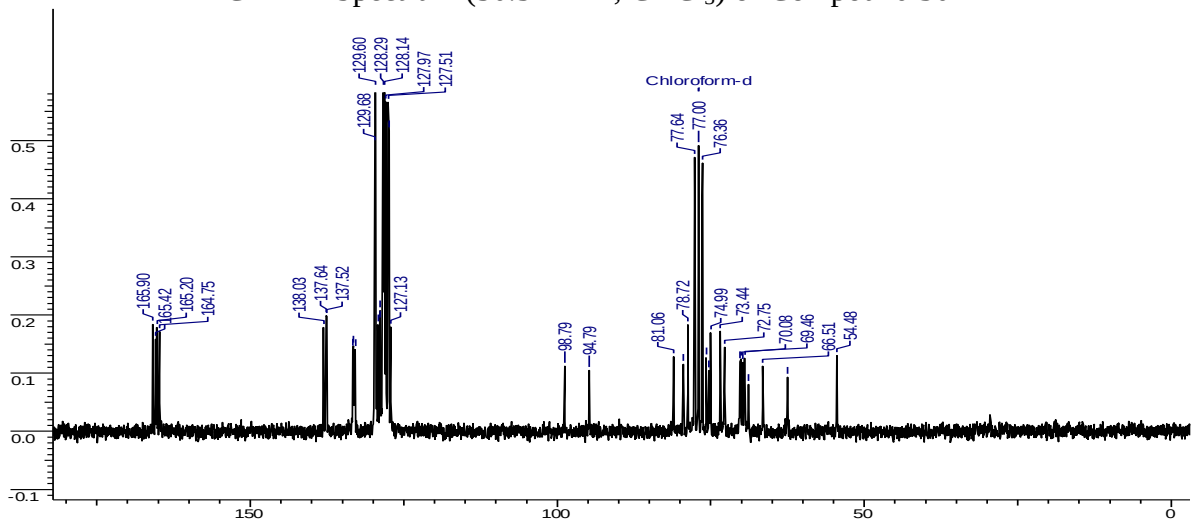
DEPT NMR Spectrum (50.32MHz, $CDCl_3$) of Compound **29**



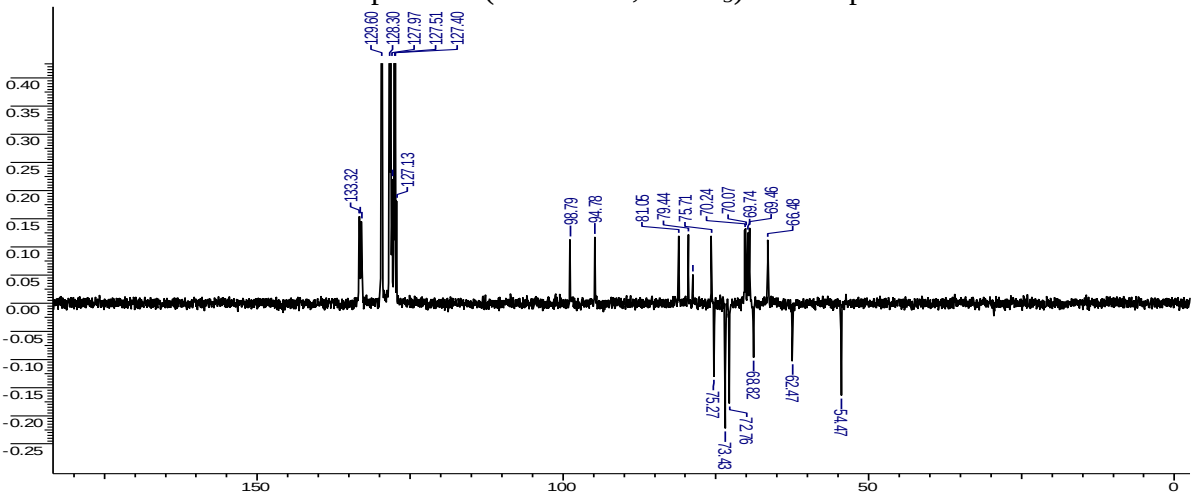
^{1}H NMR Spectrum (200.13 MHz, $CDCl_3$) of Compound **30**



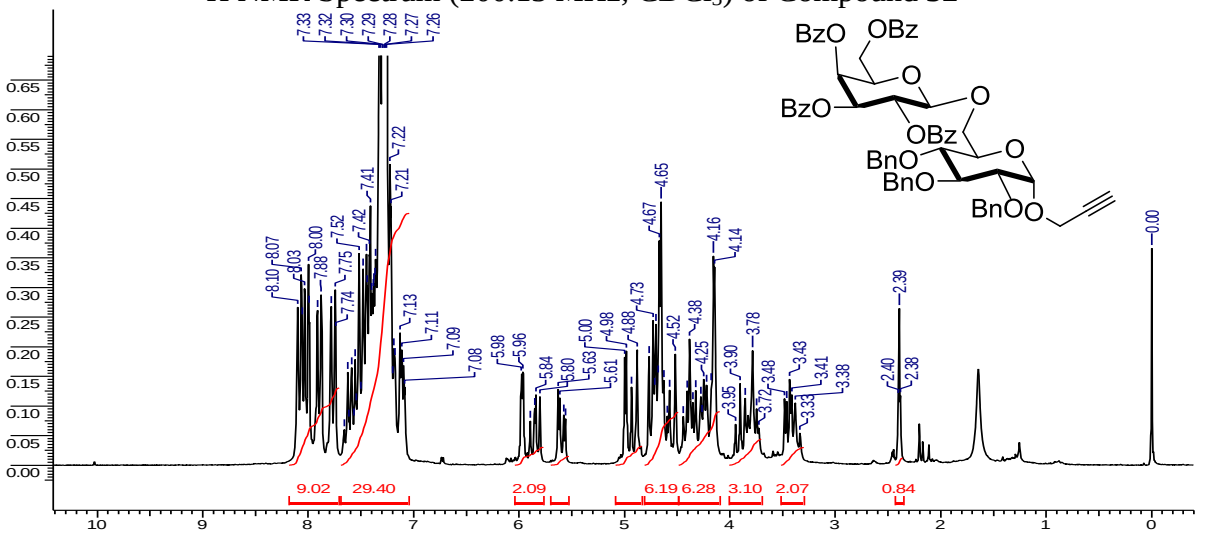
^{13}C NMR Spectrum (50.32MHz, $CDCl_3$) of Compound **30**



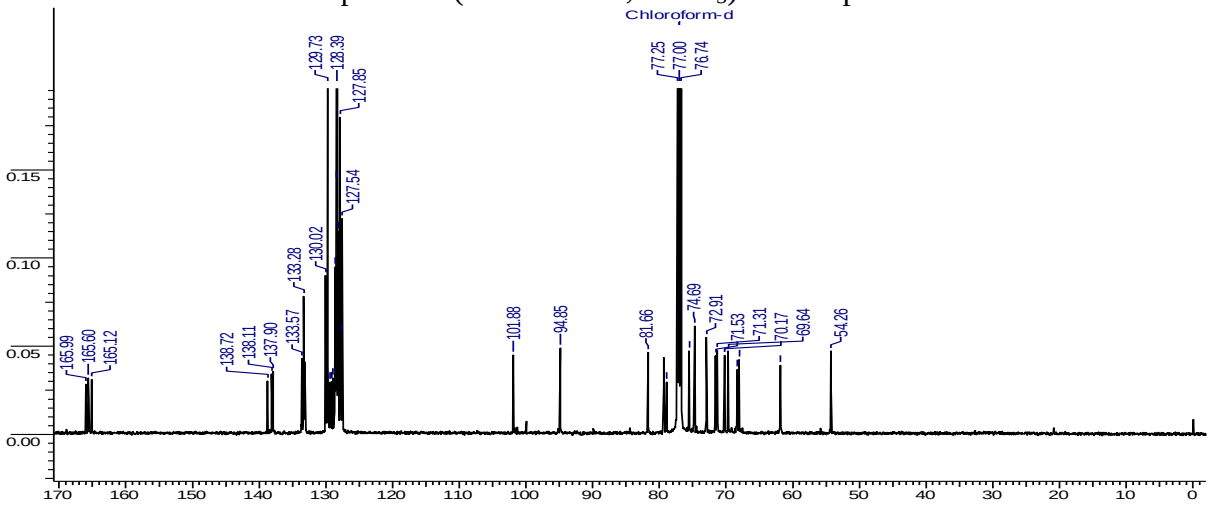
DEPT NMR Spectrum (50.32MHz, $CDCl_3$) of Compound **30**



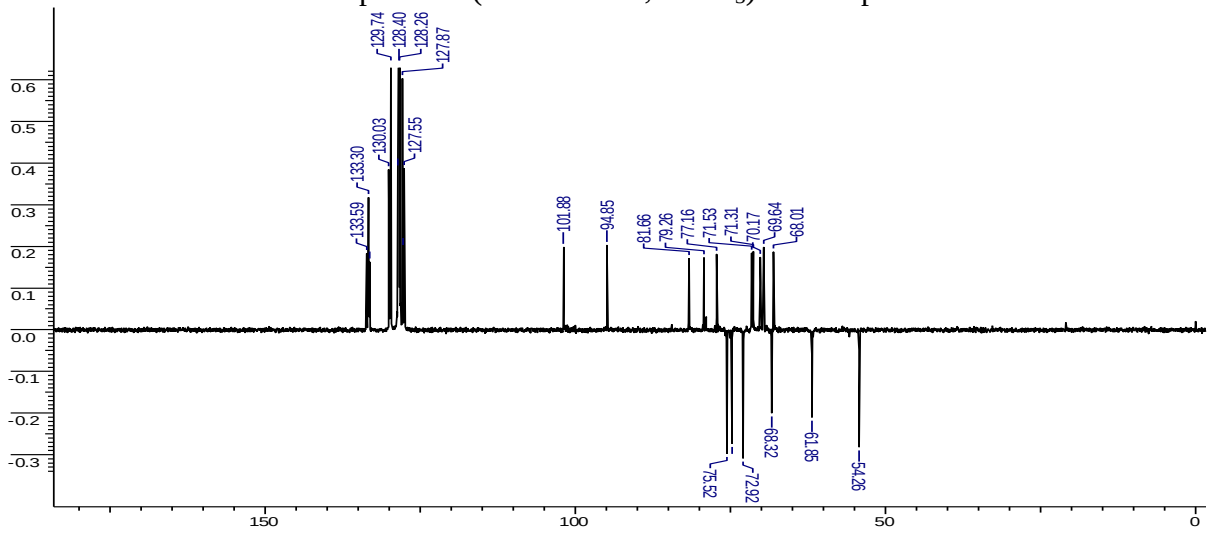
^{1}H NMR Spectrum (200.13 MHz, $CDCl_3$) of Compound **32**



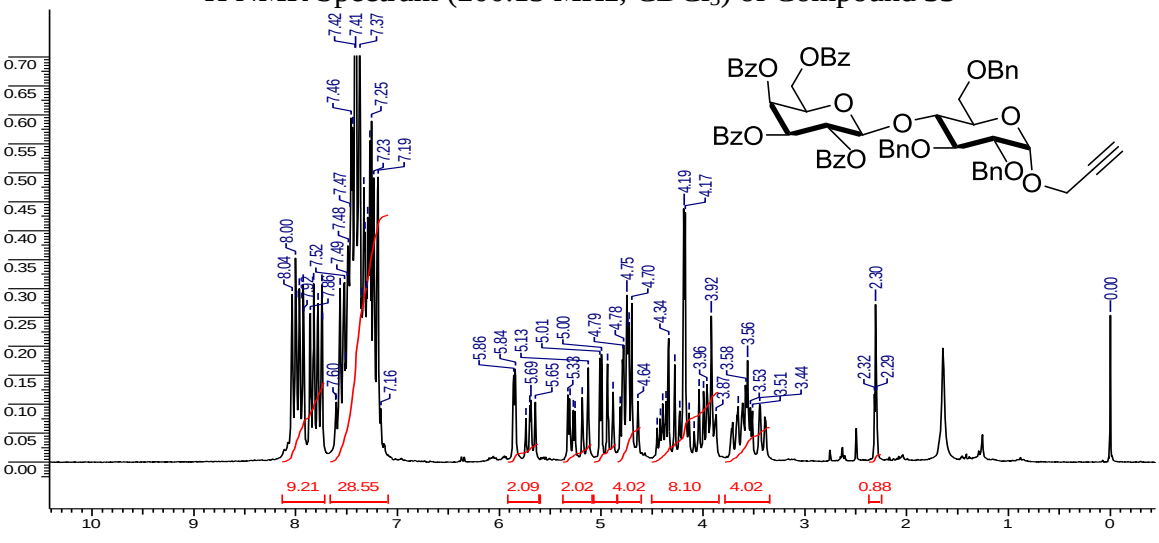
^{13}C NMR Spectrum (125.76 MHz, $CDCl_3$) of Compound **32**



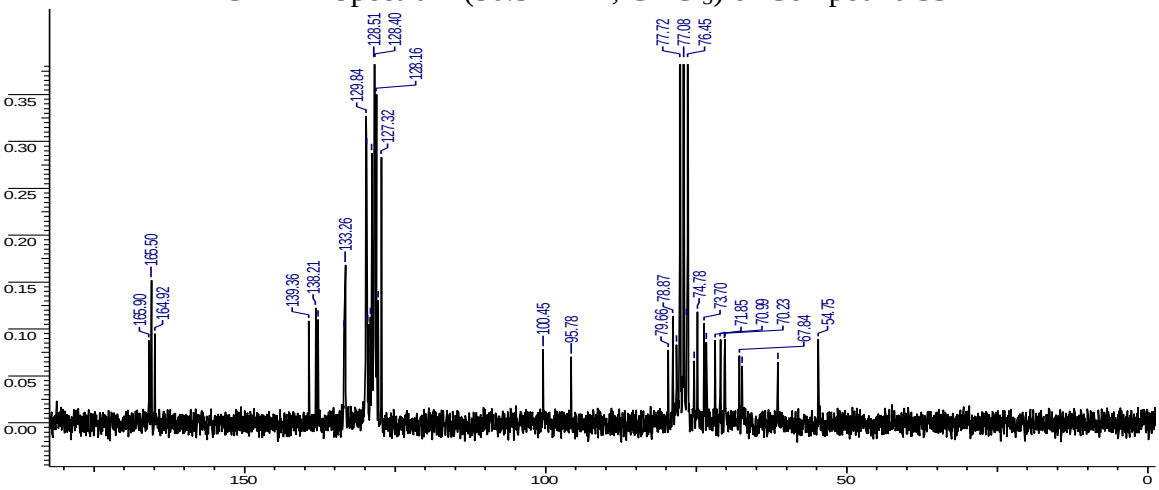
DEPT NMR Spectrum (125.76 MHz, $CDCl_3$) of Compound **32**



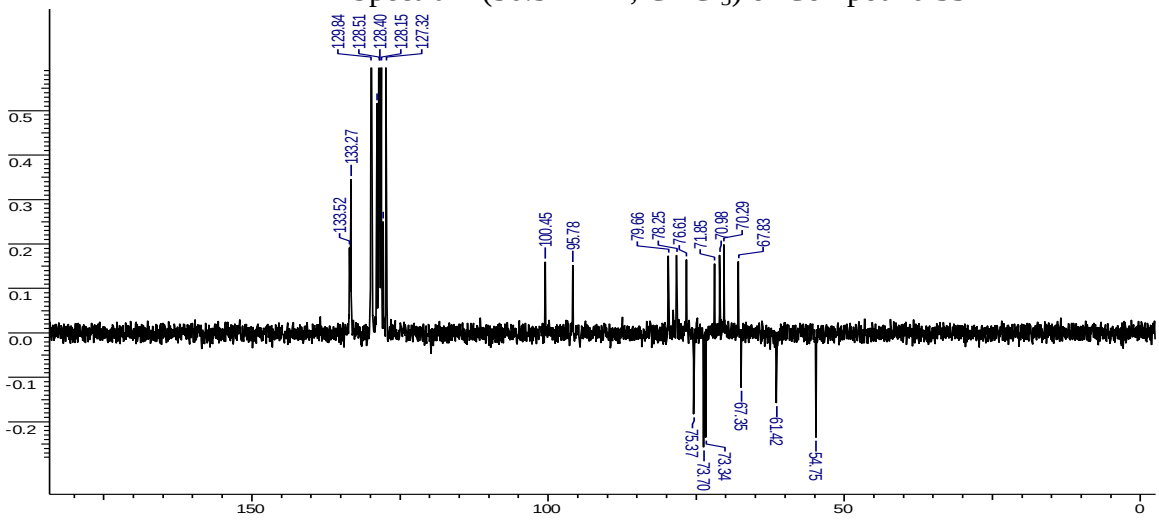
^{1}H NMR Spectrum (200.13 MHz, $CDCl_3$) of Compound **33**



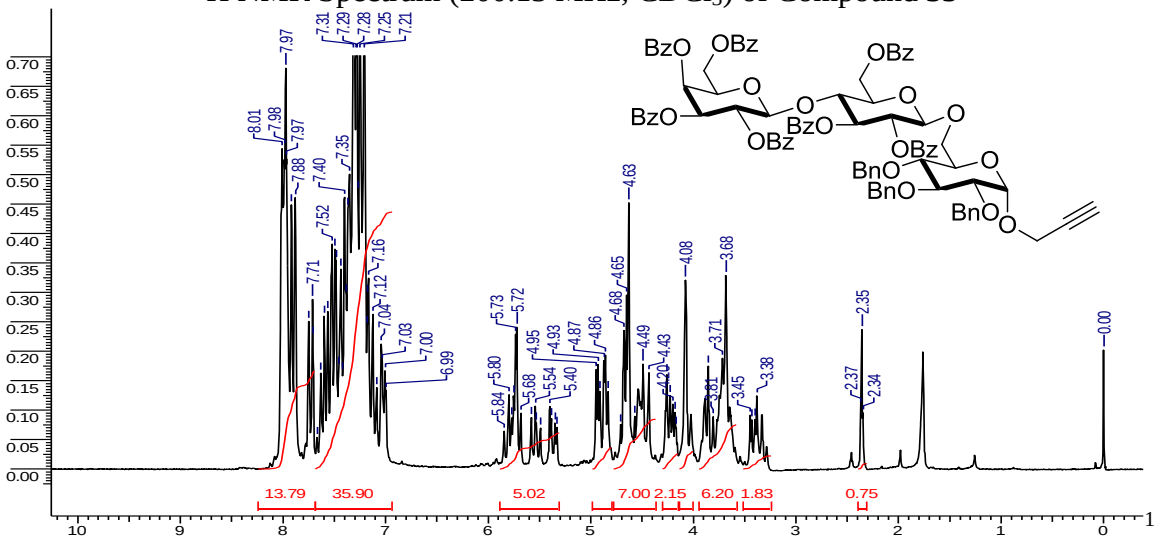
^{13}C NMR Spectrum (50.32MHz, $CDCl_3$) of Compound **33**



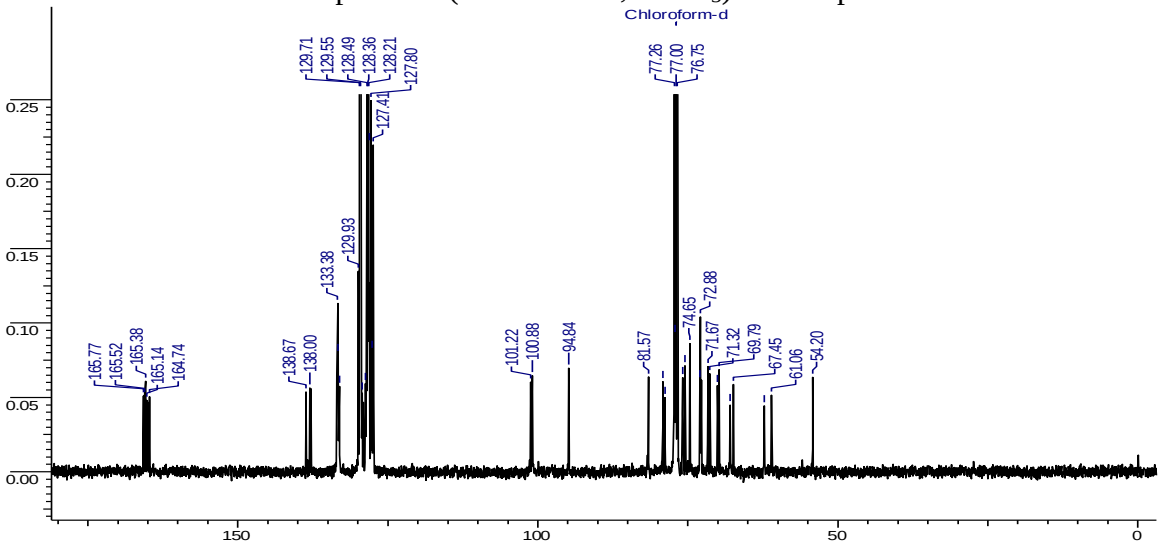
DEPT NMR Spectrum (50.32MHz, $CDCl_3$) of Compound **33**



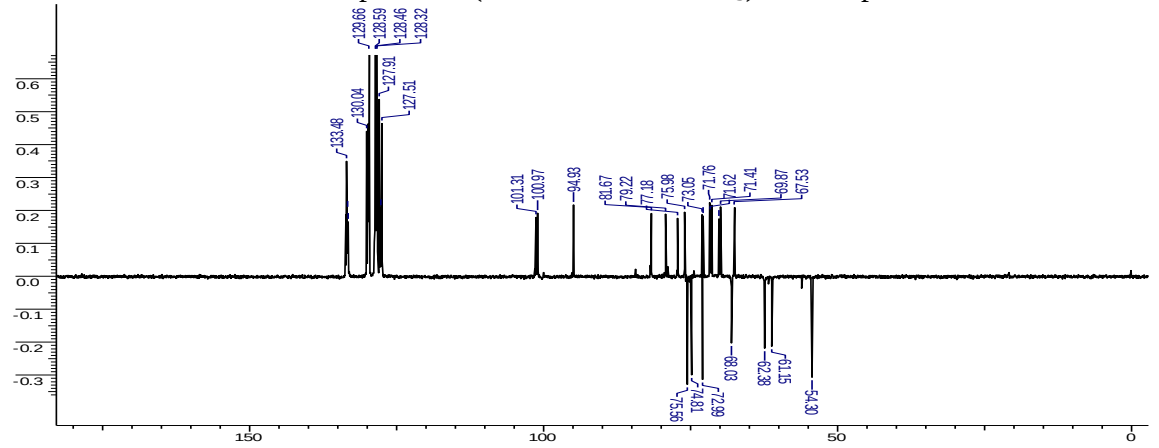
^{1}H NMR Spectrum (200.13 MHz, $CDCl_3$) of Compound **35**



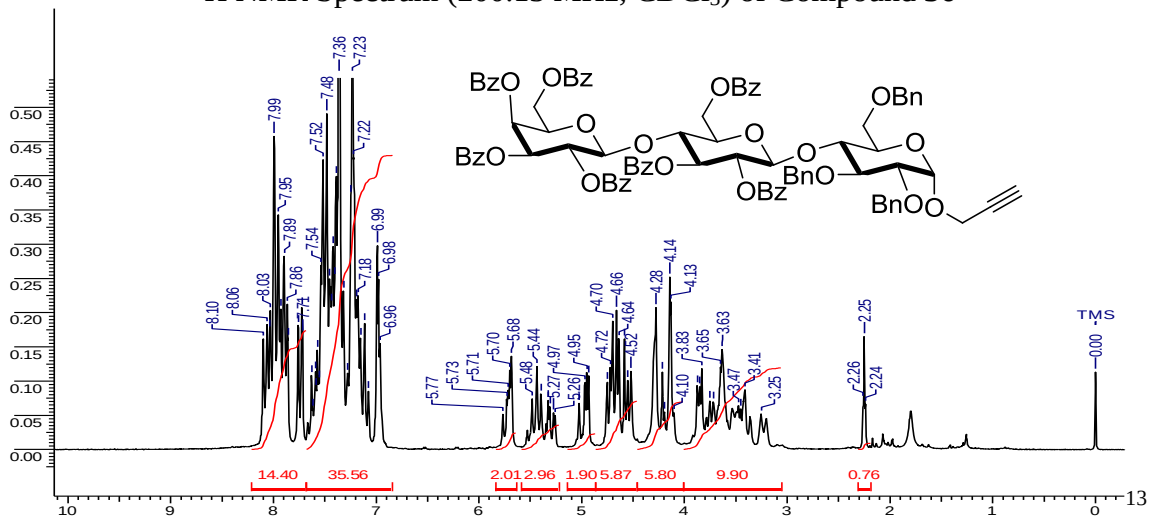
^{3}C NMR Spectrum (125.76 MHz, $CDCl_3$) of Compound **35**



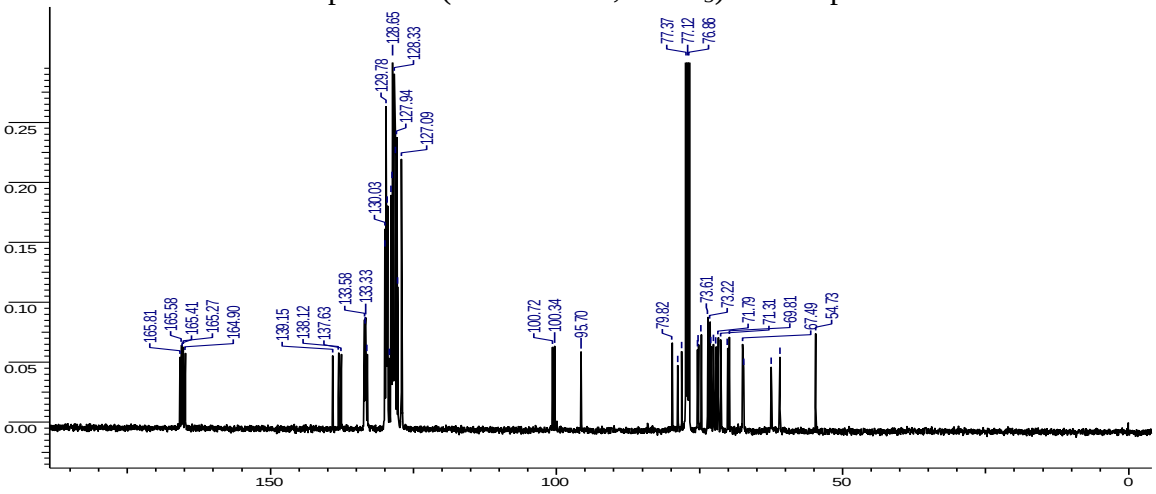
DEPT NMR Spectrum (125.76 MHz, $CDCl_3$) of Compound **35**



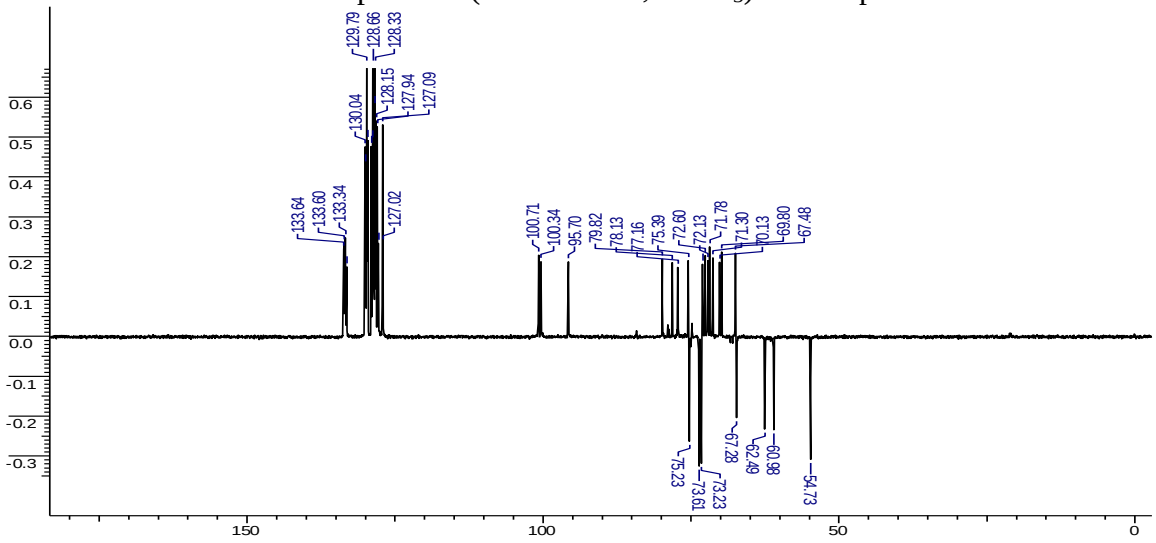
^{1}H NMR Spectrum (200.13 MHz, $CDCl_3$) of Compound **36**



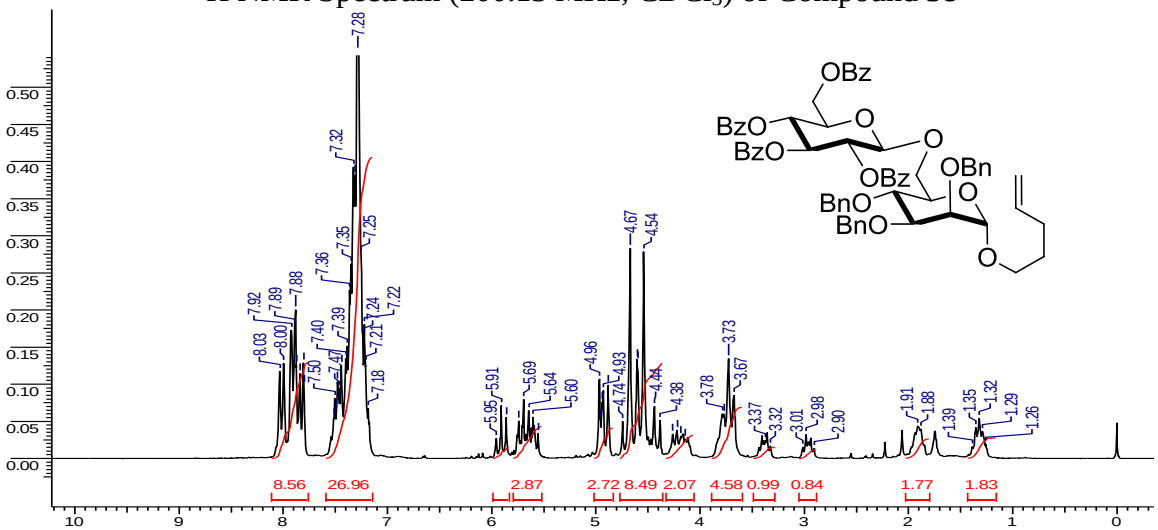
C NMR Spectrum (125.76 MHz, $CDCl_3$) of Compound **36**



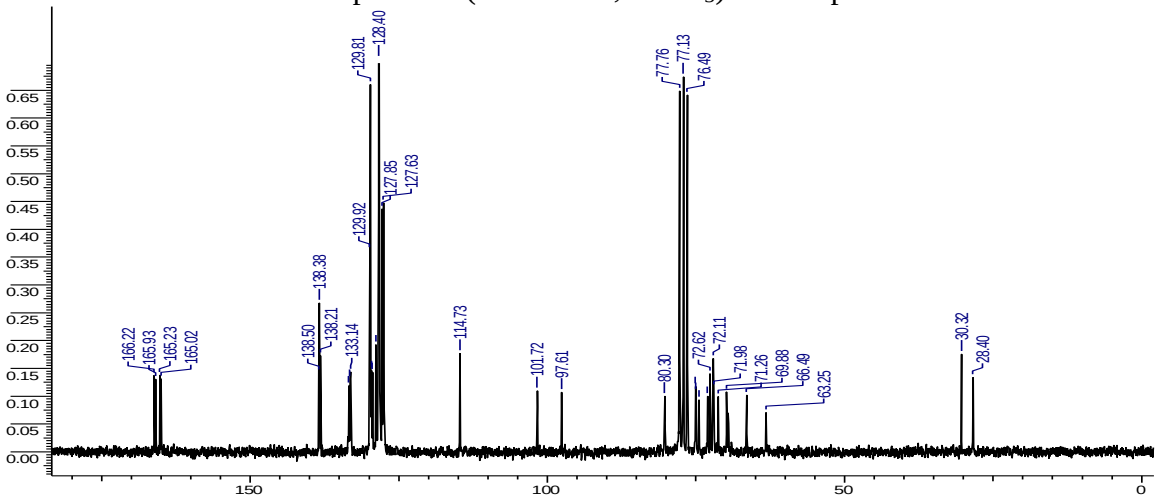
DEPT NMR Spectrum (125.76 MHz, $CDCl_3$) of Compound **36**



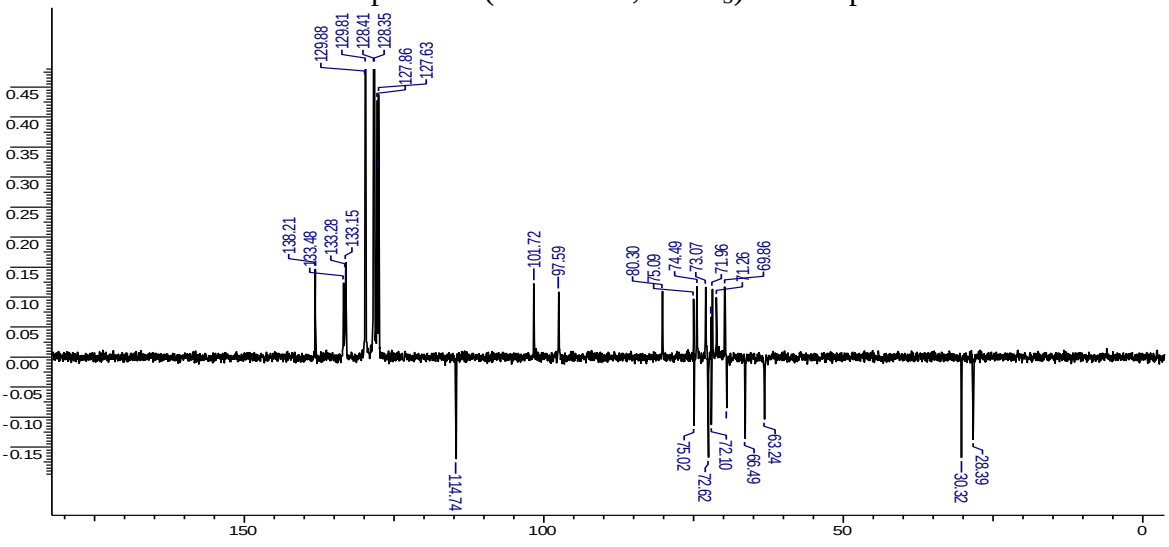
^{1}H NMR Spectrum (200.13 MHz, $CDCl_3$) of Compound **38**



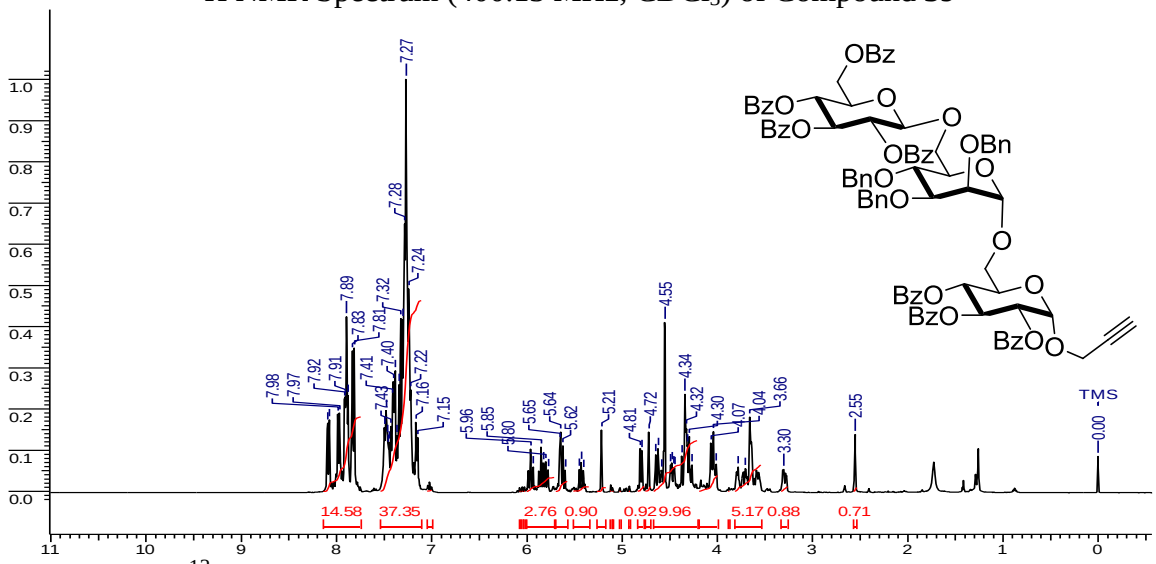
^{13}C NMR Spectrum (50.32MHz, $CDCl_3$) of Compound **38**



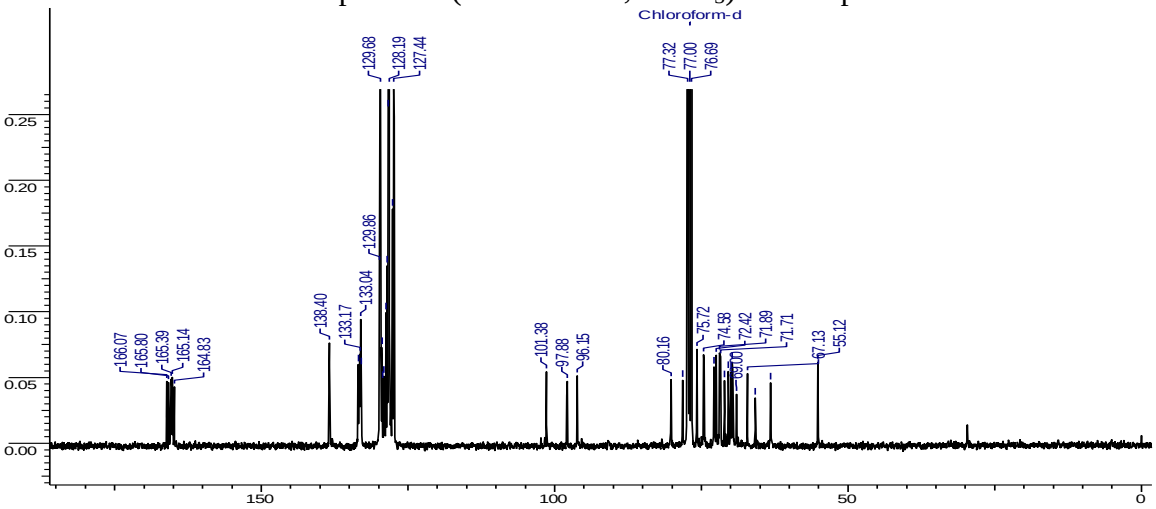
DEPT NMR Spectrum (50.32MHz, $CDCl_3$) of Compound **38**



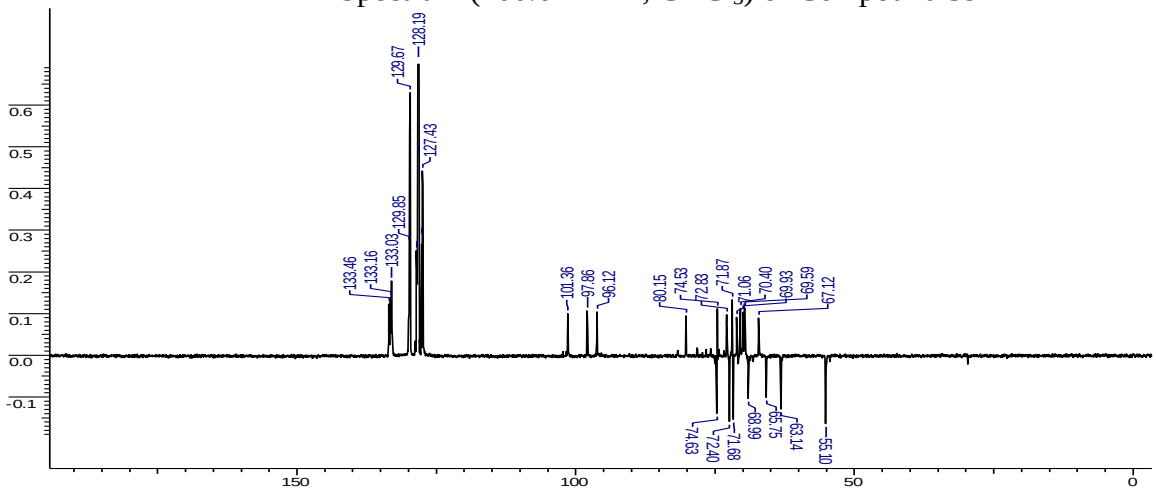
^{1}H NMR Spectrum (400.13 MHz, $CDCl_3$) of Compound **39**



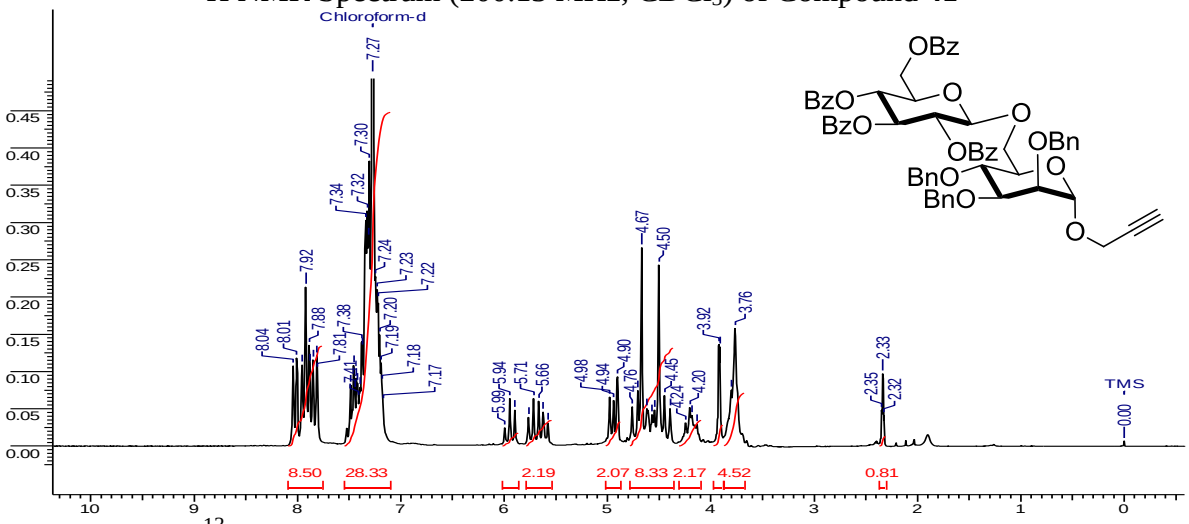
^{13}C NMR Spectrum (100.61 MHz, $CDCl_3$) of Compound **39**



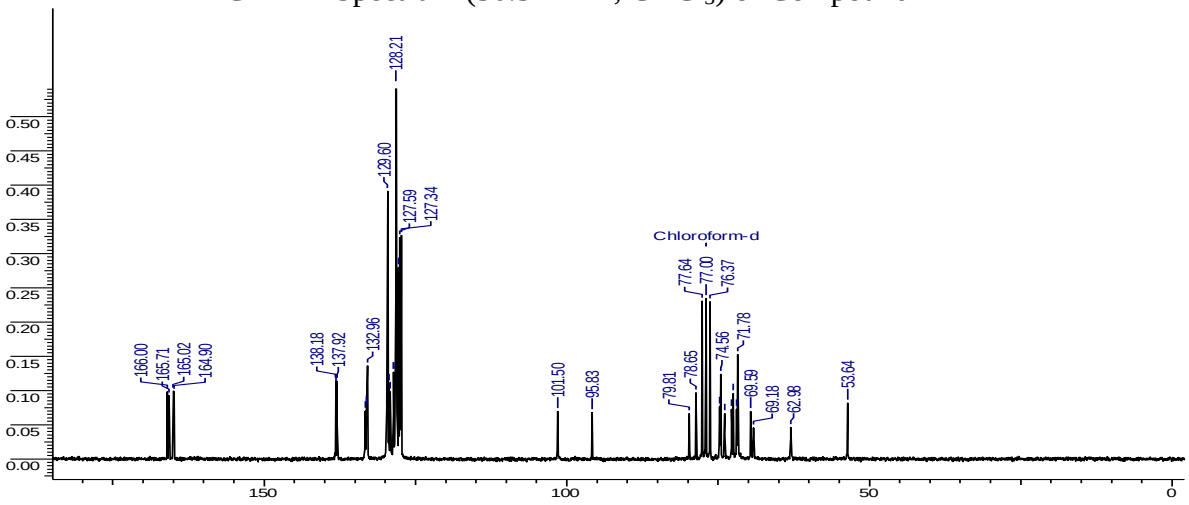
DEPT NMR Spectrum (100.61 MHz, $CDCl_3$) of Compound **39**



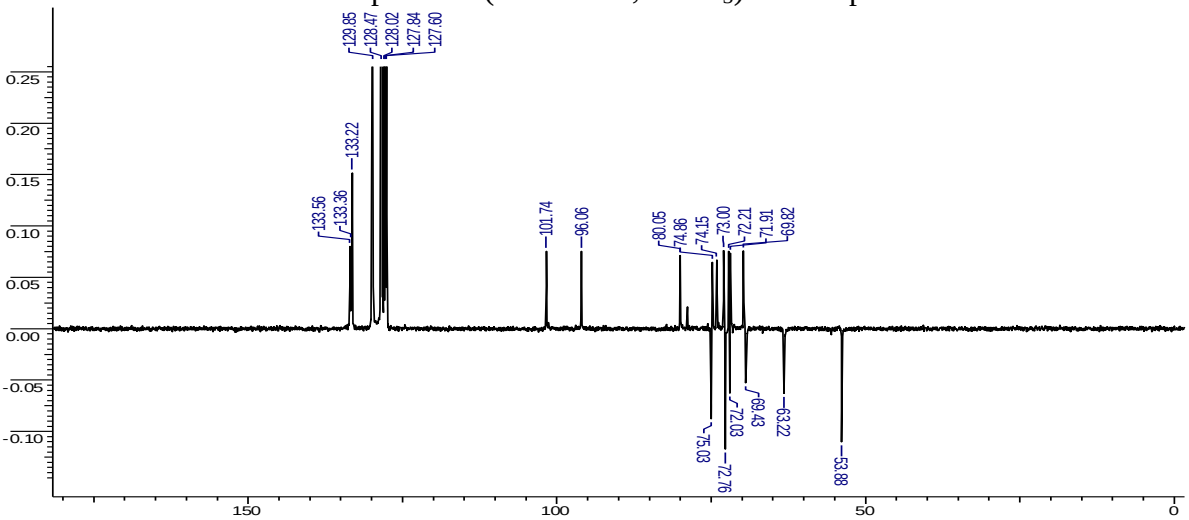
^{1}H NMR Spectrum (200.13 MHz, $CDCl_3$) of Compound **41**



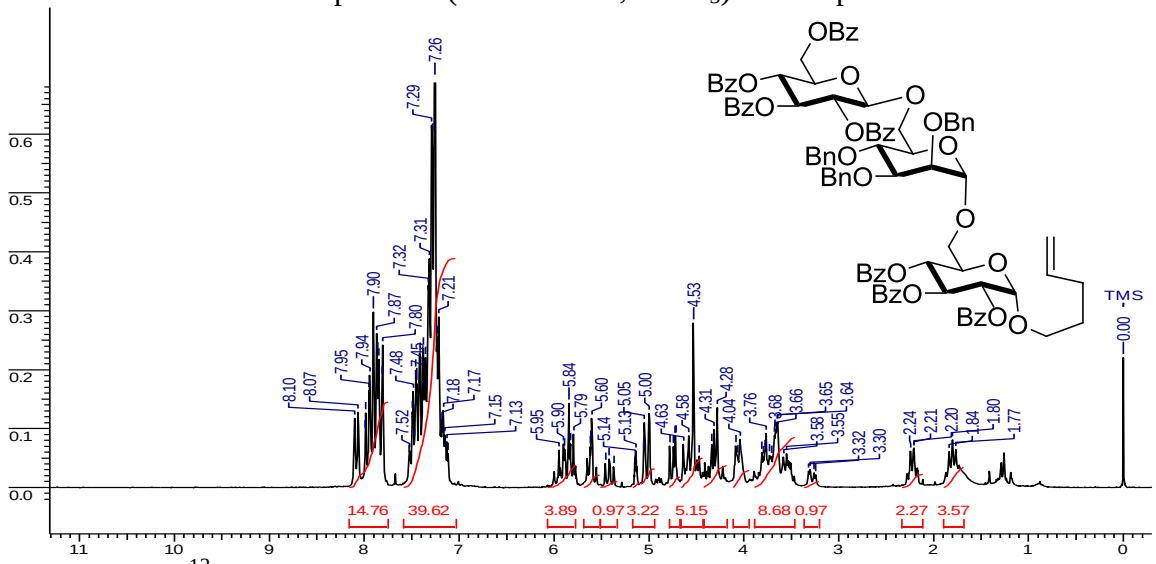
^{13}C NMR Spectrum (50.32MHz, $CDCl_3$) of Compound **41**



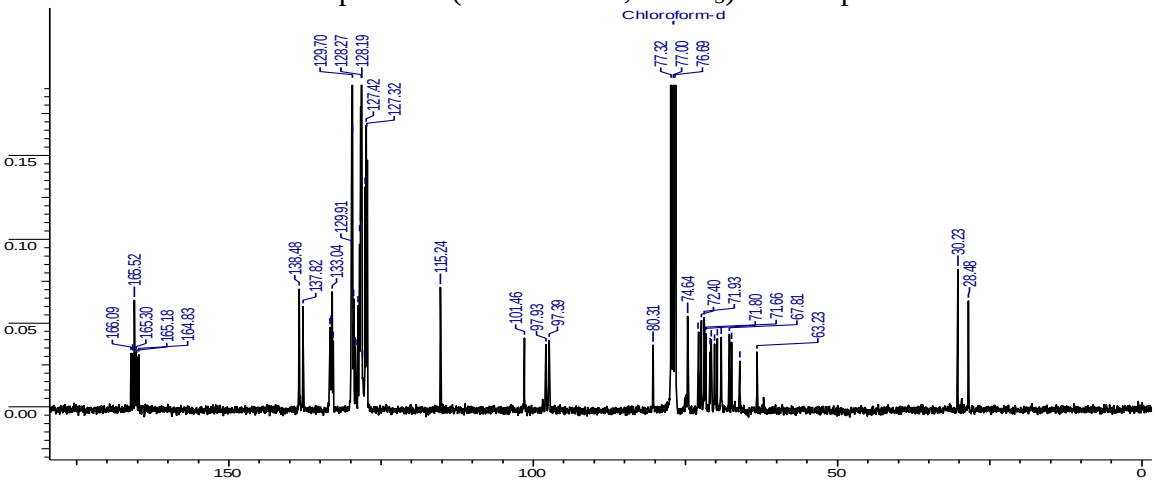
DEPT NMR Spectrum (50.32MHz, $CDCl_3$) of Compound **41**



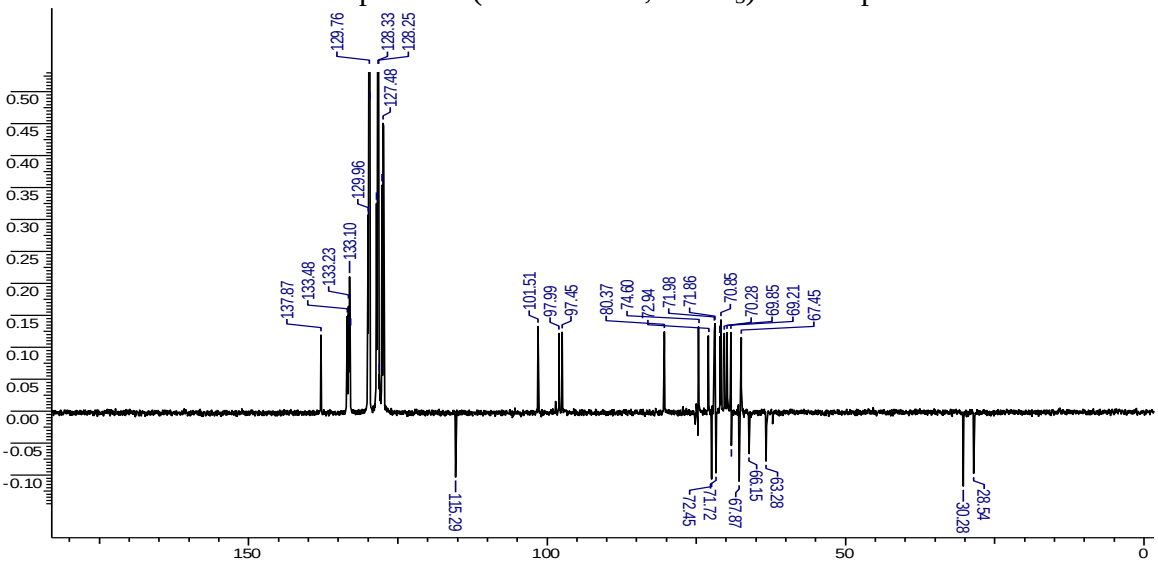
^{1}H NMR Spectrum (200.13 MHz, $CDCl_3$) of Compound **43**



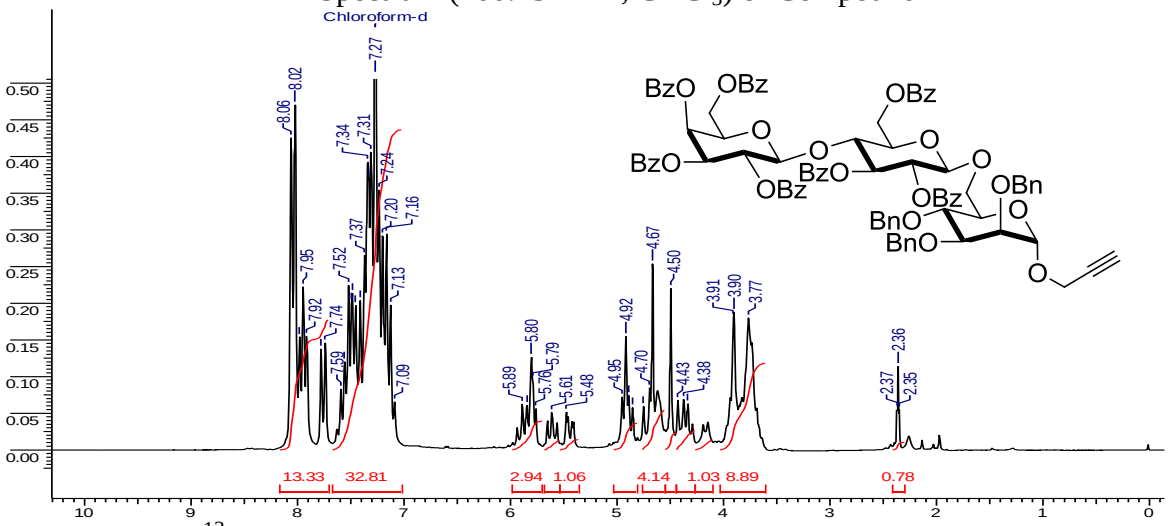
^{13}C NMR Spectrum (100.61 MHz, $CDCl_3$) of Compound **43**



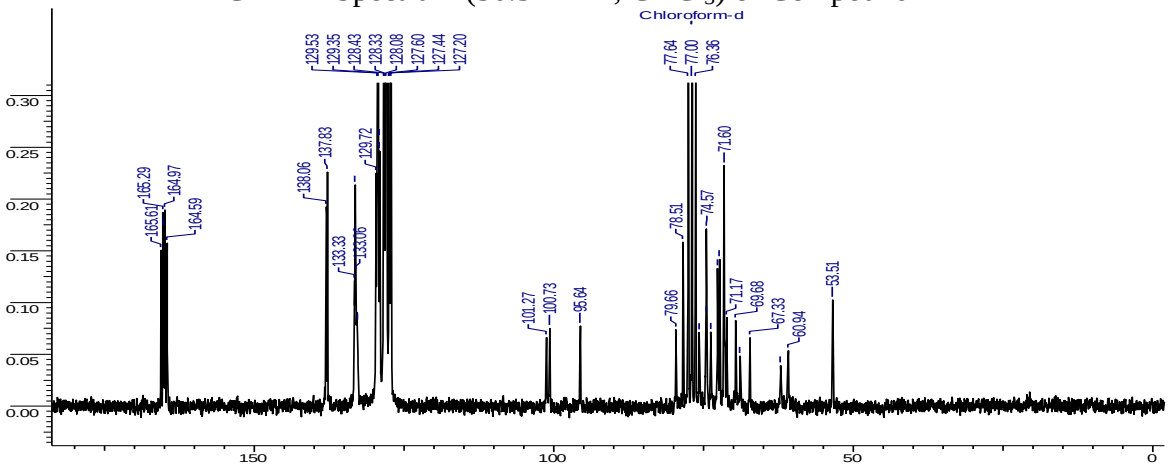
DEPT NMR Spectrum (100.61 MHz, $CDCl_3$) of Compound **43**



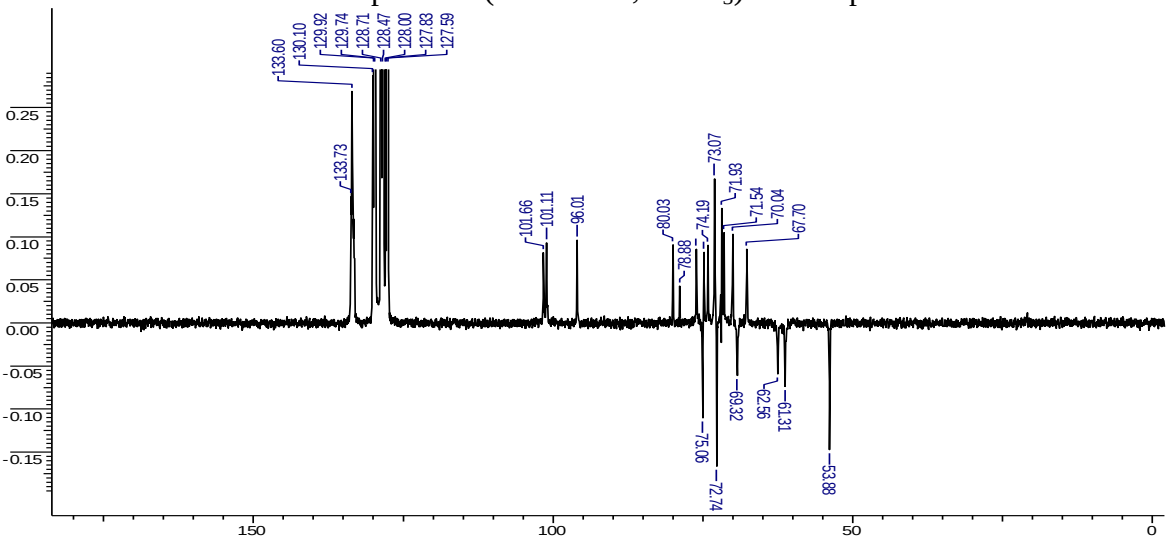
^{1}H NMR Spectrum (200.13 MHz, $CDCl_3$) of Compound **44**



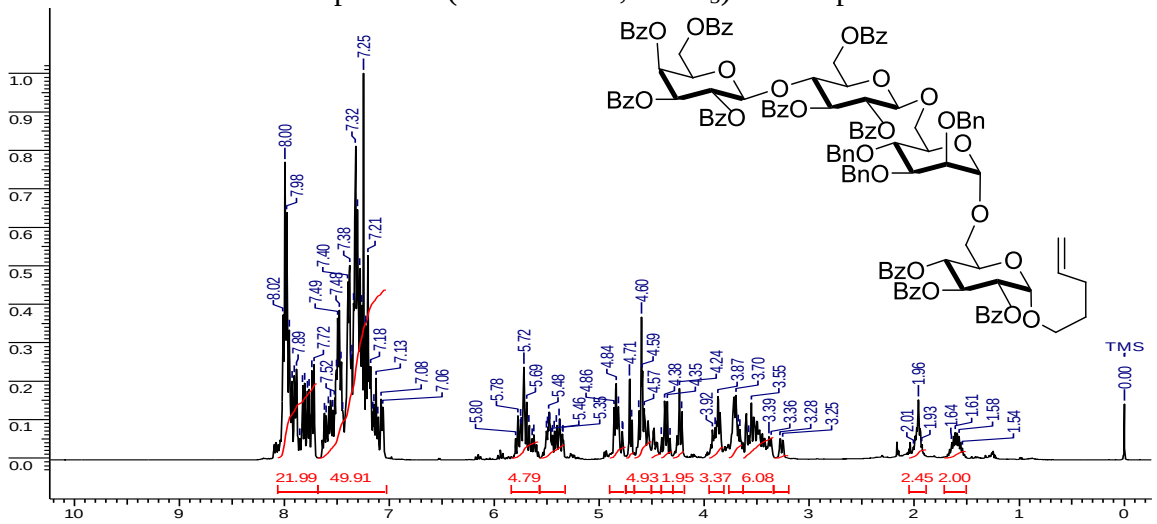
^{13}C NMR Spectrum (50.32MHz, $CDCl_3$) of Compound **44**



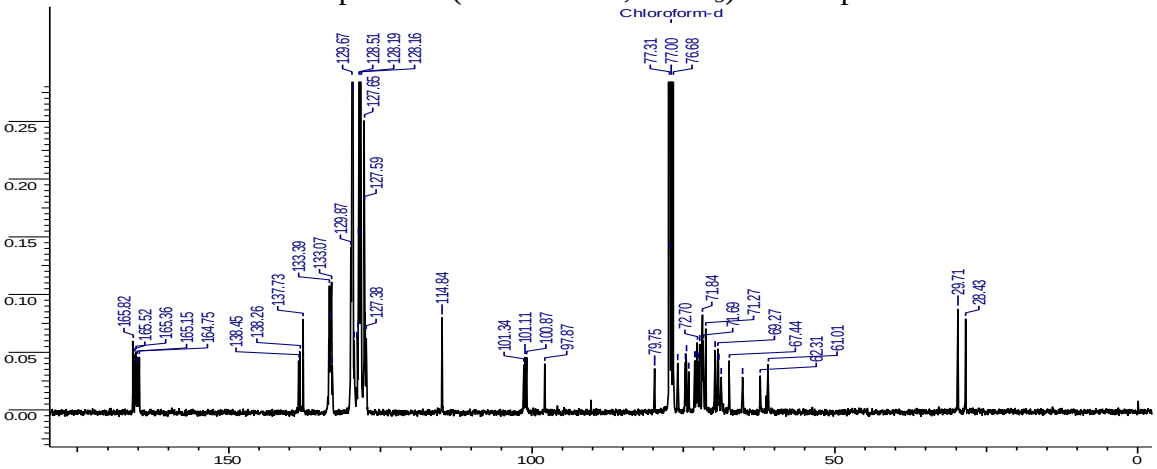
DEPT NMR Spectrum (50.32MHz, $CDCl_3$) of Compound **44**



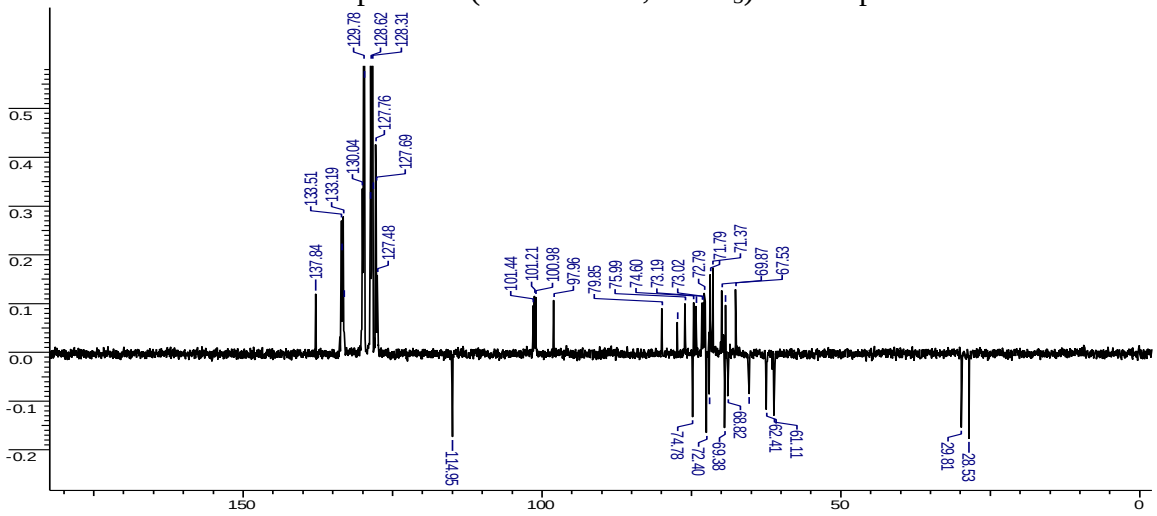
^{1}H NMR Spectrum (400.13 MHz, $CDCl_3$) of Compound **45**



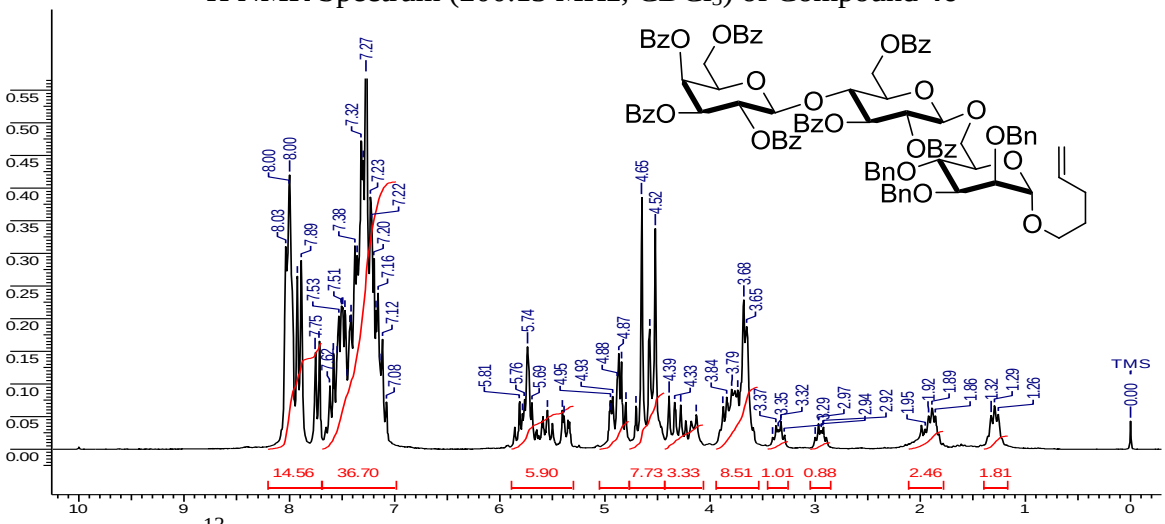
^{13}C NMR Spectrum (100.61 MHz, $CDCl_3$) of Compound **45**



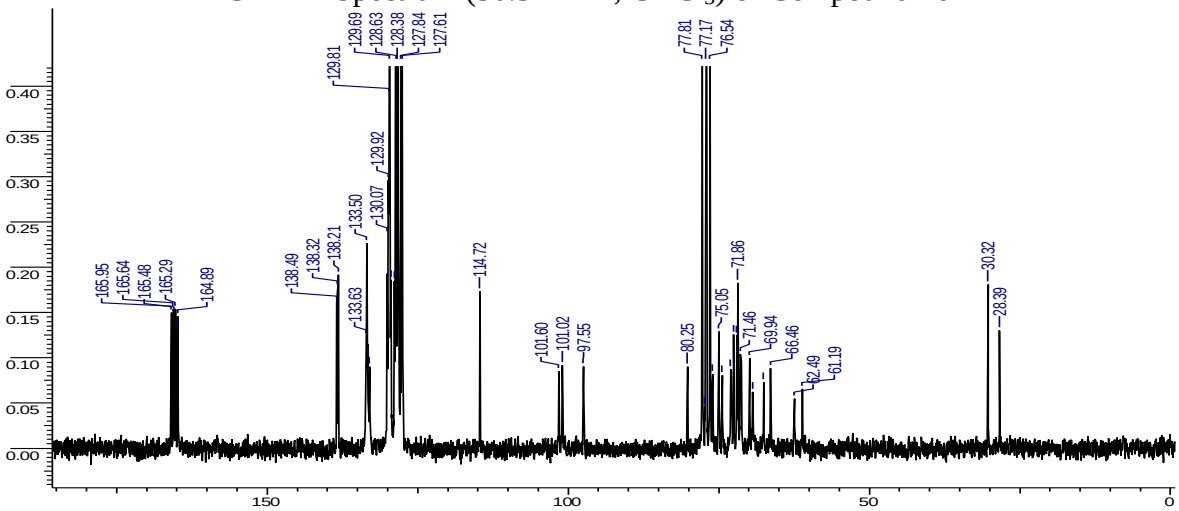
DEPT NMR Spectrum (100.61 MHz, $CDCl_3$) of Compound **45**



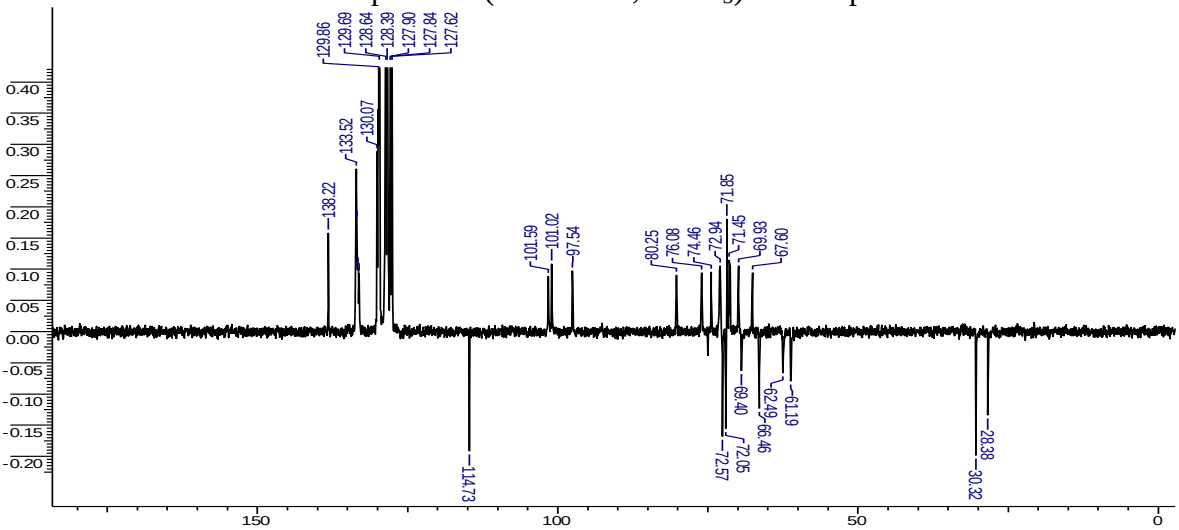
^{1}H NMR Spectrum (200.13 MHz, $CDCl_3$) of Compound **46**



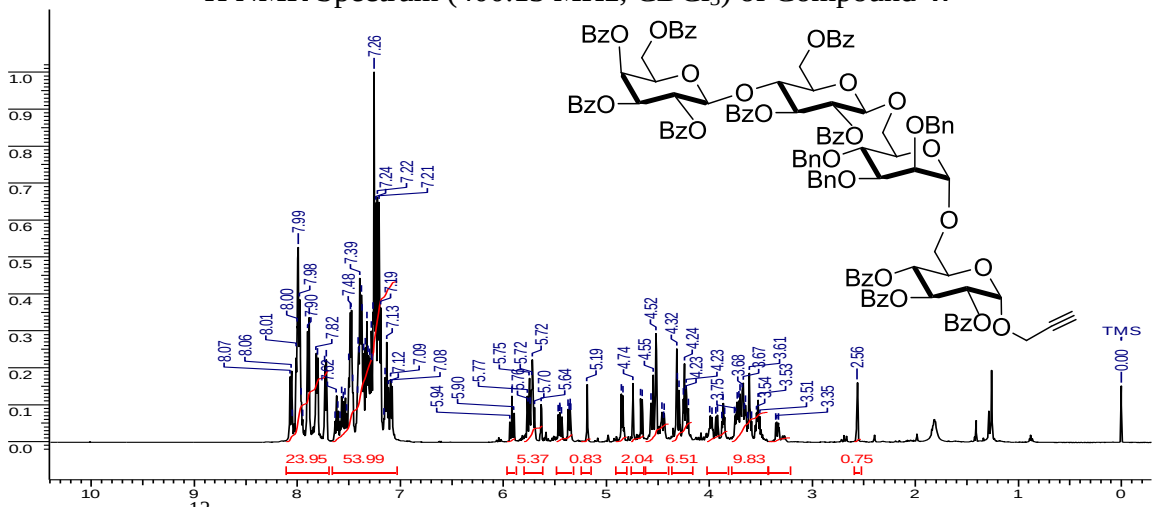
^{13}C NMR Spectrum (50.32MHz, $CDCl_3$) of Compound **46**



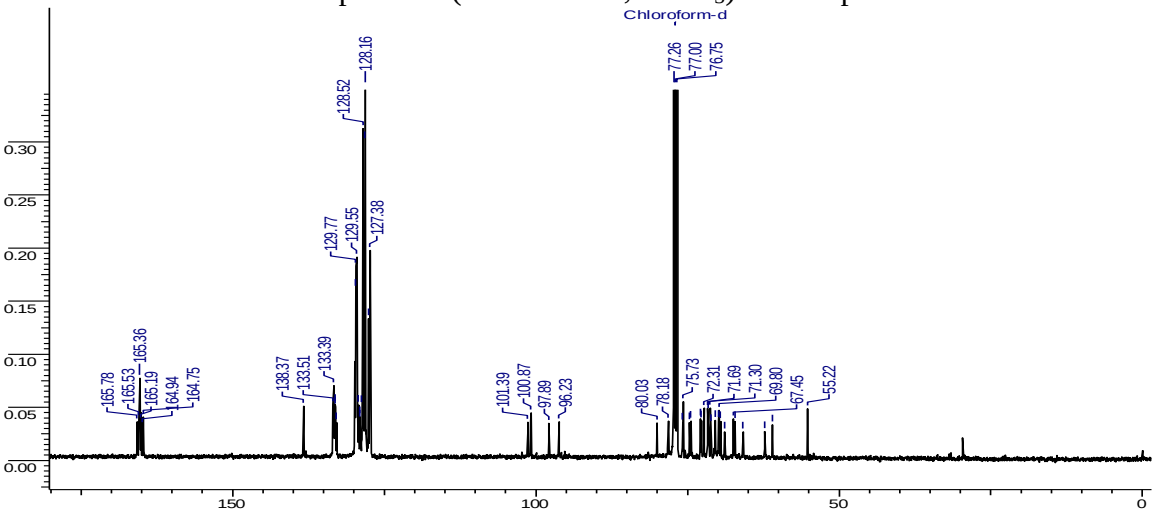
DEPT NMR Spectrum (50.32MHz, $CDCl_3$) of Compound **46**



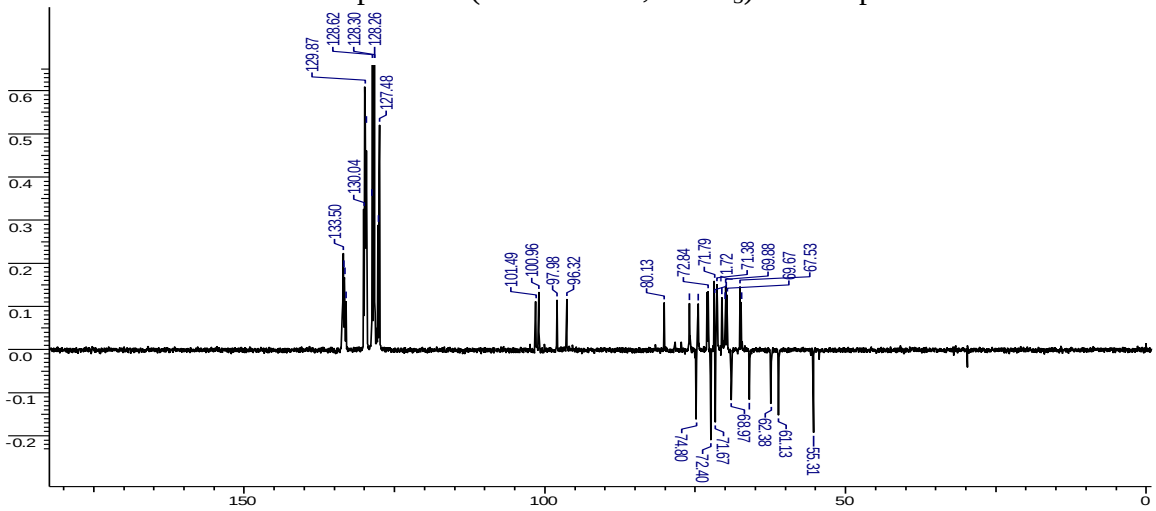
^{1}H NMR Spectrum (400.13 MHz, $CDCl_3$) of Compound **47**



^{13}C NMR Spectrum (100.61 MHz, $CDCl_3$) of Compound **47**



DEPT NMR Spectrum (100.61 MHz, $CDCl_3$) of Compound **47**



Chapter 1: References

1. a) Schmidt, R. R., *Angew. Chem. Int. Ed*. **2009**, *48*, 1900. (b) Brandley, B. K.; Schnaar, R. L. *J. Leu. Biol.* **1986**, *40*, 97. b) Rudd, P. M.; Elliott, T.; Cresswell, P.; Wilson, I. A.; Dwek, R. A. *Science* **2001**, *291*, 2370. c) McAuliffe, J. C.; Hindsgaul, O. L. E. *Mol. Cell. Glycobiol.* **2000**, *30*, 249. d) Varki, A. *Glycobiology* **1993**, *3*, 97. e) Dwek, R. A. *Chem. Rev*. **1996**, *96*, 683. f) Kiessling, L. L.; Pohl, N. L. *Chem. Biol*. **1996**, *3*, 71. g) Gordon, E. J.; Sanders, W. J.; Kiessling, L. L. *Nature* **1998**, *392*, 30. h) Helenius, A.; Aebi, M. *Science* **2001**, *291*, 2364. i) Bernfield, M.; Götte, M.; Park, P. W.; Reizes, O.; Fitzgerald, M. L.; Lincecum, J.; Zako, M. *Annu. Rev. Biochem.* **1999**, *68*, 729. j) Fukuda, M. *Cancer Res.* **1996**, *56*, 2237.
2. Yamera, K. J.; Bertozzi, C. R.; *Curr. Opin. Chem. Biol.* **1998**, *2*, 49.
3. Nicolaou, K. C.; Ueno, H. Oligosaccharide synthesis from glycosyl fluorides and sulfides, in S. Hanessian, (Ed.), *Preparative Carbohydrate Chemistry*, **1997**, 313.
4. Fraser-Reid, B.; Wu, Z.; Udodong, U. E.; Ottosson, H. *J. Org. Chem*., **1990**, *55* 6068.
5. Williams, L. J.;. Garbaccio, R. M; Danishefsky, S. J. *Carbohydrates in Chemistry and Biology*, Vol. 1, Wiley-VCH, Weinheim, **2000**, 61.
6. Ito, Y.; Kanie, O.; Ogawa, T. *Angew Chem. Int. Ed.*, **1996**, *35*, 2510.
7. Boons, G.-J.; Isles, S.; *Tetrahedron Lett*., **1994**, *35*, 3593.
8. a) Douglas, N. L.; Ley, S. V.; Lucking, U.; Warriner, S. L. *J. Chem. Soc., Perkin Trans*., **1998**, *1*, 51. b) Zhang, Z.; Ollmann, I. R.; Ye, X. S.; Wischnat, R.; Baasov, T.; Wong, C.-H. *J. Am. Chem. Soc*., **1999**, *121*, 734. c) Ye, X. S.; Wong, C.-H. *J. Org. Chem.*, **2000**, *65*, 2410.
9. Bilodeau, M. T.; Park, T. K.; Hu, S.; Randolph, J. T.; Danishefsky, S. J.; Livingston, P. O.; Zhang, S. *J. Am. Chem. Soc*., **1995**, *117*, 7840.
10. Lassaletta, J.; Schmidt, R. R.; Glycosyl imidates. *Liebigs Ann.*, **1996**, 1417.
11. Zhu, T.; Boons, G.-J. *Angew. Chem., Int. Ed. Engl*., **1999**, *38*, 3495.
12. Burkhart, F.; Zhang, A.; Wacowich-Sgarbi, S.; Wong, C.-H. *Angew. Chem. Int. Ed.*, **2001**, *40*, 1274.

13. Bosse, F.; Marcaurelle, L. A.; Seeberger, P. H.; *J. Org. Chem.*, **2002**, *67*, 6659.
14. a) Goodman, L.; Adv. Carbohydr. Chem. Biochem., 1967, 22, 109. b) Nukada, T.; Be´rces, A.; Zgierski, M. Z.; Whitfield, D. M., *J. Am. Chem. Soc*., **1998**,*120*, 13291.
15. a) Lu, J.; Fraser-Reid, B.; *Org. Lett*., **2004**, *6*, 3051. b) van den Bos, L. J.; Dinkelaar, J.; Overkleeft, H. S.; van der Marel, G. A. *J. Am. Chem. Soc*., **2006**, *128*, 13066. c) Hanashima, S.; Castagner, B.; Esposito, D.; Nokami, T.; Seeberger, P. H. *Org. Lett.*, *2007*, *9*, 1777.
16. Slaghek, T. M.; van Oijen, A. H.; Maas, A. A. M.; Kamerling, J. P.; and Vliegenthart, J. F. G. *Carbohydr. Res.*, **1990**, *207*, 237.
17. a) Koto S.; Uchida, T.; Zen, S. *Bull. Chem. Soc. Jpn*., **1973**, *46*, 2520. b) Paulsen, H. *Angew. Chem. Int. Edit. Engl*., **1982**, *21* 155. c) Ogawa, T.; Yamamoto, H.; Nukada, T.; Kitajima, T.; Sugimoto, M.; *Pure Appl. Chem*., **1984**, *56*, 779.
18. Gu, G.; Du, Y.; J. Chem. Soc., *Perkin Trans., 1*, **2002**, 2075.
19. a) Randall, J. L.; Nicolaou, K. C.; *ACS Symp. Ser*., **1988**, *13*, 374. b) Lönn, H.; *Carbohydr. Res*., **1985**, *139*, 105. c) Lönn, H. *Carbohydr. Res*., **1985**, *139*, 115.
20. a) Nicolaou, K. C.; Dolle, R. E.; Papahatjis, D. P.; Randall, J. L. *J. Am. Chem. Soc*., **1984**, *106*, 4189. b) Nicolaou, K. C.; Caulfield, T.; Kataoka, H.; Kumazawa, T. *J. Am. Chem. Soc*., **1988**, *110*, 7910.
21. Mehta, S.; Pinto, B. M. *J. Org. Chem*., **1993**, *58*, 3269.
22. Halcomb, R. L.; Danishefsky, S. J. *J. Am. Chem. Soc*., **1989**, *111*, 6661.
23. a) Paulsen, H. *Angew. Chem. Int. Ed. Engl*., **1995**, *34*, 1432. b) Demchenko, A. V.; Meo, C. D. *Tetrahedron Lett.* **2002**, *43*, 8819.
24. Kanie, O.; Ito, Y.; Ogawa, T. *J. Am. Chem. Soc*., **1994**, *116*, 12073.
25. a) Fraser-Reid, B.; Udodong, U. E.; Wu, Z. F.; Ottosson, H.; Merritt, J. R.; Rao, C. S.; Roberts, C.; Madsen, R.. *Synlett*, **1992**, 927. b) Konradsson, P.; Mootoo, D. R.; McDevitt, R. E.; Fraser-Reid, B.; *J. Chem. Soc., Chem. Commun*., **1990**, 270. c) Ratcliffe, A. J.; Konradsson, P.; Fraser-Reid, B. *J. Am. Chem. Soc*., **1990**, *112*, 5665.
26. a) Mootoo, D. R.; Konradsson, P.; Udodong, U.; Fraser-Reid, B. *J. Am. Chem. Soc.* **1988**, *110*, 5583. b) Fraser-Reid, B.; Wu, Z.; Udodong, U. E.; Ottosson, H. *J. Org.*

Chem. **1990**, *55*, 6068. c) Lu, J.; Jayaprakash, K. N.; Schlueter, U.; Fraser-Reid, B. *J. Am. Chem. Soc.* **2004**, *126*, 7540.

27. a) Pornsuriyasak, P.; Demchenko, A. V. *Tetrahedron Asymmetry*, **2005**, *16*, 433. b) Huang, X.; Huang, L.; Wang, H.; Ye, X. S. *Angew Chem., Int. Ed*., **2004**, *43*, 5221. c) Zhang, Z.; Ollmann, I. R.; Ye, X. S.; Wischnat, R.; Baasov, T.; Wong, C.-H. *J. Am. Chem. Soc*., **1999**, *121*, 734.
28. Raghavan, S.; Kahne, D. *J. Am. Chem. Soc*. **1993**, *115*, 1580.
29. a) Kim, J. H.; Yang, H.; Boons, G.-J. *Angew. Chem. Int. Ed.* **2005**, *44*, 947. b) Garegg, P. J. *Adv. Carbohydr. Chem. Biochem.* **1997**, *52*, 179. c) Danishefsky, S. J.; Biolodeau *Angew. Chem. Int. Ed. Engl.* **1996**, *35*, 1380. d) Schmidt, R. R.; Kinzy, W. *Adv. Carbohydr. Chem. Biochem.* **1994**, *50*, 21.
30. a) Mootoo, D. R.; Date, V.; Fraser-Reid, B. *J. Am. Chem. Soc.* **1988**, *110*, 2662. b) Garegg, P. J. *Adv. Carbohydr. Chem. Biochem.* **1997**, *52*, 179. c) Crich, D.; Smith, M. *J. Am. Chem. Soc.* **2001**, *123*, 9015. d) Demchenko, A. V.; Pornsuryasak, P.; Meo, C. D.; Malysheva, N. N. *Angew. Chem. Int. Ed.* **2004**, *43*, 3069. e) Boons, G.-J.; Heskamp, B.; Hout, F. *Angew. Chem. Int. Ed. Eng.* **1996**, *35*, 2845. f) Kim, K. S. ; Kim, J. H.; Lee, Y. J.; Park, J. *J. Am. Chem. Soc.* **2001**, *123*, 8477. g) Kim, J.-H.; Yang, H.; Boons, G. -J. *Angew. Chem. Int. Ed.* **2005**, *44*, 947. h) Lam, S. N.; Gervay-Hague, J. *Carbohydr. Res.* **2002**, *337*, 1953. i) Lam, S. N.; Gervay-Hague, J. *J. Org. Chem.* **2005**, *70*, 8772. j) Du, W.; Gervay-Hague, J. *Org. Lett.* **2005**, *7*, 2063.
31. a) Maurya, S. K.; Hotha, S. *Tetrahedron Lett.* **2006**, *47*, 3307. b) Kashyap, S.; Hotha, S. *Tetrahedron Lett.* **2006**, *47*, 2021. c) Kashyap, S.; Vidadala, S. R.; Hotha, S. *Tetrahedron Lett.* **2007**, *48*, 8960.
32. Hotha, S.; Kashyap, S. *J. Am. Chem. Soc.* **2006**, *128*, 9620
33. Vidadala, S. R.; Hotha, S. *Chem. Commun.* **2009**, 2505.
34. a) Sureshkumar, G.; Hotha, S. *Chem. Commun.* **2008**, 4282. b) Sureshkumar, G.; Hotha, S. *Tetrahedron Lett.* **2007**, *48*, 6564.
35. Vidadala, S. R.; Thadke, S. A.; Hotha, S. *J. Org. Chem.* **2009,** *74*, 9233.

****

Chapter 2

Alkyl glycosides as stable glycosyl donors for oligosaccharide synthesis

Chapter 2: Introduction

Glycoconjugates are the biopolymers formed by an oligosaccharide moiety joined to a protein (glycoprotein) or to a lipid moiety (glycolipids). These biopolymers together with proteins and nucleic acids are mainly responsible of information transfer between cells, cell growth, motility and morphology and differentiation which are the fundamental processes of life and central to all cellular systems.[1] Enormous number of biological studies on naturally products such as membranes, cell walls, and antibiotics and the mechanisms of these substances showed the biological significance of the glycons of glycoconjugates.[2]

Complex oligosaccharides in the form of glycolipids and glycoproteins present in the cell membranes can mediate diverse biological functions such as inflammation, immune response, metastasis, fertilization and many other important biomedical processes.[3] Compared with other biopolymers such as nucleic acids, proteins and peptides, in which their biological activity depends on their sequence of nucleotides or amino acids, in the case of oligosaccharides, the situation is more complex. For oligosaccharides, besides the sequence of monomeric structures, other aspects such as the functional groups and their stereochemistry, the conformation of sugars, selective formation of glycosidic linkages *etc* must be considered. Moreover the availability of these oligosaccharides for the study is very low as they are present in very less concentrations in nature and in micro-heterogeneous forms which complicate their isolation and characterization.

All these facts have made the area of oligosaccharide synthesis most challenging for the chemical synthesis. The chemical synthesis of oligosaccharides often involves a glycosylation reaction between a glycosyl donor and an aglycon. The glycosyl donor (**A**), a fully protected saccharide unit that possesses an appendage which can be activated to become a leaving group (L) at the anomeric position where as the aglycon (ROH) frequently bears only one hydroxyl group (Figure 1). Activators promote the easy formation of an oxocarbenium ion intermediate (**B**) which will then be attacked by the aglycon to afford glycosides (**C**) (Figure 1).

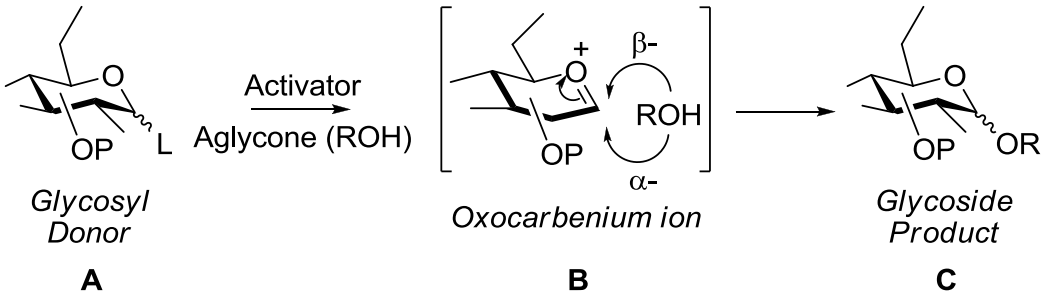


Figure 1

After the major historical advance of Koenigs-Knorr method in 1901, considerable attention has been directed toward the efficacy of *O*-glycosylations. Several glycosylation methods were developed using different glycosyl donors such as glycosyl halides[4], 1,2-orthoesters[5], thioglycosides[6], glycosyl trichloroacetimidates[7], *n*-pentenyl glycosides[8], glycosyl phosphites[9], glycosyl phosphates[10], glycosyl sulfoxides[11], selenoglycosides[12], glycals[13] and vinyl glycosides[14] (Figure 2). Recently, 1-Hydroxy sugars[15], glycosyl iodides[16], glycosyl acetates[17], glycosyl thioimidates[18], and carboxy benzyl glycosides[19] have also been reported as glycosyl donors for oligosaccharide synthesis (Figure 2).

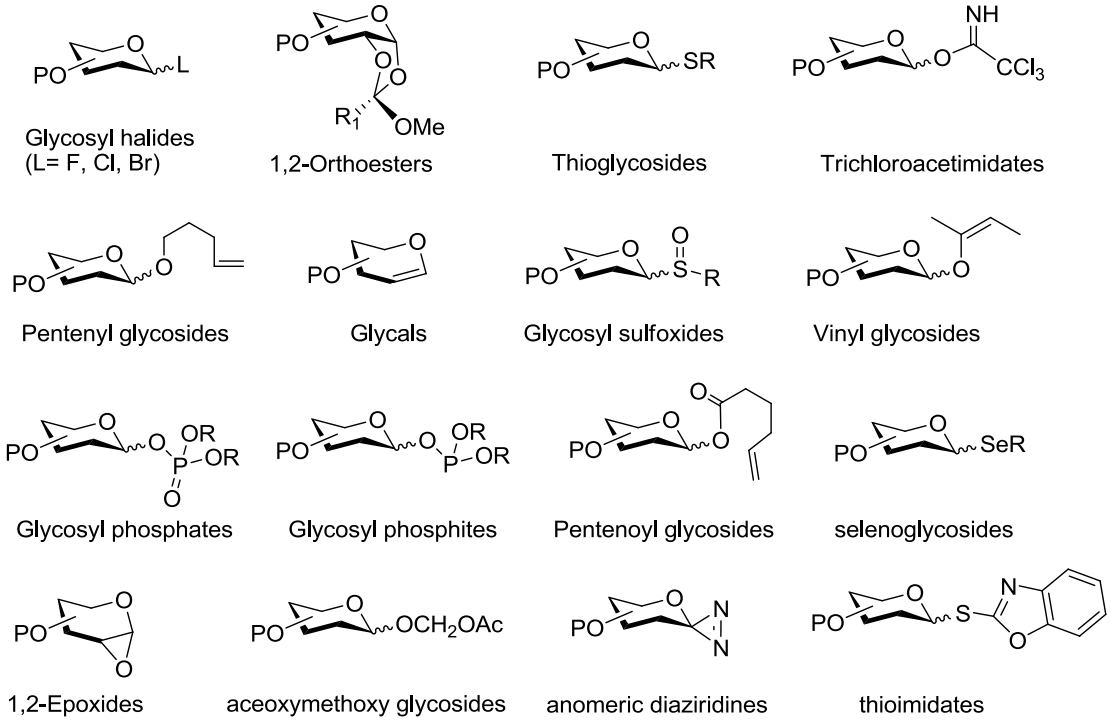
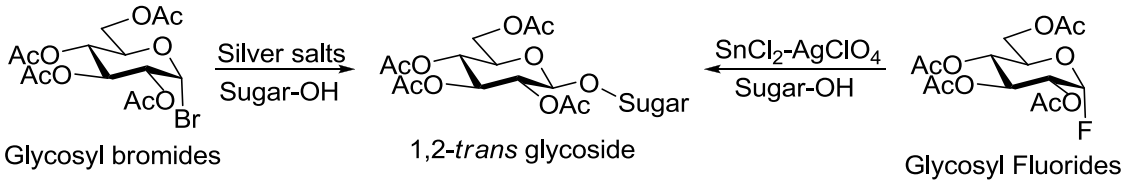


Figure 2

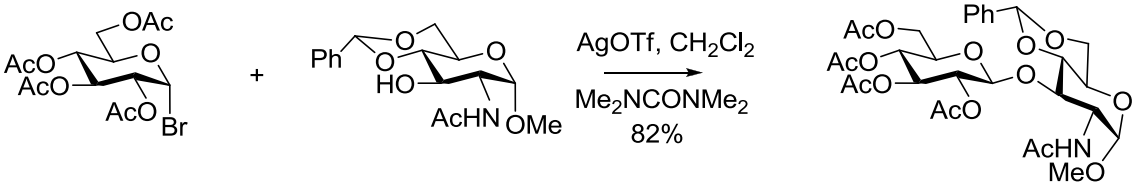
Glycosyl Halides[20]

Scheme 1



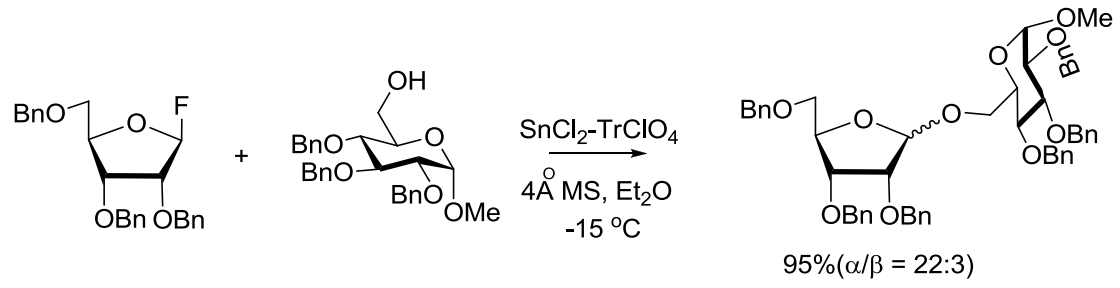
The use of glycosyl bromide or chloride as an effective glycosylation donor in the glycosylation reaction was first introduced by Koenigs and Knorr in 1901.[20] Heavy metal salts such as AgOTf, Ag_2O, Ag_2CO_3, $AgClO_4$, $AgNO_3$, Ag-silicate, $Hg(CN)_2$, $HgBr_2$, $HgCl_2$ and their combinations were used as activators (Scheme 1 & 2). Further, Tetramethyl urea, HgO, *s*-collidine were frequently used as acid scavengers and water was removed by Drierite and molecular sieves.[20] Later, Lemieux and co-workers introduced a mild glycosylation procedure using $Bu_4N^+Br^-$ that led to the elegant synthesis of several blood group antigenic determinants.[20]

Scheme 2



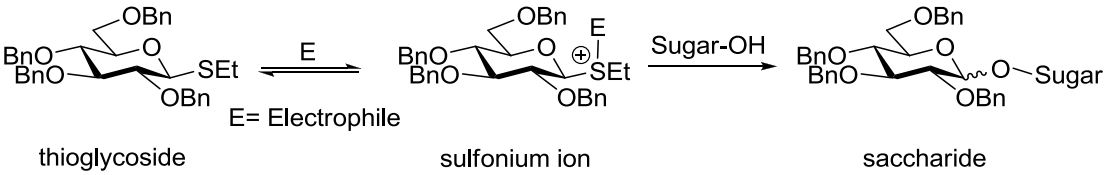
Lack of stability as well as the use of excess silver salts (usually four equivalents) and the problem concerning the disposal of mercuric salts are major drawbacks of this method. In 1981, Mukaiyama *et al*. introduced glycosyl fluorides as glycosyl donor in the presence of $SnCl_2$-$AgClO_4$.[20] The introduction of fluorine as leaving group is good alternative to the Köenings-Knorr method which was extended to furanosides as well (Scheme 3).[20]

Scheme 3



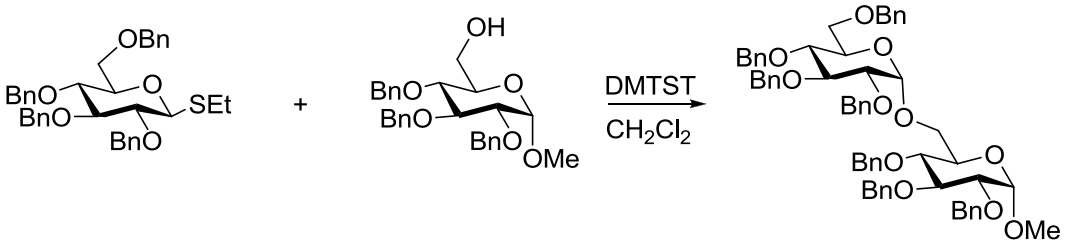
Thio glycosides[21]

Scheme 4



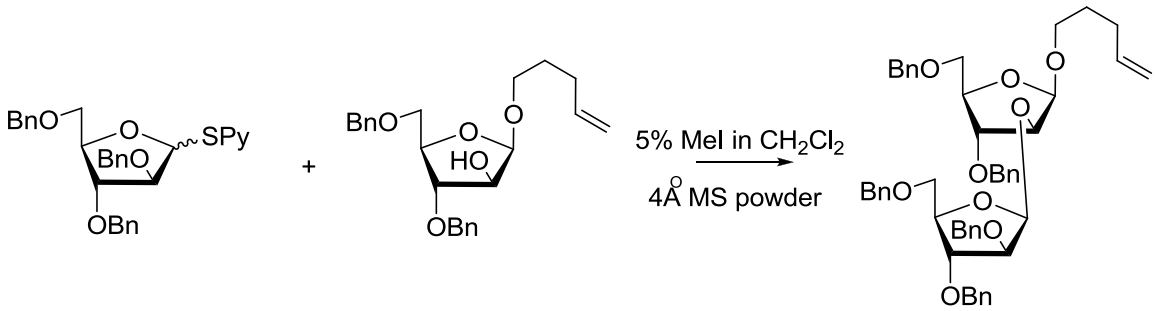
Thioglycosides have been extensively studied as useful glycosyl donors for oligosaccharide synthesis due to their weak basicity, low reactivity and stability. In this method, the promoter activates the sulphur of thioglycoside producing an intermediate sulfonium ion which in turn departs to form oxocarbenium ion and subsequently, trapped with the glycosyl acceptors to offer glycosides and saccharides (Scheme 4). After the initial observation by Ferrier, a whole range of promoters have been developed for the activation of thioglycosides which involves CH_3OTf, DMTST, PhSeOTf, NIS/TfOH and IDCP (Scheme 5).

Scheme 5



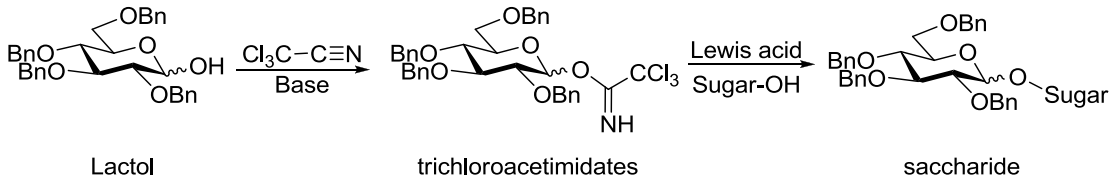
Later in 1990, the efficacy of the thioglycosides was extended to furanosides by Mereyala *et al* for the synthesis of pentaarabinofuranosyl structure motif A which is present in the cell wall of *Mycobacterium tuberculosis* (Scheme 6).[21]

Scheme 6



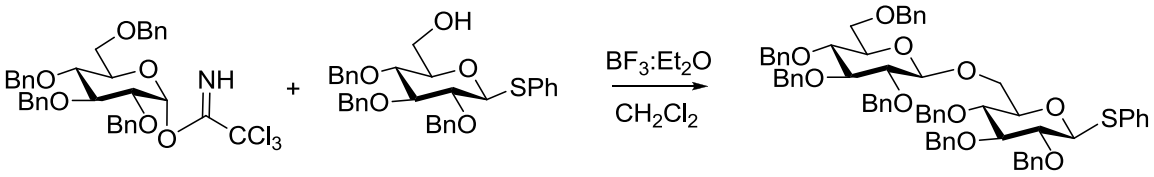
Trichloroacetimidates[22]

Scheme 7



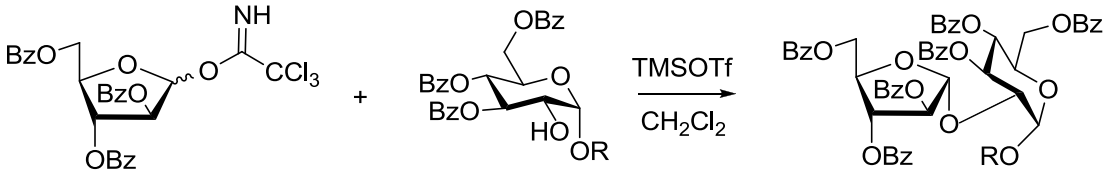
Trichloroacetimidates glycosylation was developed by Schmidt and his co-workers in 1980 as an alternative method to Koenigs-Knorr method. Trichloroimidate glycosyl donor was easily synthesized from the corresponding 1-hydroxy sugar by treatment of trichloroacetonitrile in the presence of a base such as K_2CO_3, NaH, or DBU. The glycosylation reaction can be promoted by catalytic use of $BF_3.Et_2O$ or TMSOTf (Scheme 7 & 8). Trichloroacetimidates have been widely used in the synthesis of many natural products and is the most versatile one among all.

Scheme 8



Later, Trichloroacetimidates were extended to furanosides by Kong *et al.* in 1999 and synthesized fully benzoylated tetrasaccharide, whose free form is indispensable to the antibiotic Ristomycin A (Scheme 9).[22]

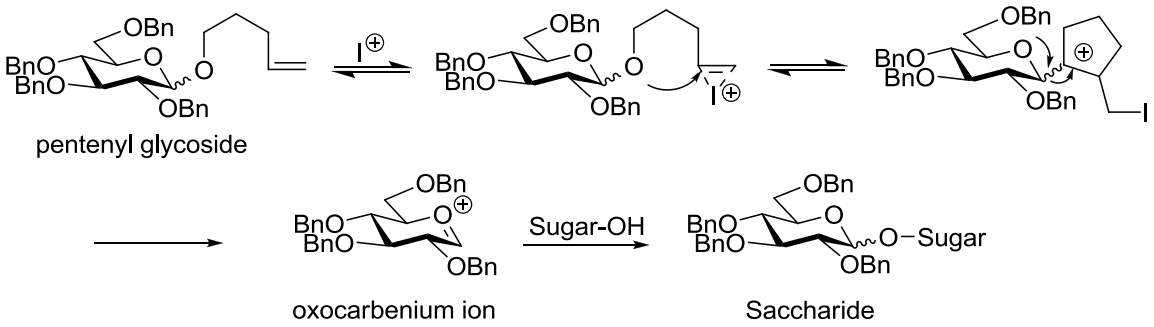
Scheme 9



4-Pentenyl Glycosides[23]

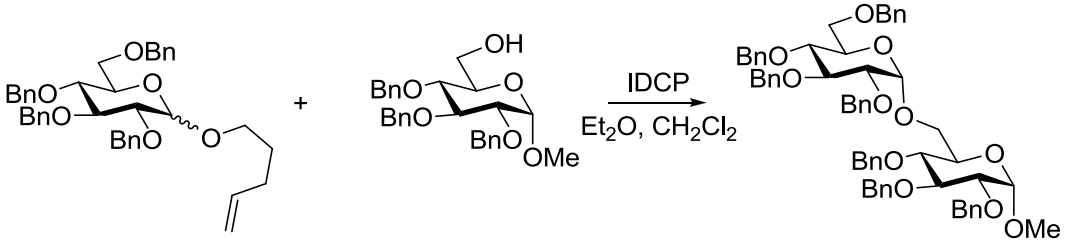
Fraser-Reid and his co-workers introduced *n*-pentenyl glycosides as effective glycosyl donors in 1988. The promoters used for these reactions are NIS alone or NIS/Et_3SiOTf or NIS/TfOH or IDCP (Scheme 10 & 11).

Scheme 10



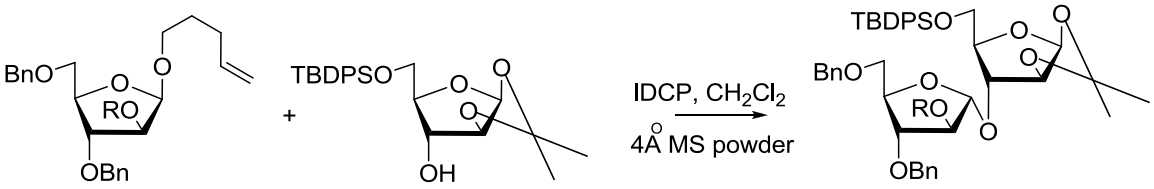
Eletrophilic addition of iodonium ion to the olefin of the *n*-pentenyl group leads to the intramolecular cyclization with simultaneous extrusion of cyclized tetrahydrofurfuryl iodide to form oxocarbenium ion that can be attacked by the aglycon to form the transglycosylated product (Scheme 10).

Scheme 11



n-pentenyl furanosides were developed by Mereyala *et al.* in 1998 for the synthesis of oligosaccharide motifs present in *Mycobacterium tuberculosis* (Scheme 12).[23]

Scheme 12

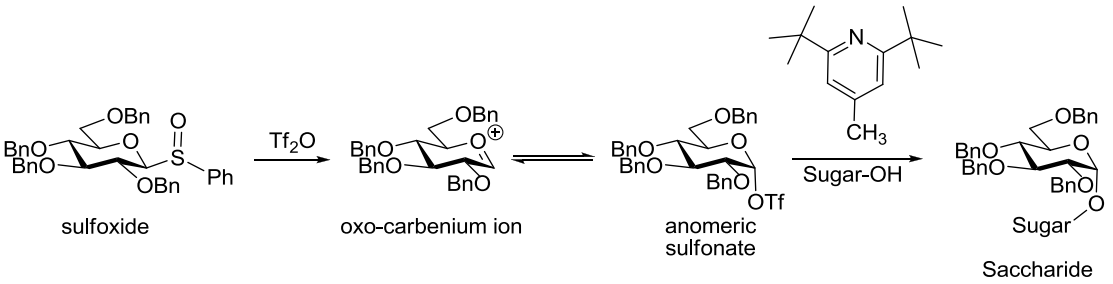


Glycosyl sulfoxides[24]

Kahne *et al*. introduced the sulfoxide method which is one of the most popular protocols especially for the synthesis of β-mannosides.[24] Glycosyl sulfoxides can be prepared by the oxidation of corresponding thioglycosides, which is activated by triflic

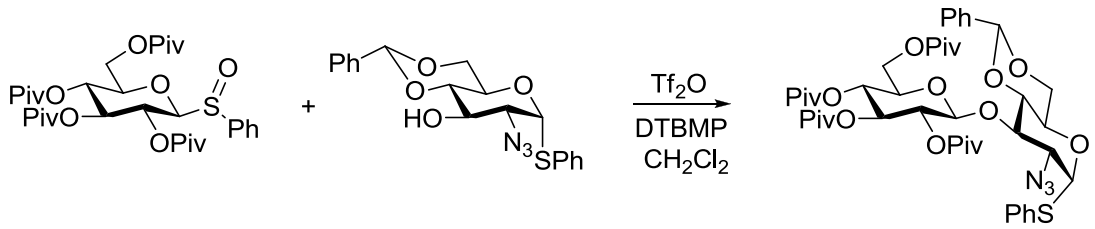
anhydride (Tf_2O) at -78°C followed by the addition of 2,6-di-*tert*-butyl-4-methylpyridine and alcohols to get glycosides (Scheme 13 & 14).

Scheme 13



David Crich suggested that the formation of intermediate glycosyl sulfonates at low temperature enhances the 1,2-*cis* glycosylation. The strength of the method is that some very unreactive acceptors also can be glycosylated under mild conditions.

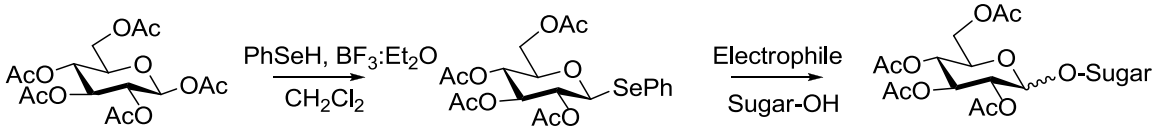
Scheme 14



Selenoglycosides[25]

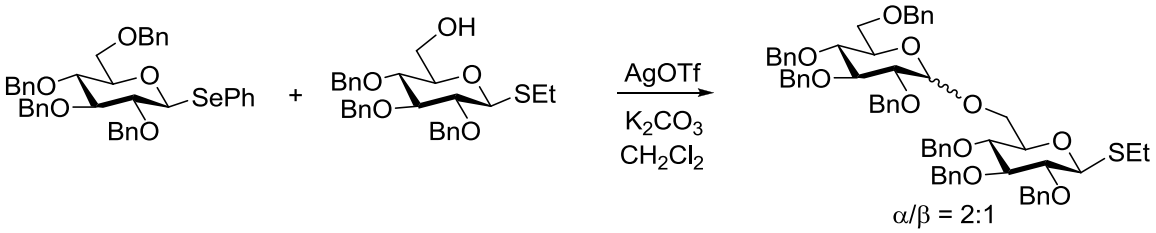
Selenoglycosides were synthesized from corresponding peracetylated glycosides, using Lewis acid and phenyl selenol. The promoters used for the reaction are $AgOTf/K_2CO_3$, NIS, IDCP, NIS/TfOH. Phenylseleno glycosides are more reactive then thioglycosides allowing chemoselective glycosylations (Scheme 15).

Scheme 15



Both *C*-2 acylated and benzylated glycosyl donors can be activated with AgOTf. The glycosylation is quenched by the addition of tetramethylurea or collidine. Thioglycosides are usually stable towards AgOTf, so orthogonal glycosylations are feasible (Scheme 16).

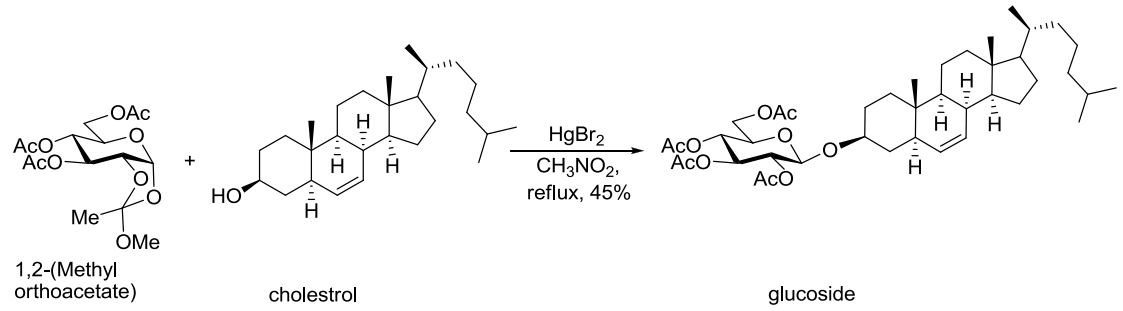
Scheme 16



1,2-Orthoesters[26]

1,2-Orthoester is a latent *C-2* glycosyl donor, widely studied by Kochetkov *et al.* in 1960, and employed for the stereoselective synthesis of 1,2-*trans* glycosides. The first paper was published in 1967 using 3,4,6-tri-*O*-acetyl-α-D-glucopyranose 1,2-(methyl orthoacetate) and cholesterol in presence of $HgBr_2$ in nitromethane at reflux temperature (Scheme 17). Glucosyl and galactosyl donors offer β-glucosides and β-galactosides whereas, mannosyl 1,2-orthoester gives α-mannosides. Further, ethyl, isopropyl, *tert*-butyl and cyano 1,2-orthoesters as glycosyl donors have been studied by Kochetkov *et al*. for the effect of leaving ability of substituted alkyl group present in the 1,2-orthoester to the stereoselective synthesis of 1,2-*trans* glycosides. Fraser-Reid *et al*. reported pentenyl 1,2-orthoesters as glycosyl donors in the presence of NIS/$Yb(OTf)_3$ to get 1,2-*trans* glycosides and saccharides.

Scheme 17



Very recently, Sureshkumar *et al*. reported propargyl 1,2-orthoesters as glycosyl donors in the presence of catalytic amount of $AuBr_3$ for the stereoselective synthesis of 1,2-*trans* glycosides as well as disaccharides. For 1,2-*trans* stereoselective glycosylation, benzoate and pivolate protected 1,2-orthoesters are generally recommended as compared to acetate since the former reduces the formation of transorthoester.

Glycals[27]

Glycals were first used in oligosaccharide synthesis by Lemieux in 1960s. Glycals can be used as glycosyl donors in two routes, *viz* in first method, *in situ* activation makes the glycal as a glycosyl donor, where as in the second method, glycal was first converted into a glycosyl donor through different reactions (epoxidation, azidonitration or sulfonamide glycosylation), followed by the actual glycosylation (Figure 3).

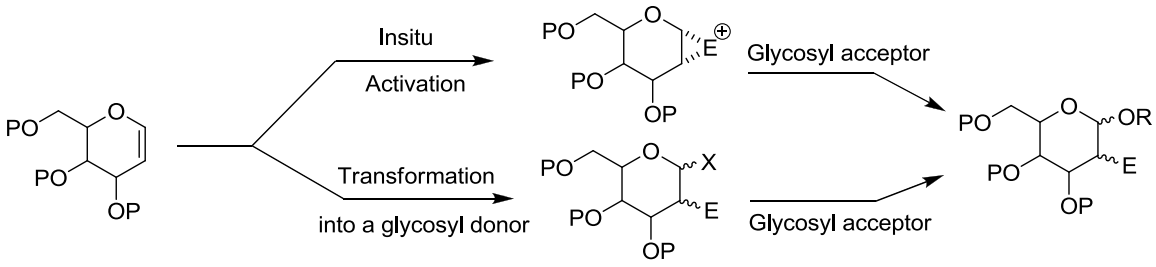
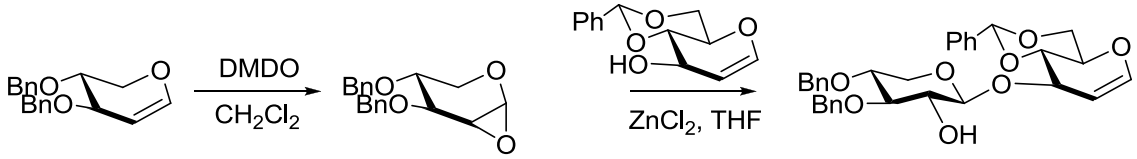


Figure 3

Promotors used for the reaction are IDCP, NBS, NIS for the synthesis of 2-deoxy-2-halo-α-glycosides, which were easily converted to 2-*deoxy*-α-glycosides upon reductive halogenation. In other way, DMDO oxidation of glycal to give 1,2-anhydrosugar, followed by activation under Lewis acids such as $ZnCl_2$ result in the disaccharide with 1,2-*trans* selectivity (Scheme 18).

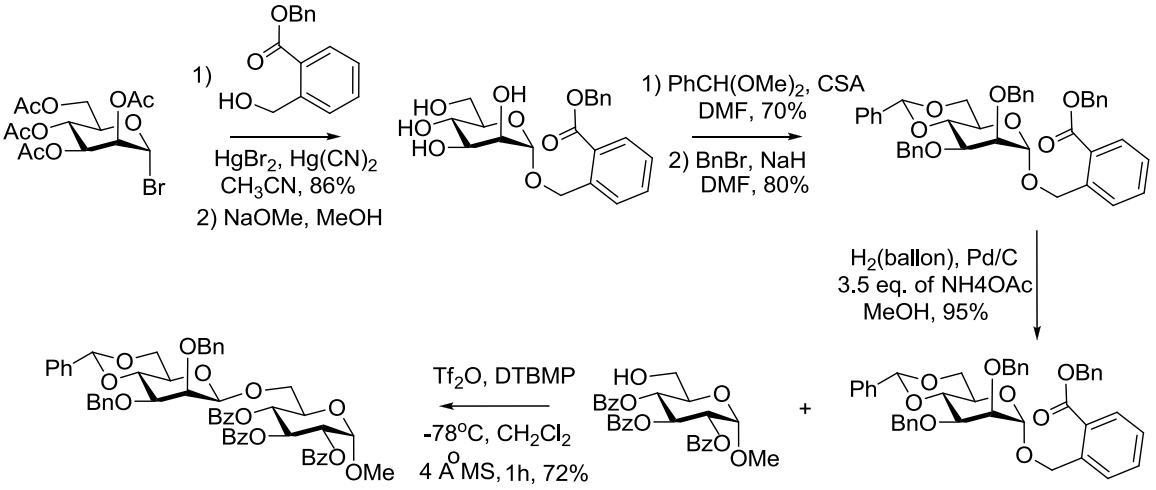
Scheme 18



Carboxy benzyl[28]

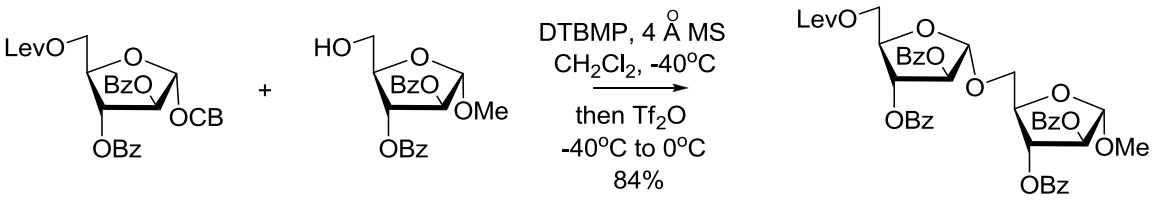
Carboxy benzyl glycosides were developed by Kim *et al.* in 2001 for the efficient synthesis of β-mannosylations. These glycosides were synthesized from the corresponding per-*O*-acetylated glycosyl bromide using $HgBr_2$, $Hg(CN)_2$, followed by deacetylation, benzylation and selective hydrogenolysis. Promoters used for the glycosylation were the combination of DTBMP and Tf_2O at -78^oC to result β-mannosides (Scheme 19).

Scheme 19



Later, the method was applied for the synthesis of β-arabinofuranosylations by acceptor dependent stereoselective glycosylations in which acyl protecting group was found to be essential for selectivity and using the glycosylation method, octaarabinofuranoside was synthesized (Scheme 20).[28]

Scheme 20



****

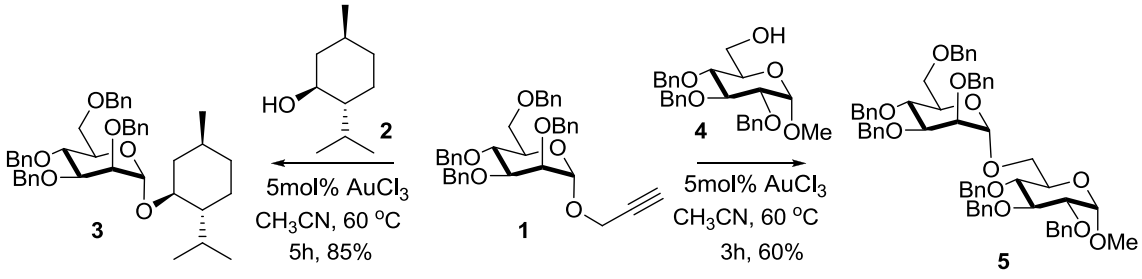
Chapter 2: Present Work

Cell surface carbohydrates are present in the form of glycolipids and glycoproteins mediate diverse biological functions. For example, glycoproteins and glycolipids are reported to implicate information transfer between cells and have important roles in stability, proliferation, embryogenesis etc. Oligosaccharides are capable of inducing a protective antibody response, which is a major contributor for the survival of the micro-organisms during infection.

The development of stable, efficient and stereoselective glycosylation methodologies has attracted a great deal of attention in recent years due to the biological significance of many complex oligosaccharides and glycoconjugates. To date, many innovative glycosylation methodologies have been developed. However, most of these address the preparation of pyranosyl glycosides. In contrast, studies on stereoselective furanosylations have been limited. Nevertheless there is a need for methods to enable preparation of furanosides in a stereoselective manner, given the critical role of furanosides in the life cycle of a number of microorganisms.[29]

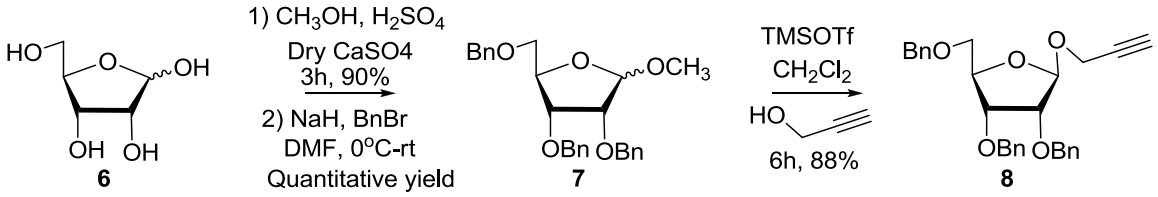
In our laboratory, propargyl pyranosides were exploited for the synthesis of various glycoconjugates using catalytic amount of gold halides.[30] For example, propargyl 2,3,4,6 tetra-*O*-benzyl-α-D-mannopyranoside (**1**) was treated with menthol (**2**) and methyl 2,3,4 tri-*O*-benzyl-α-D-glucopyanoside (**4**) in the presence of 5 mol% of $AuCl_3$ at 60°C to get corresponding menthyl mannoside (**3**) and disaccharide (**5**) in good yields (Scheme 21).

Scheme 21



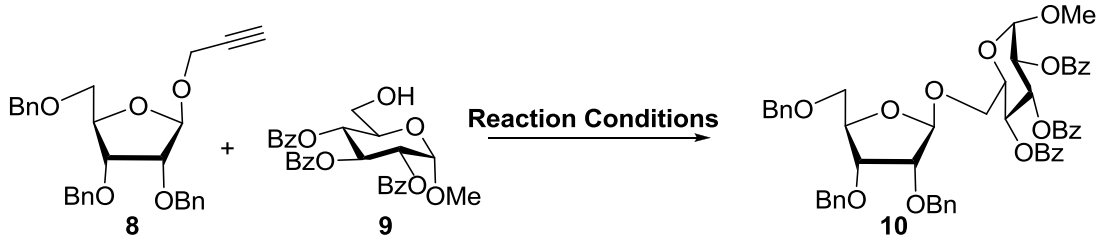
Successful synthesis of various glycoconjugates using propargyl pyranosides as glycosyl donors encouraged us to explore propoargyl furanosides as glycosyl donors. We started our synthetic endeavor with the preparation of propargyl 2,3,5-tri-*O*-benzyl-β-D-ribofuranoside (**8**).

Scheme 22



Fischer glycosylation of D-ribose in methanol and H_2SO_4 acid resulted the formation of methyl ribofuranoside which upon benzylation followed by the reaction with propargyl alcohol in the presence of TMSOTf in CH_2Cl_2 gave required propargyl ribofuranoside **8** (Scheme 22). Direct Fischer glycosylation with propargyl alcohol was not found to be suitable due to the formation of propargyl pyranoside along with furanoside which are found to be difficult for separation.

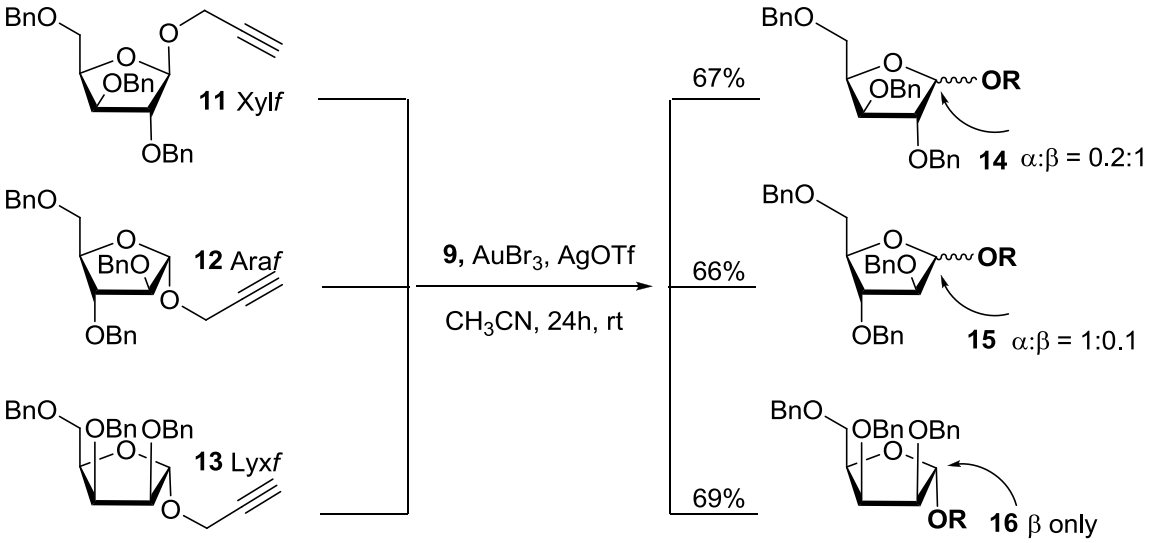
Table 1



S.No	Reagents	Temparature(°c)	Time(h)	% Yield
1	10 mol% $AuCl_3$, CH_3CN	RT	48	41
2	10 mol% $AuBr_3$, CH_3CN	RT	48	55
3	8 mol% $AuCl_3$, $AgBF_4$, CH_3CN	RT	24	54
4	8 mol% $AuCl_3$, AgOTf, CH_3CN	RT	24	60
5	8 mol% $AuBr_3$, AgOTf, CH_3CN	RT	24	72
6	8 mol% $AuBr_3$, AgOTf, CH_3CN	60	24	72

In general, furanosides are more reactive compared to pyranosides and thus initial tranglycosylations were carried out at room temperature. The glycosylation reaction between propargyl ribofuranoside (**8**) and methyl 2,3,4-tri-*O*-benzoyl-α-D-glucopyranoside (**9**) were treated with $AuCl_3$ in acetonitrile to result in the formation of disaccharide **10** (Table 1). Interestingly, 1,2-*trans* stereoselectivity was observed in the transglycosylation reaction, but the reaction did not go to completion even after 48h.[31] Changing the catalyst to $AuBr_3$ improved the yield but not satisfactorily. Then the combination of silver salts with gold catalysts were found to be beneficial, the best results were obtained for the transglycosylation with the combination of $AuBr_3$ and AgOTf to yield 72% of disaccharide **10**, after 24h (Table 1). Changing the reaction temperature from rt to 60°C did not improve the yield. Switching the solvent from acetonitrile to dichloromethane and/or addition of 4Å molecular sieves powder was harmful to the progress of the reaction. Nevertheless, above studies showed the combination of $AuBr_3$ and AgOTf as an effective promoter for the transglycosylation (Table 1).[31]

Scheme 23



Encouraged by the observed 1,2-*trans* stereoselectivity, xyl*f* **11** was subjected to the same reaction conditions (8 mol % of $AuBr_3$ and AgOTf) with aglycone **9** to observe the 5:1 diastereomeric mixture of 1,2-*trans* (β-) and 1,2-*cis* (α-) disaccharides **14** in 67% yield. Similar experiments with ara*f* derivative **12** gave again diastereomeric

mixture of 10:1 1,2-*trans* (α-) and 1,2-*cis* (β-) disaccharides **15** in 66% yield whereas lyx*f* derivative **13** resulted in **16** as 1,2-*trans* (α-) isomer only in 69% yield (Scheme 23).

To better understand reasons for the observed experimental trends molecular modeling calculations have been performed in collaboration with Dr. G. Narahari Sastry at IICT. Various conformations of the products generated along with the relative energies, obtained at AM1 level. This enabled us to systematically sample the conformational space and take the most stable conformation to be subjected to rigorous B3LYP method with 6-31G(d) basis set. The relative reaction energies at B3LYP/6-31G(d) level of theory are depicted in Figure 4.[31]

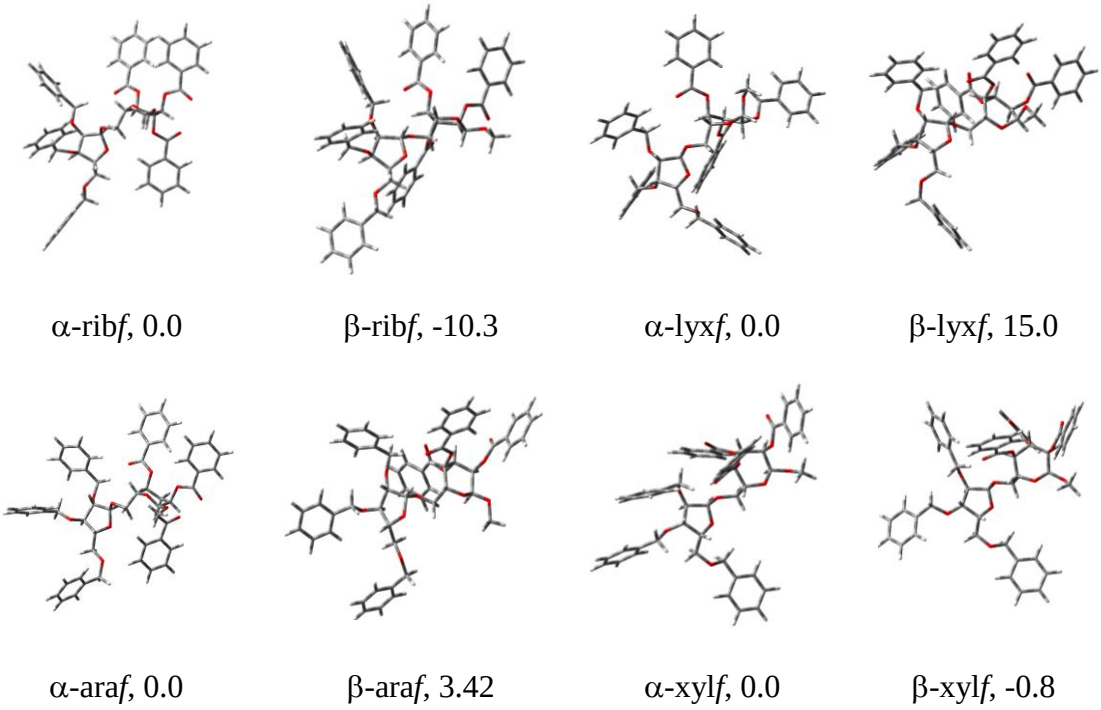


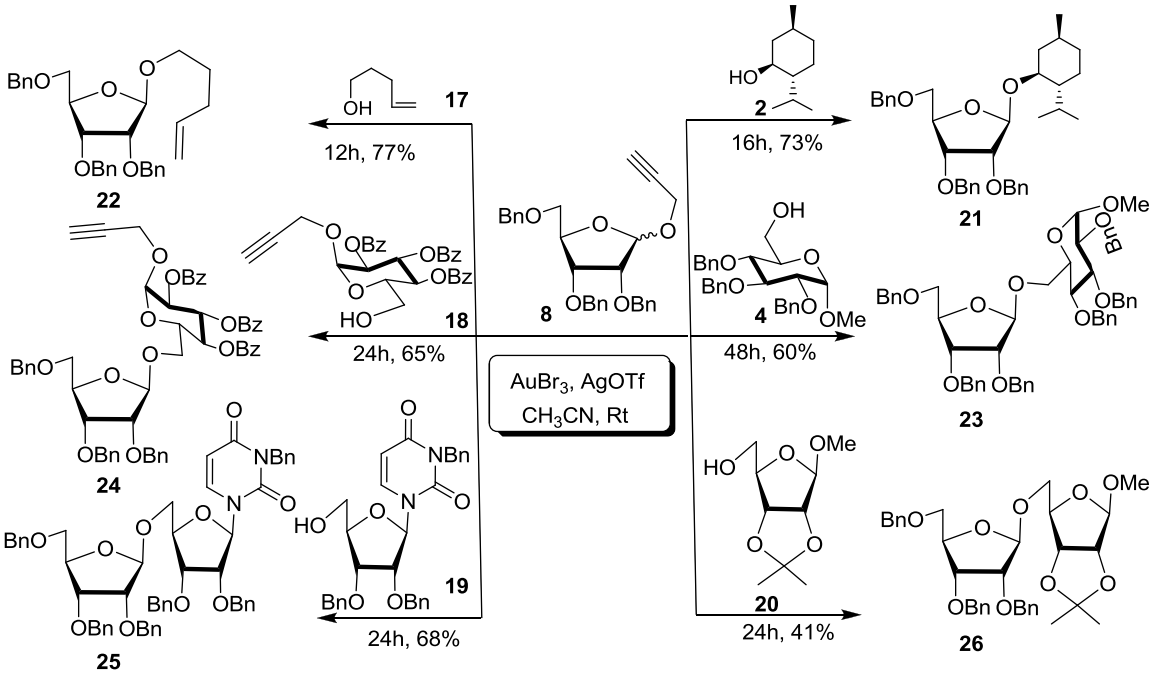
Figure 4

From Figure 4, it can be observed that the difference in the relative reaction energies of α and β isomers of rib*f* is -10.3 kcal/mol which suggests that β isomer is preferred over α isomer. In contrast to these results the difference in the relative reaction energies of α and β isomers of lyx*f* is about 15.0 kcal/mol which in turn suggests the formation of α isomer over β isomer. The differences in the relative

reaction energies of α and β isomers for ara*f* and xyl*f* derivatives are 3.42 and -0.8 kcal/mol respectively which indicates that while α isomer is more preferred in case of ara*f*, β isomer is preferred for xyl*f*. However such smaller differences in the reaction energies between the two isomers suggest the feasibility of formation of both the products. Thus the computational results corroborate well with the observed experimental trends.

To understand the generality of the observed facts transfuranosylation of rib*f* **8** were performed with various aglycons ranging from aliphatic (**17**), alicyclic (**2**), carbohydrate (**4**, **18, 20**) and nucleosidic (**19**) aglycons to result into the corresponding glycosides (**21, 22**) as well as disaccharides (**23-26**) with 1,2-*trans* selectivity in good yields except with **20**, that may be due to the presence of 1,2-acetonide and methyl glycoside as explained later in this chapter (Scheme 24).

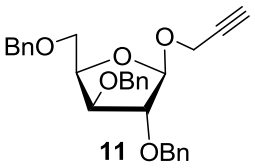
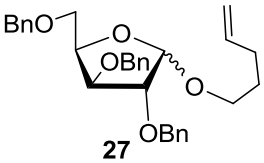
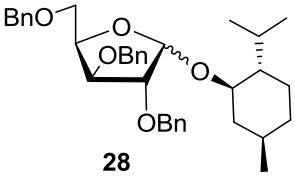
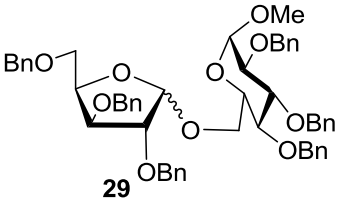
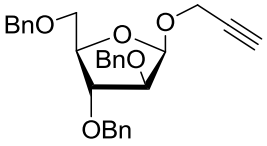
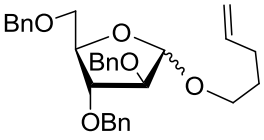
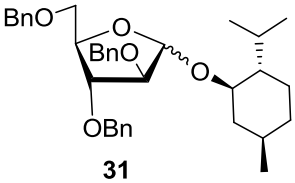
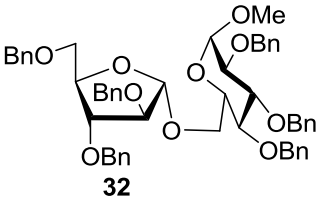
Scheme 24

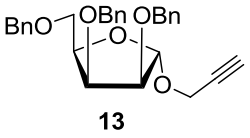
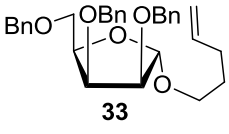
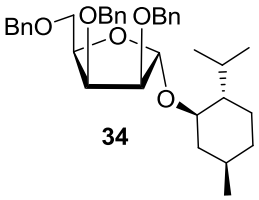
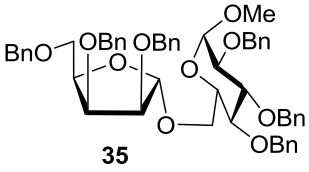
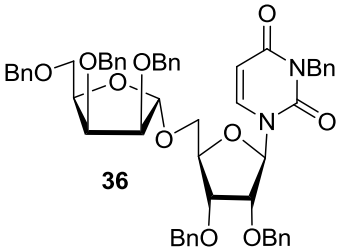


All the products were characterized thoroughly by ^{1}H, ^{13}C, DEPT NMR and mass spectral analysis. For example, the ^{1}H NMR spectrum of disaccharide **26** showed δ 1.28, 1.47 and 3.47 ppm as singlets revealing the presence of acetonide and methyl ribofuranoside, two 1,2-*trans* anomeric peaks were observed as singlets at δ 4.94, 5.02 ppm. Aromatic protons of benzyl ethers were noticed as multiplets at δ 7.24-7.40 ppm.

In addition, ^{13}C NMR spectrum pointed out the characteristic signals due to two β - anomeric carbons at δ 105.4 and 109.2 ppm, quaternary carbon of acetonide group was noticed at δ 112.3 ppm and the rest of the other signals in complete agreement with the assigned structure **26**. Further DEPT NMR spectrum confirmed the five signals with

Table 2

Donor	Acceptor	Product	Time & Yield	(α :β Ratio)
 **11**	**17**	 **27**	12h, 90%	0.2:1
11	**2**	 **28**	18h, 75 %	0.1:1
11	**4**	 **29**	24h, 68%	0.6:1
 **12**	**17**	 **30**	12h, 86%	1:0.2
12	**2**	 **31**	12h, 72%,	1:0.1
12	**4**	 **32**	24h, 65%	1:0.1

Donor	Acceptor	Product	Time & Yield	α :β ratio
 **13**	**17**	 **33**	12h, 85%	α only
13	**2**	 **34**	12h, 75 %	α only
13	**4**	 **35**	24h, 61%	α only
13	**19**	 **36**	24h, 62%	α only

Reagents & Conditions : 10 mol% $AuBr_3$ /AgOTf / CH_3CN / rt

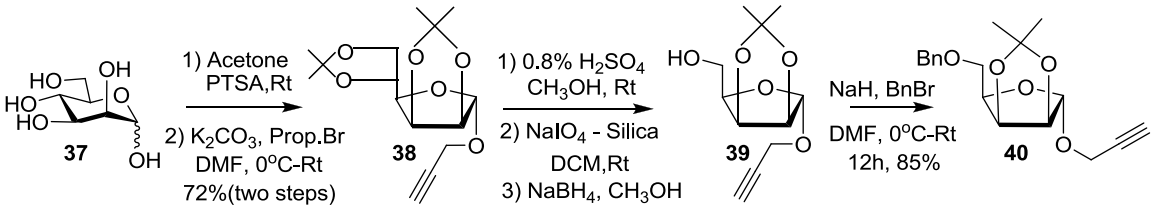
negative intensity for the presence of five methylenes in the assigned disaccharide **26**, and the LC-MS showed a molecular ion base peak at 629.47 (M^++ 23 for Na). Current strategy of transglycosylation was then successfully extended to the other furanosides as well. Propargyl xyl*f* **11**, ara*f* **12**, lyx*f* **13** furanosides were reacted with various aglycons (**2**,**4**,**17**,**19**) under similar conditions to result into the corresponding transglycosylated products (**27**-**29**, **30**-**32**, **33**-**36**) in good yields (Table 2). It has been observed that the lyx*f* gives 1,2-*trans* selectivity where as ara*f* and xyl*f* derivatives resulted in α/β mixtures.

All the products were characterized thoroughly by ^1H, ^{13}C, DEPT NMR and mass spectral analysis. For example, in the ^1H NMR spectrum of disaccharide **29** showed δ 3.32 and 3.35 ppm as methoxy singlets and in the ^{13}C NMR spectrum pointed

out the characteristic signals due to four anomeric carbons (three α and one β) at δ 97.3, 98.0, 98.0 and 104.1 ppm, indicates the α/β mixture of disaccharides. Further, LC-MS showed a molecular ion peak at 889.90 (M^++ 23 for Na).

Trapping the lyxose in furanoside form under acid catalyzed Fischer glycosylation is a difficult proposition and hence looked at the synthesis of propargyl lyxofuranoside (**13**) from mannose. Started with D-mannose followed by acetonide protection, propargylation, selective cleavage of primary acetonide and subsequent cleavage of the diol and reduction with $NaBH_4$ resulted in propargyl lyxofuranoside **39**, which upon benzylation gave mono benzylated propargyl lyxofuranoside **40** (Scheme 25). The ^1H NMR spectrum of compound **40** showed δ 1.28 and 1.47 ppm as acetonide singlets, propargyllic methine appeared at δ 2.40 ppm as triplet (J = 2.4 Hz). 1,2-*trans* anomeric proton was observed as singlet at δ 5.22 ppm. In addition, ^{13}C NMR spectrum pointed out the characteristic signals due to α-anomeric carbon at δ 104.5 ppm, quarternery carbon of acetonide group appeared at δ 112.5 ppm and the rest of the other signals were in complete agreement with the assigned structure **40**. Further, DEPT NMR spectrum showed the three signals (δ 53.9, 68.1, 73.4 ppm) with negative intensity for the three methylene groups in the assigned **40**, and the mass spectrum showed a molecular ion base peak at 341.10 (M^++ 23 for Na).

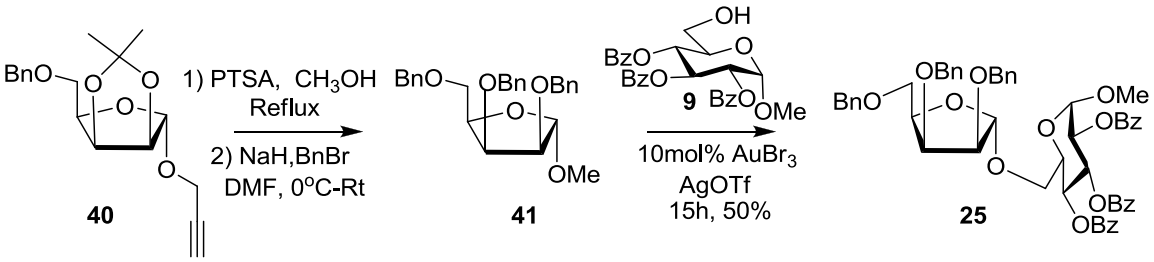
Scheme 25



Hydrolysis of secondary acetonide compound **40** under PTSA, methanol reflux followed by benzylation, shall enable in propargyl 2,3,5-tri-*O*-benzyl-α-lyxofuranoside (**13**), which was directly subjected for glycosylation without any further confirmation under aforementioned glycosylation conditions using aglycone **9** resulting the required disaccharide **25** with 1,2-*trans* stereoselectivity (Scheme 26). Later, we found to our surprise that the glycosyl donor used for the aforementioned glycosylation is not a

propargyl glycoside (**13**) but it is methyl glycoside (**41**), which was confirmed by ^{1}H, ^{13}C, DEPT NMR and mass spectral analysis.

Scheme 26



The ^{1}H NMR spectrum of methyl furanoside **41** showed absence of propargyllic methine at δ 2.40 ppm as triplet instead the presence of methoxy singlet at δ 3.37 ppm reveals the presence of methyl furanoside, resonance at δ 5.02 ppm (d, J = 1.5Hz) showed the anomeric proton 1,2-*trans* selectivity. In addition, ^{13}C NMR spectrum pointed out the α anomeric carbon at δ 106.3 ppm, and the rest of the other resonances were in complete agreement with the assigned structure **41**. Further DEPT NMR spectrum specified the four signals (δ 69.6, 72.5, 73.2 and 73.4 ppm) with negative intensity for the four methylene groups in the assigned structure **41**, and the LC-MS showed a molecular weight peak at 457.49 (M^{+}+ 23 for Na).

Table 3

Aglycone	Glycosyl Donor: Ribf **42**	Xylf **43**	Araf **44**	Lyxf **41**
	Time, Yield, α:β ratio			
9	**10** 24h, 69%, β only	**14** 24h, 65%, 0.2:1	**15** 24h, 60%, 1:0.1	**16** 24h, 60%, α only
17	**22** 12h, 90%, β only	**27** 12h, 91%, 0.4:1	**30** 12h, 85%, 1:0.2	**33** 12h, 89%, α only
2	**21** 16h, 69%, β only	**28** 18h, 75%, 0.4:1	**31** 12h, 71%, 1:0.1	**34** 12h, 66%, α only

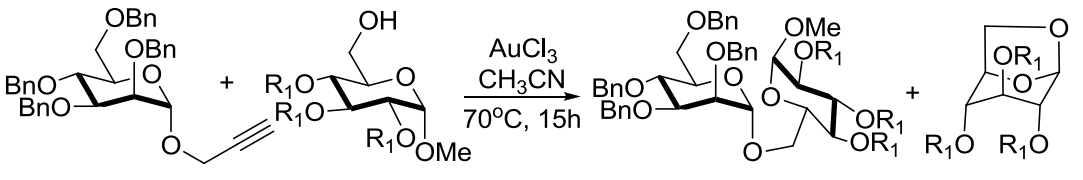
The activation of methyl lyx*f* **41** using catalytic gold bromide to result in the disaccharide **25** was quite surprising because methyl glycosides are one of the earliest

synthesized glycosides which can be easily synthesized from aldoses to lock the anomeric configuration under Fischer's acidic conditions with a wishful thinking that they rarely act as glycosyl donors and they are known to be inert to diverse chemical manipulations. So we probed the utility of methyl furanosides for the synthesis of various glycosides as well as disaccharides.

Initial reaction of the methyl furanosides (**41**-**44**) with aglycone **9** at room temperature did not afford the desired transglycosylated products and hence resorted to optimize reaction conditions. The optimum temperature was found to be 65^{o}C with acetonitrile as the solvent. Using these standard conditions methyl rib*f* **42**, ara*f* **43**, xyl*f* **44** and lyx*f* **41**, furanosyl derivatives were activated with various aglycons (**2**, **9**, **17**) to get corresponding glycosides and disaccharides.[31] Likewise as in case of propargyl furanosides, 1,2-*trans* selectivity was observed with rib*f*- as well as lyx*f*- derivatives and α/β mixture in case of ara*f*- and xyl*f*- derivatives (Table 3). Similar kind of activation of methyl glycosides were observed in glycoconjugate synthesis using propargyl mannopyranoside (**1**) as glycosyl donor and aglycone **4** to synthesize a disaccharide **5** in the presence of 3 mol% of $AuCl_3$ in acetonitrile at 70^{o}C (Scheme 27).[31]

Interstingly, we observed the formation of required disaccharide **5**, along with anhydrosugar (20%) **45**. Fortunately similar kind of anhydro sugar formation was not observed by changing armed benzyl to disarmed benzoates which indicates the activation of methyl glycoside leading to the oxocarbenium ion which was trapped intramolecularly by primary hydroxyl group. For the confirmation, methyl per-*O*-benzyl-α-D-mannopyranoside was synthesized by simple Fischer glycosylation followed by benzylation and reacted with aglycone **9** in the presence of $AuCl_3$ in acetonitrile at 70^{o}C for 24h to afford the disaccharide **46** in 47% of yield, which inferences the fact that methyl glycosides are ***indeed*** acting as stable glycosyl donors under catalytic $AuCl_3$.

Scheme 27

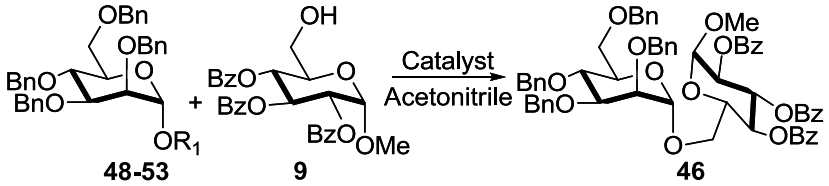


1 **4** R_1 = Bn, **9** R_1 = Bz; **5** R_1 = Bn (60%), **46** R_1 = Bz (78%); **45** R_1 = Bn (20%), **47** R_1 = Bz (0%)

^{1}H NMR spectrum of compound **46** revealed the presence of methoxy protons at δ 3.38 ppm as a singlet. In addition, aromatic protons of benzoates and benzyl ethers were noticed as multiplets at δ 7.13-7.51 and 7.84-8.00 ppm. Further, the ^{13}C NMR spectrum of compound **46** showed two α-anomeric carbons at δ 96.9 and 98.2 ppm and rest of the resonances in complete agreement with the assigned structure. DEPT NMR spectrum of disaccharide **46** indicated the presence of six methylene groups and the LC-MS showed a molecular ion peak at 1051.84 (M^{+}+ 23 for Na).

Changing the catalyst from $AuCl_3$ to $AuBr_3$ improved the yield to 65% (Table 4). AuCl resulted in 32% of the disaccharide **46** whereas Au_2O_3 and $AuPPh_3Cl$ did not show any disaccharide **46** even after 36h (Entries 2-5).[31] $HAuCl_4$ promoted the glycosylation affording **46** in 55% yield along with 15% of the unwanted lactol (Entry 6). Addition of

Table 4



Entry	*R_1*	*Catalyst*	*Glycosyl Donor*	*Time (h)*	*Temp (^{o}C)*	*% Yield*
1.	-CH_3	$AuCl_3$	**48**	24	70	47
2.	-CH_3	$AuBr_3$	**48**	24	70	65
3.	-CH_3	AuCl	**48**	36	70	32
4.	-CH_3	Au_2O_3	**48**	36	70	0
5.	-CH_3	$Au(PPh_3)Cl$	**48**	36	70	0
6.	-CH_3	$HAuCl_4$	**48**	24	70	55
7.	-CH_3	$AuBr_3$,Et_3N	**48**	24	70	0
8.	-CH_3	$BF_3.Et_2O$	**48**	12	30	47
9.	-CH_3	$Sc(OTf)_3$	**48**	24	70	46
10.	-CH_2CH_3	$AuBr_3$	**49**	24	70	31
11.	-$CH(CH_3)_2$	$AuBr_3$	**50**	24	70	45
12.	-CH_2Ph	$AuBr_3$	**51**	36	70	10
13.	-Cholesteryl	$AuBr_3$	**52**	36	70	5
14.	-Allyl	$AuBr_3$	**53**	24	70	15

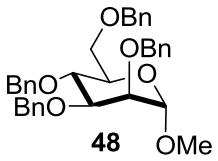
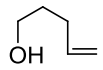
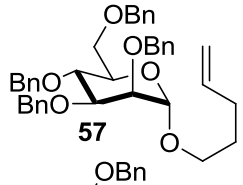
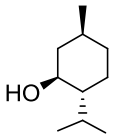
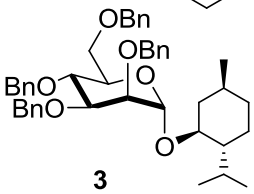
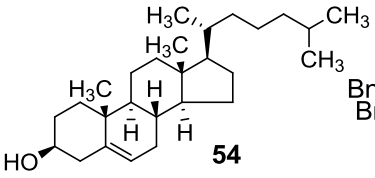
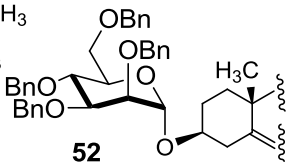
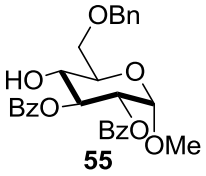
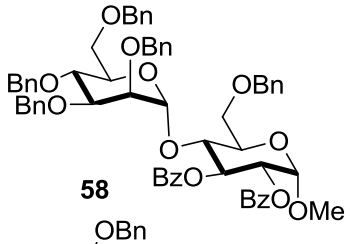
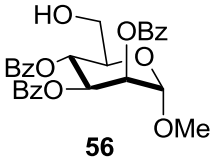
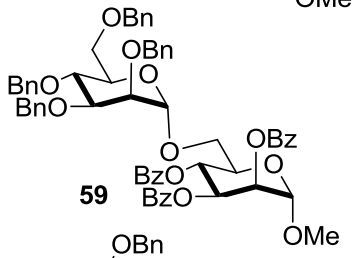
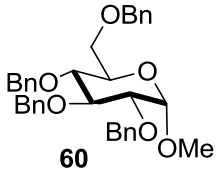
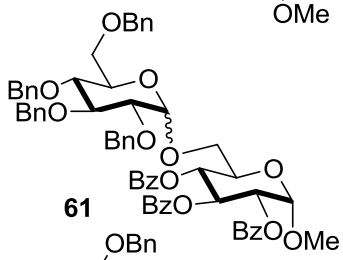
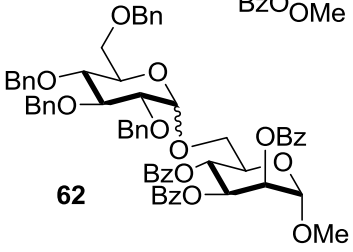
organic bases such as triethylamine was detrimental to the progress of the reaction (Entry 7).[10] The efficacy of the reaction was also checked with other Lewis acids

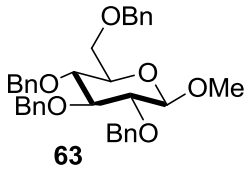
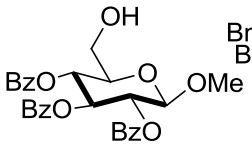
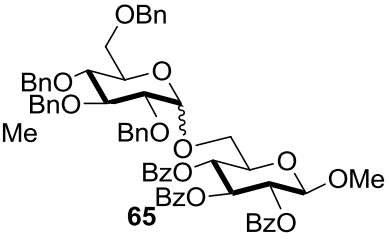
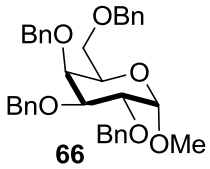
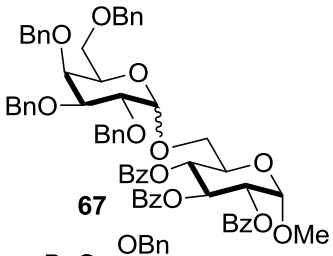
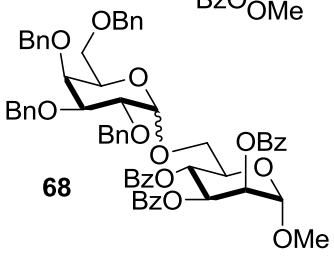
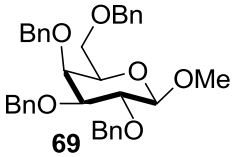
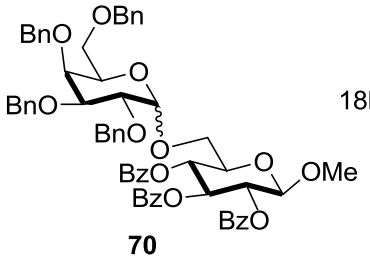
($BF_3.Et_2O$ and $Sc(OTf)_3$) and found to give lower yields (Entries 8,9).[31] The effect of $AuBr_3$ in acetonitrile on selected panel of alkyl glycosides (**49**-**53**) was then investigated. Interestingly, ethyl- (**49**), isopropyl- (**50**) mannosides gave disaccharide **46** in average yields whereas benzyl- (**51**), cholesteryl- (**52**) and allyl- (**53**) glycosides resulted in poor yields of **46** (Entries 10-14) (Table 4). Switching the solvent from acetonitrile to dichloromethane and/or addition of 4Å molecular sieves powder was harmful to the progress of the reaction. Nevertheless, above studies clearly signified that methyl mannopyranoside (**48**) emerged as the best glycosyl donor and $AuBr_3$ in acetonitrile as the promoter, may be due to the inherent Lewis and Brønsted acidity of $AuBr_3$.

Furthermore, the scope of the reaction was gauged by a panel of aglycons comprising 4-penten-1-ol (**11**), menthol (**2**), cholesterol (**54**), and sugar aglycons (**9**, **55**, **56**) and found that the methyl mannoside (**48**) behaves as a glycosyl donor giving good yields of corresponding glycosides (**3, 52, 57**) and disaccharides (**58, 59**) except with **52** which can be attributed to the poor solubility of cholesterol **54** in acetonitrile. The overall yield of **52** could be improved to 64% when the reaction was conducted in acetonitrile-dichloromethane (4:1) (Table 5). All the products were characterized by ^1H, ^{13}C, DEPT NMR and mass spectral analysis. For example, in the ^1H NMR spectrum of disaccharide **58** showed δ 3.41 ppm as singlet for methoxy group, aromatic protons of benzoates and benzyl ethers were noticed as multiplets at δ 6.96-7.50 ppm and δ 7.92-8.01 ppm and the remaining peaks in complete agreement with the assigned structure. In addition, ^{13}C NMR spectrum pointed out two α-anomeric carbons at δ 96.8 and 100.5 ppm. Further DEPT NMR spectrum specified the seven signals (δ 68.9, 69.4, 71.6, 72.5, 73.4, 73.4 and 75.0 ppm) with negative intensity for the presence of seven methylene groups in the assigned disaccharide **58**, and the LC-MS showed a molecular weight peak at 1051.91 (M^++ 23 for Na).

1, 2-*trans* Diastereoselectivity of the transglycosyled products can be endorsed to the steric crowding due to the axially disposed benzyl ether at *C*-2 of the donor as well as the anomeric effect. It is pertinent to declare that the current strategy has been

Table 5

Entry	Glycosyl Donor	Aglycone	Product	*Time* (Yield) *α:β ratio*
1	 **48**	 **11**	 **57**	*10h* (73%)
2	**48**	 **2**	 **3**	*16h* (70%)
3	**48**	 **54**	 **52**	*48h* (48%)
4	**48**	 **55**	 **58**	*36h* (54%)
5	**48**	 **56**	 **59**	*24h* (61%)
6	 **60**	**9**	 **61**	*18h* (65%) *3:1*
7	**60**	**56**	 **62**	*24h* (60%) *3:1*

Entry	Glycosyl Donor	Aglycone	Product	*Time* (Yield) *α:β ratio*
8	 **63**	**9**	**61**	18h(62%) 3:1
9	**63**	 **64**	 **65**	18h (60%) 2:1
10	 **66**	**9**	 **67**	*28h* (58%) *3:1*
11	**66**	**56**	 **68**	*24h* (62%) *4:1*
12	 **69**	**9**	**67**	18h (61%) 3:1
13	**69**	**64**	 **70**	18h (59%) 2:1

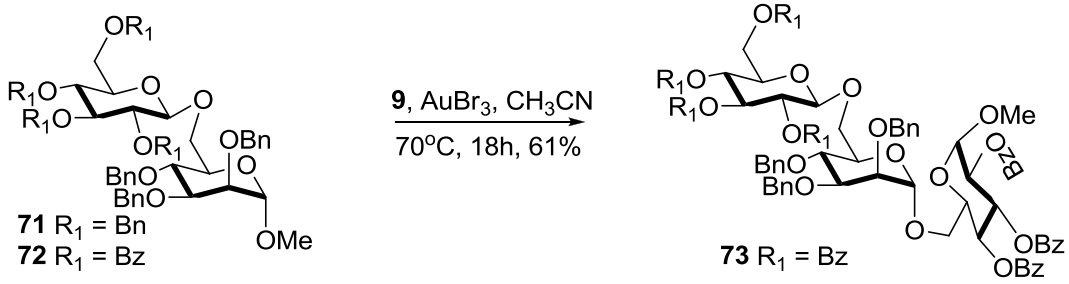
Reagents & Conditions : 10 mol% $AuBr_3$ / CH_3CN / 70°C

successfully extended to the methyl per-*O*-benzylated glucoside (**60**) and galactoside (**66**) to obtain disaccharides (**61**, **62**, **67, 68**) as α,β-mixtures[31] (Table 5). The effect of anomeric configuration of the glycosyl donor and acceptor was then investigated. β-Methyl glycosyl donor (**63**) reacted with aglycone (**9**) to give disaccharide (**61**) in a

diastereomeric ratio and yield comparable to the corresponding reaction with α-methyl glucosyl donor (**48** + **9** to give **46**). The acceptor containing the β-methyl residue (**64**) gave disaccharide (**65**) upon reaction with glucosyl donor (**63**). Similar results were also noticed with galactosyl residues (entries 12-13). In addition, we envisioned that the novel gold catalyzed activation of methyl glycosides could be ideal for the addition of a sugar residue to methyl glycosides of di- and tri-saccharides.

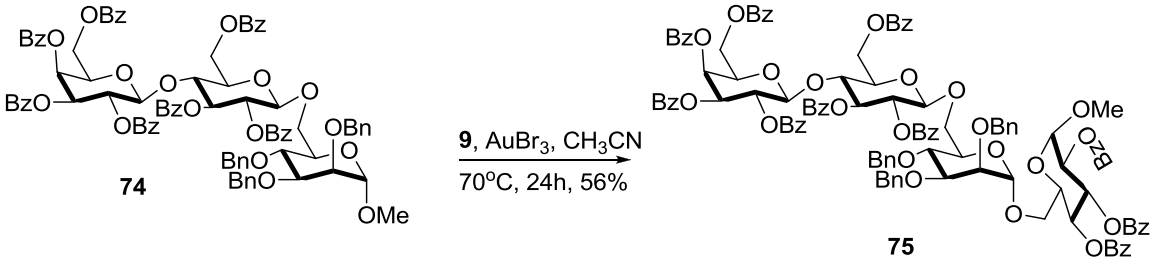
Accordingly, a methyl per-*O*-benzylated disaccharide (**71**) was synthesized exploiting gold mediated propargyl 1,2-orthoester methodology. The $AuBr_3$-promoted reaction between **71** and aglycone **9** under above identified conditions gave a complex mixture of products may be due to the presence of more sensitive interglycosidic bond. However, swiping the protecting groups from benzyls to benzoates as in disaccharide **72** gave the required trisaccharide (**73**) in 61% yield (Scheme 28). In the ^{1}H NMR of compound **73,** singlet at δ 3.40 ppm depicts the presence of methoxy group and aromatic protons of benzoates and benzyl ethers were noticed as multiplets at δ 7.16-7.52 and 7.82-8.00 ppm. In addition, ^{13}C NMR spectrum showed three anomeric carbons (two α and one β) at δ 96.9, 98.0 and 101.3 ppm, and the rest of the other signals in agreement with the assigned structure **73**. Further DEPT NMR spectrum specified the six signals (δ 63.2, 65.3, 68.9, 72.1, 72.6 and 74.7 ppm) with negative intensity for the presence of six methylene groups in the assigned disaccharide **73**, and the LC-MS showed a molecular ion peak at 1540.20 (M^++ 23 for Na).

Scheme 28



Similarly, methyl glycoside of the trisaccharide **74** was reacted with aglycone **9** under similar conditions to afford corresponding tetrasaccharide **75** (Scheme 29). The ^{1}H NMR of compound **75** showed singlet at δ 3.39 ppm for methoxy group along the remaining resonances in agreement with the assigned structure.

Scheme 29



In addition, ^{13}C NMR spectrum revealed the four anomeric carbons (two α and two β) at δ 96.9, 97.9, 100.8 and 101.3 ppm. Further DEPT NMR spectrum specified the seven signals (δ 61.1, 62.4, 65.4, 68.8, 72.0, 72.5, 74.7 ppm) with negative intensity for the presence of seven methylene groups in the assigned disaccharide **75**, and the LC-MS showed a molecular ion peak at 2015.44 (M^++ 23 for Na).

In conclusion, methyl glycosides were identified as novel and stable glycosyl donors. A diverse range of aglycons are shown to react with methyl glycosides, resulting in the formation of corresponding glycosides and disaccharides in good yields. The anomeric configuration of either the glycosyl donor or the glycosyl acceptor did not influence progress of the reaction nor the anomeric diastereoselectivity of the resulting product. Interesting to note that tri- and tetra- saccharides were synthesized from respective di- and tri- saccharides exploiting salient features of this novel glycosylation protocol.

****

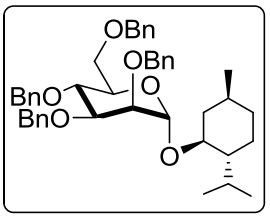
Note: Characterization data and full spectral charts for all compounds can also be found in ***Chem Comm*** **2011** (DOI:10.1039/C1CC13134F) and ***Chem Comm*** **2009**, 2505-2507.

General Procedure for Glycosylations using Propargyl furanosides as Glycosyl Donor: To a solution of glycosyl donor (0.1 mmol) and aglycone (0.12 mmol) in anhydrous acetonitrile (5 ml) was added a solution of 10 mol% of $AuBr_3$ and 5mol% of AgOTf in anhydrous acetonitrile (2 ml) under argon atmosphere. The resulting mixture stirred at room temperature till the completion of the reaction as judged by TLC analysis. The reaction mixture was concentrated *in vacuo* to obtain a crude residue which was purified by conventional silica gel column chromatography using ethyl acetate-petroleum ether as mobile phase.

General Procedure for Glycosylations using Methyl glycosides as Glycosyl Donor: To a solution of glycosyl donor (0.1 mmol) and aglycone (0.12 mmol) in anhydrous acetonitrile (5 ml) was added a solution of 10 mol% of $AuBr_3$ in anhydrous acetonitrile (2 ml) under argon atmosphere at room temperature. The resulting mixture was heated to 65 ^oC and stirred till the completion of the reaction as judged by TLC analysis. The reaction mixture was concentrated *in vacuo* to obtain a crude residue which was purified by conventional silica gel column chromatography using ethyl acetate-petroleum ether as mobile phase.

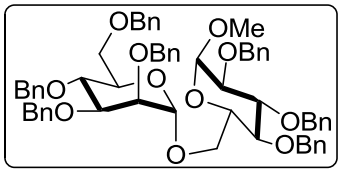
Compound Characterization Data:

Menthyl 2,3,4,6-tetra-*O*-benzyl-α-D-mannopyranoside (3) : $[\alpha]_D$ ($CHCl_3$, *c* 1.0) = +12.2; ^1H NMR (200.13 MHz, $CDCl_3$): δ 0.64(d, 3H, J = 6.9Hz), 0.76-1.40(m, 6H), 0.80, 0.80, 0.83, 0.84(4s, 6H), 1.50-1.84(m, 4H), 2.14(td, 1H, J = 4.8, 12.4Hz), 3.25(dt, 1H, J = 4.3, 10.5Hz), 3.64-4.00(m, 5H), 4.60(ABq, 2H, J = 12.5Hz), 4.63(d, 2H, J = 2.0Hz), 4.70(d, 1H, J =2.8Hz), 4.70(ABq, 2H, J = 10.6Hz), 4.87(s, 1H), 7.15-7.38(m, 20H) ; ^{13}C NMR (50.32 MHz, $CDCl_3$): δ 16.3, 20.1, 22.1, 23.2, 25.7, 31.6, 34.2, 42.8, 48.6, 69.5, 71.8, 72.2, 72.4, 73.3, 74.4, 75.1, 75.2, 80.1, 81.1, 99.8, 127.4-128.3, 138.2, 138.5, 138.5, 138.6; Mol. Wt. calculated for $C_{44}H_{54}O_6Na$: 701.886, Found: 701.020 (M^++23 for Na).

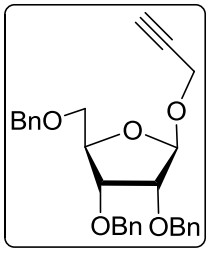


Methyl 2,3,4-tri-*O*-benzyl-6-*O*-(2,3,4,6-tetra-*O*-benzyl-α-D-mannopyranosyl)-α-D-glucopyranoside (5) : $[\alpha]_D$ ($CHCl_3$, *c* 1.0) = +33.6; ^1H NMR (200.13 MHz, $CDCl_3$): δ 3.30(s, 3H), 3.45(dd, 1H, J = 3.4, 9.7Hz), 3.55-4.05(m, 8H), 4.40-4.75(m, 14H), 4.87(dd,

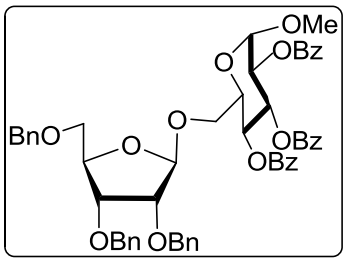
2H, J = 3.2, 11.2Hz), 4.89(ABq, 2H, J = 10.4Hz), 4.96(d, IH, J = 2.0Hz), 7.10-7.40(m, 35H); ^{13}C NMR (50.32 MHz, $CDCl_3$): δ 55.2, 65.9, 69.2, 69.9, 72.0, 72.1, 72.5, 73.3, 73.3, 74.7, 74.9, 75.0, 75.1, 75.9, 77.6, 79.6, 80.1, 82.2, 97.9, 98.3, 127.4-128.6, 138.2, 138.3, 138.4, 138.5, 138.5, 138.7, 138.7; Mol. Wt. calculated for $C_{62}H_{66}O_{11}Na$: 1010.171, Found: 1010.029.



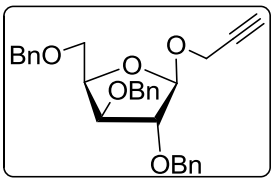
Prop-2-ynyl 2,3,5-tri-*O*-benzyl-β-D-ribofuranoside (8) : $[\alpha]_D$($CHCl_3$, *c* 1.6) = -37.6; ^{1}H NMR (200.13 MHz, $CDCl_3$): δ 2.37(t, 1H, J = 2.4Hz), 3.48(dd, 1H, J = 5.4, 10.6Hz), 3.62(dd(1H, J = 3.3, 10.6Hz), 3.90(d, 1H, J = 4.9Hz), 4.07(dd, 1H, J = 4.6, 7.4Hz), 4.15(d, 2H, J = 2.3Hz), 4.31-4.71(m, 5H), 4.54(ABq, 2H, J = 11.8Hz), 5.21(s, 1H), 7.16-7.40(m, 15H) ; ^{13}C NMR (55.32 MHz, $CDCl_3$): δ 53.9, 70.6, 72.2, 72.3, 72.9, 74.5, 78.0, 79.0, 79.4, 80.5, 103.0, 127.4-128.3, 137.6, 137.6, 138.1; Mol. Wt. calculated for $C_{29}H_{30}O_5Na$: 481.5353, Found: 481.512 (M^++23 for Na).



Methyl 2,3,4-tri-O-benzoyl-6-O-(2,3,5-tri-*O*-benzyl-β-D-ribofuranosyl)-α-D-gluco-pyranoside (10) : $[\alpha]_D$ ($CHCl_3$, *c* 1.2) = +42.9; ^{1}H NMR (200.13 MHz, $CDCl_3$): δ 3.38(s, 3H), 3.46-3.65(m, 1H), 3.51(dd, 1H, J = 5.7, 10.5Hz), 3.62(dd, 1H, J = 4.1, 10.5Hz), 3.91(dd, 1H, J = 2.2, 11.5Hz), 3.95(d, 1H, J = 4.9Hz), 4.02(dd, 1H, J = 4.7, 7.3Hz), 4.14(qd, 1H, J = 2.5, 9.9Hz), 4.31(dd, 1H, J = 3.5, 6.1Hz), 4.45(ABq, 2H, J = 11.9Hz), 4.51(s, 2H), 4.66(d, 2H, J =4.4Hz), 5.00(s, 1H), 5.16(dd, 1H J = 3.6, 8.4Hz), 5.23(dd, 1H, J = 3.6, 14.9Hz), 5.58(t, 1H, J = 9.9Hz), 6.12(t, 1H, 9.9Hz), 7.21-7.55(m, 24H), 7.85-8.00(m, 6H) ; ^{13}C NMR (55.32 MHz, $CDCl_3$): δ 55.4, 66.1, 68.6, 69.3, 70.6, 71.4, 72.1, 72.3, 73.1, 77.2, 78.2, 79.3, 80.6, 96.9, 106.0, 127.5-129.9, 13.1, 133.3, 133.4, 137.8, 137.9, 138.3, 165.2, 165.8, 165.8; Mol. Wt. calculated for $C_{54}H_{52}O_{13}Na$: 931.97, Found: 932.75 (M^++23 for Na).

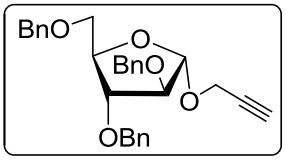


Prop-2-ynyl 2,3,5-tri-*O*-benzyl-β-D-xylofuranoside (11) : $[\alpha]_D$ ($CHCl_3$, *c* 1.3) = +52.2; ^{1}H NMR (200.13 MHz, $CDCl_3$): δ 2.41(t, 1H, J = 2.4Hz), 3.70(dd, 1H, J = 7.2, 10.2Hz), 3.77(dd, 1H, J = 4.8, 10.1Hz), 4.06(s, 1H), 4.08(dd, 1H J = 2.8, 8.3Hz), 4.27(dd, 2H, J = 1.4, 2.3Hz), 4.42-4.61(m, 6H), 4.45(dd, 1H, J = 3.3, 5.1Hz), 5.27(s,

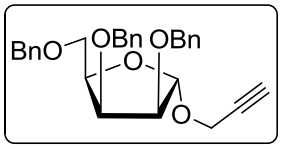


1H), 7.22-7.38(m, 15H); ^{13}C NMR (55.32 MHz, $CDCl_3$): δ 54.5, 69.6, 71.9, 72.1, 73.4, 74.5, 79.2, 80.4, 81.6, 86.6, 104.8, 127.5-128.4, 137.4, 137.7, 138.2; Mol. Wt. calculated for $C_{29}H_{30}O_5Na$: 481.5353, Found: 481.44 (M^++23 for Na).

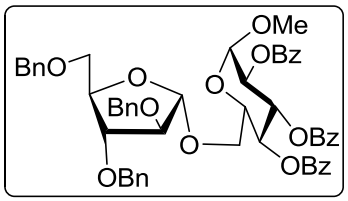
Prop-2-ynyl 2,3,5-tri-*O*-benzyl-α-D-arabinofuranoside (12) : $[\alpha]_D$ ($CHCl_3$, *c* 1.6) = -20.4; ^{1}H NMR (200.13 MHz, $CDCl_3$): δ 2.41(t, 1H, J = 2.4Hz), 3.60(d, 1H, J = 2.4 Hz), 3.62(d, 1H, J = 1.0Hz), 3.92(dd, 1H, J = 3.0, 6.6Hz), 4.05(dd, 1H J = 0.9, 3.0Hz), 4.22(m, 1H), 4.28(d, 2H, J = 2.2Hz), 4.51(ABq, 2H, J = 12.0), 4.53(ABq, 2H, J = 12.0Hz), 4.56(s, 2H), 5.32(s, 1H), 7.22-7.32(m, 15H); ^{13}C NMR (55.32 MHz, $CDCl_3$): δ 54.0, 69.6, 71.9, 72.1, 73.4, 74.4, 79.2, 81.1, 83.4, 88.0, 104.2, 127.6-128.4, 137.4, 137.7, 138.0; Mol. Wt. calculated for $C_{29}H_{30}O_5Na$: 481.53, Found: 481.51 (M^++23 for Na).



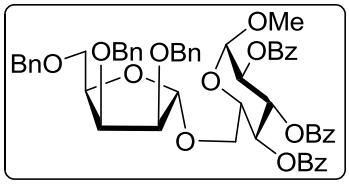
Prop-2-ynyl 2,3,5-tri-*O*-benzyl-α-D-lyxofuranoside (13) : $[\alpha]_D$ ($CHCl_3$, *c* 1.5) = +29.4; ^{1}H NMR (200.13 MHz, $CDCl_3$): δ 2.40(t, 1H, J = 2.4Hz), 3.77(d, 2H, J = 5.9Hz), 3.94(dd, 1H, J = 2.0, 4.6Hz), 4.23(dd, 2H, J = 2.4, 5.0Hz), 4.34(t, 1H, J = 5.9Hz), 4.46(d,1H, J = 0.7Hz), 4.52(s, 2H), 4.60(dd, 2H, J = 7.4, 12.0Hz), 4.68(dd, 2H, J = 4.5, 12.1Hz), 5.31(d, 1H, J = 2.0Hz), 7.22-7.34(m, 15H); ^{13}C NMR (55.32 MHz, $CDCl_3$): δ 54.7, 69.6, 72.4, 73.1, 73.3, 74.4, 77.8, 78.5, 79.2, 82.1, 103.5, 127.5-128.3, 137.7, 137.9, 138.1; Mol. Wt. calculated for $C_{29}H_{30}O_5Na$: 481.5353, Found: 481.51 (M^++23 for Na).



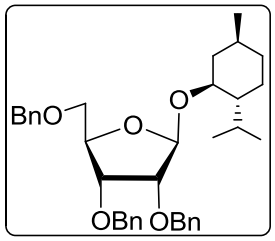
Methyl 2,3,4-tri-O-benzoyl-6-O-(2,3,5-tri-*O*-benzyl-α-D-arabinofuranosyl)-α-D-glucopyranoside (15) :$[\alpha]_D$ ($CHCl_3$, *c* 1.3) = +0.8; ^{1}H NMR (200.13 MHz, $CDCl_3$): δ 3.38(s, 3H), 3.44-3.68(m, 3H), 3.75-4.20(m, 4H), 4.27-4.80(m, 3H), 4.46(ABq, 2H, J = 11.8Hz), 4.66(ABq, 2H, J = 11.8Hz), 5.01(s, 1H), 5.22(dd, 1H, J = 3.5, 9.4Hz), 5.25(dd, 1H, J = 3.5, 19.5Hz), 5.59(t, 1H, J = 9.8Hz), 6.13(t, 1H, J = 9.8Hz), 7.24-7.50(m, 24H), 7.86-8.00(m, 6H); ^{13}C NMR (55.32 MHz, $CDCl_3$): δ 55.4, 66.1, 68.6, 69.2, 70.5, 71.3, 72.0, 72.0, 72.2, 73.0, 78.2, 79.2, 80.5, 96.8, 105.9, 127.4-129.8, 133.0, 133.3, 133.3, 137.8, 137.8, 138.2, 165.2, 165.7, 165.8 ; Mol. Wt. calculated for $C_{54}H_{52}O_{13}Na$: 931.97, Found: 931.91 (M^++23 for Na).



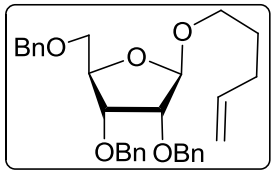
Methyl 2,3,4-tri-O-benzoyl-6-O-(2,3,5-tri-*O*-benzyl-α-D-lyxofuranosyl)-α-D-gluco-pyranoside (16) : $[\alpha]_D$ ($CHCl_3$, *c* 1.8) = +54.2; ^1H NMR (200.13 MHz, $CDCl_3$): δ 3.44(s, 3H), 3.56-3.74(m, 3H), 3.92-4.03(m, 2H), 4.15-4.35(m, 3H), 4.40-4.60(m, 2H), 4.53(ABq, 2H, J = 11.8Hz), 4.59(ABq, 2H, J = 11.9Hz), 5.12(d, 1H, J = 1.3Hz), 5.23-5.31(m, 1H), 5.24(s, 1H), 5.68(t, 1H, J = 9.8Hz), 6.12(t, 1H, J = 9.5Hz), 7.20-7.55(m, 24H), 7.86-8.01(m, 6H) ; ^{13}C NMR (55.32 MHz, $CDCl_3$): δ 55.6, 65.3, 68.3, 68.8, 69.8, 70.7, 72.1, 72.4, 73.0, 73.2, 77.9, 78.1, 81.7, 97.1, 104.6, 127.3-129.9, 133.0, 133.2, 133.3, 137.9, 138.1, 138.3, 165.0, 165.8, 165.8 ; Mol. Wt. calculated for $C_{54}H_{52}O_{13}Na$: 931.97, Found: 931.90 (M^++23 for Na).



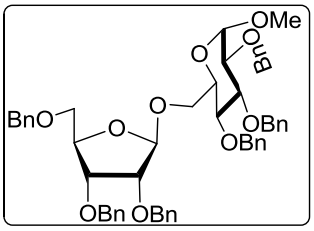
Menthyl 2,3,5-tri-*O*-benzyl-β-D-ribofuranoside (21) : $[\alpha]_D$($CHCl_3$, *c* 1.0) = -20.8; ^1H NMR (200.13 MHz, $CDCl_3$): δ 0.70(d, 3H, J = 7.0Hz), 0.81, 0.84, 0.88, 0.91(4s, 6H), 1.28(m, 3H), 1.61(m, 4H), 2.03(m, 2H), 3.40(dd, 1H, J = 4.0, 10.5Hz), 3.49(dd, 1H, J = 6.6, 10.4Hz), 3.61(dd, 1H, J = 4.0, 10.4Hz), 3.80(dd, 1H, J = 1.2, 4.7Hz), 3.91(m, 1H), 4.36(dt, 1H, J = 4.1, 7.0Hz), 4.52(dd, 2H, J = 11.7, 18.7Hz), 4.55(d, 2H, J = 1.8Hz), 4.64(s, 2H), 5.21(d, 1H, J = 0.7Hz), 7.25-7.39(m, 15H) ; ^{13}C NMR (55.32 MHz, $CDCl_3$): δ 15.9, 21.1, 22.3, 23.0, 25.1, 29.7, 31.3, 34.4, 39.8, 47.9, 72.0, 72.3, 73.1, 75.3, 78.8, 79.7, 80.4, 101.6, 127.5-128.4, 137.8, 138.0, 138.3; Mol. Wt. calculated for $C_{36}H_{46}O_5Na$: 581.7372, Found: 581.23 (M^++23 for Na).



Pent-4-enyl 2,3,5-tri-*O*-benzyl-β-D-ribofuranoside (22) : $[\alpha]_D$($CHCl_3$, *c* 1.8) = +11.8; ^1H NMR (200.13 MHz, $CDCl_3$): δ 1.68(m, 2H), 2.11(m, 2H), 3.25-3.60(m, 4H), 3.92(dd, 1H, J = 3.1, 6.8Hz), 4.03(dd, 1H, J = 1.2, 3.3Hz), 4.05-4.25(m, 2H), 4.44-4.67(m, 6H), 4.96(dq, 1H, J = 1.0, 8.8Hz), 5.04(s, 1H), 5.80(m, 1H), 7.22-7.36(m, 15H); ^{13}C NMR (55.32 MHz, $CDCl_3$): δ 28.6, 30.2, 67.2, 71.4, 72.2, 72.3, 73.1, 78.5, 79.7, 80.3, 105.2, 114.7, 127.4-128.3, 129.6, 137.8, 138.1, 138.2; Mol. Wt. calculated for $C_{31}H_{36}O_5Na$: 511.60, Found: 511.55 (M^++23 for Na).

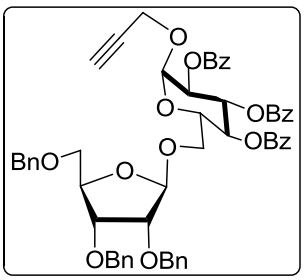


Methyl 2,3,4-tri-O-benzyl-6-O-(2,3,5-tri-*O*-benzyl-β-D-ribofuranosyl)-α-D-gluco-pyranoside (23) : $[\alpha]_D$ ($CHCl_3$, *c* 1.5) = +5.3; ^1H NMR (200.13 MHz, $CDCl_3$): δ 3.29(s, 3H), 3.31-3.65(m, 5H), 3.72(dd, 1H, J = 4.0, 9.7Hz), 3.89(dt, 1H, J = 0.9, 4.7Hz), 3.90-

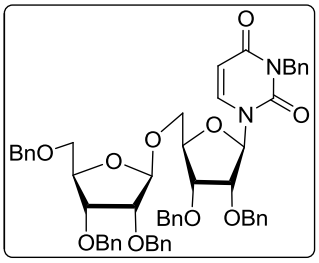


4.05(m, 3H), 4.33(dd, 1H, J = 5.7, 10.8Hz), 4.41-4.65(m, 8H), 4.72(ABq, 2H, J = 12.2Hz), 4.82(t, 1H, J = 10.9Hz), 4.88(ABq, 2H, J = 10.8Hz), 5.06(d, 1H, J = 0.8Hz), 7.22-7.33(m, 30H) ; ^{13}C NMR (55.32 MHz, $CDCl_3$): δ 55.0, 66.5, 69.9, 71.3, 72.2, 72.3, 73.1, 73.3, 74.9, 75.7, 77.9, 78.3, 79.7, 78.8, 80.5, 82.0, 97.8, 105.7, 127.4-128.4, 137.7, 137.7, 138.1, 138.1, 138.2, 138.6 ; Mol. Wt. calculated for $C_{54}H_{58}O_{10}Na$: 890.02, Found: 889.90 (M^++23 for Na).

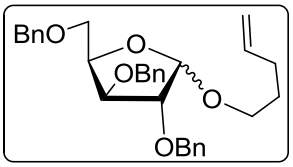
Prop-2-ynyl 2,3,4-tri-O-benzoyl-6-O-(2,3,5-tri-*O*-benzyl-β-D-ribofuranosyl)-α-D-glucopyranoside (24) : $[\alpha]_D$ ($CHCl_3$, *c* 2.1) = +61.3; ^{1}H NMR (200.13 MHz, $CDCl_3$): δ 2.34(t, 1H, J = 2.3Hz), 3.42-3.67(m, 3H), 3.85-4.00(m, 2H), 4.04(dd, 1H, J = 4.6, 7.2Hz), 4.15-4.55(m, 8H), 4.66(d, 2H, J = 3.6Hz), 4.99(s, 1H), 5.31(dd, 1H J = 3.7Hz), 5.50(dd, 1H, J = 3.5Hz), 5.61(t, 1H, J = 9.9Hz), 6.13(t, 1H, J = 10.0Hz), 7.24-7.56(m, 24H), 7.85-8.01(m, 6H) ; ^{13}C NMR (55.32 MHz, $CDCl_3$): δ 55.2, 66.0, 69.1, 69.2, 70.4, 71.3, 71.6, 72.1, 72.3, 73.1, 75.3, 78.2, 78.3, 79.3, 80.6, 94.7, 106.0, 127.5-129.9, 133.1, 133.3, 133.4, 137.8, 137.9, 138.2, 165.2, 165.7, 165.8 ; Mol. Wt. calculated for $C_{56}H_{52}O_{13}Na$: 955.9940, Found: 955.54 (M^++23 for Na).



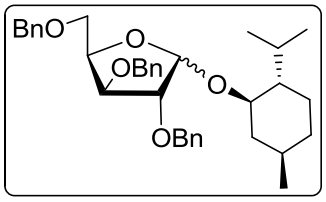
2, 3, *N*-tri-*O*-benzyl-5-*O*-(2, 3, 5-tri-*O*-benzyl-α-D-ribofuranosyl) uridine (25) : $[\alpha]_D$ ($CHCl_3$, *c* 1.3) = +48.1; ^{1}H NMR (200.13 MHz, $CDCl_3$): δ 3.44-3.52(m, 2H), 3.60(dd, 1H, J = 3.5, 10.6Hz), 3.70(dd, 1H J = 1.2, 4.6Hz), 3.73-3.83(m, 2H), 4.00(dd, 1H, J = 4.8, 6.6Hz), 4.16(dd, 1H, J = 2.0, 11.6Hz), 4.27(ABq, 2H, J = 11.9Hz), 4.30(dd, 1H , J = 3.0, 7.9Hz), 4.47(d, 1H, J = 1.4Hz), 4.50(ABq, 2H, J = 11.6Hz), 4.56(s, 2H), 4.80(s, 2H), 4.95(d, 1H, J = 1.1Hz), 5.11(s, 2H), 5.36(d, 1H, J = 8.1Hz), 5.91(d, 1H, J = 1.0Hz), 7.14-7.38(m, 30H), 7.51(d, 1H, J = 1.7Hz), 7.58(d, 2H, J = 8.1Hz) ; ^{13}C NMR (55.32 MHz, $CDCl_3$): δ 43.9, 65.5, 70.0, 71.3, 72.0, 72.4, 73.3, 74.0, 77.4, 78.1, 79.7, 80.8, 80.9, 89.2, 100.9, 105.8, 127.5-128.7, 129.3, 136.7, 137.2, 137.2, 137.4, 137.4, 137.5, 137.8, 150.6, 162.4 ; Mol. Wt. calculated for $C_{56}H_{56}N_2O_{10}Na$: 940.0410, Found: 939.89 (M^++23 for Na).



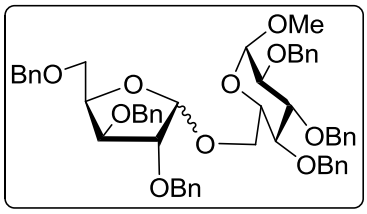
Pent-4-enyl 2,3,5-tri-*O*-benzyl-(α/β)-D-xylofuranoside (27) : ^{1}H NMR (200.13 MHz, $CDCl_3$): δ 1.68(m, 4H), 2.13(m, 4H), 3.25-3.80, 8H), 3.92(dd, 1H, J = 3.3, 6.8Hz), 4.03(dd, 1H, J = 1.2, 3.2Hz), 4.05-4.12(m, 2H), 4.16-4.24(m, 2H), 4.44-4.68(m, 12H), 4.85-5.10(m, 6H), 5.68-5.93(m, 2H), 7.20-7.45(m, 30H); ^{13}C NMR (55.32 MHz, $CDCl_3$): δ 28.6, 28.7, 29.6, 30.2, 66.8, 67.2, 69.7, 71.9, 72.0, 72.2, 72.4, 72.6, 73.3, 73.3, 80.1, 80.4, 83.4, 83.5, 84.2, 88.3, 100.5, 106.1, 114.8, 114.8, 127.5-128.4, 137.5, 137.7, 137.9, 138.0, 138.1, 138.1, 138.2, 138.2 ; Mol. Wt. calculated for $C_{31}H_{36}O_5Na$: 511.60, Found: 511.55 (M^++23 for Na).



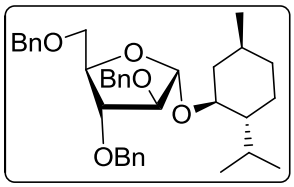
Menthyl 2,3,5-tri-*O*-benzyl-(α/β)-D-xylofuranoside (28) : ^{1}H NMR (200.13 MHz, $CDCl_3$): δ 0.69-0.92(m, 22H), 0.95-1.49(m, 6H), 1.54-1.70(m, 4H), 2.05-2.40(m, 4H), 3.30-3.58(m, 2H), 3.60-3.85(m, 4H), 3.96-4.05(m, 4H), 4.30-4.70(m, 14H), 5.17(d, 1H, J = 4.3Hz), 5.25(s, 1H), 7.18-7.40(m, 30H) ; ^{13}C NMR (55.32 MHz, $CDCl_3$): δ 15.8, 15.9, 21.1, 21.1, 22.2, 22.4, 22.8, 23.0, 24.8, 25.1, 31.3, 31.7, 34.3, 34.5, 39.6, 43.2, 48.0, 48.0, 48.4, 69.5, 71.8, 71.9, 72.5, 72.6, 73.3, 73.3, 74.8, 75.5, 80.0, 80.2, 81.4, 81.7, 84.4, 86.3, 100.8, 102.8, 127.4-128.4, 137.8, 138.1, 138.2, 138.3, 138.3, 138.4; Mol. Wt. calculated for $C_{36}H_{46}O_5Na$: 581.7372, Found: 581.23 (M^++23 for Na).



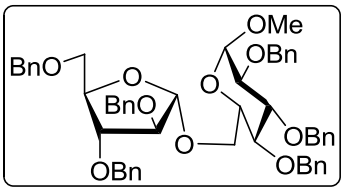
Methyl 2,3,4-tri-O-benzyl-6-O-(2,3,5-tri-*O*-benzyl-(α/β)-D-xylofuranosyl)-α-D-glucopyranoside (29) : ^{1}H NMR (200.13 MHz, $CDCl_3$): δ 3.28(s, 3H), 3.34(s, 3H), 3.35(dd, 1H, J = 9.4, 16.8Hz), 3.43(dd, 1H, J = 3.7, 9.5Hz), 3.49(ABq, 2H, J = 9.4Hz), 3.57(dd, 2H, J = 6.7, 10.7Hz), 3.63-3.80(m, 8H), 3.96-4.13(m, 8H), 4.28(dd, 1H, J = 5.8, 7.0Hz), 4.37(m, 1H), 4.42-4.88(m, 22H), 4.93-4.98(m, 2H), 5.07(d, 1H, J = 1.5Hz), 5.13(d, 1H, J = 4.3Hz), 7.20-7.38(m, 60H); ^{13}C NMR (55.32 MHz, $CDCl_3$): δ 55.0, 55.1, 66.5, 66.9, 69.3, 69.6, 70.0, 70.2, 71.9, 72.1, 72.1, 72.4, 73.3, 73.3, 73.4, 73.4, 75.0, 75.1, 75.6, 75.7, 76.2, 77.8, 78.1, 80.0, 80.0, 80.0, 81.6, 81.8, 82.0, 82.0, 83.6, 86.7, 97.9, 98.1, 100.5, 107.3, 127.5-128.4, 137.5, 137.8, 138.0, 138.1, 138.2, 138.2, 138.2, 138.2, 138.3, 138.3, 138.7, 138.9 ; Mol. Wt. calculated for $C_{54}H_{58}O_{10}Na$: 890.02, Found: 890.81 (M^++23 for Na).



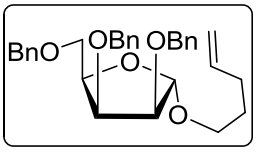
Menthyl 2,3,5-tri-*O*-benzyl-α-D-arabinofuranoside (31) : $[\alpha]_D$ ($CHCl_3$, *c* 1.2) = +14.4; ^{1}H NMR (200.13 MHz, $CDCl_3$): δ 0.79(d, 3H, J = 6.9Hz), 0.87, 0.90, 0.90, 0.94(4s, 6H), 1.01(m, 2H), 1.25(m, 3H), 1.63(m, 2H), 2.16(m, 2H), 3.36(dt, 1H, J = 4.3, 10.4Hz), 3.63(t, 1H, J = 10.9Hz), 3.63(dd, 1H, J = 10.9, 19.8Hz), 3.90(dd, 1H, J = 3.3, 7.1Hz), 4.03(dd, 1H, J = 1.2, 3.4Hz), 4.25(m, 1H), 4.51(ABq, 2H, J = 11.9Hz), 4.52(ABq, 2H, J = 11.8Hz), 4.56(d, 2H, J = 1.5Hz), 5.16(s, 1H), 7.26-7.32(m, 15H); ^{13}C NMR (55.32 MHz, $CDCl_3$): δ 16.1, 21.2, 22.2, 23.0, 25.6, 31.6, 34.3, 43.3, 48.4, 69.7, 71.9, 72.0, 73.2, 79.7, 80.0, 83.7, 88.6, 107.6, 127.5-128.4, 137.6, 138.0, 138.2; Mol. Wt. calculated for $C_{36}H_{46}O_5Na$: 581.7372, Found: 581.42 (M^++23 for Na).



Methyl 2,3,4-tri-O-benzoyl-6-O-(2,3,5-tri-*O*-benzyl-α-D-arabinofuranosyl)-α-D-glucopyranoside (32) : $[\alpha]_D$($CHCl_3$, *c* 2.3) = +24.4; ^{1}H NMR (200.13 MHz, $CDCl_3$): δ 3.36(s, 3H), 3.47-3.78(m, 5H), 3.97(dd, 2H, J = 8.8, 17.2Hz), 4.04-4.15(m, 2H), 4.20(dd, 1H, J = 4.9, 9.5Hz), 4.40-4.65(m, 8H), 4.74(ABq, 2H, J = 3.7Hz), 4.76(t, 2H, J = 8.6Hz), 4.89(ABq, 2H, J = 11.0Hz), 5.18(s, 1H), 7.23-7.33(m, 30H) ; ^{13}C NMR (55.32 MHz, $CDCl_3$): δ 55.1, 65.7, 69.6, 69.9, 71.7, 72.0, 73.2, 73.3, 75.0, 75.9, 77.6, 79.8, 81.1, 82.0, 83.2, 87.8, 98.1, 106.7, 127.5-128.4, 137.4, 137.7, 138.0, 138.1, 138.3, 138.8 ; Mol. Wt. calculated for $C_{54}H_{58}O_{10}Na$: 890.02, Found: 889.83 (M^++23 for Na).

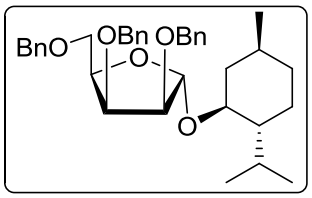


Pent-4-enyl 2,3,5-tri-*O*-benzyl-α-D-lyxofuranoside (33) : $[\alpha]_D$ ($CHCl_3$, *c* 1.3) = +27.2; ^{1}H NMR (200.13 MHz, $CDCl_3$): δ 1.64(m, 2H), 2.18(m, 2H), 3.41(dd, 1H, J = 6.6, 16.1Hz), 3.66-3.80(m, 3H), 3.90(dd, 1H, J = 2.6, 4.6Hz), 4.10(t, 1H, J = 4.9Hz), 4.35(m, 1H), 4.55(ABq, 2H, J = 12.0Hz), 4.61(ABq, 2H, J = 12.0Hz), 4.62(d, 2H, J = 2.5Hz), 4.91-5.06(m, 2H), 5.10(d, 1H, J = 2.5Hz), 5.80(m, 1H), 7.22-7.40(m, 15H); ^{13}C NMR (55.32 MHz, $CDCl_3$): δ 28.7, 30.2, 67.6, 70.0, 72.4, 73.2, 73.4, 77.9, 78.1, 82.5, 105.2, 114.8, 127.5-128.3, 137.8, 138.1, 138.1, 138.2; Mol. Wt. calculated for $C_{31}H_{36}O_5Na$: 511.6043, Found: 511.55 (M^++23 for Na).

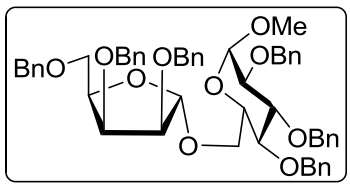


Menthyl 2,3,5-tri-*O*-benzyl-α-D-lyxofuranoside (34) : $[\alpha]_D$ ($CHCl_3$, *c* 1.3) = +1.2; ^{1}H NMR (200.13 MHz, $CDCl_3$): δ 0.76(d, 3H, J = 6.9Hz), 0.86, 0.87, 0.89, 0.90(4s, 6H),

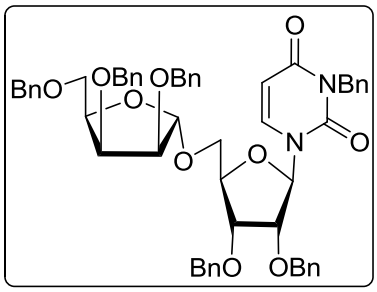
0.80-1.00(m, 2H), 1.10-1.35(m, 3H), 1.51-1.70(m, 2H), 2.00-2.20(m, 2H), 3.31(dt, 1H, J = 4.27, 10.5Hz), 3.76(dd, 1H, J = 6.8, 10.0Hz), 3.79(dd, 1H, J = 5.2, 10.1Hz), 3.89(dd, 1H, J = 2.7, 4.5Hz), 4.19(t, 1H, J = 5.0Hz), 4.38(dd, 1H J = 5.3, 12.0Hz), 4.56(ABq, 2H, 11.9Hz), 4.60(ABq, 2H, J = 11.9Hz), 4.60(s, 2H), 5.18(d, 1H, J = 2.5Hz), 7.22-7.40(m, 15H) ; ^{13}C NMR (55.32 MHz, $CDCl_3$): δ 16.2, 21.1, 21.2, 23.1, 25.5, 31.5, 34.3, 43.1, 48.5, 69.6, 72.5, 73.2, 73.3, 77.6, 77.9, 79.8, 82.6, 106.5, 127.5-128.3, 137.8, 138.1, 138.3; Mol. Wt. calculated for $C_{36}H_{46}O_5Na$: 581.7372, Found: 581.42 (M^++23 for Na).



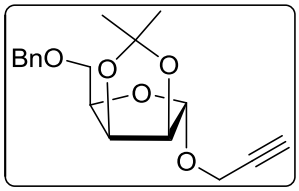
Methyl 2,3,4-tri-O-benzyl-6-O-(2,3,5-tri-*O*-benzyl-α-D-lyxofuranosyl)-α-D-gluco-pyranoside (35) : $[\alpha]_D$ ($CHCl_3$, *c* 1.2) = +28.1; ^{1}H NMR (200.13 MHz, $CDCl_3$): δ 3.34(s, 3H), 3.41-3.75(m, 6H), 3.96(dd, 1H, J = 2.4, 4.5Hz), 4.07(dd, 1H, J = 3.2, 10.8Hz), 4.21(dd, 1H, J = 4.5, 5.8Hz), 4.33(dd, 1H, J = 5.8, 11.5Hz), 4.46-4.86(m, 12H), 4.9(ABq, 2H, J = 10.9Hz), 5.21(d, 1H, J = 1.9Hz), 7.24-7.38(m, 30H) ; ^{13}C NMR (55.32 MHz, $CDCl_3$): δ 55.1, 66.3, 69.7, 69.9, 72.3, 73.2, 73.2, 73.3, 75.1, 75.8, 77.2, 77.8, 77.9, 78.2, 79.8, 82.0, 98.0, 105.4, 127.4-128.4, 137.9, 137.9, 138.1, 138.1, 138.2, 138.7 ; Mol. Wt. calculated for $C_{54}H_{58}O_{10}Na$: 890.0221, Found: 889.90 (M^++23 for Na).



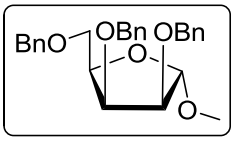
2, 3, *N*-tri-O-benzyl-5-O-(2,3,5-tri-*O*-benzyl-α-D-lyxofuranosyl) uridine (36) :$[\alpha]_D$ ($CHCl_3$, *c* 1.3) = +48.1; ^{1}H NMR (200.13 MHz, $CDCl_3$): δ 3.70-3.85(m, 4H), 3.93(dd, 1H, J = 2.1, 11.6Hz), 4.05(dd, 1H, J = 5.1, 9.9Hz), 4.18-4.37(m, 4H), 4.46(dd, 2H, J = 2.4, 11.8Hz), 4.54-4.63(m, 4H), 4.79(s, 2H), 5.12(s, 2H), 5.14(d, 1H, J = 2.4Hz), 5.34(d, 1H, J = 8.1Hz), 6.00(d, 1H, J = 1.4Hz), 7.16-7.38(m, 30H), 7.50-7.55(m, 2H), 7.64(d, 1H, J = 8.3Hz); ^{13}C NMR (55.32 MHz, $CDCl_3$): δ 44.0, 65.7, 69.3, 71.2, 72.2, 72.5, 73.3, 73.4, 74.4, 78.2, 78.6, 81.0, 82.2, 89.1, 101.1, 105.1, 127.56-128.67, 129.2, 136.7, 137.1, 137.1, 137.1, 137.2, 137.6, 137.9, 150.6, 162.4 ; Mol. Wt. calculated for $C_{56}H_{56}N_2O_{10}Na$: 940.04, Found: 939.89 (M^++23 for Na).



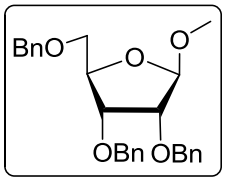
Prop-2-ynyl 2,3-O-isopropylidene-5-O-benzyl-α-D-lyxofuranoside (40): $[\alpha]_D$ ($CHCl_3$, *c* 1.2) = +81.2; ^{1}H NMR (200.13 MHz, $CDCl_3$): δ 1.29(s, 3H), 1.44(s, 3H), 2.42(t, 1H, J = 2.4Hz), 3.70(dd, 1H, J = 7.1, 10.5Hz), 3.82(dd, 1H, J = 4.5, 10.5Hz), 4.15-4.25(m, 3H), 4.60(ABq, 2H, J = 12.1Hz), 4.61(d, 1H, J = 6.1Hz), 4.73(dd, 1H, J = 3.7, 6.0Hz), 5.22(s, 1H), 7.20-7.38(m, 5H); ^{13}C NMR (55.32 MHz, $CDCl_3$): δ 24.8, 26.0, 54.0, 68.1, 73.4, 74.6, 78.9, 79.4, 79.7, 84.8, 104.5, 112.5, 127.6-128.3, 138.0; Mol. Wt. calculated for $C_{18}H_{22}O_5Na$: 341.1365, Found: 341.03 (M^++23 for Na).



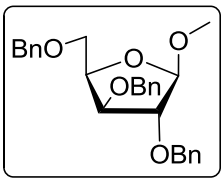
Methyl 2,3,5-tri-*O*-benzyl-α-D-lyxofuranoside (41) : $[\alpha]_D$ ($CHCl_3$, *c* 1.2) = +16.9; ^{1}H NMR (200.13 MHz, $CDCl_3$): δ 3.37(s, 3H), 3.75(d, 1H, J = 0.6Hz), 3.78(s, 1H), 3.89(dd, 1H, J = 2.4, 4.5Hz), 4.19(m, 1H), 4.36(dd, 1H, J = 5.5, 11.9Hz), 4.58(ABq, 2H, J = 12.1Hz), 4.59(ABq, 2H, J = 12.0Hz), 4.60(s, 2H), 5.02(d, 1H, J = 1.5Hz), 7.20-7.38(m, 15H); ^{13}C NMR (55.32 MHz, $CDCl_3$): δ 55.5, 69.6, 72.5, 73.2, 73.4, 77.8, 78.2, 82.4, 106.3, 127.5-128.3, 137.8, 138.0, 138.2; Mol. Wt. calculated for $C_{27}H_{30}O_5Na$: 457.51, Found: 457.49(M^++23 for Na).



Methyl 2,3,5-tri-*O*-benzyl-β-D-ribofuranoside (42) :$[\alpha]_D$ ($CHCl_3$, *c* 1.7) = +13.7; ^{1}H NMR (200.13 MHz, $CDCl_3$): δ 3.28(s, 3H), 3.49(dd, 1H, J = 5.6, 10.6Hz), 3.60(dd, 1H, J = 3.7, 10.5Hz), 3.83(d, 1H, J = 4.5Hz), 4.02(d, 1H, J = 4.8Hz), 4.35(dd, 1H, J = 3.9, 5.9Hz), 4.46(ABq, 2H, J = 11.9Hz), 4.53(d, 2H, J = 1.7Hz), 4.60(dd, 2H, J = 12.0, 16.8Hz), 4.92(s, 1H), 7.15-7.38(m, 15H) ; ^{13}C NMR (55.32 MHz, $CDCl_3$): δ 54.7, 71.0, 72.0, 72.1, 72.8, 78.1, 79.4, 80.2, 106.1, 127.2-128.1, 137.6, 137.6, 138.1; Mol. Wt. calculated for $C_{27}H_{30}O_5Na$: 457.51, Found: 457.42 (M^++23 for Na).

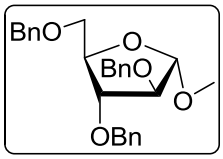


Methyl 2,3,5-tri-*O*-benzyl-β-D-xylofuranoside (43) : $[\alpha]_D$ ($CHCl_3$, *c* 1.6) = -17.7; ^{1}H NMR (200.13 MHz, $CDCl_3$): δ 3.39(s, 3H), 3.71(dd, 1H, J = 6.9, 10.2Hz), 3.79(dd, 1H, J = 5.0, 10.2Hz), 3.97(dd, 1H, J = 1.4, 2.5Hz), 4.05(dd, 1H, J = 2.5, 5.8Hz), 4.42(m, 1H), 4.49(d, 2H, J = 2.5Hz), 4.52(ABq, 2H J = 10.7Hz), 4.55(dd, 2H, J = 6.6, 12.3Hz), 4.92(d, 1H,

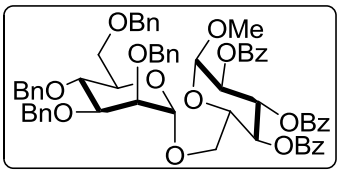


J = 1.4Hz), 7.21-7.38(m, 15H); ^{13}C NMR (55.32 MHz, $CDCl_3$): δ 55.6, 69.6, 71.8, 72.1, 73.3, 80.0, 81.4, 86.7, 108.0, 127.5-128.4, 137.4, 137.7, 138.2; Mol. Wt. calculated for $C_{27}H_{30}O_5Na$: 457.51, Found: 457.49 (M^++23 for Na).

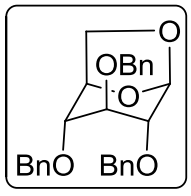
Methyl 2,3,5-tri-*O*-benzyl-α-D-arabinofuranoside (44) : $[\alpha]_D$($CHCl_3$, *c* 1.3) = +53.3; ^{1}H NMR (200.13 MHz, $CDCl_3$): δ 3.39(s, 3H), 3.60(d, 1H, J = 0.6Hz), 3.61(s, 1H), 3.90(dd, 1H, J = 2.6, 6.2Hz), 3.99(d, 1H, J = 1.9Hz), 4.22(dd, 1H, J = 4.9, 10.6Hz), 4.50(ABq, 2H, J = 11.9Hz), 4.53(Abq, 2H, J = 12.7Hz), 4.53(d, 2H, J = 10.6Hz), 4.96(s, 1H), 7.16-7.41(m, 15H) ; ^{13}C NMR (55.32 MHz, $CDCl_3$): δ 54.9, 69.8, 71.8, 72.0, 73.3, 80.8, 83.4, 88.0, 107.2, 127.5-128.3, 137.5, 17.8, 138.0; Mol. Wt. calculated for $C_{27}H_{30}O_5Na$: 457.51, Found: 457.42 (M^++23 for Na).



Methyl 2,3,4-tri-*O*-benzoyl-6-*O*-(2,3,4,6-tetra-*O*-benzyl-α-D-mannopyranosyl)-α-D-glucopyranoside (46) : $[\alpha]_D$ ($CHCl_3$, *c* 3.7) = +63.5; ^{1}H NMR (200.13 MHz, $CDCl_3$): δ 3.38(s, 3H), 3.46-3.70(m, 5H),3.81-4.00(m, 3H), 4.15(dd, 1H, J = 4.1, 13.8Hz), 4.43-4.49(m, 3H), 4.46(ABq, 2H, J = 12.0Hz), 4.69(d, 2H, J = 1.1Hz), 4.86(d, 1H, J = 10.9), 4.90(d, 1H, J = 1.6Hz), 5.17(t, 1H, J = 3.9Hz), 5.25(d, 1H, J = 3.6Hz), 5.56(t, 1H, J = 9.8Hz),6.11(t, 1H, J = 9.8Hz), 7.13-7.51(m, 29H), 7.84-8.00(m, 6H); ^{13}C NMR (50.32 MHz, $CDCl_3$): δ 55.5, 66.1, 68.1, 69.8, 70.5, 71.9, 72.1, 72.6, 73.2, 74.7, 74.8, 75.0, 77.2, 79.9, 96.9, 98.2, 127.4-128.4, 133.0, 133.2, 133.3, 138.4, 138.4, 138.8, 138.7, 165.1, 165.8, 165.8 ; Mol. Wt. calculated for $C_{62}H_{60}O_{14}Na$: 1052.121, Found: 1051.837 (M^++23 for Na).

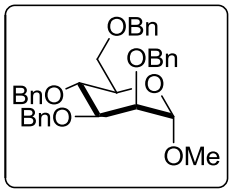


1,6-anhydro-2,3,4-tri-*O*-benzyl-β-D-glucopyranoside (47) : $[\alpha]_D$ ($CHCl_3$, *c* 1.1) = -20.0; ^{1}H NMR (200.13 MHz, $CDCl_3$): δ 3.34(d, 2H, J = 1.7Hz), 3.58(m, 1H), 3.67(dd, 1H, J = 5.7, 7.1Hz), 3.91(dd, 1H, J = 0.9, 7.1Hz), 4.41(d, 2H, J = 1.8Hz), 4.50-4.61(m, 1H), 4.54(d, 2H, J = 1.5Hz), 4.57(d, 2H, J = 3.2Hz), 5.46(s, 1H), 7.21-7.42(m, 15H) ; ^{13}C NMR (50.32 MHz, $CDCl_3$): δ 65.4, 71.1, 71.7, 72.0, 74.3, 76.1, 76.2, 76.8, 100.6, 127.6-128.6, 137.8, 137.8, 137.9 ; Mol. Wt. calculated for $C_{27}H_{28}O_5Na$: 455.498, Found: 456.378 (M^++23 for Na).

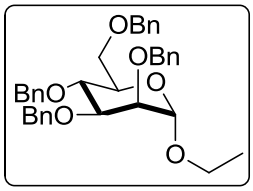


Methyl 2,3,4,6-tetra-*O*-benzyl-α-D-mannopyranoside (48) : $[\alpha]_D$ ($CHCl_3$, *c* 1.0) = +24.2; ^{1}H NMR (200.13 MHz, $CDCl_3$): δ 3.32(s, 3H), 3.71(dd, 1H, J = 1.9, 4.6Hz),

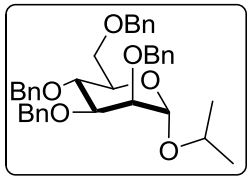
3.76(bs, 2H), 3.78(dd, 1H, J = 1.9, 3.0Hz), 3.90(d, 1H, J = 2.9Hz), 3.98(t, 1H, J = 9.0Hz), 4.49(d, 1H, J = 9.3Hz), 4.60(s, 2H), 4.61(ABq, 2H, J = 12.2Hz), 4.73(s, 2H), 4.77(d, 1H, 1.8Hz) 4.88(d, 1H, J = 10.9Hz), 7.13-7.40(m, 20H) ; ^{13}C NMR (50.32 MHz, $CDCl_3$): δ 54.8, 69.4, 71.7, 72.2, 72.7, 73.4, 74.6, 75.0, 75.1, 80.3, 99.0, 127.5-128.3, 138.4, 138.4, 138.6, 138.6 ; Mol. Wt. calculated for $C_{35}H_{38}O_6Na$: 577.662, Found: 577.400 (M^++23 for Na).



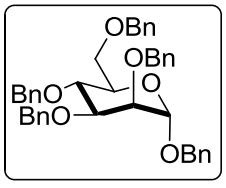
Ethyl 2,3,4,6-tetra-*O*-benzyl-α-D-mannopyranoside (49) : $[\alpha]_D$($CHCl_3$, *c* 1.0) = +26.8; ^{1}H NMR (200.13 MHz, $CDCl_3$): δ 1.14(t, 3H, J = 7.1Hz), 3.34-3.50(m, 1H), 3.63-3.70(m, 5H), 3.94(d, 2H, J = 2.7Hz), 4.50(d, 1H, J = 10.3Hz), 4.62(s, 2H), 4.61(ABq, 2H, J = 12.2Hz), 4.74(s, 2H), 4.87(d, 1H, J = 7.0Hz), 4.90(d, 1H, J = 1.8Hz), 7.12-7.40(m, 20H) ; ^{13}C NMR (50.32 MHz, $CDCl_3$): δ 14.9, 63.0, 69.3, 71.7, 72.1, 72.5, 73.3, 74.8, 75.0, 75.1, 80.3, 97.6, 127.4-128.3, 138.4, 138.4, 138.4, 138.6; Mol. Wt. calculated for $C_{36}H_{40}O_6Na$: 591.689, Found: 591.499 (M^++23 for Na).



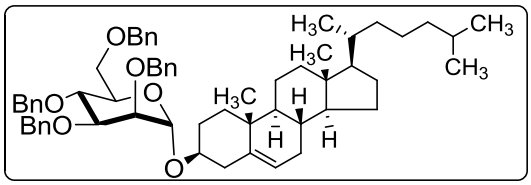
Isopropyl 2,3,4,6-tetra-*O*-benzyl-α-D-mannopyranoside (50) : $[\alpha]_D$ ($CHCl_3$, *c* 1.0) = +36.8; ^{1}H NMR (200.13 MHz, $CDCl_3$): δ 1.05(d, 3H, J = 6.1Hz), 1.16(d, 3H, J = 6.3Hz), 3.69-4.01(m, 7H), 4.50(d, 1H, J = 10.6Hz), 4.61(ABq, 2H, J = 12.3Hz), 4.63(bs,2H), 4.74(d, 2H, J = 4.2Hz), 4.81(d, 1H, J = 10.6Hz), 4.96(d, 1H, J = 1.8Hz), 7.12-7.41(m, 20H) ; ^{13}C NMR (50.32 MHz, $CDCl_3$): δ 21.2, 23.2, 68.9, 69.3, 71.7, 72.1, 72.6, 73.3, 75.1, 75.2, 75.2, 80.3, 95.8, 127.4-128.3, 138.4, 138.4, 138.4, 138.6 ; Mol. Wt. calculated for $C_{37}H_{42}O_6Na$: 605.716, Found: 605.583 (M^++23 for Na).



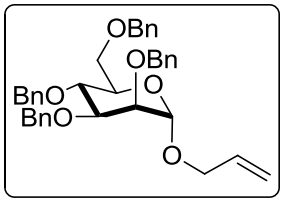
1,2,3,4,6-penta-*O*-benzyl-α-D-mannopyranoside (51) : $[\alpha]_D$ ($CHCl_3$, *c* 1.0) = +55.7; ^{1}H NMR (200.13 MHz, $CDCl_3$): δ 3.70-3.87(m, 4H), 3.97(d, 1H, J = 2.8Hz), 4.00(dd, 1H, J = 9.1, 13.2Hz), 4.41-4.65(m, 3H), 4.61(s, 2H), 4.63(ABq, 2H, J = 12.0Hz), 4.71(s,2H), 4.88(d, 1H, J = 10.6Hz), 4.97(d, 1H, J = 1.5Hz), 7.13-7.40(m, 25H) ; ^{13}C NMR (50.32 MHz, $CDCl_3$): δ 68.9, 69.2, 72.0, 72.1, 72.5, 73.3, 74.6, 74.9, 75.1, 80.2, 97.1, 127.4-128.3, 137.3, 138.2, 138.4, 138.4, 138.5; Mol. Wt. calculated for $C_{41}H_{42}O_6Na$: 653.758, Found: 653.555 (M^++23 for Na).



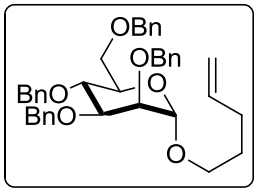
Cholesteryl 2,3,4,6-tetra-*O*-benzyl-α-D-mannopyranoside (52) : $[\alpha]_D$($CHCl_3$, *c* 1.0) = +22.0; ^{1}H NMR (200.13 MHz, $CDCl_3$): δ 0.67(s, 3H), 0.80-2.11(m, 29H), 0.85, 0.86, 0.97(3s, 9H), 2.28(d, 2H, J = 4.5Hz), 3.47(m, 1H), 3.66-4.05(m, 6H), 4.47-4.74(m, 3H), 4.60(ABq, 2H, J = 12.0Hz), 4.63(s, 2H), 4.88(d, 1H, J = 10.6Hz), 5.02(d, 1H, J = 1.7Hz), 5.27(d, 1H, J = 4.7Hz), 7.14-7.40(m, 20H) ; ^{13}C NMR (50.32 MHz, $CDCl_3$): δ 11.8, 18.7, 19.3, 21.0, 22.5, 22.8, 23.8, 24.3, 27.6, 28.0, 28.2, 29.7, 31.9, 31.9, 35.8, 36.2, 36.7, 37.0, 39.5, 39.8, 39.9, 42.3, 50.1, 56.1, 56.7, 69.4, 71.7, 72.1, 72.6, 73.7, 75.2, 75.2, 76.5, 80.4, 95.6, 121.8, 127.4-128.3, 138.4, 138.5, 138.5, 138.7, 140.6; Mol. Wt. calculated for $C_{61}H_{80}O_6Na$: 932.274, Found: 932.130 (M^++23 for Na).



Allyl 2,3,4,6-tetra-*O*-benzyl-α-D-mannopyranoside (53) : $[\alpha]_D$ ($CHCl_3$, *c* 1.0) = +29.7; ^{1}H NMR (200.13 MHz, $CDCl_3$): δ 3.70-4.07(m, 7H), 4.12(dt, 1H, J = 1.4, 4.9Hz), 4.60(ABq, 2H, J = 12.1Hz), 4.61(s, 2H), 4.70(ABq, 2H, J = 10.8Hz), 4.73(s, 2H), 4.92(d, 1H, J = 1.8Hz), 5.14(qd,1H, J = 1.6, 10.2Hz), 5.20(qd, 1H, J = 1.6, 17.2Hz), 5.84(m, 1H), 7.13-7.40(m, 20H); ^{13}C NMR (50.32 MHz, $CDCl_3$): δ 67.7, 69.2, 71.8, 72.1, 72.5, 73.3, 74.6, 74.9, 75.1, 80.1, 97.0, 117.1, 127.4-128.2, 133.7, 138.3, 138.3, 138.4, 138.5; Mol. Wt. calculated for $C_{37}H_{40}O_6Na$: 603.700, Found: 603.529 (M^++23 for Na).

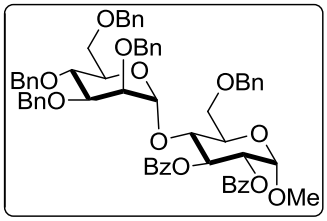


Pent-4-enyl 2,3,4,6-tetra-*O*-benzyl-α-D-mannopyranoside (57) : $[\alpha]_D$ ($CHCl_3$, *c* 1.0) = +26.5; ^{1}H NMR (200.13 MHz, $CDCl_3$): δ 1.61(m, 2H), 2.06(m, 2H), 3.35(dd, 1H, J = 6.5, 16.2Hz), 3.62-4.05(m, 7H), 4.56(ABq, 2H, J = 12.2Hz), 4.63(s, 2H), 4.70(ABq, 2H, J = 10.7Hz), 4.73(s, 2H), 4.85(d, 1H, J = 1.4Hz), 4.92-5.04(m, 2H), 5.76(m, 1H), 7.13-7.40(m, 20H) ; ^{13}C NMR (50.32 MHz, $CDCl_3$): δ 28.5, 30.2, 66.8, 69.3, 71.8, 72.1, 72.5, 73.3, 74.8, 75.0, 75.0, 75.1, 80.2, 97.8, 114.8, 127.4-128.2, 138.0, 138.3, 138.4, 138.5; Mol. Wt. calculated for $C_{39}H_{44}O_6Na$: 631.753, Found: 631.403 (M^++23 for Na).

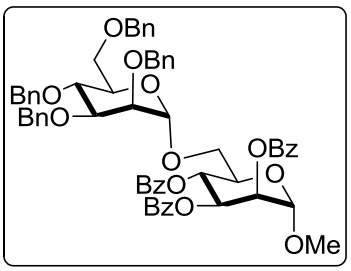


Methyl 2,3-di-*O*-benzoyl-4-O-(2,3,4,6-tetra-*O*-benzyl-α-D-mannopyranosyl)-6-*O*-benzyl-α-D-glucopyranoside (58) : $[\alpha]_D$ ($CHCl_3$, *c* 1.0) = +43.7; ^{1}H NMR (200.13 MHz, $CDCl_3$): δ 3.41(s, 3H), 3.56-4.00(m, 10H), 4.13(t, 1H, J = 12.2Hz), 4.43(dd, 2H, J = 2.8, 9.2 Hz), 4.46(d, 2H, J = 3.1Hz), 4.55(dd, 2H, J = 6.0Hz), 4.56(ABq, 2H, J = 6.4Hz),

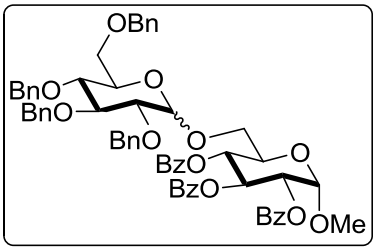
4.81(d, 1H, J = 10.9Hz), 5.10-5.18(m, 3H), 6.00(t, 1H, J = 9.6Hz), 6.96-7.50(m, 29H), 7.92-8.01(m, 6H); ^{13}C NMR (50.32 MHz, $CDCl_3$): δ 55.4, 68.8, 69.4, 69.9, 71.5, 72.0, 72.5, 72.9, 73.1, 73.3, 73.4, 74.4, 74.9, 75.8, 76.7, 80.0, 96.8, 100.5, 127.1-130.0, 133.2, 133.5, 138.2, 138.3, 138.3, 138.3, 138.5, 138.5, 165.5, 165.9 ; Mol. Wt. calculated for $C_{62}H_{62}O_{14}Na$: 1052.121, Found: 1051.911 (M^++23 for Na).



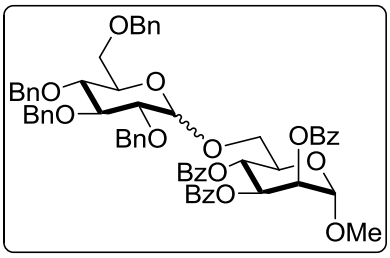
Methyl 2,3,4-tri-*O*-benzoyl-6-*O*-(2,3,4,6-tetra-*O*-benzyl-α-D-mannopyranosyl)-α-D-mannopyranoside (59) : $[\alpha]_D$ ($CHCl_3$, *c* 1.0) = -40.0; ^{1}H NMR (200.13 MHz, $CDCl_3$): δ 3.43(s, 3H), 3.50-3.75(m, 5H), 3.84(dd, 1H, J = 2.8, 9.2Hz), 3.90-4.05(m, 2H), 4.18(m, 1H), 4.37(d, 2H, J = 2.7Hz), 4.46(d, 1H, J = 12.0Hz), 4.49(Abq, 2H, J = 12.1Hz), 4.62(s, 2H), 4.84(d, 1H, J = 10.8Hz), 4.95(dd, 2H, J = 1.6, 5.6Hz), 5.63(dd, 1H, J = 1.8, 2.9Hz), 5.87(d, 1H, J = 3.7Hz), 5.92(t, 1H, J = 10.1Hz), 7.12-7.56(m, 29H), 7.80-8.10(m, 6H) ; ^{13}C NMR (50.32 MHz, $CDCl_3$): δ 55.4, 66.7, 67.9, 68.9, 69.1, 69.9, 70.6, 71.8, 71.9, 72.5, 73.2, 74.7, 74.8, 75.0, 80.1, 98.1, 98.5, 127.4-129.8, 133.1, 133.3, 133.5, 138.3, 138.4, 138.5, 138.6, 165.4, 165.4, 165.5; Mol. Wt. calculated for $C_{62}H_{60}O_{14}Na$: 1052.121, Found: 1051.911 (M^++23 for Na).



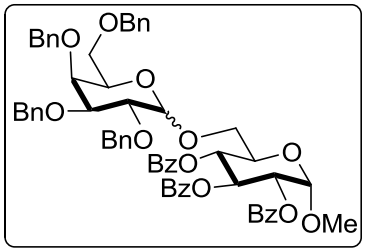
Methyl 2,3,4-tri-*O*-benzoyl-6-*O*-(2,3,4,6-tetra-*O*-benzyl-(α/β)-D-glucopyranosyl)-α-D-glucopyranoside (61) : ^{1}H NMR (200.13 MHz, $CDCl_3$): δ 3.25-3.68(m, 12H), 3.43(s, 3H), 3.45(m, 3H), 3.82-4.20(m, 4H), 4.25-4.95(m, 20H), 5.04-5.35(m, 4H), 5.40-5.70(m, 2H), 5.80(t, 1H, J = 9.6Hz), 6.15(t,1H, J = 7.5Hz), 7.11-7.50(m, 58H), 7.85-8.00(m, 12H) ; ^{13}C NMR (50.32 MHz, $CDCl_3$): δ 55.5, 55.5, 66.6, 68.2, 68.5, 68.8, 69.6, 69.9, 70,0, 70.2, 70.5, 70.6, 71.3, 71.7, 72.1, 72.2, 73.1, 73.3, 73.8, 74.7, 74.8, 74.9, 75.5, 75.6, 77.2, 77.5, 79.9, 81.7, 82.3, 84.5, 96.7, 97.1, 97.2, 104.0, 127.4-129.9, 133.0,130.0, 133.3, 133.3, 133.3, 133.3, 137.9, 138.0, 138.1, 138.3, 138.4, 138.5, 138.6, 138.8, 165.2, 165.4, 165.7, 165.7, 165.8, 165.8; Mol. Wt. calculated for $C_{62}H_{60}O_{14}Na$: 1052.121, Found: 1051.911 (M^++23 for Na).



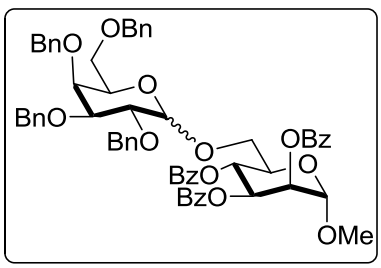
Methyl 2,3,4-tri-*O*-benzoyl-6-*O*-(2,3,4,6-tetra-*O*-benzyl-(α/β)-D-glucopyranosyl)-α-D-mannopyranoside (62) : ^{1}H NMR (200.13 MHz, $CDCl_3$): δ 3.30-3.75(m, 12H), 3.49(s, 3H), 3.53(s, 3H), 3.90(dd, 1H, J = 10.2, 19.6Hz), 4.10(dd, 1H, J = 10.1, 19.6Hz), 4.20-5.18(m, 24H), 5.56-6.02(m, 6H), 7.01-7.68(m, 58H), 7.81-8.19(m, 12H) ; ^{13}C NMR (50.32 MHz, $CDCl_3$): δ 55.4, 55.5, 62.8, 66.9, 67.2, 67.4, 67.5, 68.2, 68.5, 69.3, 69.5, 69.8, 70.0, 70.1, 70.3, 70.5, 73.0, 73.3, 73.4, 74.7, 74.7, 74.9, 75.5, 75.6, 77.5, 77.6, 79.9, 81.8, 82.3, 84.4, 97.2, 98.5, 98.6, 104.1, 127.5-129.9, 133.0, 133.1, 133.3, 133.4, 133.4, 133.5, 137.8, 138.0. 138.0. 138.3, 138.4, 138.5, 138.5, 138.8, 165.4, 165.4, 165.4, 165.4, 165.5, 165.6; Mol. Wt. calculated for $C_{62}H_{60}O_{14}Na$: 1052.121, Found: 1051.911 (M^++23 for Na).



Methyl 2,3,4-tri-*O*-benzoyl-6-*O*-(2,3,4,6-tetra-*O*-benzyl-(α/β)-D-galactopyranosyl)-α-D-glucopyranoside (67) : ^{1}H NMR (200.13 MHz, $CDCl_3$): δ 3.34(s, 3H), 3.35(s, 3H), 3.41-4.13(m, 16H), 4.25-4.81(m, 16H), 4.86-5.32(m, 8H), 5.42(t, 1H, J = 10.0Hz), 5.54(t, 1H, 10.0Hz), 6.13(t, 1H, J = 9.7Hz), 6.16(t, 1H, J = 9.7Hz), 7.15-7.55(m, 58H), 7.81-8.05(m, 12H) ; ^{13}C NMR (50.32 MHz, $CDCl_3$): δ 55.4, 55.4, 66.5, 66.5, 68.4, 68.6, 68.6, 68.9, 68.9, 69.2, 69.5, 69.9, 70.5, 70.5, 70.6, 72.1, 72.8, 73.0, 73.1, 73.2, 73.4, 73.4, 74.5, 74.7, 75.0, 75.1,77.2, 78.5, 79.6, 82.0, 96.7, 96.9, 97.8, 104.1, 127.4-129.9, 133.0, 133.0, 133.3, 133.3, 133.3, 133.3, 137.8, 138.1, 138.5, 138.5, 138.7, 138.7, 138.7, 138.8, 165.3, 165.5, 165.7, 165.8, 165.8, 165.8; Mol. Wt. calculated for $C_{62}H_{60}O_{14}Na$: 1052.121, Found: 1051.911 (M^++23 for Na).

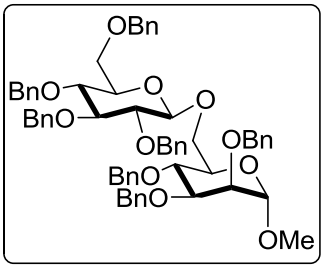


Methyl 2,3,4-tri-*O*-benzoyl-6-*O*-(2,3,4,6-tetra-*O*-benzyl-(α/β)-D-galactopyranosyl)-α-D-manopyranoside (68) : ^{1}H NMR (200.13 MHz, $CDCl_3$): δ 3.32-3.54(m, 5H), 3.40(s, 3H), 3.41(s, 3H), 3.63(dd, 1H, J = 1.9, 11.0Hz), 3.80-4.83(m, 28H), 4.89-5.17(m, 4H), 5.64-5.95(m, 6H), 7.11-7.61(m, 58H), 7.79-8.09(m, 12H) ; ^{13}C NMR (50.32 MHz, $CDCl_3$): δ 55.3, 55.3, 67.0, 67.0, 67.3, 67.6, 68.6, 68.7, 69.2, 69.3, 69.4, 69.8, 69.9, 70.0, 70.3, 70.4, 70.5, 72.9, 73.1, 73.1, 73.4, 73.5, 74.5, 74.7, 75.0, 75.1, 78.7, 79.6, 80.8, 81.9, 97.9, 98.2, 98.5,

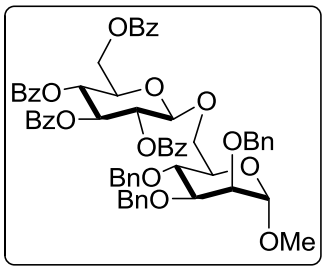


104.4, 127.4-129.9, 133.0, 133.1, 133.3, 133.3, 133.4, 133.4, 137.8, 138.0, 138.5, 138.6, 138.7, 138.7, 138.7, 138.8, 165.4, 165.4, 165.5, 165.6, 165.6, 165.7; Mol. Wt. calculated for $C_{62}H_{60}O_{14}Na$: 1052.121, Found: 1051.837(M^++23 for Na).

Methyl 2,3,4-tri-*O*-benzyl-6-*O*-(2,3,4,6-tetra-*O*-benzyl-β-D-glucopyranosyl)-α-D-mannopyranoside (71) : $[\alpha]_D$ ($CHCl_3$, *c* 1.1) = +20.5; ^1H NMR (500.13 MHz, $CDCl_3$): δ 3.25(s, 3H), 3.45(ddd, 1H, J = 1.8, 4.2, 6.1, 9.1Hz), 3.51(t, 1H, J = 8.3Hz), 3.61(d, 1H, J = 3.2Hz), 3.62(ABq, 2H, J = 9.0Hz), 3.67-3.84(m, 5H), 3.90(dd, 1H, J = 3.1, 9.3Hz), 3.96(t, 1H, J = 9.5Hz), 4.27(dd, 1H, J = 1.2, 10.7Hz), 4.40(d, 1H, J = 7.9Hz), 4.58(s, 2H), 4.61(ABq, 2H, J = 12.5Hz), 4.66(ABq, 2H, J = 12.1Hz), 4.67(ABq, 2H, J = 11.0Hz), 4.70(s, 2H), 4.77(s, 2H), 4.95(d, 1H, J = 10.8Hz), 5.06(d, 1H, J = 11.0Hz), 7.15-7.38(m, 35H) ; ^{13}C NMR (125.76 MHz, $CDCl_3$): δ 54.7, 69.0, 69.0, 71.3, 71.9, 72.7, 73.4, 74.5, 74.7, 74.9, 74.9, 74.9, 74.9, 75.6, 77.8, 80.1, 82.1, 84.6, 98.9, 104.1, 127.3-128.3, 138.1, 138.2, 138.2, 138.5, 138.5, 138.5, 138.6; Mol. Wt. calculated for $C_{62}H_{66}O_{11}Na$: 1010.171, Found: 1009.882 (M^++23 for Na).

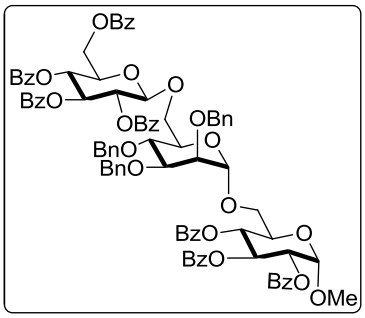


Methyl 2,3,4-tri-*O*-benzyl-6-*O*-(2,3,4,6-tetra-*O*-benzoyl-β-D-glucopyranosyl)-α-D-mannopyranoside (72) : $[\alpha]_D$ ($CHCl_3$, *c* 1.0) = +25.7; ^1H NMR (200.13 MHz, $CDCl_3$): δ 2.96(s, 3H), 3.60-3.84(m, 5H), 4.13(dd, 1H, J = 4.7, 9.9Hz), 4.18(dd, 1H, J = 9.8, 15.0Hz), 4.51(s, 2H), 4.58(ABq, 2H, J = 11.1Hz), 4.52(d, 2H, J = 1.8Hz), 4.57(dd, 1H, J = 3.2, 10.6Hz), 4.66(s, 2H), 4.97(d, 1H, J = 7.9hz), 5.58(dd, 1H, J = 7.8, 9.7Hz), 5.69(t, 1J, J = 9.7Hz), 5.91(t, 1H, J = 9.7Hz), 7.17-7.55(m, 27H), 7.80-8.03(m, 8H) ; ^{13}C NMR (125.76 MHz, $CDCl_3$): δ 54.3, 63.1, 69.5, 69.8, 71.3, 71.9, 72.0, 72.1, 72.6, 73.0, 74.3, 74.8, 75.0, 80.2, 98.6, 101.7, 127.5-129.8, 133.0, 133.0, 133.2, 133.4, 138.2, 138.3, 138.4, 165.0, 165.1, 165.9, 166.1; Mol. Wt. calculated for $C_{62}H_{58}O_{15}Na$: 1066.105, Found: 1066.012 (M^++23 for Na).

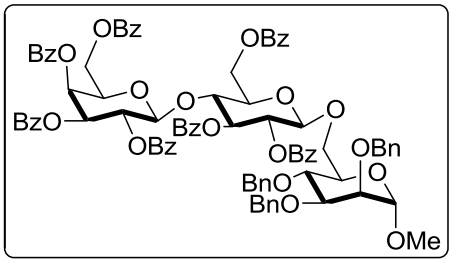


Methyl 2,3,4-tri-*O*-benzoyl-6-*O*-(2,3,4-tri-*O*-benzyl)-6-*O*-(2,3,4,6-tetra-*O*-benzoyl-β-D-glucopyranosyl)-α-D-mannopyranosyl)-α-glucopyranoside (73) : $[\alpha]_D$ ($CHCl_3$, *c* 1.0) = +57.2; ^1H NMR (500.13 MHz, $CDCl_3$): δ 3.17(dd, 1H, J = 3.2, 11.3Hz), 3.40(s, 3H), 3.54(quintet, 2H, J = 6.9Hz), 3.60-3.66(m, 3H), 3.81(dd, 1H, J = 3.1, 9.4Hz), 3.91(td, 1H, J = 3.4, 10.0Hz), 4.00(d, 1H, J = 9.1Hz), 4.05(m ,1H), 4.34(d, 1H, J =

11.2Hz), 4.46(ABq, 2H, J = 11.5Hz), 4.47(dd, 1H, J = 5.2, 12.0Hz), 4.58(dd, 1H, J = 3.6, 12.4Hz), 4.63(d, 2H, J = 1.3Hz), 4.65-4.69(m, 2H), 4.78(d, 1H, J = 7.7Hz), 5.13(d, 1H, J = 3.6Hz), 5.19(dd, 1H, J = 3.7, 10.3Hz), 5.38(dd, 1H, J = 7.8, 9.9Hz), 5.55(t, 1H, J = 9.9Hz), 5.61(t, 1H, J = 9.8Hz), 5.84(t, 1H, J = 9.8Hz), 6.04(t, 1H, J = 9.9Hz), 7.16-7.52(m, 36H), 7.82-8.00(m, 14H) ; ^{13}C NMR (125.76 MHz, $CDCl_3$): δ 55.6, 63.2, 65.3, 68.0, 68.9, 69.1, 69.8, 70.1, 71.1, 71.9, 71.9, 72.0, 72.0, 72.6, 72.9, 74.6, 74.6, 74.7, 79.8, 96.9, 98.0, 101.3, 127.4-130.0, 133.0, 133.0, 133.0, 133.2, 133.2, 133.3, 133.3, 138.4, 138.5, 138.5, 164.8, 165.0, 165.2, 165.8, 165.8, 165.8, 166.1; Mol. Wt. calculated for $C_{89}H_{80}O_{23}Na$: 1540.564, Found: 1540.203 (M^++23 for Na).

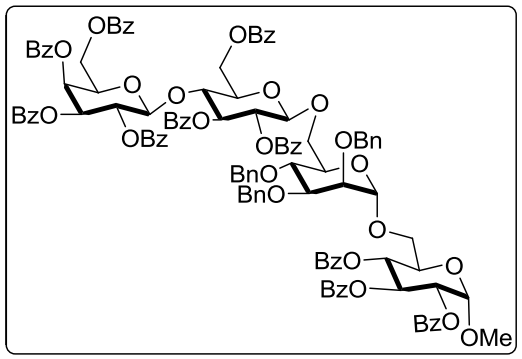


Methyl 2,3,4-tri-*O*-benzyl-6-*O*-(2,3,6-tri-*O*-benzoyl)-4-*O*-(2,3,4,6-tetra-*O*-benzoyl-β-D-galactopyranosyl)-β-D-glucopyranosyl)-α-glucopyranoside (74) : $[\alpha]_D$($CHCl_3$, *c* 1.0) = +44.5; ^{1}H NMR (500.13 MHz, $CDCl_3$): δ 2.93(s, 3H), 3.55-3.95(m, 8H), 4.10(m, 2H), 4.27(t, 1H, J = 9.5Hz), 4.50(s, 2H), 4.50(d, 1H, J = 1.7Hz), 4.53(dd, 2H, J = 4.0, 8.2Hz), 4.54(ABq, 2H, J = 11.1Hz), 4.64(s, 2H), 4.86(dd, 2H, J = 2.7, 7.8Hz), 5.37(dd, 1H, J = 3.3, 10.4Hz), 5.52(dd, 1H, J = 7.9, 9.9Hz), 5.65-5.87(m, 3H), 7.08-7.75(m, 36H), 7.87-8.03(m, 14H) ; ^{13}C NMR (125.76 MHz, $CDCl_3$): δ 54.2, 61.0, 62.3, 67.4, 69.3, 69.8, 71.3, 71.3, 71.7, 71.7, 71.8, 72.5, 72.8, 72.9, 74.1, 74.8, 74.8, 75.9, 80.0, 98.5, 100.9, 101.5, 127.4-129.9, 132.9, 133.0, 133.2, 133.3, 133.3, 133.3, 133.4, 138.1, 138.2, 138.3, 164.7, 165.0, 165.1, 165.3, 165.4, 165.5, 165.8; Mol. Wt. calculated for $C_{89}H_{80}O_{23}Na$: 1540.564, Found: 1540.074 (M^++23 for Na).



Methyl 2,3,4-tri-*O*-benzoyl-6-*O*-(2,3,4-tri-*O*-benzyl)-6-*O*-(2,3,6-tetra-*O*-benzoyl)-4-O-(2,3,4,6-tetra-O-benzoyl-β-D-galactopyranosyl)-β-D-glucopyranosyl)-α-D-manno-pyranosyl)-α-D-glucopyranoside (75) : $[\alpha]_D$ ($CHCl_3$, *c* 1.0) = +56.7; ^{1}H NMR (500.13 MHz, $CDCl_3$): δ 3.23(dd, 1H, J = 2.8, 11.1Hz), 3.39(s, 3H), 3.35-3.93(m, 12H), 4.15-4.70(m, 6H), 4.26(d, 2H, J = 10.5Hz), 4.42(dd, 2H, J = 11.7, 14.7Hz), 4.86(d, 1H, J = 7.9Hz), 5.12(t, 1H, J = 3.5Hz), 5.18(dd, 1H, J = 3.6, 7.0Hz), 5.33-5.55(m, 4H), 5.68-5.80(m, 3H), 6.02(t, 1H, J = 9.8Hz), 6.95-7.65(m, 45H), 7.71-8.03(m, 20H) ; ^{13}C NMR

(125.76 MHz, $CDCl_3$): δ 55.6, 61.1, 62.3, 65.3, 67.5, 68.0, 68.8, 69.1, 69.8, 70.5, 71.2, 71.3, 71.7, 71.7, 71.9, 72.0, 72.4, 72.7, 72.9, 74.5, 74.6, 74.7, 75.9, 79.7, 96.9, 97.9, 100.8, 101.3, 127.4-130.0, 132.9, 132.9, 133.0, 133.0, 13.2, 133.3, 133.3, 133.4, 133.4, 133.5, 138.3, 138.4, 138.5, 164.7, 165.0, 165.0, 165.1, 165.3, 165.4, 165.5, 165.7, 165.7, 165.7; Mol. Wt. calculated for $C_{89}H_{80}O_{23}Na$: 2015.022, Found: 2015.441 (M^++23 for Na).

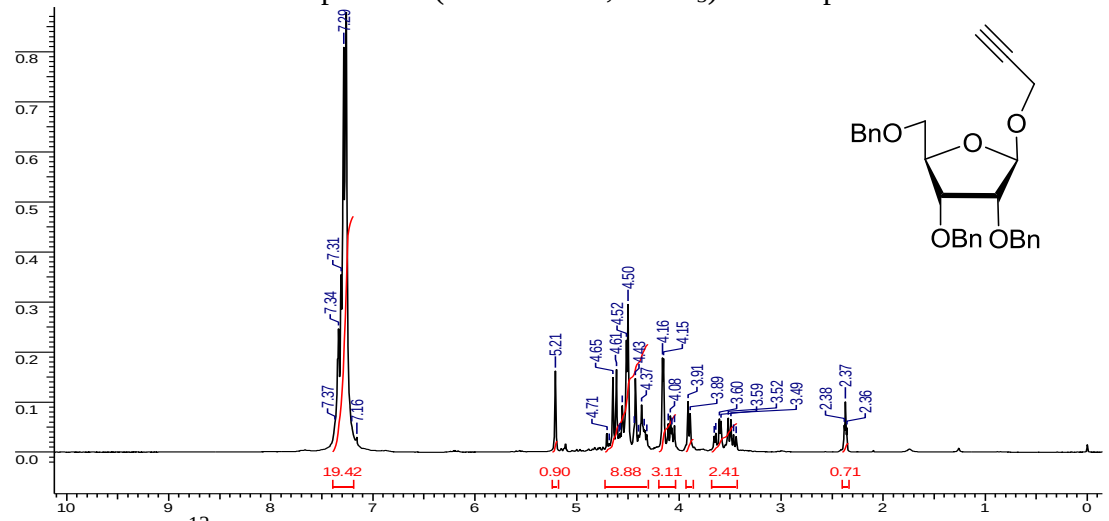


****

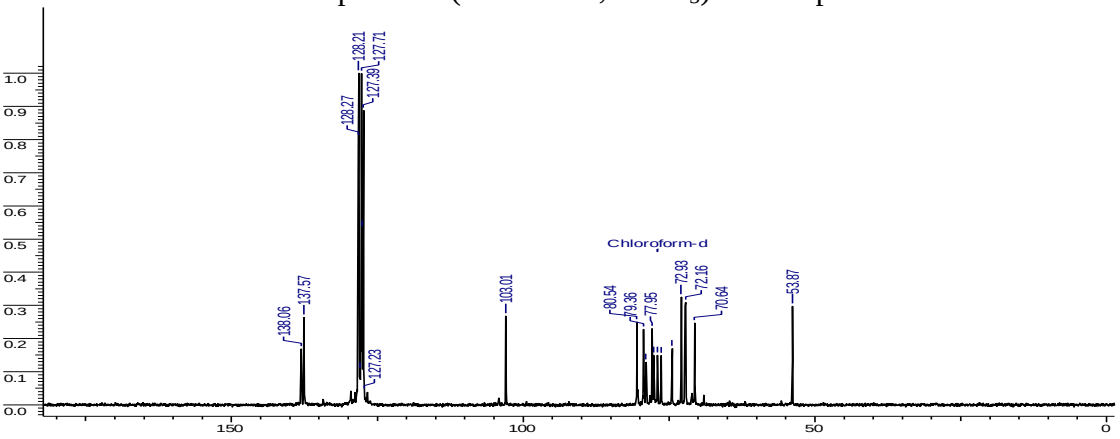
Chapter 2: Spectral Charts

(Characterization data and full spectral charts for all compounds can also be found in ***Chem Comm* 2011** (DOI:10.1039/C1CC13134F) and ***Chem Comm* 2009**, 2505-2507)

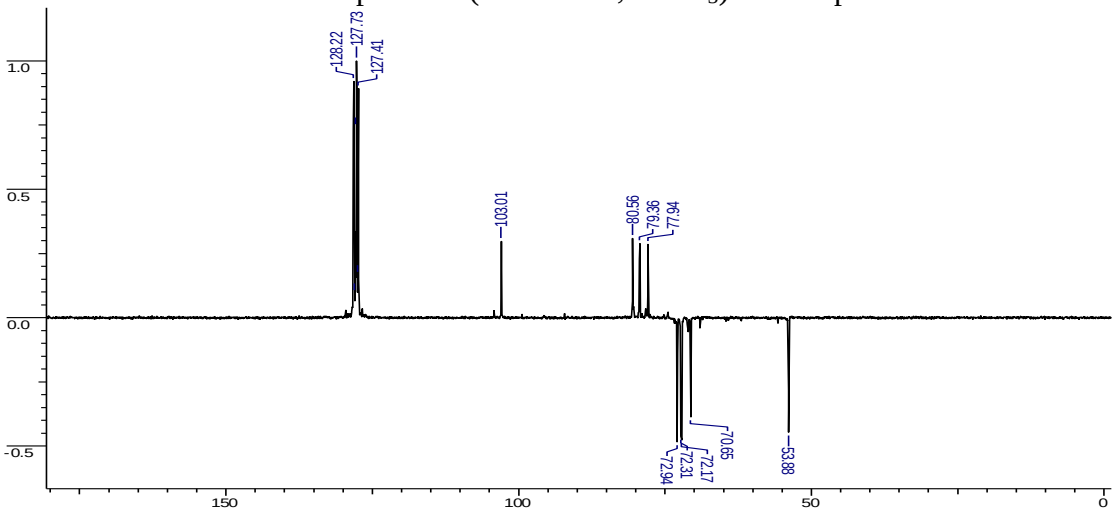
^{1}H NMR Spectrum (200.13 MHz, $CDCl_3$) of Compound **8**



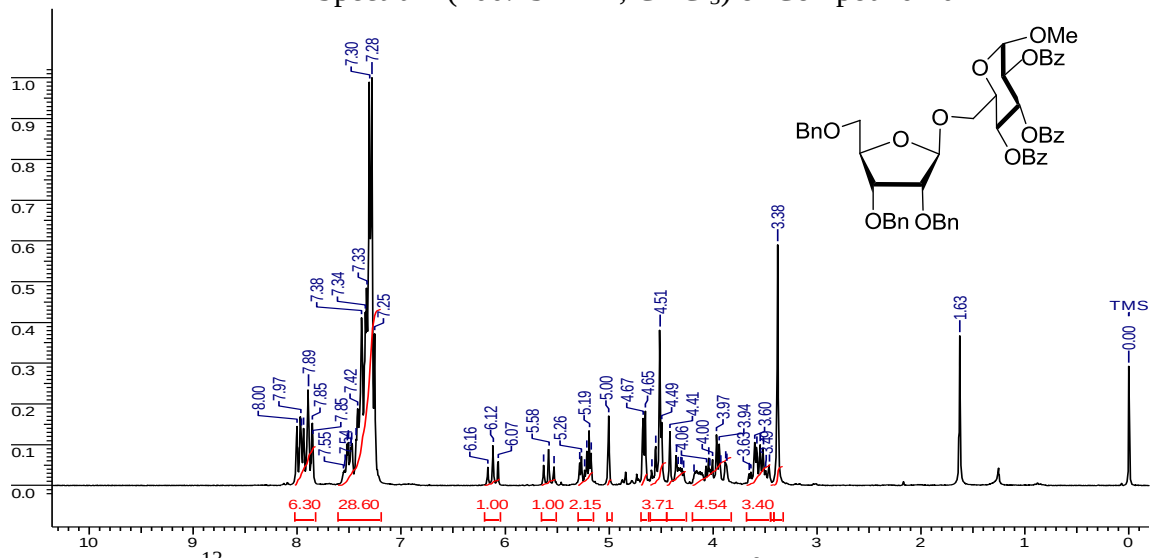
^{13}C NMR Spectrum (50.32MHz, $CDCl_3$) of Compound **8**



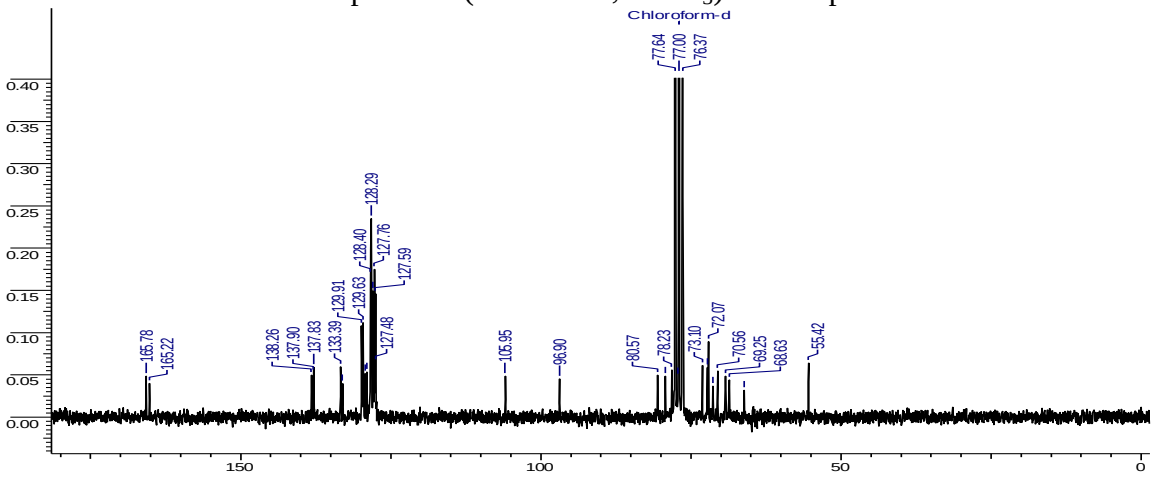
DEPT NMR Spectrum (50.32MHz, $CDCl_3$) of Compound **8**



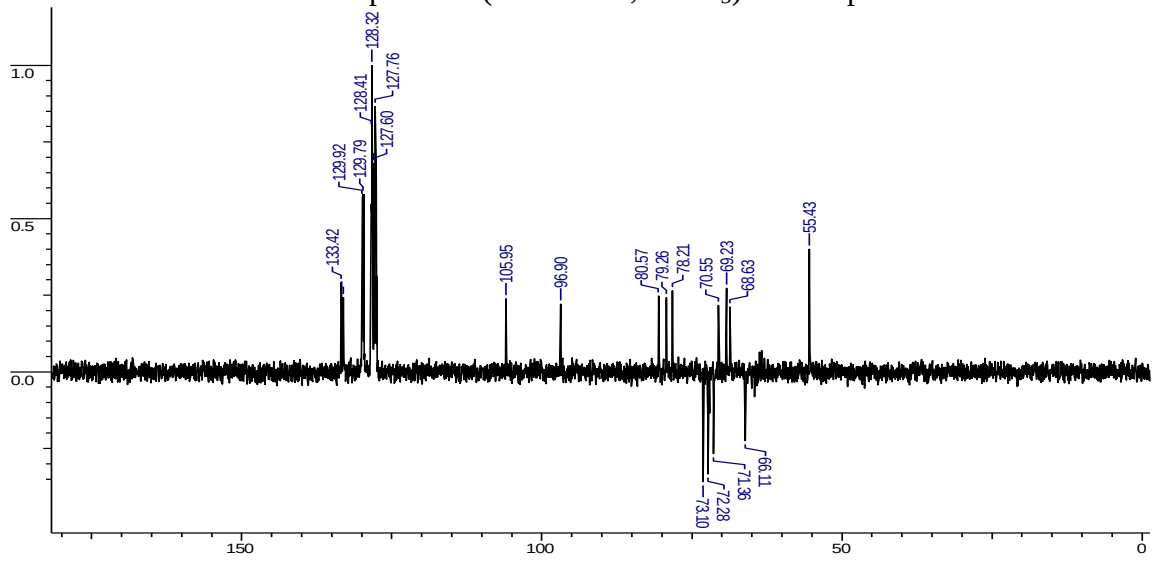
^{1}H NMR Spectrum (200.13 MHz, $CDCl_3$) of Compound **10**



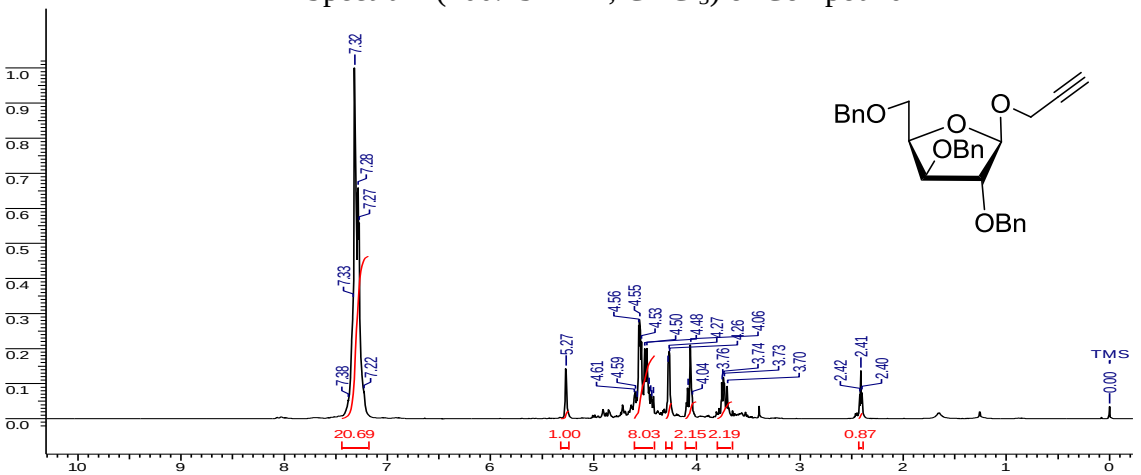
^{13}C NMR Spectrum (50.32MHz, $CDCl_3$) of Compound **10**



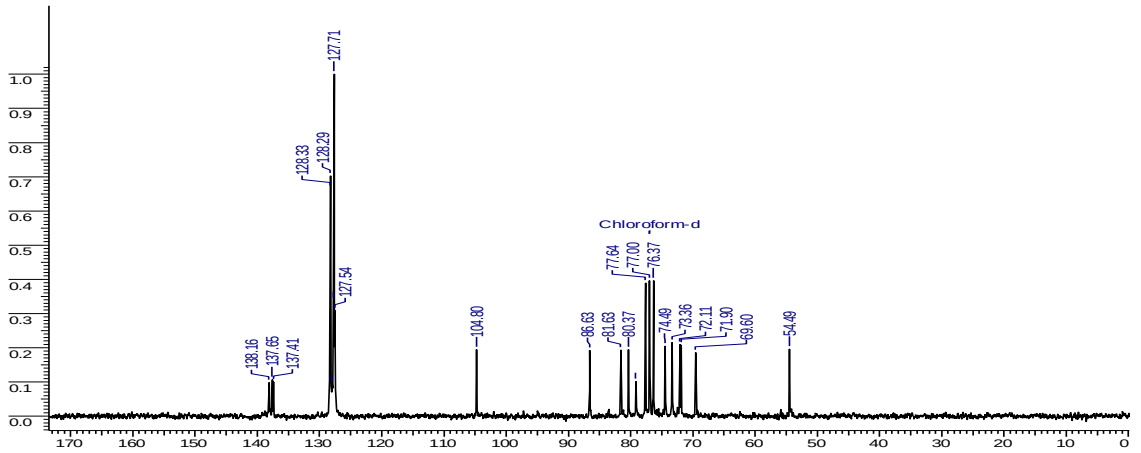
DEPT NMR Spectrum (50.32MHz, $CDCl_3$) of Compound **10**



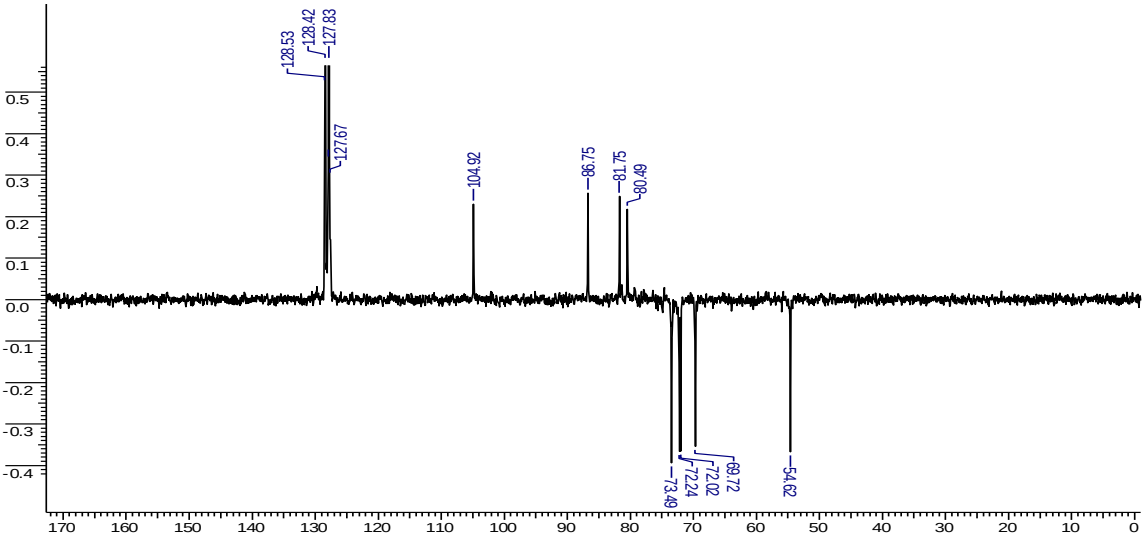
^{1}H NMR Spectrum (200.13 MHz, $CDCl_3$) of Compound **11**



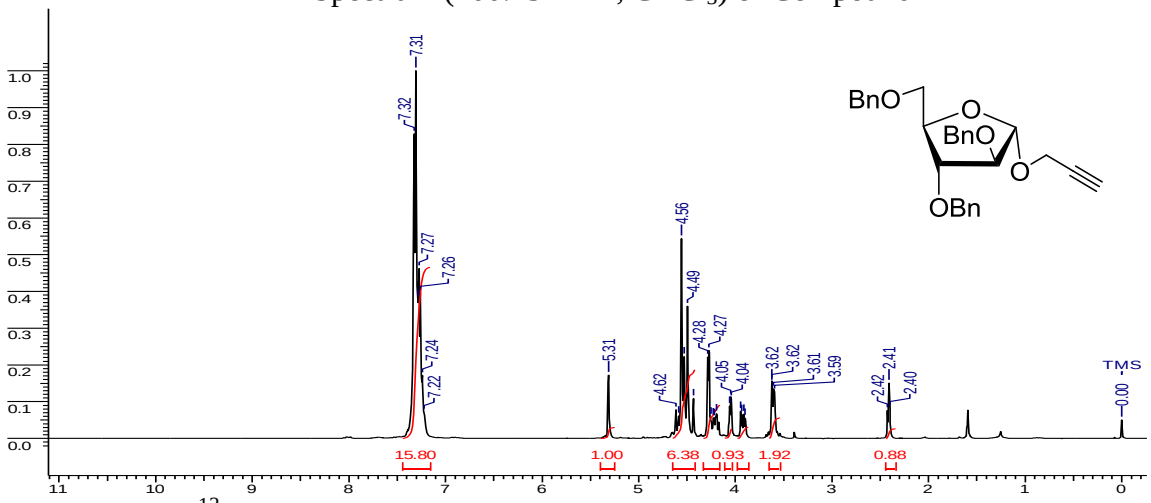
^{13}C NMR Spectrum (50.32MHz, $CDCl_3$) of Compound **11**



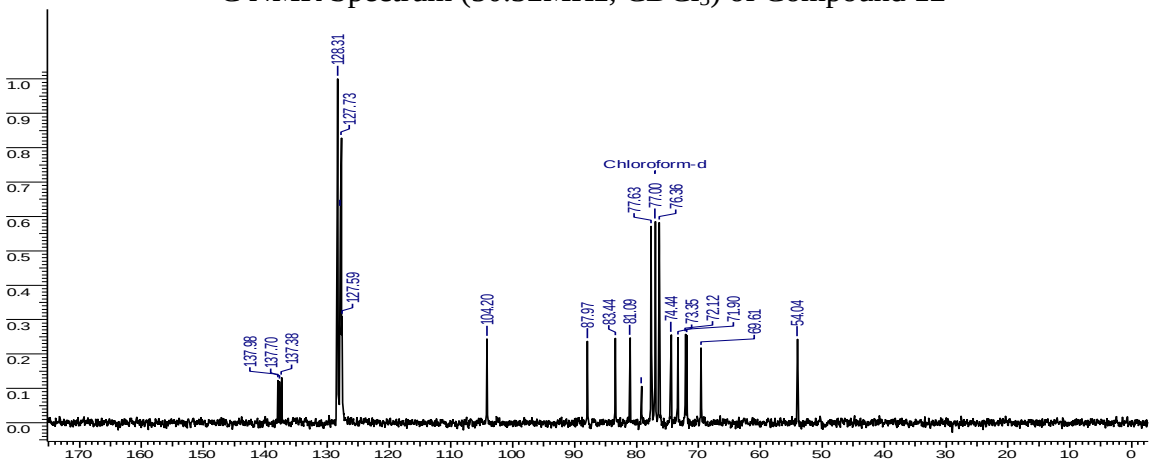
DEPT NMR Spectrum (50.32MHz, $CDCl_3$) of Compound **11**



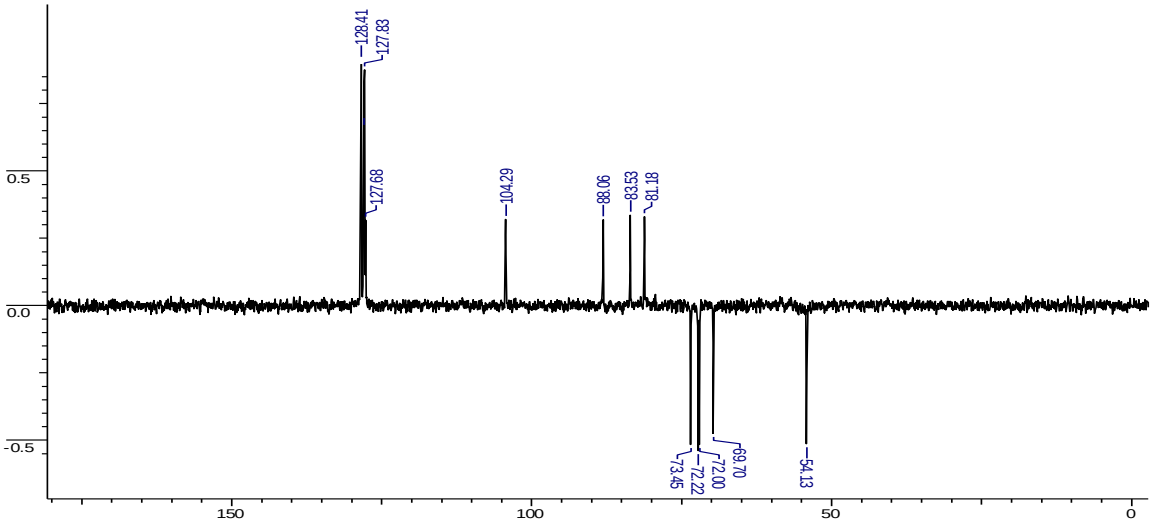
^{1}H NMR Spectrum (200.13 MHz, $CDCl_3$) of Compound **12**



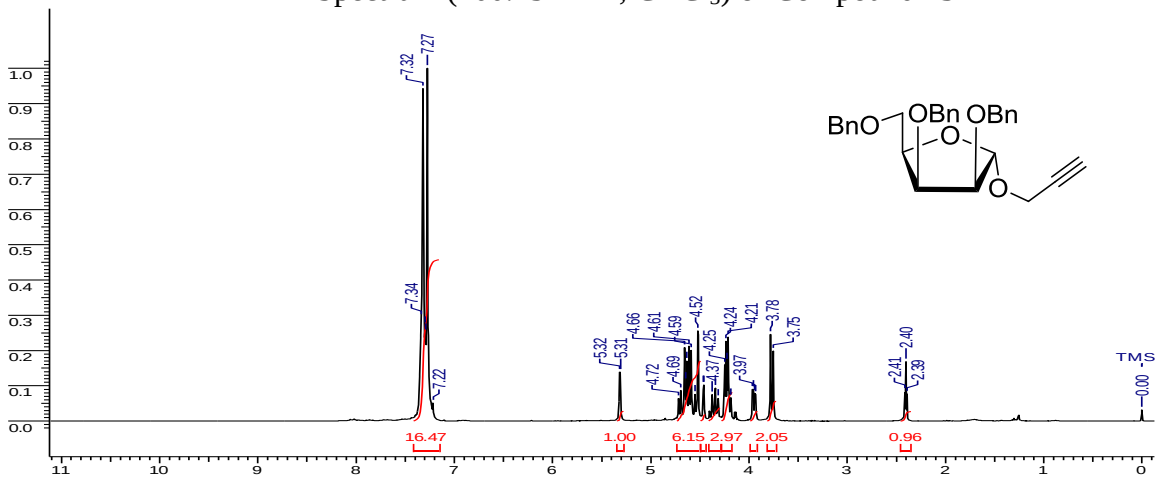
^{13}C NMR Spectrum (50.32MHz, $CDCl_3$) of Compound **12**



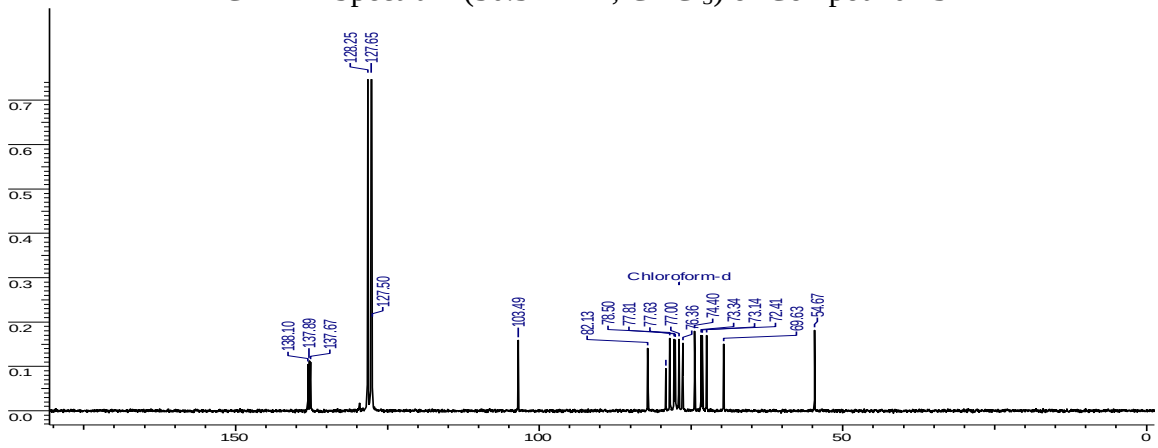
DEPT NMR Spectrum (50.32MHz, $CDCl_3$) of Compound **12**



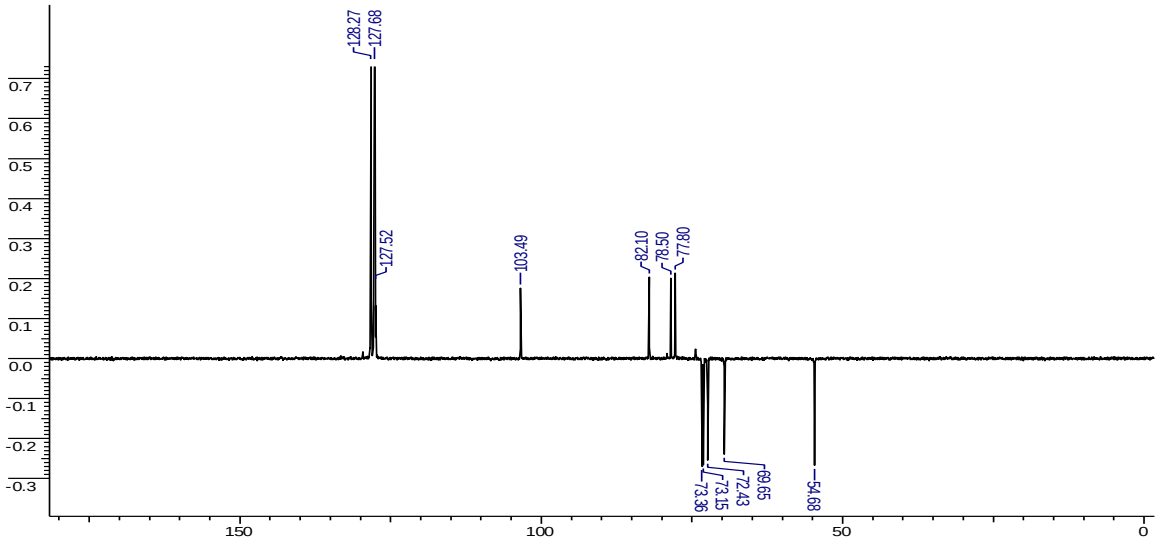
^{1}H NMR Spectrum (200.13 MHz, $CDCl_3$) of Compound **13**



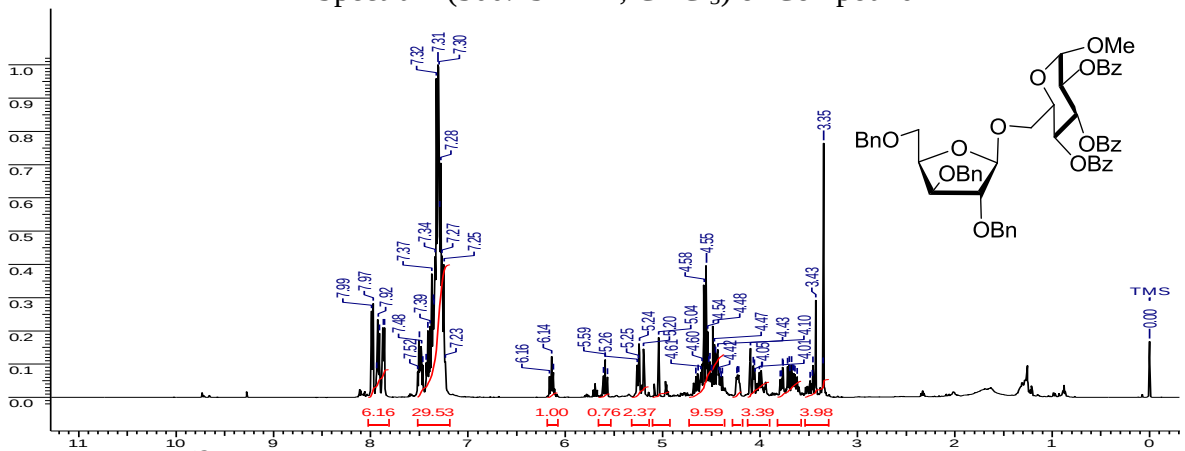
^{13}C NMR Spectrum (50.32MHz, $CDCl_3$) of Compound **13**



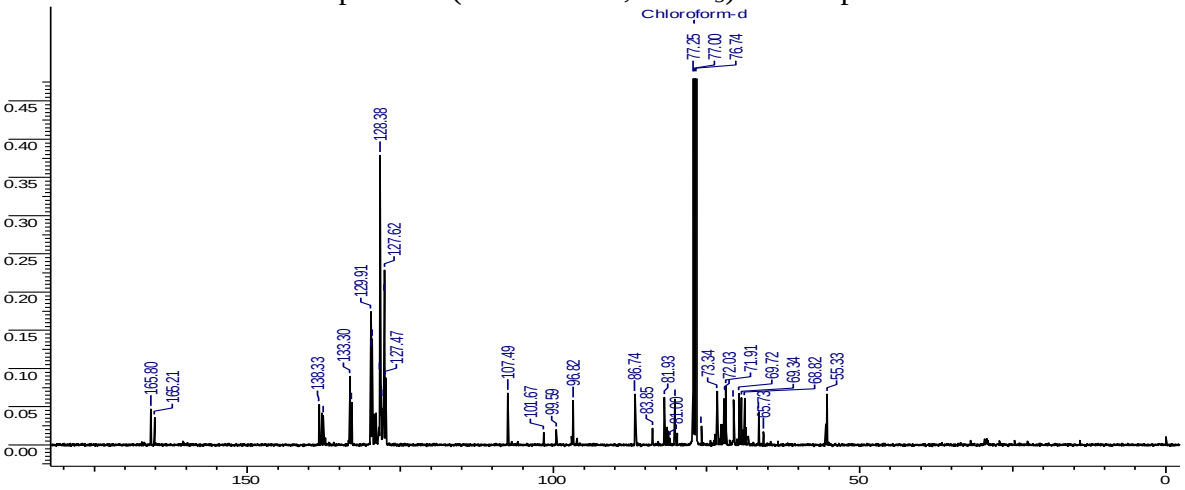
DEPT NMR Spectrum (50.32MHz, $CDCl_3$) of Compound **13**



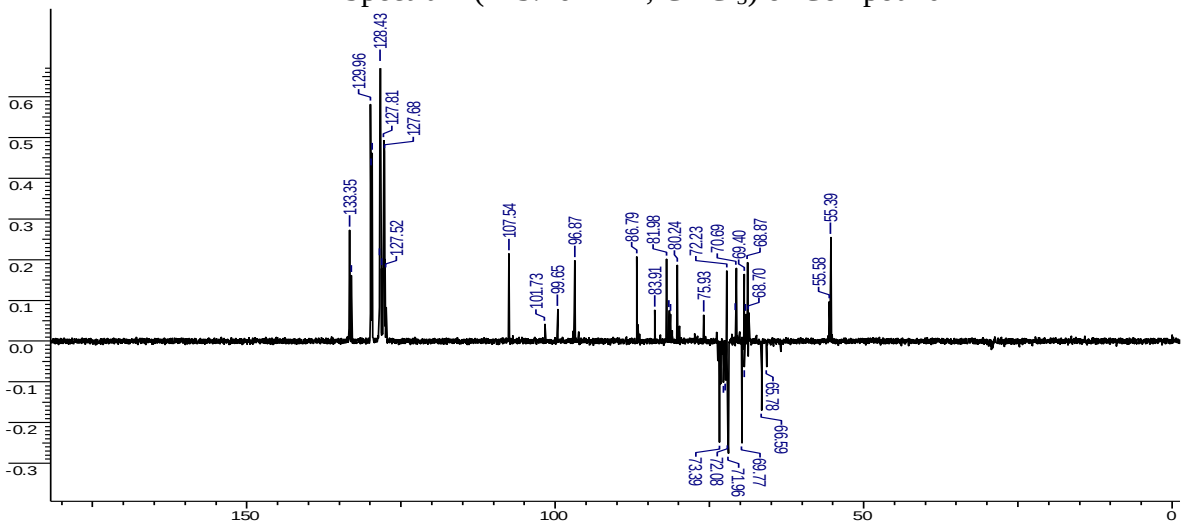
^{1}H NMR Spectrum (500.13 MHz, $CDCl_3$) of Compound **14**



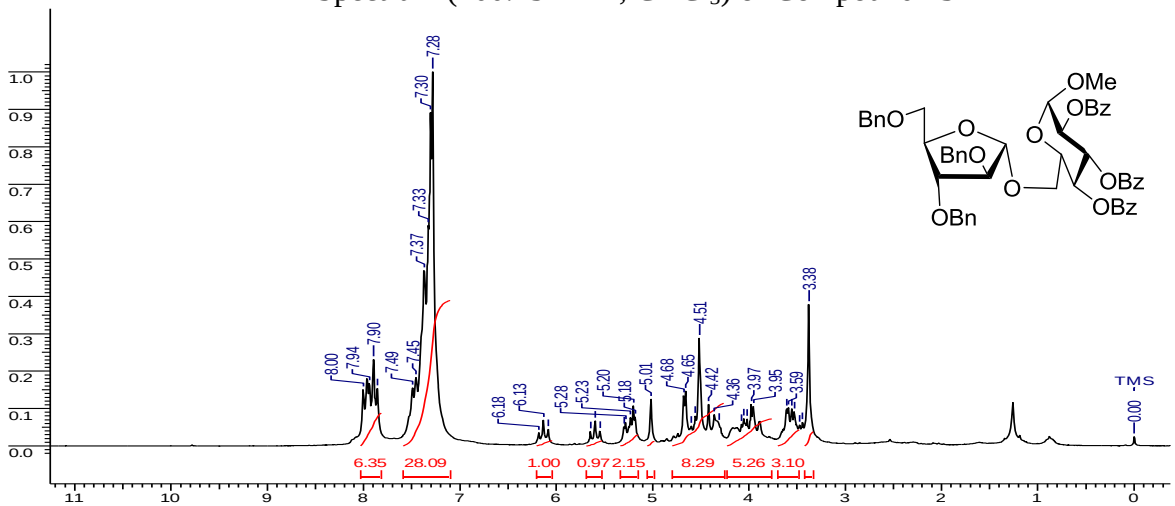
^{13}C NMR Spectrum (125.76 MHz, $CDCl_3$) of Compound **14**



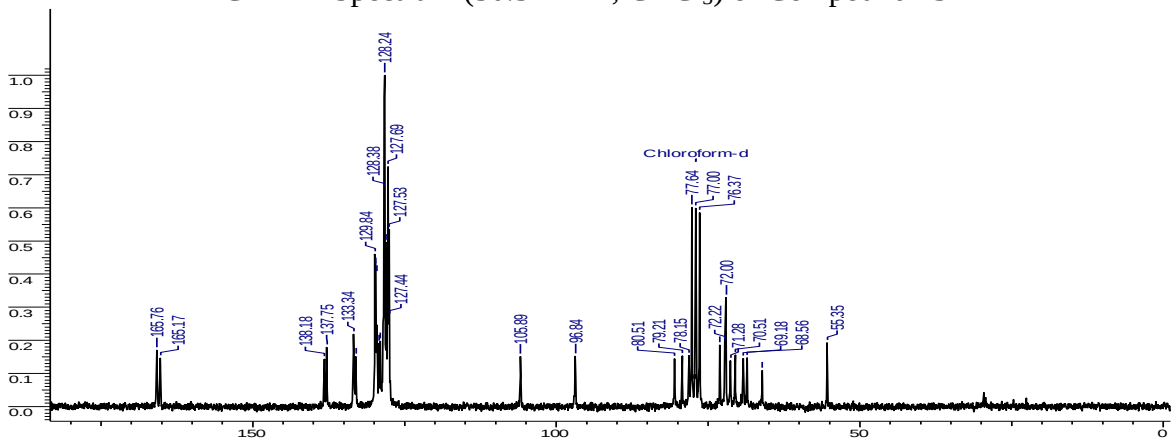
DEPT NMR Spectrum (125.76 MHz, $CDCl_3$) of Compound **14**



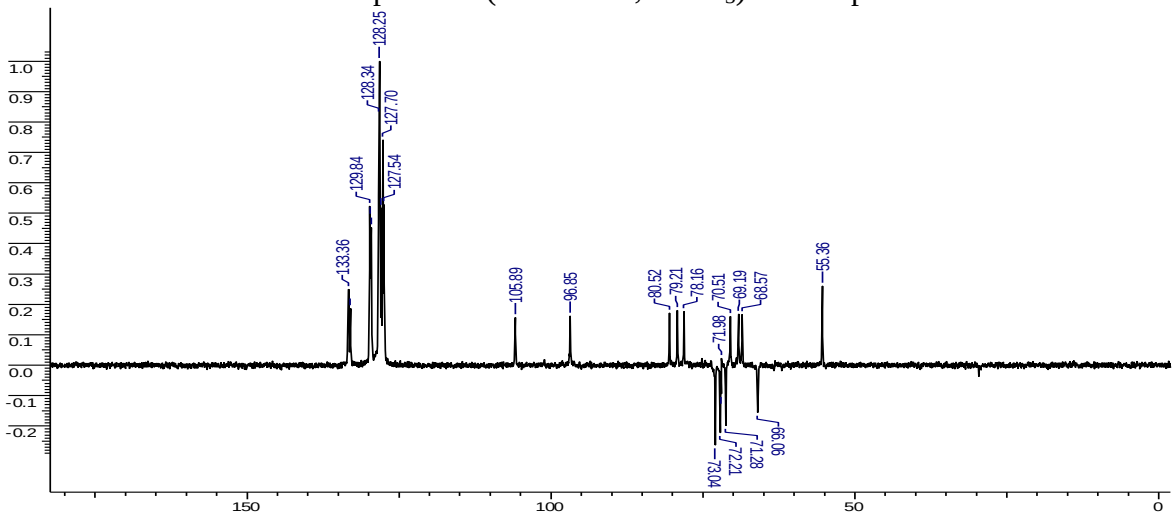
^{1}H NMR Spectrum (200.13 MHz, $CDCl_3$) of Compound **15**



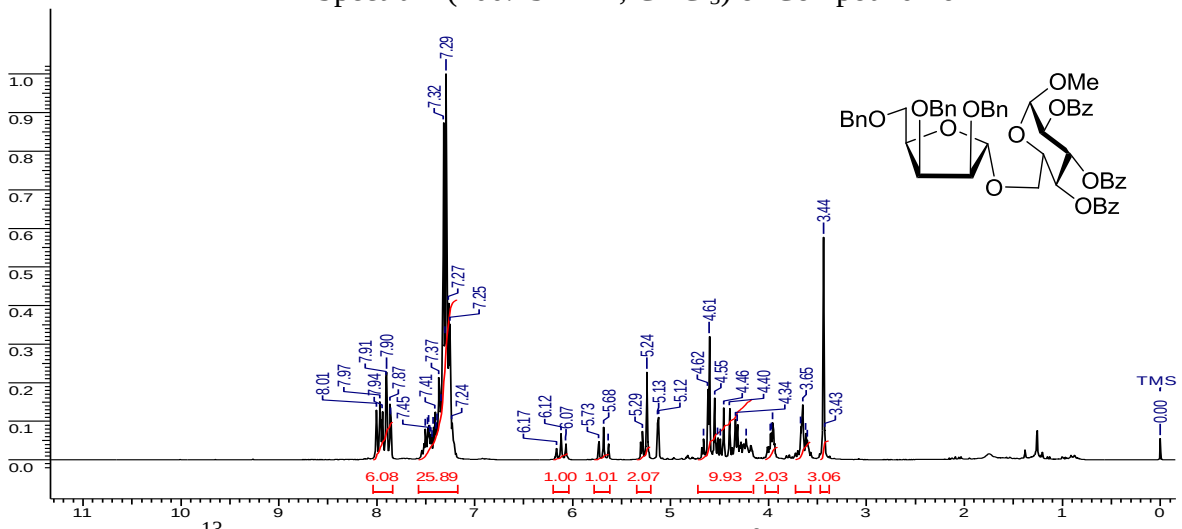
^{13}C NMR Spectrum (50.32MHz, $CDCl_3$) of Compound **15**



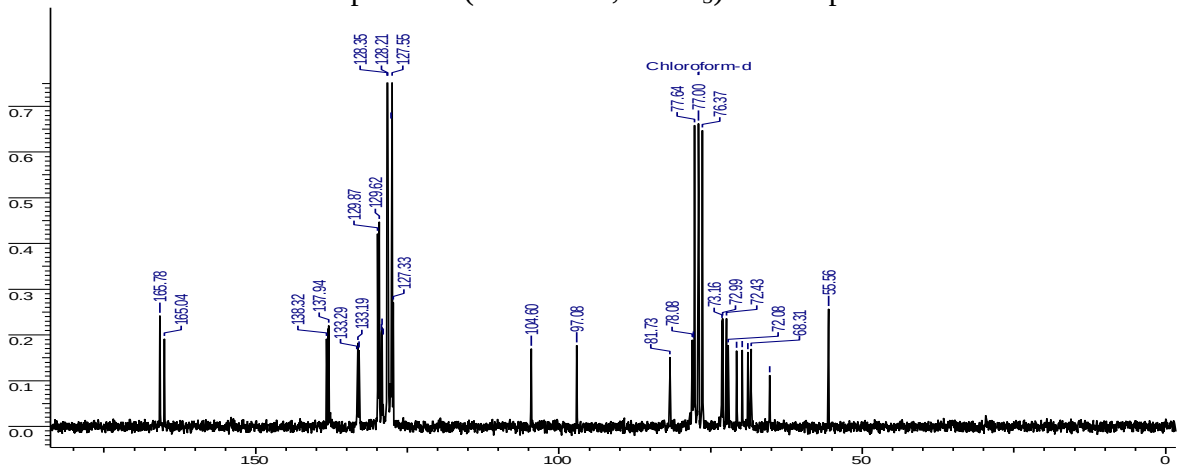
DEPT NMR Spectrum (50.32MHz, $CDCl_3$) of Compound **15**



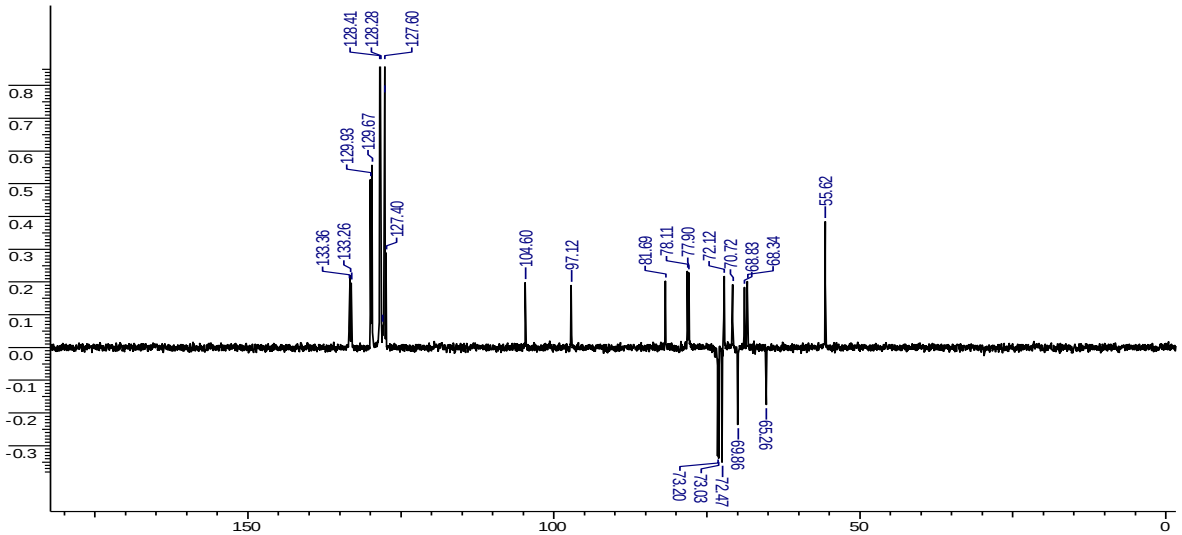
^{1}H NMR Spectrum (200.13 MHz, $CDCl_3$) of Compound **16**



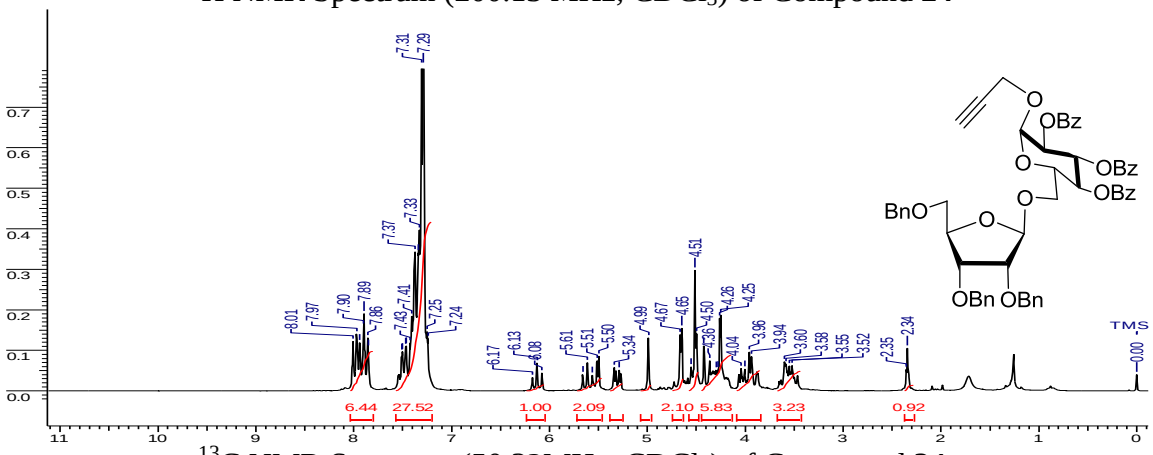
^{13}C NMR Spectrum (50.32MHz, $CDCl_3$) of Compound **16**



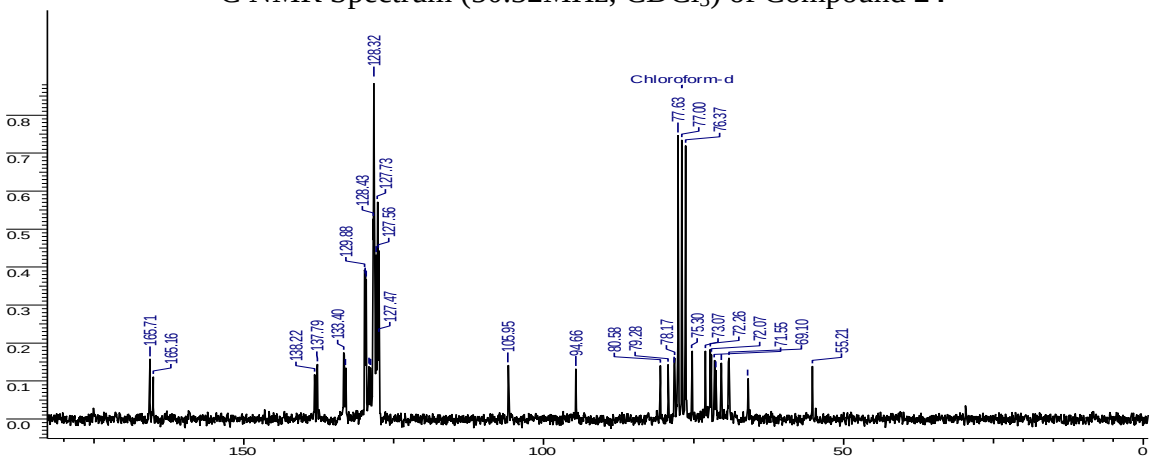
DEPT NMR Spectrum (50.32MHz, $CDCl_3$) of Compound **16**



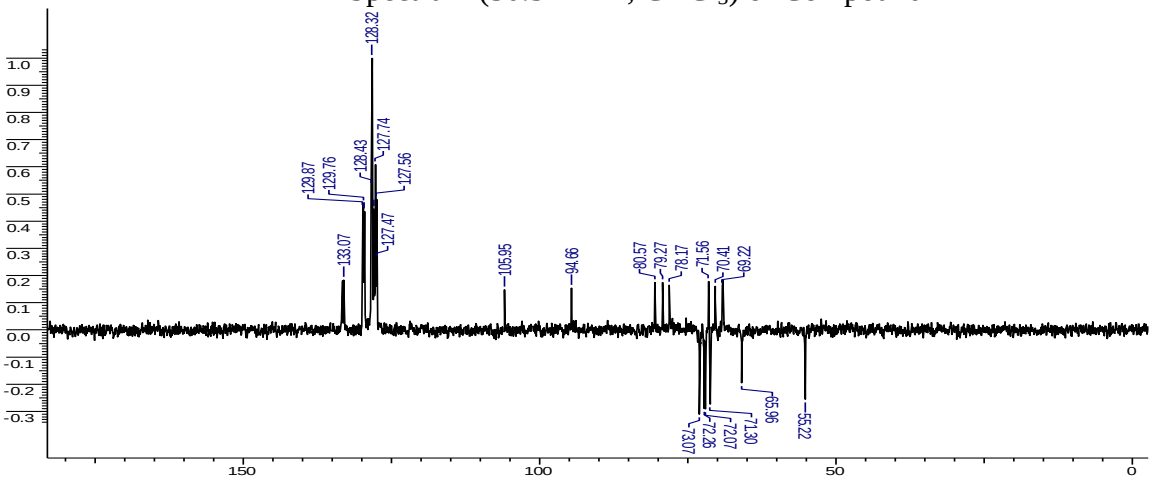
^{1}H NMR Spectrum (200.13 MHz, $CDCl_3$) of Compound **24**



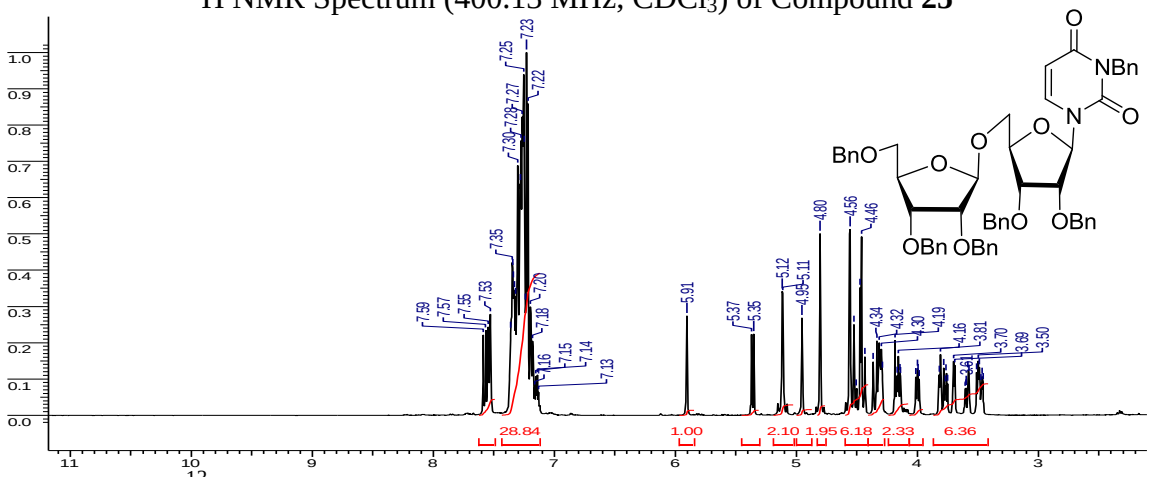
^{13}C NMR Spectrum (50.32MHz, $CDCl_3$) of Compound **24**



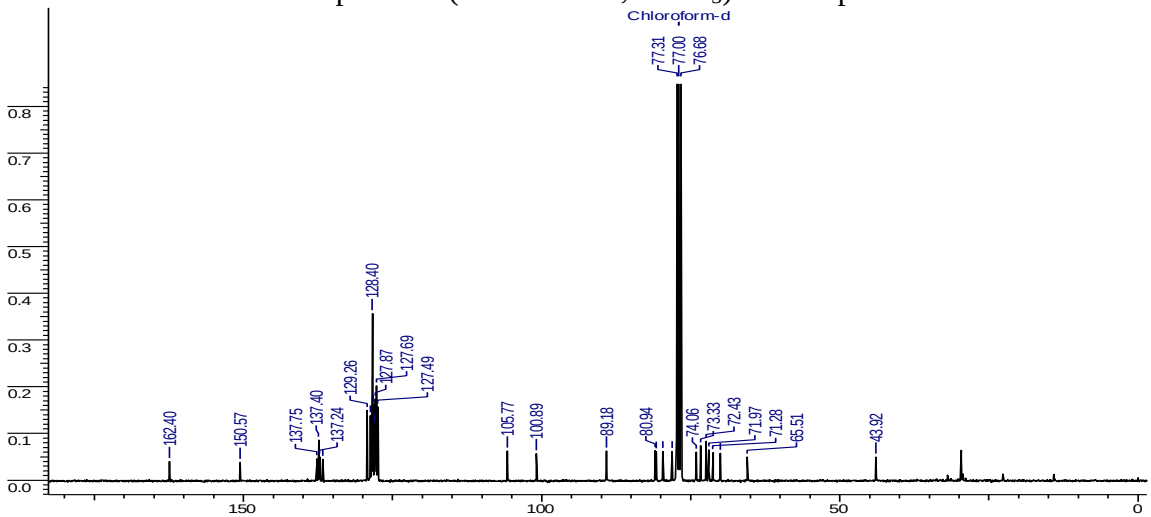
DEPT NMR Spectrum (50.32MHz, $CDCl_3$) of Compound **24**



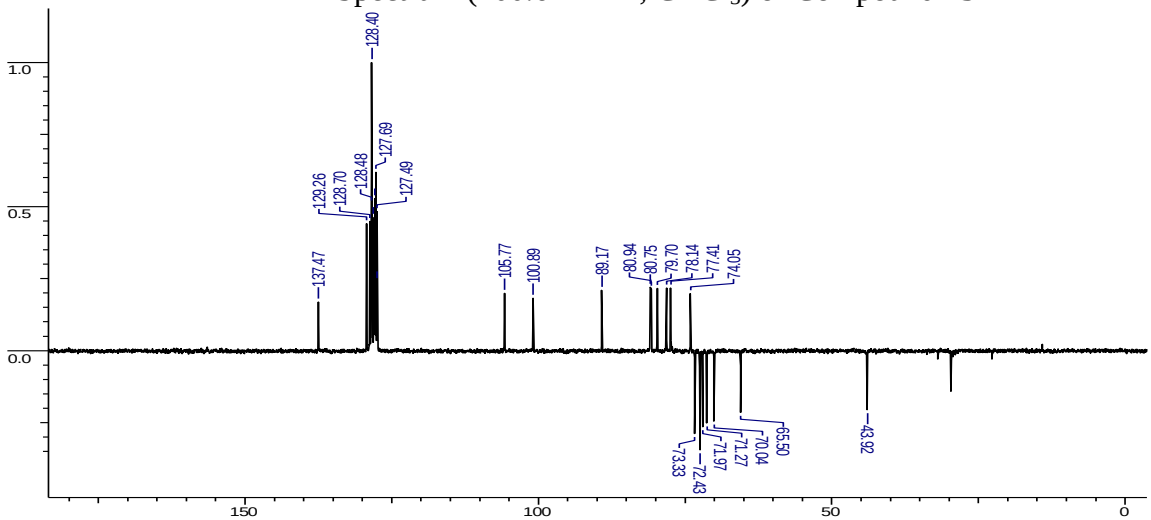
^{1}H NMR Spectrum (400.13 MHz, $CDCl_3$) of Compound **25**



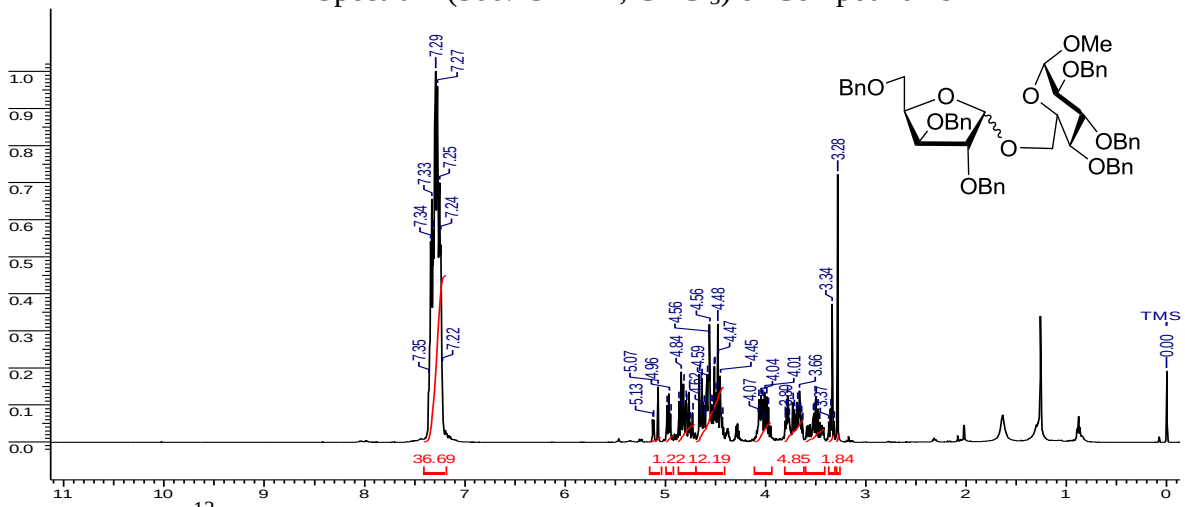
^{13}C NMR Spectrum (100.61 MHz, $CDCl_3$) of Compound **25**



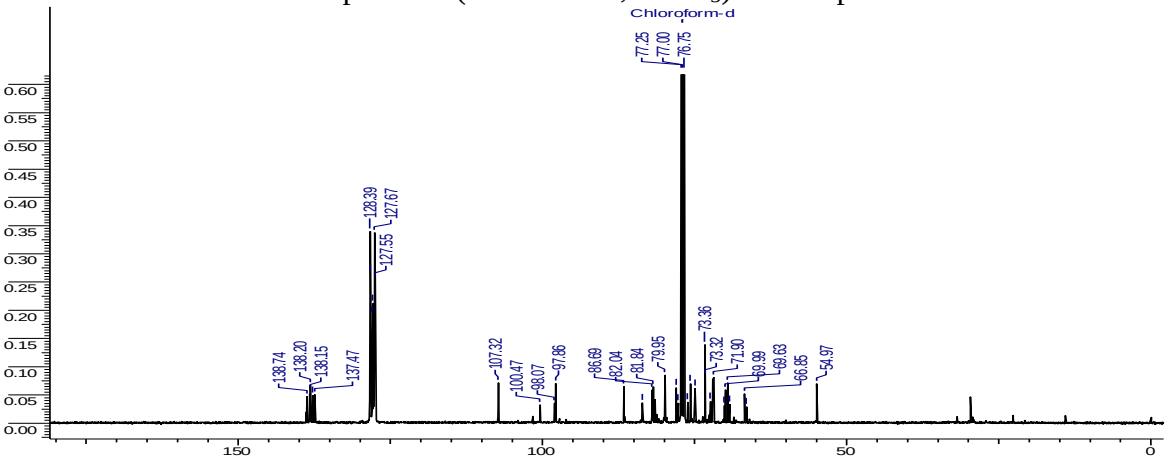
DEPT NMR Spectrum (100.61 MHz, $CDCl_3$) of Compound **25**



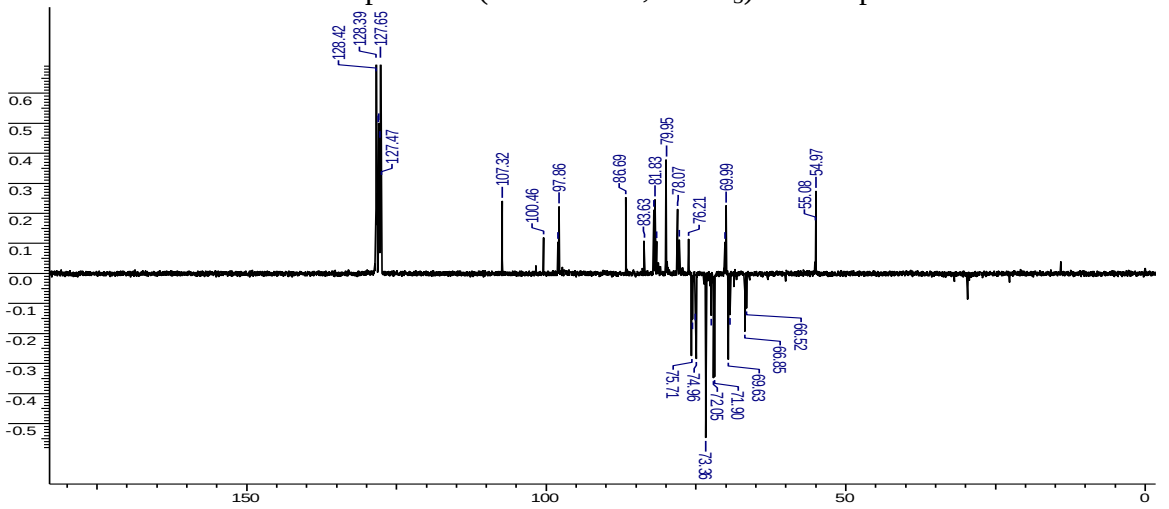
^{1}H NMR Spectrum (500.13 MHz, $CDCl_3$) of Compound **29**



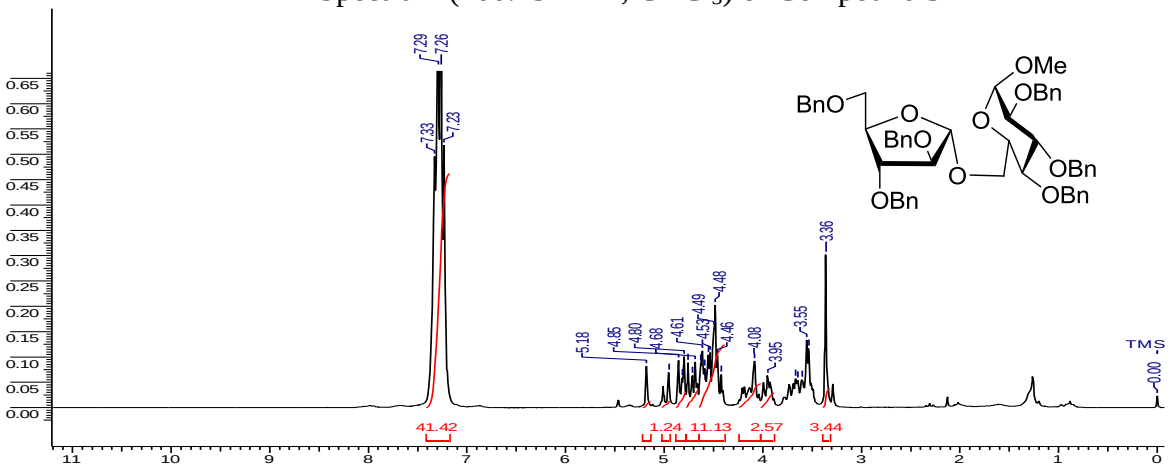
^{13}C NMR Spectrum (125.76MHz, $CDCl_3$) of Compound **29**



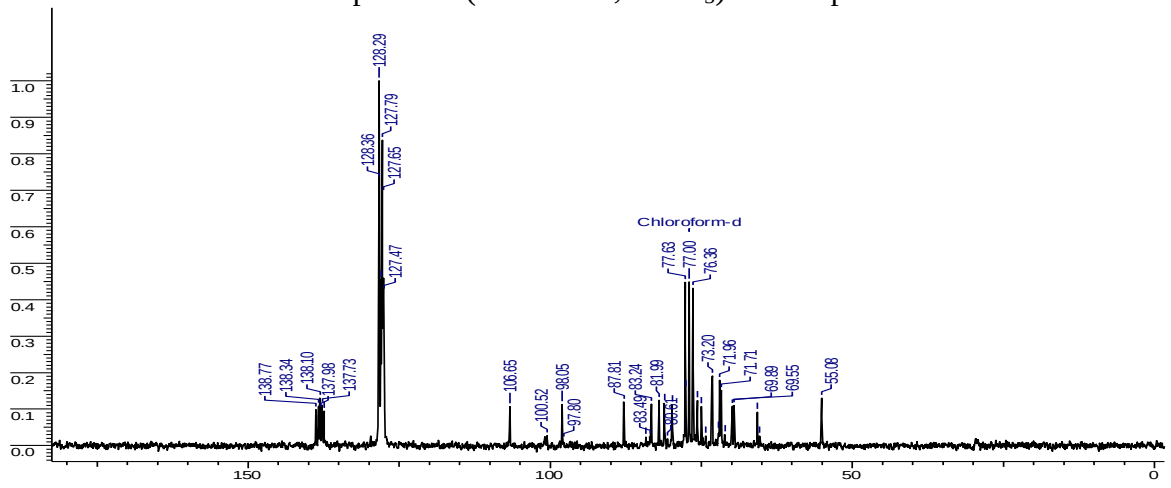
DEPT NMR Spectrum (125.76MHz, $CDCl_3$) of Compound **29**



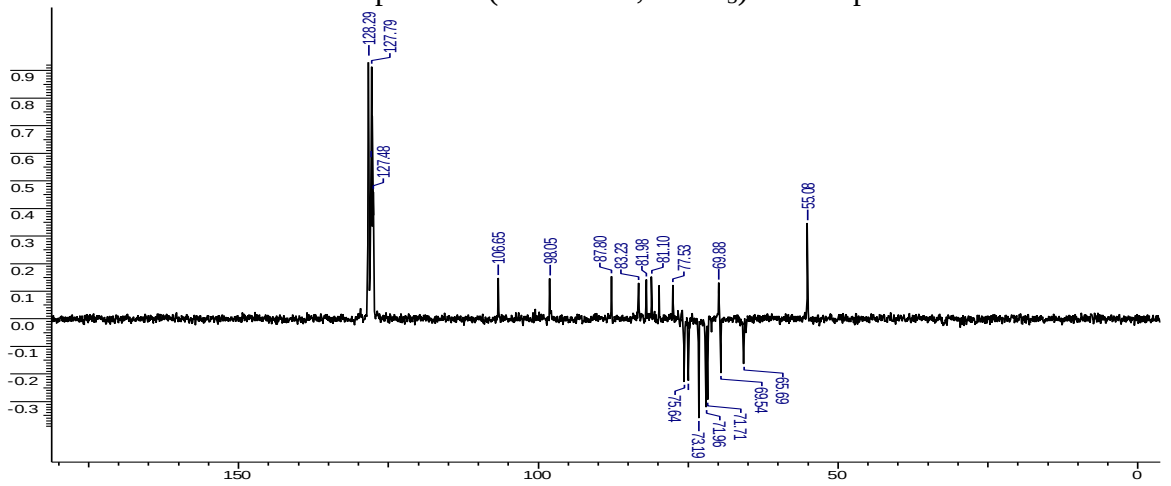
^{1}H NMR Spectrum (200.13 MHz, $CDCl_3$) of Compound **32**



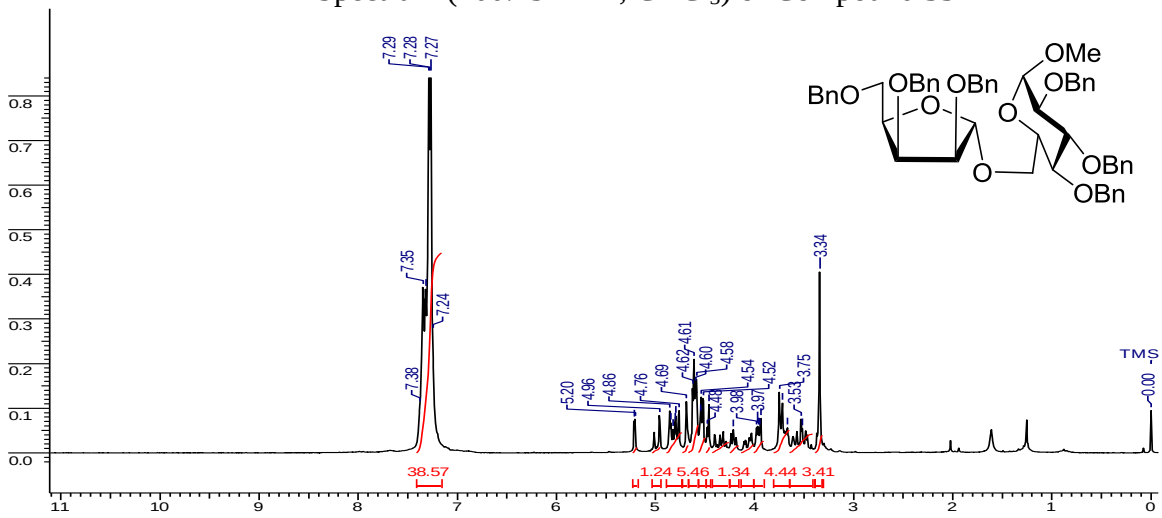
^{13}C NMR Spectrum (50.32MHz, $CDCl_3$) of Compound **32**



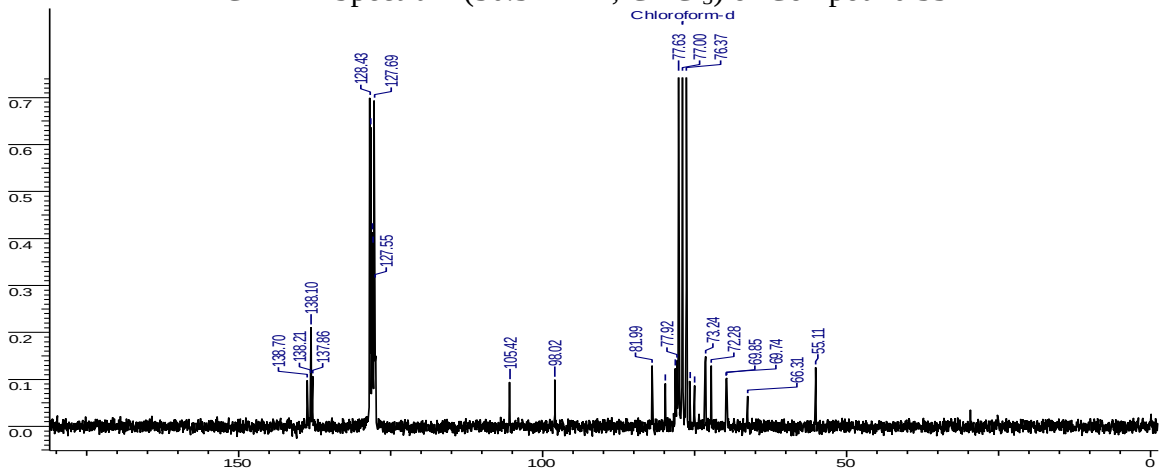
DEPT NMR Spectrum (50.32MHz, $CDCl_3$) of Compound **32**



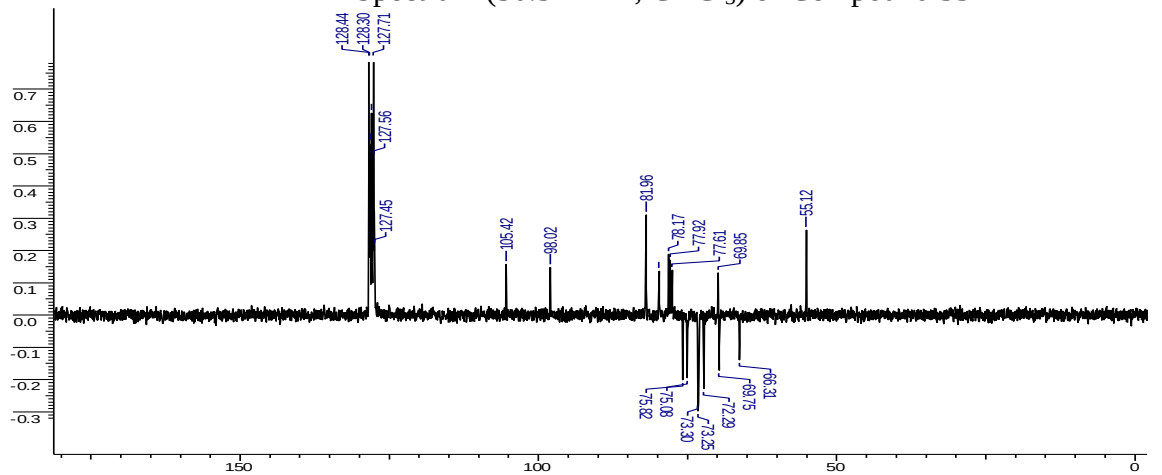
^{1}H NMR Spectrum (200.13 MHz, $CDCl_3$) of Compound **35**



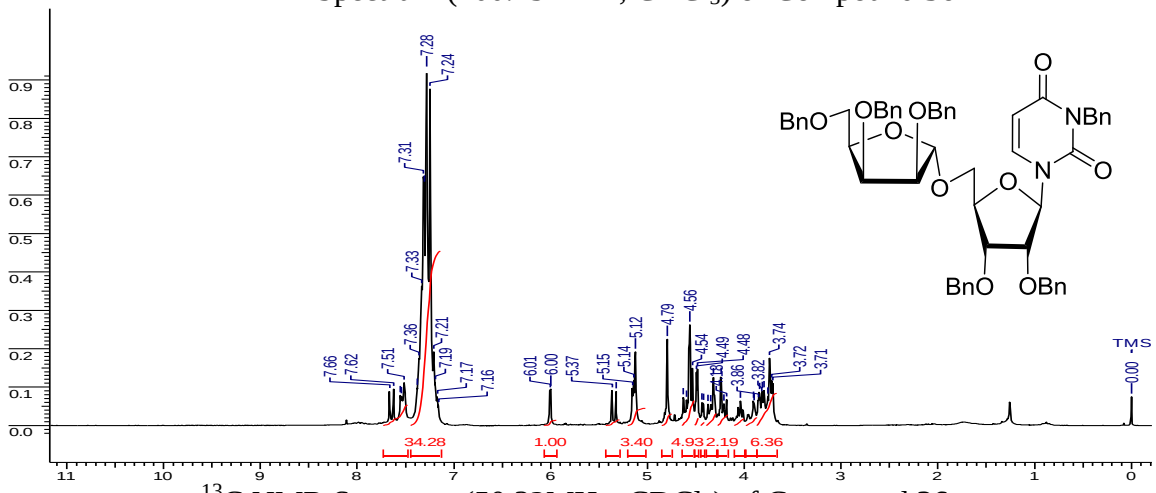
^{13}C NMR Spectrum (50.32MHz, $CDCl_3$) of Compound **35**



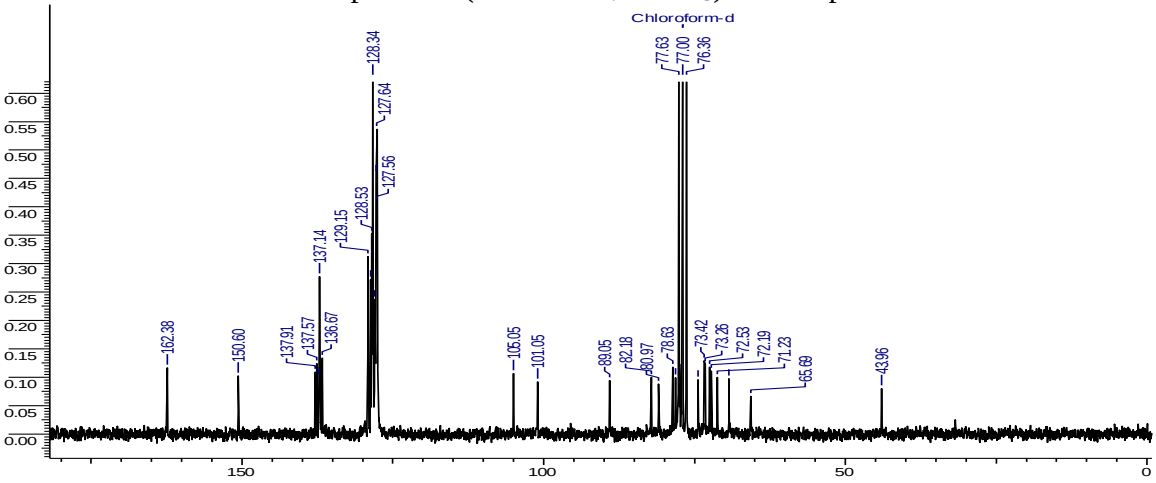
DEPT NMR Spectrum (50.32MHz, $CDCl_3$) of Compound **35**



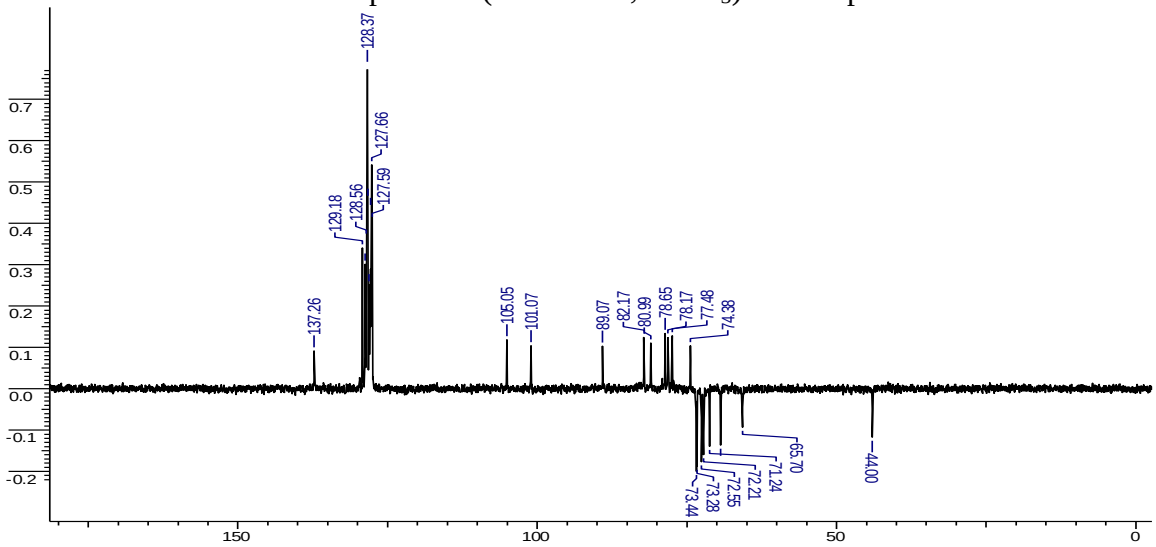
^{1}H NMR Spectrum (200.13 MHz, $CDCl_3$) of Compound **36**



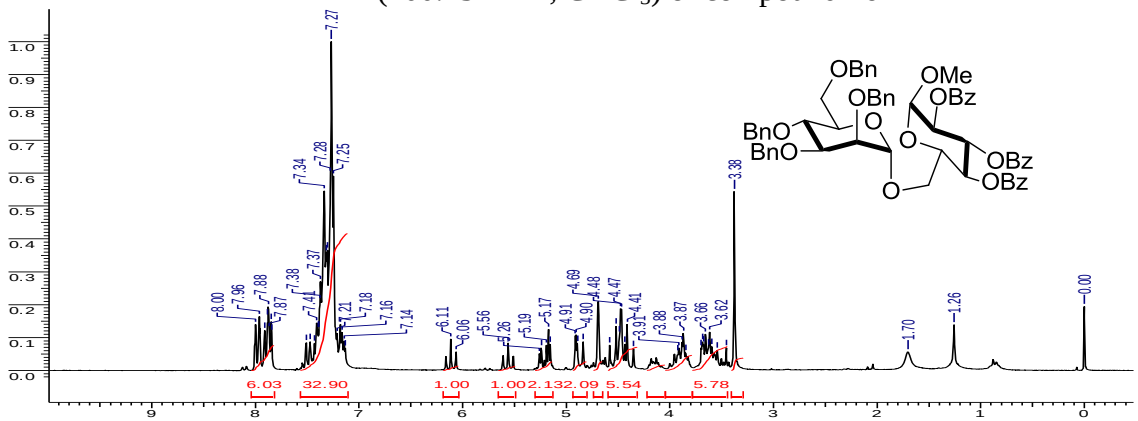
^{13}C NMR Spectrum (50.32MHz, $CDCl_3$) of Compound **36**



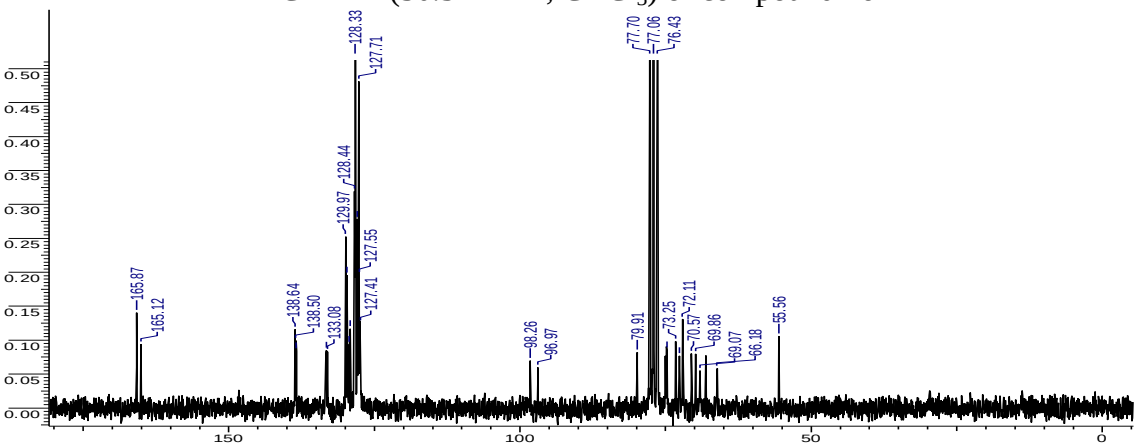
DEPT NMR Spectrum (50.32MHz, $CDCl_3$) of Compound **36**



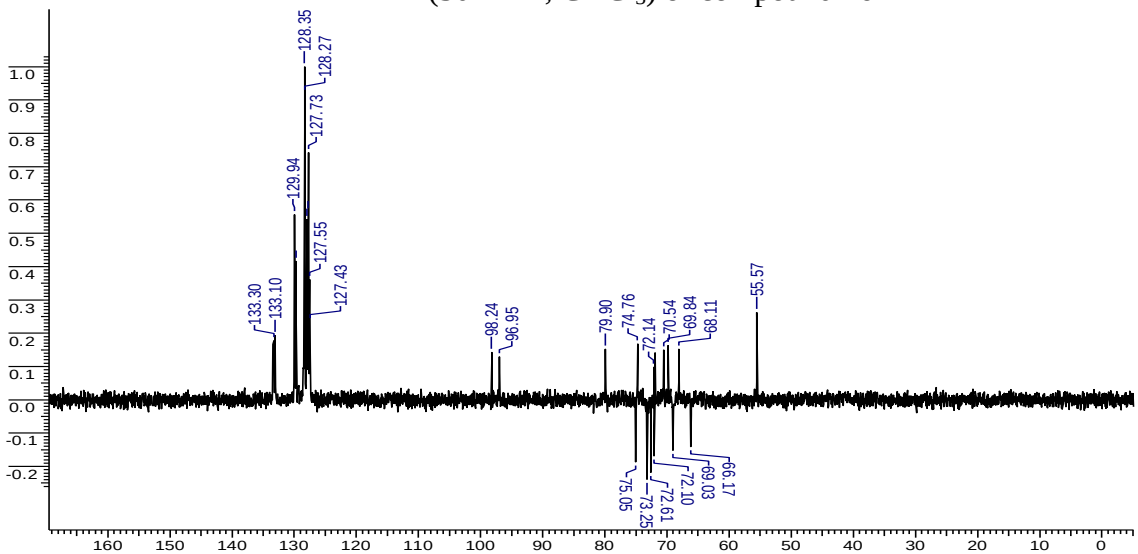
^{1}H NMR (200.13 MHz, $CDCl_3$) of compound **46**



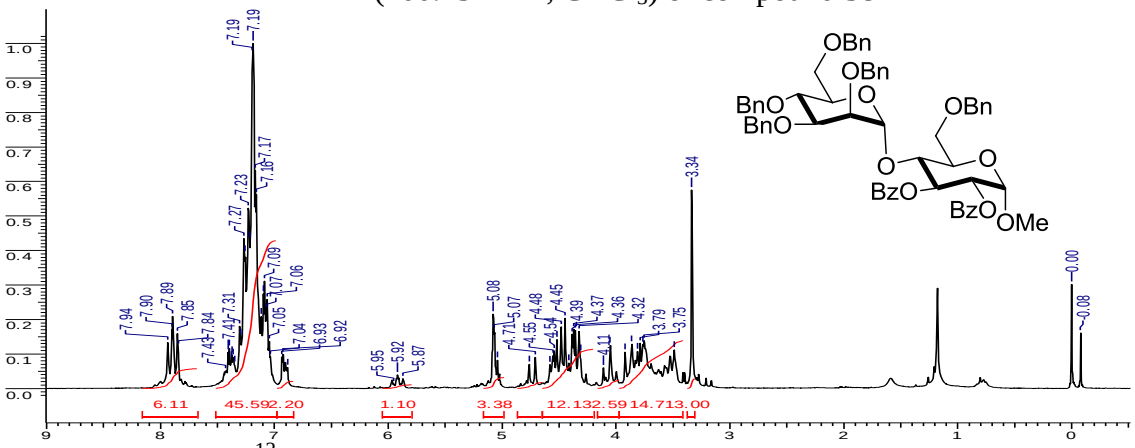
^{13}C NMR (50.32 MHz, $CDCl_3$) of compound **46**



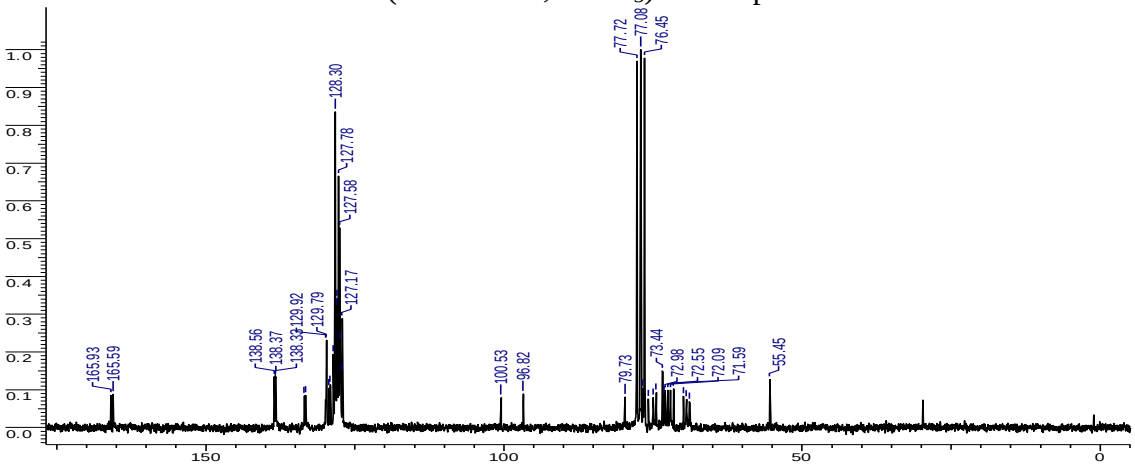
DEPT NMR (50 MHz, $CDCl_3$) of compound **46**



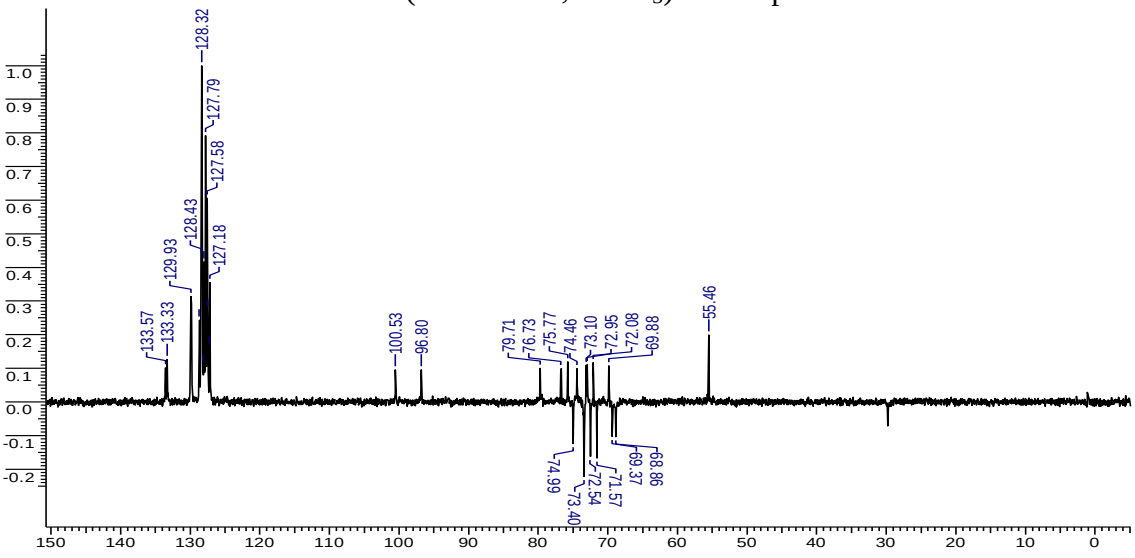
^{1}H NMR (200.13 MHz, $CDCl_3$) of compound **58**



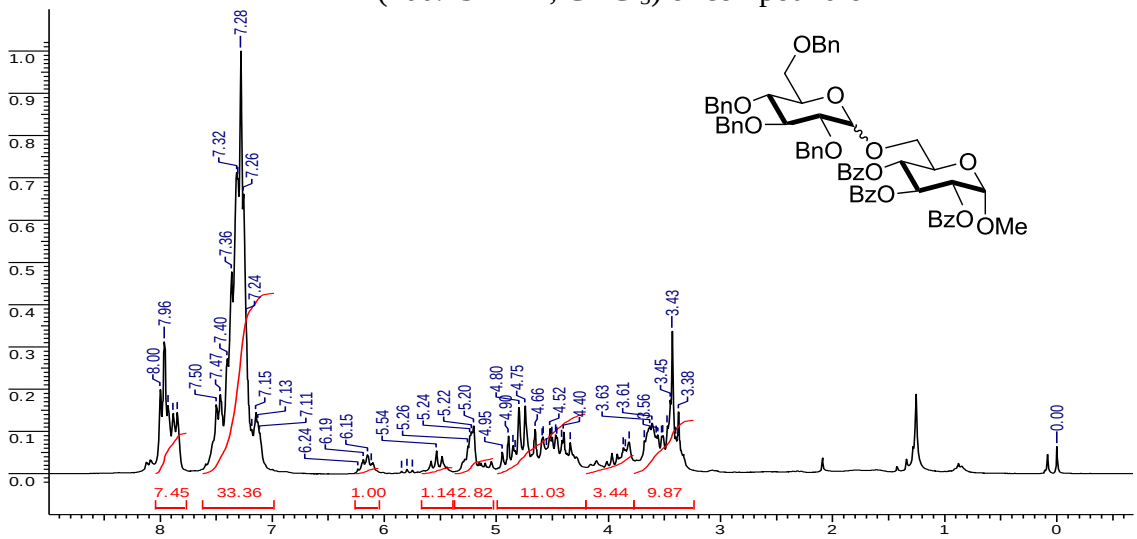
^{13}C NMR (50.32 MHz, $CDCl_3$) of compound **58**



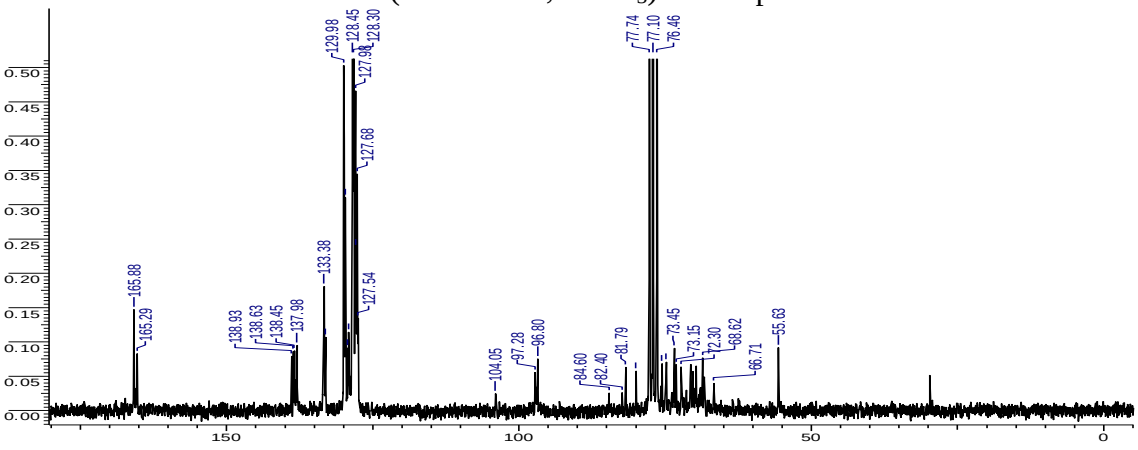
DEPT NMR (50.32 MHz, $CDCl_3$) of compound **58**



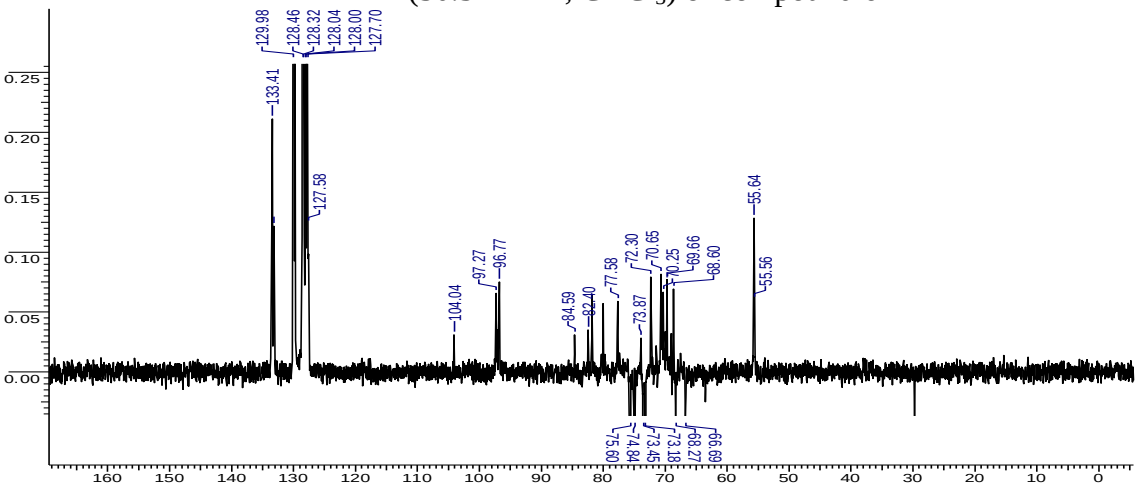
^{1}H NMR (200.13 MHz, $CDCl_3$) of compound **61**



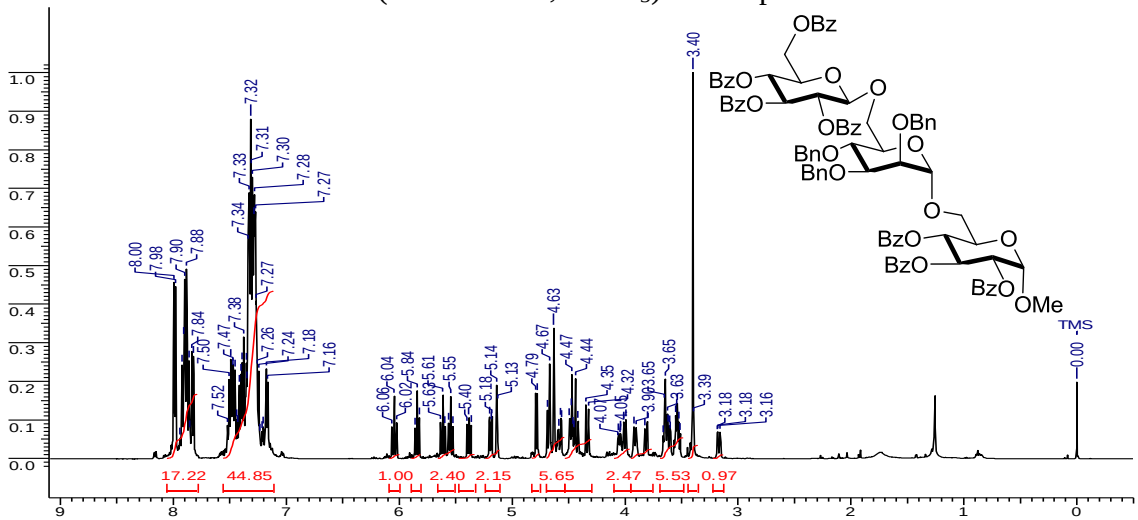
^{13}C NMR (50.32 MHz, $CDCl_3$) of compound **61**



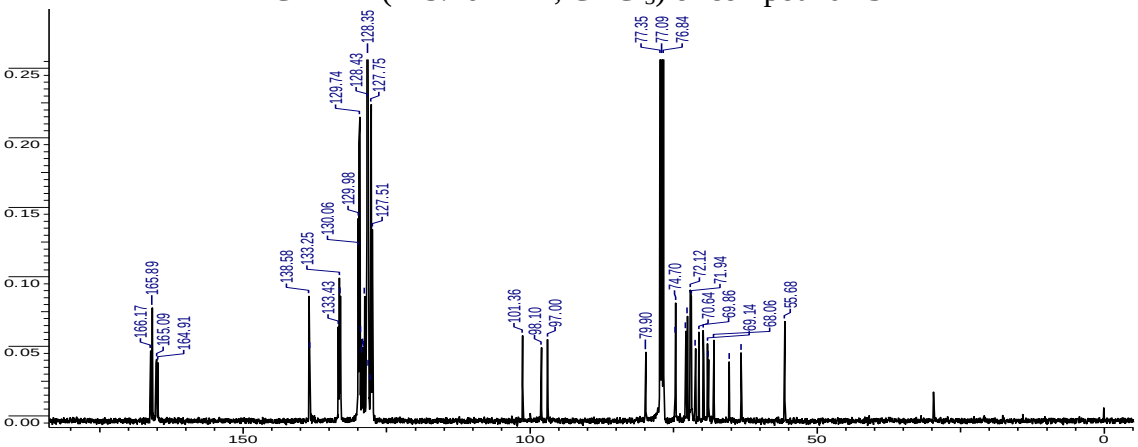
DEPT NMR (50.32 MHz, $CDCl_3$) of compound **61**



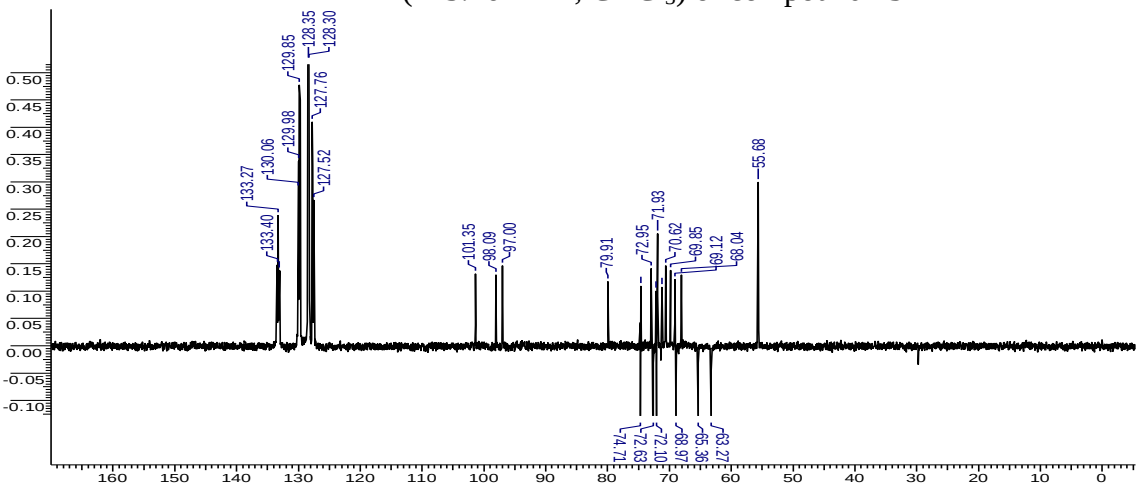
^{1}H NMR (500.13 MHz, $CDCl_3$) of compound **73**



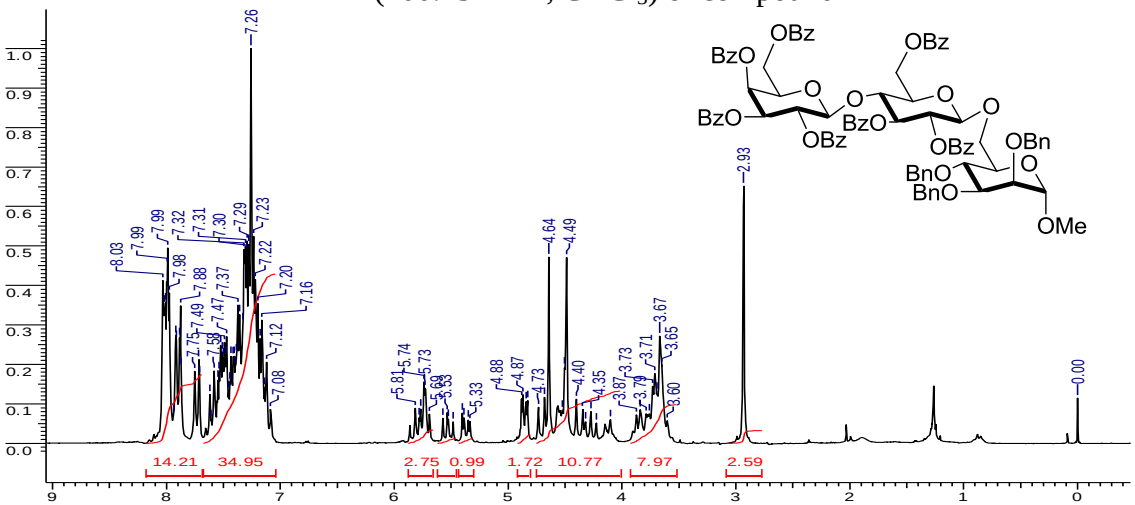
^{13}C NMR (125.76 MHz, $CDCl_3$) of compound **73**



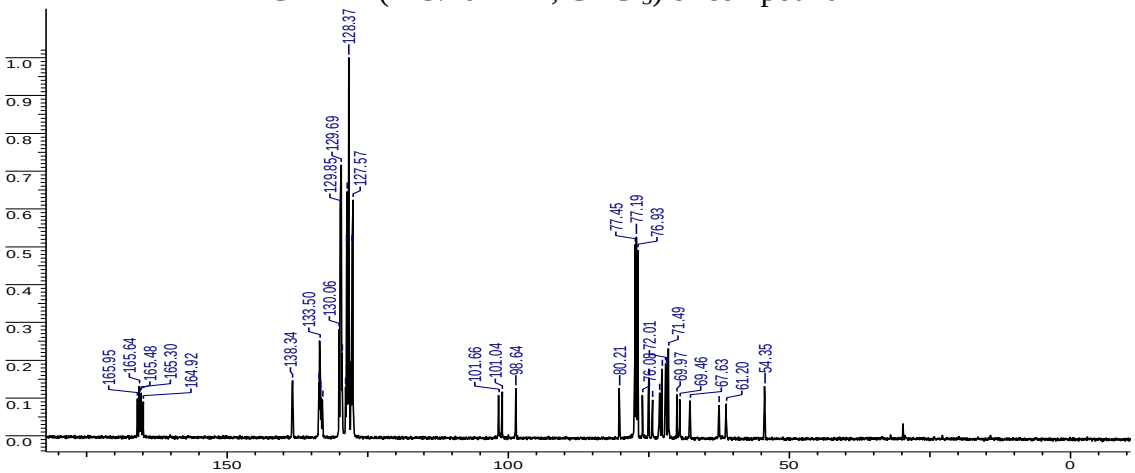
DEPT NMR (125.76 MHz, $CDCl_3$) of compound **73**



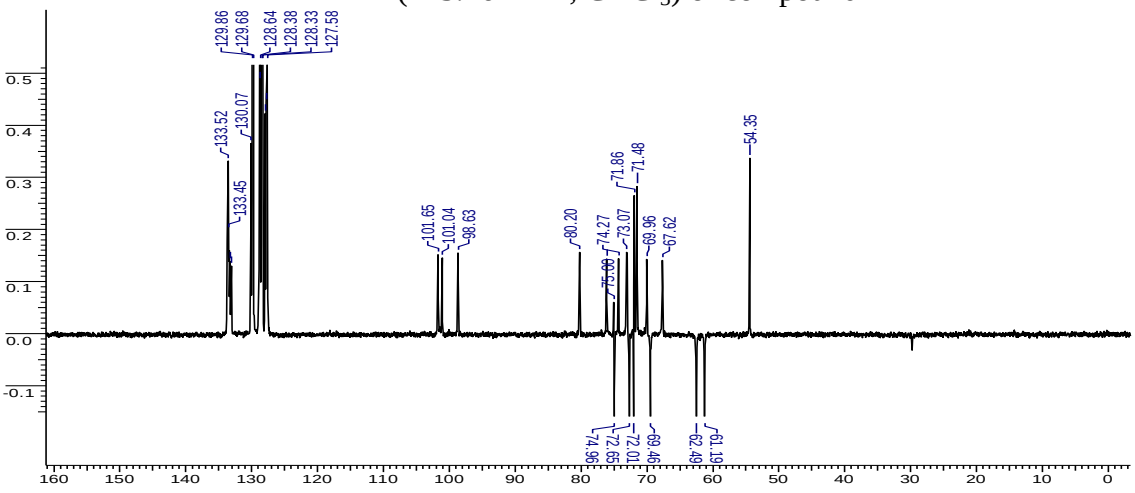
^{1}H NMR (200.13 MHz, $CDCl_3$) of compound **74**



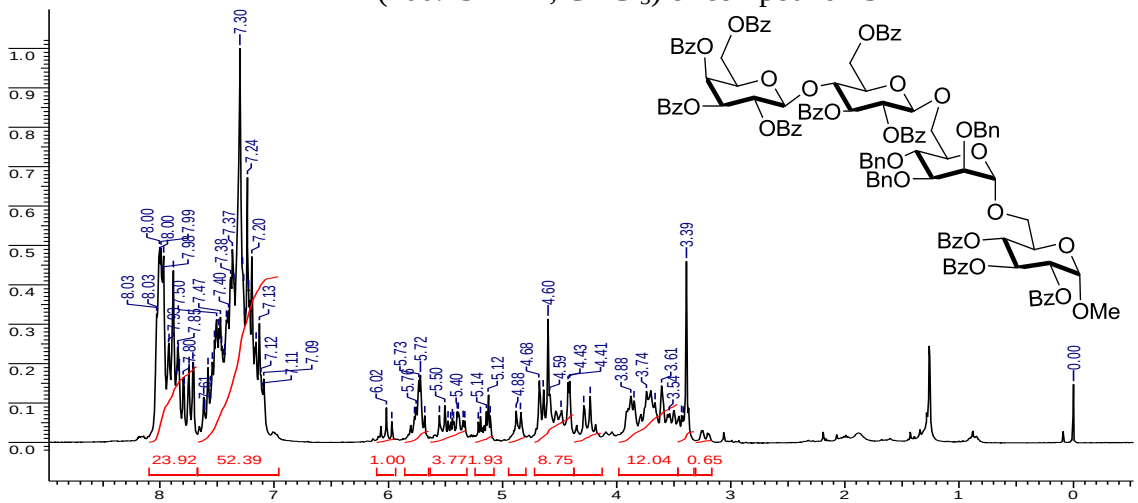
^{13}C NMR (125.76 MHz, $CDCl_3$) of compound **74**



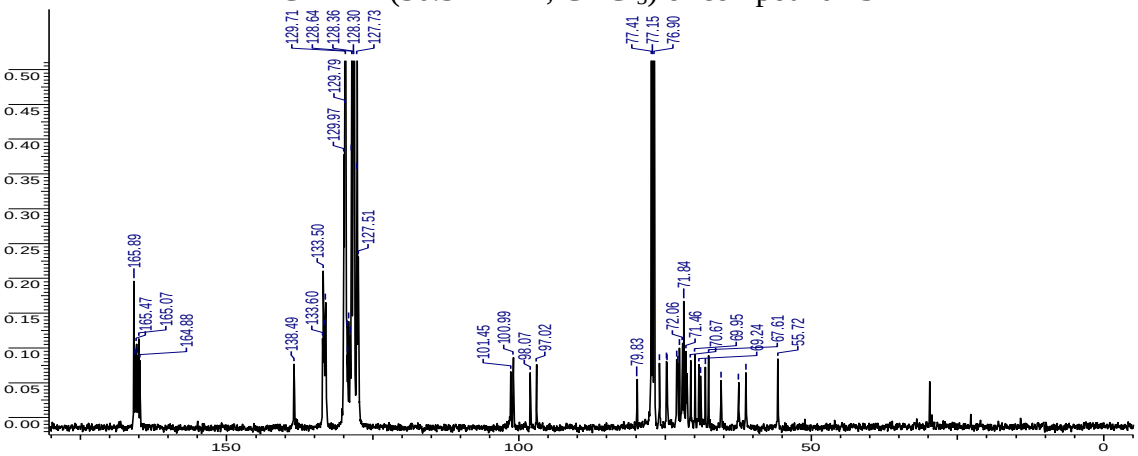
DEPT NMR (125.76 MHz, $CDCl_3$) of compound **74**



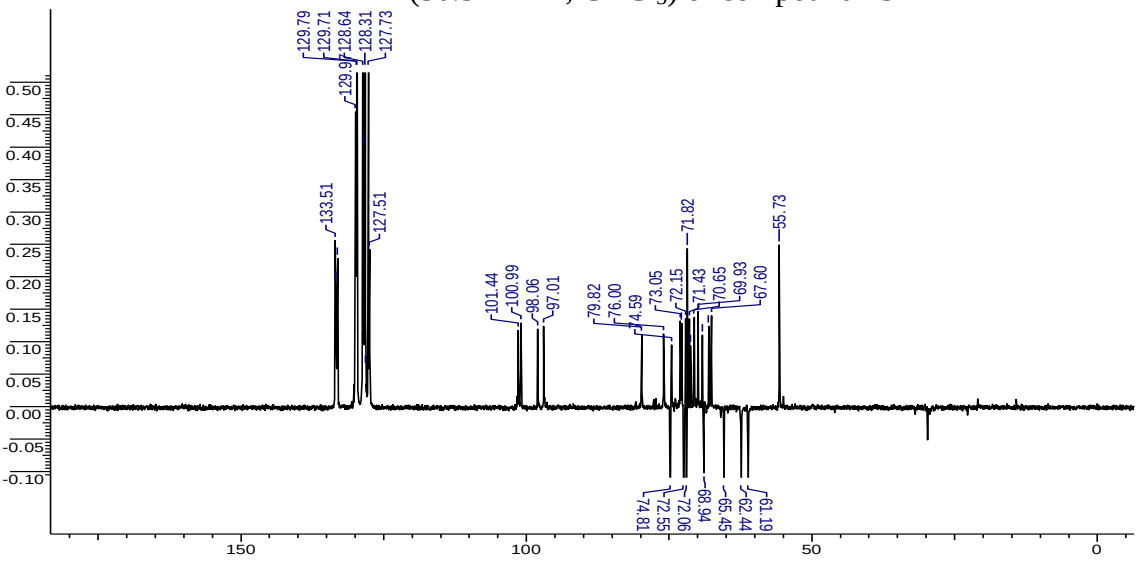
^{1}H NMR (200.13 MHz, $CDCl_3$) of compound **75**



^{13}C NMR (50.32 MHz, $CDCl_3$) of compound **75**



DEPT NMR (50.32 MHz, $CDCl_3$) of compound **75**



Chapter 2: References

1. a) Varki, A. *Glycobiology* **1993**, *3*, 97. b) Rudd, P. M.; Elliott, T.; Cresswell, P.; Wilson, I. A.; Dwek, R. A. *Science* **2001**, *291*, 2370. c) Dwek, R. A. *Chem. Rev.* **1996**, *96*, 683. d) *Essentials of Glycobiology*; Varki, A., Cummings, R., Esko, J., Freeze, H., Hart, G., Marth, J., Eds.; Cold Spring Harbor Laboratory Press: Cold Spring Harbor, NY, **1999**. e) Bertozzi, C. R.; Kiessling, L. L. *Science* **2001**, *291*, 2357.
2. a) Kennedy, J. F.; White, C. A. *Bioactiue Carbohydrates in Chemistry, Biochemistry and Biology*, **1983**. b) Watkins, W. M. *Glycoprotiem,* **1972**, 830. c) Takeuchi, M.; Inoue, N.; Strickland, T. W.; Kubota, M.; Wada, M.; Shimizu, R.; Hoshi, S.; Kozutzumi, H.; Takahashi, S.; Kobata, A. *Proc. Natl. Acad. Sci. U.S.A.* **1989**, *86*, 7819. d) Goelz, **S.** E.; Hesson, C.; Goff, D.; Griffiths, B.; Tedrd, R.; Newman, B.; Chi-Rosso, G.; Lobb, R. *Cell*, **1990**, *63*, 1349.
3. a) Kiessling, L. L.; Pohl, N. L. *Chem. Biol*. **1996**, *3*, 71. b) Gordon, E. J.; Sanders, W. J.; Kiessling, L. L. *Nature* **1998**, *392*, 30. c) Helenius, A.; Aebi, M. *Science* **2001**, *291*, 2364. d) Bernfield, M.; Götte, M.; Park, P. W.; Reizes, O.; Fitzgerald, M. L.; Lincecum, J.; Zako, M. *Annu. Rev. Biochem.* **1999**, *68*, 729. e) Fukuda, M. *Cancer Res.* **1996**, *56*, 2237.
4. a) Shimizu, M.; Togo, H.; Yokoyama, M. *Synthesis* **1998**, 799. b) Koenigs, W.; Knorr, E. *Chem. Ber*. **1901**, *34*, 957. c) Lemieux, R. U.; Hayami, J. I. *Can. J. Chem.* **1965**, *43*, 2162.
5. a) Kochetkov, N. K.; Khorlin, A. J.; Bochkov, A. F. *Tetrahedron Lett.* **1964**, *5*, 289. b) Kochetkov, N. K.; Bochkov, A. F.; Sokolovekaya, T. A.; Snyatkova, V. J. *Carbohydr. Res.*, **1971**, *16*, 17. c) Bochkov, A. F.; Kochetkov, N. K. *Carbohydr. Res.* **1975**, *39*, 355. d) Betaneli, V. I.; Ovchinnikov, M. V.; Backinowsky, L. V.; Kochetkov, N. K. *Carbohydr. Res.* **1979**, *76*, 252.
6. a) Ferrier, R. J.; Hay, R. W.; Vethaviyaear, N. *Carbohydr. Res.* **1973**, *27*, 65. b) Tsai, T**.** Y. R.; Jin, H.; Wiesner, K. *Can. J. Chem.* **1984**, *62*, 1403. c) Garegg, P. J.; Henrichson, C.; Norberg, T. *Carbohydr. Res.*, **1983**, *116*, 162. d) van Cleve, J. W. *Carbohydr. Res.* **1979**, *70*, 161.

7. a) Schmidt, R. R.; Michel, J. *Angew. Chem., Znt. Ed. Engl.* **1980**, *19*, 731. b) Pougny, J.-R.; Sinas, P. *Tetrahedron Lett.* **1976**, 4073. c) Pougny, J.-R.; Jacquinet, J.-C.; Naear, M.; Duchet, D.; Milat, M.-L.; Sinas, P. *J. Am. Chem. Soc.* **1977**, *99*, 6762. d) Schmidt, R. R.; Gaden, H.; Jatzke, H. *Tetrahedron Lett.*, **1990**, 31, 327. e) Nicolaou, K. C.; Dainee, R. A.; Chakraborty, T. K.; Ogawa, Y. *J. Am. Chem. Soc.* **1987**, *109*, 2821. (f) Nicolaou, K. C.; Daines, R. A.; Ogawa, Y.; Chakraborty, T. K. *J. Am. Chem. Soc.* **1988**, *110*, 4696.
8. a) Fraser-Reid, B.; Konradsaon, P.; Mootoo, D. R.; Udodong, U. *J. Chem. Soc. Chem. Commun.* **1988**, 823. b) Mootoo, D. R.; Data, V.; Fraaer-Reid, B. J. *Chem.* Soc., *Chem.Commun.* **1987**, 1462. c) Mootoo, D. R.; Date, V.; Fraeer-Reid, B. *J. Am. Chem. Soc.* **1988**, *110*, 2662. d) Mootoo, D. R.; Konradeeon, P.; Udodong, U.; Fraser-Reid, B. *J. Am. Chem. Soc.* **1988**, *110*, 5583.
9. Zhang, Z. Y.; Wong, C.-H. *Carbohydrates in Chemistry and Biology*; **2000**, *1*, 117.
10. a) Hashimoto, **S.;** Honda, T.; Ikegami, S. *J. Chem. SOC., Chem.Commun.* **1989**, 685. b) Hashimoto, S.; Honda, T.; Ikegami, S. *Heterocycles,* **1990**, *30*, 775. c) Hashimoto, S.; Honda, T.; Ikegami, S. *Chem. Pharm. Bull.* **1990**, *38*, 2323. d) Hashimoto, S.; Honda, T.; Ikegami, S. *Tetrahedron Lett.* **1991**, *32*, 1653. e) Hashimoto, S.; Yanagiya, Y.; Honda, T.; Harada, H.; Ikegami, S. *Tetrahedron Lett.* **1992**, *33*, 3523.
11. Kahne, D.; Walker, S.; Cheng, Y.; van Engen, D. *J. Am. Chem. Soc.* **1989**, *111*, 6881.
12. Witczak, Z. J.; Czernecki, S. *Adv. Carbohydr. Chem. Biochem.* **1998**, *53*, 143
13. a) Lemiem, R. U.; Morgan, A. R. *Can.* J. *Chem.* **1966**, *43*, 2190. b) Friesen, R. W.; Danishefsky, S. J. *J. Am. Chem. Soc.***1989**, *111*, 6656. c) Suzuki, K.; Sulikowski, G. A.; Friesen, R. W.; Daniahefsky, S. J. *J. Am. Chem.*Soc.**1990**, *112*, 8895. d) Friesen, R. W.; Danishefsky, S. J. *Tetrahedron* **1990**, *46*, 103. Tatsuta, K.; Fujimoto, K.; Kinoshita, M.; Umezawa, S. *Carbohydr.Res.* **1977**, *54*, 85. e) Thiem, J.; Karl, H.; Schwentner, J. *Synthesis* **1978**, 696. f) Thiem, J.; Karl, H. *Tetrahedron Lett.* **1978**, 4999.
14. Marra, A.; Esnault, J.; Veyrieres, A.; Sinay, P. *J. Am. Chem. Soc.* **1992**, *114*, 6354.
15. Garcia, B. A.; Poole, J. L.; Gin, D. Y. *J. Am. Chem. Soc* **1997**, *119*, 7597.

16. Hadd, M. J.; Gervay, J. *Carbohydr. Res.* **1999**, *320*, 61.
17. a) Mukaiyama, T.; Kobayaehi, S.; Shoda, S. *Chem. Lett.* **1984**, 907. b) Gurjar, M. K.; Viswanadham, G. *TetrahedronLett.* **1991**, *32*, 6191.
18. a) Mukaiyama, T.; Nakatsuka, T.; Shoda, S. I. *Chem. Lett.* **1979**, 487. b) Hanessian, S.; Bacquet, C.; Lehong, N. *Carbohydr. Res.* **1980**, *80*, c17.
19. a) Kim, K. S; Park, J; Lee Y J, and Seo, Y. S. *Angew. Chem. Int. Ed.* **2003**, *42*, 459. b) Lee, Y. J; Lee, K; Jung, E. H; Jeon, H. B; Kim. K. S. *Org. Lett.*, **2005,** 7, 3263.
20. a) Betaneli, V.; Ovchinnikov, M. V.; Backinowsky, Kotchekov, N. K., *Carbohydr. Res*. **1980**, *84*, 211. b) Banoub, J. *Methods in Carbohydrate Chemistry Vol. 8*, **1980**, 247. c) Toshima, K. *Carbohydr. Res.* **2000**, *327*, 15. d) Mukaiyama, T.; Hashimoto, Y.; Shodo, S. *Chem. Lett*. **1983**, 935.
21. a) Galonić, D. P.; Gin, D. Y. *Nature* **2007**, *446*, 1000. b) Wang, C.-C.; Lee, J.-C.; Luo, S.-Y.; Kulkarni, S. S.; Huang, Y.-W.; Lee, C.-C.; Chang, K.-L.; Hung, S.-C. *Nature* **2007**, *446*, 896. c) Anderson, F.; Fugedi, P.; Garegg, P. J.; Nashe, M. *Tetrahedron. Lett*., **1986**, *27*, 3919. d) Mereyala, H.B.; Hotha, S.; Gurjar, M. K. *Chem.Commun*.**1998**, 685.
22. a) Schmidt, R. R.; Kinzy, W. *Adv. Carbohydr. Chem. Biochem.* **1994**, *50*, 21. b) Schmidt, R. *Angew. Chem. Int. Ed. Engl.* **1986**, *25*, 212. c) Klotz, W.; Schmidt, R. R. *J. Carbohydr. Chem.* **1994**, *13*, 1093. d) Rembold, H.; Schmidt, R. R. *Carbohydr. Res.* **1993**, *246*, 137. e) Robina, I.; López-Barba, E; Fuentes, J. *Tetrahedron* **1996**, *52*, 10771. f) Salto, S.; Mori, M.; Ito, Y.; Ogawa, T. *Tetrahedron Lett.* **1986**, *27*, 3919. g) Zhang, M.; Du, Y.; Kong, F. *Carbohydr. Res.* **2001**, *330*, 319.
23. a) Mootoo, D. R.; Konradsson, P.; Udodong, U.; Fraser-Reid, B. *J. Am. Chem. Soc.* **1988**, *110*, 5583. b) Fraser-Reid, B.; Wu, Z.; Udodong, U. E.; Ottosson, H. *J. Org. Chem.* **1990**, *55*, 6068. c) Lu, J.; Jayaprakash, K. N.; Schlueter, U.; Fraser-Reid, B. *J. Am. Chem. Soc.* **2004**, *126*, 7540. d) Roberts, C.; Madsen, R.; Fraser-Reid, B. *J. Am. Chem. Soc.* **1995**, *117*, 1546. e) Christopher, S. B.; Vollerthun, R.; Fraser-Reid, B. *J. Org. Chem.* **1996,** *61*, 1609.
24. a) Crich, D.; Sun, S. *Tetrahedron* **1998**, *54*, 8321. b) Crich, D.; Sun, S. *J. Org. Chem* **1997**, *62*, 1198. c) Crich, D.; Sun, S. *J. Org. Chem* **1996**, *61*, 4506.

25. a) Mehta. S.; Pinto, B. M. *J. Org. Chem.* **1993**, *58*, 3269. b) Zuurmond, H. M.; vander Meer, P. H.; Vander Klein, P. A.; Van Boom, J. H. J. *Carbohydr. Chem*, **1993**, *12*, 1091. c) Grice, P.; Ley, S. V.; pietruszka, J.; Priepke, H. W. M.; Walter, E. P. E. *Synlett*, **1995**, 781.

26. a) Kochetkov, N. K.; Khorlin, A. J.; Bochkov, A. F. *Tetrahedron* **1967**, *23*, 693. b) Kochetkov, N. K.; Bochkov, A. F.; Sokolavskaya, T. A.; Snyatkova, V. J. *Carbohydr. Res.* **1971**, *16*, 17. c) Kochetkov, N. K.; Bochkov, A. F. *Carbohydr. Res.* **1975**, *39*, 355. d) Kochetkov, N. K.; Backinowsky, L. V.; Tsvetkov, Y. E. *Tetrahedron Lett.* **1977**, *41*, 3681.

27. a) Lemiem, R. U.; Morgan, A. R. *Can.* J. *Chem.* **1966**, *43*, 2190. b) Friesen, R. W.; Danishefsky, S. J. *J.Am. Chem. Soc* **1989**, *111*, 6656. c) Suzuki, K.; Sulikowski, G. A,; Friesen, R. W.; Daniahefsky, S. J. *J. Am. Chem. Soc*. **1990,** *112*, 8895. d) Friesen, R. W.; Danishefsky, S. J. *Tetrahedron* **1990**, *46*, 103. e) Tatsuta, K.; Fujimoto, K.; Kinoshita, M.; Umezawa, S. *Carbohydr. Res.* **1977**, *54*, 85. f) Randolph, J. T.; Danishefsky, S. J. *J. Am. Chem. Soc.* **1993**, *115*, 8473.

28. a) Kim, K. S.; Kim, J. H.; Lee, Y. J.; Lee, Y. J.; Park, J. *J. Am. Chem. Soc.* **2001,** *123*, 8477. b) Lee, Y. J.; Lee, K.;. Jung, E. H.; Jeon H. B., Kim, K. S. *Org. Lett.*, **2005,** *15*, 3263.

29. a) D'Souza, F. W.; Lowary, T. L. *Org. Lett.* **2000**, *2*, 1493. b) Yin, H.; D'Souza, F. W.; Lowary, T. L. *J. Org. Chem.* **2002**, *67*, 892. c) Yin, H.; Lowary, T. L. *Tetrahedron Lett.* **2001**, *42*, 5829.

30. a) Hotha, S.; Kashyap, S. *J. Am. Chem. Soc.* **2006**, *128*, 9620. b) Sureshkumar, G.; Hotha, S. *Chem. Commun.* **2008**, 4282. c) Sureshkumar, G.; Hotha, S. *Tetrahedron Lett.* **2007**, *48*, 6564. d) Vidadala, S. R.; Thadke, S. A.; Hotha, S. *J. Org. Chem.* **2009,** *74*, 9233.

31. a) Vidadala, S. R.; Gayatri, G.; Sastry, G. N.; Hotha, S. *Chem. Commun.* **2011**(DOI: 10.1039/C1CC13134F). b) Vidadala, S. R.; Hotha, S. *Chem. Commun.* **2009**, 2505.

****

Chapter 3

Synthesis of *C*-2 functionalized glycosides exploiting methyl glycosides

Introduction

Glycosamines are the amino sugars and are prominent precursors in the biochemical synthesis of glycosylated proteins and lipids. D-(+)-glucosamine ($C_6H_{13}NO_5$), is shown to be a component of many biological important systems widely spread in nature.[1] It is a part of the connective tissues, membranes, lipopolysaccharides and mucopolysaccharides and participates in detoxic function of the liver and kidneys. The data from literature reviewed permit concluding that glucosamine and its derivatives are potentially useful and possess antiinflammatory, liver-defending, antihypoxic and other pharmacological activities.[2]

Glucosamine has proved to be effective at improving the rate of recovery form injury and severity of joint pain. One of the major benefits of glucosamine, compared to nonsteroidal anti-inflamatory drugs (NSAIDs), is that they can reduce symptoms without any side effects by rebuilding the damaged cartilage.[3] Glucosamine, like chondroitin, is known as a symptomatic slow-acting drug for osteoarthritis (degenerative joint disease), which is the most common form of arthritis.[4] Glucosamine, a preferred substrate for the biosynthesis of glycosaminoglycan chains and subsequently, for the production of aggrecan and other proteoglycans of cartilage.[5] These aggrecans play essential role in giving the cartilage its hydrophilicity, which is beneficial in cases of osteoarthritis.[6]

Glycosamines are present in nature in the form of chitin (polymer of *N*-acetyl glucosamine) and glycosaminoglycan (polymer of *N*-acetyl glucosamine and glucaric acid). These are most frequently β-linked glycosides and *N*-acetylated (Figure 1).

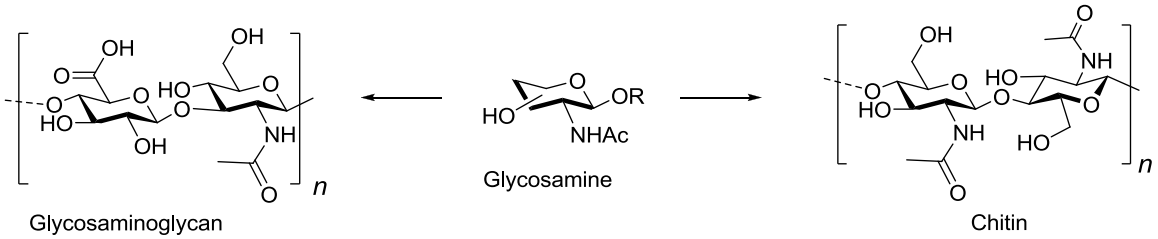
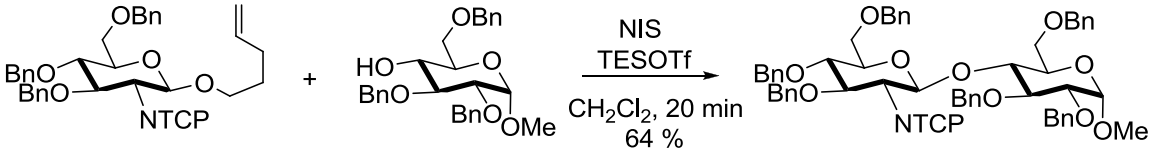


Figure 1

Glycoside bond formation with donors derived from *N*-acetylglucosamine resulted in oxazoline formation via neighboring group participation.[7] This intermediate does not exert strong glycosyl donor property even with strong acids since methyl substituted *N*-

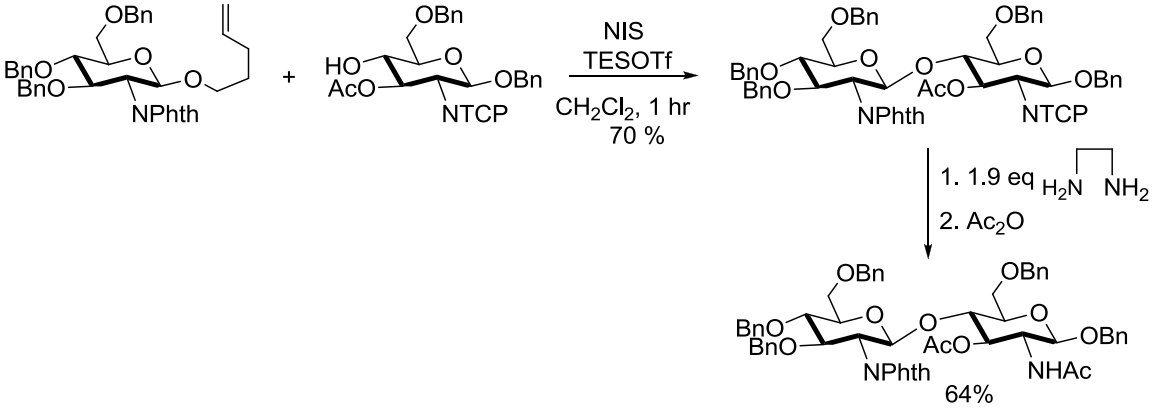
protonated oxazolinium system rather stable. Therefore, various glycosamine donors, containing modified amino functionalities have been investigated for this endeavour amongst them pthalimido group[8] and azido group[9] gained importance. Phthalimido (Phth-) group of glucosamine in combination with glycosyl donors would result in β-glycoside formation *via* highly reactive *N*-acylated oxazolinium intermediate. However, the phthalimido cleavage requires basic conditions which can often lead to partial decomposition of the product.[10] Later, readily available and low cost tatrachlorophthaloyl (TCP) group was introduced in combination with *n*-pentenyl glycosides to ensure high yields of glycosylation as well as the β-selectivity (Scheme 1).[11]

Scheme 1



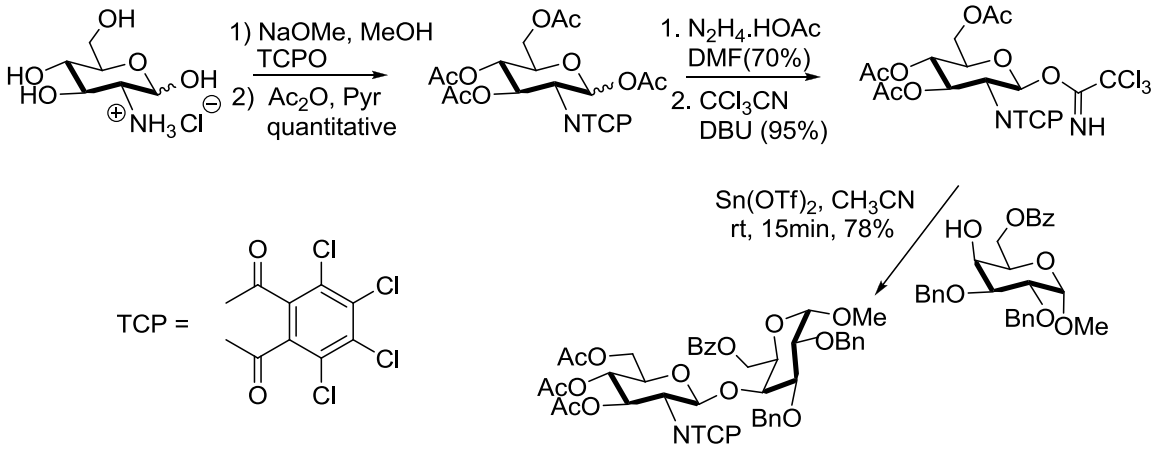
Phth- and TCP protecting groups are comparable to each other with respect to their installation and substantial reactivity. However, TCP group can be cleaved under mild conditions using ethylenediamine. TCP group may also be placed on the acceptor as shown in scheme 2 forming the differentially protected chitobiose, which was latter chemoselectively cleaved.[12]

Scheme 2



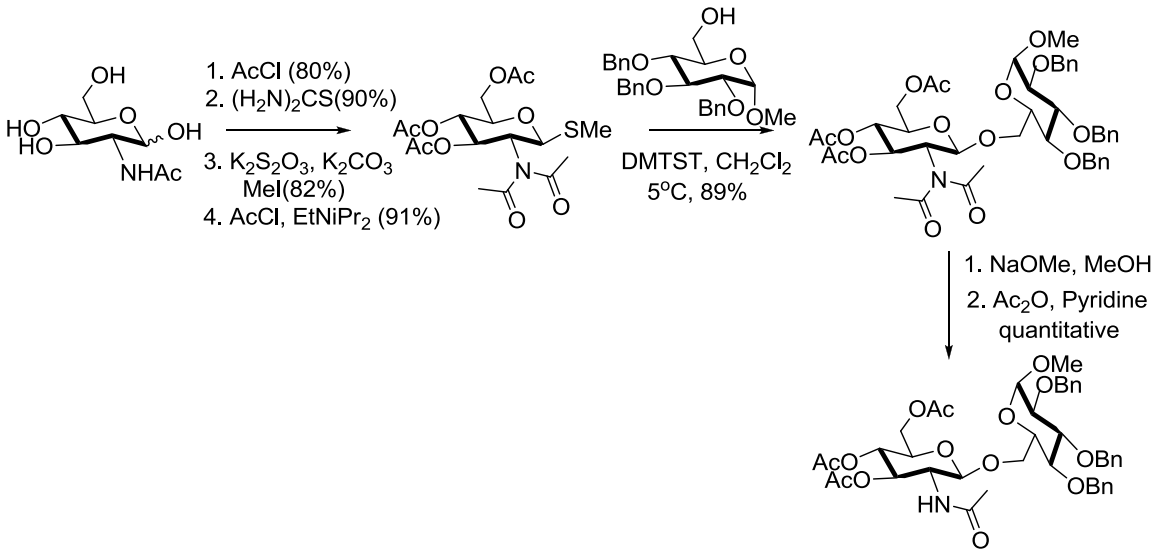
Similarly, tetrachlorophthaloyl (TCP) containing trichloroacetimidate glycosyl donors were used for glycosylation using $Sn(OTf)_2$ to result 1,2-*trans* glycosylated product[13] (Scheme 3).

Scheme 3



The intermediate generation of free amino groups is quite frequently disadvantageous. Therefore, the methods that enable retention of the *N*-acetyl group in the activated species are of great interest.

Scheme 4

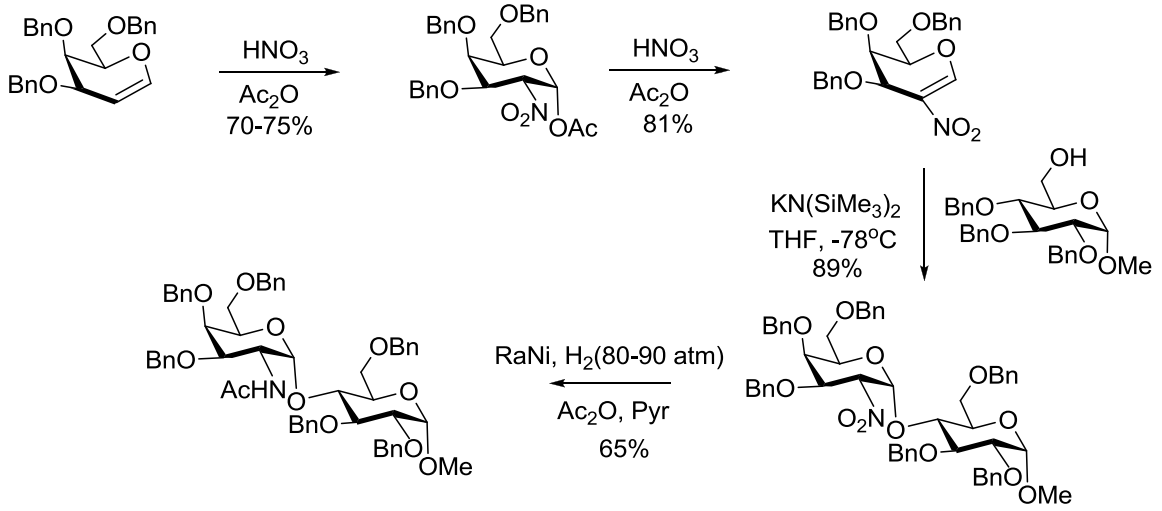


A convenient solution for this problem is the use of *N*,*N*-diacetyl derivatives of amino sugars which was upon anomeric activation to highly reactive *N*-acetyl oxazolinium intermediate followed by the reaction with acceptor gave desired β-linked glycoside. Removal of one of the acetyl group was done under NaOMe, MeOH conditions (Scheme 4).[14]

Unlike, the aforementioned glycosylation methods for the synthesis of β-linkages assisted by neighbouring group participation, the synthesis of α-glycosides

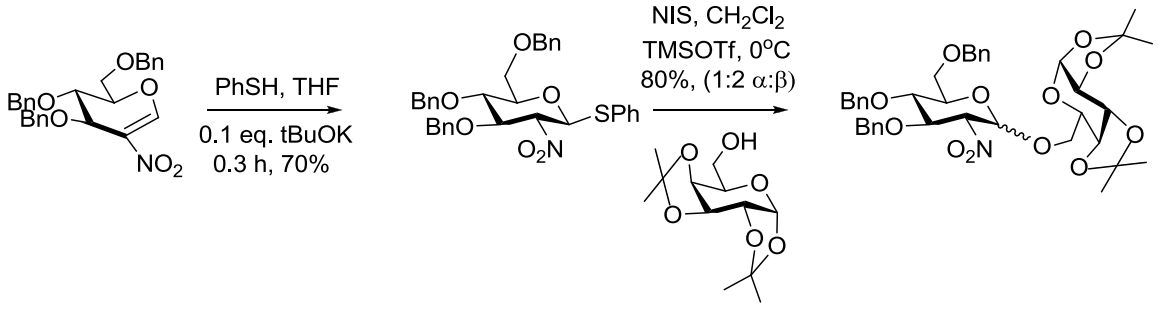
stereoselectively is still difficult as they are primarily dependent on the solvent and stereoelectronic effects.[15] For example use of non-assisted latent amino sugar such as azide group whose synthesis is still not economical. Later, Schmidt *et al.* synthesized galacto- amino sugars from Michael-type addition to 2-Nitro-D-galactal. Using carbohydrate Michael donor with HMDS at -78 ^{o}C gave exclusively α-glycoside, which was reduced and acetylated to obtain *N*-acetylated glycoside (Scheme 5).[16]

Scheme 5



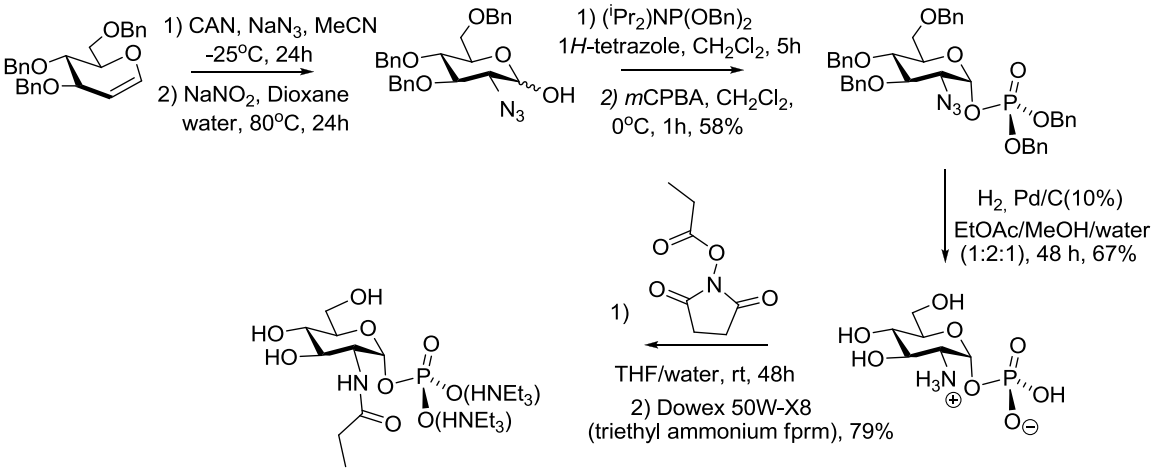
Later, 2-Nitro thioglycosides were synthesized by the same group as versatile precursors for the amino glycosides.[17] 2-Nitro glucal was converted into 2-Nitrothio glycoside by

Scheme 6



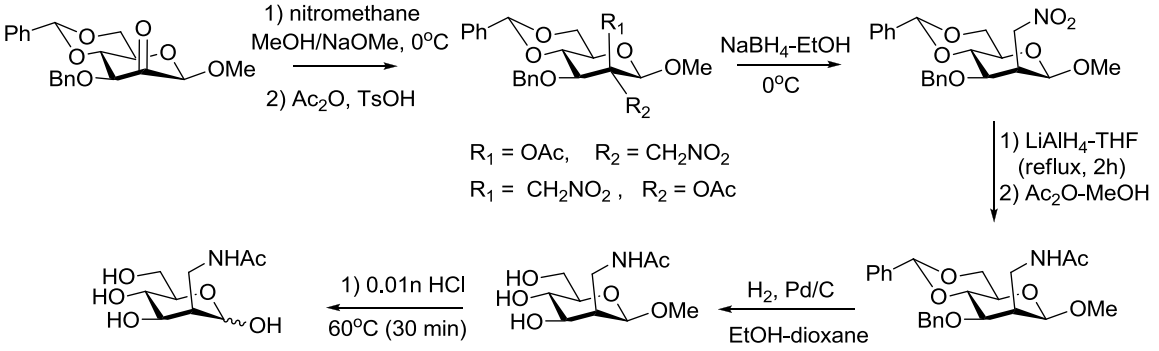
base catalyzed glycosylation with thiophenol followed by a glycosylation with carbohydrate containing aglycon using NIS/TMSOTf to get corresponding *C*-2 substituted nitro disaccharide (Scheme 6). Using the same carbohydrate template of tri-*O*-benzyl glucal, Thiem *et al.* developed analogues of UDP-GlcNAc modified at the 2-acetamido group of the GlcNAc moiety in order to study their role in the mechanism of *N*-acetylglucosaminyl tranferase mediated glycosylations.[18]

Scheme 7



Azidonitration of glucal followed by reductive hydrolysis and phosphorylation results the glucosyl phosphate which upon hydrogenation and *N*-acetylation gives glycosamino phosphate (Scheme 7).

Scheme 8

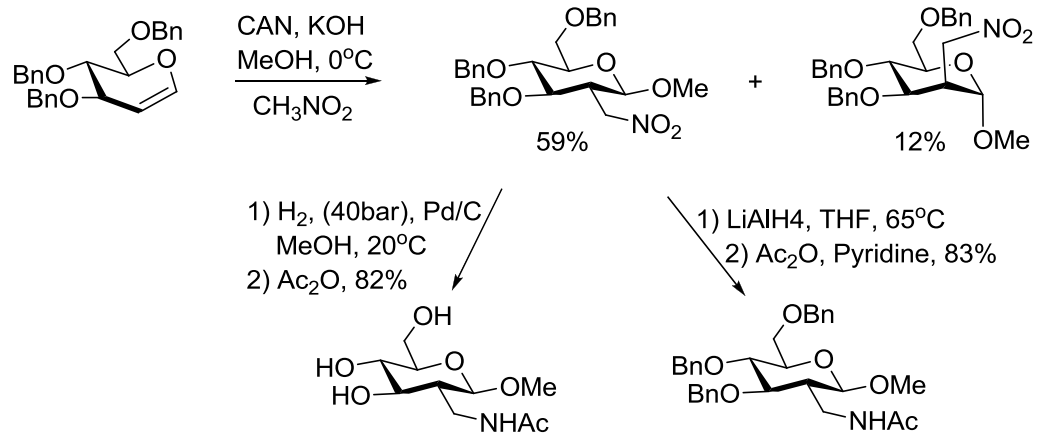


More recently, it was found that glycosamine analogs also have promising enzyme inhibition activity.[19] *C*-2 branched chain glycosamines was synthesized by Brossmer *et al.* starting from Methyl-4,6-*O*-benzylidine-3-*O*-benzyl-β-D-glucopyranoside.[20] More interestingly, these *C*-2 branched chain glycosamines were incorporated into unnatural sialic acids (Scheme 8).[20]

The most convenient synthesis of *C*-2 branched chain glycosamines were synthesized by Linker's group starting from easily available glycals in a simple three step sequence.[21] Radical addition of nitromethane to glycals using cerium (IV) ammonium nitrate (CAN) as one electron oxidant and subsequent reduction followed by acetylation

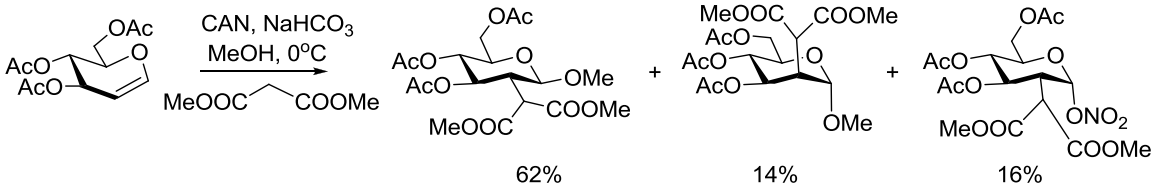
gave access to glycosamino analogues. This method is applicable to pentoses, hexoses, and disaccharides (Scheme 9).[21]

Scheme 9



Similarly, radical addition of dimethyl malonate to the glucal using CAN as one electron oxidant resulted in the *C*-2 functionalized gluco- and manno- isomers along with anomeric nitrate. This additional nitrate compound was suppressed completely using anhydrous CAN (Scheme 10).[22]

Scheme 10



Bi-cyclic lactones: Lactones represent an important class of organic compounds, are industrial intermediates, and can be synthesized by various methods.[23] γ -Lactones, in particular, are widespread in nature and possess promising pharmacological properties as enzyme inhibitors,[24] due to their common ring opening by nucleophiles. Interestingly, linking of carbohydrates to the reactive heterocycle increases water solubility, which is advantageous for the bioavailability.

D-Gluco 1,5-lactone is the cheapest chiral building blocks for organic chemists and is easily synthesized in large scale by the oxidation of anomeric hydroxyl group.[25] On the other hand, carbohydrate fused lactones have been less intensely studied. These compounds allow stereoselective glycosylations by nucleophilic ring opening at the anomeric centre (Figure 2).[26]

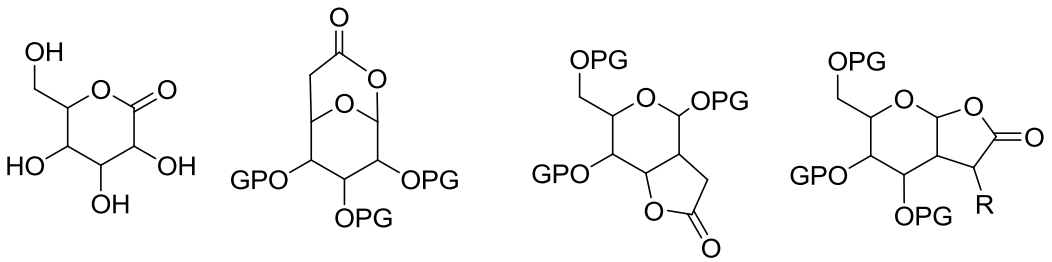
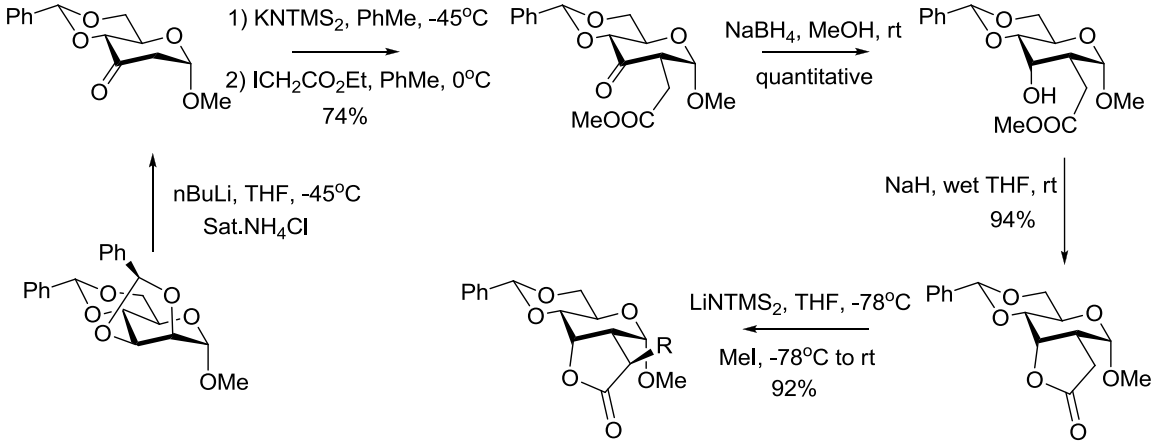


Figure 2

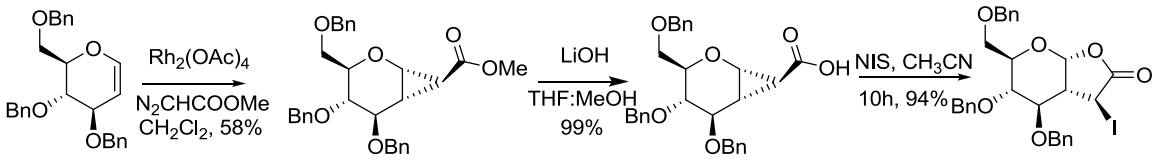
Synthesis of 2, 3-carbohydrate bicyclic lactones were done by many steps starting from readily available D-mannose to known ketoester.[27] Reduction of the keto- group facilitates the axial hydroxy-ester followed by cyclization resulting in the required bicyclic lactone which was later alkylated with methyl iodide to get stereoselectively *exo*-isomer (Scheme 11).

Scheme 11



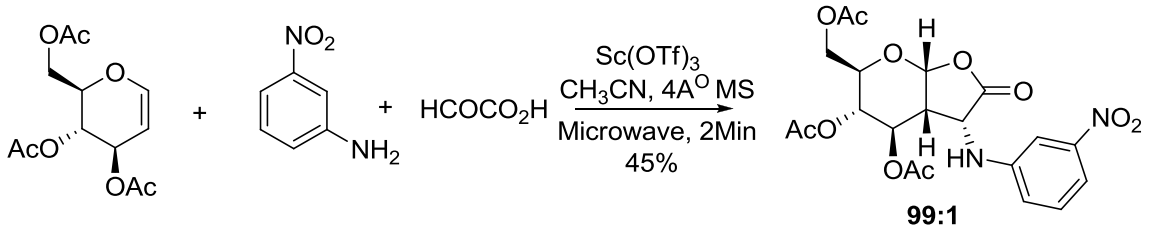
Carbohydrate derived 1,2-bicyclic lactones were synthesized by Chandrasekaran *et al.* starting from tri-*O*-benzyl-D- glucal, upon Rhodium catalysed cyclopropanation using methyl diazoacetate followed by reduction to give carboxylated sugar.[28] Acid catalysed cyclization of carboxylic acid using NIS resulting in iodo- substituted 1,2-bicyclic lactones (Scheme 12).

Scheme 12



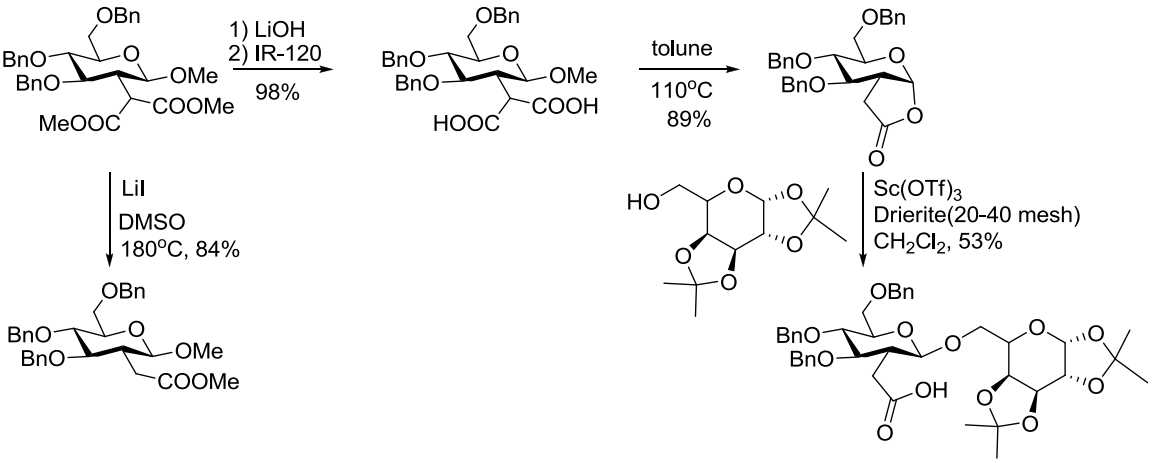
Another synthesis of 1,2-carbohydrate bicyclic lactones were developed by Lavilla *et al*. using microwave assisted multicomponent reaction.[29] A three component reaction of tri-*O*-acetyl-D-glucal, 3-nitro aniline and glyoxylic acid using scandium triflate under microwave irradiation resulted into amino substituted 1,2-bicyclic lactones (Scheme 13).[29]

Scheme 13



Very recently, Linker *et al*. showed the synthesis of carbohydrate 1,2-bicyclic lactones from the corresponding malonate addition products which were obtained by the radical addition of dimethylmalonate to glycals using CAN as one electron oxidant.[30] Cleavage of one of the ester groups was achieved under drastic conditions and for milder conditions, saponification to malonic acid followed by heating to 110^{o}C to get 1,2-carbohydrate bicyclic lactone was followed (Scheme 14).

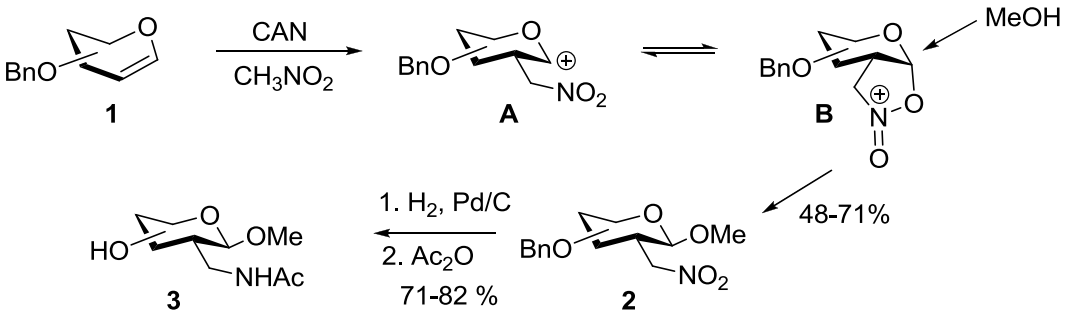
Scheme 14



****

Glycosamine containing glycopeptides and glycolipids play pivotal roles in a variety of cellular processes such as cell-cell adhesion, cell growth, fertilization and infection.[31] Glycosamine lacking glycopeptides are found to be ineffective as anti-freeze agents or other biological applications thereby emphasizing the overall significance of glycosamines.[32] Artificial and unnatural *N*-functionalized glucosamines were studied as substrates for the inhibition of *N*-acetylglucosaminyl transferases. Additionally, glycosamine homologs (e.g. **3**) are interesting as they modulate the cellular molecular recognition events. Linker *et al.* developed transition-metal-mediated radical reactions in carbohydrate chemistry for the synthesis of glycosamine homologs **3** (Scheme 15).

Scheme 15

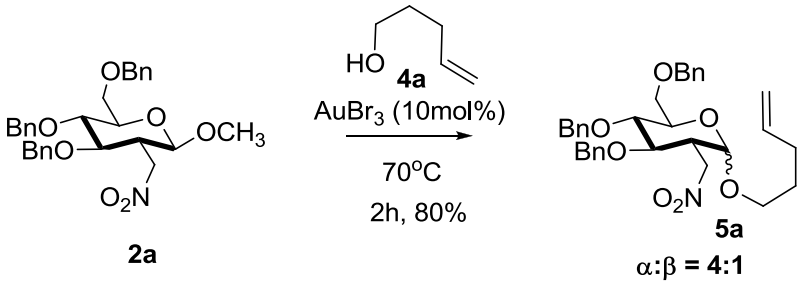


Radical addition of nitromethane to protected glycals **1** proceeds smoothly in the presence of cerium ammonium nitrate (CAN) via glycosyl carbenium ions **A**. Cyclization with the adjacent nitro group to the intermediate **B** stabilizes reversibly the whole system. This explains the highly stereoselective attack of methanol from the opposite face, affording exclusively 1,2-*trans* configured 2-*C*-branched chain carbohydrates **2**. Finally, glycosamine homologs **3** are obtained by catalytic hydrogenation and acetylation in good yields in analytically pure form (Scheme 15).

Although method is applicable to unsaturated hexoses, pentoses and disaccharides, the predetermined configuration at the anomeric center is disadvantageous. Thus, due to the selective opening of intermediate **B**, methyl α-glucosides are not available, which would represent interesting structures common in nature. Furthermore, the formation of more complex glycosidic bonds, especially attractive disaccharides, during the radical

addition of nitromethane is not possible, since methanol is the superior solvent for such reactions. Thus, activating the anomeric position of the methyl glycosides was the only way to afford either lactol or transglycosylated products. However, conventional procedures like heating in acidic medium failed, due the instability of the branched chain carbohydrates. Many known glycosylation methods were tried before and in all the cases, either decomposition of the starting material happened or the starting material did not react at all. As we identified that methyl glycosides are potential glycosyl donors in the presence of catalytic amount of gold(III) salts, we thought that nitromethyl carbohydrates such as **2** might directly serve as precursors for transglycosidations. We started our initial studies with *gluco*-isomer **2a**, which is easily available and has the most common configuration in nature. Indeed, reaction with 1 equiv. of 4-penten-1-ol (**4a**) proceeded smoothly in the presence of 10 mol% of $AuBr_3$ in acetonitrile at 70 °C, and an α:β (4:1) mixture of transglycosylated *n*-pentenyl glucoside **5a** was isolated after 2 h in 65 % yield (Scheme 16).

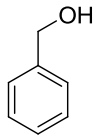
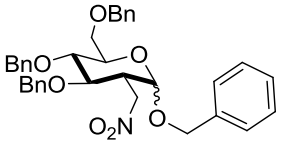
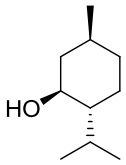
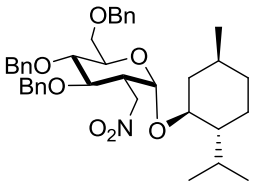
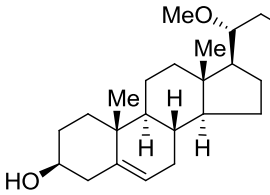
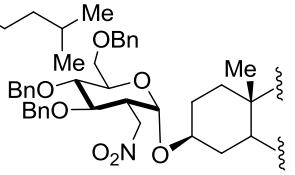
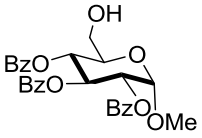
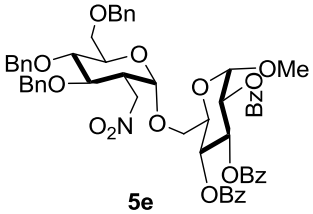
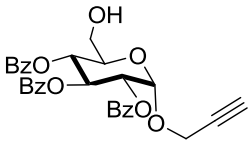
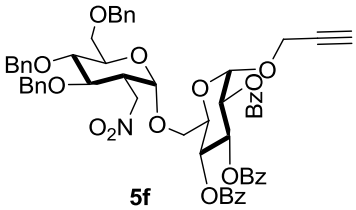
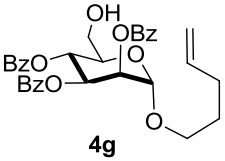
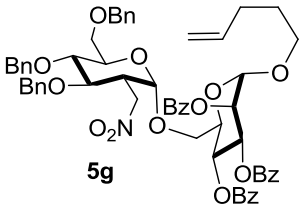
Scheme 16



Surprisingly, methyl 3,4,6-tri-*O*-benzyl-2-*deoxy*-2-*C*-nitromethyl gluco-α-D-pyranoside (**6a**) was obtained as a by-product in 20% yield. This anomerization was hypothesized to proceed by an interesting mechanism, giving strong evidence for an endocyclic C–O bond cleavage, but could be completely suppressed by employing three equiv. of the aglycone and the overall yield increased to 80 % (Scheme 16). Thus, gold(III) bromide is an ideal catalyst for the transglycosidation of 2-*C*-nitromethyl carbohydrates.

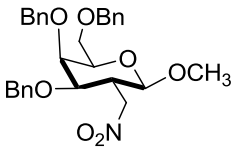
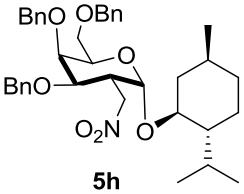
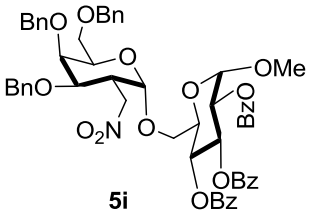
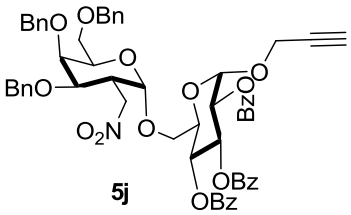
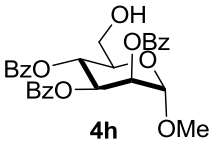
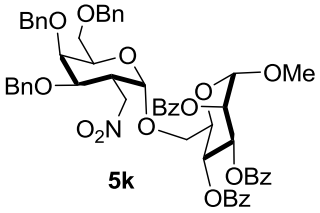
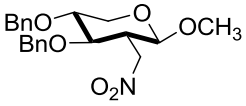
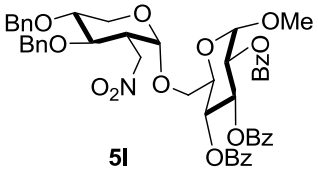
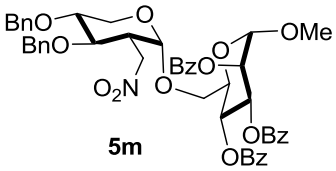
In the ^{1}H NMR spectrum of compound **5a** two multiplets at δ 1.55-1.80 and 1.98-2.38 ppm due to pentenyl moiety and the ^{13}C NMR spectrum showed two resonances corresponding to α/β mixture of anomeric carbons at δ 96.9 and 100.5 ppm. DEPT NMR

Table 1.

Entry	ROH 4	Product 5	Time (h)	Ratio α:β	Yield %
1	 **4b**	 **5b**	2	2:1	76
2	 **4c**	 **5c**	6	α only	72
3	 **4d**	 **5d**	24	α only	45
4	 **4e**	 **5e**	6	α only	56
5	 **4f**	 **5f**	12	α only	55
6	 **4g**	 **5g**	12	α only	52

Reagents & Conditions : 10 mol% $AuBr_3$ / CH_3CN / 70°C

Table 2

Glycosyl Donor 2	ROH	Product 5	Time (h)	Yield %
 **2b**	**4c**	 **5h**	6	71
	4e	 **5i**	12	54
	4f	 **5j**	12	54
	 **4h**	 **5k**	12	58
 **2c**	**4e**	 **5l**	12	48
	4h	 **5m**	12	50

Reagents & Conditions : 10 mol% $AuBr_3$ / CH_3CN / 70°C

spectrum indicated the presence of eighteen methylene groups of pentenyl glycoside **5a**, and the HRMS (MALDI-ToF) showed a molecular weight peak at 584.2710 calculated for $C_{33}H_{39}NO_7Na$.

To further extend this method and to prove its generality we investigated other nucleophiles **4** (Table 1). Thus, benzyl glucoside **5b** was synthesized from another primary alcohol (BnOH, **4b**) in good yield as an anomeric mixture (entry 1). Surprisingly, sterically demanding secondary alcohols such as menthol (**4c**) and cholesterol (**4d**) afforded the corresponding glycosides **5c** and **5d** as sole α-anomers after prolonged reaction times (entries 2 and 3). The moderate yield of cholesteryl α-glucopyranoside **5d** is due to the bad solubility of cholesterol (**4d**) in acetonitrile.

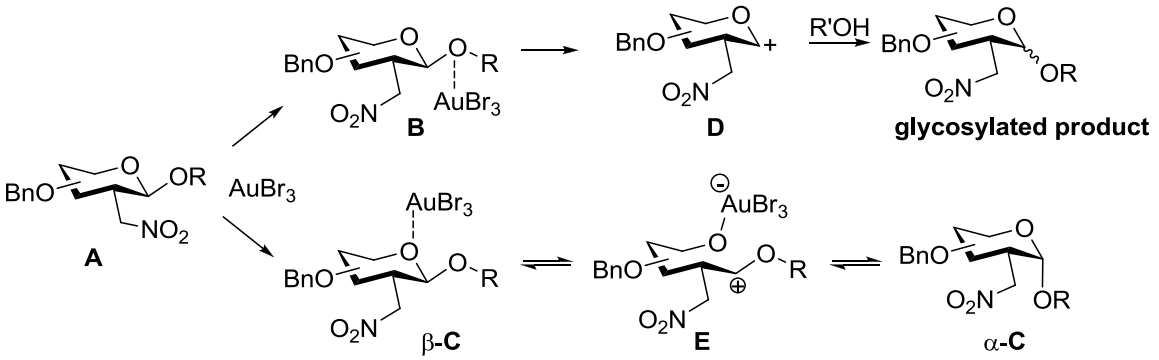
All the products were characterized thoroughly by ^1H, ^{13}C, DEPT NMR and mass spectral analysis. For example, the ^1H NMR spectrum of disaccharide **5e** shows δ 2.75 as dddd of *C*-2 nitromethyl group and δ 3.42 ppm as a singlet for the methoxy group. In addition, ^{13}C NMR spectrum pointed out the characteristic signals due to two α -anomeric carbons at δ 97.0 and 97.5ppm. Further DEPT NMR spectrum specified the six (δ 65.4, 68.1, 73.3, 73.5, 74.7 and 75.1 ppm) signals with negative intensity for the presence of six methylene groups in the assigned disaccharide **5e**, and the HRMS (MALDI-ToF) showed a molecular weight peak at 1004.3471 calculated for $C_{56}H_{55}NO_{15}Na$.

Finally, synthetically interesting disaccharides **5e**–**g** were synthesized by the same procedure from sugar aglycons (**4e**-**g**). Again, only α-anomers were isolated in moderate yields (entries 4–6). Thus, we developed a general strategy for the introduction of the nitromethyl group in the non-reducing sugar ring of disaccharides, whereas in previous studies by Linker's group gave access to the reducing sugar only.

Our successful method of gold-catalyzed transglycosidations under mild conditions could be applied for other 2-*deoxy*-*C*-nitromethyl pyranosides **2** (Table 2). Thus, the *galacto*-isomer **2b** afforded various 2-*C*-branched carbohydrates **5h**–**k** in moderate to good yields. Again, longer reaction times were necessary, resulting in the selective formation of α-anomers. Even pentose derivative **2c** reacted smoothly to the disaccharides **5l** and **5m**, demonstrating the general applicability of 2-*C*-branched methyl glycosides as glycosyl donors in the presence of $AuBr_3$.

The selective formation of α-anomers is interesting from the mechanistic point of view. During our studies on radical additions of nitromethane to glycals, we established a stabilization of anomeric cations by the adjacent nitro group. Thus, nucleophiles can only attack from the opposite face, resulting in β-glucosides with high selectivity. The difference in our herein described gold-catalyzed reactions might be a complexation of the nitro group by the transition-metal, inhibiting its neighbouring-group-participation.

Scheme 17

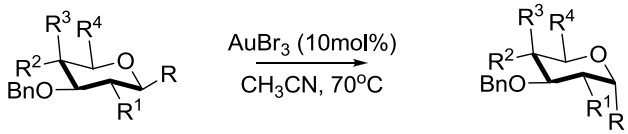


On the other hand, we see a remarkable time dependence on the α:β ratio (Tables 1 and 2). This speaks for a gold-catalyzed anomerization with formation of the thermodynamically more stable α-glycoside after longer reaction times[35]. In the first step, the Lewis acidic $AuBr_3$, might activate the anomeric center by coordination to the adjacent exocyclic oxygen atom (intermediate **B**), as postulated very recently for Au(I)-catalyzed glycosidation.[36] However, our studies reveal that the ring oxygen (intermediate **C**) might be attacked as well. The issue of exo- or endocyclic oxygen activation during anomerization has been discussed for many years[37] and was kinetically studied very recently.[38] Both of these pathways afford different oxocarbenium ions **D** and **E**, leading to transglycosylated products **5** or α/β-anomerization (Scheme 17).[39]

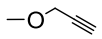
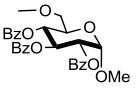
To demonstrate the generality of this anomerization, we investigated various carbohydrates under gold-catalysis without addition of a nucleophile (Table 3).[39] Thus, 2-deoxy-*C*-nitromethyl pyranosides β-**2a**–**c** reacted smoothly with 10 mol% of $AuBr_3$ in acetonitrile at 70 °C. Complete conversion was achieved within 1–2 h and the α-methyl glycosides α-**6a**–**c** were isolated in good to high yields (entries 1–3). Interestingly, this anomerization proceeds faster than the transglycosidations, explaining why compound α-**6a** was formed as by-product in our initial experiments (Table 1). Furthermore, simple

methyl per-*O*-benzyl β-glycosides **7a** and **7b** reacted selectively to the corresponding α-anomers **8a** and **8b** (Table 3, entries 3 and 4). This important finding demonstrates that

Table 3



1,2-*trans or* β 1,2-*cis or* α

Entry	Substrate	R^1	R^2	R^3	R^4	R	Product	Time Yield (%)[a]
1	**2a**	-CH_2NO_2	-OBn	H	-CH_2OBn	-OCH_3	**6a**	2h 86%
2	**2b**	-CH_2NO_2	H	-OBn	-CH_2OBn	-OCH_3	**6b**	1h 80%
3	**2c**	-CH_2NO_2	-OBn	H	H	-OCH_3	**6c**	2h 71%
4	**7a**	-OBn	-OBn	H	-CH_2OBn	-OCH_3	**8a**	12h 55%
5	**7b**	-OBn	H	-OBn	-CH_2OBn	-OCH_3	**8b**	8h 70%
6	**7c**	-OBn	-OBn	H	-CH_2OBn		**8c**	12h 51%
7	**9**	-OBn	-OBn	H	-CH_2OBn		**10**	12h 41%

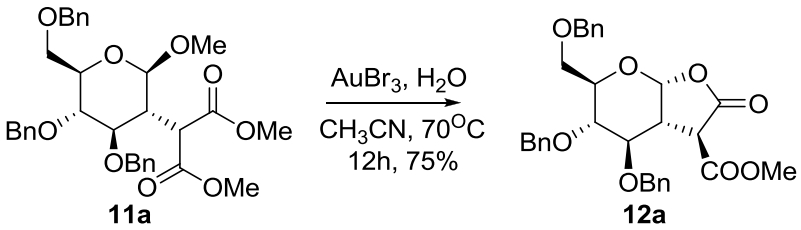
the complexation of Au(III) by the nitro group is not a prerequisite for the anomerizations. Finally, propargyl glucoside β-**7c** and even disaccharide β-**9** can be converted into their α-anomers **8c** and **10** in slightly lower yields (entries 5 and 6). Although anomerizations in the presence of $SnCl_4$ or other Lewis acids are known for many years, our gold-catalyzed reactions proceed under mild conditions and give very high α-selectivities. All the products were characterized thoroughly by ^1H, ^{13}C, DEPT NMR and mass spectral analysis. For example, the comparison of ^1H and 13C NMR spectra of α- and β-Disaccharides are shown below (Table 4).

Table 4

β-Disaccharide **9**	α-Disaccharide **10**
^{1}H NMR (200.13 MHz, $CDCl_3$): δ = **3.37**(s, 3H), 3.39(m, 1H), 3.58(t, *J* = 9.1 Hz, 1H), 3.62(s, 1H), 3.63(d, *J* = 1.3 Hz, 1H), 3.66(dd, *J* = 2.5, 10.8 Hz, 2H), 3.81(dd, *J* = 7.5, 11.0 Hz, 1H), 4.11(dd, *J* = 2.0, 11.0 Hz, 1H), 4.37(m, 1H), 4.42(s, 1H), 4.44-4.54(m, 2H), 4.68(d, *J* = 10.9 Hz, 1H), 4.71-4.84(m, 2H), 4.93(ABq, *J* = 11.2 Hz, 2H), 5.05(d, *J* = 11.0 Hz, 1H), 5.20(m, 1H), 5.25(dd, *J* = 3.6, 10.2 Hz, 1H), 5.47(t, *J* = 10.0 Hz, 1H), 6.17(t, *J* = 10.0 Hz, 1H), 7.10-7.53 (m, 29H), 7.82-7.99(m, 6H). ^{13}C NMR (125.76 MHz, $CDCl_3$): δ = 55.5, 68.6, 68.7, 68.9, 69.1, 70.0, 70.6, 72.2, 73.5, 74.8, 75.0, 75.7, 77.7, 82.4, 84.6, **96.8**, **104.0**, 127.5-130.0, 133.0, 133.3, 133.4, 138.2, 138.2, 138.5, 138.7, 165.5, 165.8, 165.8.	^{1}H NMR (200.13 MHz, $CDCl_3$): δ = 3.42(m, 1H), **3.43**(s, 3H), 3.54(dd, *J* = 3.4, 9.5 Hz, 2H), 3.63(m, 2H), 3.84(m, 2H), 3.96(t, *J* = 9.4 Hz, 1H), 4.34(m, 1H), 4.46(ABq, *J* = 12.2 Hz, 2H), 4.68(ABq, *J* = 11.2 Hz, 2H), 4.69(ABq, *J* = 12.3 Hz, 2H), 4.77(d, *J* = 10.8Hz, 2H), 4.83(d, *J* = 10.1 Hz, 1H), 5.20(m, 2H), 5.53(t, *J* = 10.0 Hz, 1H), 6.15(m, 1H), 7.10-7.55(m, 29H), 7.83-8.05(m, 6H). ^{13}C NMR (125.76 MHz, $CDCl_3$): δ = 55.5, 66.6, 68.2, 68.5, 69.6, 70.2, 70.6, 72.2, 73.1, 73.3, 74.7, 75.5, 77.5, 79.9, 81.7, **96.7**, **97.2**, 127.4-130.0, 133.0, 133.3, 133.3, 137.9, 138.3, 138.5, 138.8, 165.2, 165.8, 165.8.

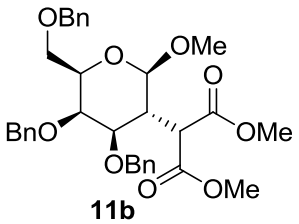
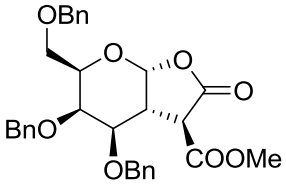
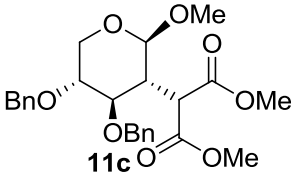
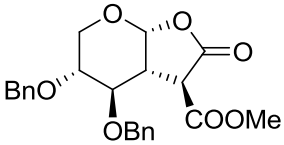
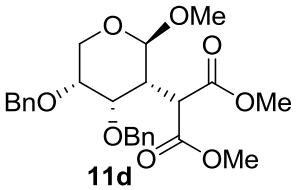
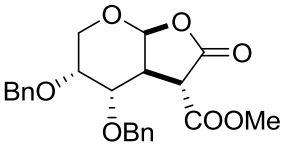
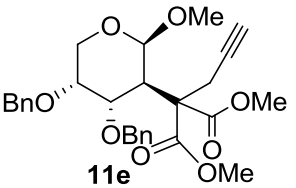
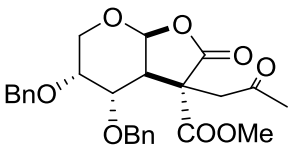
Development of transition metal mediated radical reactions by Prof. Torsten linker showed a one step entry for the synthesis of 2-*C*-malonyl derivatives **11**. Reactions of the 2-*C*-malonyl derivative *gluco*-**11a** with various alcohols in the presence of gold (III) bromide afforded low yields of transglycosylated products besides some lactone *gluco*-**12a**. To further optimize this reaction and to establish a general entry to carbohydrate 1, 2-lactones, we investigated the gold-catalysis in the non-nucleophilic solvent acetonitrile. Without any additive we found no conversion of the starting material *gluco*-**11a**. However, the simple addition of two equivalents of water afforded the lactone *gluco*-**12a** in 75% yield in analytically pure form.

Scheme 18



^{1}H NMR spectrum of compound **12a** revealed methoxy group of ester as a singlet at δ 3.76 ppm and the anomeric proton appeared as a doublet at δ 6.05 ppm. The ^{13}C NMR spectrum showed the anomeric carbon at δ 100.9 ppm. DEPT NMR spectrum confirmed the presence of four methylene groups of **12a** as four negatively phased resonances were observed and the LC-MS showed a molecular weight peak at 555.569 calculated for $C_{31}H_{32}O_8Na$.

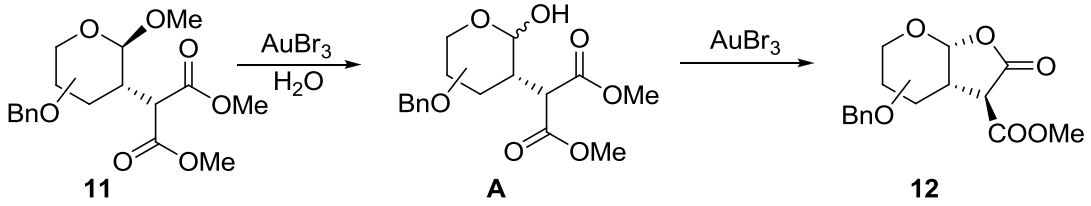
Table 5

Substrate	Product	Time(h) & yield(%)
 **11b**	 **12b**	12h, 58%
 **11c**	 **12c**	12h, 67%
 **11d**	 **12d**	12h, 68%
 **11e**	 **12e**	12h, 57%

The *galacto*-configured 2-*C*-malonyl carbohydrate **11b** reacted under the same conditions in somewhat lower yield (Table 5). Furthermore, pentoses *xylo*-**11c** and *arabino*-**11d** are suitable substrates for the lactonization as well (Table 5). Thus, gold (III) bromide is a mild catalyst for the convenient synthesis of the hitherto unknown carbohydrate 1,2-lactones form easily available malonates in only one step. Attempts for the trapping of lactol with other functional group such as with alkyne (**11e**) are not successful. Instead, hydrolysis of alkyne as well as formation of lactone was observed in the same step (**12e**) (Table 5).

From the mechanistic point of view, the addition of water is essential for the lactonizations (Table 5). Therefore, we propose the formation of the reducing hemi acetals **A** as an intermediate, by cleavage of the methyl glycoside in the first step (Scheme 19). Subsequent cyclization affords lactones **12**, and thus both steps are catalyzed by gold(III) bromide. The preferred formation of the *exo*-isomer **12** for all lactonizations can be explained by steric interactions of the ester group with the sugar ring, which is minimized in the *exo*-configuration.

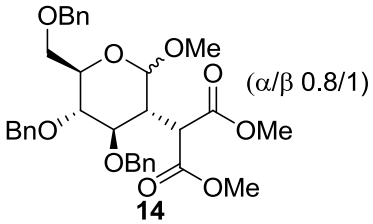
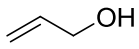
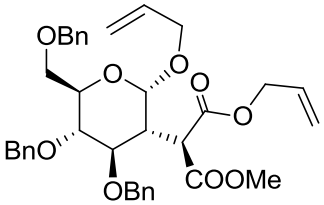
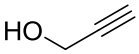
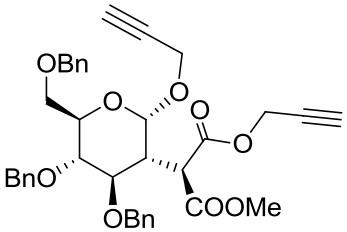
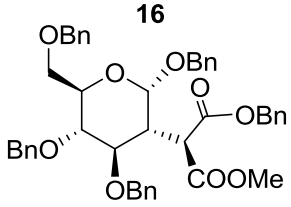
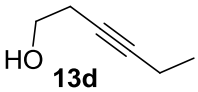
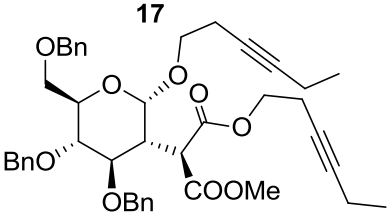
Scheme 19



To demonstrate the potential of lactones **12** as glycosyl donors, we investigated the opening of the lactone ring with nucleophiles next. We found that TMSOTf is a suitable Lewis acid to drive reactions smoothly with various alcohols (**13a-d**) to give corresponding ester-glycoside **14** – **18** (Table 6). Only the hexynol **13d** required longer reaction times and gave somewhat lower yields (entry 5). Interestingly, the methyl ester group remains intact in the products, whereas the former lactone is converted into a new ester group. Furthermore, the stereocenter at the 7-position is conserved during the lactone opening, giving access to unsymmetric 2-*C*-malonyl carbohydrates in diastereomerically pure form. This can be rationalized by a selective attack of TMSOTf at the lactone carbonyl group and subsequent esterification with alcohols. The oxocarbenium ion at the anomeric center is trapped by the alcohols as well. The anomeric mixture for methyl glycoside **14** (entry 1) and the very high

α-selectivity for all other products **15-18** (entries 2–5) is in accordance to our openings of lactone *gluco*-**12a** and can be explained by an anomerization during the Lewis acid catalyzed reaction. Thus, all stereocenters of starting material *gluco*-**12a** are conserved during lactone opening and the products might be suitable precursors for further transformations.

Table 6

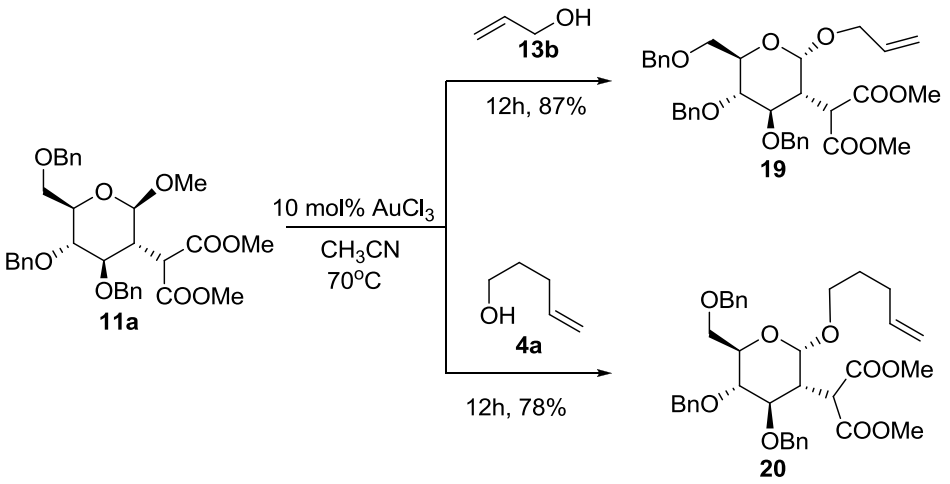
Nucleophile	Product	Time(h) & yield(%)
MeOH **13a**	 **14** (α/β 0.8/1)	4h, 90%
 **13b**	 **15**	2h, 78%
 **13c**	 **16**	2h, 81%
BnOH **4b**	 **17**	4h, 72%
 **13d**	 **18**	12h, 61%

Reagents & Conditions : TMSOTf / CH_3CN / rt

All the products were characterized thoroughly by ^{1}H, ^{13}C, DEPT NMR and mass spectral analysis. For example, the ^{1}H NMR spectrum of **15** shows δ 2.71 ppm (1H, ddd, J = 3.1, 6.2, 9.3 Hz) for 2-H and δ 3.47 ppm as a singlet for the -$CO_2C\underline{H}_3$. In addition, ^{13}C NMR spectrum pointed out the α -anomeric carbon at δ 97.4 ppm and the rest of the other resonances in agreement with the assigned structure **15**. Further DEPT NMR spectrum specified the eight (δ 66.0, 68.4, 68.6, 73.6, 74.7, 74.9, 117.3 and 118.6 ppm) signals with negative intensity for the presence of eight methylene groups in the assigned disaccharide **15**, and the LC-MS showed a molecular weight peak at 653.7137 calculated for $C_{37}H_{42}O_9Na$.

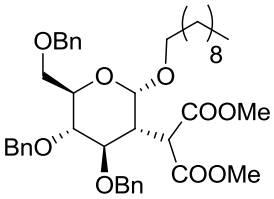
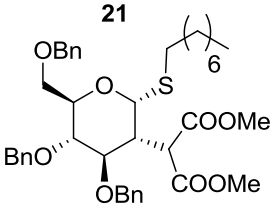
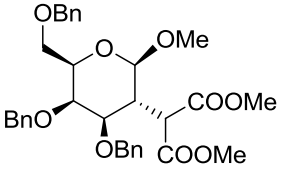
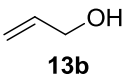
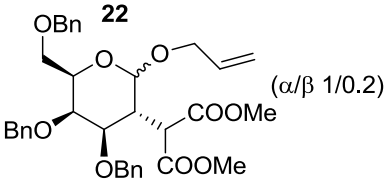
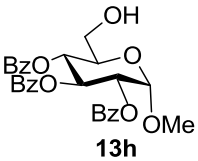
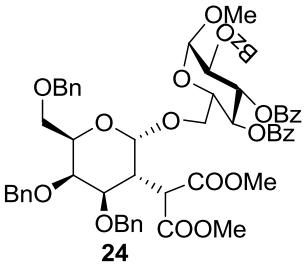
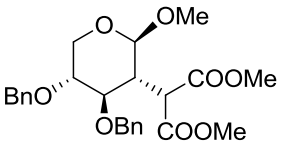
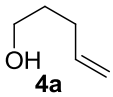
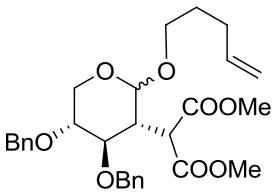
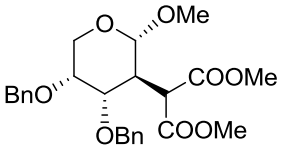
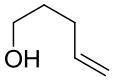
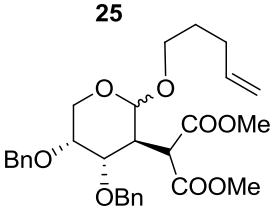
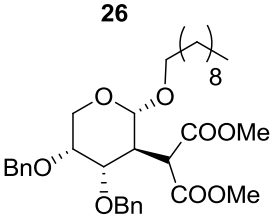
Later, activation of methyl glycosides containing malonate addition products under similar conditions in the presence of various aglycons was then investigated. $AuCl_3$ (10 mol%) was found to be as effective as $AuBr_3$ for transglycosylation reactions. Glycosylation reaction of methyl glycoside (**11a**) with aglycons (**13b**, **4a**) under 10 mol% of $AuCl_3$ at 70°C to result the corresponding transglycosylated products (**19**, **20**) in good yields (Scheme 19).

Scheme 19



^{1}H NMR spectrum of compound **20** revealed the presence of two methoxy groups at 3.46 and 3.61 ppm and the vinylic -CH proton appeared as a multiplet at δ 5.78 ppm. Further, the ^{13}C NMR spectrum in showed the anomeric carbon at δ 98.1 ppm and DEPT NMR spectrum indicated the presence of eight (δ 28.5, 30.2, 67.2, 68.5,

Table 7

Substrate	Nucleophile	Product	Time(h) & yield(%)
11a	 **13f**	 **21**	2h, 61%
11a	 **13g**	 **22**	4h, 53%
 **11b**	 **13b**	 (α/β 1/0.2) **23**	6h, 85%
11b	 **13h**	 **24**	24h, 31%
 **11c**	 **4a**	 (α/β 1/0.2) **25**	6h, 69%
 **11d**	 **4a**	 (α/β 1/0.2) **26**	6h, 71%
11d	 **13f**	 **27**	12h, 51%

Reagents & Conditions : 10 mol% $AuCl_3$ / CH_3CN / 70°C

73.5, 74.5, 74.8 and 114.9 ppm) signals with negative intensity for the presence of eight methylene groups of **20**, and the LC-MS showed a molecular ion base peak at 655.40 calculated for $C_{37}H_{44}O_9Na$.

Transglycosylation protocol was then extended to other aglycons (**13f, 13g**) to get corresponding glycosylated products (**21, 22**). It is pertinent to declare that the current strategy has been successfully extended to the other malonate addition products of galactoside (**11b**), xyloside (**11c**) and arabinoside (**11d**) to obtain corresponding *C*-2 functionalized glycosides (**23, 25-27**) and disaccharide (**24**) in good yields. All the products were thoroughly by ^1H, ^{13}C, DEPT NMR and mass spectral analysis. For example, in the ^1H NMR spectrum of disaccharide **24** δ 3.44, 3.49, 3.67 ppm three singlets for the presence of three methoxy groups were noticed. In addition, ^{13}C NMR spectrum pointed out the two anomeric carbons (two α) at δ 96.9 and 99.1 ppm, and the rest of the other signals in agreement with the assigned structure **24**. Further DEPT NMR spectrum specified the five (δ 66.2, 68.9, 71.3, 73.2 and 74.4 ppm) signals with negative intensity for the presence of five methylene groups in the assigned disaccharide **24**, and the LC-MS showed a molecular ion base peak at 1075.921 calculated for $C_{60}H_{60}O_{17}Na$.

In summary, gold-catalyzed transglycosylations were applied for 2-*C*-branched carbohydrates. Methyl glycosides are found to be suitable glycosyl donors, which react with various alcohols at the anomeric center. Thus, 2-*C*-nitromethyl as well as melonate functionalized glycosides are available for the first time. During the gold-catalysis study we observed an interesting anomerization under mild conditions. Synthesis of various carbohydrate γ-bicylic lactones and selective ring opening of lactones implicates the utility of methyl glycosides under gold catalysis.

****

Note: Characterization data and full spectral charts for all nitro addition products can also be found in ***Eur. J. Org. Chem***. **2011**, 2426-2430.

Chapter 3: Experimental section

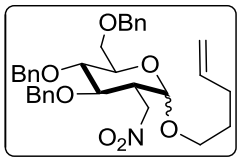
General Procedure for $AuBr_3$-mediated transglycosylation: To a solution of glycosyl donor (0.2 mmol) and aglycone (0.6 mmol) in anhydrous acetonitrile (5 mL) was added 10 mol% of $AuBr_3$ under argon atmosphere at room temperature. The resulting mixture was heated to 70^{o}C and stirred till the completion until TLC showed complete conversion. The reaction mixture was concentrated *in vacuo* to obtain a crude residue which was purified by silica gel column chromatography using ethyl acetate-petroleum ether as mobile phase.

General Procedure for $AuBr_3$-mediated Anomerization: To a solution of β-glycoside (0.2 mmol) in anhydrous acetonitrile (4 mL) was added 10 mol% of $AuBr_3$ under argon atmosphere at room temperature. The resulting mixture was heated to 70 ^{o}C and stirred until TLC showed complete conversion. The reaction mixture was concentrated *in vacuo* to obtain a crude residue which was purified by silica gel column chromatography using ethyl acetate-petroleum ether as mobile phase.

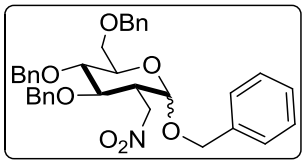
General Procedure for $AuBr_3$-catalyzed lactonizations: To a solution of methyl glycosides **(**0.2 mmol) in acetonitrile (3 mL) was added water (0.4 mmol) and 8 mol% of $AuBr_3$ at room temperature. The resulting mixture was heated to 70 °C and stirred until TLC showed complete conversion. The reaction mixture was concentrated *in vacuo* to obtain a crude residue which was purified by silica gel column chromatography (ethyl acetate-petroleum ether) to give lactones in analytically pure form.

General Procedure for lactone openings: To a solution of lactone (0.2 mmol) in acetonitrile (3 mL) was added nucleophile (0.6 mmol) and TMSOTf (0.2 mmol) at room temperature. The mixture was stirred at this temperature until TLC showed complete conversion. After dilution with water (5 mL), the mixture was extracted with ethyl acetate (3 x 10 mL). The combined organic layers were washed with brine (10 mL) and dried over anhydrous sodium sulphate. After removal of the solvent *in vacuo*, the residue was purified by silica gel column chromatography (ethyl acetate-petroleum ether) to afford the lactone opening product.

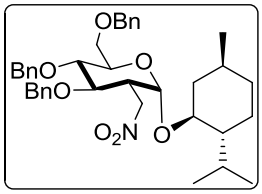
Compound 5a (4:1 α:β mixture) **:** ^{1}H NMR (200.13 MHz, $CDCl_3$): δ = 1.55-1.80(m, 4H), 1.98-2.38(m, 4H), 2.73 (dddd, *J* = 3.4, 4.6, 8.5, 11.9 Hz, 1H), 3.12(m, 1H), 3.25-3.55(m, 3H), 3.58-3.95(m, 11H), 4.27-5.03(m, 20H), 5.03-5.14(m, 2H), 5.63-5.92(m, 2H), 7.10-7.43(m, 30H); ^{13}C NMR (50.32 MHz, $CDCl_3$): δ = 28.4, 28.6, 30.0, 30.2, 44.6, 46.6, 67.2, 68.3, 68.6, 69.2, 71.0, 72.1, 73.5, 73.6, 73.6, 73.6, 74.7, 74.8, 75.0, 75.1, 77.9, 79.1, 79.5, 79.9, 96.9, 100.5, 114.9, 115.0, 126.6-128.9, 137.7, 137.7, 137.8, 137.8, 137.8, 137.9, 138.0, 138.0; HRMS (MALDI-TOF): *m/z*: calculated for $[C_{33}H_{39}NO_7+Na]^+$: 584.2624; found: 584.2710.; elemental analysis (%)calculated for $C_{33}H_{39}NO_7$: C 70.57, H 7.00, N 2.49; found: C 70.61, H 6.98, N 2.51.



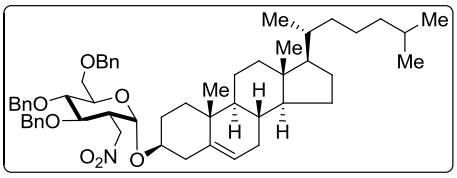
Compound 5b (2:1 α:β mixture) : ^{1}H NMR (200.13 MHz, $CDCl_3$): δ = 2.39(m, 1H), 2.78(m, 1H), 3.40-3.85(m, 10H), 4.35-4.98(m, 20H), 4.65(s, 1H), 5.01(d, *J* = 3.3 Hz, 1H), 7.10-7.40(m, 40H); ^{13}C NMR (50.32 MHz, $CDCl_3$): δ = 44.6, 46.5, 68.3, 68.6, 69.7, 71.1, 71.2, 72.0, 73.5, 73.6, 73.6, 74.7, 74.9, 75.1, 75.1, 75.2, 78.0, 79.2, 79.5, 79.9, 96.4, 99.3, 127.6-128.6, 136.7, 136.8, 137.6, 137.7, 137.8, 137.8, 138.0, 138.0; HRMS (MALDI-TOF): *m/z*: calculated for $[C_{35}H_{37}NO_7+Na]^+$: 606.2468; found: 606.2577.



Compound 5c: $[\alpha]^{D}_{25}$ = +37.6 (*c* = 1.2 in $CHCl_3$); ^{1}H NMR (200.13 MHz, $CDCl_3$): δ = 0.68(d, *J* = 6.9 Hz, 3H), 083, 0.87, 0.88, 0.91(4s, 6H), 1.25(m, 3H), 1.63(m, 2H), 1.93(dddd, *J* = 2.5, 6.9, 9.6, 14.0 Hz, 1H), 2.15-2.31(m, 2H), 2.75(m, 1H), 3.32(dt, *J* = 4.3, 10.6 Hz, 1H), 3.59-4.00(m, 5H), 4.23-4.98(m, 9H), 5.05(d, *J* = 3.3 Hz, 1H), 7.11-7.40(m, 15H); ^{13}C NMR (50.32 MHz, $CDCl_3$): δ = 15.4, 21.2, 22.2, 22.6, 25.4, 31.5, 34.1, 42.6, 45.4, 48.7, 48.4, 71.2, 73.3, 73.6, 74.9, 75.1, 79.7, 81.1, 97.1, 98.3, 127.6-128.6, 137.6, 137.8, 137.9; HRMS (MALDI-TOF): *m/z*: calculated for $[C_{38}H_{49}NO_7+Na]^+$: 654.3407; found: 654.3327.

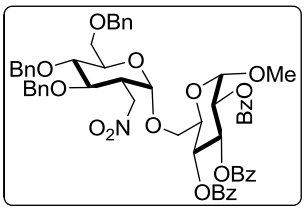


Compound 5d: $[\alpha]^{D}_{25}$ = +71.9 (*c* = 1.3 in $CHCl_3$); ^{1}H NMR (200.13 MHz, $CDCl_3$): δ = 0.67(s, 3H), 080-2.11(m, 37H), 2.28(d, *J* = 7.7Hz, 3H), 2.72(dddd, *J* = 3.2, 4.5, 7.9, 10.2 Hz, 1H), 3.45(m, 1H), 3.60-3.95(m, 6H), 4.28-4.98(m, 7H),

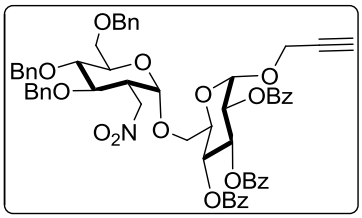


5.05(d, *J* = 3.5 Hz, 1H), 5.29(d, *J* = 5.2 Hz, 1H), 7.12-7.40(m, 15H); ^{13}C NMR (50.32 MHz, $CDCl_3$): δ = 11.8, 18.7, 19.3, 21.0, 22.5, 22.8, 23.8, 24.3, 27.5, 28.0, 28.2, 29.7, 31.8, 31.9, 35.8, 36.2, 36.6, 36.8, 39.5, 39.7, 39.9, 42.3, 44.6, 50.0, 56.1, 56.7, 70.9, 73.6, 73.7, 74.9, 75.2, 77.3, 78.0, 79.6, 95.1, 122.0, 127.7-128.6, 137.7, 137.8, 137.8, 140.0; HRMS (MALDI-TOF): *m/z*: calculated for $[C_{55}H_{75}NO_7+Na]^+$: 884.5441; found: 884.5386.

Compound 5e: $[\alpha]^D_{25}$ = +101.5 (*c* = 1.6 in $CHCl_3$); ^{1}H NMR (200.13 MHz, $CDCl_3$): δ = 2.75(dddd, *J* = 3.5, 4.6, 6.4, 8.1 Hz, 1H), 3.42(s, 3H), 3.44(dd, *J* = 3.1, 10.7 Hz, 1H), 3.63(td, *J* = 2.6, 4.9, 10.9 Hz, 2H), 3.67-3.80(m, 2H), 3.82(dd, *J* = 4.2, 11.6 Hz, 1H), 4.17(ddd, *J* = 2.3, 4.0, 6.5 Hz, 1H), 4.48(d, *J* = 1.6 Hz, 1H), 4.51(ABq, *J* = 12.0 Hz, 2H), 4.53(d, *J* = 6.0 Hz, 2H), 4.68(ABq, *J* = 11.0 Hz, 2H), 4.78(ABq, *J* = 10.8 Hz, 2H), 5.01(d, *J* = 3.3 Hz, 1H), 5.21(dd, *J* = 3.6, 18.8 Hz, 1H), 5.31(d, *J* = 3.7 Hz, 1H), 5.62(t, *J* = 10.0 Hz, 1H), 6.12(t, *J* = 10.0 Hz, 1H), 7.14-7.56(m, 24H), 7.84-8.04(m, 6H); ^{13}C NMR (50.32 MHz, $CDCl_3$): δ = 44.5, 55.6, 65.4, 68.1, 68.4, 68.9, 70.6, 71.2, 72.0, 73.3, 73.5, 74.7, 75.1, 77.3, 79.4, 97.0, 97.5, 127.6-130.0, 133.0, 133.3, 133.3, 137.7, 137.8, 138.0, 165.1, 165.7, 165.8; HRMS (MALDI-TOF): *m/z*: calculated for $[C_{56}H_{55}NO_{15}+Na]^+$: 1004.3469; found: 1004.3471; elemental analysis (%) calculated for $C_{56}H_{55}NO_{15}$: C 68.49, H 5.65, N 1.43; found: C 68.60, H 5.78, N 1.51.

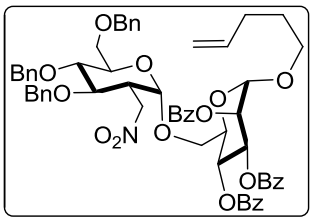


Compound 5f: $[\alpha]^D_{25}$ = +84.6 (*c* = 1.5 in $CHCl_3$); ^{1}H NMR (200.13 MHz, $CDCl_3$): δ = 2.36(t, *J* = 2.4 Hz, 1H), 2.73(dddd, *J* = 3.5, 4.7, 6.2, 7.5 Hz, 1H), 3.35-3.85(m, 8H), 4.31(d, *J* = 2.4 Hz, 1H), 4.34-5..02(m, 10H), 5.34(dd, *J* = 3.7, 10.2 Hz, 1H), 5.48(d, *J* = 3.8 Hz, 1H), 5.65(t, *J* = 10.0 Hz, 1H), 6.12(t, *J* = 10.0 Hz, 1H), 7.15-7.53(m, 24H), 7.81-8.04(m, 6H); ^{13}C NMR (50.32 MHz, $CDCl_3$): δ = 34.5, 55.6, 65.9, 68.1, 68.8, 69.1, 70.5, 71.1, 71.5, 73.3, 73.4, 74.7, 75.2, 75.3, 77.3, 78.3, 79.4, 95.0, 97.5, 127.6-130.0, 133.1, 133.3, 133.4, 137.7, 137.7, 138.0, 165.1, 165.7, 165.8; HRMS (MALDI-TOF): *m/z*: calculated for $[C_{58}H_{55}NO_{15}+Na]^+$: 1028.3469; found: 1028.3448.

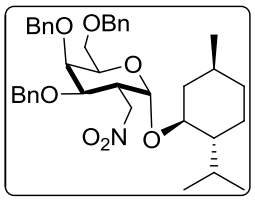


Compound 5g: $[\alpha]^D_{25}$ = -4.2(*c* = 1.3 in $CHCl_3$); ^{1}H NMR (200.13 MHz, $CDCl_3$): δ = 1.80(m, 2H), 2.22(m, 2H), 2.77(dddd, *J* = 3.2, 4.7, 6.3, 9.2 Hz, 1H), 3.35-3.98(m, 9H),

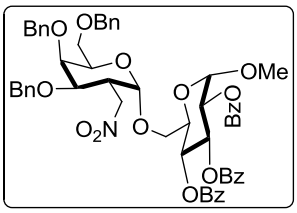
4.13-4.68(m, 7H), 4.73(m, 2H), 4.85-5.17(m, 4H), 5.65(dd, *J* = 1.7, 3.2 Hz, 1H), 5.73-6.05(m, 3H), 7.10-7.56(m, 24H), 7.81-8.12(m, 6H); ^{13}C NMR (50.32 MHz, $CDCl_3$): δ = 28.5, 30.2, 44.6, 66.3, 66.8, 67.8, 68.1, 69.3, 70.2, 70.9, 71.1, 73.4, 73.4, 74.7, 75.2, 78.3, 79.3, 97.7, 97.8, 115.2, 127.5-129.9, 133.1, 133.4, 133.5, 137.7, 137.8, 137.8, 138.0, 165.3, 165.5, 165.6; HRMS (MALDI-TOF): *m/z*: calculated for $[C_{60}H_{61}NO_{15}+Na]^+$: 1058.3939; found: 1058.3769.



Compound 5h: $[\alpha]^D_{25}$ = +54.7(*c* = 1.1 in $CHCl_3$); ^{1}H NMR (200.13 MHz, $CDCl_3$): δ = 0.67(d, *J* = 6.9 Hz, 3H), 0.80, 0.83, 0.86, 0.90(4s, 6H), 1.12-1.40(m, 3H), 1.58(m, 4H), 1.89(dddd, *J* = 2.6, 7.0, 9.6, 14.0 Hz, 1H), 2.14(m, 1H), 3.20-3.37(m, 2H), 3.56(ABq, *J* = 9.0 Hz, 1H), 3.60(ABq, *J* = 9.1 Hz, 1H), 3.69(dd, *J* = 2.3, 11.0 Hz, 1H), 4.02(d, *J* = 3.0 Hz, 1H), 4.05(t, *J* = 6.5 Hz, 1H), 4.48(d, *J* = 2.1 Hz, 2H), 4.72(ABq, *J* = 11.5, 2H), 4.31-4.75(m, 4H), 5.08(d, *J* = 3.4 Hz, 1H), 7.25-7.39(m, 15H); ^{13}C NMR (50.32 MHz, $CDCl_3$): δ = 15.4, 21.2, 22.2, 22.6, 25.4, 31.5, 34.1, 40.0, 42.5, 48.7, 68.9, 69.6, 71.1, 71.3, 73.5, 73.7, 74.5, 76.0, 80.5, 98.6, 127.6-128.6, 137.2, 137.9, 138.4; HRMS (MALDI-TOF): *m/z*: calculated for $[C_{38}H_{49}NO_7+Na]^+$: 654.3407; found: 654.3523.

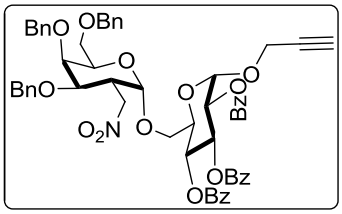


Compound 5i: $[\alpha]^D_{25}$ = +77.8(*c* = 1.3 in $CHCl_3$); ^{1}H NMR (200.13 MHz, $CDCl_3$): δ = 3.26(dddd, *J* = 3.4, 4.9, 8.3, 11.8 Hz, 1H), 3.39(s, 3H), 3.45(d, *J* = 2.8 Hz, 1H), 3.52(td, *J* = 2.1, 4.4, 9.2 Hz, 1H), 3.61(d, *J* = 2.1 Hz, 1H), 3.80(d, *J* = 11.4 Hz, 1H), 3.81(dd, *J* = 7.3, 11.4 Hz, 1H), 3.99(s, 1H), 4.14(ddd, *J* = 2.2, 3.7, 5.8 Hz, 1H), 4.33(ABq, *J* = 12.3 Hz, 2H), 4.58(ABq, *J* = 11.4 Hz, 2H), 4.70(ABq, *J* = 11.6, 2H), 4.53(d, *J* = 8.1 Hz, 2H), 4.62(d, *J* = 4.9 Hz, 1H), 5.02(d, *J* = 3.3 Hz, 1H), 5.15(d, *J* = 3.6 Hz, 1H), 5.28(dd, *J* = 3.6, 10.2 Hz, 1H), 5.61(t, *J* = 10.1 Hz, 1H), 6.11(t, *J* = 9.8 Hz, 1H), 7.18-7.53(m, 24H), 7.85-8.02(m, 6H); ^{13}C NMR (50.32 MHz, $CDCl_3$): δ = 39.3, 55.5, 65.5, 68.3, 68.7, 68.9, 69.7, 70.7, 71.1, 71.2, 71.9, 73.3, 73.7, 74.5, 75.5, 97.0, 97.9, 127.6-130.0, 133.0, 133.3, 133.4, 137.2, 137.9, 138.3, 165.3, 165.7, 165.8; HRMS (MALDI-TOF): *m/z*: calculated for $[C_{56}H_{55}NO_{15}+Na]^+$: 1004.3469; found: 1004.3378.

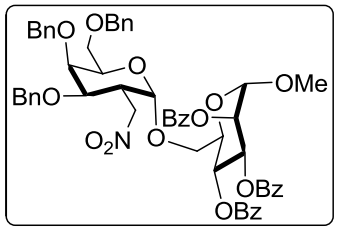


Compound 5j: $[\alpha]^D_{25}$ = +86.3 (*c* = 1.4 in $CHCl_3$); ^{1}H NMR (500.13 MHz, $CDCl_3$): δ = 2.35(t, *J* = 2.3 Hz, 1H), 3.25(dddd, *J* = 3.5, 8.4, 12.1, 15.6 Hz, 1H), 3.41(dd, *J* = 6.0, 9.2

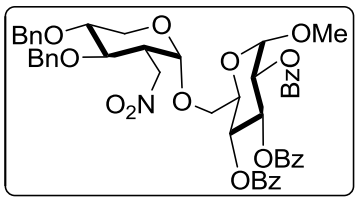
Hz, 1H), 3.48(dd, *J* = 7.2, 9.1 Hz, 1H), 3.59(dd, *J* = 2.1, 11.8 Hz, 1H), 3.81(dd, *J* = 3.1, 11.6 Hz, 1H), 3.87(t, *J* = 6.6 Hz, 1H), 3.98(s, 1H), 4.24(td, *J* = 2.9, 5.9, 10.1 Hz, 1H), 4.29(d, *J* = 2.4 Hz, 1H), 4.33(ABq, *J* = 11.9 Hz, 2H), 4.33(dt, *J* = 2.6, 11.1, 13.4 Hz, 1H), 4.47(d, *J* = 11.3 Hz, 1H), 4.51(dd, *J* = 8.9, 13.7 Hz, 1H), 4.54(d, *J* = 11.6 Hz, 2H), 4.65(dd, *J* = 4.5, 13.7 Hz, 1H), 4.71(d, *J* = 11.6 Hz, 1H), 4.86(d, *J* = 11.4 Hz, 1H), 5.02(d, *J* = 3.2 Hz, 1H), 5.23(dd, *J* = 3.8, 10.2 Hz, 1H), 5.47(d, *J* = 3.8 Hz, 1H), 5.64(t, *J* = 10.1 Hz, 1H), 6.12(t, *J* = 10.1 Hz, 1H), 7.18-7.54(m, 24H), 7.86-8.02(m, 6H); ^{13}C NMR (125.76 MHz, $CDCl_3$): δ = 39.3, 55.6, 65.4, 68.8, 68.8, 69.0, 69.7, 70.6, 71.3, 71.3, 71.5, 73.3, 73.7, 74.5, 75.3, 75.6, 78.4, 95.1, 97.9, 127.5-130.0, 133.1, 133.3, 133.4, 137.3, 137.9, 138.4, 165.2, 165.7, 165.8; HRMS (MALDI-TOF): *m/z*: calculated for $[C_{58}H_{55}NO_{15}+Na]^+$: 1028.3469; found: 1028.3414.



Compound 5k: $[\alpha]^D_{25}$ = -15.7 (*c* = 1.3 in $CHCl_3$); ^{1}H NMR (500.13 MHz, $CDCl_3$): δ = 3.28(dddd, *J* = 3.4, 5.3, 8.1, 11.4, 1H), 3.41(dd, *J* = 6.1, 15.3 Hz, 1H), 3.45(s, 3H), 3.48(dd, *J* = 7.2, 8.6 Hz, 2H), 3.60(dd, *J* = 3.3, 11.5 Hz, 1H), 3.78(dd, *J* = 2.4, 11.5 Hz, 1H), 3.86-3.92(m, 1H), 3.97(m, 1H), 4.19(ddd, *J* = 2.1, 4.2, 6.5 Hz, 1H), 4.31(ABq, *J* = 11.9 Hz, 2H), 4.37-4.47(m, 1H), 4.49(t, *J* = 3.9 Hz, 1H), 4.52(d, *J* = 6.4 Hz, 1H), 4.58(dd, *J* = 5.4, 13.8 Hz, 1H), 4.68(d, *J* = 11.7 Hz, 1H), 4.81(d, *J* = 11.3 Hz, 1H), 4.93(d, *J* = 1.5 Hz, 1H), 5.03(d, *J* = 3.4 Hz, 1H), 5.65(dd, *J* = 1.8, 3.4 Hz, 1H), 5.84(dd, *J* = 3.4, 11.2 Hz, 1H), 5.95(t, *J* = 10.2 Hz, 1H), 7.15-7.52(m, 24H), 7.83-8.10(m, 6H); ^{13}C NMR (125.76 MHz, $CDCl_3$): δ = 34.9, 55.4, 66.3, 66.8, 68.7, 69.2, 69.7, 70.2, 70.6, 71.1, 71.2, 73.2, 73.8, 74.5, 76.5, 98.1, 98.6, 127.5-130.2, 133.1, 133.4, 133.5, 137.3, 137.9, 138.3, 165.4, 165.5, 165.5; HRMS (MALDI-TOF): *m/z*: calculated for $[C_{56}H_{55}NO_{15}+Na]^+$: 1004.3469; found: 1004.3407.

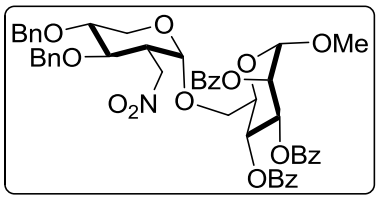


Compound 5l: $[\alpha]^D_{25}$ = +79.0 (*c* = 1.4 in $CHCl_3$); ^{1}H NMR (400.13 MHz, $CDCl_3$): δ = 2.65(m, 1H), 3.44(s, 3H), 3.45-3.75(m, 5H), 3.83(dd, *J* = 4.6, 11.6 Hz, 1H), 4.17(ddd, *J* = 2.1, 4.2, 6.5 Hz, 1H), 3.55(t, *J* = 3.5 Hz, 1H), 4.62(ABq, *J* = 8.2 Hz, 2H), 4.80(ABq, *J* = 10.4 Hz, 2H), 4.81(ABq, *J* = 10.0 Hz, 2H), 5.13-5.34(m, 2H), 5.62(t, *J* = 10.0 Hz, 1H), 6.13(t, *J* = 10.0 Hz, 1H), 7.24-7.57(m, 19H), 7.81-8.04(m,

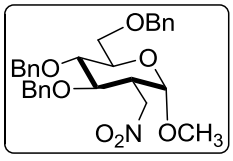


6H); ^{13}C NMR (50.32 MHz, $CDCl_3$): δ = 43.9, 55.6, 60.5, 65.5, 68.5, 69.0, 70.6, 72.0, 72.7, 73.3, 74.9, 76.0, 79.0, 97.0, 97.5, 126.9-130.0, 133.0, 133.3, 133.4, 137.8, 138.0, 165.1, 165.7, 165.8; HRMS (MALDI-TOF): *m/z*: calculated for $[C_{48}H_{47}NO_{14}+Na]^+$: 884.2894; found: 884.2857.

Compound 5m: $[\alpha]^D_{25}$ = -32.0 (*c* = 1.3 in $CHCl_3$); ^{1}H NMR (400.13 MHz, $CDCl_3$): δ = 2.67(dddd, *J* = 3.2, 6.3, 9.7, 13.1 Hz, 1H), 3.50(s, 3H), 3.50-3.62(m, 3H), 3.63(t, *J* = 4.3, 1H), 3.68(dd, *J* = 8.0, 10.3 Hz, 1H), 3.92(dd, *J* = 5.0, 11.6 Hz, 1H), 4.21(ddd, *J* = 2.2, 4.5, 6.4 Hz, 1H), 4.51(d, *J* = 6.3 Hz, 2H), 4.54-4.65(m, 3H), 4.91(dd, *J* = 3.7, 15.1 Hz, 2H), 4.96(d, *J* = 1.5 Hz, 1H), 5.65(dd, *J* = 1.7, 3.3 Hz, 1H), 5.85(dd, *J* = 3.3, 10.0 Hz, 1H), 5.95(t, *J* = 10.0 Hz, 1H), 7.23-7.60(m, 19H), 7.83-8.12(m, 6H); ^{13}C NMR (100.61 MHz, $CDCl_3$): δ = 43.8, 55.5, 60.7, 66.5, 66.8, 69.3, 70.1, 70.7, 72.6, 73.3, 74.8, 76.6, 78.8, 97.8, 98.6, 127.7-130.2, 133.1, 133.4, 133.5, 137.8, 137.9, 165.4, 165.4, 165.6; HRMS (MALDI-TOF): *m/z*: calculated for $[C_{48}H_{47}NO_{14}+Na]^+$: 884.2894; found: 884.2768.

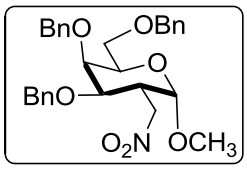


Compound 6a: $[\alpha]^D_{25}$ = +36.5 (c = 1.02 in $CHCl_3$); 1H NMR (600 MHz, $CDCl_3$): δ = 2.65 (dddd, *J* = 11.1, 9.0, 4.8, 3.1 Hz, 1H, 2-H), 3.24 (s, 3H, OMe), 3.58 (dd, *J* = 8.5, 5.5 Hz, 1H, 6-H), 3.62 (dd, *J* = 8.5, 6.1 Hz, 1H, 6´-H), 3.67 (dd, *J* = 10.4, 9.6, Hz, 1H, 4-H), 3.68 (ddd, *J* = 9.6, 6.1, 5.5 Hz, 1H, 5-H), 3.71 (dd, *J* = 11.1, 10.4 Hz, 1H, 3- H), 4.26 (dd, *J* = 13.2, 9.0 Hz, 1H, 7-H), 4.37 (dd, *J* = 13.2, 4.8 Hz, 1H, 7´-H), 4.45(d, *J* = 12.1 Hz, 1H, CH_2Ph), 4.47 (d, *J* = 10.4 Hz, 1H, CH_2Ph), 4.49 (d, *J* = 11.2 Hz, 1H, CH_2Ph), 4.59 (d, *J* = 12.1, 1H, CH_2Ph), 4.70 (d, *J* = 10.4 Hz, 1H, CH_2Ph), 4.71 (d, *J* = 3.1 Hz, 1H, 1-H), 4.82 (d, *J* = 11.2 Hz, 1H, CH_2Ph), 7.07-7.28 (m, 15H, arom. H); 13C NMR (150 MHz, CDCl3): δ = 44.6 (d, C-2), 55.1 (q, OMe), 68.4 (t, C-6), 73.5(t, -CH_2NO_2), 73.6, 74.8 (2t, CH_2Ph), 75.1 (d, C-3), 77.8, 79.6, 98.0 (3d, C- 4, C-5, C-1), 127.7, 127.7, 127.8, 127.9, 127.9, 128.0 (m, arom. C-H), 137.6, 137.8, 137.9 (arom. C-CH_2O); HRMS (MALDI-TOF): *m/z*: calculated for $[C_{29}H_{33}NO_7+Na]^+$: 530.2155; found: 530.2146.

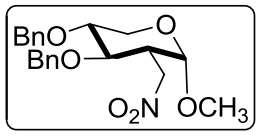


Compound 6b : $[\alpha]^D_{25}$ = +19.3 (c = 1.00 in $CHCl_3$); ^{1}H NMR (600 MHz, $CDCl_3$): δ = 3.20 (dddd, *J* = 11.5, 8.9, 4.8, 3.4 Hz, 1H, 2-H), 3.22 (s, 3H, OMe), 3.50 (dd, *J* = 9.2, 5.8 Hz, 1H, 6-H), 3.57 (dd, *J* = 9.2, 7.5 Hz, 1H, 6´-H), 3.60 (dd, *J* = 11.5, 2.5, Hz, 1H, 3-H),

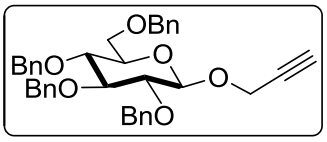
3.80 (ddd, *J* = 7.5, 5.8, 1.0 Hz, 1H, 5-H), 3.93 (dd, *J* = 2.5, 1.0 Hz, 1H, 4-H), 4.31 (dd, *J* = 13.4, 8.9 Hz, 1H, 7-H), 4.32 (d, *J* = 11.5 Hz, 1H, CH_2Ph), 4.37 (d, *J* = 11.7 Hz, 1H, CH_2Ph), 4.44 (d, *J* = 11.7 Hz, 1H, CH_2Ph), 4.48 (d, *J* = 11.5, 1H, CH_2Ph), 4.52 (dd, *J* = 13.4, 4.8 Hz, 1H, 7´-H), 4.60 (d, *J* = 11.5 Hz, 1H, CH_2Ph), 4.73 (d, *J* = 3.4 Hz, 1H, 1-H), 4.78 (d, *J* = 11.5 Hz, 1H, CH_2Ph), 7.15-7.29 (m, 15H, arom. H); 13C NMR (150 MHz, CDCl3): δ = 39.4 (d, C-2), 55.3 (q, OMe), 69.0 (t, C-6), 69.5(t, $-CH_2NO_2$), 71.2, 73.6 (2t, CH_2Ph), 73.9 (d, C-3), 74.5, 75.6, 98.4 (3d, C- 4, C-5, C-1), 127.6, 127.8, 128.0, 128.3, 128.4, 128.6 (m, arom. C-H). 137.2, 137.9, 138.3 (arom. C-CH_2O); HRMS (MALDI-TOF): *m/z*: calculated for $[C_{29}H_{33}NO_7+Na]^+$: 530.2155; found: 530.2146;



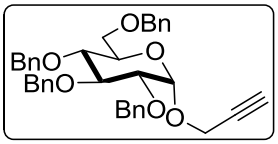
Compound 6c: $[\alpha]^D_{25}$ = +65.3 (*c* = 1.4 in $CHCl_3$); ^{1}H NMR (200.13 MHz, $CDCl_3$): δ = 2.64(dddd, *J* = 3.2, 4.9, 8.3, 10.2 Hz, 1H), 3.31(s, 3H), 3.50-3.79(m, 3H), 4.38(dd, *J* = 8.5, 13.5 Hz, 1H), 4.49(d, *J* = 5.1Hz, 1H), 4.59(m, 1H), 4.66(d, *J* = 2.2Hz, 2H), 4.69(d, *J* = 3.2Hz, 1H), 4.76 (ABq, *J* = 11.1 Hz, 2H), 7.23-7.39(m, 10H); ^{13}C NMR (50.32 MHz, $CDCl_3$): δ = 44.0, 55.2, 60.2, 72.8, 73.5, 74.9, 76.4, 79.1, 98.1, 127.7-128.5, 137.8, 137.9; HRMS (MALDI-TOF): *m/z*: calculated for $[C_{21}H_{25}NO_6+Na]^+$: 410.1580; found: 410.1562.



Compound 7c: $[\alpha]^D_{25}$ = +19.9 (*c* = 1.0 in $CHCl_3$); ^{1}H NMR (200.13 MHz, $CDCl_3$): δ = 2.42 (t, *J* = 2.4 Hz, 1H), 3.44-3.57 (m, 2H), 3.61-3.73 (m, 4H), 4.43 (t, *J* = 2.6 Hz, 2H), 4.50 (s, 1H), 4.55-4.66 (m, 4H), 4.73 (d, *J* = 6.3 Hz, 1H), 4.79 (d, *J* = 1.8 Hz, 1H), 4.90-5.00 (m, 2H), 7.10-7.40 (m, 20H); ^{13}C NMR (50.32 MHz, $CDCl_3$): δ = 54.4, 68.8, 73.5, 74.7, 74.8, 74.9, 75.0, 75.7, 77.6, 79.0, 82.0, 84.6, 101.4, 127.5-128.4, 138.1, 138.1, 138.4, 138.6; HRMS (MALDI-TOF): *m/z*: calculated for $[C_{37}H_{38}O_6+Na]^+$: 601.2566; found: 601.2557.

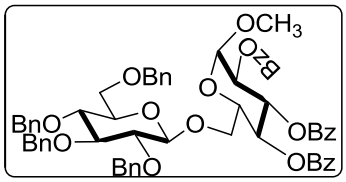


Compound 8c: $[\alpha]^D_{25}$ = +31.9 (*c* = 0.9 in $CHCl_3$); ^{1}H NMR (200.13 MHz, $CDCl_3$): δ = 2.42 (t, *J* = 2.5 Hz, 1H), 3.57-3.62 (m, 1H), 3.64 (d, *J* = 1.5 Hz, 1H), 3.72 (d, *J* = 11.6 Hz, 2H), 3.99 (t, *J* = 9.2 Hz, 1H), 4.25 (d, *J* = 2.4 Hz, 2H) , 4.43 (d, *J* = 4.8 Hz, 1H), 4.48 (d, *J* = 3.4 Hz, 1H), 4.56 (s, 1H), 4.64 (d, *J* = 6.6 Hz, 1H), 4.72 (d, *J* = 2.8 Hz, 2H), 4.81 (q, *J* = 5.4 Hz, 2H), 4.99 (d, *J* = 10.9 Hz, 1H), 5.08 (d, *J* = 3.7 Hz, 1H), 7.10-7.40 (m, 20H); ; ^{13}C NMR

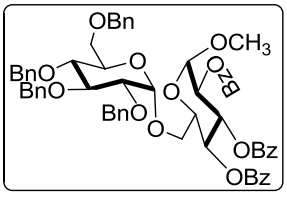


(50.32 MHz, $CDCl_3$): δ = 54.4, 68.3, 70.9, 72.9, 73.4, 74.7, 75.0, 75.7, 77.4, 78.9, 79.3, 82.9, 95.2, 127.5-128.3, 137.8, 137.9, 138.1, 138.7; HRMS (MALDI-TOF): *m/z*: calculated for $[C_{37}H_{38}O_6+Na]^+$: 601.2566; found: 601.2522.

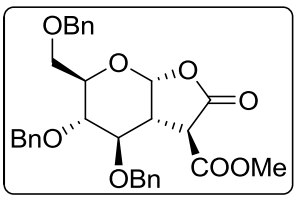
Compound 9: $[\alpha]^D_{25}$ = -3.0 (*c* = 1.1 in $CHCl_3$); ^{1}H NMR (200.13 MHz, $CDCl_3$): δ = 3.37(s, 3H), 3.39(m, 1H), 3.58(t, *J* = 9.1 Hz, 1H), 3.62(s, 1H), 3.63(d, *J* = 1.3 Hz, 1H), 3.66(dd, *J* = 2.5, 10.8 Hz, 2H), 3.81(dd, *J* = 7.5, 11.0 Hz, 1H), 4.11(dd, *J* = 2.0, 11.0 Hz, 1H), 4.37(m, 1H), 4.42(s, 1H), 4.44-4.54(m, 2H), 4.68(d, *J* = 10.9 Hz, 1H), 4.71-4.84(m, 2H), 4.93(ABq, *J* = 11.2 Hz, 2H), 5.05(d, *J* = 11.0 Hz, 1H), 5.20(m, 1H), 5.25(dd, *J* = 3.6, 10.2 Hz, 1H), 5.47(t, *J* = 10.0 Hz, 1H), 6.17(t, *J* = 10.0 Hz, 1H), 7.10-7.53 (m, 29H), 7.82-7.99(m, 6H); ^{13}C NMR (125.76 MHz, $CDCl_3$): δ = 55.5, 68.6, 68.7, 68.9, 69.1, 70.0, 70.6, 72.2, 73.5, 74.8, 75.0, 75.7, 77.7, 82.4, 84.6, 96.8, 104.0, 127.5-130.0, 133.0, 133.3, 133.4, 138.2, 138.2, 138.5, 138.7, 165.5, 165.8, 165.8; HRMS (MALDI-TOF): *m/z*: calculated for $[C_{62}H_{60}O_{14}+Na]^+$: 1051.3881; found: 1051.3920.



Compound 10: $[\alpha]^D_{25}$ = +66.9 (*c* = 1.0 in $CHCl_3$); ^{1}H NMR (200.13 MHz, $CDCl_3$): δ = 3.42(m, 1H), 3.43(s, 3H), 3.54(dd, *J* = 3.4, 9.5 Hz, 2H), 3.63(m, 2H), 3.84(m, 2H), 3.96(t, *J* = 9.4 Hz, 1H), 4.34(m, 1H), 4.46(ABq, *J* = 12.2 Hz, 2H), 4.68(ABq, *J* = 11.2 Hz, 2H), 4.69(ABq, *J* = 12.3 Hz, 2H), 4.77(d, *J* = 10.8Hz, 2H), 4.83(d, *J* = 10.1 Hz, 1H), 5.20(m, 2H), 5.53(t, *J* = 10.0 Hz, 1H), 6.15(m, 1H), 7.10-7.55(m, 29H), 7.83-8.05(m, 6H); ^{13}C NMR (125.76 MHz, $CDCl_3$): δ = 55.5, 66.6, 68.2, 68.5, 69.6, 70.2, 70.6, 72.2, 73.1, 73.3, 74.7, 75.5, 77.5, 79.9, 81.7, 96.7, 97.2, 127.4-130.0, 133.0, 133.3, 133.3, 137.9, 138.3, 138.5, 138.8, 165.2, 165.8, 165.8; HRMS (MALDI-TOF): *m/z*: calculated for $[C_{62}H_{60}O_{14}+Na]^+$: 1051.3881; found: 1051.3801.

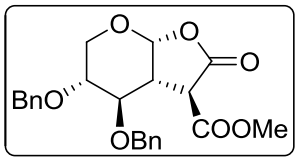


Compound 12a: $[\alpha]_D$ ($CHCl_3$, *c* 1.3) = +26.4; ^{1}H NMR (200.13 MHz, $CDCl_3$): δ 3.07(ddd, 1H, J = 3.9, 5.8, 9.9Hz), 3.51(dd, 1H, J = 5.1, 7.0Hz), 3.55(d, 1H, J = 4.0Hz), 3.63-3.85(m, 4H), 3.76(s, 3H), 4.50-4.80(m, 2H), 4.56(ABq, 2H, J = 12.0 Hz), 4.61(ABq, 2H, J = 11.3Hz), 6.05(d, 1H, J = 5.7Hz), 7.15-7.40(m, 15H); ^{13}C NMR (55.32 MHz, $CDCl_3$): δ 43.4, 51.5, 53.3, 68.2, 72.7, 73.5, 73.6, 73.6, 75.7, 76.9, 100.9, 127.8-

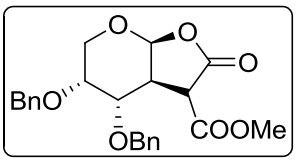


128.6, 137.3, 137.4, 137.6, 166.8, 168.5; Mol. Wt. calculated for $C_{31}H_{32}O_8Na$: 555.5707, Found: 555.28(M^++23 for Na).

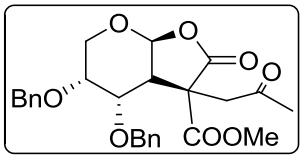
Compound 12c: $[\alpha]_D$ ($CHCl_3$, *c* 1.7) = -22.0; ^1H NMR (200.13 MHz, $CDCl_3$): δ 2.91(ddd, 1H, J = 3.5, 4.2, 9.8 Hz), 3.50(m, 1H), 3.72(t, 1H, J = 3.7Hz), 3.79(s, 3H), 3.91(d, 2H, J = 2.6Hz), 4.14(d, 1H, J = 10.0Hz), 4.56(ABq, 2H, J = 12.0Hz), 4.61(s, 2H), 5.71(d, 1H, J = 4.2Hz), 7.24-7.40(m, 10H) ; ^{13}C NMR (55.32 MHz, $CDCl_3$): δ 42.6, 47.2, 53.2, 62.2, 71.5, 72.4, 72.9, 73.0, 97.8, 127.6-128.6, 137.2, 137.2, 167.4, 170.0; Mol. Wt. calculated for $C_{23}H_{24}O_7Na$: 435.4222, Found: 435.01(M^++23 for Na).



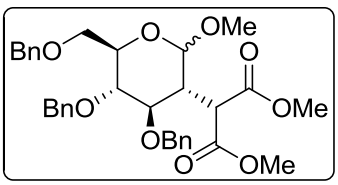
Compound 12d: $[\alpha]_D$($CHCl_3$, *c* 1.6) = -34.2; ^1H NMR (200.13 MHz, $CDCl_3$): δ 3.10(ddd, 1H, J = 2.5, 4.6, 9.5 Hz), 3.37(dd, 1H, J = 2.5, 9.7Hz), 3.55(d, 1H, J = 2.4Hz), 3.70-3.85(m, 2H), 3.77(s, 3H), 4.07(dd, 1H, J = 3.6, 12.5Hz), 4.51(ABq, 2H, J = 11.7Hz), 4.67(ABq, 2H, J = 12.2Hz), 6.09(d, 1H, J = 4.5Hz), 7.26-7.41(m, 10H) ; ^{13}C NMR (55.32 MHz, $CDCl_3$): δ 41.6, 48.9, 53.2, 62.2, 68.6, 70.9, 71.2, 74.5, 101.94, 127.3-128.6, 136.9, 137.5, 168.5, 168.8; Mol. Wt. calculated for $C_{23}H_{24}O_7Na$: 435.4222, Found: 435.18(M^++23 for Na).



Compound 12e: $[\alpha]_D$ ($CHCl_3$, *c* 1.3) = -23.6; ^1H NMR (200.13 MHz, $CDCl_3$): δ 1.62(s, 3H), 2.83(d, 1H, J = 18.7Hz), 3.34(dd, 1H J = 2.7, 10.4Hz), 3.41-3.70(m, 2H), 3.57(dd, 1H, J = 4.3, 10.5Hz), 3.72(s, 3H), 3.90(m, 1H), 4.12(dd, 1H, J = 2.9, 12.7Hz), 4.18(d, 1H, J = 11.4Hz), 4.60(d, 1H, J = 12.0Hz), 4.64(ABq, 2H, J = 12.4Hz), 6.29(d, 1H, J = 4.3Hz), 7.20-7.41(m, 10H) ; ^{13}C NMR (55.32 MHz, $CDCl_3$): δ 28.6, 43.0, 44.8, 53.5, 58.6, 61.2, 67.5, 68.7, 70.8, 73.7, 102.1, 127.0-128.5, 136.9, 137.4, 167.8, 170.6, 203.7; Mol. Wt. calculated for $C_{26}H_{28}O_8Na$: 491.4855, Found: 491.18(M^++23 for Na).

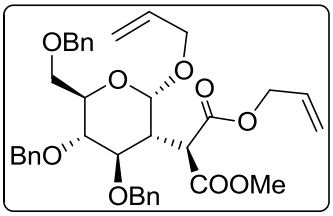


Compound 14 (0.8:1 α:β mixture) **:** ^1H NMR (200.13 MHz, $CDCl_3$): δ 2.50(ddd, 1H, J = 3.8, 8.8, 11.1Hz), 2.67(ddd, 1H, J = 3.0, 5.6, 8.7 Hz), 3.27, 3.46, 3.52, 3.58, 3.63, 3.69(6s, 18H), 3.34-3.76(m, 10H), 3.81(d, 1H, J = 2.8Hz), 3.92(d, 1H, J = 3.7Hz), 4.40-4.87(m, 12H), 4.94(d, 1H, J = 4.5Hz),

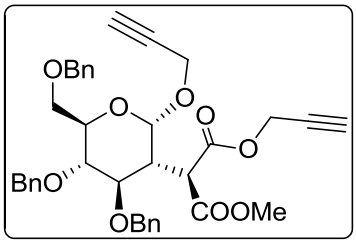


5.02(d, 1H, J = 3.2Hz), 7.05-7.40(m, 30H); ^{13}C NMR (55.32 MHz, $CDCl_3$): δ 46.1, 48.0, 48.2, 49.8, 52.2, 52.2, 52.3, 52.3, 55.2, 57.3, 68.5, 68.8, 70.9, 72.1, 73.5, 73.5, 74.7, 74.7, 74.8, 74.9, 78.6, 80.0, 80.1, 80.3, 99.2, 101.8, 127.4-128.4, 137.9, 137.9, 138.0, 138.1, 138.2, 138.5, 168.7, 168.9, 169.0, 169.6; Mol. Wt. calculated for $C_{33}H_{38}O_9Na$: 601.6392, Found: 601.23(M^++23 for Na).

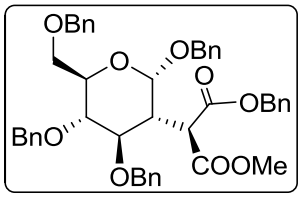
Compound 15: $[\alpha]_D$ ($CHCl_3$, *c* 1.8) = +69.2; ^{1}H NMR (200.13 MHz, $CDCl_3$): δ 2.72(ddd, 1H, J = 3.1, 6.2, 9.3 Hz), 3.47(s, 3H), 3.59-3.89(m, 7H), 4.04-4.18(m, 2H), 4.50(d, 2H, J = 3.6Hz), 4.55(m, 1H), 4.60(ABq, 2H, J = 13.1Hz), 4.87(ABq, 2H, J = 11.3Hz), 5.11-5.32(m, 4H), 5.29(dd, 1H,J = 1.4, 5.7Hz), 5.70-5.95(m, 2H), 7.05-7.38(m, 15H); ^{13}C NMR (55.32 MHz, $CDCl_3$): δ 46.0, 50.3, 52.2, 65.9, 68.3, 68.5, 71.1, 73.5, 74.6, 74.8, 78.8, 80.2, 97.4, 117.3, 118.5, 127.2-128.4, 131.6, 133.7, 137.9, 137.9, 138.6, 167.8, 168.7; Mol. Wt. calculated for $C_{37}H_{42}O_9Na$: 653.7138, Found: 653.13(M^++23 for Na).



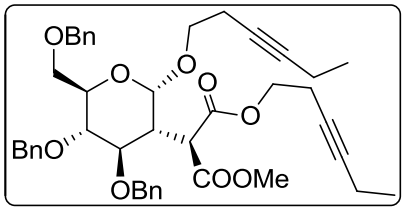
Compound 16: $[\alpha]_D$ ($CHCl_3$, *c* 1.8) = +64.0; ^{1}H NMR (200.13 MHz, $CDCl_3$): δ 2.40(t, 1H, J = 2.3Hz), 2.48(t, 1H, J = 2.4Hz), 2.72(ddd, 1H, J = 3.2, 5.9, 9.1Hz), 3.50(s, 3H), 3.62-3.82(m, 6H), 4.14(dd, 2H, J = 2.4, 5.3Hz), 4.60(ABq, 2H, J = 12.1Hz), 4.63(d, 2H, J = 2.2Hz), 4.65(ABq, 2H, J = 10.5Hz), 4.87(ABq, 2H, J = 11.2Hz), 5.28(d, 1H, 3.1Hz), 7.06-7.38(m, 15H) ; ^{13}C NMR (55.32 MHz, $CDCl_3$): δ 45.8, 49.7, 52.4, 52.8, 54.7, 68.3, 71.5, 73.5, 74.5, 74.7, 74.8, 75.3, 77.1, 78.4, 78.8, 80.0, 97.1, 127.3-128.4, 137.8, 137.9, 138.5, 167.3, 168.3; Mol. Wt. calculated for $C_{37}H_{38}O_9Na$: 649.6820, Found: 649.07(M^++23 for Na).



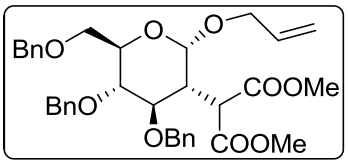
Compound 17: $[\alpha]_D$ ($CHCl_3$, *c* 1.6) = +55.1; ^{1}H NMR (200.13 MHz, $CDCl_3$): δ 2.75(ddd, 1H, J = 3.3, 6.3, 9.6 Hz), 3.38(s, 3H), 3.62-3.92(m, 4H), 4.06(dd, 1H, J = 8.5, 11.2Hz), 4.23(d, 1H, J = 11.3Hz), 4.48-4.96(m, 10H), 5.28(d, 1H J = 3.2Hz), 7.02-7.40(m, 25H) ; ^{13}C NMR (55.32 MHz, $CDCl_3$): δ 46.1, 50.4, 52.2, 67.0, 68.4, 69.6, 71.2, 73.5, 74.5, 74.6, 78.8, 80.2, 97.7, 126.9-128.6, 135.2, 137.2, 137.8, 137.9, 138.6, 167.9, 168.7; Mol. Wt. calculated for $C_{45}H_{46}O_9Na$: 753.8311, Found: 753.21(M^++23 for Na).



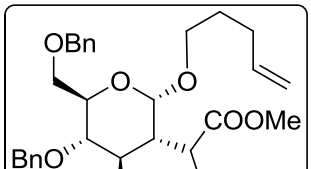
Compound 18: $[\alpha]_D(CHCl_3, c\ 1.3) = +53.5$; ^1H NMR (200.13 MHz, $CDCl_3$): δ 1.04(t, 3H, J = 7.4Hz), 1.10(t, 3H, J = 7.5Hz), 2.01-2.20(m, 4H), 2.32-2.50(m, 4H), 2.64(ddd, 1H, J = 3.2, 5.8, 9.0Hz), 3.50(s, 3H), 3.55-3.86(m, 8H), 4.10(dd, 2H, J = 4.5, 6.7Hz), 4.60(ABq, 2H, J = 12.1Hz), 4.64(ABq, 2H, J = 10.7Hz), 4.87(ABq, 2H, J = 11.2Hz), 5.22(d, 1H, J = 3.2Hz), 7.05-7.40(m, 15H) ; ^{13}C NMR (55.32 MHz, $CDCl_3$): δ 12.3, 12.3, 12.3, 14.0, 14.1, 14.1, 19.1, 19.8, 46.0, 49.8, 52.3, 63.8, 66.6, 68.5, 68.7, 71.1, 73.5, 74.7, 75.7, 78.6, 80.2, 83.0, 98.0, 127.2-128.4, 138.0, 138.0, 138.7, 168.1, 168.8; Mol. Wt. calculated for $C_{43}H_{50}O_9Na$: 733.8415, Found: 733.17(M^++23 for Na).



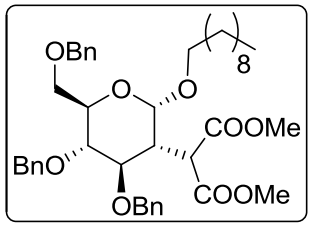
Compound 19: $[\alpha]_D$ ($CHCl_3$, *c* 1.6) = +67.5; ^1H NMR (200.13 MHz, $CDCl_3$): δ 2.70(ddd, 1H, J = 3.2, 5.8, 9.0Hz), 3.43-3.90(m, 6H), 3.50(s, 3H), 3.60(s, 3H), 4.06-4.16(m, 2H), 4.60(ABq, 2H, J = 12.1Hz), 4.62(ABq, 2H, J = 11.0Hz), 4.87(ABq, 2H, J = 11.0Hz), 5.10-5.30(m, 3H), 5.83(m, 1H), 7.05-7.38(m, 15H); ^{13}C NMR (55.32 MHz, $CDCl_3$): δ 46.1, 50.0, 52.3, 52.3, 68.3, 68.5, 71.1, 73.5, 74.6, 74.8, 78.6, 80.2, 97.4, 117.3, 127.3-128.4, 133.7, 137.9, 137.9, 138.6, 168.6, 168.8; Mol. Wt. calculated for $C_{35}H_{40}O_9Na$: 627.6765, Found: 627.29 (M^++23 for Na).



Compound 20: $[\alpha]_D$ ($CHCl_3$, *c* 1.9) = +55.2; ^1H NMR (200.13 MHz, $CDCl_3$): δ 1.63(q, 2H, J = 6.9, 14.1 Hz), 2.07(q, 2H, J = 6.9, 14.6Hz), 2.70(ddd, 1H, J = 3.3, 6.5, 9.8Hz), 3.30(dd, 1H, J = 6.3, 16.0Hz), 3.42-3.83(m, 6H), 3.46(s, 3H), 3.61(s, 3H), 4.06(dd, 1H, J = 8.1, 11.2Hz), 4.49-4.76(m, 6H), 4.93-5.06(m, 2H), 5.11(d, 1H, J = 3.1Hz), 5.78(m, 1H), 7.04-7.40(m, 15H) ; ^{13}C NMR (55.32 MHz, $CDCl_3$): δ 28.5, 30.2, 46.0, 50.5, 52.2, 52.3, 67.2, 68.5, 71.0, 73.5, 74.5, 74.8, 78.8, 80.2, 98.1, 114.9, 127.2-128.3, 137.8, 137.9, 137.9, 138.6, 168.6, 168.6; Mol. Wt. calculated for $C_{37}H_{44}O_9Na$: 655.7296, Found: 655.40(M^++23 for Na).

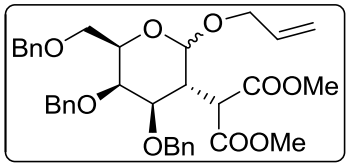


Compound 21: $[\alpha]_D$ ($CHCl_3$, *c* 1.5) = +47.0; ^1H NMR (200.13 MHz, $CDCl_3$): δ 0.88(m, 3H), 1.26(m, 16H), 2.70(ddd, 1H, J = 3.2, 6.4, 9.7Hz), 3.26(dd, 1H, J = 6.4, 15.9 Hz), 3.42-3.80(m, 6H), 3.46(s, 3H), 3.61(s, 3H), 4.05(dd, 1H, J = 8.0, 11.1Hz),

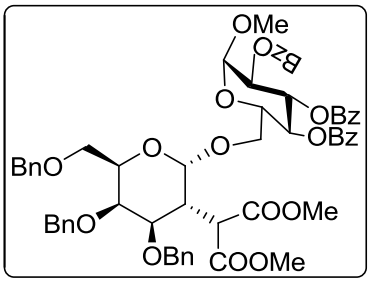


4.60(ABq, 2H, J = 12.0Hz), 4.62(ABq, 2H, J = 10.4Hz), 4.86(Abq, 2H, J = 11.1Hz), 5.10(d, 1H, J = 3.3Hz), 7.04-7.40(m, 15H); ^{13}C NMR (55.32 MHz, $CDCl_3$): δ 14.1, 22.7, 26.1, 29.3, 29.4, 29.4, 29.6, 29.6, 31.9, 46.1, 50.5, 52.2, 52.3, 68.0, 68.6, 71.0, 73.5, 74.5, 74.8, 78.9, 80.3, 98.1, 127.3-128.4, 137.7, 138.0, 138.7, 168.7, 168.7; Mol. Wt. calculated for $C_{42}H_{56}O_9Na$: 727.8784, Found: 727.44(M^++23 for Na).

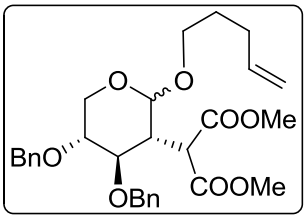
Compound 23 (1:0.2 α:β mixture) **:** ^{1}H NMR (200.13 MHz, $CDCl_3$): δ 3.02(ddd, 1H, J = 3.9, 8.8, 11.4Hz), 3.25(ddd, 1H, J = 3.5, 6.1, 9.6Hz), 3.51(s, 3H), 3.55-3.70(m, 4H), 3.56(s, 3H), 3.58(s, 3H), 3.59(s, 3H), 3.81-4.18(m, 10H), 4.45-4.71(m, 12H), 4.83(d, 1H, J = 5.1Hz), 4.89(d, 1H, J = 11.5Hz), 5.10-5.28(m, 6H), 5.74-5.93(m, 2H), 7.22-7.35(m, 30H) ; ^{13}C NMR (55.32 MHz, $CDCl_3$): δ 41.0, 43.2, 47.9, 50.3, 51.9, 52.0, 52.0, 52.2, 68.4, 68.9, 69.1, 69.7, 69.7, 70.4, 70.9, 71.3, 71.5, 71.9, 73.4, 73.4, 74.3, 74.4, 77.3, 78.7, 97.8, 100.1, 117.2, 117.6, 127.4-128.4, 133.7, 134.0, 137.4, 137.8, 137.8, 138.0, 138.6, 138.7, 168.8, 168.9, 169.3, 169.7; Mol. Wt. calculated for $C_{35}H_{40}O_9Na$: 627.6765, Found: 627.29(M^++23 for Na).



Compound 24: $[\alpha]_D$($CHCl_3$, *c* 1.9) = +56.9; ^{1}H NMR (200.13 MHz, $CDCl_3$): δ 3.29(ddd, 1H, J = 3.7, 7.9, 11.3Hz), 3.38-3.57(m, 2H), 3.44(s, 3H), 3.49(s, 3H), 3.67(s, 3H), 3.69-4.03(m, 6H), 4.14(m, 1H), 4.32(dd, 2H, J = 11.9, 19.5Hz), 4.49(dd, 2H, J = 4.2, 11.2Hz), 4.79(ABq, 2H, J = 11.3Hz), 5.16(dd, 2H, J = 3.6, 5.6Hz), 5.26(dd, 1H, J = 3.6, 10.1Hz), 5.63(t, 1H, J = 9.9Hz), 6.14(t, 1H, J = 9.9Hz), 7.18-7.60(m, 24H), 7.89-8.00(m, 6H) ; ^{13}C NMR (55.32 MHz, $CDCl_3$): δ 49.0, 51.5, 52.2, 52.4, 55.5, 66.2, 68.3, 68.9, 69.1, 69.6, 70.6, 71.3, 71.7, 72.2, 73.2, 74.4, 78.0, 96.9, 99.1, 127.4-129.9, 133.1, 133.3, 133.3, 137.8, 138.1, 138.7, 165.1, 165.8, 165.8, 168.6, 168.7; Mol. Wt. calculated for $C_{60}H_{60}O_{17}Na$: 1076.0980, Found: 1075.921(M^++23 for Na).

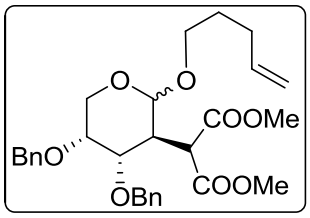


Compound 25: ^{1}H NMR (400.13 MHz, $CDCl_3$): δ 1.62(q, 4H, J = 6.9, 14.4Hz), 2.09(q, 4H, J = 6.5, 14.3Hz), 2.43(ddd, 1H, J = 4.0, 8.6, 11.3Hz), 2.50(ddd, 1H, J = 3.3, 6.7, 9.8 Hz), 3.26(dd, 1H, J = 6.4, 15.8Hz), 3.46, 3.56, 3.62, 3.68(4s, 12H), 3.52-3.77(m, 12H), 3.97(dd, 1H, J = 8.6, 11.2Hz), 4.53-4.74(m, 8H), 4.93-5.05(m,

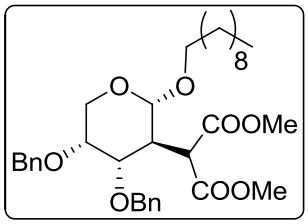


6H), 5.79(m, 2H), 7.24-7.37(m, 20H) ; ^{13}C NMR (100.61 MHz, $CDCl_3$): δ 28.5, 28.5, 30.0, 30.2, 45.7, 47.1, 48.1, 50.5, 52.1, 52.1, 52.2, 52.3, 60.3, 63.6, 67.2, 69.2, 72.8, 72.9, 74.6, 74.7, 77.8, 78.5, 80.2, 80.2, 98.0, 101.2, 114.8, 114.9, 127.3-128.4, 137.9, 137.9, 138.0, 138.0, 138.2, 138.6, 168.7, 168.7, 169.0, 169.5; Mol. Wt. calculated for $C_{29}H_{36}O_8Na$: 535.5811, Found: 535.27(M^++23 for Na).

Compound 26(1:0.2 α:β mixture)**:** ^{1}H NMR (200.13 MHz, $CDCl_3$): δ 1.62(q, 4H, J = 7.6, 14.6Hz), 2.07(q, 4H, J = 7.1, 14.3Hz), 3.15-3.37(m, 2H), 3.40-3.83(m, 12H), 3.52, 3.57, 3.62, 3.66(4s, 12H), 4.01(dd, 1H, J = 2.6, 11.1Hz), 4.12(dd, 1H, J= 2.0, 12.8Hz), 4.23-4.75(m, 8H), 4.93-5.07(m, 5H), 5.11(d, 1H, J = 3.4Hz), 5.69-5.89(m, 2H), 7.25-7.40(m, 20H); ^{13}C NMR (55.32 MHz, $CDCl_3$): δ 28.5, 28.8, 30.0, 30.2, 41.1, 43.3, 47.9, 50.4, 52.0, 52.1, 52.2, 52.7, 60.4, 61.1, 67.3, 67.6, 69.7, 70.2, 70.8, 70.9, 71.0, 71.4, 75.4, 76.7, 98.6, 101.5, 114.7, 114.8, 127.5-128.4, 133.7, 138.0, 138.0, 138.0, 138.1, 138.4, 168.9, 169.0, 169.3, 170.0 ; Mol. Wt. calculated for $C_{29}H_{36}O_8Na$: 535.5811, Found: 535.27(M^++23 for Na).



Compound 27: $[\alpha]_D$($CHCl_3$, *c* 1.5) = -82.6; ^{1}H NMR (400.13 MHz, $CDCl_3$): δ 0.88(m, 3H), 1.26(m, 16H), 3.20(ddd, 1H, J = 3.3, 6.3, 9.8Hz), 3.27(dd, 1H, J = 6.5, 16.0Hz), 3.52(s, 3H), 3.55-3.81(m, 5H), 3.62(s, 3H), 3.99(dd, 1H, J = 2.8, 11.3Hz), 4.50(ABq, 2H, J = 11.0Hz), 4.70(bs, 2H), 5.10(d, 1H, J = 3.3Hz), 7.26-7.38(m, 10H) ; ^{13}C NMR (100.61 MHz, $CDCl_3$): δ 14.1, 22.7, 26.1, 29.3, 29.4, 29.4, 29.6, 29.6, 31.9, 41.2, 50.4, 52.1, 52.2, 60.4, 68.1, 70.8, 70.9, 71.4, 75.5, 98.5, 127.5-128.3, 138.0, 138.5, 168.9, 169.0; Mol. Wt. calculated for $C_{34}H_{48}O_8Na$: 607.7299, Found: 607.38(M^++23 for Na).

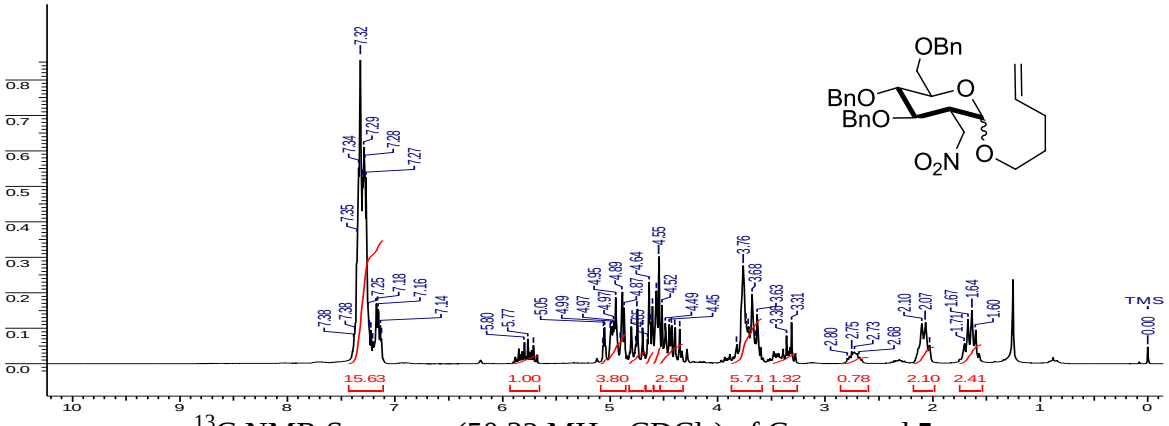


******

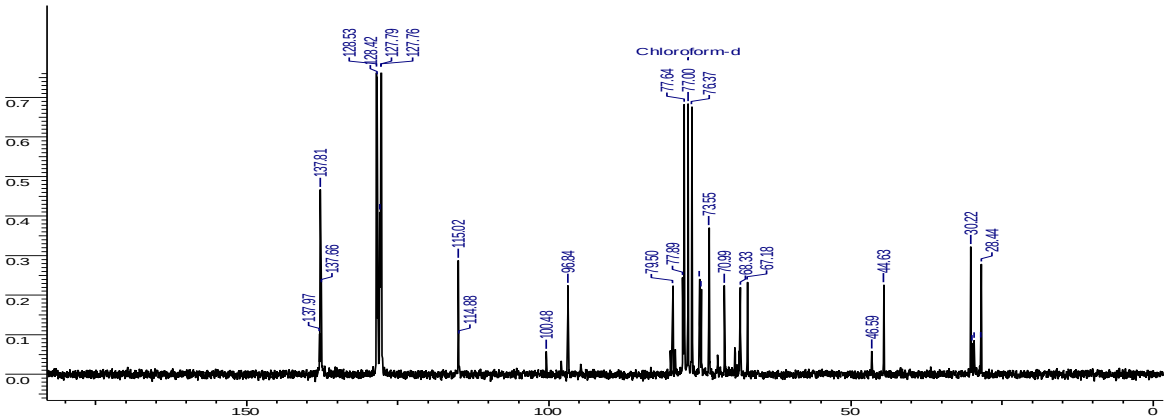
Chapter 3: Spectral Charts

(For full characterization data and spectral charts of all nitro addition products see: ***Eur. J. Org. Chem.*** **2011**, 2426)

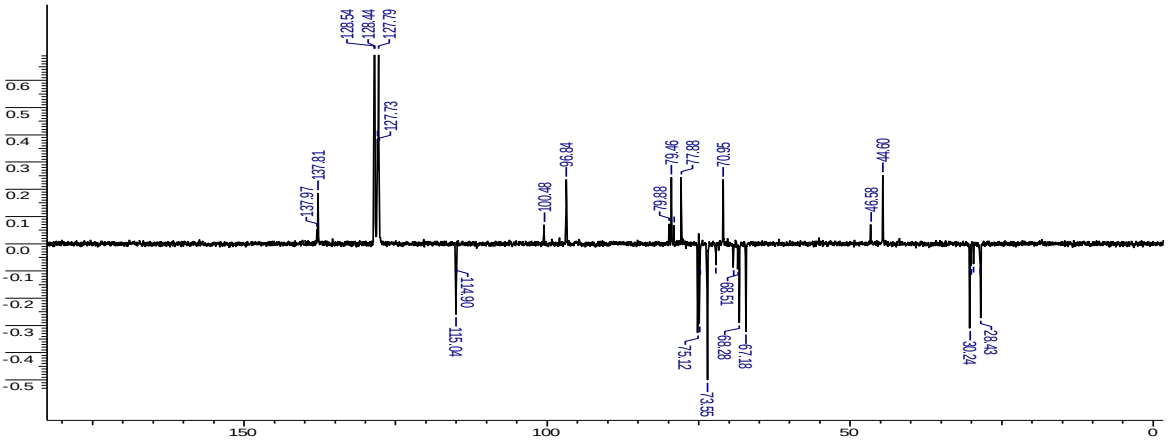
^{1}H NMR Spectrum (200.13 MHz, $CDCl_3$) of Compound **5a**



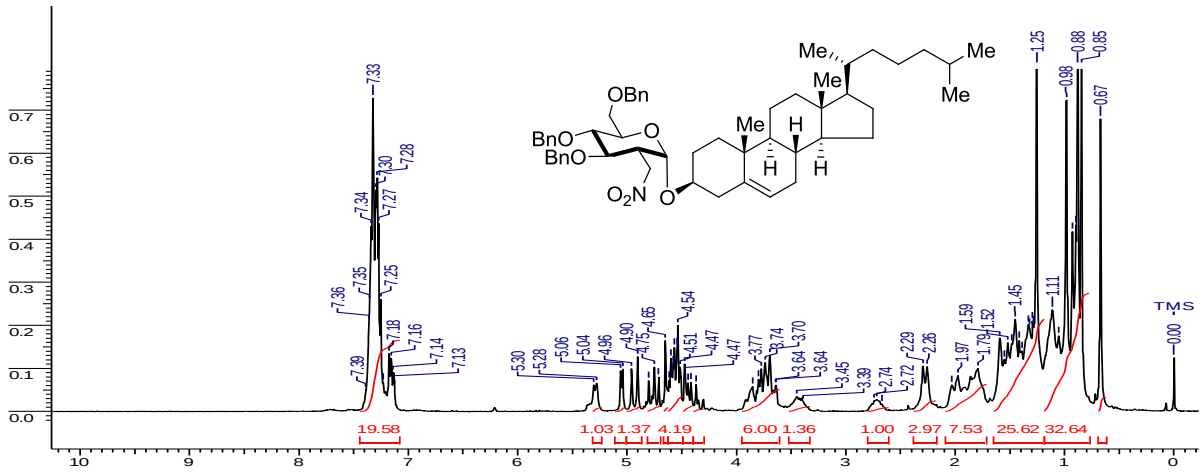
^{13}C NMR Spectrum (50.32 MHz, $CDCl_3$) of Compound **5a**



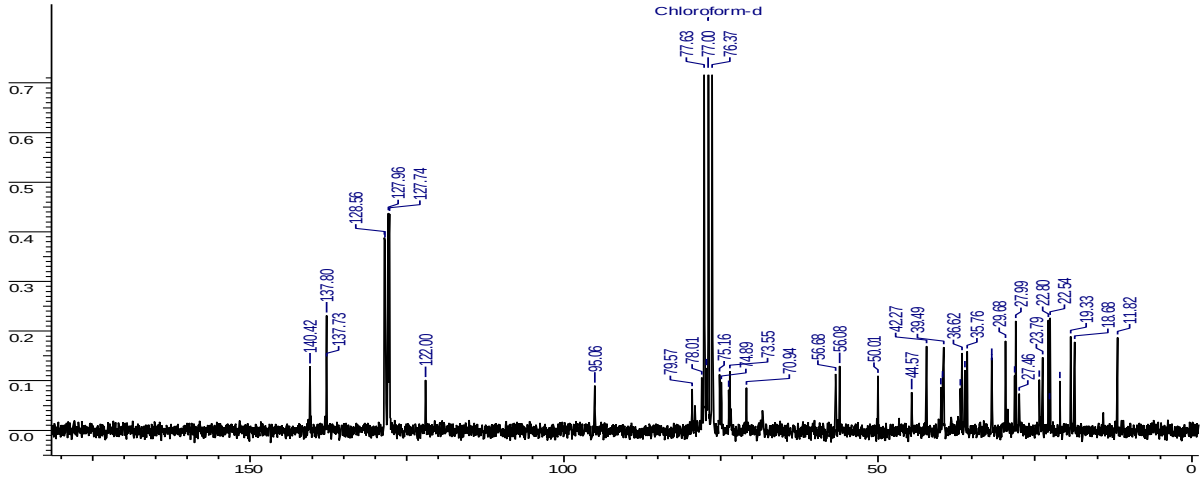
DEPT NMR Spectrum (50.32 MHz, $CDCl_3$) of Compound **5a**



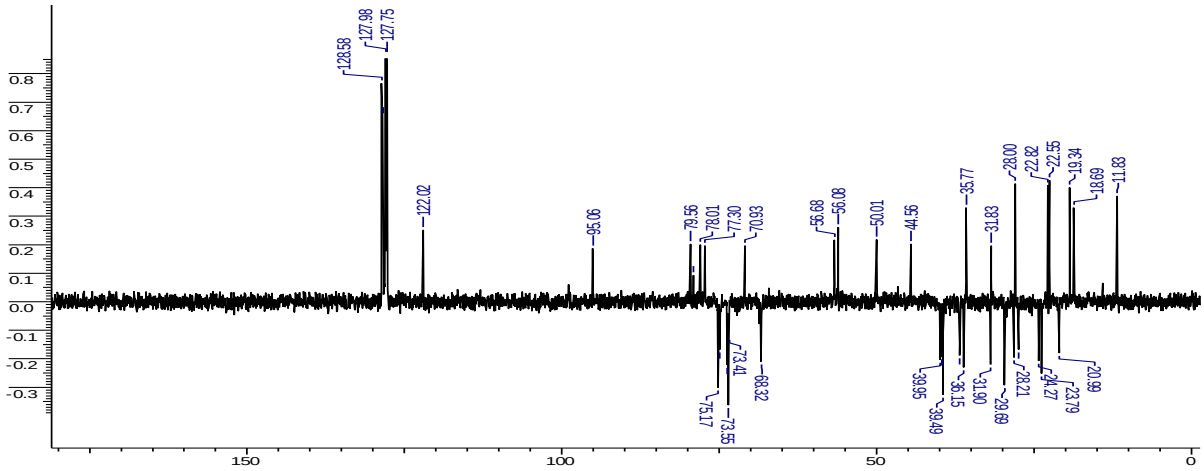
^{1}H NMR Spectrum (200.13 MHz, $CDCl_3$) of Compound **5d**



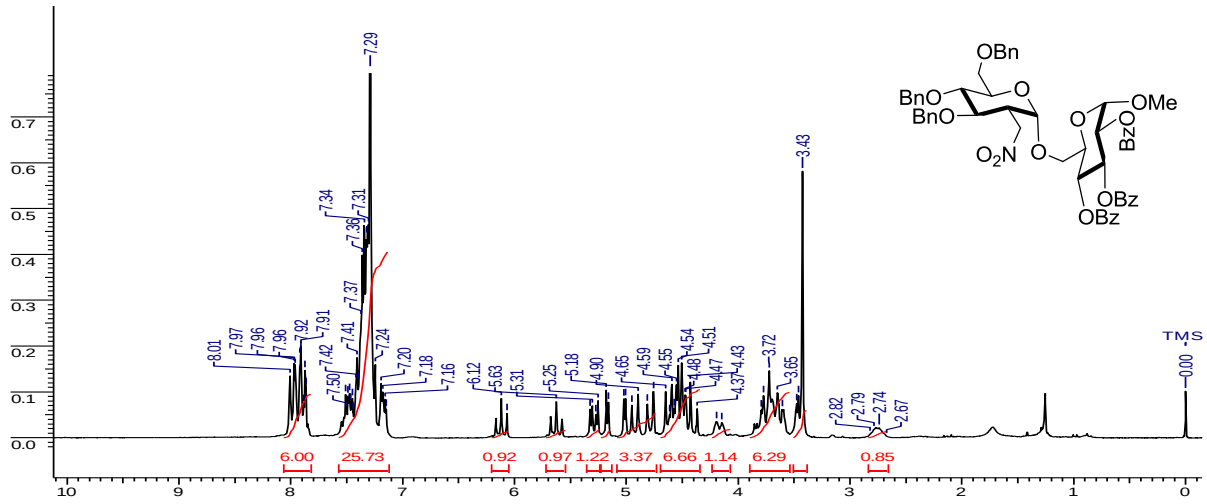
^{13}C NMR Spectrum (50.32MHz, $CDCl_3$) of Compound **5d**



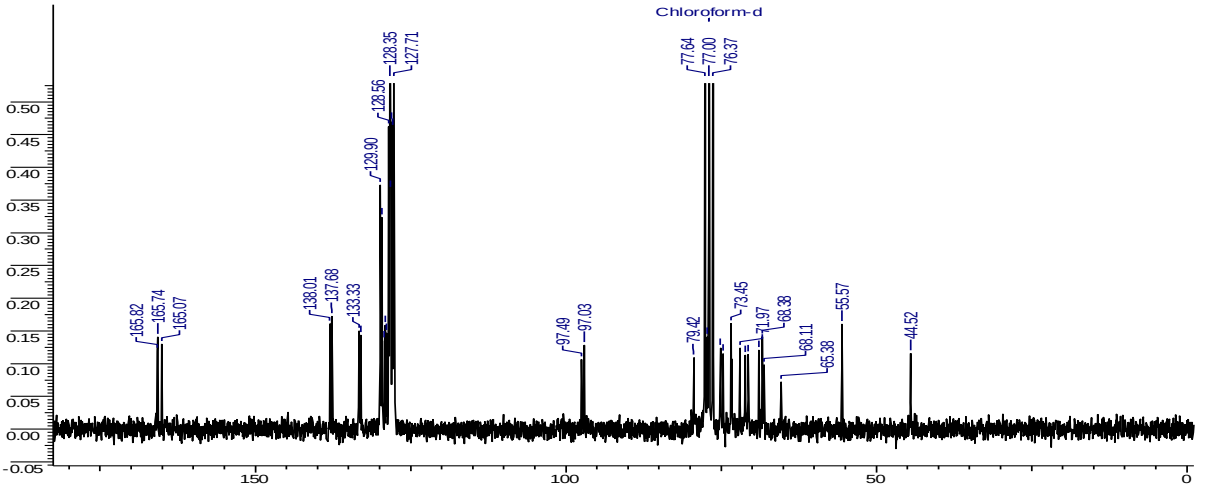
DEPT NMR Spectrum (50.32MHz, $CDCl_3$) of Compound **5d**



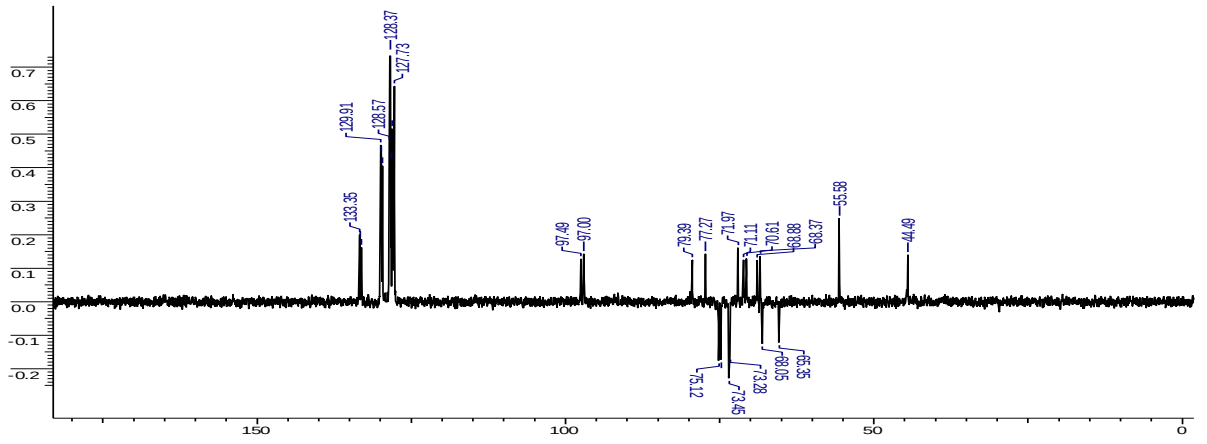
^{1}H NMR Spectrum (200.13 MHz, $CDCl_3$) of Compound **5e**



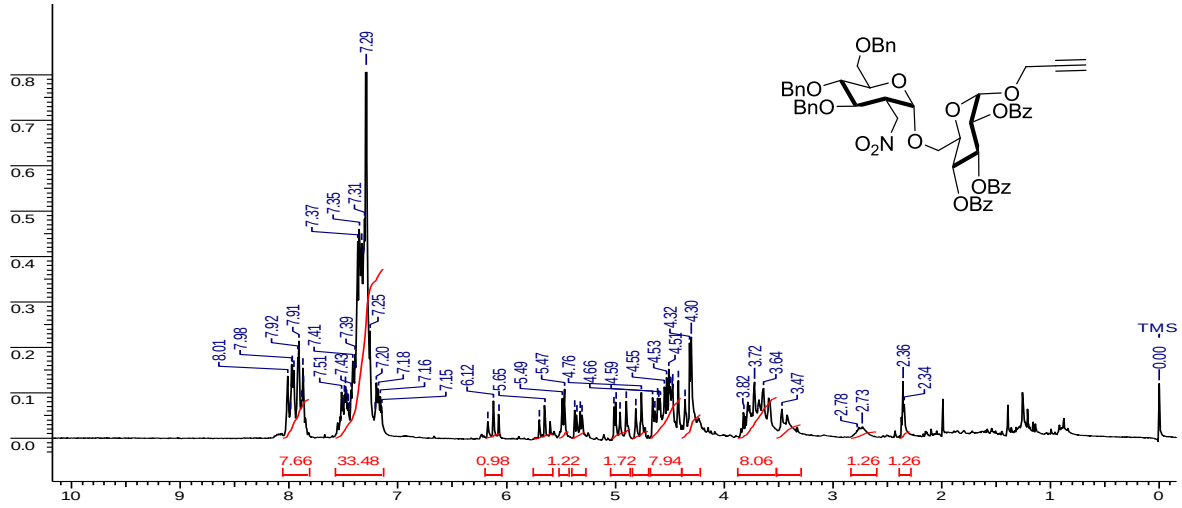
^{13}C NMR Spectrum (50.32MHz, $CDCl_3$) of Compound **5e**



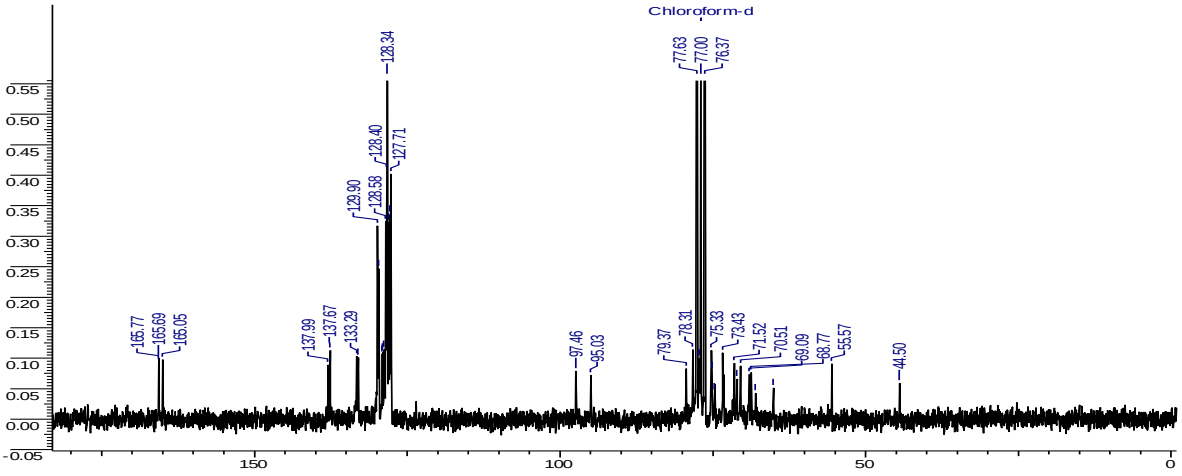
DEPT NMR Spectrum (50.32MHz, $CDCl_3$) of Compound **5e**



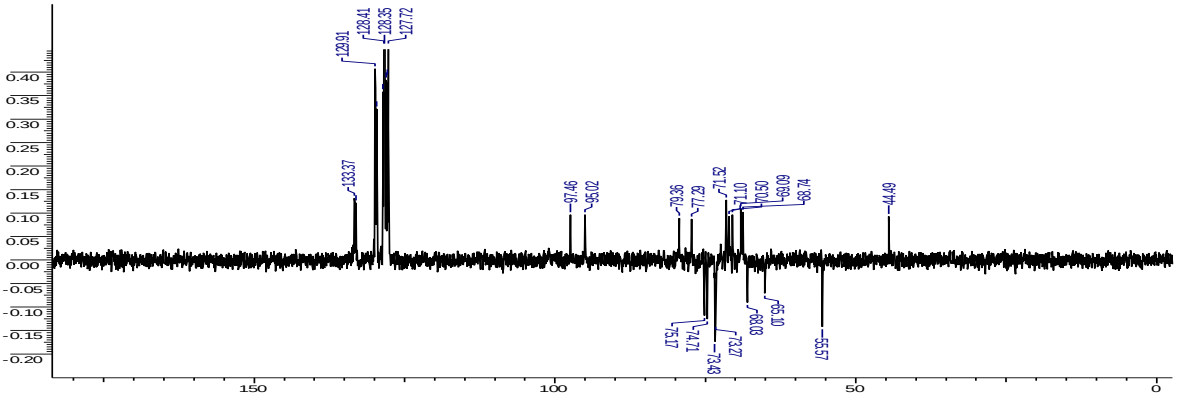
^{1}H NMR Spectrum (200.13 MHz, $CDCl_3$) of Compound **5f**



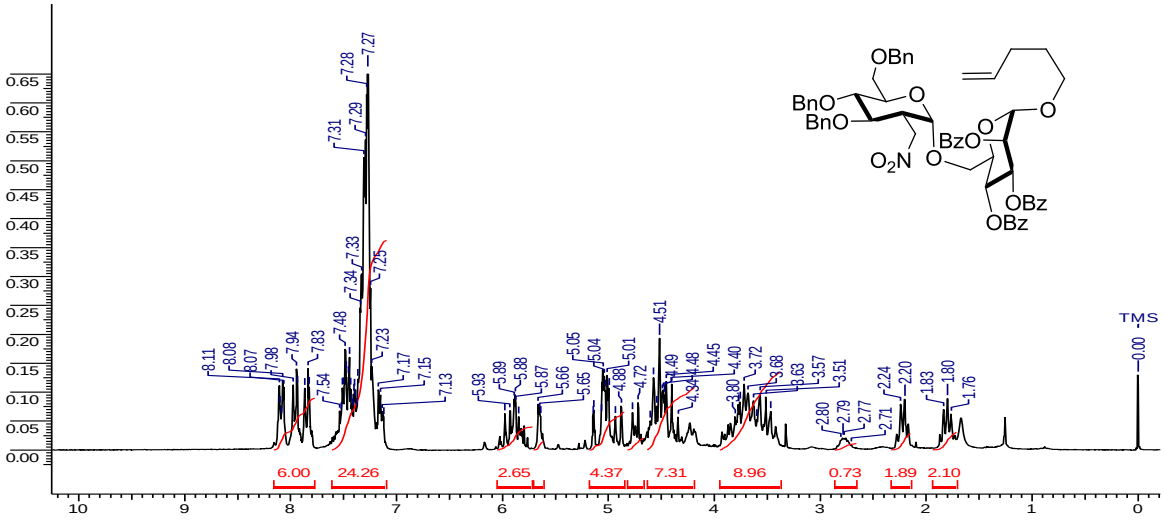
^{13}C NMR Spectrum (50.32MHz, $CDCl_3$) of Compound **5f**



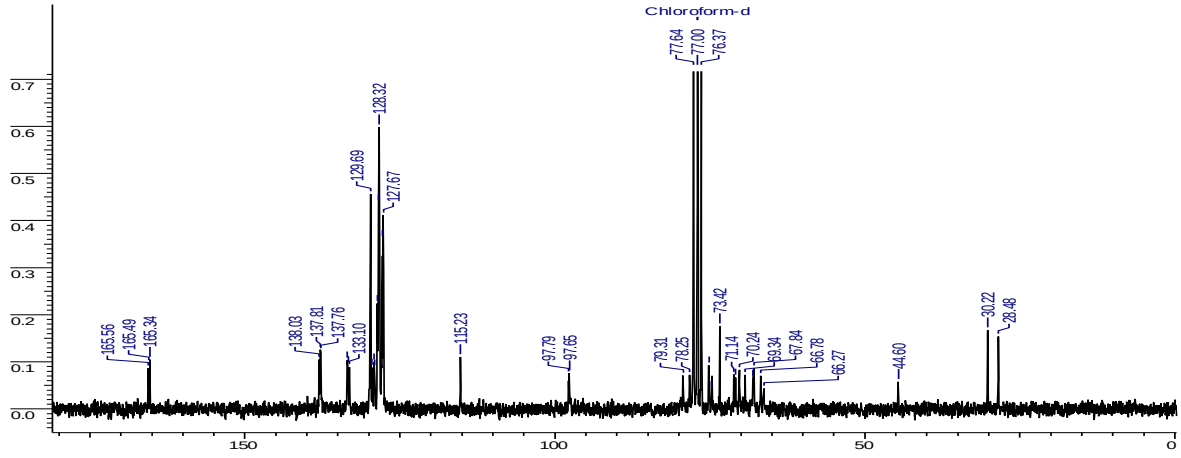
DEPT NMR Spectrum (50.32MHz, $CDCl_3$) of Compound **5f**



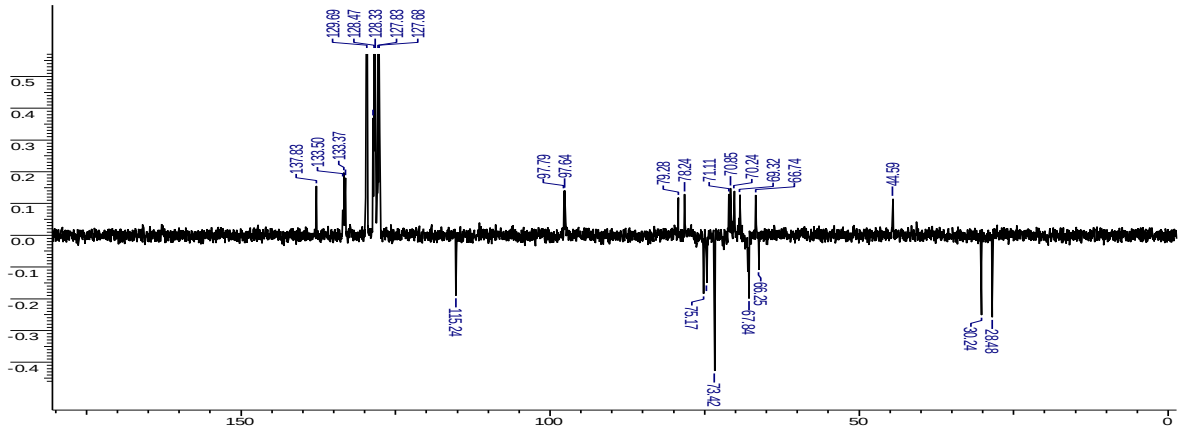
^{1}H NMR Spectrum (200.13 MHz, $CDCl_3$) of Compound **5g**



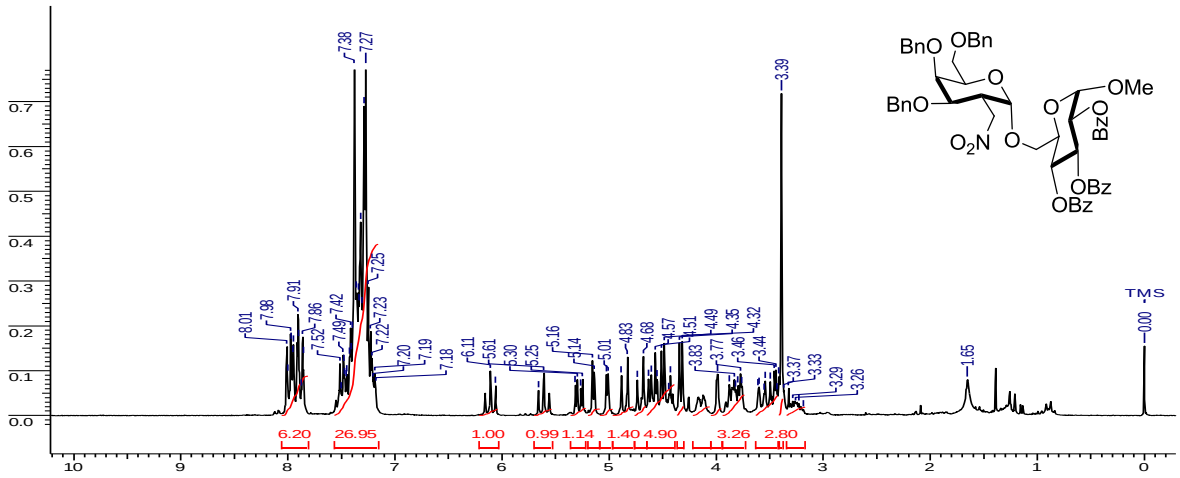
^{13}C NMR Spectrum (50.32MHz, $CDCl_3$) of Compound **5g**



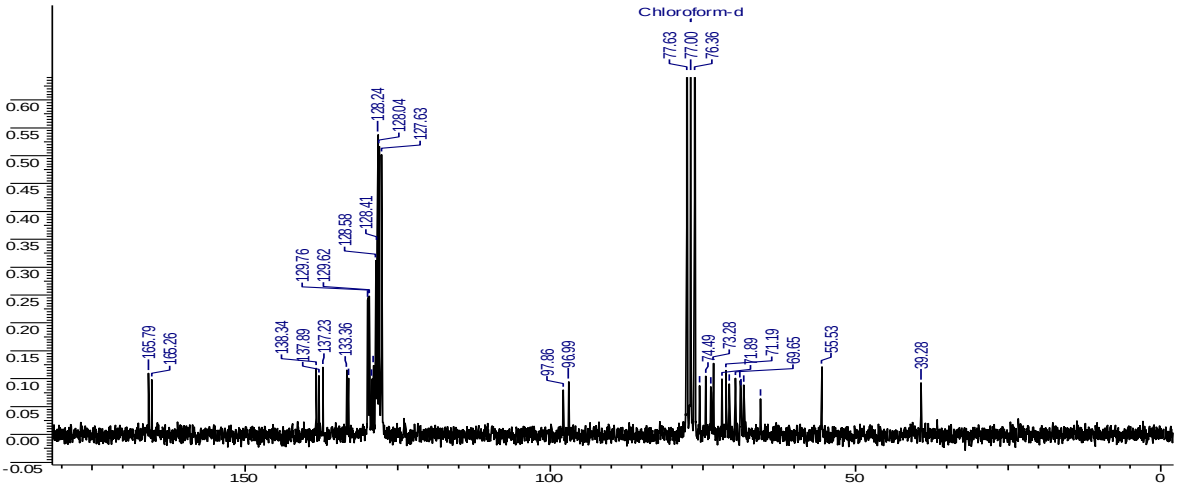
DEPT NMR Spectrum (50.32MHz, $CDCl_3$) of Compound **5g**



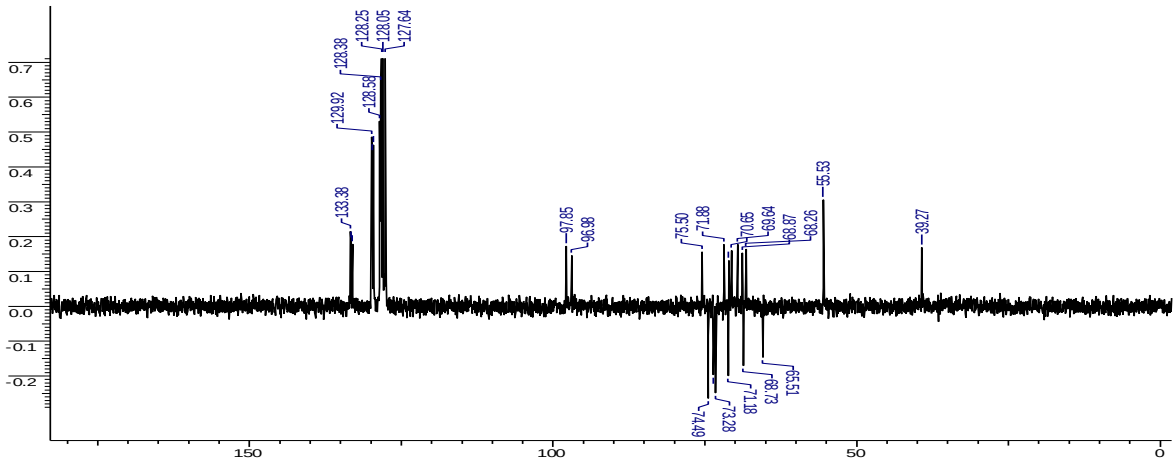
^{1}H NMR Spectrum (200.13 MHz, $CDCl_3$) of Compound **5i**



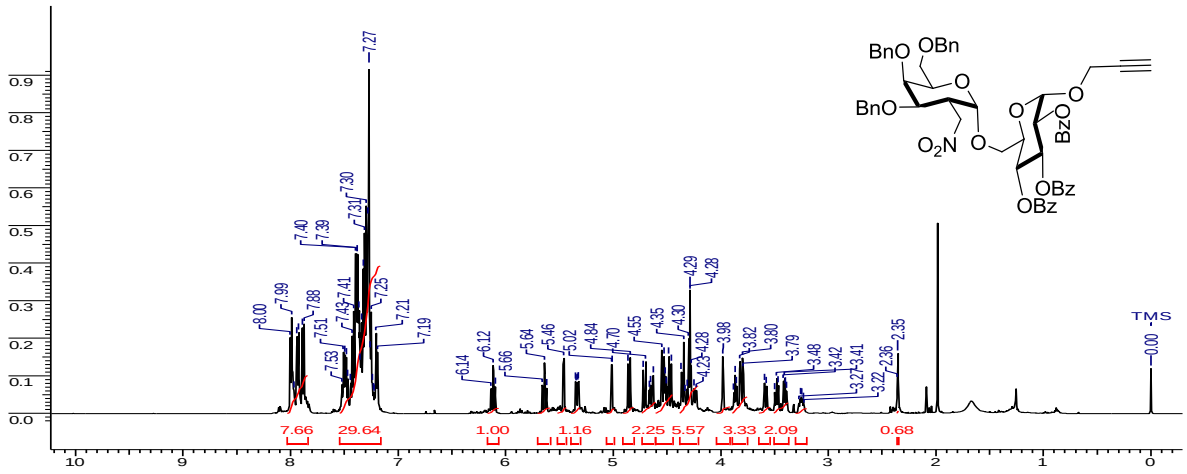
^{13}C NMR Spectrum (50.32 MHz, $CDCl_3$) of Compound **5i**



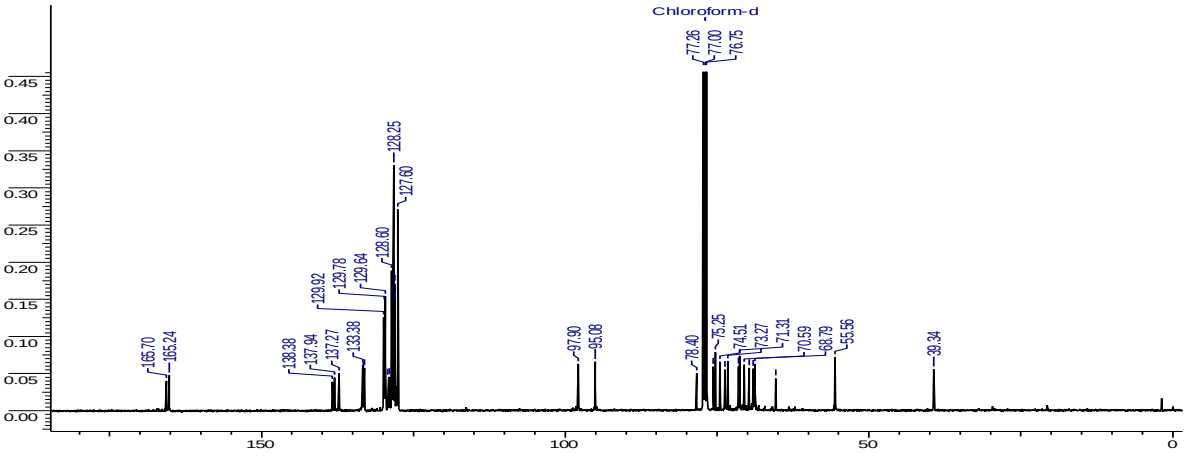
DEPT NMR Spectrum (50.32 MHz, $CDCl_3$) of Compound **5i**



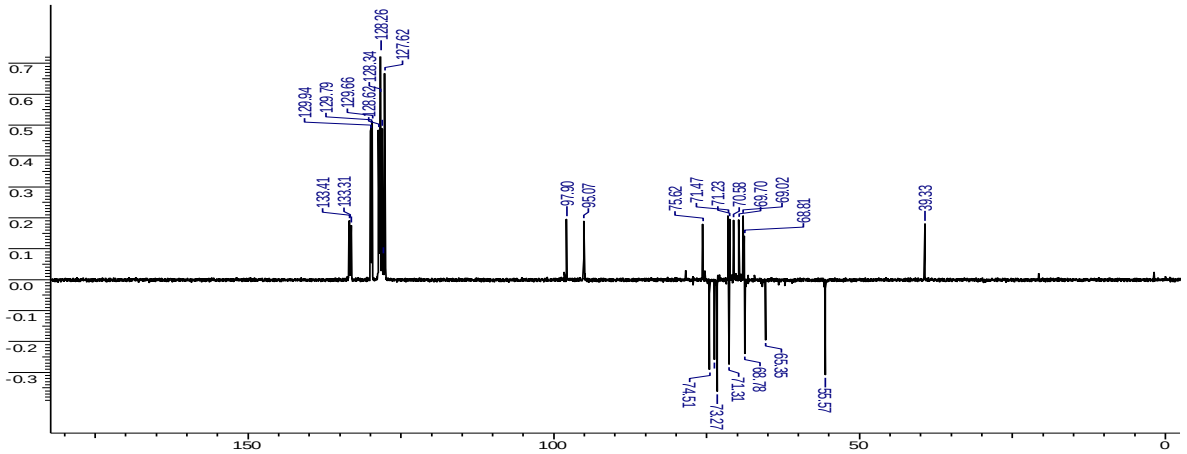
^{1}H NMR Spectrum (500.13 MHz, $CDCl_3$) of Compound **5j**



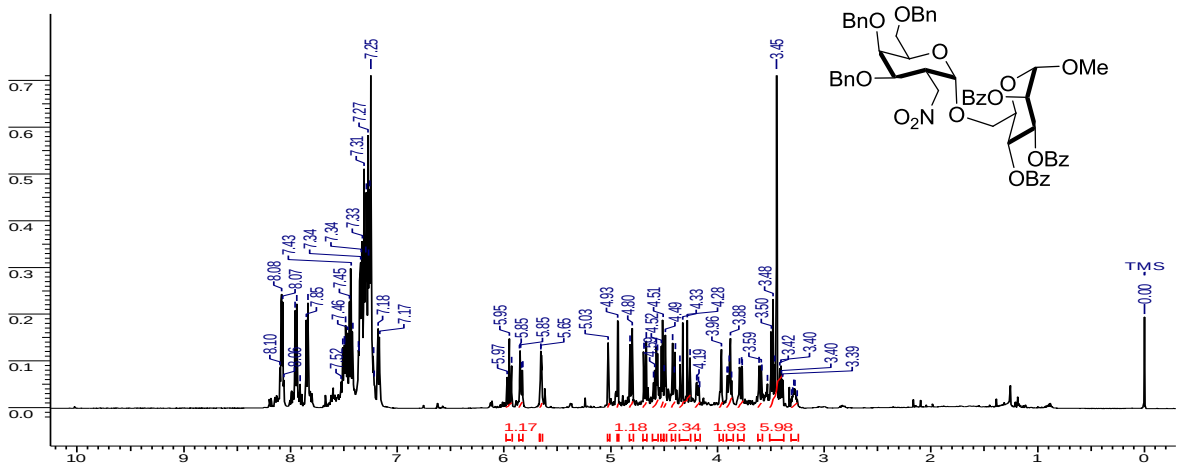
^{13}C NMR Spectrum (125.76 MHz, $CDCl_3$) of Compound **5j**



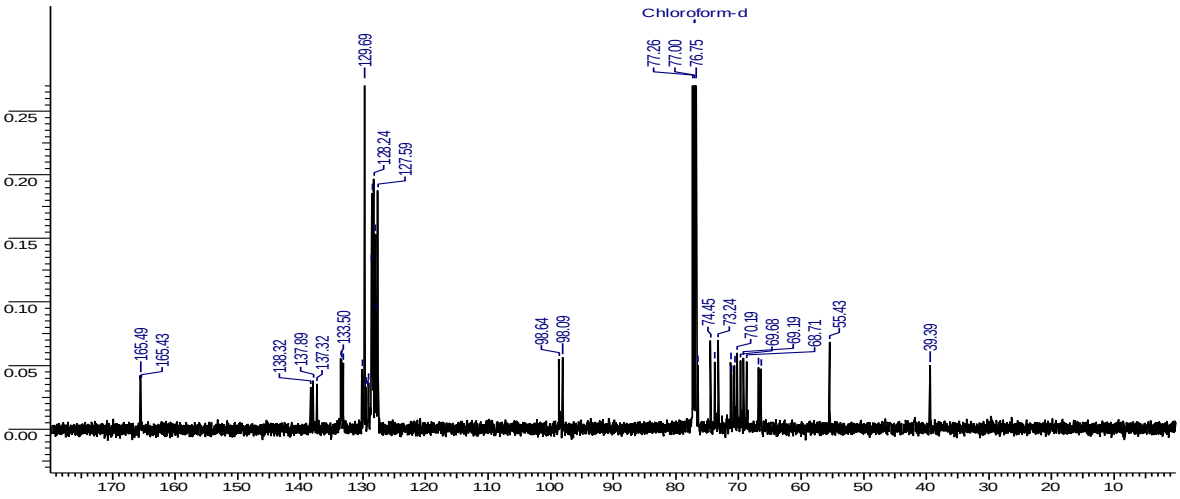
DEPT NMR Spectrum (125.76 MHz, $CDCl_3$) of Compound **5j**



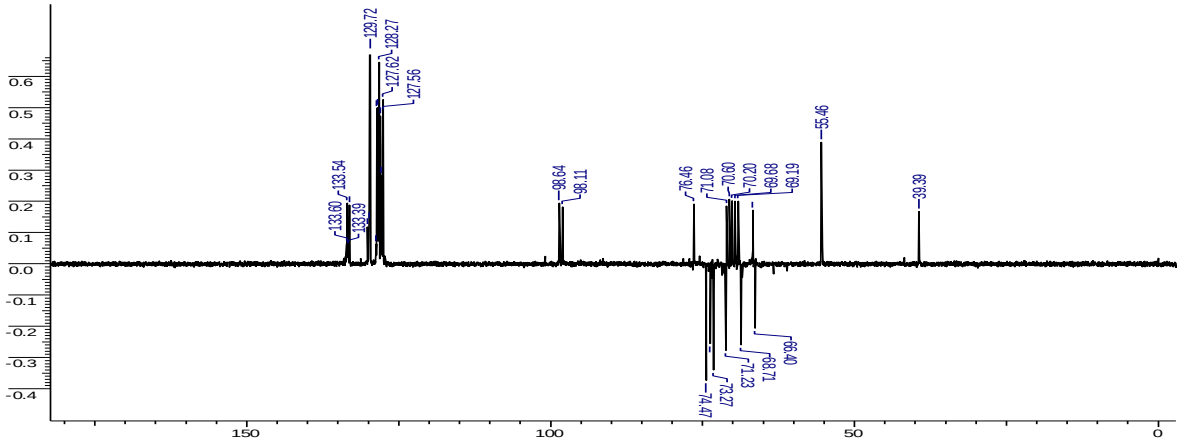
^{1}H NMR Spectrum (500.13 MHz, $CDCl_3$) of Compound **5k**



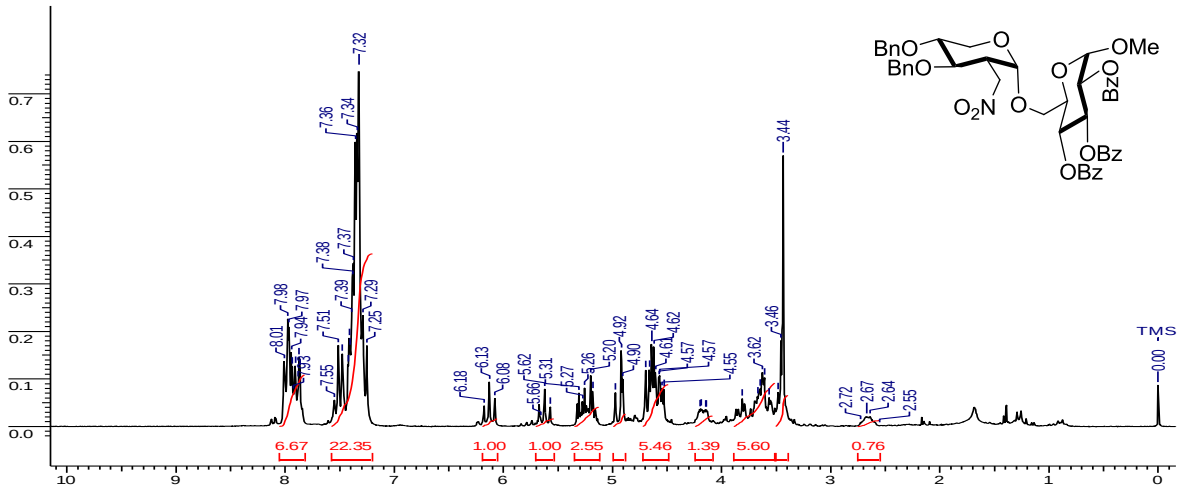
^{13}C NMR Spectrum (125.76 MHz, $CDCl_3$) of Compound **5k**



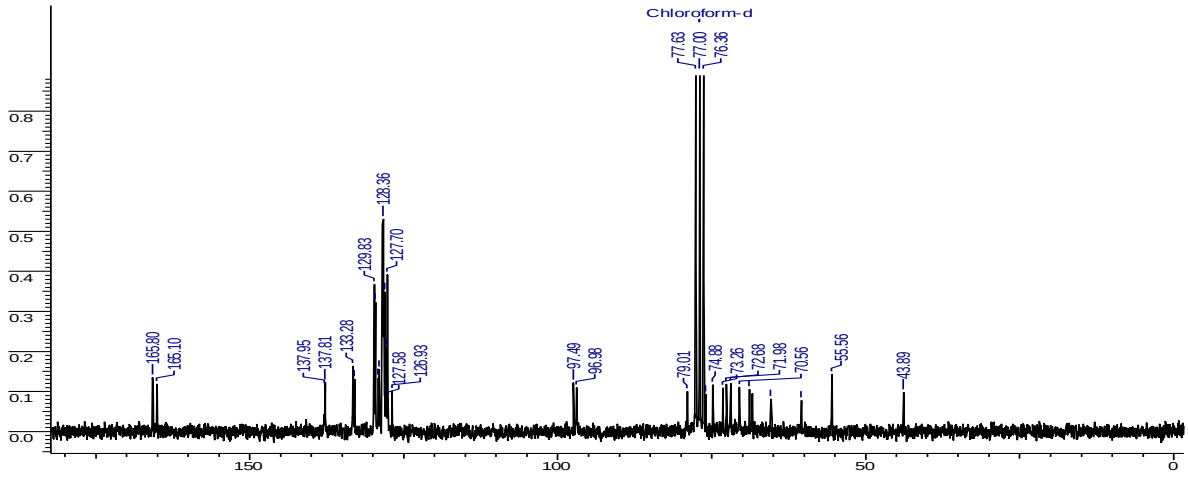
DEPT NMR Spectrum (125.76 MHz, $CDCl_3$) of Compound **5k**



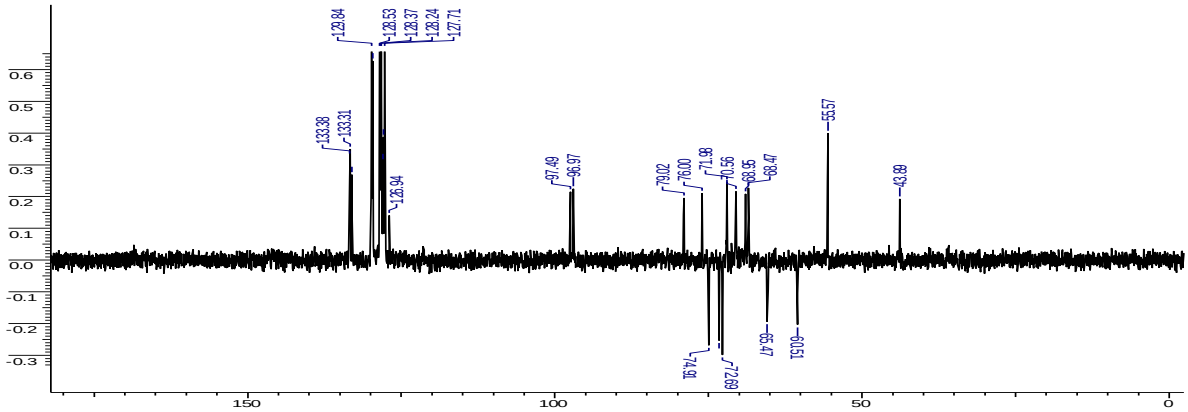
^{1}H NMR Spectrum (200.13 MHz, $CDCl_3$) of Compound **5l**



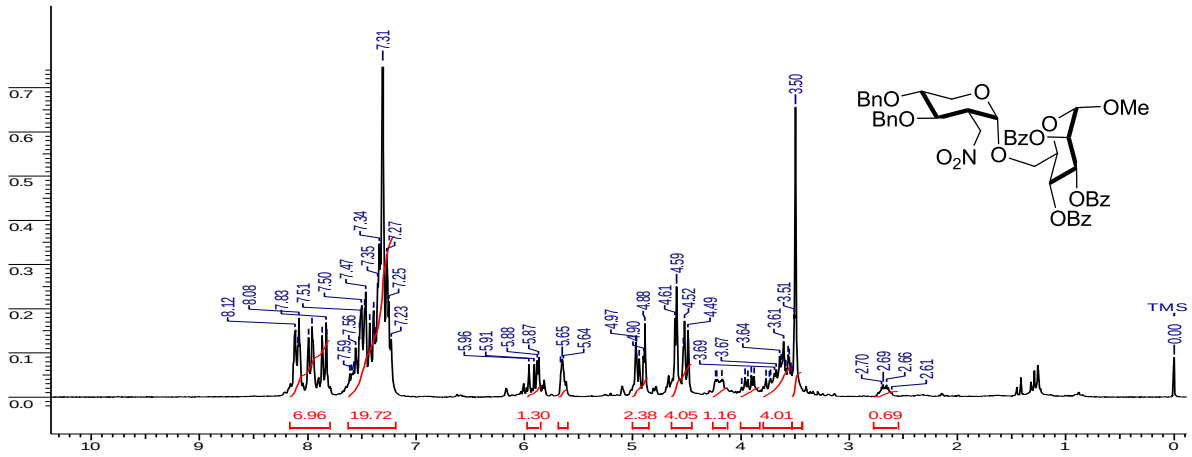
^{13}C NMR Spectrum (50.32MHz, $CDCl_3$) of Compound **5l**



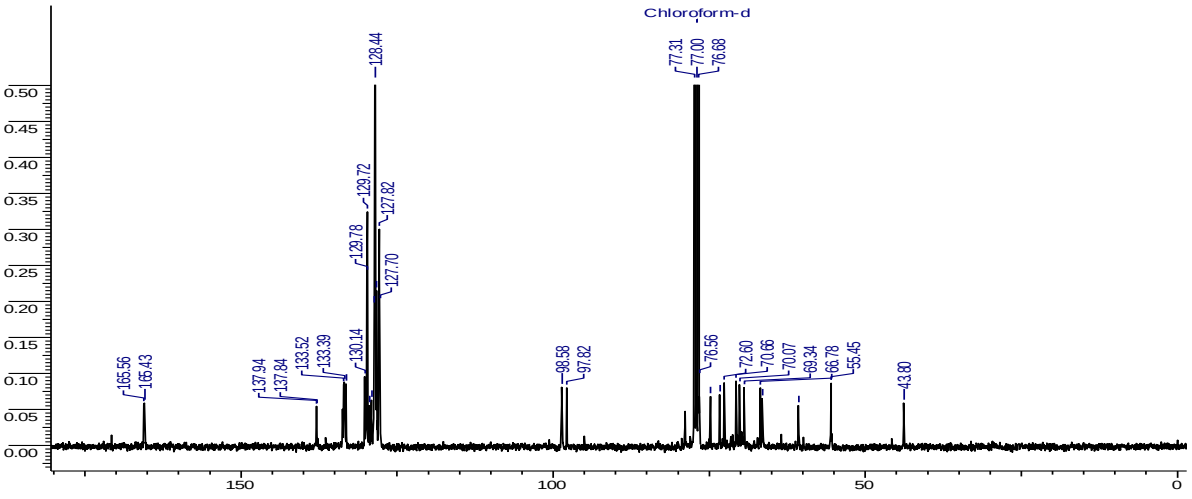
DEPT NMR Spectrum (50.32MHz, $CDCl_3$) of Compound **5l**



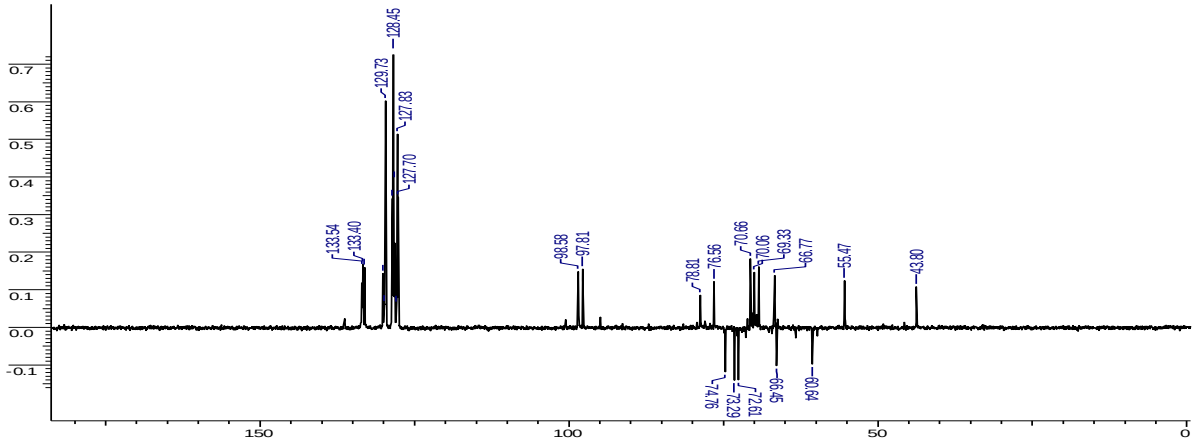
^{1}H NMR Spectrum (200.13 MHz, $CDCl_3$) of Compound **5m**



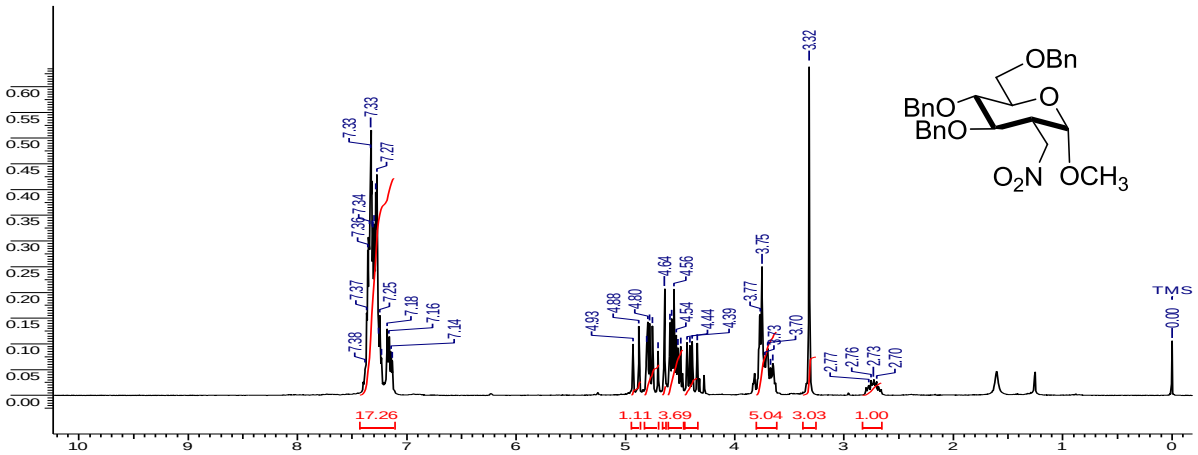
^{13}C NMR Spectrum (100.61 MHz, $CDCl_3$) of Compound **5m**



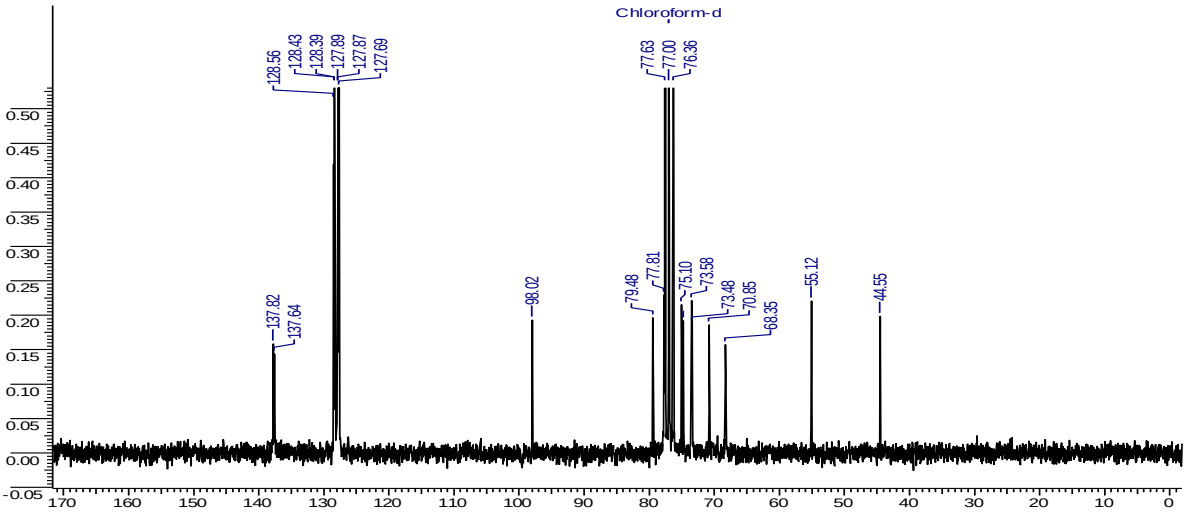
DEPT NMR Spectrum (100.61 MHz, $CDCl_3$) of Compound **5m**



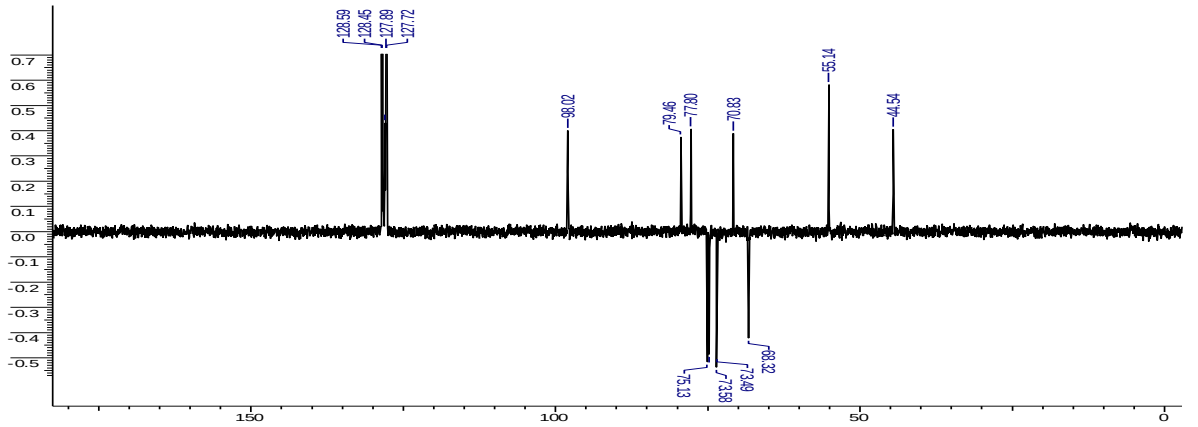
^{1}H NMR Spectrum (200.13 MHz, $CDCl_3$) of Compound **6a**



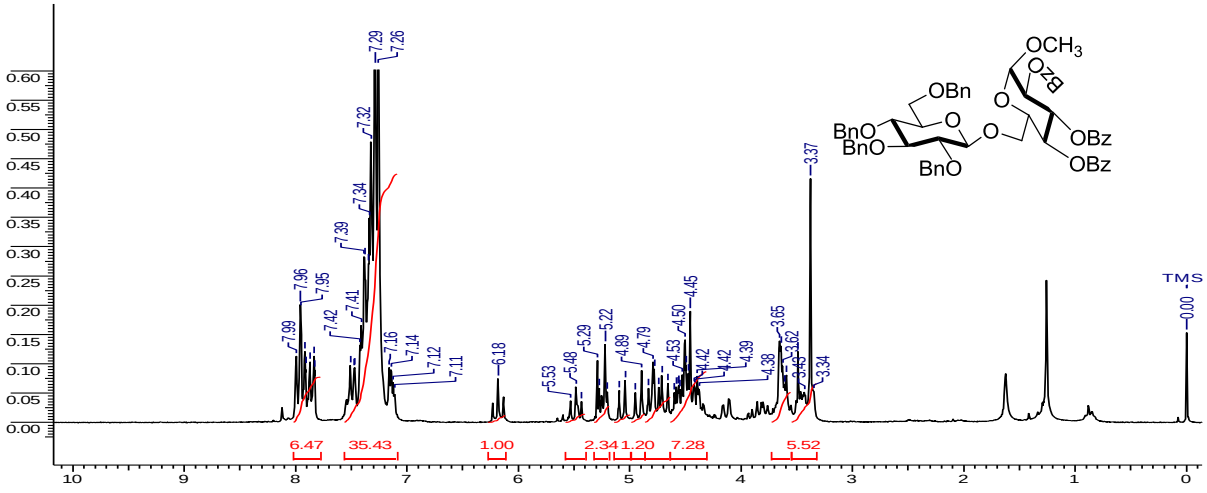
^{13}C NMR Spectrum (50.32MHz, $CDCl_3$) of Compound **6a**



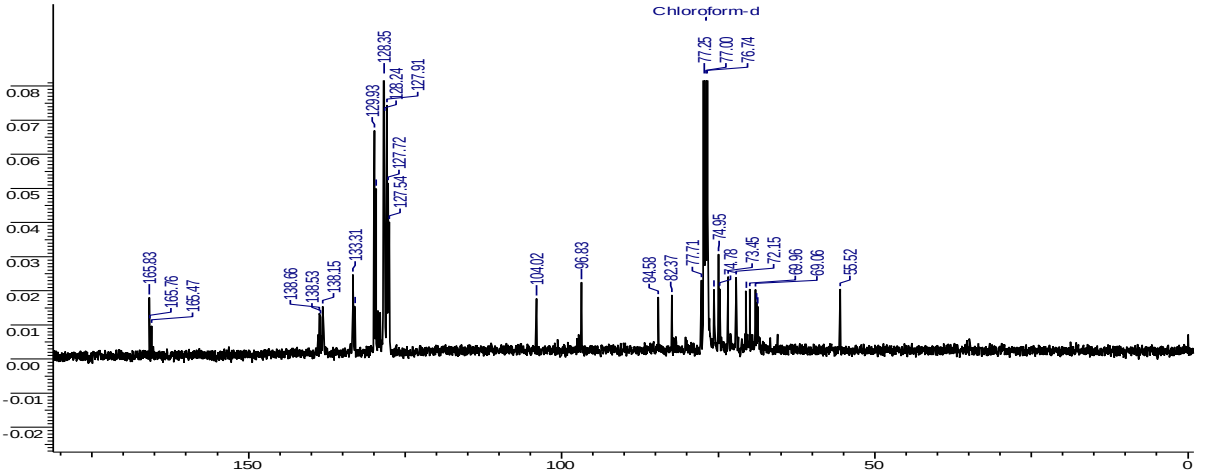
DEPT NMR Spectrum (50.32MHz, $CDCl_3$) of Compound **6a**



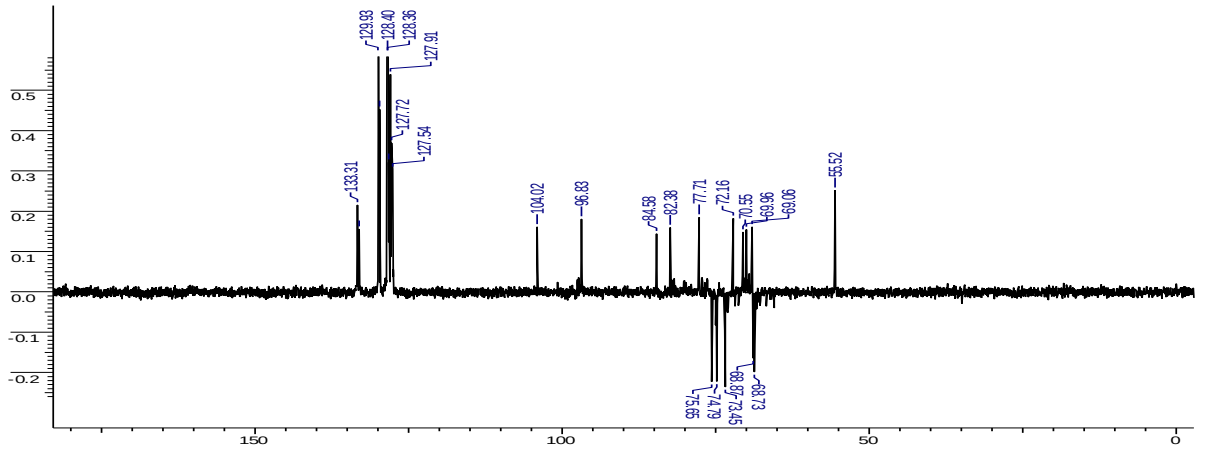
^{1}H NMR Spectrum (200.13 MHz, $CDCl_3$) of Compound **9**



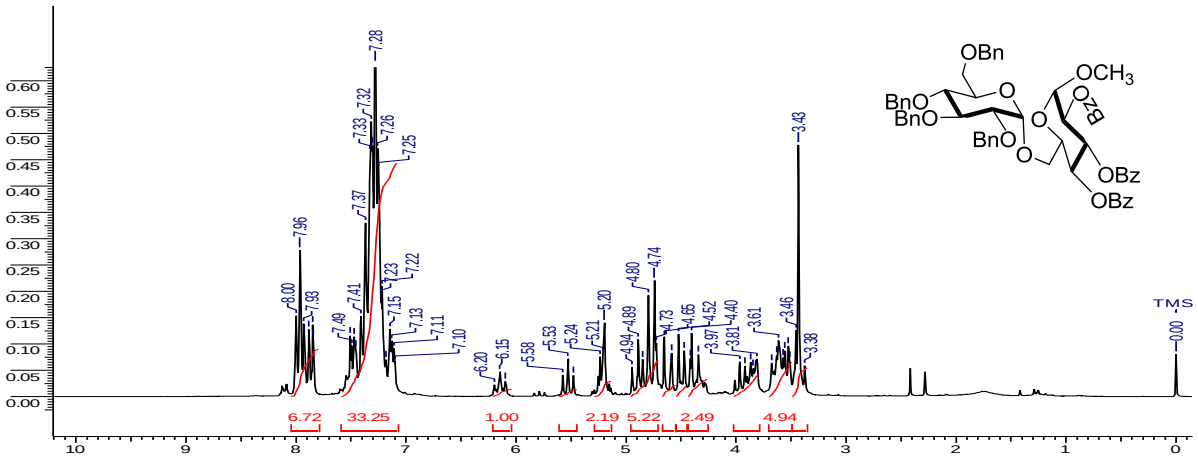
^{13}C NMR Spectrum (125.76 MHz, $CDCl_3$) of Compound **9**



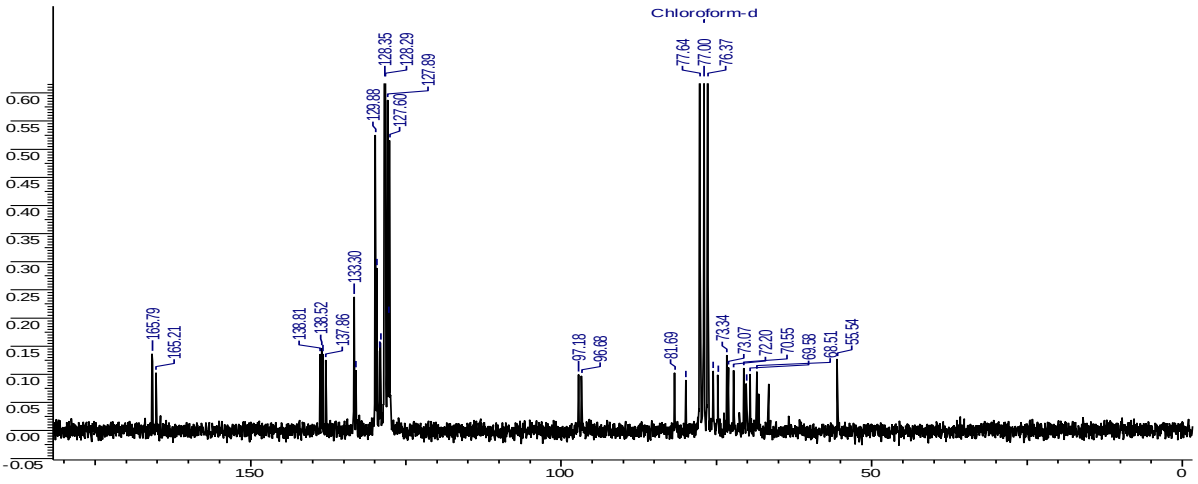
DEPT NMR Spectrum (125.76 MHz, $CDCl_3$) of Compound **9**



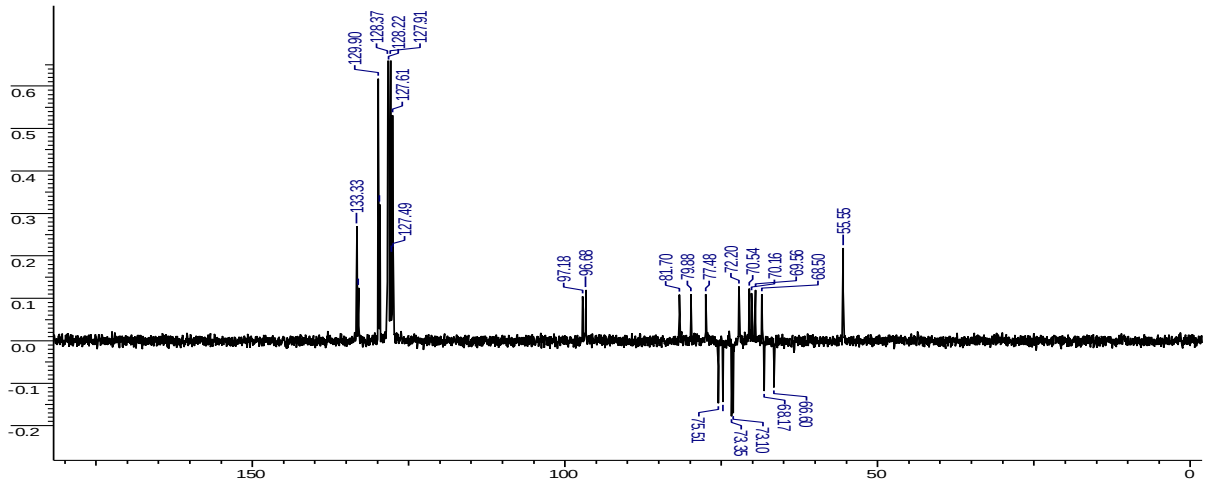
^{1}H NMR Spectrum (200.13 MHz, $CDCl_3$) of Compound **10**



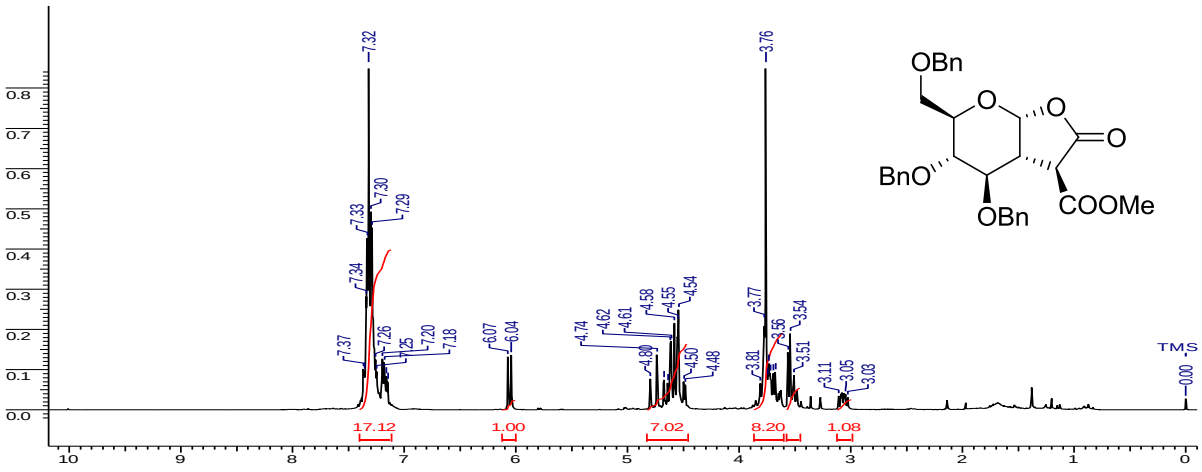
^{13}C NMR Spectrum (50.32MHz, $CDCl_3$) of Compound **10**



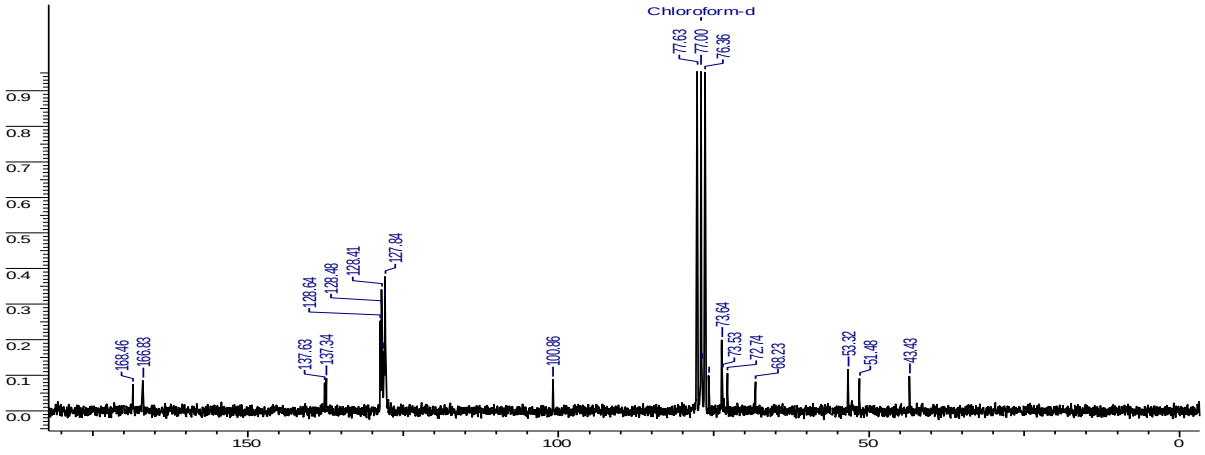
DEPT NMR Spectrum (50.32MHz, $CDCl_3$) of Compound **10**



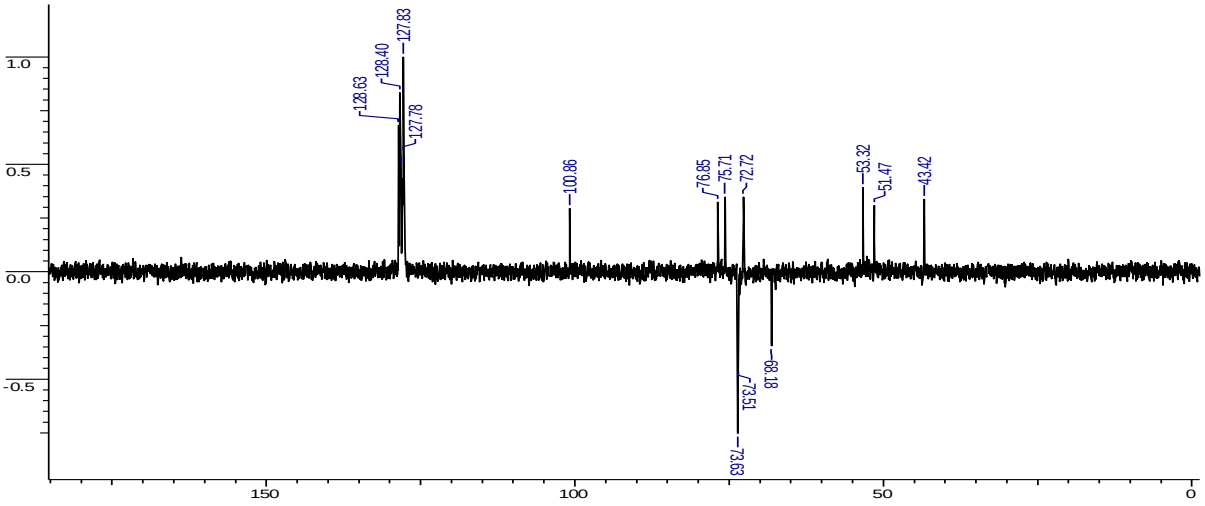
^{1}H NMR Spectrum (200.13 MHz, $CDCl_3$) of Compound **12a**



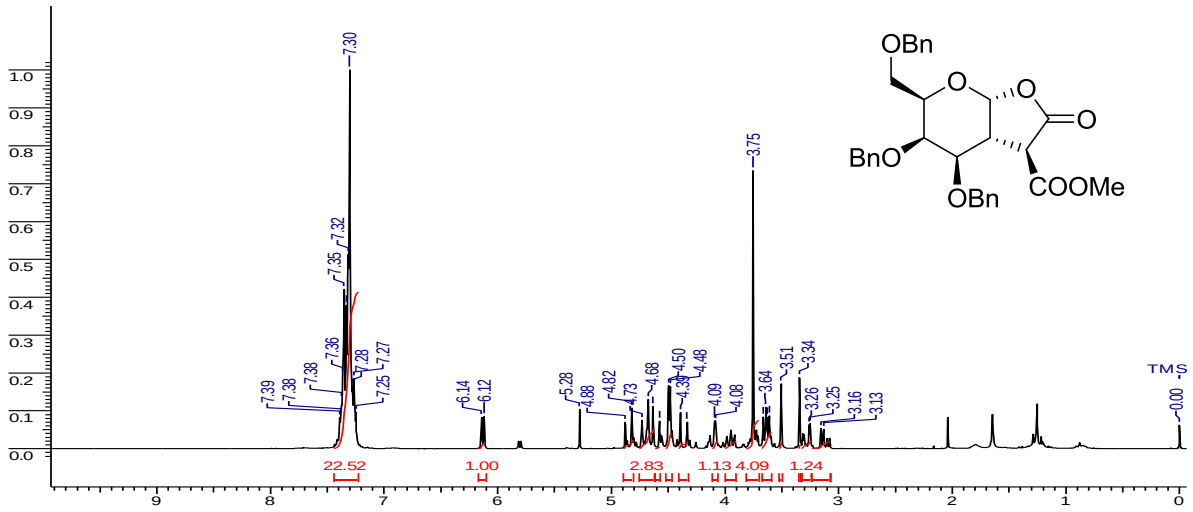
^{13}C NMR Spectrum (50.32 MHz, $CDCl_3$) of Compound **12a**



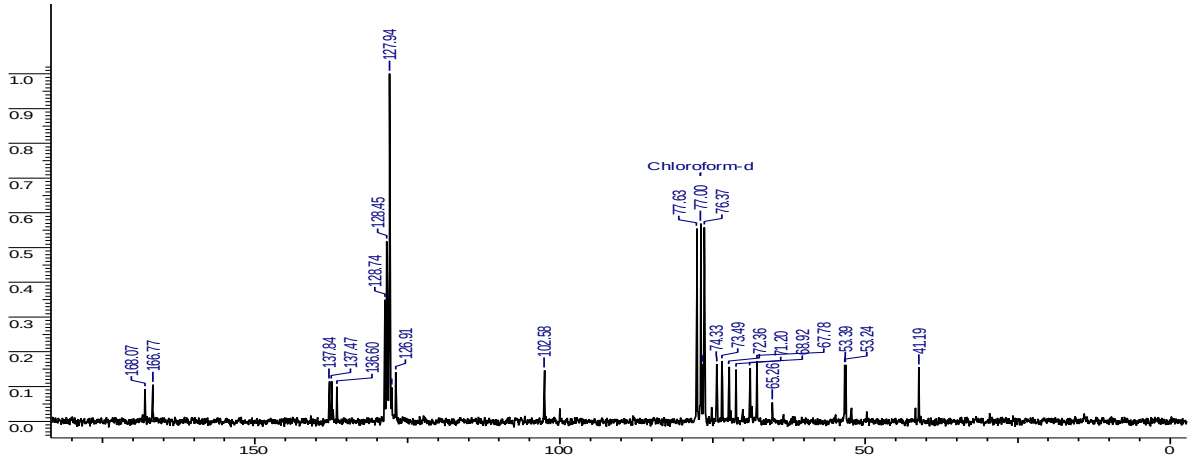
DEPT NMR Spectrum (50.32 MHz, $CDCl_3$) of Compound **12a**



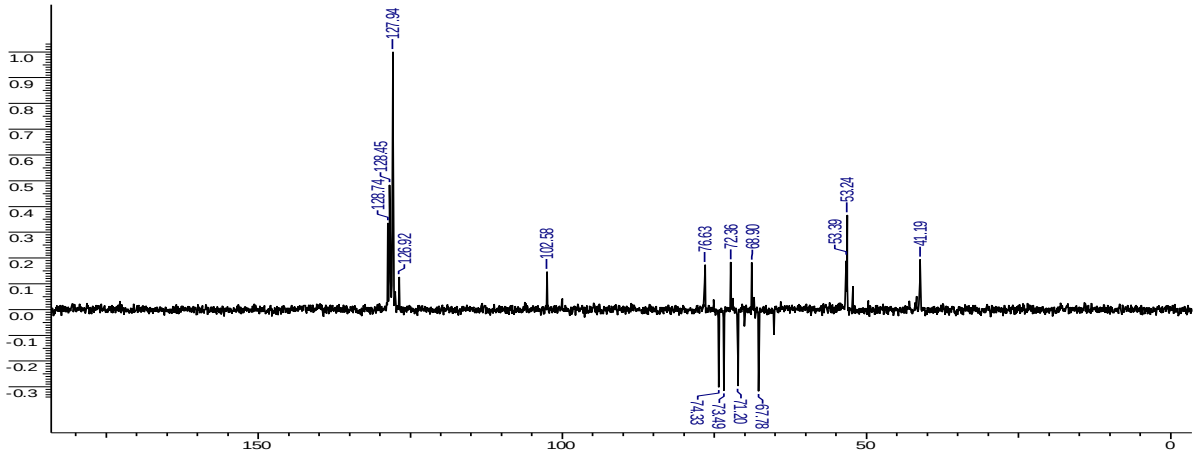
^{1}H NMR Spectrum (200.13 MHz, $CDCl_3$) of Compound **12b**



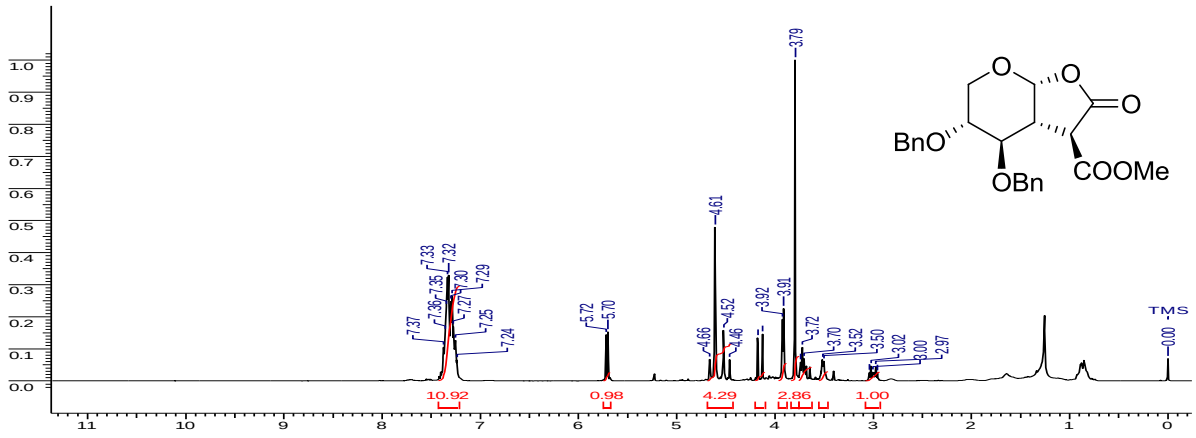
^{13}C NMR Spectrum (50.32 MHz, $CDCl_3$) of Compound **12b**



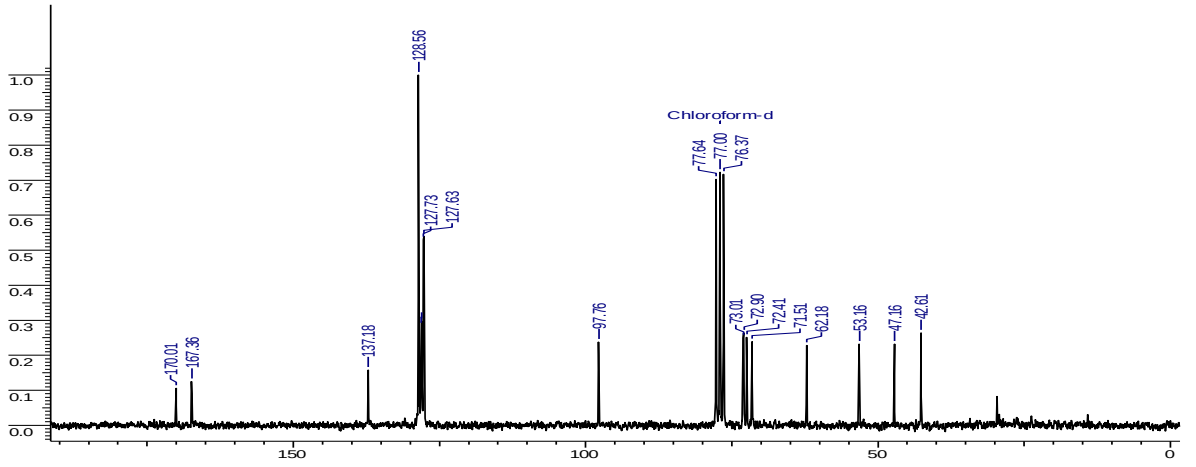
DEPT NMR Spectrum (50.32 MHz, $CDCl_3$) of Compound **12b**



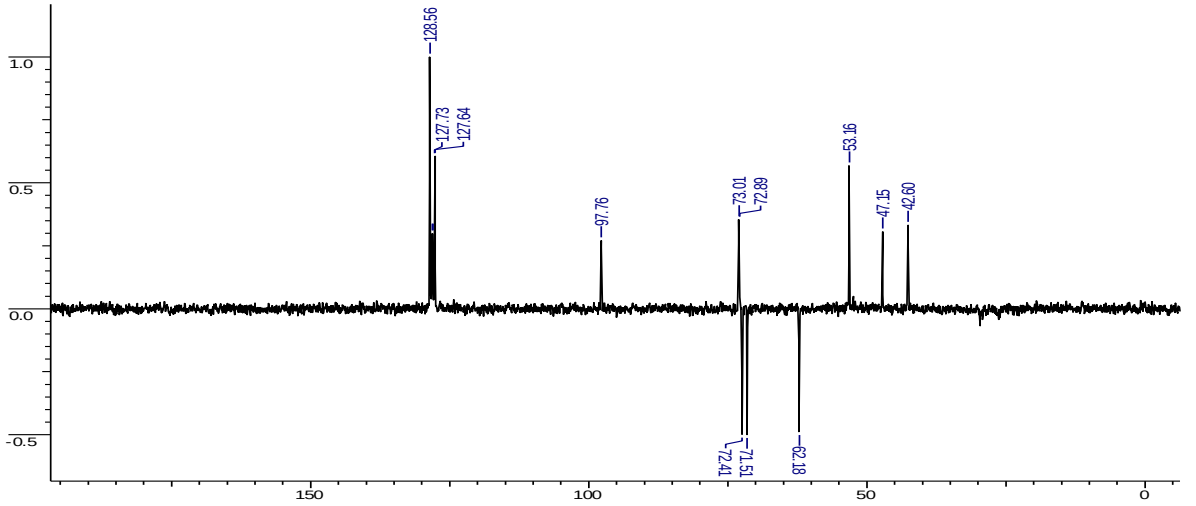
^{1}H NMR Spectrum (200.13 MHz, $CDCl_3$) of Compound **12c**



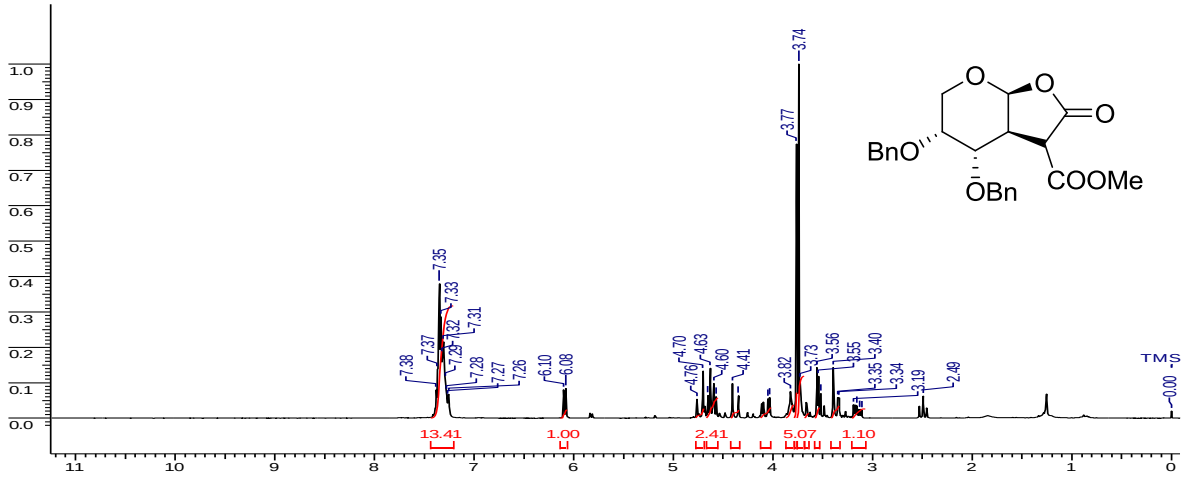
^{13}C NMR Spectrum (50.32 MHz, $CDCl_3$) of Compound **12c**



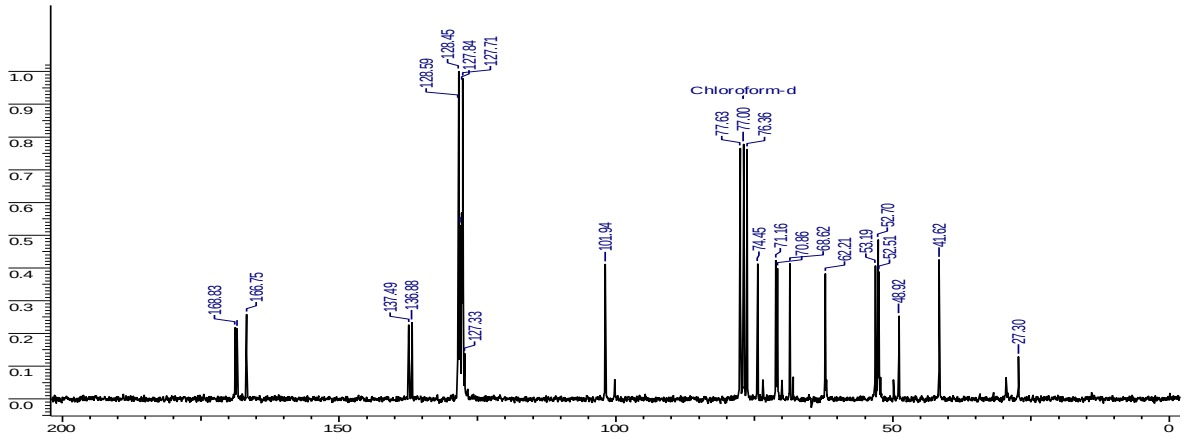
DEPT NMR Spectrum (50.32 MHz, $CDCl_3$) of Compound **12c**



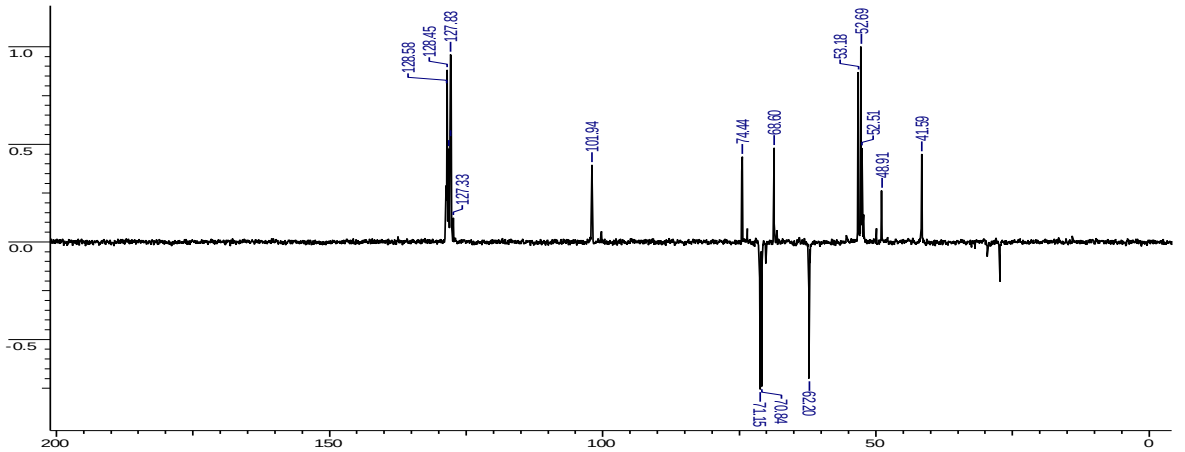
^{1}H NMR Spectrum (200.13 MHz, $CDCl_3$) of Compound **12d**



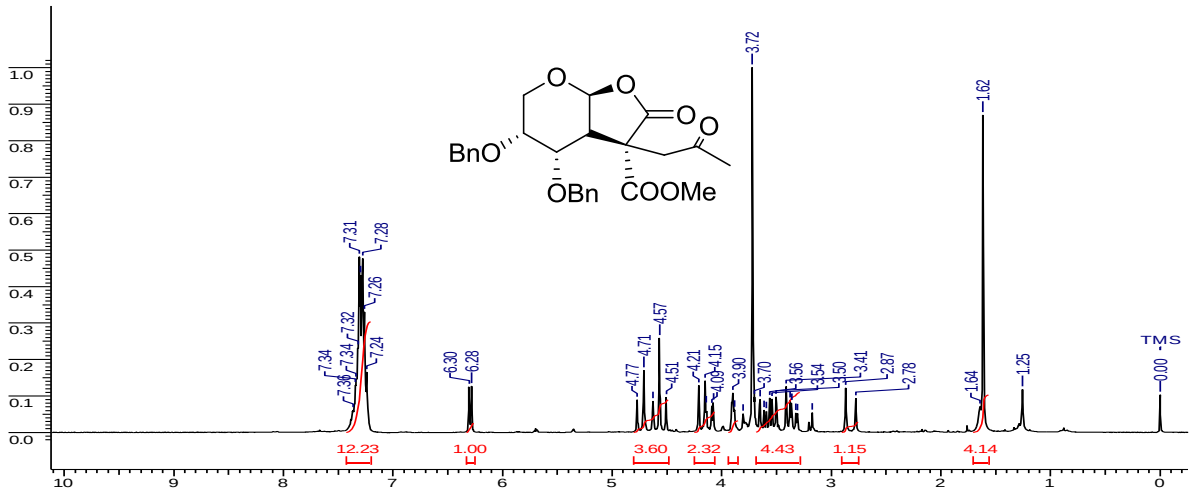
^{13}C NMR Spectrum (50.32 MHz, $CDCl_3$) of Compound **12d**



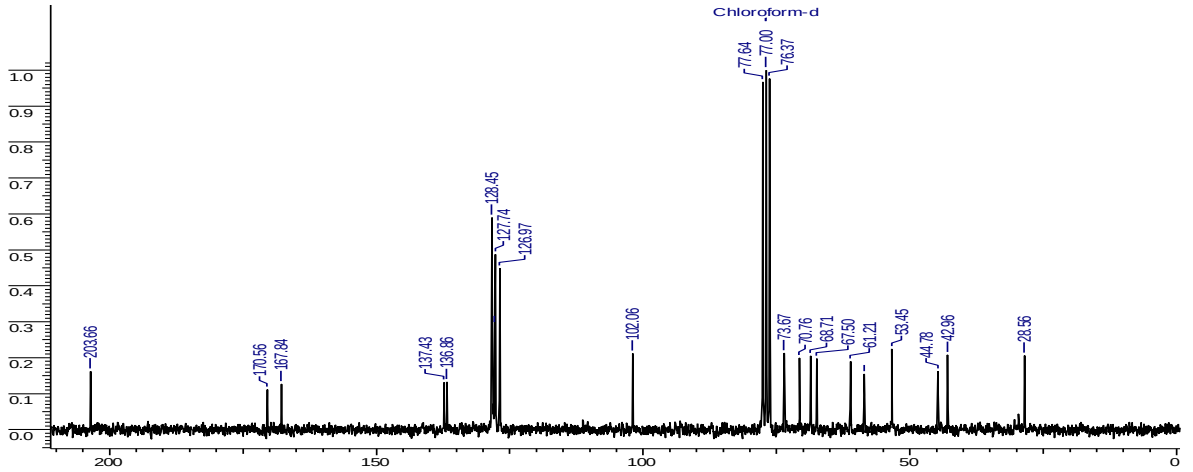
DEPT NMR Spectrum (50.32 MHz, $CDCl_3$) of Compound **12d**



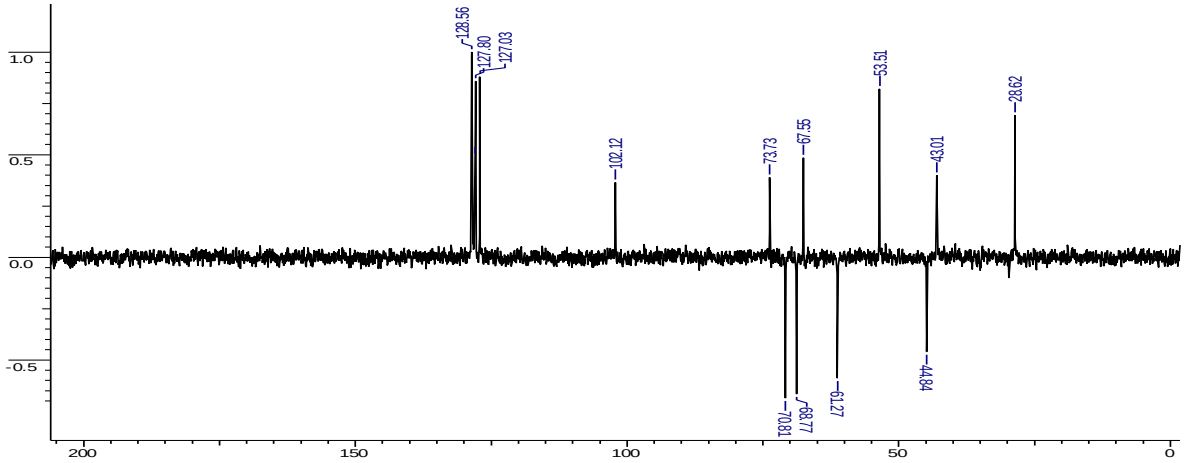
^{1}H NMR Spectrum (200.13 MHz, $CDCl_3$) of Compound **12e**



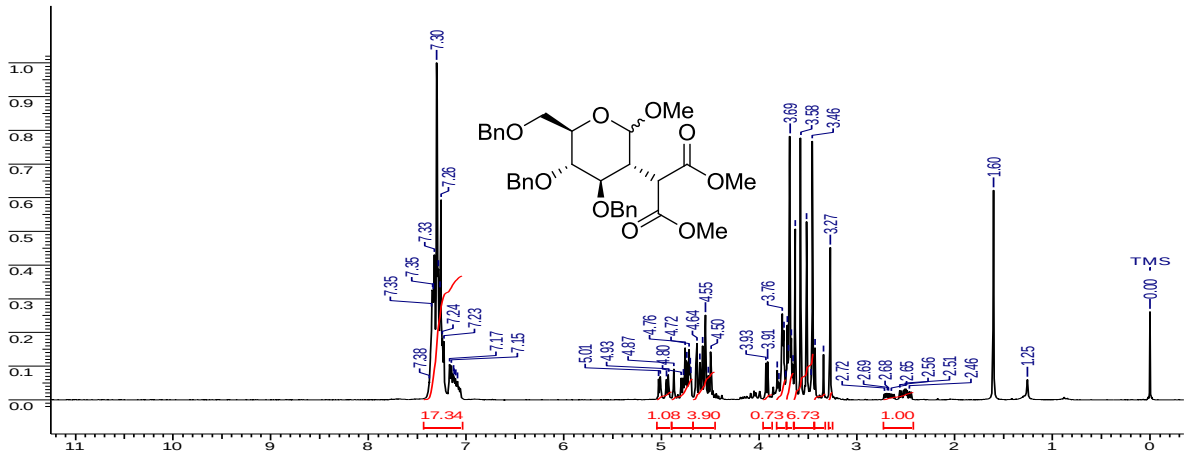
^{13}C NMR Spectrum (50.32 MHz, $CDCl_3$) of Compound **12e**



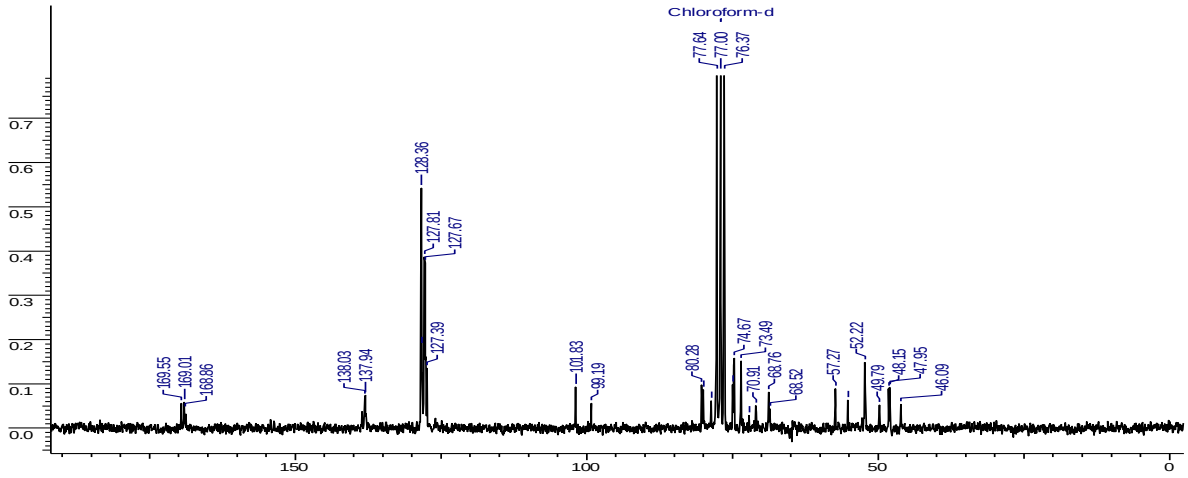
DEPT NMR Spectrum (50.32 MHz, $CDCl_3$) of Compound **12e**



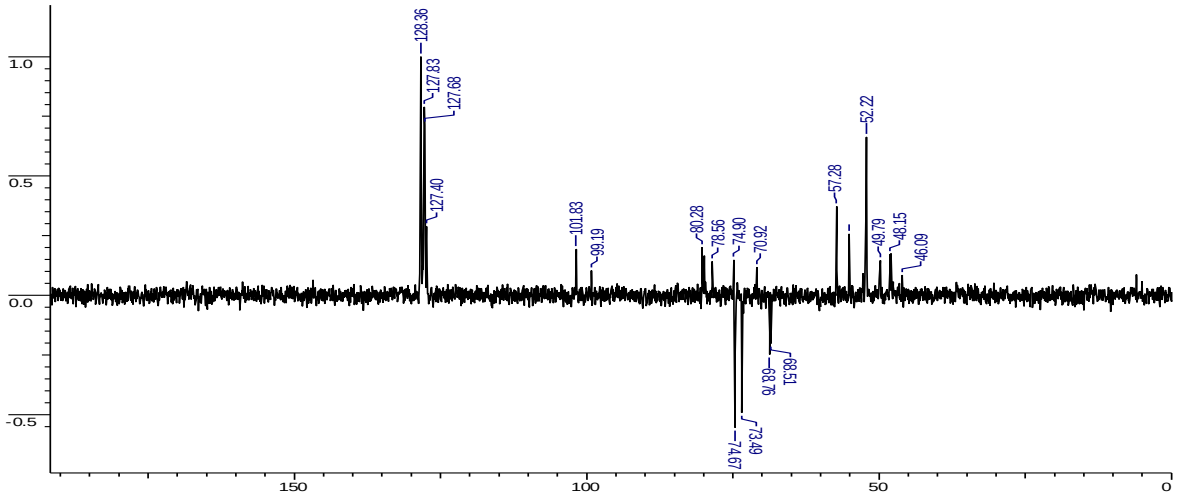
^{1}H NMR Spectrum (200.13 MHz, $CDCl_3$) of Compound **14**



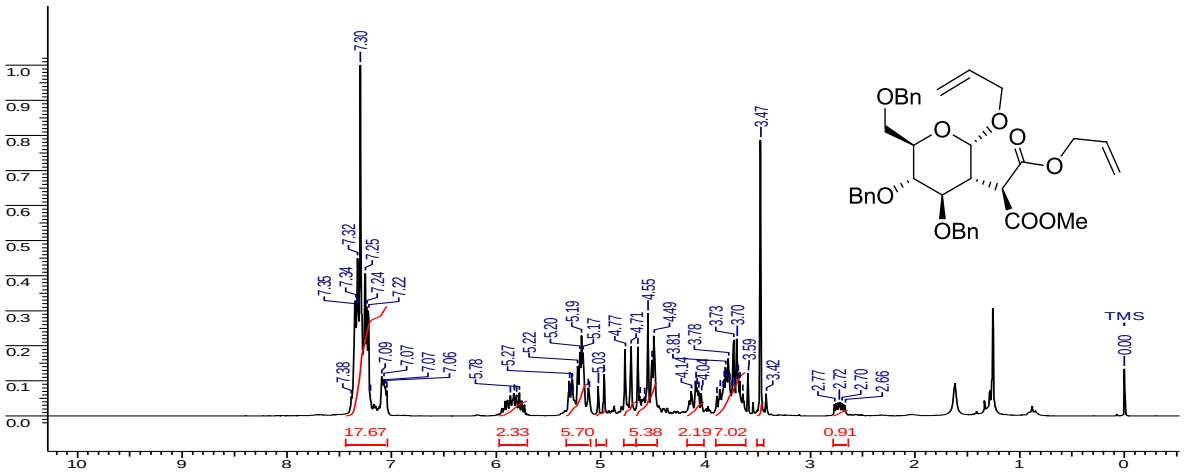
^{13}C NMR Spectrum (50.32 MHz, $CDCl_3$) of Compound **14**



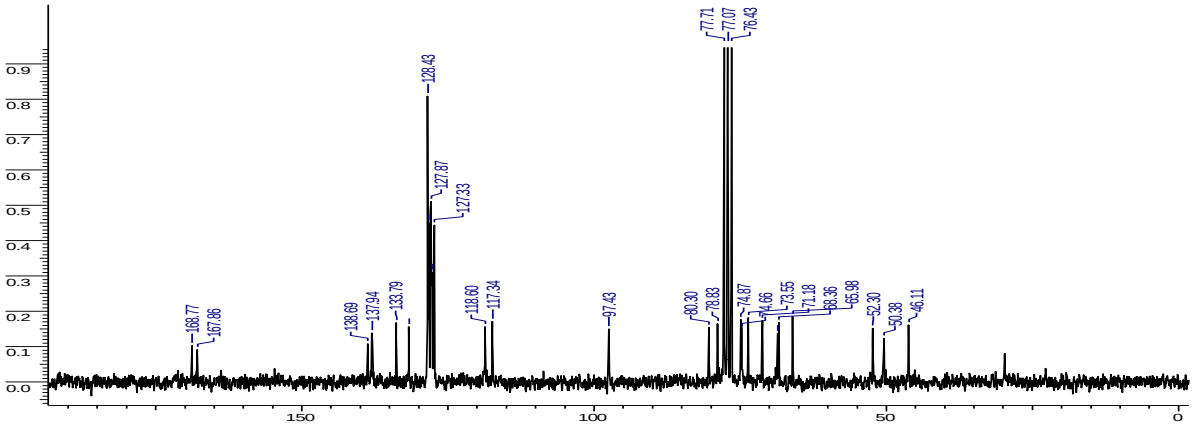
DEPT NMR Spectrum (50.32 MHz, $CDCl_3$) of Compound **14**



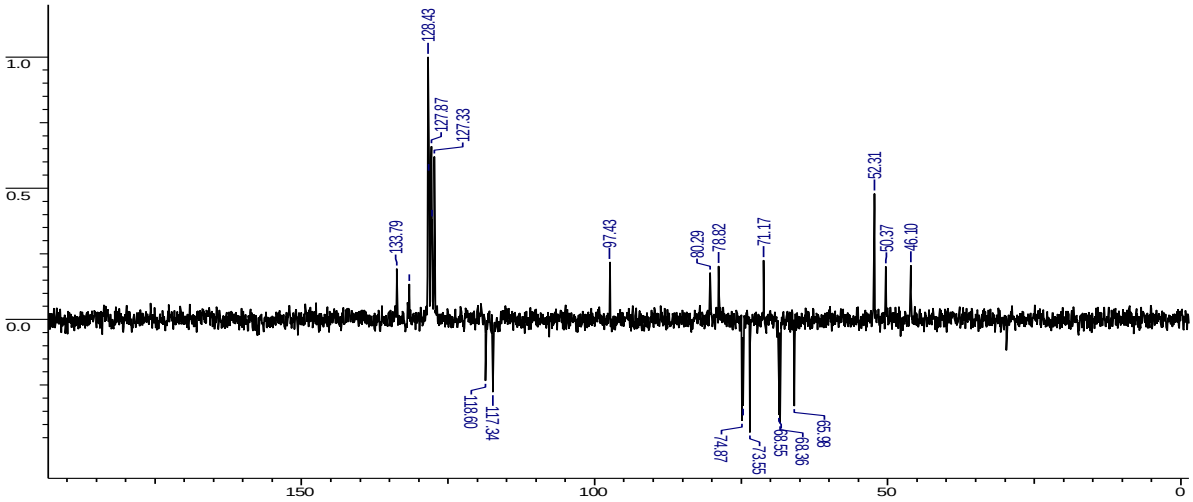
^{1}H NMR Spectrum (200.13 MHz, $CDCl_3$) of Compound **15**



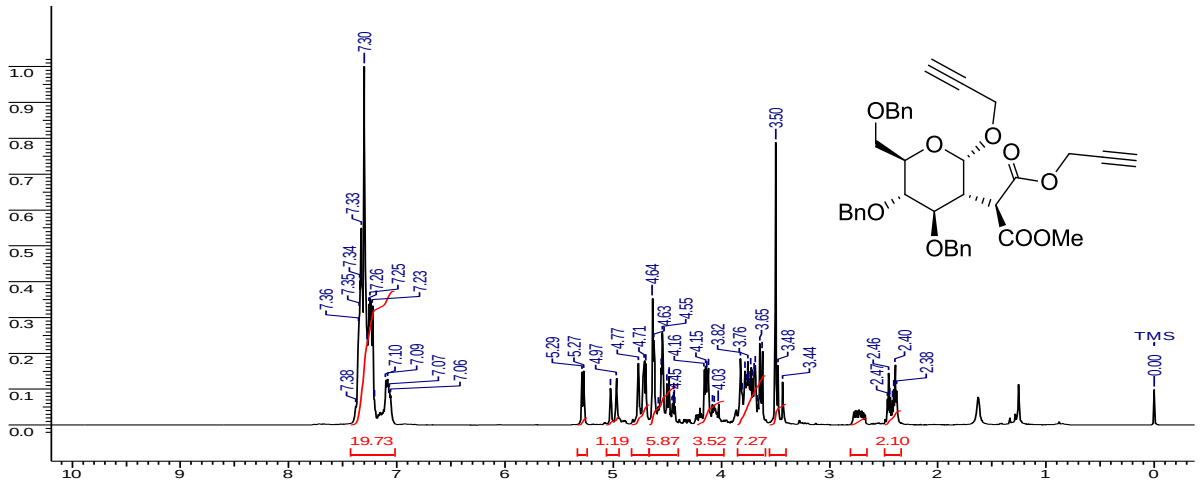
^{13}C NMR Spectrum (50.32 MHz, $CDCl_3$) of Compound **15**



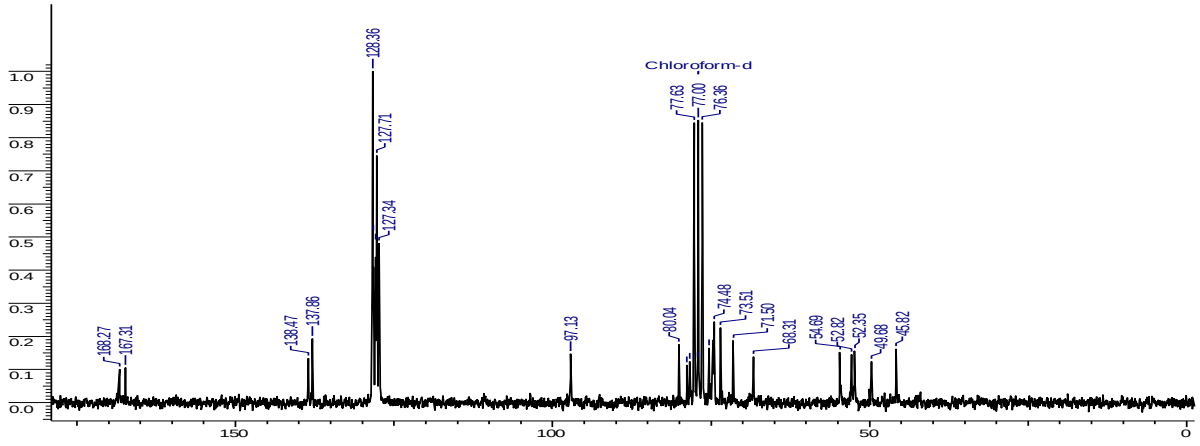
DEPT NMR Spectrum (50.32 MHz, $CDCl_3$) of Compound **15**



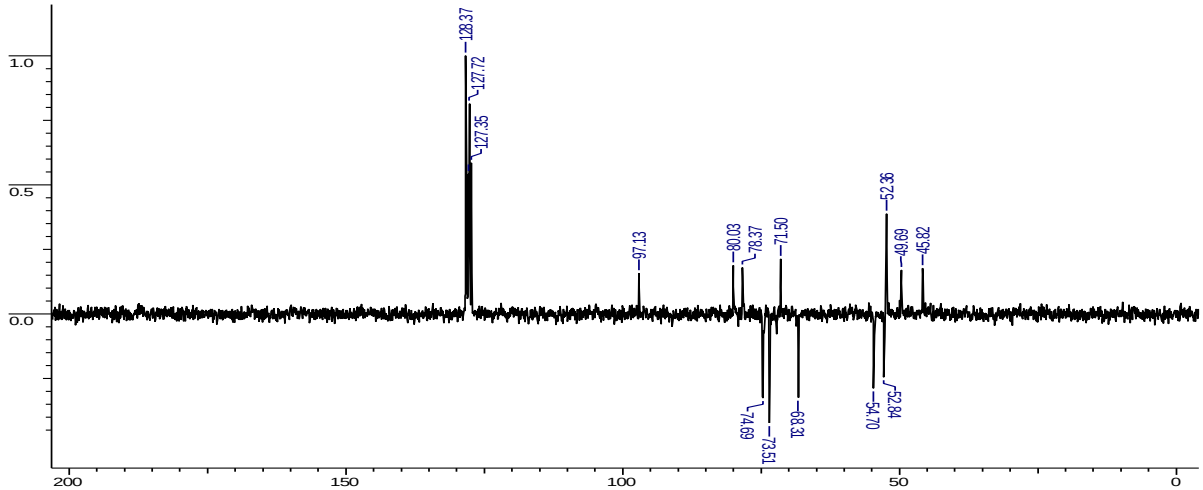
^{1}H NMR Spectrum (200.13 MHz, $CDCl_3$) of Compound **16**



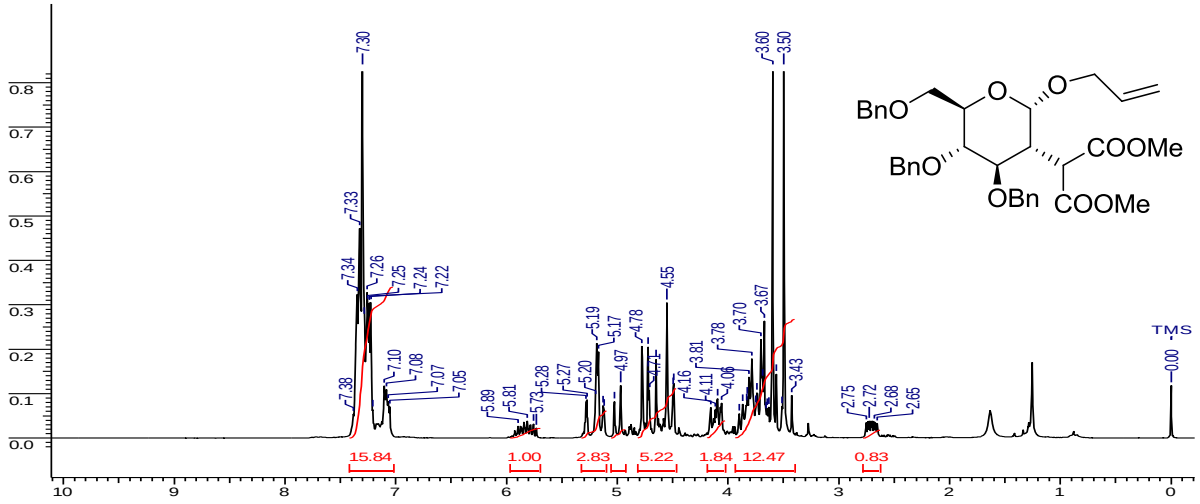
^{13}C NMR Spectrum (50.32 MHz, $CDCl_3$) of Compound **16**



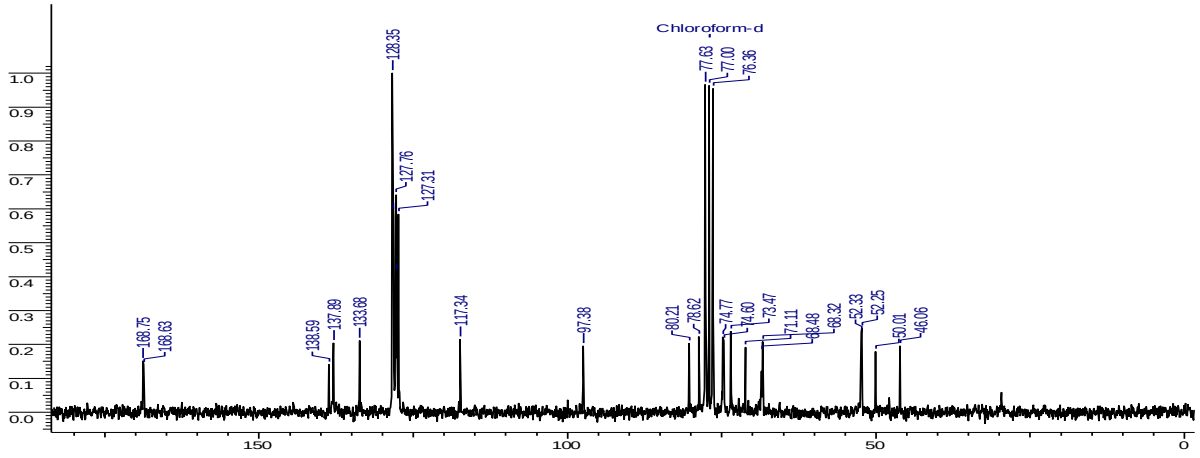
DEPT NMR Spectrum (50.32 MHz, $CDCl_3$) of Compound **16**



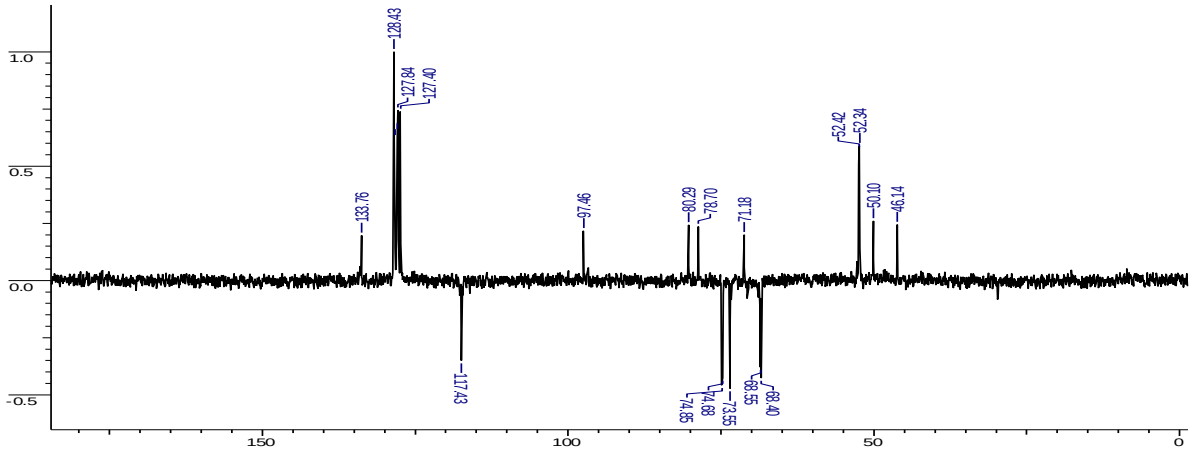
^{1}H NMR Spectrum (200.13 MHz, $CDCl_3$) of Compound **19**



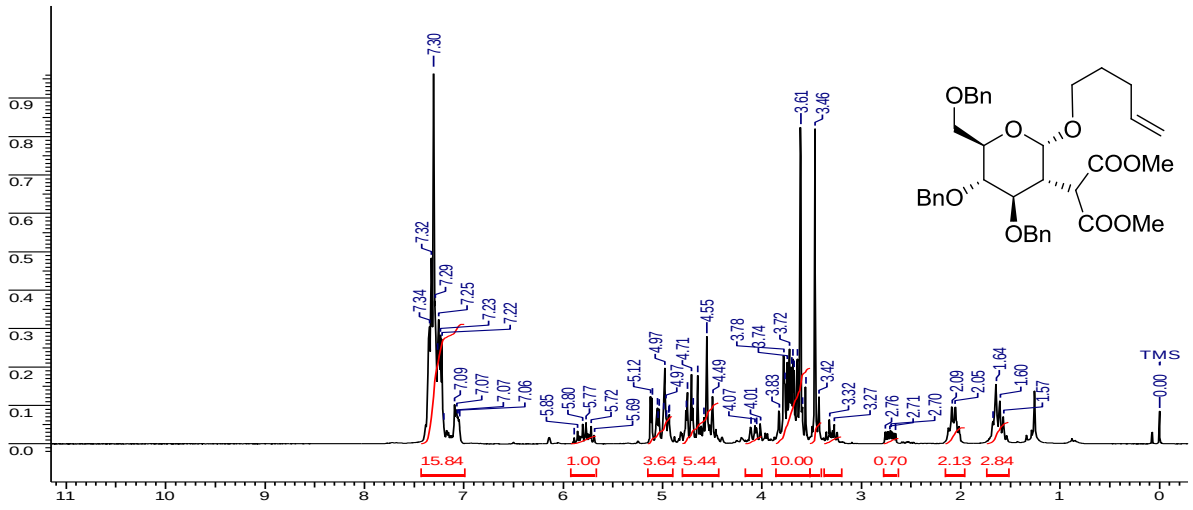
^{13}C NMR Spectrum (50.32 MHz, $CDCl_3$) of Compound **19**



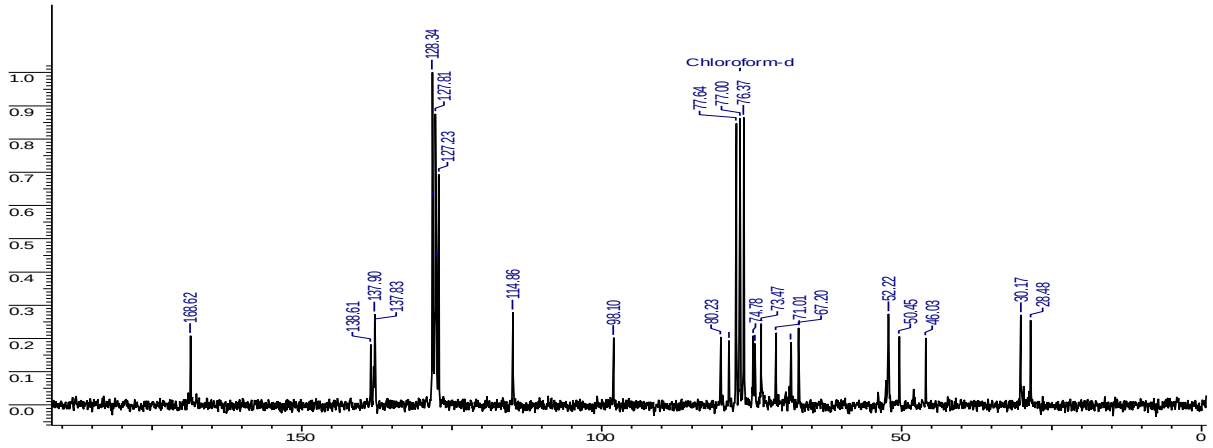
DEPT NMR Spectrum (50.32 MHz, $CDCl_3$) of Compound **19**



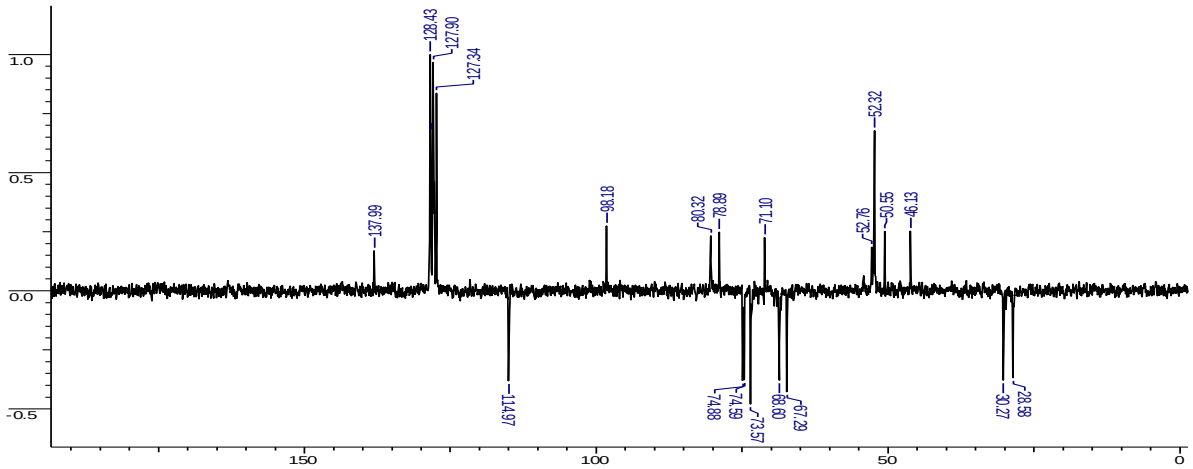
^{1}H NMR Spectrum (200.13 MHz, $CDCl_3$) of Compound **20**



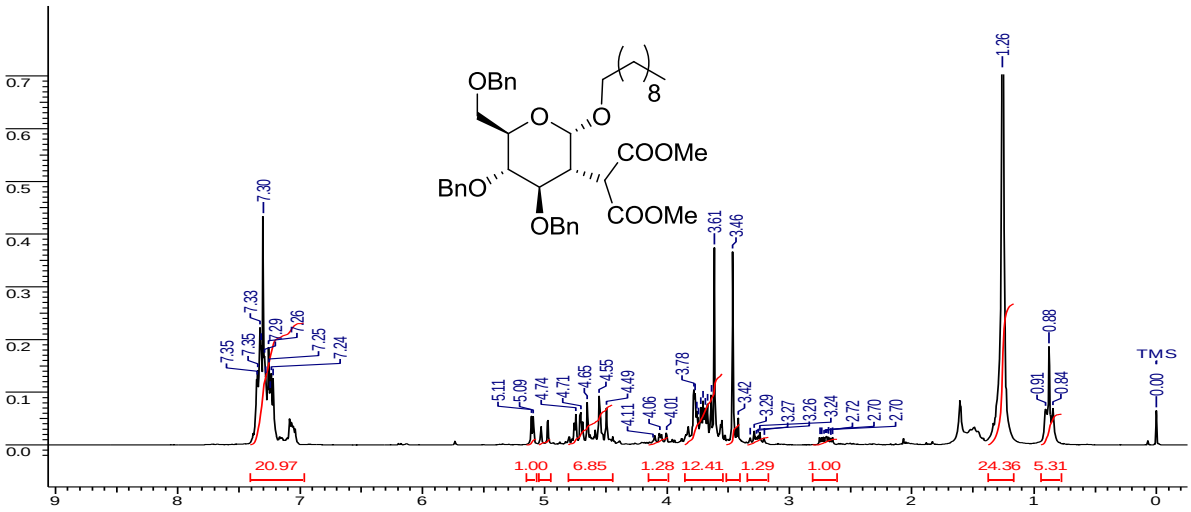
^{13}C NMR Spectrum (50.32 MHz, $CDCl_3$) of Compound **20**



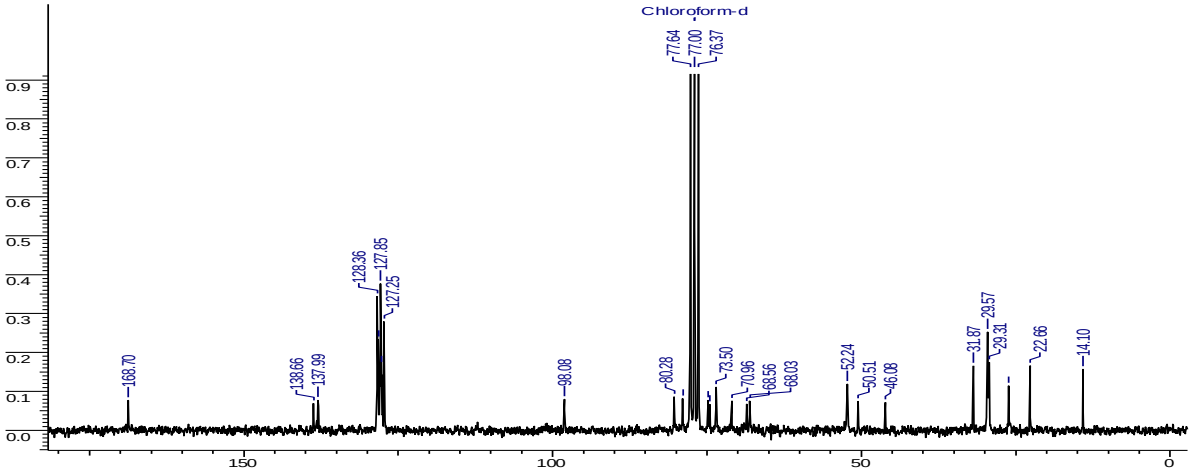
DEPT NMR Spectrum (50.32 MHz, $CDCl_3$) of Compound **20**



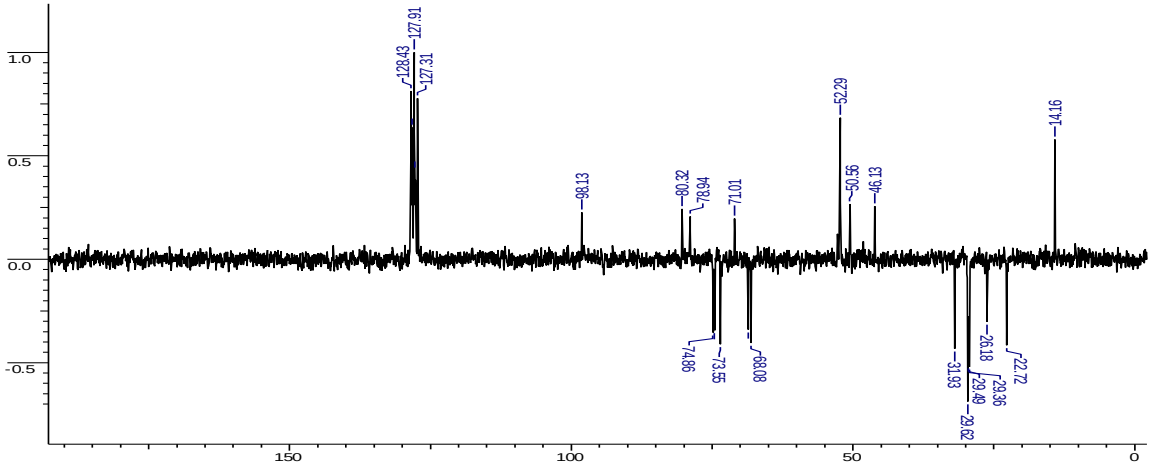
^{1}H NMR Spectrum (200.13 MHz, $CDCl_3$) of Compound **21**



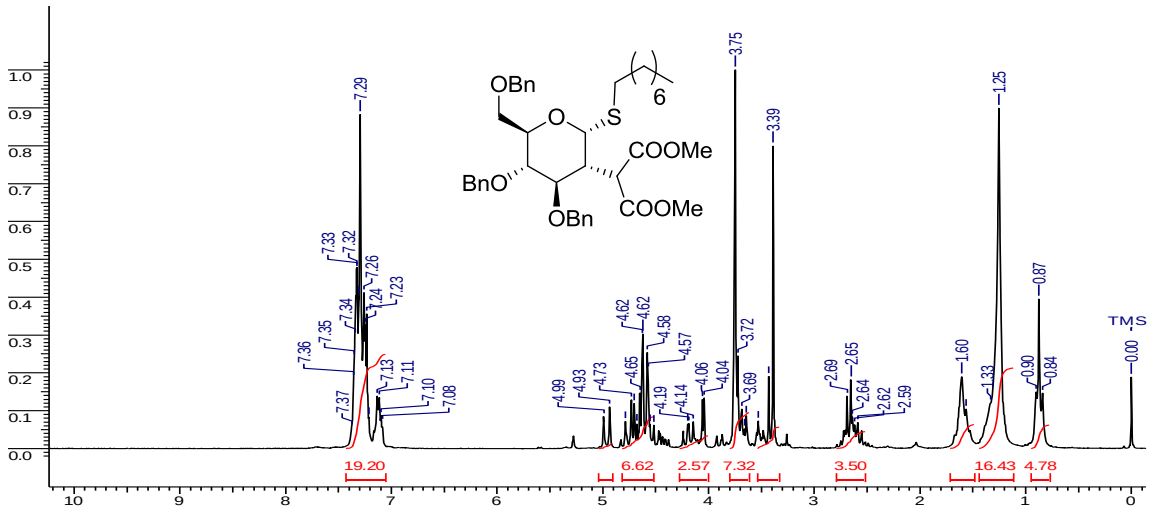
^{13}C NMR Spectrum (50.32 MHz, $CDCl_3$) of Compound **21**



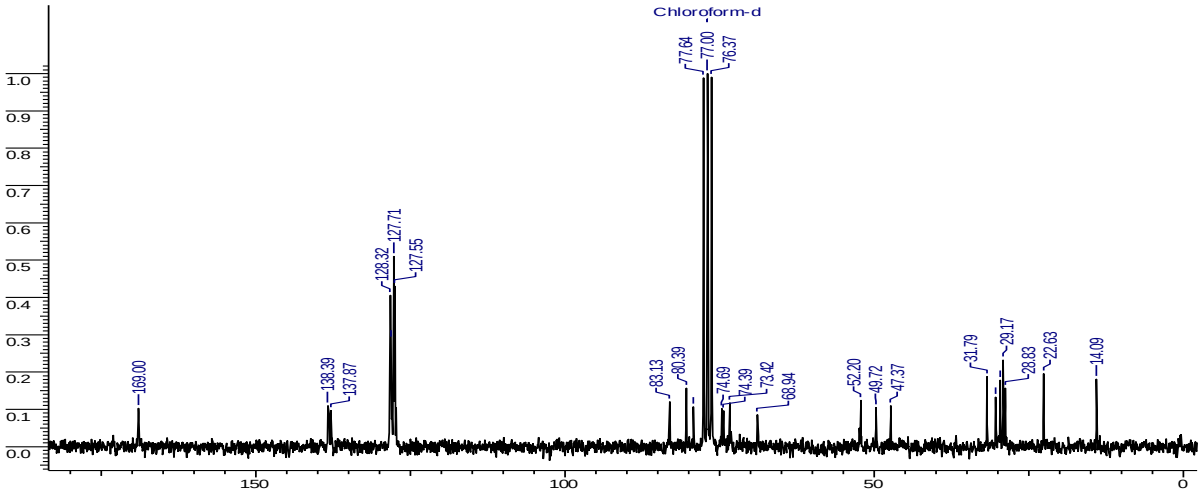
DEPT NMR Spectrum (50.32 MHz, $CDCl_3$) of Compound **21**



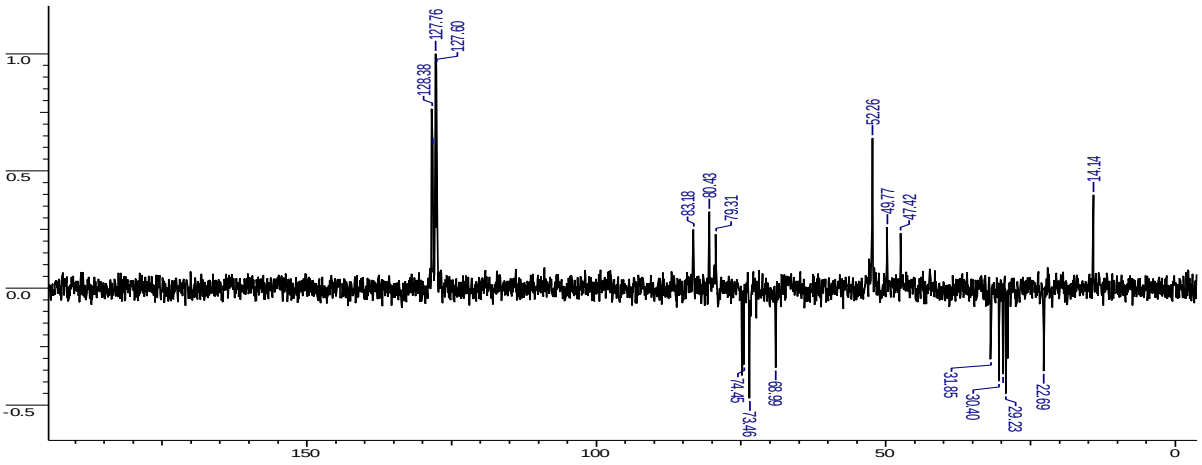
^{1}H NMR Spectrum (200.13 MHz, $CDCl_3$) of Compound **22**



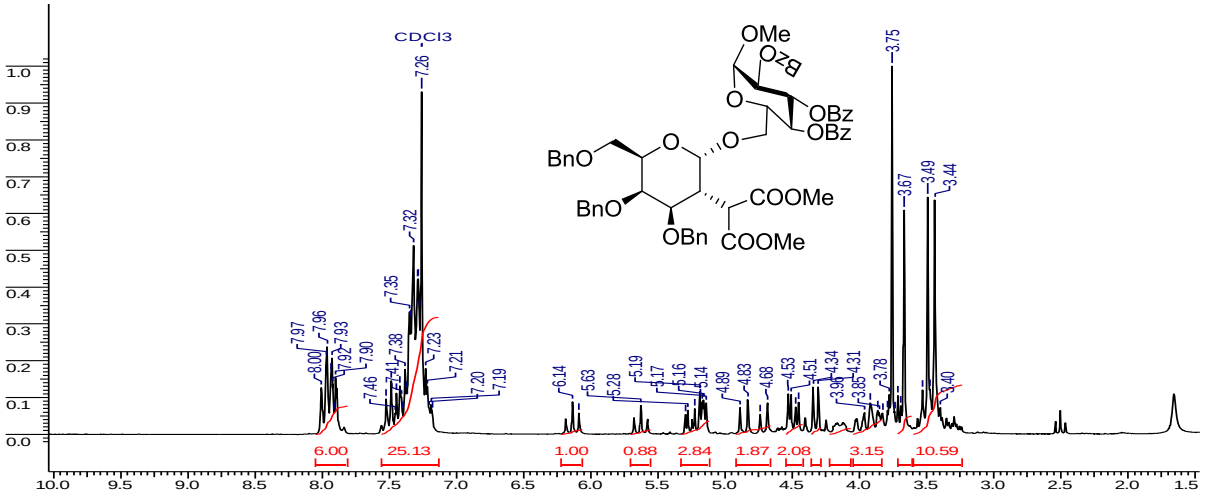
^{13}C NMR Spectrum (50.32 MHz, $CDCl_3$) of Compound **22**



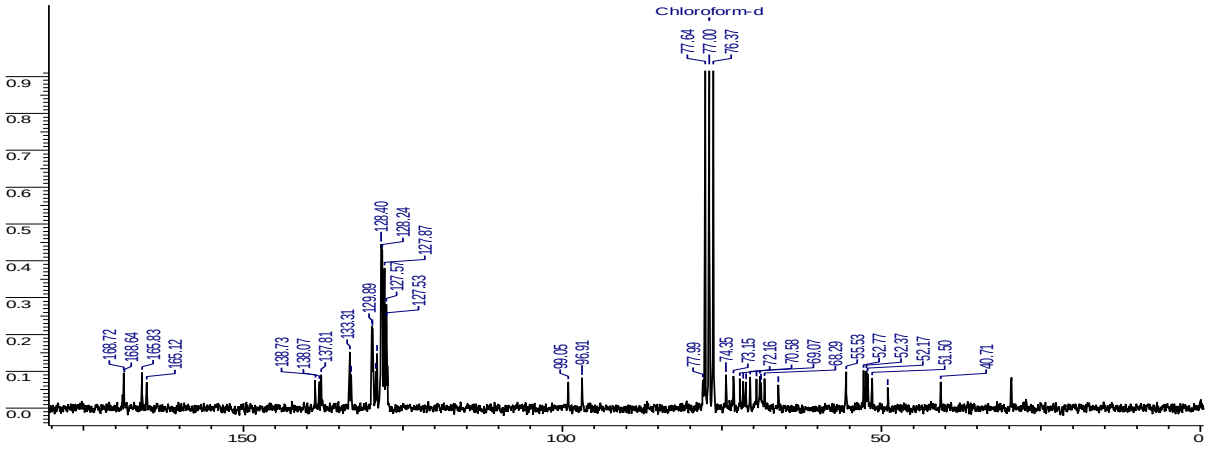
DEPT NMR Spectrum (50.32 MHz, $CDCl_3$) of Compound **22**



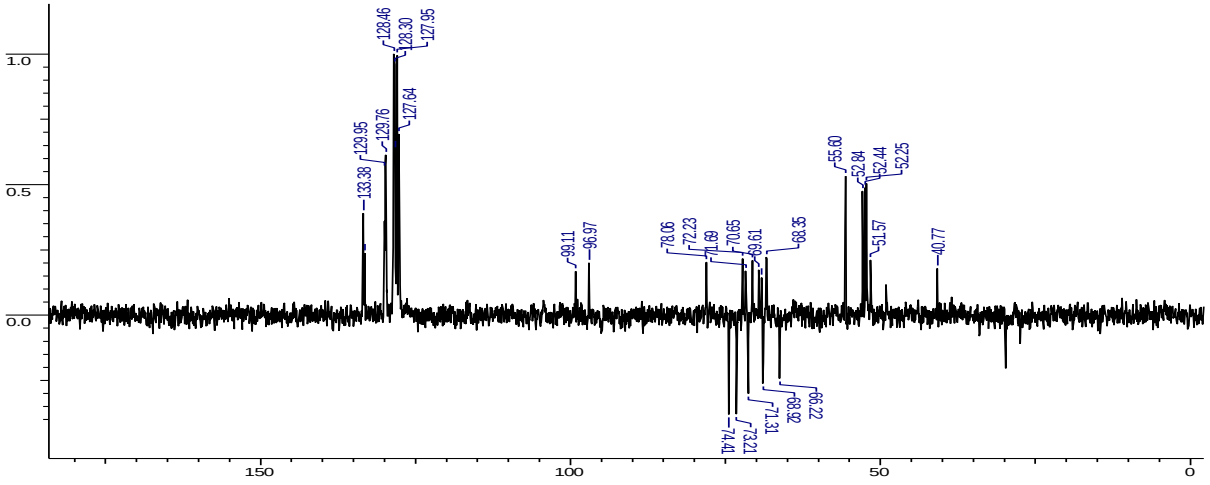
^{1}H NMR Spectrum (200.13 MHz, $CDCl_3$) of Compound **24**



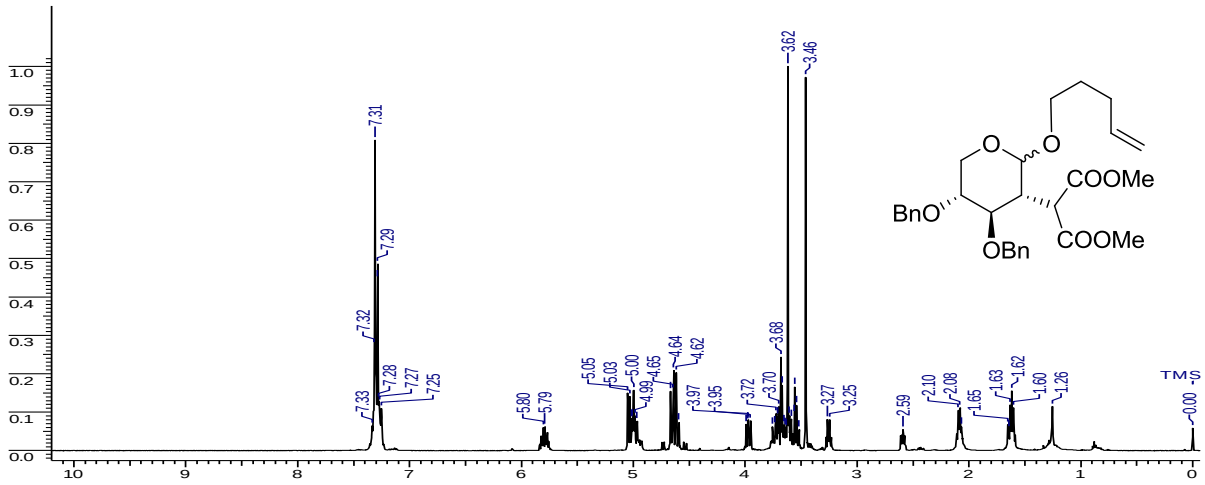
^{13}C NMR Spectrum (50.32 MHz, $CDCl_3$) of Compound **24**



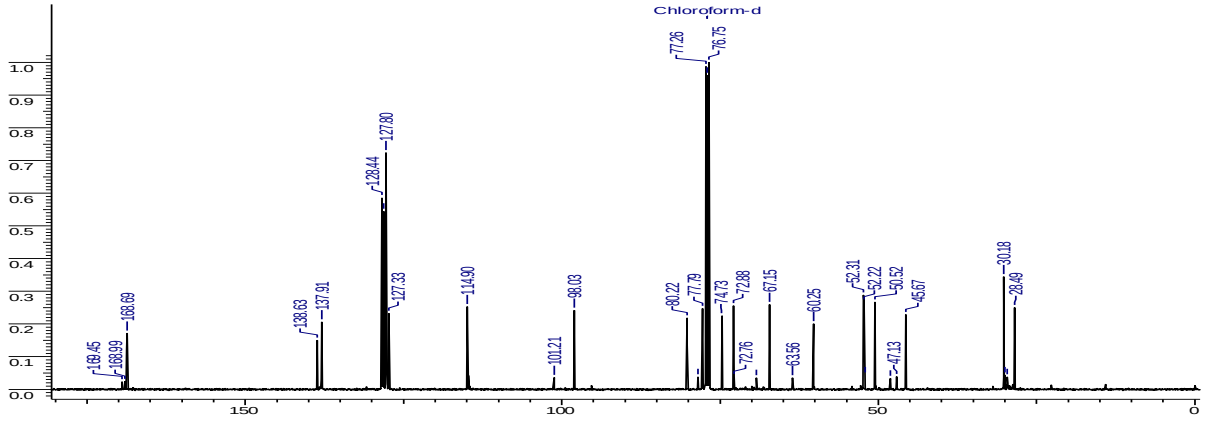
DEPT NMR Spectrum (50.32 MHz, $CDCl_3$) of Compound **24**



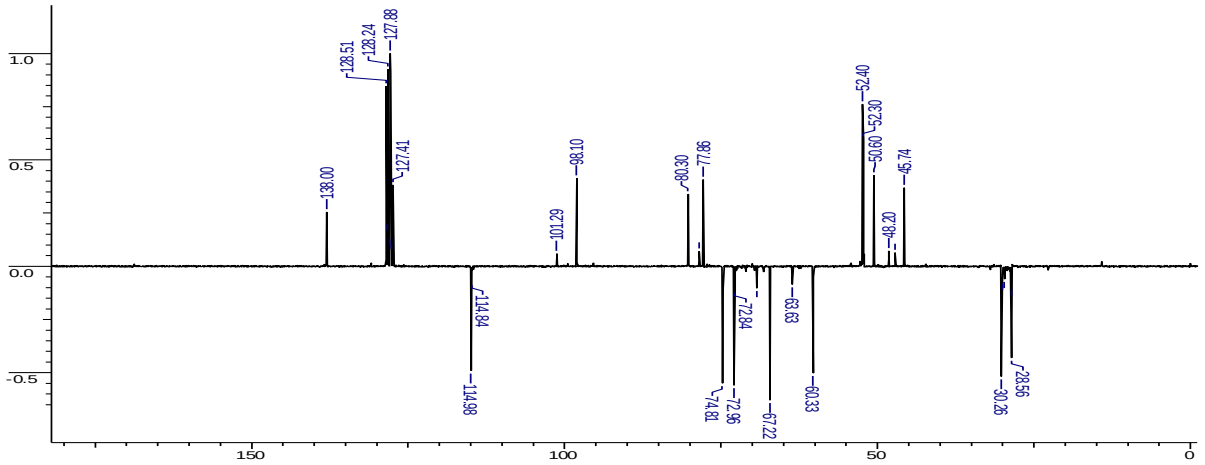
^{1}H NMR Spectrum (400.13 MHz, $CDCl_3$) of Compound **25**



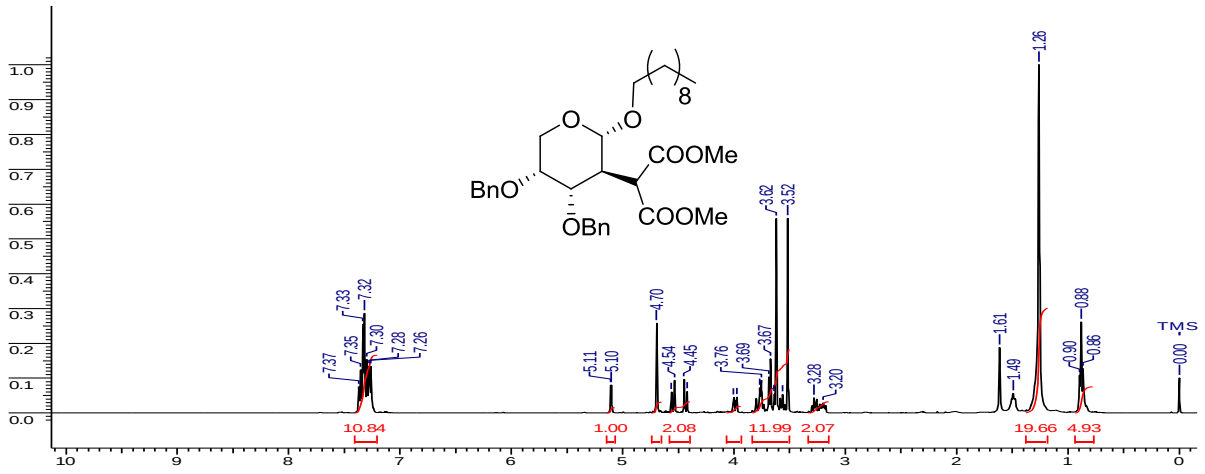
^{13}C NMR Spectrum (125.76 MHz, $CDCl_3$) of Compound **25**



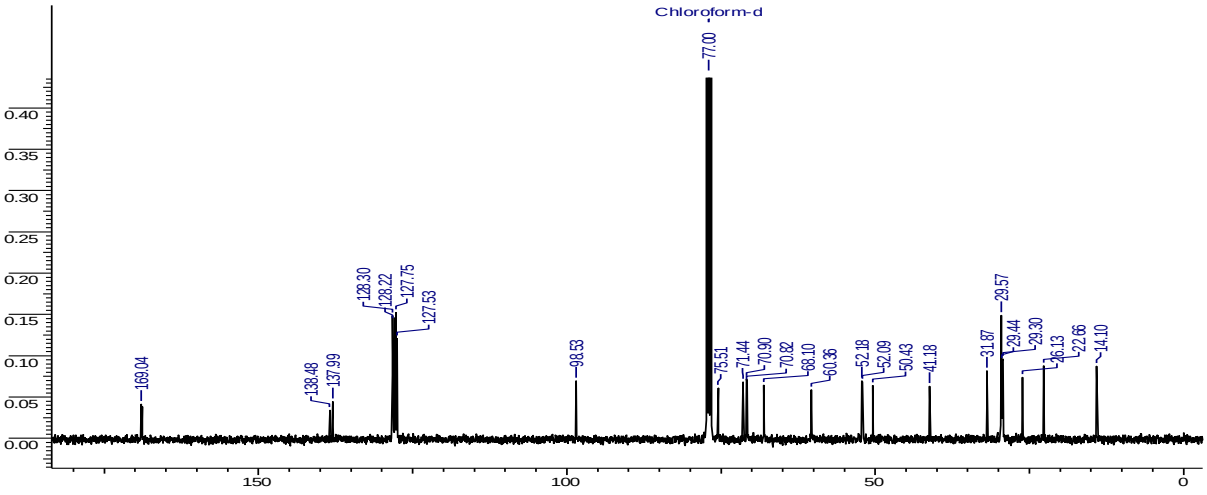
DEPT NMR Spectrum (125.76 MHz, $CDCl_3$) of Compound **25**



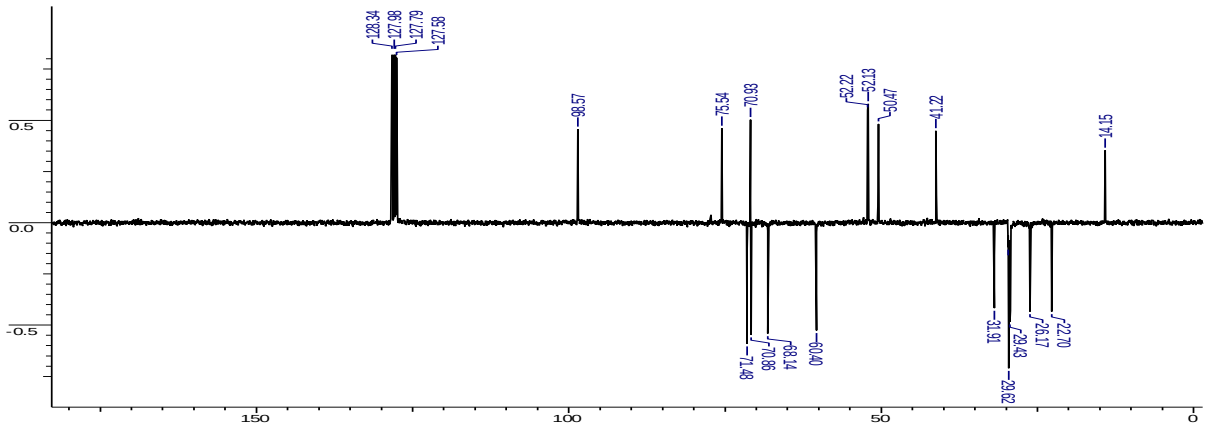
^{1}H NMR Spectrum (400.13 MHz, $CDCl_3$) of Compound **27**



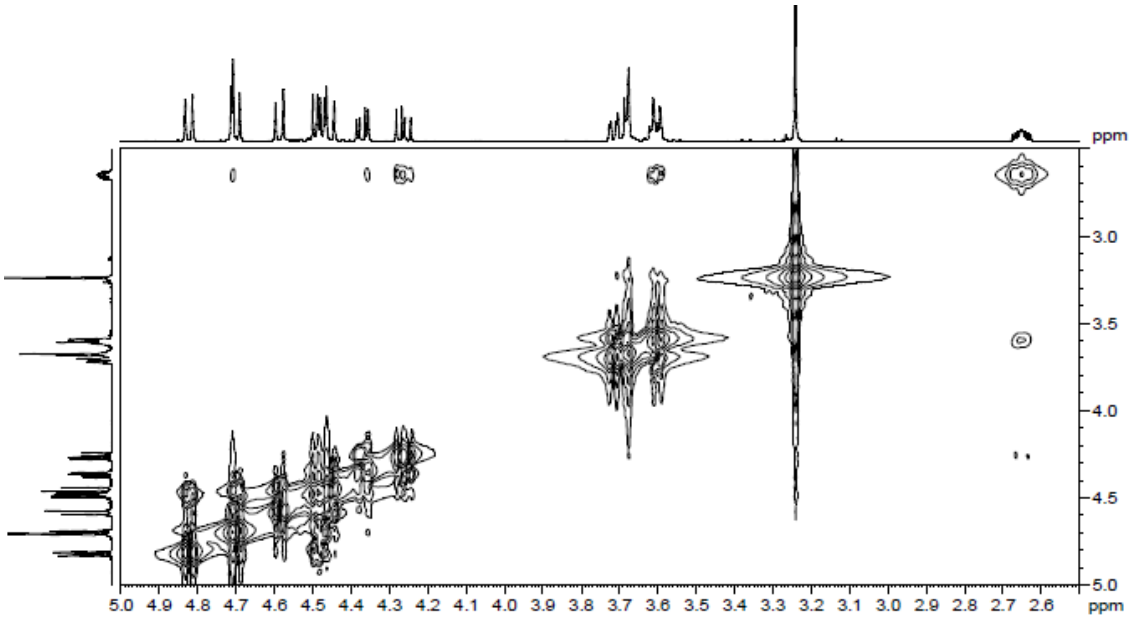
^{13}C NMR Spectrum (125.76 MHz, $CDCl_3$) of Compound **27**



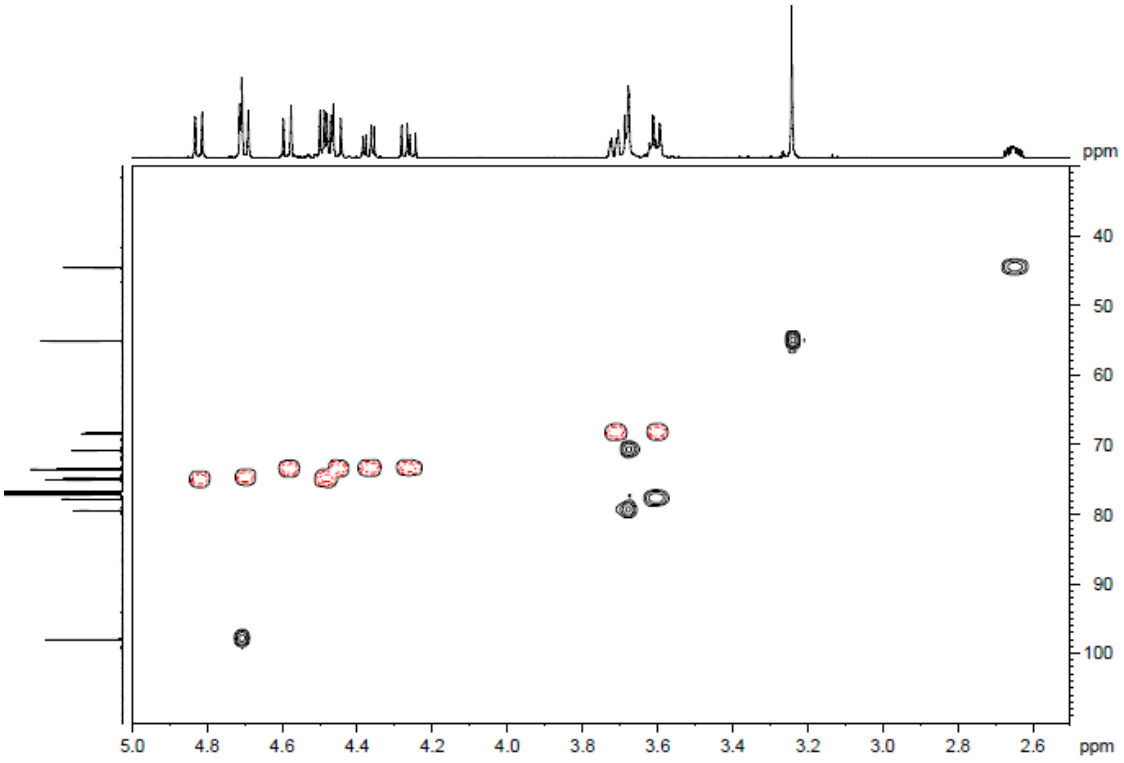
DEPT NMR Spectrum (125.76 MHz, $CDCl_3$) of Compound **27**



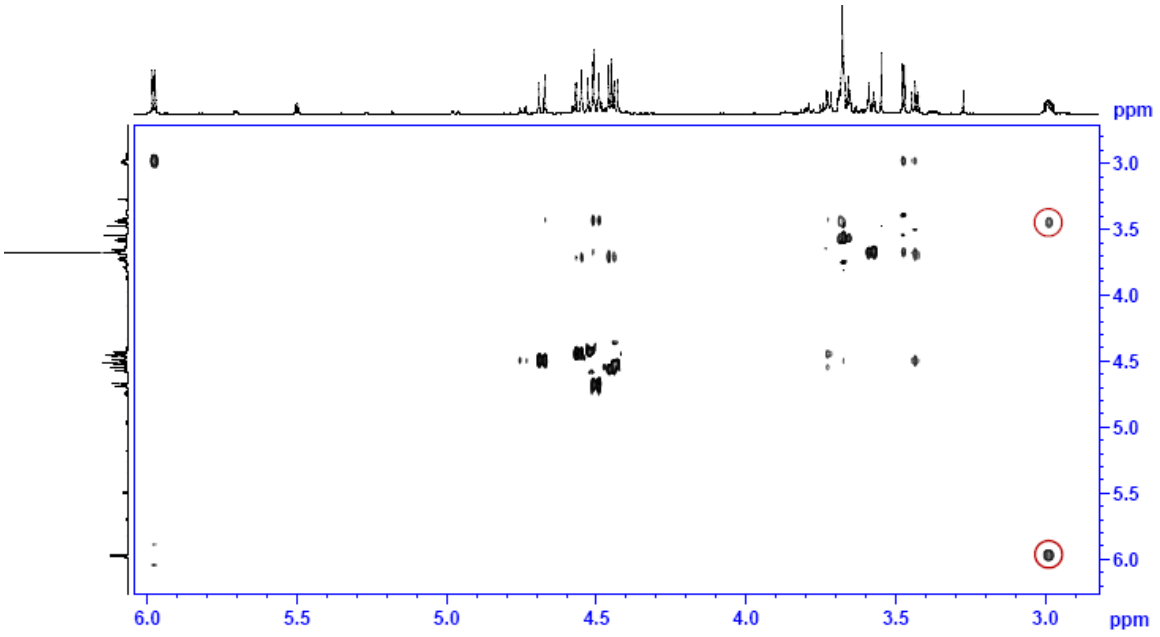
H, H-COSY NMR Spectrum (600 MHz, $CDCl_3$) of Compound **6a**



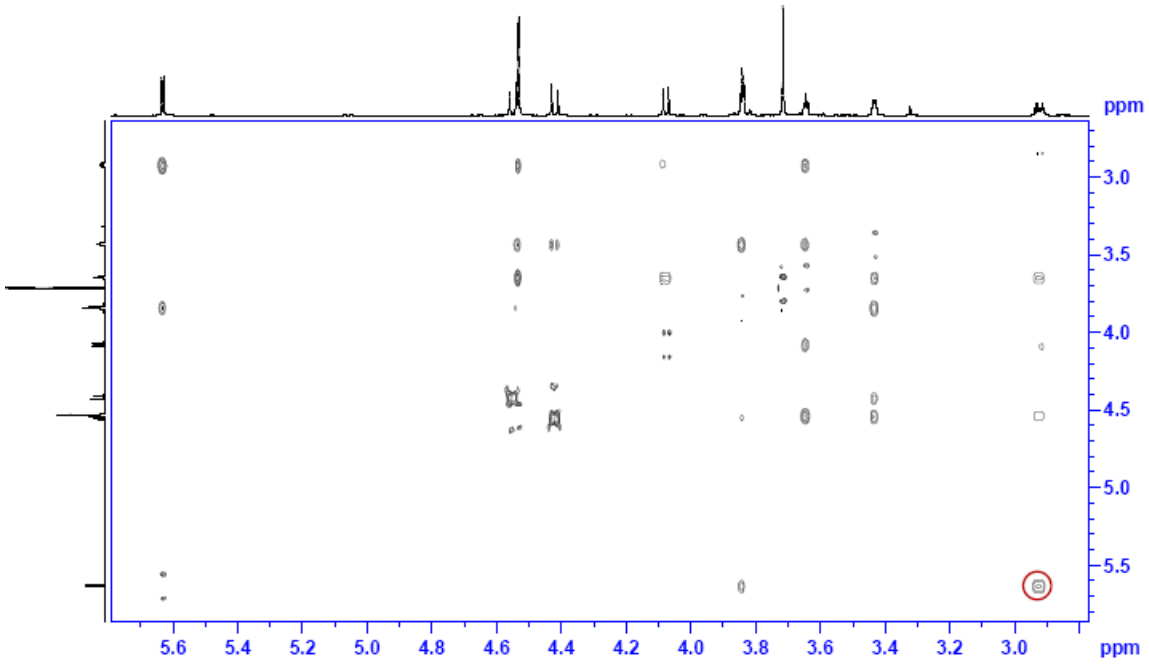
HSQC NMR Spectrum (600 MHz, $CDCl_3$) of Compound **6a**



NOESY Spectrum (500 MHz, $CDCl_3$) of compound **12a**



NOESY Spectrum (500 MHz, $CDCl_3$) of compound **12c**



Chapter 3: References

1. Horton, D.; Wander, J. D.; *The Carbohydrates*. Vol IB. Acad. Press, **1980**, 727.
2. a) Largo, R.; Alvarez-Soria, M . A.; Díez-Ortego, I. *Osteoarthritis Research Society*, **2003**, *11*, 290. b) Chan, P. S.; Caron, J. P.; Orth, M.W., *J. Rheum.* **2006**, *33*, 1329.
3. Houpt, J. B.; Mcmillan, R.; Wein, C.; Paget-Dellio, S. D., *J. Rheum.*, **1991**, 26, 2423.
4. Simanek, V.; Kren, V.; Ulrichova, J.; Gallo, J., *Biomed papers*, **2005**, 149(1), 51.
5. Setnikar, I.; Cereda, R.; Pacine, M. A.; Revel, L., *Arzneimittelforschung* **1991**, *41*, 157.
6. Reginster, J. Y.; Bruyere, O.; Fraikin, G.; Henrotin, Y., *Bull Hosp Joint Dis***, 2005**, *63*, 31.
7. a) Zurabyan, S. E.; Antenenko, T. S.; Khorlin, A.Y., *Carbohydr. Res.* **1970**, *15*, 21; b) Kiso, M.; Anderson, L., *Carbohydr. Res.*, **1979**, *72*, 15. c) Banoub, J.; Boullanger, P.; Lafont, D., *Chem. Rev*. **1992**, *92*, 1167.
8. Lemieux, R.U.; Takeda, T.; Chung, B.; in *Synthetic Methods for Carbohydrates;* Elkhadem, H.S. *ACS Symposium Series 39*; American Chemical Society, Washington D.C., 1976, pp. 90-115.
9. a) Schmidt, R.R.; Kinzy, W.; *Adv. Carbohydr. Chem. Biochem.* **1994**, *50*, 21; b) Schmidt, R.R., *Angew. Chem. Int. Ed. Engl.* 1986, 25, 212-235; c) Toepfer, A.; Kinzy, W.; Schmidt, R.R., *Liebigs Ann. Chem.* **1994**, 449.
10. a) Spijker, N.M.; WestErduin, P.;. van Boeckel, C.A.A.; *Tetrahedron* **1992**, *48*, 6297; b) Matsuzaki, Y.; Ito, Y.; Nakahara, Y.; Ogawa, T. *Tetrahedron Lett.* **1993**, *34*, 1061; c) Koeman, F.A.W.; Meisauer, J.W.G.; van Ritter, H.R.P.; Kamerling, J.P.; Vliegenthart, J.F.G.; *J. Carbohydr.Chem.* **1994**, *13*, 1. d) Kanie, O.; Crawley, S.C.; Palcic, M.M; Hindsgaul, O. *Carbohydr. Res.* **1993**, *243*, 139.
11. Debenham, J. S.; Madsen, R.; Reberts, C.; Fraser-reid, B.; *J. Am. Chem. Soc*. **1995**, *117*, 3302.
12. Debenham, J. S.; Fraser-reid, B.; *J. Org. Chem.* **1996**, *61*, 432.
13. Castro-Palomino, J. C.; Schmidt, R. R.; *Tetrahedron Lett.*, **1995**, *30*, 5343.

14. Castro-Palomino, J. C.; Schmidt, R. R.; *Tetrahedron Lett.*, **1995**, *38*, 6871.
15. a) Schmidt, R. R.; Kinzy, W. *Adv. Carbohydr. Chem. Biochem*. **1994**, *50*, 21. b) Garg, H. G.; Von dem Bruch, K.; Kunz, H. *Adv. Carbohydr. Chem. Biochem.* **1994**, *50*, 277. c) Banoub, J.; Boullanger, P.; Lafont, D. *Chem. Rev*. **1992**, *92*, 1167. d) Lafont, D.; Boullanger, P.; J. Carbohydr. Chem. 1992, 11, 567-586.
16. Das, J.; Schmidt, R. R. *Eur. J. Org. Chem.* **1998**, 1609.
17. Barroca, N.; Schmidt, R. R. *Org. Lett.* **2004**, *10*, 1551.
18. Lazarevic, D.; Theim, *J. Carbohydr. Res*. **2006**, *341*, 569.
19. Chen, H.-M.; Wither, S. G.; *Carbohydr. Res.* **2007**, *342*, 2212.
20. Koppert, K.; Brossmer, R.; *Tetrahedron Lett.* **1992**, *52*, 8031.
21. a) Elamparuthi, E.; Linker, T.; *Org. Lett.* **2008**, *10*, 1361. b) Elamparuthi, E.; Kim, B. G.; Yin, J.; Maurer, M.; Linker, T.; *Tetrahedron* **2008**, *64*, 11925.
22. a) Linker, T.; Hartmann, K.; Sommermann, T.; Scheutzow, D.; Ruckdeschel, E. *Angew. Chem.* **1996**, *15*, 108. b) Yin, J.; Sommermann, T.; Linker, T. *Chem. Eur. J.* **2007**, *13*, 10152. c) Linker, T.; Schanzenbach, D.; Elamparuthi, E.; Sommermann, T.; Fudickar, W.; Gyóllai, V.; Somsák, L.; Demuth, W.; Schmittel, M. *J. Am. Chem. Soc.* **2008**, *130*, 16003; d) Elamparuthi, E.; Linker, T.; *Angew. Chem.* **2009**, *121*, 1885; *Angew. Chem. Int. Ed.* **2009**, *48*, 1853; e) Yin, J.; Linker, T. *Org. Biomol. Chem.* **2009**, *7*, 4829.
23. a) Grieco, P. A. *Synthesis* **1975**, 67. b) Seitz, M.; Reiser, O. *Curr. Opin. Chem. Biol.* **2005**, *9*, 285. c) Burstein, C.; Tschan, S.; Xie, X.; Glorius, F. *Synthesis* **2006**, 2418.
24. Konaklieva, M. I.; Plotkin, B. J.; *Mini-Rev. Med. Chem.* **2005**, *5*, 73.
25. a) Lehmann, J.; Kohlenhydrate, Chemie und Biologie, 2nd ed., Thieme, Stuttgart, 1996; b) Bols, M. Carbohydrate Building Blocks, Wiley, New York, 1996; c) Lindhorst, T. K. Essentials of Carbohydrate Chemistry and Biochemistry 3rd ed., Wiley-VCH, Weinheim, 2007.
26. a) Gaertzen, O.; Misske, A. M.; Wolbers, P.; Hoffmann, H. M. R.. *Synlett* **1999**, 1041. b) Gaertzen, O.; Misske, A. M.; Wolbers, P.; Hoffmann, H. M. R.. *Tetrahedron Lett*. **1999**, *40*, 6359. c) Poláková, M.;. Pitt, N.; Tosin, M.; Murphy, P. V. *Angew. Chem. Int. Ed*. **2004**, *43*, 2518. d) Rat, S.; David, M.; Michaud, P.;

Kovensky, J.; Wadouachi, A.; *Tetrahedron* **2007**, *63*, 12424.

27. Alker, D.; Jones, D. N.; Taylor, G. M.; Wood, W. W. *Tetrahedron Lett*., **1991**, *13*, 1667.
28. Haveli, S. D.; Sridhar, P. R.; Suguna, P.; Chandrasekaran, S. *Org. Lett*., **2007**, 7, 1331.
29. Jimenez, O.; Rosa. G.; Lavilla, R. *Angew. Chem. Int. Ed*. **2005**, *44*, 6521.
30. Yin, J.; Linker, T.; *Chem. Eur. J*. **2009**, *15*, 49.
31. a) Brocke, C.; Kunz, H.; *Bioorg. Med. Chem.* **2002**, *10*, 3085. b) Winterfeld, G. A.; Schmidt, R. R.; *Angew. Chem. Int. Ed.* **2001**, *40*, 2654–2657. c) A. Varki, *Glycobiology* **1993**, 3, 97.
32. a) Ben, R. N. *Chem. Biochem.* **2001**, *2*, 161. b) Tsuda, T.; Nishimura, S.-I. *Chem. Commun.* **1996**, 2779.
33. a) Hotha, S.; Kashyap, S. *J. Am. Chem. Soc.* **2006**, *128*, 9620. b) Sureshkumar, G.; Hotha, S. *Chem. Commun.* **2008**, 4282. c) Sureshkumar, G.; Hotha, S. *Tetrahedron Lett.* **2007**, *48*, 6564.
34. Vidadala, S. R.; Hotha, S. *Chem. Commun.* **2009**, 2505.
35. a) Crich, D. *Acc. Chem. Res.* **2010**, *43*, 1144. b) Tvaroska, I.; Bleha, T. *Adv. Carbohydr. Chem. Biochem.* **1989**, *47*, 45.
36. Götze, S.; Fitzner, R.; Kunz, H. *Synlett* **2009**, 3346.
37. a) Lindberg, B. *Act. Chem. Scand.* **1949**, *3*, 1153. b) Lemieux, R. U.; Shyluk, W. P. *Can. J. Chem.* **1955**, *33*, 120.
38. Pilgrim, W.; Murphy, P. V. *J. Org. Chem.* **2010**, *75*, 6747.
39. Vidadala, S. R.; Pimpalpale, T. M.; Linker, T.; Hotha, S. *Eur. J. Org. Chem*, **2011**, 2426.

****

List of Publications

1. Synthesis of *C*-2 methylene glycosides from *C*-2 propargyloxymethyl glycals exploiting alkynophilicity of $AuCl_3$. Sudhir Kashyap, **Srinivasa Rao Vidadala** and Srinivas Hotha. *Tetrahedron Lett.* **2007**, *48,* 8960-8962.

2. Orthogonal Activation of Propargyl and *n*-Pentenyl Glycosides and 1,2-Orthoesters. **Srinivasa Rao Vidadala**, Shivaji A. Thadke and Srinivas Hotha. *J. Org. Chem.* **2009**, *74,* 9233-9236.

3. Methyl Glycosides Are Identified as Glycosyl Donors for the Synthesis of Glycosides, Disaccharides and Oligosaccharides. **Srinivasa Rao Vidadala** and Srinivas Hotha. *Chem. Commun.* **2009**, 2505-2507.

4. Gold Catalyzed Reactions of 2-*C*-Branched Carbohydrates: Mild Glycosidations and Selective Anomerizations. **Srinivasa Rao Vidadala**, Tukaram M. Pimpalpalle, Torsten Linker, and Srinivas Hotha. *Eur. J. Org. Chem.* **2011**, 2426-2430.

5. Propargyl Furanosides as Glycosyl Donors: synthesis of glycosides and Disaccharides. **Srinivasa Rao Vidadala,** Gaddamannugu Gayatri, G. Narahari Sastry and Srinivas Hotha. *Chem. Commun.* **2011** (DOI: 10.1039/C1CC13134F, In Press).

6. Lewis acid-catalyzed stereoselective lactonization and subsequent glycosidation of 2-*C*-malonyl carbohydrates., Tukaram Pimpalpalle, **Srinivasa Rao Vidadala**, Srinivas Hotha and Torsten Linker. *Chem. Commun.* **2011** (In Press).

7. Exploitation of C-2 functionlized methyl glycosides under Lewis acid catalysis. **Srinivasa Rao Vidadala**, Tukaram M. Pimpalpalle, Torsten Linker, and Srinivas Hotha (**Manuscript under preparation**).

8. Synthesis of Thioglycosides from Propargyl Glycosides Exploiting Gold Catalysts. Sudhir Kashyap, **Srinivas Rao Vidadala** and Srinivas Hotha. (**Manuscript under preparation**).

****