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Studies on Improving the Regioselectivity of Reactions of Sucrose: The Role of Molecular Recognition and Polymer Supported Syntheses

Ran Jiang

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Studies on Improving the Regioselectivity of Reactions of Sucrose:

The Role of Molecular Recognition and Polymer Supported Syntheses
<center>(TITLE)</center>

<center>BY</center>

<center>Ran Jiang</center>

THESIS

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IN THE GRADUATE SCHOOL, EASTERN ILLINOIS UNIVERSITY
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1992
<center>YEAR</center>

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Studies on Improving the Regioselectivity of

Reactions of Sucrose:

The Role of Molecular Recognition and

Polymer Supported Syntheses

Date Submitted: June 9, 1992

By Ran Jiang

Adviser: Dr. Jerry W. Ellis

Approved by the Thesis Committee

6/29/92

6-22-92

6/22/92

6/22/92

ABSTRACT

The world economy is critically dependent upon
natural resources. Because sucrose can be inexpensively
produced in large quantities and refined to a purity
unequalled by almost all other natural products, it has
been exploited as an industrial raw material for many
years, primarily as a sweetener. A major difficulty in
utilizing sucrose as an industrial feedstock is the lack
of regioselectivity in synthetic reactions due to its
eight hydroxyl groups of similar reactivity.

The long range goal in this work is to apply the
technique of molecular recognition by template
imprinting to the creation of a material that will bind
to sucrose and block certain of the hydroxyl groups.
Sucrose is a disaccharide composed of **D**-fructose and **D**-
glucose with the glucose in a chair conformation. The
strategy is to use **D**-glucose as a template to synthesize
a monomer with covalently bonded vinyl groups. The
monomer would be copolymerized with another monomer and
a crosslinking agent to prepare a three-dimensional
polymer, incorporating the glucose template. Removal of
the glucose would leave a cavity with the same

conformation as the glucose part of the sucrose molecule. Sucrose should then bind to the polymer cavity. This method could increase the regioselectivity of reactions of sucrose by blocking the glucose end of sucrose to permit reactions to occur on the fructose portion. Alternatively, a reaction could occur within the cavity. The stereochemistry of the functional groups inside the cavity would be primarily responsible for the molecular recognition characteristics of the cavity.

Methyl 2,3,4,6-tetra-*O*-methacryloyl-α-**D**-glucopyranoside, 4-nitrophenyl 2,3,4,6-tetra-*O*-methacryloyl-α-**D**-Glucopyranoside, and 4-nitrophenyl 2,3,4,6-tetra-*O*-methacryloyl-ß-**D**-glucopyranoside were chosen as possible monomers. These monomers have been synthesized and characterized by spectroscopy and elemental analysis.

Copolymerization of these three monomers with styrene and divinylbenzene have been carried out by using azobisisobutryonitrile (AIBN) as the initiator. A high concentration of crosslinking agent (divinylbenzene 50% in reaction mixture) was present in

the polymerization mixtures and three-dimensional polymers were formed with high rigidity. The polymers have been characterized by spectroscopy and other techniques.

DEDICATION

To my adviser, Professor Jerry W. Ellis, for his tremendous contribution in providing me guidance, inspiration, and assistance time and again.

ACKNOWLEDGEMENTS

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CHAPTER 1

INTRODUCTION

A. Background

The world economy is critically dependent upon oil
which is a non-renewable material. In order to maintain
an economic order in the world it is therefore
imperative that the future energy and chemical needs are
secured. In the short-term we must curb the wasteful
consumption of oil and in the long-term the dependence
upon oil must be reduced. Alternative resources such as
coal, tarsands, shale oil, natural gas and lignite,
agricultural and aquatic materials must be considered as
sources of energy and chemicals and the feasibility of
their utilization has been demonstrated, but not yet
commercially realized except in a few instances.
Although cellulose is the most abundant carbohydrate and
many cellulose derivatives are industrially important,
several technical difficulties in its processing make it
economically unattractive as a raw material for energy
and chemicals. Starch is also readily amenable to
chemical and biochemical modifications giving a range of
compounds presently derived through petrochemical
routes, as well as new derivatives of potential

commercial significance.

With a view to exploiting sucrose as an industrial raw material, the fundamental chemistry of sucrose has been investigated and has led to development of a number of products of commercial importance.

A major difficulty in utilizing sucrose as an industrial feedstock is the lack of regioselectivity in synthetic reactions due to the eight hydroxyl groups of similar reactivity on the sucrose molecule. Sucrose can form eight possible mono-substitution products, twenty-eight possible di-substitution products, and fifty-six possible tri-substitution products for example. So the typical reaction results in a very complex mixture requiring difficult separations in order to isolate a particular product in pure form. With so many products formed, the yield of any one of these is necessarily low. Selective acetylation of sucrose using 1.6 molar equivalents of acetic anhydride in pyridine has been claimed to give a mono-O-acetylsucrose in 95% yield.[1] However, the product was not characterized, and it is almost certainly not a homogenous material. Treatment of sucrose with 1.1 molar equivalents of acetic

anhydride in pyridine at -40°C gave, after chromatographic separation, 6-O-acetylsucrose in 40% yield. Evidence for its structure has been provided by NMR.[2] So while a few specific reactions do give reasonable laboratory yields of particular compounds, there exists no general method for the synthesis of specific derivates of sucrose.

Molecular recognition might be used as a technique to increase the regioselectivity of some reactions of sucrose. This would involve using glucose as a template molecule and creating a glucose specific cavity in a polymer matrix. This method should increase the regioselectivity of certain reactions, perhaps to allow a particular hydroxyl on sucrose to react.

B. Carbohydrates

Carbohydrates are among the most abundant constituents of plants and animals. They serve as sources of energy (sugars), as stores of energy (starch and glycogen), and provide structural stability as in the woody plants (cellulose). Carbohydrates may be divided into two broad groups: sugars and polysaccharides. Sugars are sweet, crystalline, and soluble in water. They are classified as monosaccharides, disaccharides and trisaccharides. The monosaccharides are further classified as trioses, tetroses, pentoses, etc., according to the number of carbon atoms in the molecule. Thus glucose (Fig. 1), $C_6H_{12}O_6$, is a hexose. Glucose, sometimes called dextrose, is the commonest monosaccharide, occurring free in the juice of fruits and in honey. Many disaccharides and polysaccharides, such as maltose, cellulose, and starch, give glucose upon hydrolysis.

Glucose contains four chiral centers, marked by asterisks, as shown in sixteen stereoisomers, so eight pairs of enantiomers, are expected. All sixteen of

4

```
        CHO
         |
       *CHOH
         |
       *CHOH
         |
       *CHOH
         |
       *CHOH
         |
       CH₂OH
```

Fig. 1   (+)-Glucose

```
           CHO
            |
    H ——————|—————— OH
            |
   OH ——————|—————— H
            |
    H ——————|—————— OH
            |
    H ——————|—————— OH
            |
          CH₂OH
```

Fig. 2   D-(+)-Glucose

```
           CHO
            |
   HO ——————|—————— H
            |
    H ——————|—————— OH
            |
   HO ——————|—————— H
            |
   HO ——————|—————— H
            |
          CH₂OH
```

Fig. 3   L-(-)-Glucose

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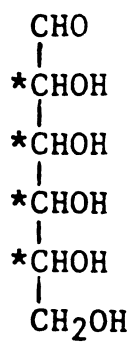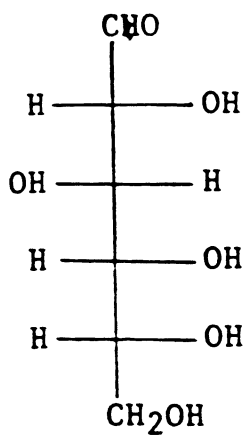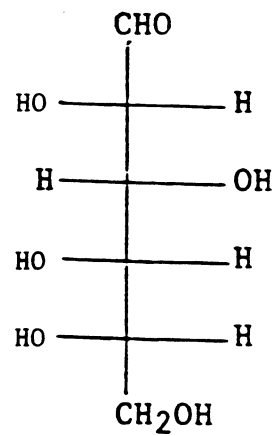
these possible stereoisomers are now known, through either synthesis in the laboratory or isolation from natural sources. Only three, (+)-glucose, (+)-mannose, and (+)-galactose, are found in abundance. The evidence upon which Fischer assigned the relative configuration to (+)-glucose leads to either of the enantiomeric structures **D**-(+)-glucose (Fig. 2) and **L**-(-)-glucose (Fig. 3).

The cyclic structures of **D**-(+)-glucose, called anomers, are hemiacetals whose structures are shown in Fig. 4 and Fig. 5. The specific rotations of α-D-(+)-glucopyranoside (Fig. 4) and ß-**D**-(+)-glucopyranoside (Fig. 5) are +112° and +19°, respectively.

Like **D**-(+)-glucose, methyl D-glucopyranoside, an acetal, occurs as anomers whose cyclic structures are represented in Fig. 6 and Fig. 7. The disaccharides are also glycosides and are acetals, which explains their ready hydrolysis by dilute acid. Of the disaccharides, only two, sucrose and lactose, are found abundantly in nature. (+)-Sucrose has the molecular formula $C_{12}H_{22}O_{11}$ and is a non-reducing sugar. When it is hydrolyzed by dilute aqueous acid,
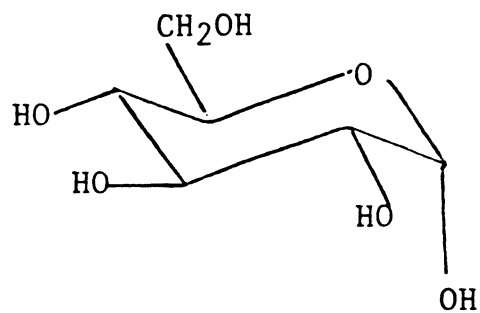
Fig. 4   Alpha-D-(+)-Glucose
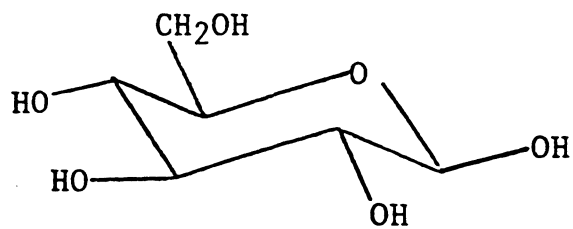
Fig. 5 Beta-D-(+)-Glucose
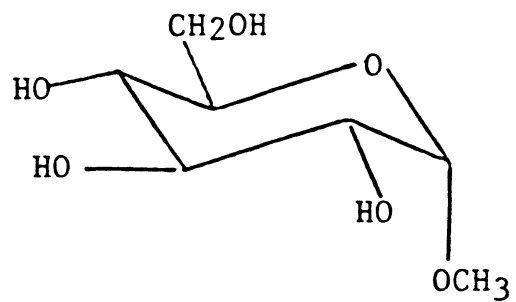
Fig. 6 Methyl Alpha-D-Glucopyranoside
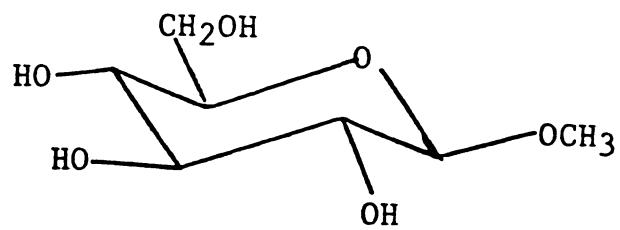
Fig. 7 Methyl Beta-D-Glucopyranoside

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or by the action of the enzyme invertase, it yields equal amounts of **D**-(+)-glucose and **D**-(-)-fructose. This hydrolysis is accompanied by a change in the sign of rotation from positive to negative. (+)-Sucrose is also called α-**D**-glucopyranosyl ß-**D**-fructofuranoside or ß-**D**-fructofuranosyl α-**D**-glucopyranoside (Fig. 8).

The configuration and conformation of sucrose have been determined by X-ray crystallography,[3] neutron diffraction,[4] and NMR spectroscopy.[5] The positions of the hydrogen atoms in crystalline sucrose were determined by neutron diffraction. Based on Laser-Raman[6] and X-ray diffraction[7] studies of sucrose in aqueous solution, it has been suggested that in dilute solution sucrose lacks intramolecular hydrogen bonds but as the concentration is increased, the bridging together by hydrogen bonds is accompanied by a twisting around the glycosidic linkage that leads to the form of sucrose molecule found in crystal (Fig. 9).[7]

With so many hydroxyl groups with similar reactivities, the technique of blocking or protecting groups must be employed to gain regioselectivity.

α-D-Glucopyranoside   β-D-Fructofuranoside
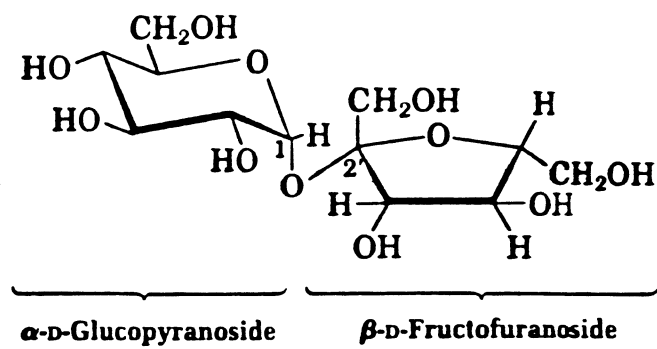
Fig. 8 Sucrose
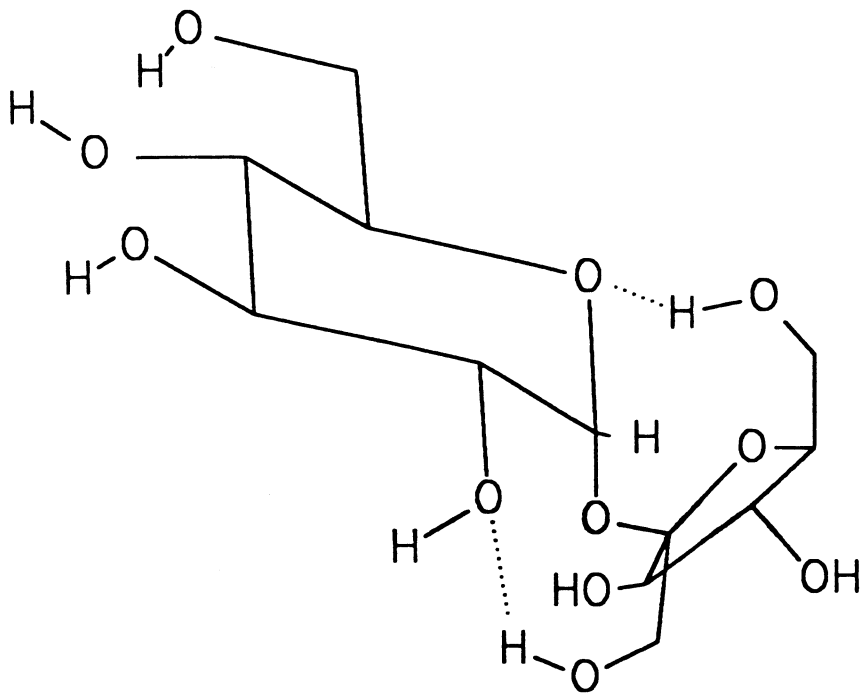
Sucrose

Fig. 9 Hydrogen bonding in sucrose molecule

Even with this advantage, certain derivatives of even the simple monosaccharides are still difficult to prepare. There are various groups which are used to protect or block certain hydroxyl groups in a carbohydrate, so that these hydroxyl groups will not participate in reactions which are used to prepare derivatives of the carbohydrate. The most commonly used blocking groups are esters, ethers and cyclic acetals. Esters include acetate, benzoate, carbonate, nitrate, sulfonate, trifluoroacetate, carbanilate and phosphate. Ethers typically used are methyl, benzyl, triphenylmethyl, vinyl and 2,4-dinitrophenyl. Cyclic acetals include isopropylidene, benzylidene, methylene, ethylidene and cyclohexylidene.

C. Molecular Recognition

The construction of molecular size cavities containing a defined arrangement of functional groups has attracted much attention. As binding sites, the cavities of cyclodextrins,[8,9,10] crown ethers, cryptates,[11,12,13] cyclophanes,[14,15,16] and similar ring systems have been studied. Of special interest in this respect would be the use of polymeric substances for preparing specific binding sites and catalytically active compounds as receptor and enzyme models. The use of polymeric substances would be aesthetically pleasing since enzymes are polymers as well. Many of their unique features are directly related to their polymeric nature.

Molecular recognition might be greatly enhanced by incorporating stereochemical features in the cavity.[17,18] This approach was introduced by Wulff to prepare cavities specific for D-mannose.[19,20,21] When applied to sucrose this would involve using glucose as a template molecule from which an appropriate monomer molecule would be synthesized. The monomer would then be used to prepare the polymer, thus creating a glucose

specific cavity. This cavity should have the exactly same conformation as the glucose template from which it was prepared. Then the glucose portion of sucrose should bind to the polymer cavity. Conversely, by using **D**-fructose as a template, a polymer could be made that would bind the fructose end of sucrose. This method should allow new studies on the regioselectivity of certain reactions, perhaps to allow a particular hydroxyl on each monosaccharide unit of sucrose to react.

It is common practice[22,23,24,25] to introduce catalytically active groups and binding groups into a polymer by the copolymerization of monomers containing functional groups. Ion exchange resins are an example. By this method a polymer is obtained with randomly distributed groups (Scheme 1, A). Another possibility is the grafting of side chains already containing the desired arrangement of functional groups onto a polymer (Scheme 1, B). A third possibility is the polymerization of monomers already containing the desired functional groups in the backbone. In this case the groups are localized
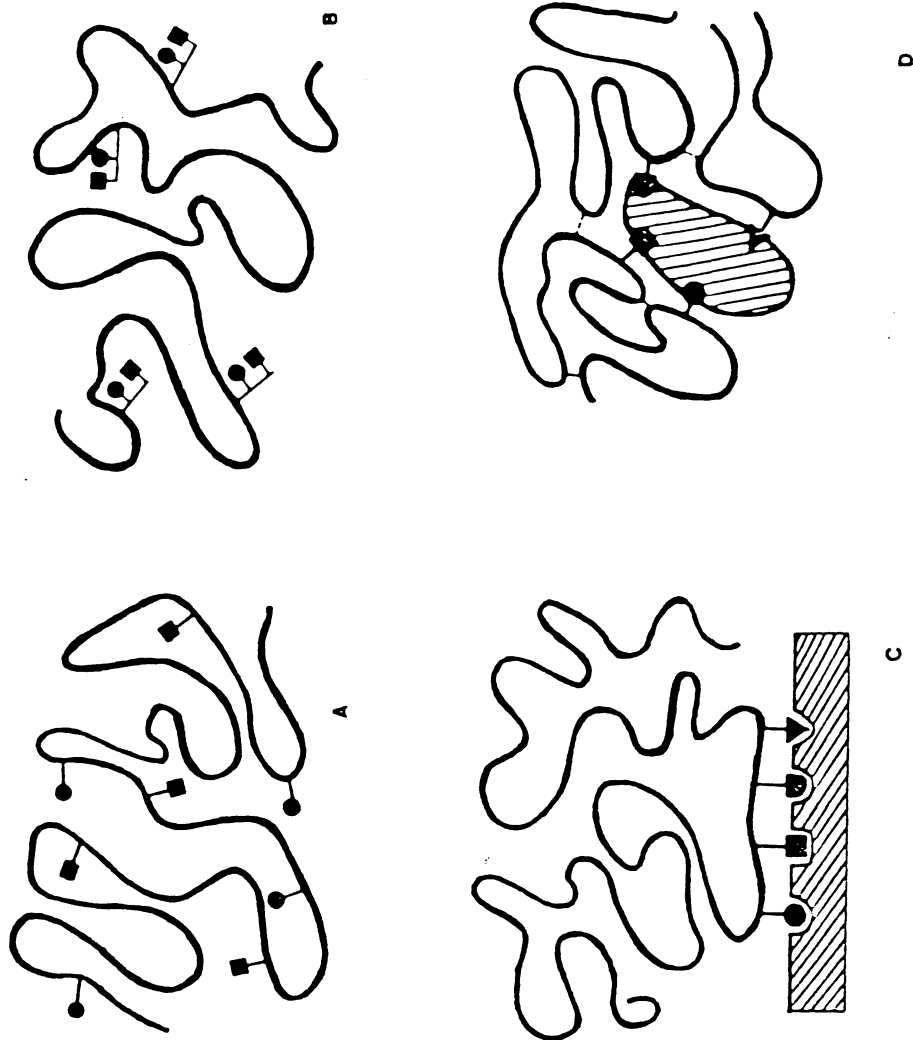
Scheme 1. Possible arrangements of functional groups in synthetic and natural polymers.

(Reproduced from "Polymeric Reagents and Catalysts", Ford, W. T., ed. Wulff, G., p189)

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in the main chain one after another (Scheme 1, C). In this case, called "continued words" arrangement[26], only two dimensional structures can be formed. G. Wulff[17,19] described for the first time synthetic polymers with functional groups in a "discontinued word" arrangement (Scheme 1, D).

The functional groups to be introduced were bound in the form of polymerizable vinyl derivatives to a suitable template molecule. This monomer then was copolymerized under conditions such that highly crosslinked polymers were formed. After removal of the template, a polymer remained with cavities stamped by the template and with functional groups in a fixed stereochemistry that corresponded to that of the template.

The stereochemistry of the functional groups inside the cavity is primarily responsible for the observed molecular recognition.[33]

Vyas[27] has studied glucose binding protein. Binding specificity and affinity are conferred primarily by polar planar side-chain residues that form intricate

networks of cooperative and bidentate hydrogen bonds with the sugar substrates, and secondarily by aromatic residues that sandwich the pyranose ring. The similarity of the binding protein structures, the nature of the binding sites and the ligand-binding properties of these proteins are essential for function in both active transport and chemotaxis.[28,29,30] Vyas found that glucose binding protein utilizes thirteen hydrogen-bonds to glucose as shown in Scheme 2. These hydrogen bonds are formed between peptide residues and the hydroxyl groups or pyranose oxygen of D-glucose to give a very high affinity for the sugar.

The most widespread binding interaction in biological recognition involves a hydrogen bond directed from protein to substrate. Thus a cavity containing several directed hydrogen bonding groups should lead to binding and potential orientation of a substrate with complementary groups.[31] This would suggest that a large number of binding groups inside the cavity would increase selectivity.

In the approach used by Wulff[33] only two
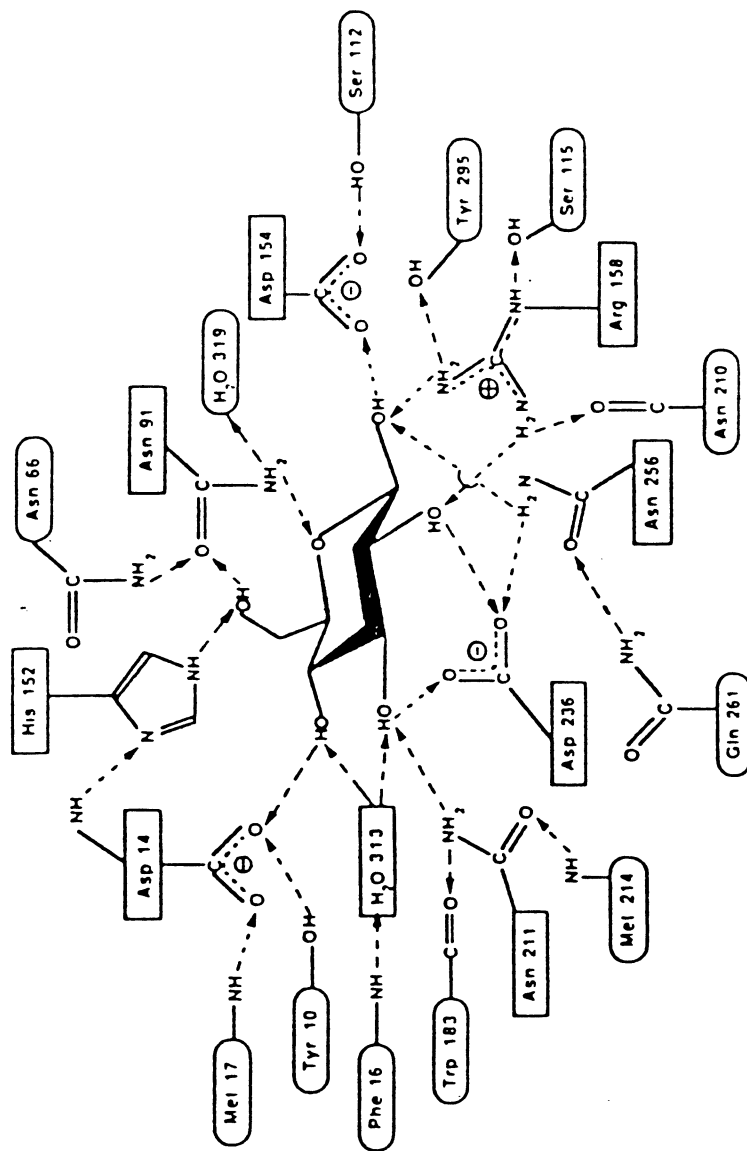
Scheme 2 The hydrogen bond network starting at the D-glucopyranose
and extending to two shells of residues.

(Reproduced from Science Vol. 242, p1291, Vyas, N. K.,
Vyas, M. N., Quiocho, F. A., 1985)

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polymerizable binding groups were linked to phenyl α-**D**-mannopyranoside as a template molecule, and this was copolymerized to form the highly crosslinked, macroporous polymers. Removal of the template leaves behind cavities possessing a shape and an arrangement of the functional groups corresponding to that of the **D**-mannose template. The maintenance of the stereochemical arrangement of the functional groups as well as the shape of the cavities has been evaluated by the ability of the polymer to recognize the template molecules used for their preparation. This concept is outlined in Scheme 3. Thus, for optically active templates the ability for resolution of the racemate of the template was taken as a measure for the exactness of the shape of the cavity and of the orientation of functional groups within the free cavities.[32,33] In the studies reported by Wulff[33] for a monomer with only two polymerizable groups to imprint the stereochemical information, equilibrium constants for the resolution of racemic mannose were in the range of only 1-4.

Another important question which still remains unsolved in the molecular imprinting procedure is the
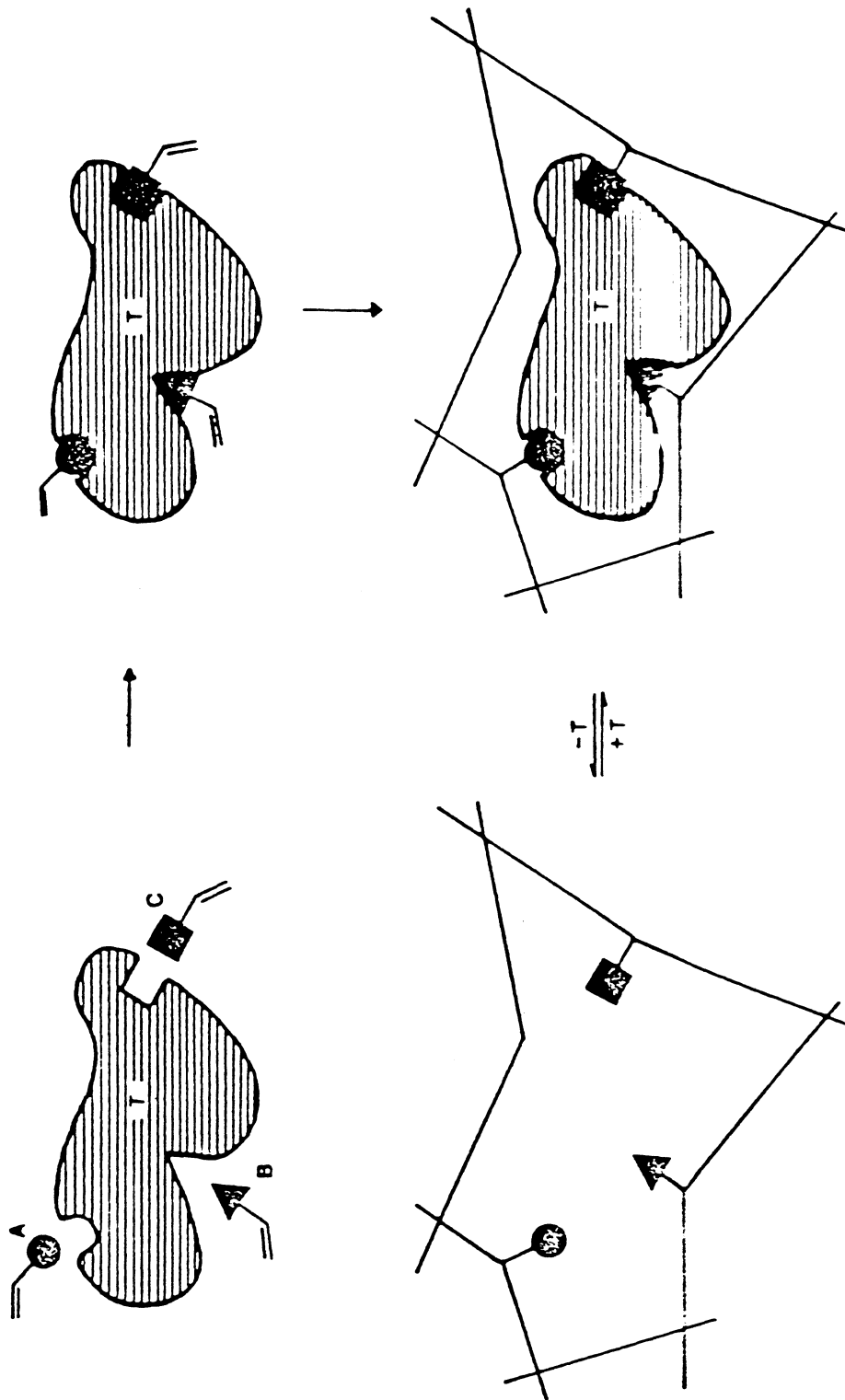
Scheme 3. The preparation of microcavities with functional groups in a "discontinuate word" arrangement.

(Reproduced from "Polymeric Reagents and Catalysts", Ford, W. T., ed. Wulff, G., p190)

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precise mechanism of molecular recognition. The high selectivity observed is believed on one hand to be mainly due to the shape of the cavity and the binding sites within the cavity which are primarily responsible for the driving force to bring the substrates inside the cavity. On the other hand, the molecular recognition could also be due to the spatial arrangement of the functional groups (binding sites) within the cavity.[34,35,36] Certainly, the shape of the cavity plays an important role.[37,38,39] A study by Shea and Sasaki[40] showed that shape selectivity may be the most important factor for molecular recognition observed in the their system.

D. Polymerization

The copolymerization of two or more monomers was not investigated until about 1911, when copolymers of olefins and diolefins were found to have rubbery properties and were more useful than homopolymers made from the single monomers. A copolymer system is said to be ideal when the two radicals show the same preference for adding one of the monomers over the other: $k_{11}/k_{12} = k_{21}/k_{22}$.

Reaction	Rate
$M_1\cdot + M_1 \longrightarrow M_1\cdot$	$k_{11}[M_1\cdot][M_1]$
$M_1\cdot + M_2 \longrightarrow M_2\cdot$	$k_{12}[M_1\cdot][M_2]$
$M_2\cdot + M_1 \longrightarrow M_1\cdot$	$k_{21}[M_2\cdot][M_1]$
$M_2\cdot + M_2 \longrightarrow M_2\cdot$	$k_{22}[M_2\cdot][M_2]$

Table 1 Rate of Copolymerization

From Table 1, two extreme types of kinetic behavior can be recognized for a copolymerization. In the first, $k_{12}/k_{11} = k_{21}/k_{22} = 0$, and no copolymerization will occur. Instead, parallel polymerizations of the two monomers M_1 and M_2 will lead to the formation of two

homopolymers $(M_1)_n$ and $(M_2)_m$. In the second extreme case, $k_{11}/k_{12} = k_{22}/k_{21} = 0$ and a copolymerization will take place to produce an alternating copolymer $(M_1M_2)_n$. Most copolymerizations fall between these two extremes.

The reactivity of monomers toward free radicals is a function of the reactivity of the monomers and also depends on the nature of the attacking radical. The reactivity of monomers and radicals in copolymerization is determined by the nature of the substituents on the double bond of the monomer. The substituents may activate the double bond, making the monomer more reactive; may stabilize the resulting radical by resonance; or may provide steric hindrance at the reaction site. These considerations are important in this study since all of the vinyl groups in the monomer should be successfully incorporated into the three-dimensional polymer matrix if total imprinting of the stereochemical information is to occur.

In a copolymerization, chain propagation involves the addition of a free radical to the double bond of a monomer molecule. The product must itself be a free radical and the process can be repeated. In fact, it is

common for thousands of monomer molecules to add successively to the end of the chain. The most likely form of monomer addition is called head-to-tail addition. Alternatively, the addition may involve a head-to-head or a tail-to-tail reaction. Free-radical chains can be terminated by reaction of a growing polymer radical with some other free radical in the system. The various steps of an addition polymerization are shown in Scheme 4.

It is important to note that the polymer chain can be terminated by chain transfer reactions. The chain transfer reactions will remove a radical fragment from the second molecule with concurrent generation of a radical residue from that second molecule. When the second molecule is a polymer molecule, the result is generally the formation of a branched polymer. When the second molecule is a branched polymer molecule, the result is generally the formation of crosslinked polymers or network polymers. Such materials are usually swelled by solvents, but they do not dissolve. In fact, this insolubility can

Initiation

$$\text{(C}_6\text{H}_5)\text{-C-O-O-C-(C}_6\text{H}_4) \xrightarrow{\Delta} 2 \text{ (C}_6\text{H}_5)\text{-C-O}^{\cdot} \longrightarrow 2 \text{ (C}_6\text{H}_5)^{\cdot} + 2CO_2$$

$$\text{(C}_6\text{H}_5)^{\cdot} + CH_2=CH\text{-(C}_6\text{H}_5) \longrightarrow CH_2\text{-}\overset{\cdot}{C}H\text{-(C}_6\text{H}_5)$$

Propagation

$$\text{(C}_6\text{H}_5)\text{-}CH_2\text{-}\overset{\cdot}{C}H + nCH_2=CH \longrightarrow \text{(C}_6\text{H}_5)\text{-}(CH_2\text{-}CH)_n CH_2\text{-}\overset{\cdot}{C}H$$

Termination (Coupling)

$$2 \text{ (C}_6\text{H}_5)(CH_2\text{-}\overset{\cdot}{C})_n CH_2\text{-}\overset{\cdot}{C}H \longrightarrow$$

$$\text{(C}_6\text{H}_5)(CH_2\text{-}CH)_n CH_2\text{-}CH - CH - CH_2(CH\text{-}CH_2)_n \text{(C}_6\text{H}_5)$$
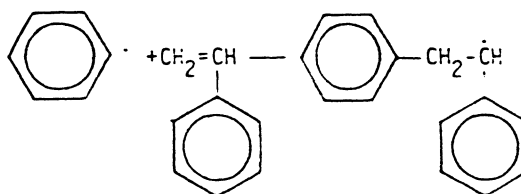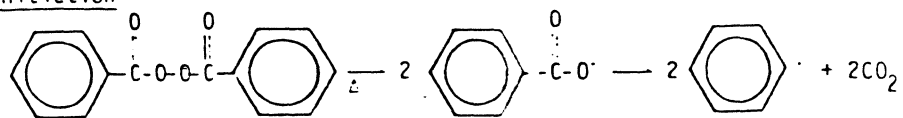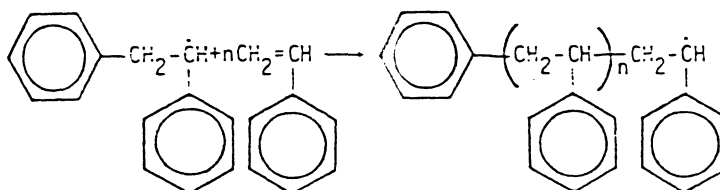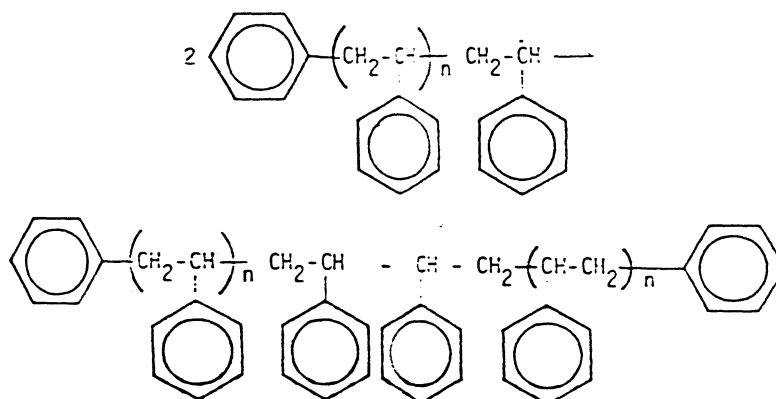
Termination (Disproportionation)

$$2 \text{ (C}_6\text{H}_5)(CH_2\text{-}CH) CH_2\text{-}\overset{\cdot}{C}H \longrightarrow \text{(C}_6\text{H}_5)(CH_2\text{-}CH)_n CH=CH_2 +$$

$$\text{(C}_6\text{H}_5)(CH_2\text{-}CH)_n CH_2\text{-}CH_2$$
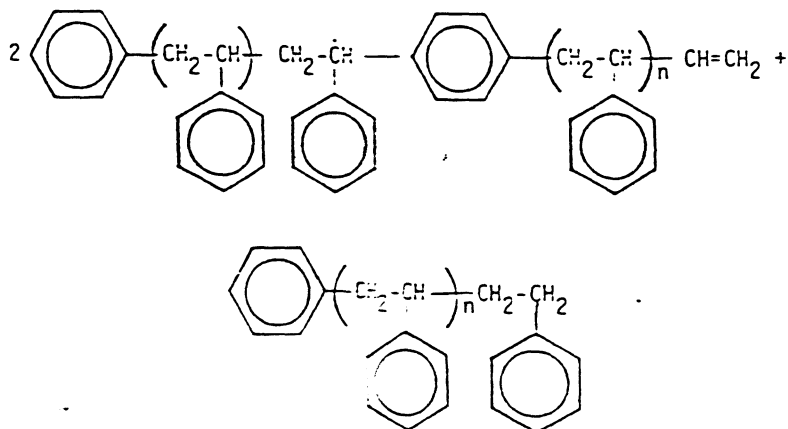
Scheme 4. The various steps of an addition polymerization

be used as a cautious criterion of a crosslinked structure. Actually, the amount by which the polymer is swelled by a liquid depends on the density of crosslinking: the more crosslinks present, the smaller is the amount of swelling. If the degree of crosslinking is high enough, the polymer may be a rigid, high-melting, unswellable solid, such as diamond. Light crosslinking of chains favors the formation of rubbery elastomeric properties.

CHAPTER 2

RESULTS AND DISCUSSION

A. The Choice of Monomers

The overall strategy in this work was to accomplish molecular recognition by applying the technique of template imprinting to the creation of a polymer that will bind to sucrose and block certain of the hydroxyl groups. The choice of monomers was very critical. The more complete chemistry and conformation information of α-glucose make it a good choice for the template, as opposed to **D**-fructose. The glucose binding protein with thirteen hydrogens bonds would suggest using a monomer with <u>several</u> polymerizable units to capture the stereochemical information of the glucose template. Wulff[33] relatively low equilibrium constants for the resolution of racemic mannose by the polymer imprinted with just <u>two</u> polymerizable unites would also suggest this. Since complete substitution on a sugar is the easiest reaction to complete, a <u>tetra</u>-substituted monomer would be an obvious choice.

Given the shape of sucrose (Fig. 8), it is unclear it an alpha linked glucose template is absolutely

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necessary or not. Either anomer may work. Those that are readily obtained or prepared are clear choices here.

For the aglycon, a benzene derivative would be preferable since phenols readily react with glycosyl halides to produce glycosides. Including a nitro group would provide nitrogen for an additional elemental analysis check and stretching absorption bands in the infrared region for additional analytical use.

For the polymerizable units, methacrylate was a good choice due to low cost of starting materials. Since methyl methacrylate easily copolymerized with styrene, the methacrylate esters of glucose would preassembly have similar characteristics.

B. Synthesis of the Monomers

In this study it was found that the completely esterified glycosides could be formed from methacrylic anhydride in pyridine. The synthetic route is shown in Scheme 5 and Scheme 6.

Methyl 2,3,4,6-tetra-O-methacryloyl-α-D-glucopyranoside (Fig. 12) exhibits a stretching frequency for the ester carbonyl groups at 1728 cm-1 and a strong band for the C-O-C stretching vibrations at 1164 cm^{-1}. The absorption for conjugated C=C bonds appears as a strong band at about 1635 cm^{-1}. Tetra-O-acetyl-α-D-glucopyranosyl bromide Fig. 14), 4-nitrophenyl tetra-O-acetyl-ß-D-glucopyranoside (Fig. 15), 4-Nitrophenyl 2,3,4,6-tetra-O-methacryloyl-α-D-glucopyranoside (Fig. 20) and 4-nitrophenyl 2,3,4,6-tetra-O-methacryloyl-ß-D-glucopyranoside (Fig. 17) all exhibit similar absorption bands as the methyl 2,3,4,6-tetra-O-methacryloyl-α-D-glucopyranoside. In addition the stretching frequencies for aromatic C=C bonds give bands at about 1596, 1516, 1456 cm^{-1} and the nitro group shows absorption bands at 1496 and 1343 cm^{-1}. The nitro groups stretching absorption
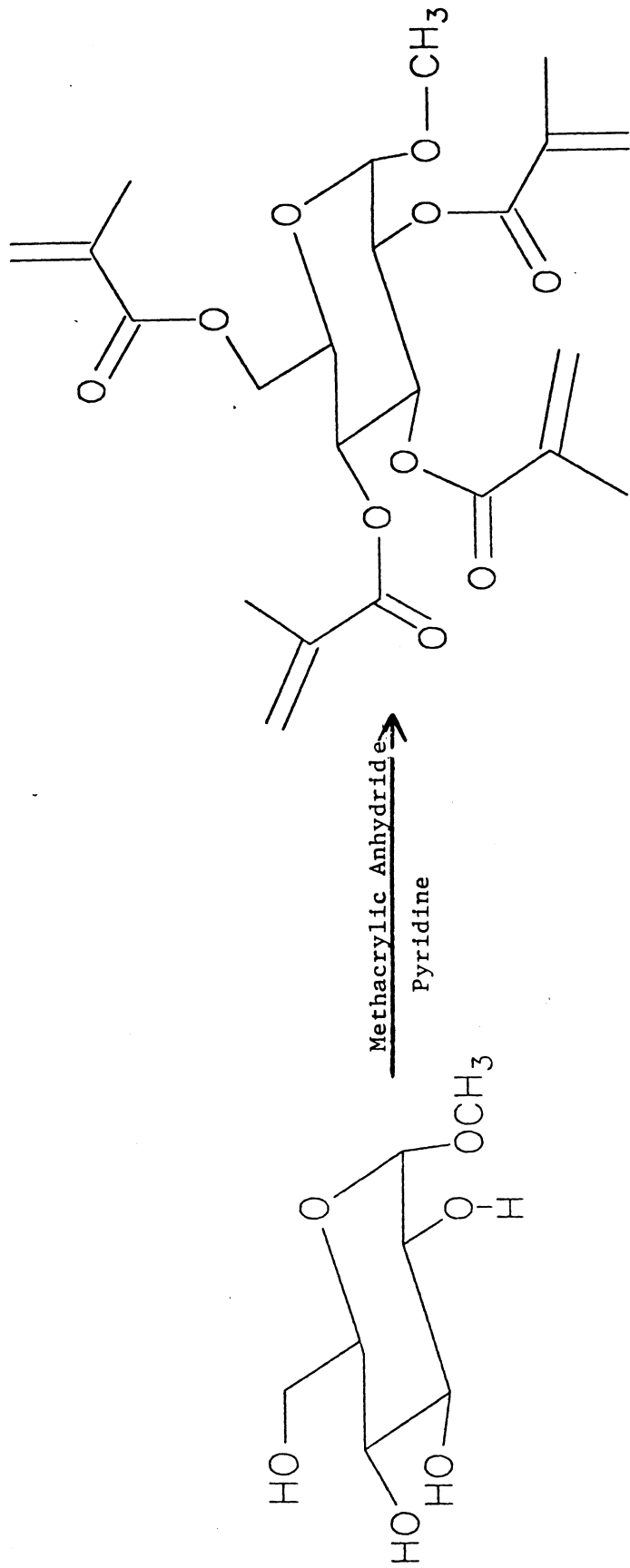
Scheme 5. The synthetic route of methyl 2,3,4,6-tetra-O-methacryloyl-alpha-D-glucopyranoside.
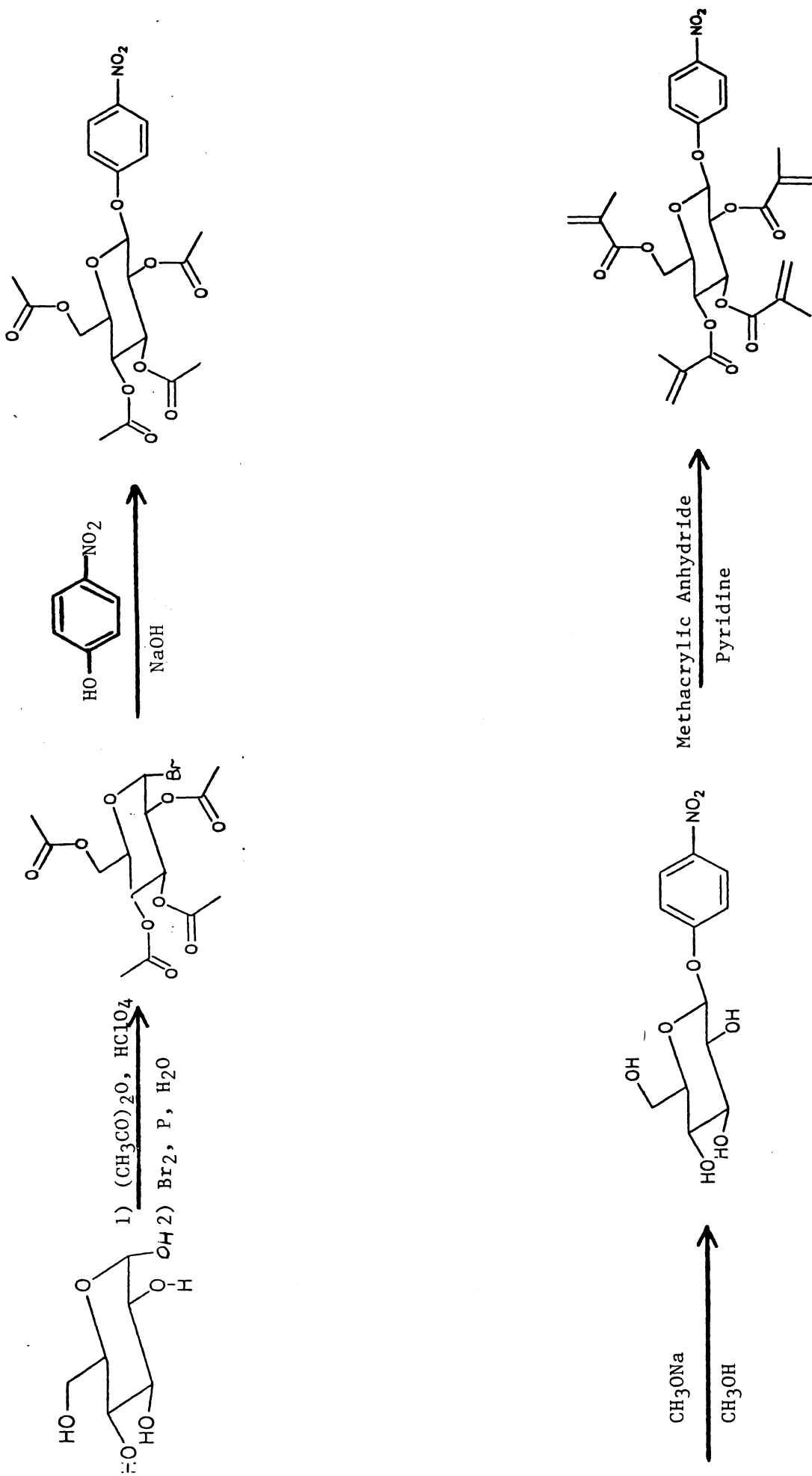
Scheme 6. The synthetic route of p-nitrophenyl 2,3,4,6-tetra-O-methacryloyl-beta-D-glucopyranoside

bands are also evident in the IR spectrum of p-nitrophenyl ß-**D**-glucopyranoside (Fig. 16).

A ^{1}H NMR spectrum of methyl 2,3,4,6-tetra-*O*-methacryloyl-α-**D**-glucopyranoside was obtained by using DMSO-d$_6$ as the solvent (Fig. 25-26). The methoxyl methyl group appears a singlet at 3.3 ppm. The four methacrylate methyl groups are singlets at 1.76-2.03 ppm. Four of the vinyl protons appear as singlets at 6.10, 5.98, 5.96, and 5.92 ppm. They were shifted downfield due to the anisotropic effect of the neighboring ester carbonyl group. The other four vinyl protons appear as a multiplet centered at 4.24 ppm. The anomeric proton, the only one bonded to a carbon bearing two oxygens, is usually easily identified by its downfield chemical shift and coupling constant. The anomeric proton appears as a doublet with a coupling constant dependent upon whether it was α or ß.

The vicinal proton-proton coupling constants depend upon the dihedral angle (φ) separating the two protons.[41] The magnitude of the vicinal couplings constant(J) exhibits an angular dependence of the approximate form:

$$J = J_o \cos^2\phi + C$$

Where J_o and C are constants. These were allocated values[42] of J_o = 8.5 for $0° < \phi < 90°$, J_o = 9.5 for $90° < \phi < 180°$, and C = -0.28. Karplus[43] emphasized that the dihedral angular dependence is only one of several factors influencing the magnitude of vicinal couplings. The Karplus dependence shows that large (about 10 Hz) vicinal coupling constants indicate antiparallel protons, whereas small values (about 3-4 Hz) are typical of gauche-disposed protons. Williams and Bhacca[44] found that the values of $J_{a,e}$ differed significantly from the values of $J_{e,e}$, even though a dihedral angle of 60 °C should be present in both relationships. The anomeric proton appears as a doublet at 5.08 ppm with a coupling constant 4 Hz which corresponds to the α anomer.

A ^{1}H NMR spectrum of tetra-O-acetyl **α-D**-glucopyranosyl bromide was obtained by using $CDCl_3$ as the solvent (Fig. 27-28). The four methyl groups appear as singlets at 2.08-2.21 ppm. The anomeric proton, the only one bonded to a carbon bearing an oxygen and a bromine, appears as a doublet at 6.62 ppm with a

coupling constant 4 Hz which is consistent with the α anomer.

A ^{1}H NMR spectrum of 4-nitrophenyl 2,3,4,6-tetra-O-acetyl-ß-**D**-glucopyranoside was obtained by using DMSO-d$_6$ as the solvent (Fig. 29-30). Again the four methyl groups appear as singlets at 2.08-2.21 ppm. The four hydrogens on the benzene ring show two doublets centered at 8.18 and 7.08 ppm. The anomeric proton appears as a doublet at 5.82 ppm with a coupling constant 10 Hz which is corresponds to the ß anomer.

A ^{1}H NMR spectrum of 4-nitrophenyl ß-**D**-glucopyranoside was obtained using DMSO-d$_6$ as the solvent (Fig. 35-37). The four hydrogens on the benzene ring show two doublets centered at 8.21 and 7.24 ppm. The anomeric proton appears as a doublet at 5.08 ppm. The addition of D$_2$O changed the intensities of signals for hydrogens at hydroxyl groups which show at 5.47, 5.18, 5.11, 4.61 ppm and allowed for easy identification of the anomeric proton which appears as a doublet at 5.08 ppm.

A ^{1}H NMR spectrum of 4-nitrophenyl 2,3,4,6-tetra-O-

methacryloyl-ß-**D**-glucopyranoside was obtained by using DMSO-d_6 and $CDCl_3$ as the solvent (Fig 10 and Fig. 38-41). The four methyl groups are singlets at 1.88-1.89 ppm. The four hydrogens on the benzene ring appear as two doublets centered at 8.22 and 7.22 ppm. Four of the vinyl protons appear as singlets at 6.08, 6.02, 6.00, and 5.98 ppm. They are shifted downfield due to the anisotropic effect of the neighboring ester carbonyl group. The other four vinyl protons appeared as a multiplet centered at 5.70 ppm. The anomeric proton appears as a doublet at 5.98 ppm with a coupling constant of 8 Hz. In a similar manner the proton at carbon 2 can be easily identified as two doublets centered at 5.35 ppm, which $J_{1,2}$ = 8 Hz and $J_{2,3}$ = 10 Hz for antiparallel coupling. The proton on carbon 3 appears as triplet at 5.30 ppm with J = 10 Hz and the proton on carbon 4 appears as triplet at 5.72 ppm with J = 10 Hz. The proton on carbon 5 is also unique since it is the only proton not bonded to a carbon bearing an ester group. Ester groups cause downfield shifts of nearby protons. The most upfield
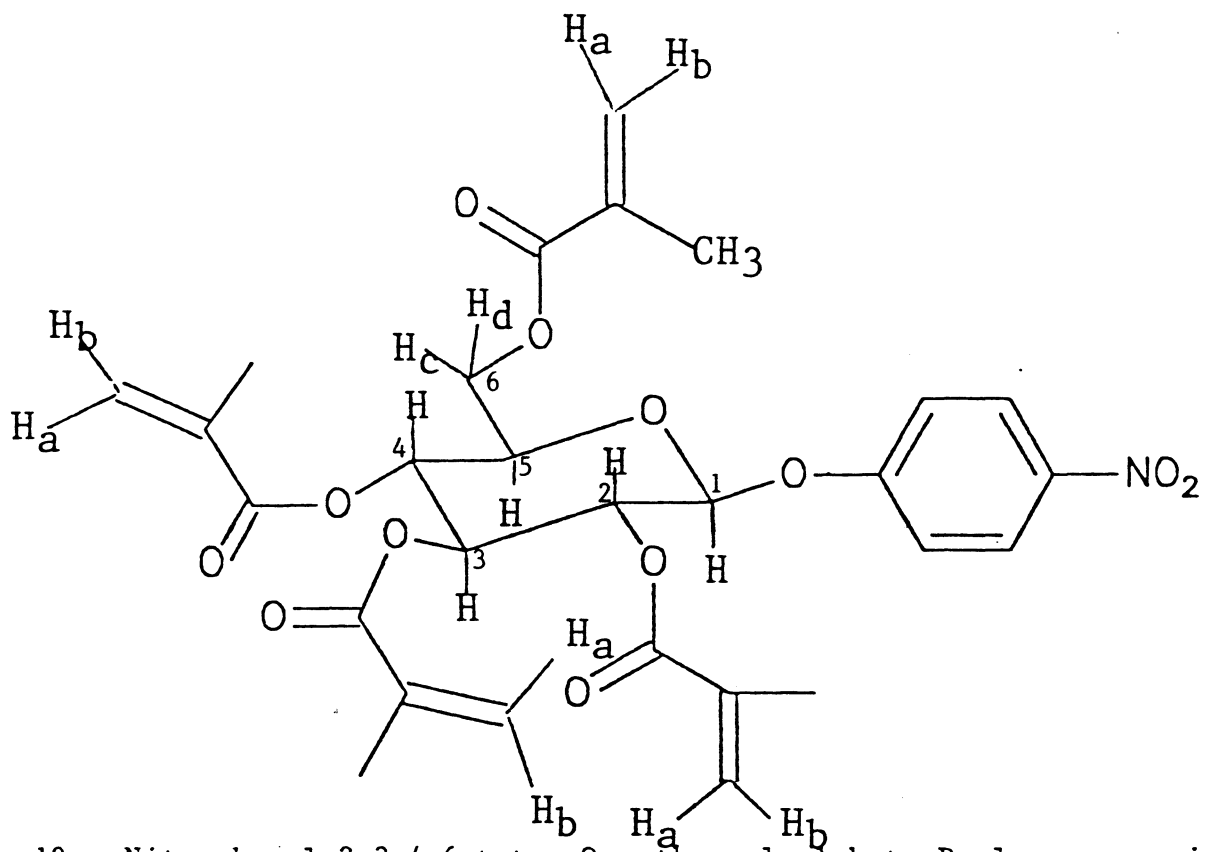
Fig. 10 p-Nitrophenyl 2,3,4,6-tetra-O-methacryloyl-beta-D-glucopyranoside

single proton with complex coupling could be labelled as that proton on carbon 5 at about 4.55 ppm. It should be split by the proton on carbon 4 and the two non-equivalent protons on carbon 6. The remaining protons on carbon 6 also appear upfield at 4.35-4.22 ppm, near the proton on carbon 5. This chemical shift is not clearly understood.

A ^{1}H NMR spectrum of 4-nitrophenyl 2,3,4,6-tetra-O-methacryloyl-α-D-glucopyranoside was obtained by using $CDCl_3$ as the solvent (Fig. 11 and Fig. 43-44). The four methyl groups show one singlet at 1.89 ppm. The four hydrogens on the benzene ring show two doublets at 8.21 and 7.25 ppm. The four singlets at 6.13, 6.10, 6.06, and 6.04 ppm integrating to one proton each were again assigned to the vinyl protons as before. The other four vinyl protons appeared as a multiplet centered at 5.60 ppm. A coupling constant of 4 Hz for the doublet at 5.90 ppm for the α monomer was consistent with the expected values for both coupling constant and chemical shift. In a similar manner the proton at carbon 2 can be easily identified as two doublets at 5.18 ppm, $J_{1,2}$ = 4 Hz and $J_{2,3}$ = 10 Hz. The protons on carbons 3 and 4 appear as triplets
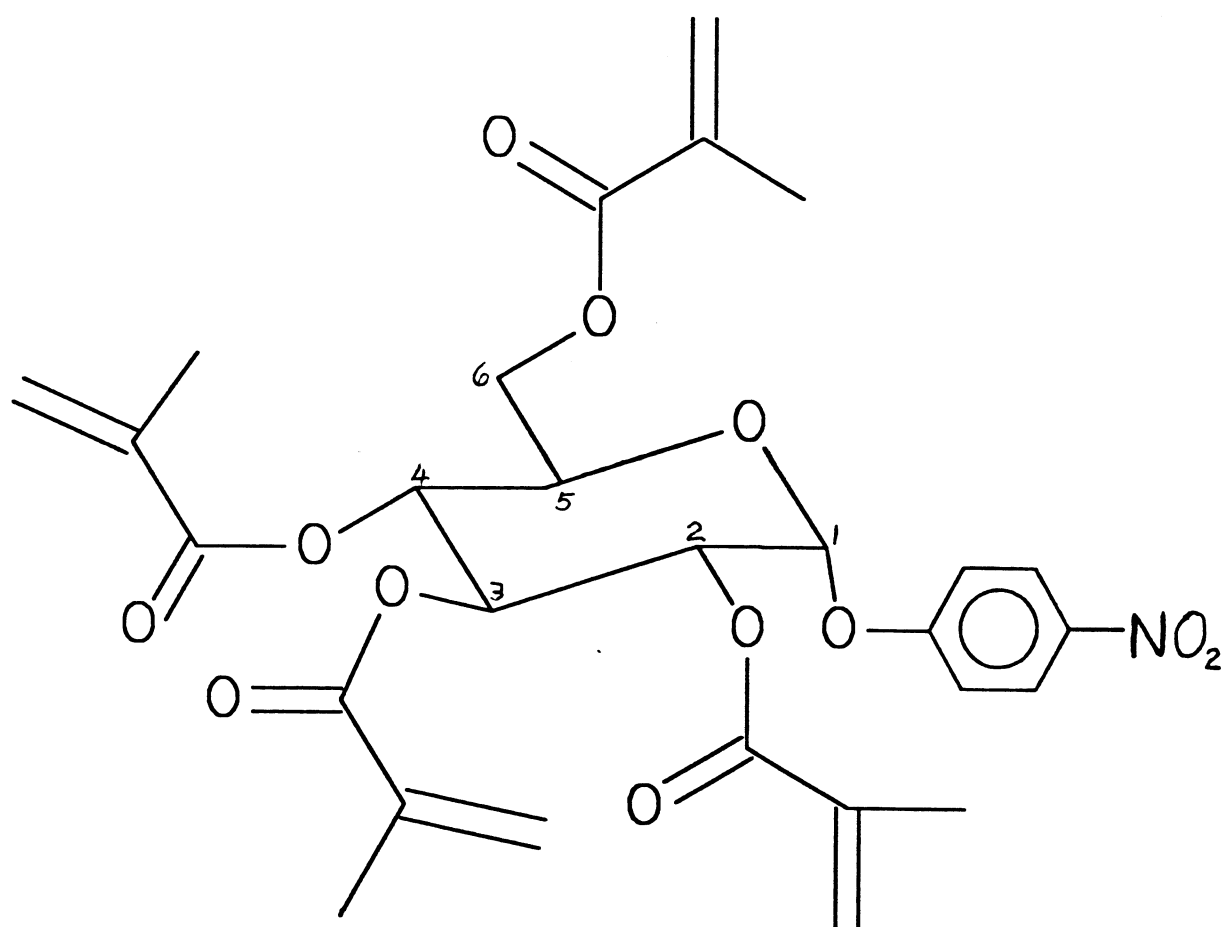
Fig. 11 p-Nitrophenyl 2,3,4,6-tetra-O-methacryloyl-alpha-D-glucopyranoside

at 5.93 and 5.34 ppm and each with J = 10 Hz. Proton on carbon 5 appear at about 4.20 ppm and the remaining protons on carbon 6 appear nearby at 4.30-4.18 ppm.

The ^{13}C NMR spectrum of 4-nitrophenyl 2,3,4,6-tetra-*O*-methacryloyl-**α**-**D**-glucopyranoside shows methyl groups at about 18 ppm, cyclic carbons at 62-71 ppm with C_1 at 94 ppm, vinyl groups at 117-126 ppm, aromatic carbons at 126-128 ppm except the one substituted by the nitro group which is at 143 ppm and the other substituted by oxygen which appears at 161 ppm, carbonyl groups at 166-167 ppm and the carbons **α** to the carbonyl groups at 135-136 ppm.

C. Polymerization

The bulk of the polymer was formed from styrene with an equal-molar amount of divinylbenzene as a crosslinking agent to give a three-dimensional polymer with 100% crosslinking.

The copolymer with methyl tetra-O-methacryloyl-α-**D**-glucopyranoside exhibits the ester stretching frequency at 1728 cm-1 (Fig. 13). The stretching frequency for conjugated C=C bonds is moderate band at about 1635 cm^{-1}. The strong band for the C-O-C stretching vibrations is shown at 1164 cm^{-1}. The lack of absorption for conjugated C=C at 1635 cm^{-1} indicates that there are no detectable conjugated vinyl groups in the polymer. The copolymers of 4-nitrophenyl 2,3,4,6-tetra-O-methacryloyl-α-**D**-glucopyranoside (Fig. 21 and Fig. 22) and 4-nitrophenyl 2,3,4,6-tetra-O-methacryloyl-ß-**D**-glucopyranoside (Fig. 18 and Fig. 19) with styrene and divinylbenzene have similar absorption bands as the methyl 2,3,4,6-tetra-O-methacryloyl-α-**D**-glucopyranoside copolymer except the stretching frequencies for aromatic C=C bonds at about 1596, 1516, 1443 cm^{-1} and the nitro group absorption bands at 1483 and 1350 cm^{-1}. A band at

1635 cm^{-1} for stretching vibrations of conjugated C=O indicated that there may be a trace of unpolymerized monomer in the methyl 2,3,4,6-tetra-*O*-methacryloyl-α-**D**-glucopyranoside copolymer. After extraction with acetone and chloroform to remove monomer, this peak disappeared although very little polymer weight reduction was observed.

A high concentration of crosslinking agent (50% divinylbenzene in the reaction mixture) was present in the polymerization mixtures in order to produce a high rigidity polymer.

CHAPTER 3

CONCLUSIONS

Tetramethacrylate esters of glucose derivatives can be prepared and purified. The methacrylate monomers can be copolymerized with styrene and divinylbenzene to form a three-dimensional crosslinked polymer. Based on the current evidence, essentially all of the monomer was incorporated and apparently all four of the polymerizable methacrylate units were complete incorporated into the three-dimensional polymer network.

The 4-nitrophenyl group was not as suitable for quantitative analytical purposes as expected since the frequencies of nitrophenyl group were small due to the fact that the nitro group was such a small fraction of the polymer.

CHAPTER 4

EXPERIMENTAL

A. Methods and Materials

Pyridine was dried by distilling from barium oxide after refluxing for four hrs, then it was dried by molecular sieves (3A) or dried by molecular sieves (3A) only. Styrene and divinylbenzene were run through a column of alumina to remove inhibitors. Red phosphorus was washed with hot water, filtered and kept under vacuum. All the other chemicals are obtained from Aldrich Chemical Co. and used as received. Thin layer chromotograms were run on chromatography plates with Silica Gel GF 250 microns (Analtech, Newark, DE) and column chromatography was accomplished with silica gel 70-230 mesh, 60 A (Aldrich Chemical Company, Milwaukee, WI) and using chloroform and acetone (20:1 volume). Melting points were recorded on a Fisher-Johns Melting Point Apparatus or a Thomas Hoover Capillary Melting Point Apparatus (Arthur H. Thomas Company, Philadelphia, PA) and are uncorrected.

B. Instruments

Nuclear magnetic resonance spectra were recorded on a General Electric QE-300 FT-NMR (General Electric Nuclear Magnetic Resonance Instruments, Fremont, CA) and reported in ppm (δ) relative to TMS in DMSO-d$_6$ or CDCl$_3$. Infrared spectra were recorded on a Nicolet 20DX-B (Nicolet, St. Louis, MO). Samples were made as KBr pellets or as films on NaCl plates.

C. Procedures

Methyl 2,3,4,6-tetra-*O*-methacryloyl-α-D-Glucopyranoside. In a 50 mL flask, methyl α-D-glucopyranoside(1.00 g, 5.15 mmol) and methacrylic anhydride (7.67 mL, 51.5 mmol) were added to distilled pyridine (20 mL). The suspension was stirred in an ice-water bath until the methyl α-D-glucopyranoside was all dissolved and the stirring was continued at room temperature for seven days. The solution was poured with stirring into a beaker containing a mixture of ice and water and then 20 mL of ether was added with stirring. The organic layer was separated and the aqueous layer was twice extracted with 10 mL portions of ether. The ether solutions were combined, washed once with water, then with saturated sodium bicarbonate solution until basic, then with sulfuric acid until neutral, and again with water. The ether solution was dried over magnesium sulfate overnight. After removal of the drying agent and ether, the product was purified by flash chromatography with chloroform and acetone (20:1 volume) as the solvent. The rapid chromatography reduced separation times to 1-2 hrs and allowed the resolution of components having $\Delta R_f > 0.15$ on analytical

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TLC. Purification gave 1.19 g (49.5%) of methyl 2,3,4,6-tetra-*O*-methacryloyl-α-**D**-glucopyranoside as an oil: IR 2957, 2930, 1728, 1635, 1456, 1317, 1297, 1164, 1044, 945, 812, 759 cm^{-1}, ^{1}H NMR (DMSO-d$_6$) δ 6.10 (s, 1H), 5.98 (s, 1H), 5.96 (s, 1H), 5.92 (s, 1H), 5.71 (ddd, J=6 Hz, 1H), 5.67 (dd, J=6 Hz, 1H), 5.56 (dd, J=10 Hz, 1H), 5.21 (dd, J=10 Hz, 1H), 5.08 (d, J=4 Hz, 1H), 4.98 (d, J=4 Hz, 1H), 4.95 (d, J=4 Hz, 1H), 4.35-4.05 (m, 4H), 3.30 (s, 3H), 2.03 (s, 3H), 1.92 (s, 3H), 1.84 (s, 3H), 1.76 (s, 3H).

Tetra-*O*-acetyl α-D-Glucopyranosyl Bromide. This material was synthesized according to a literature procedure[45]. In a 500 mL flask equipped with an efficient stirrer and a thermometer, 40 mL of acetic anhydride was cooled in an ice and water mixture, and 0.24 mL of 70% perchloric acid was added slowly. The solution was warmed to room temperature and 10.0 g of anhydrous D-glucose was added to the stirred mixture at such a rate, over an about 0.5 hrs period, to keep the reaction temperature between 30 and 40 °C. Red phosphorus was added after cooling the reaction mixture to 20 °C and followed by addition of 18 g (5.8 mL) of bromine at such a rate as to keep the reaction

temperature below 20 °C.   Water (3.6 mL) was added

slowly to the continuously stirred and cooled mixture

over an about 0.5 hour period to prevent the temperature

from rising above 20 °C.   The reaction mixture was kept

2 hrs at room temperature.   Chloroform (30 mL) was

added, and the mixture was filtered through a glass

fiber filter paper.   The reaction flask and the filter

funnel were washed with 5 mL of chloroform.   The

filtrate was poured into 80 mL of water (near 0 °C)

contained in a separatory funnel.   After washing, the

chloroform layer was drawn off into a separatory funnel

which contained 30 mL of 0 °C water.   The operation was

repeated by adding 50 mL of chloroform to the original

aqueous mixture and combining the chloroform extracts.

After vigorous shaking, the chloroform layer was poured

into 500 mL of a stirred, saturated aqueous solution of

sodium hydrogen carbonate in a beaker.   The mixture was

transferred to a separatory funnel with the aid of a

little chloroform and shaken vigorously.   The chloroform

layer was dried 10 min with dry sodium sulfate.   The

mixture was filtered, and the faintly yellow solution

was evaporated under reduced pressure below 60 °C in a

rotary   evaporator.   Pure   tetra-O-acetyl   **α-D-**

glucopyranosyl bromide was obtained by recrystallization

from ether: 18.2 g (79.5% yield), m.p. 84-86 °C
(reported[42] 88-89 °C); IR 3017, 2997, 2969, 1742, 1383,
1250, 1044, 932, 912, 885, 852, 759, 666, 613 cm^{-1}; ^{1}H
NMR (CDCl$_3$) δ 6.62 (d, J = 4 Hz, 1H), 5.55 (t, J = 9 Hz,
1H), 5.17 (t, J = 9 Hz, 1H), 4.87 (d, J = 4 Hz, 1H),
4.83 (d, J = 4 Hz, 1H), 4.36 (d, J = 4 Hz, 1H), 4.32 (d,
J = 3 Hz, 1H), 2.21 (s, 3H), 2.10 (s, 3H), 2.09 (s, 3H),
2.08 (s, 3H).

4-Nitrophenyl 2,3,4,6-Tetra-*O*-acetyl-ß-D-glucopyranoside. In a 200 mL round bottom flask, 4.2 g
(33.6 mmol) of 4-nitrophenol was dissolved in a solution
of 1.7 g of sodium hydroxide in 42 mL of water. To this
was added a solution of 8.8 g (21.4 mmol) of tetra-O-acetyl-α-**D**-glucopyranosyl bromide in 62 mL of acetone.
After stirring five hrs at room temperature, the
solution was concentrated by rotary evaporation at 25-30
°C. As concentration proceeded, the product
precipitated, whereupon the solution was cooled to 0 °C
for 15 min and filtered. Evaporation was continued
until no more product appeared (the solution being about
half its original volume). The combined crops were
recrystallized from 95% ethanol, to give 5.10 g (50.8%
yield) 4-nitrophenyl 2,3,4,6-tetra-O-acetyl-ß-**D**-

glucopyranoside: m.p. 172-172.5 °C (reported[41] 172-173 °C); IR 1755, 1616, 1596, 1523, 1496, 1376, 1343, 1237, 1111, 1084, 1064, 1044, 912, 865, 752 cm^{-1}; ^{1}H NMR (CDCl$_3$) δ 8.25 (d, J = 8 Hz, 2H), 7.12 (d, J = 8 Hz, 2H), 5.34 (d, J = 3 Hz, 1H), 4.34 (d, J = 5 Hz, 1H), 4.30 (d, J = 5 Hz, 1H), 4.23 (d, J = 3 Hz, 1H), 4.18 (d, J = 3 Hz, 1H), 3.96-4.00 (m, 2H), 2.21 (s, 3H), 2.10 (s, 3H), 2.09 (s, 3H), 2.08 (s, 3H), ^{1}H NMR DMSO-d$_6$) δ 8.18 (d, J=8 Hz, 2H), 7.08 (d, J=8 Hz, 2H), 5.82 (d, J=10 Hz, 1H), 5.45 (t, J=10 Hz, 1H), 5.15 (dd, J=10 Hz, 1H), 5.05 (t, J=10 Hz, 1H), 4.30-4.38 (m, 1H), 4.22 (dd, J=5 Hz, 1H), 4.10 (dd, J=5 Hz, 1H), 2.21 (s, 3H , 2.10 (s, 3H), 2.09 (s, 3H), 2.08 (s, 3H).

4-Nitrophenyl ß-D-glucopyranoside. In a 100 mL flask, 2.40 g (5.12 mmol) of 4-nitrophenyl 2,3,4,6-tetra-*O*-acetyl-ß-**D**-glucopyranoside was dissolved in 10 mL of dry methanol to which was added 7.2 mL of a freshly prepared solution of sodium methoxide (1.17 g of sodium methoxide dissolved in 100 mL of methanol) with stirring at room temperature. The reaction was stirred for 20 min. The sodium ion was removed by stirring with a slight excess of Amberlite IR-120 (H$^+$) until the solution was neutral. The resin was filtered and the

solution was evaporated under reduced pressure. The solid was dissolved in a small quantity of water, filtered with decolorizing carbon and evaporated again under reduced pressure. The 4-nitrophenyl ß-**D**-glucopyranoside crystallized from 95% ethanol to give 1.40 g (90.9% yield): m.p. 168-169 °C (reported[41] 166-168 °C); IR 3362, 2930, 2891, 1609, 1596, 1509, 1496, 1350, 1257, 1078, 865, 852, 752, 686, 666 cm^{-1}; ^{1}H NMR (DMSO-d$_6$) δ 8.21 (d, J = 4 Hz, 2H), 7.24 (d, J = 4 Hz, 2H), 5.47 (d, J = 4 Hz, 1H), 5.18 (d, J = 4 Hz, 1H), 5.11 (d, J = 4 Hz, 1H), 5.08 (s, 1H), 4.61 (d, J = 6 Hz, 1H), 3.68 (q, J = 4 Hz, 1H), 3.47 (q, J = 4 Hz, 1H), 3.35-3.41 (m, 1H), 3.27-3.32 (m, 1H), 2.51 (t, d = 2 Hz, 2H).

4-Nitrophenyl 2,3,4,6-tetra-*O*-methacryloyl-ß-D-Glucopyranoside. In a 50 mL flask, 4-nitrophenyl ß-**D**-glucopyranoside (0.117 g, 0.389 mmol) and methacrylic anhydride (1.25 mL, 8.39 mmol) were added to distilled pyridine (10 mL). The suspension was stirred in an ice-water bath until the 4-nitrophenyl ß-**D**-glucopyranoside was dissolved. The stirring was continued at room temperature for seven days. The solution was poured with stirring into a beaker containing a mixture of ice

and water. Then 15 mL of ether was added with stirring and the organic layer was separated and the aqueous layer was twice extracted with 10 mL portions of ether. The ether solutions were combined, washed once with water, then with saturated sodium bicarbonate solution until basic, then with sulfuric acid until neutral, and again with water. The ether solution was dried over magnesium sulfate for overnight. Removal of the drying agent and ether gave 0.156 g (70.1%) of 4-nitrophenyl 2,3,4,6-tetra-O-methacryloyl-ß-D-glucopyranoside: m.p. 174-175 °C; IR 2964, 2930, 1722, 1635, 1456, 1317, 1297, 1171, 1044, 945, 812, 759 cm^{-1}; ^{1}H NMR (DMSO-d$_3$) δ 8.22(d, J = 8z, 2H), 7.22 (d, J = 8 Hz, 2H), 6.08 (s, 1H), 6.02 (s, 1H), 6.00 (s, 1H), 5.98 (s, 1H), 5.98 (d, J=8 Hz, 1H), 5.70 (t, J=10 Hz, 1H), 5.71 (m, 4H), 5.35 (dd, J=10 Hz, J= 8Hz, 1H), 5.30 (t, J=10 Hz, 1H), 4.56 (t, 10 Hz, 1H), 4.35-4.22 (m, 2H), 1.89 (s, 3H), 1.89 (s, 3H), 1.88 (s, 3H), 1.88 (s, 3H).

4-Nitrophenyl 2,3,4,6-tetra-O-methacryloyl-α-D-Glucopyranoside. In a 100 mL flask, 4-nitrophenyl α-D-glucopyranoside (4.00 g, 13.3 mmol) and methacrylic anhydride (20.0 mL, 134 mmol) were added to distilled pyridine (50 mL). A procedure identical to that of 4-

nitrophenyl 2,3,4,6-tetra-O-methacryloyl-ß-D-glucopyranoside was followed to give 4.97 g (65.2%) of 4-nitrophenyl 2,3,4,6-tetra-O-methacryloyl-α-**D**-glucopyranoside: m.p. 158-159 °C; IR 3003, 2970, 2930, 1728, 1635, 1596, 1516, 1496, 1456, 1343, 1297, 1257, 1164, 1111, 1038, 958, 872, 852, 812, 752 cm^{-1}; ^{1}H NMR (CDCl$_3$) δ 8.21 (d, J = 10 Hz, 2H), 7.25 (d, J = 10 Hz, 2H), 6.13 (s, 1H), 6.10 (s, 1H), 6.06 (s, 1H), 6.04 (s, 1H), 5.93 (t, J=10H, 1H), 5.90 (d, J = 4 Hz, 1H), 5.60 (m, 4H), 5.34 (t, J=10 Hz, 1H), 5.18 (dd, J=4 Hz, 1H), 4.30-4.18 (m, 3H), 1.89 (s, 12H) ppm; ^{13}C NMR (CDCl$_3$) δ 18.07, 18.18, 18.24, 62.25, 68.42, 69.09, 69.72, 70.69, 76.73, 77.15, 77.58, 94.43, 116.75, 125.84, 126.37, 126.94, 127.40, 127.72, 134.89, 134.96, 135.14, 135.60, 143.10, 160.76, 165.75, 166.32, 166.65 ppm.

Anal. Calcd for C$_{28}$H$_{31}$NO$_{12}$: C, 58.64; H, 5.45; N, 2.44. Found: C, 58.63; H, 5.56; N, 2.48.

Copolymerization of methyl 2,3,4,6-tetra-O-methacryloyl-α-D-glucopyranoside, styrene and divinylbenzene. The mixture of 1.15 mL (10 mmol) of styrene and 2.60 mL (10 mmol) of divinylbenzene (including 45% ethylvinylbenzene) was added to 0.466 g

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(1 mmol) of methyl 2,3,4,6-tetra-*O*-methacryloyl-α-**D**-glucopyranoside. Azobisisobutryonitrile (AIBN) (10mg) was added as an initiator. The mixture of monomers was stirred until the AIBN was all dissolved. The contents were swept with nitrogen for several min to exclude oxygen which can inhibit the polymerization. The test tube was placed at 60 °C in a water bath for 24 hrs resulting in formation of the polymer. The test tube was broken to recover the polymer which was crushed and extracted with acetone in a Soxhlet apparatus for 24 hrs followed by a similar extraction with chloroform. The polymer was dried under vacuum overnight to give 3.71 g (86.9% yield) of product: m.p. above 300 °C; IR 3090, 3063, 3030, 2970, 2924, 2857, 1941, 1868, 1801, 1742, 1609, 1469, 1456, 912, 832, 799, 766, 699 cm⁻¹.

Copolymerization of 4-nitrophenyl 2,3,4,6-tetra-*O*-methacryloyl-α-D-glucopyranoside, styrene and divinylbenzene. The mixture of 1.15 mL (10 mmol) of styrene and 2.60 mL (2.37g) of commercial divinylbenzene (containing 45% ethylvinylbenzene) which corresponds to 1.30 g (10 mmol) of divinylbenzene and 1.07 g (8 mmol) of ethylstyrene were added to 0.573 g (1 mmol) of 4-nitrophenyl 2,3,4,6-tetra-*O*-methacryloyl-α-**D**-

glucopyranoside. AIBN (10mg) was added and the mixture was stirred until the AIBN all dissolved. THF was added as a solvent. The test tube was swept with nitrogen for several min to exclude oxygen and the test tube was placed in a water bath at 60 °C for 24 hrs resulting in formation of the polymer. The polymer was crushed and dried under vacuum at 100 °C to constant weight. Then the polymer was extracted with acetone in a Soxhlet extraction for 24 hrs and dried under vacuum at 100 °C to a constant weight of 3.48 g. The extraction was repeated using chloroform as solvent. The polymer was dried under vacuum at 100 °C until constant weight to give 3.48 g (84.6% yield) of product: m.p. above 300 °C; IR 3083, 3057, 3023, 2924, 2851, 1941, 1868, 1801, 1735, 1602, 1529, 1496, 1450, 1337, 1151, 1091, 1031, 985, 898, 832, 792, 752, 706 cm^{-1}.

Copolymerization of 4-nitrophenyl 2,3,4,6-tetra-*O*-methacryloyl-ß-D-glucopyranoside, styrene and divinylbenzene. The procedure was similar with the procedure for the copolymerization of 4-nitrophenyl 2,3,4,6-tetra-*O*-methacryloyl-α-D-glucopyranoside, styrene and divinylbenzene and give 3.57 g (86.8% yield) of product: m.p. above 300 °C, IR 3063, 3030, 2970,

2930, 1941, 1861, 1801, 1735, 1596, 1523, 1489, 1456, 1350, 1244, 1157, 1064, 985, 898, 832, 792, 759, 699 cm^{-1}.

APPENDIX

SPECTRA
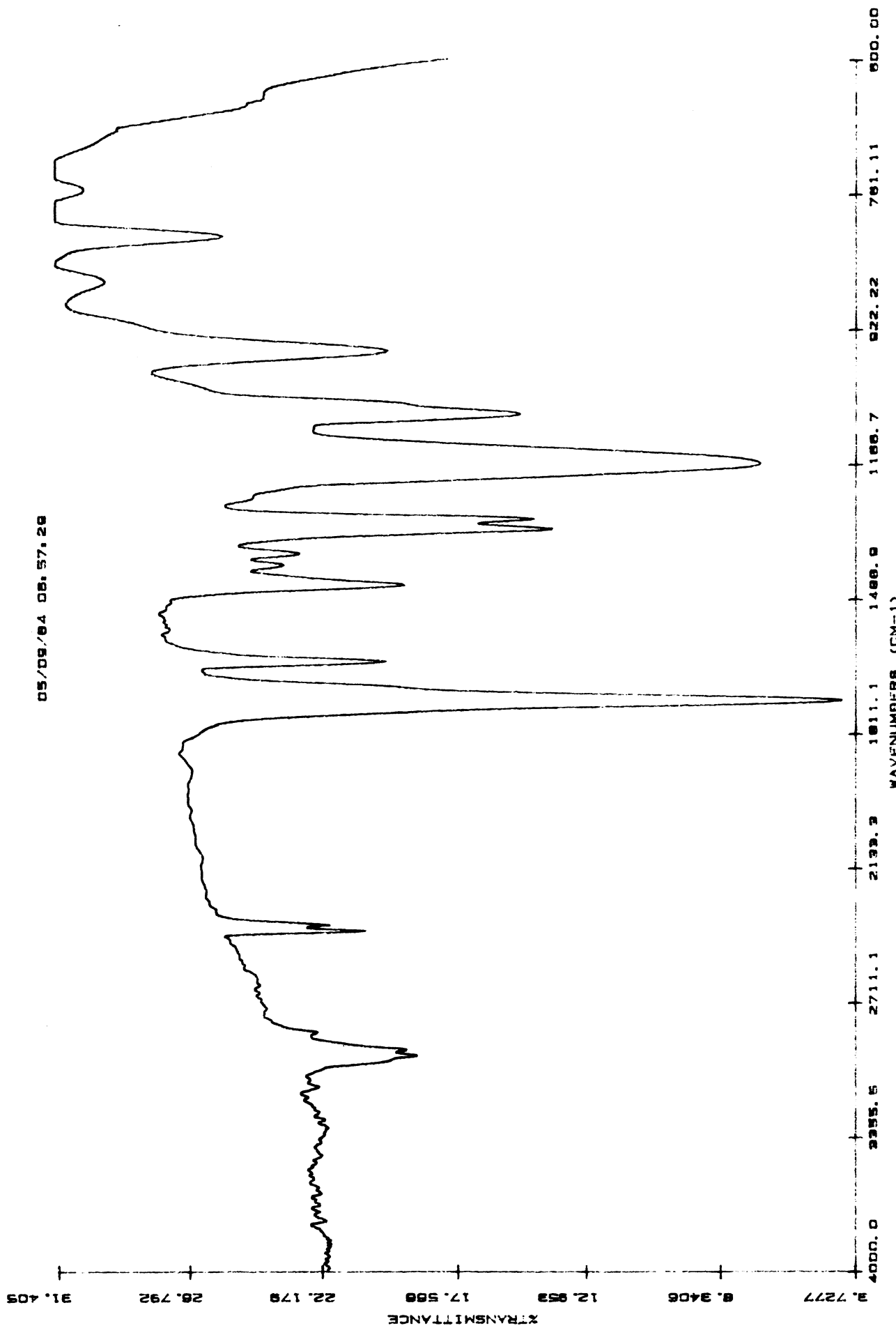
Fig. 12 IR of Methyl Tetra-O-methacryloyl-alpha-D-glucopyranoside
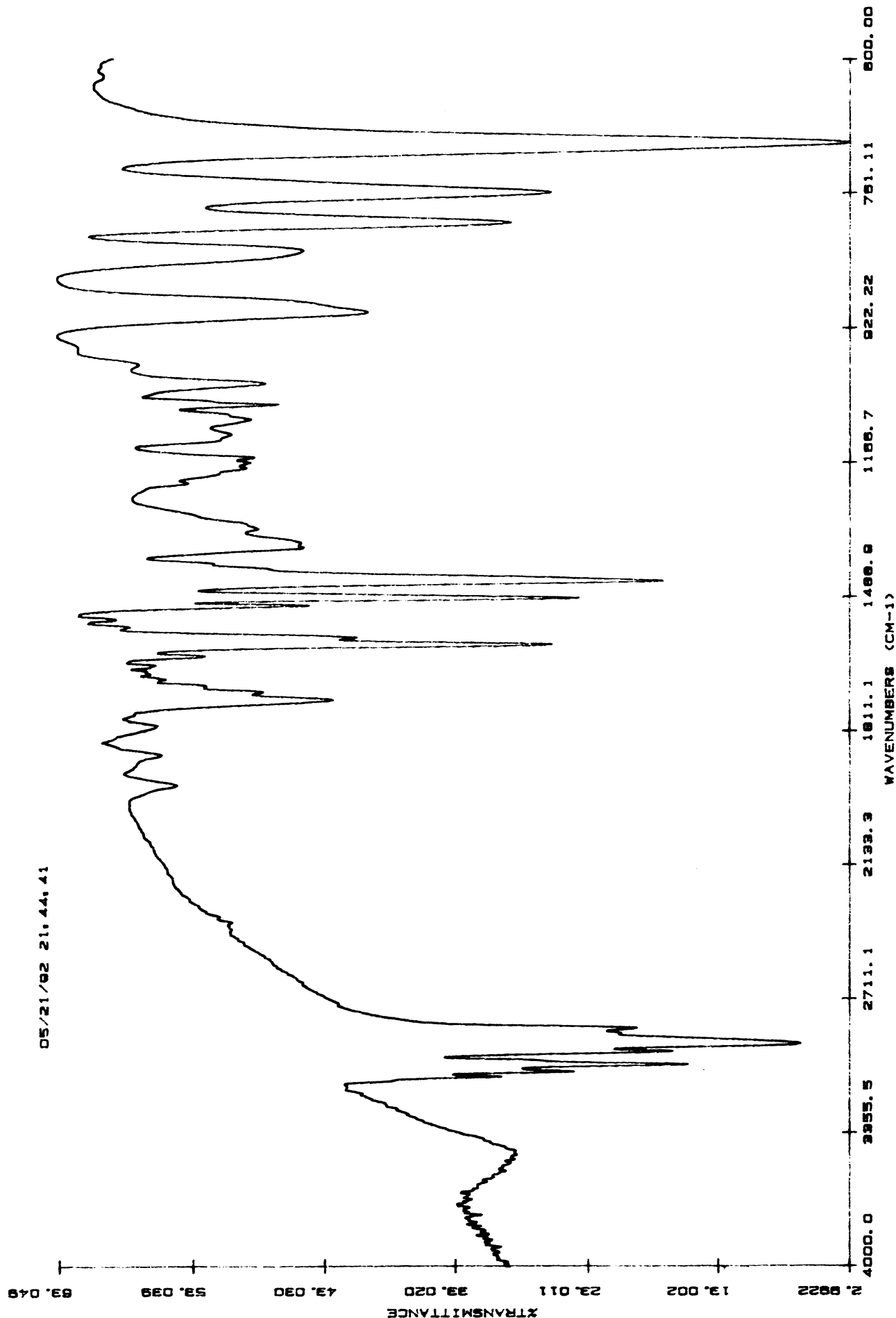
Fig. 13 IR of Copolymer of Methyl Tetra-O-methacryloyl-alpha-D-glucopyranoside Styrene and divinylbenzene
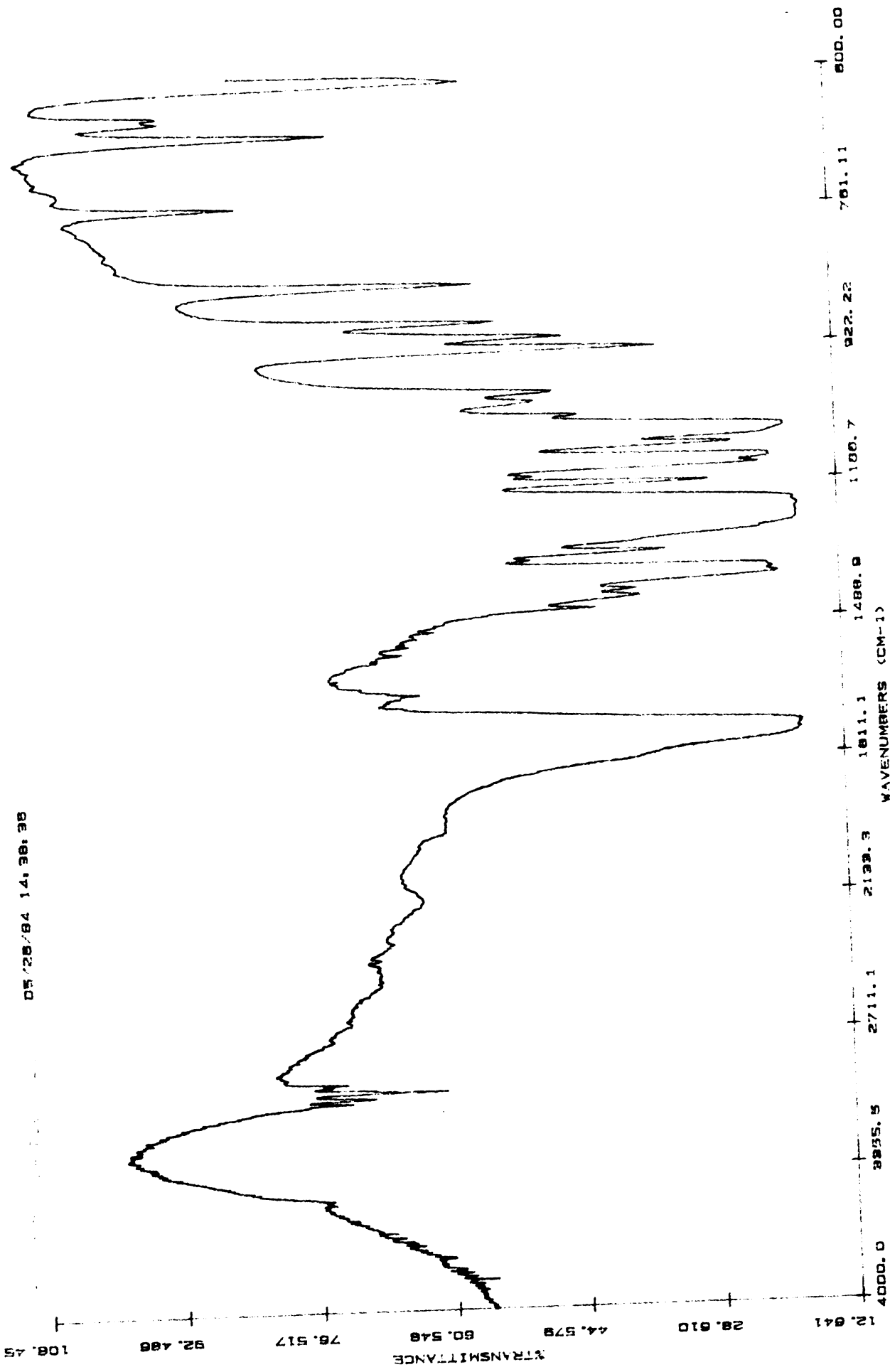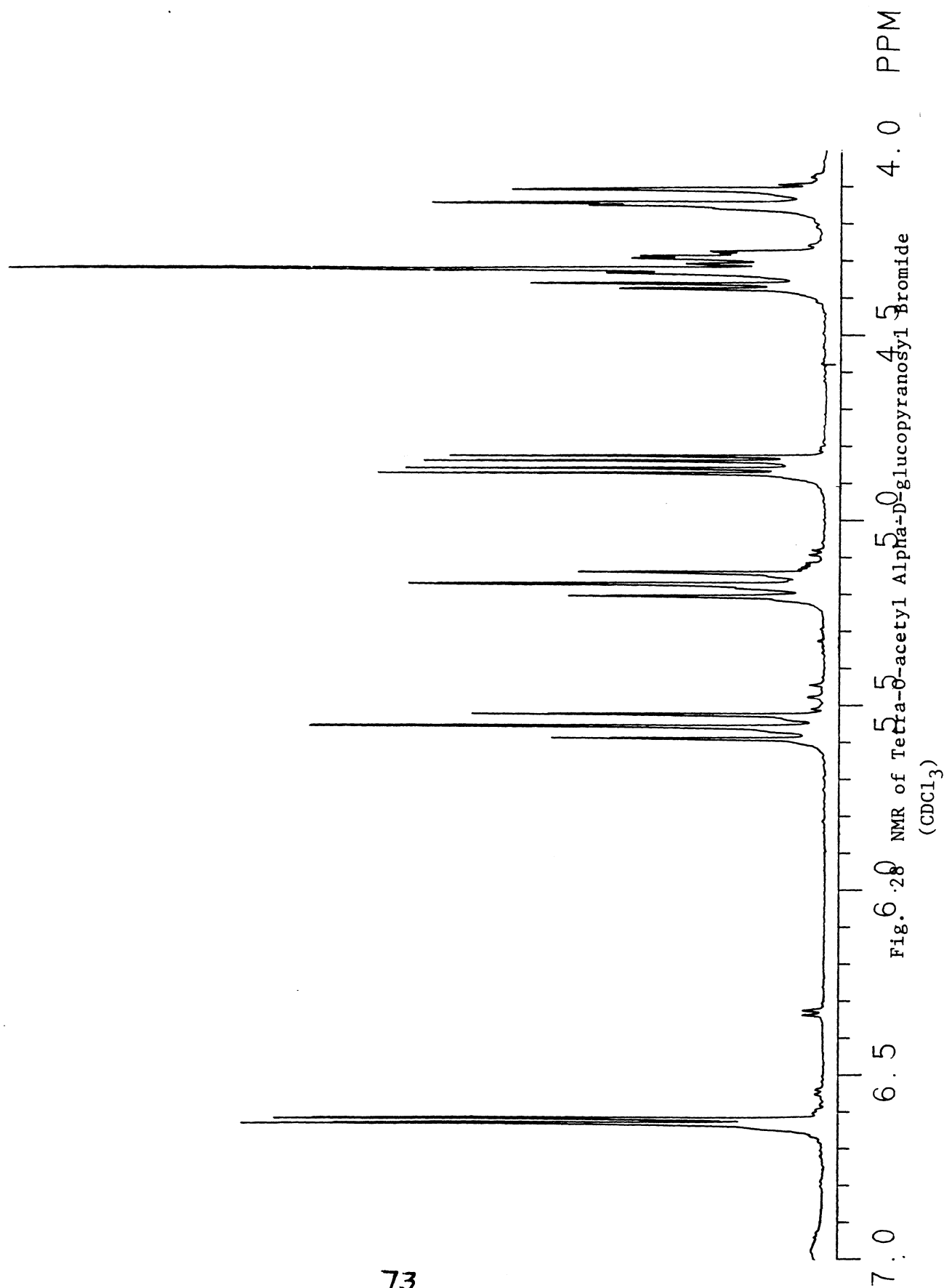
Fig. 14 IR of Tetra-O-acetyl Alpha-D-glucopyranosyl Bromide

59
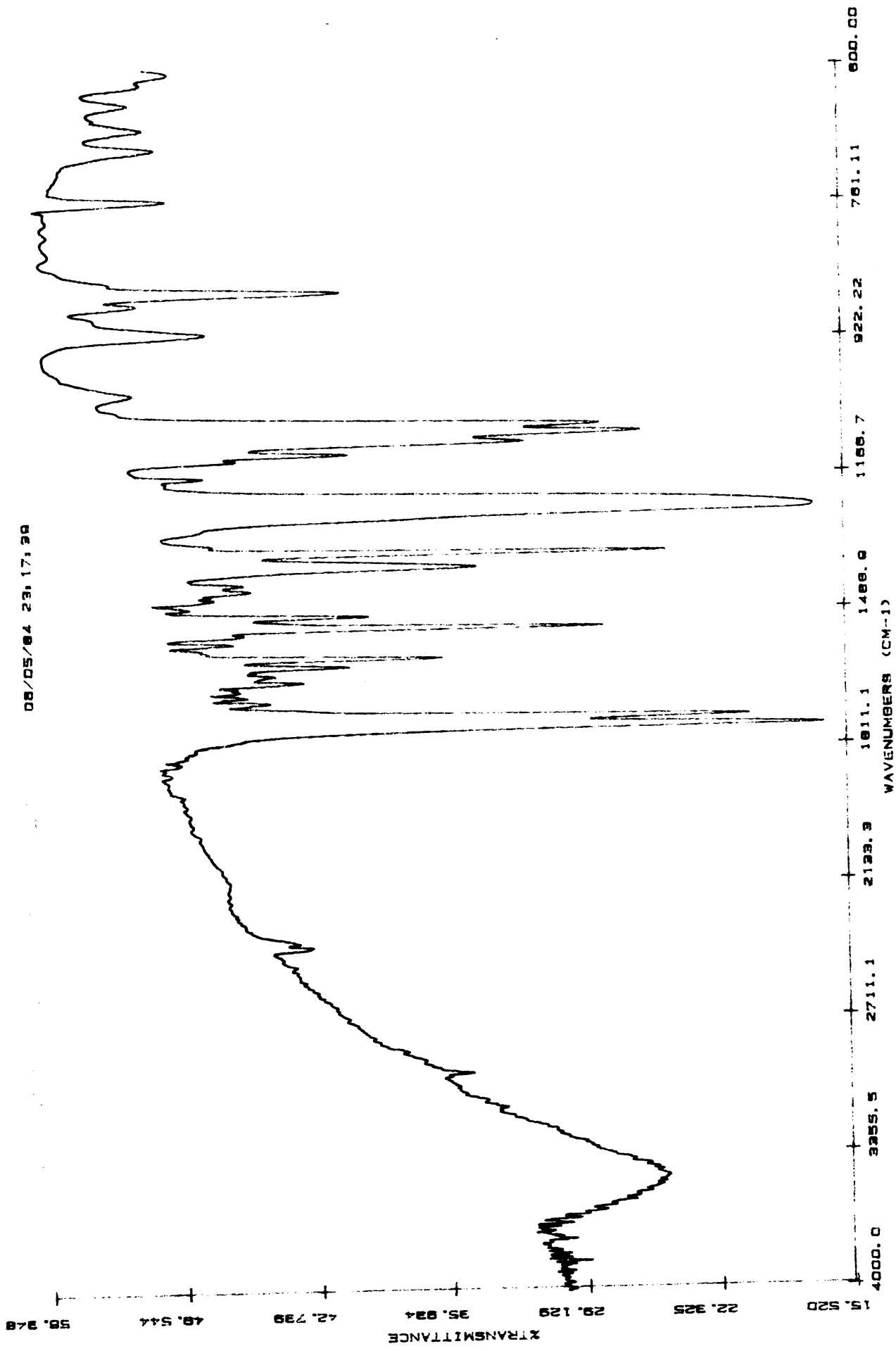
Fig. 15 IR of p-Nitrophenyl Tetra-O-acetyl-beta-D-glucopyranoside

60
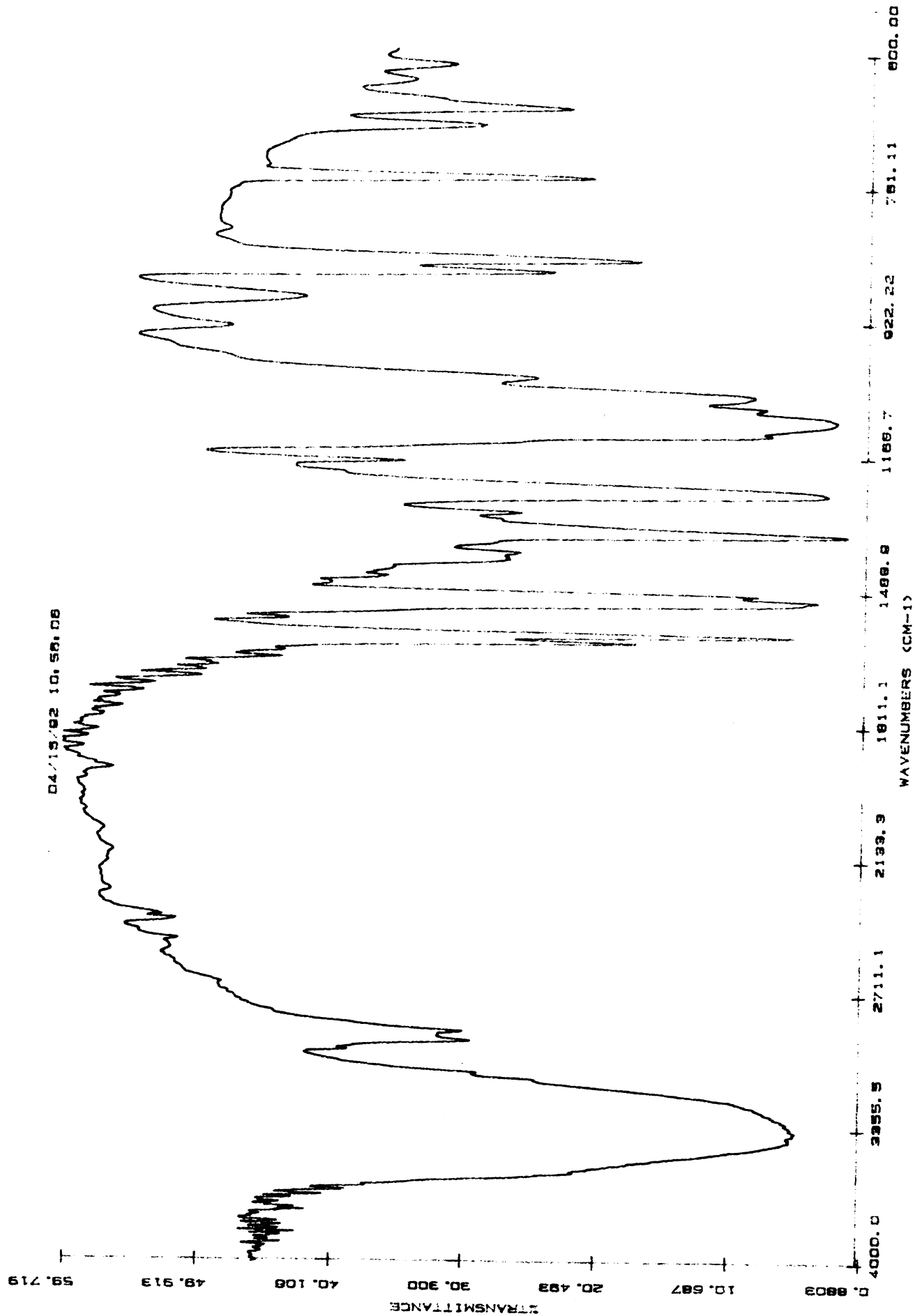
Fig. 16 IR of p-Nitrophenyl Beta-D-glucopyranoside
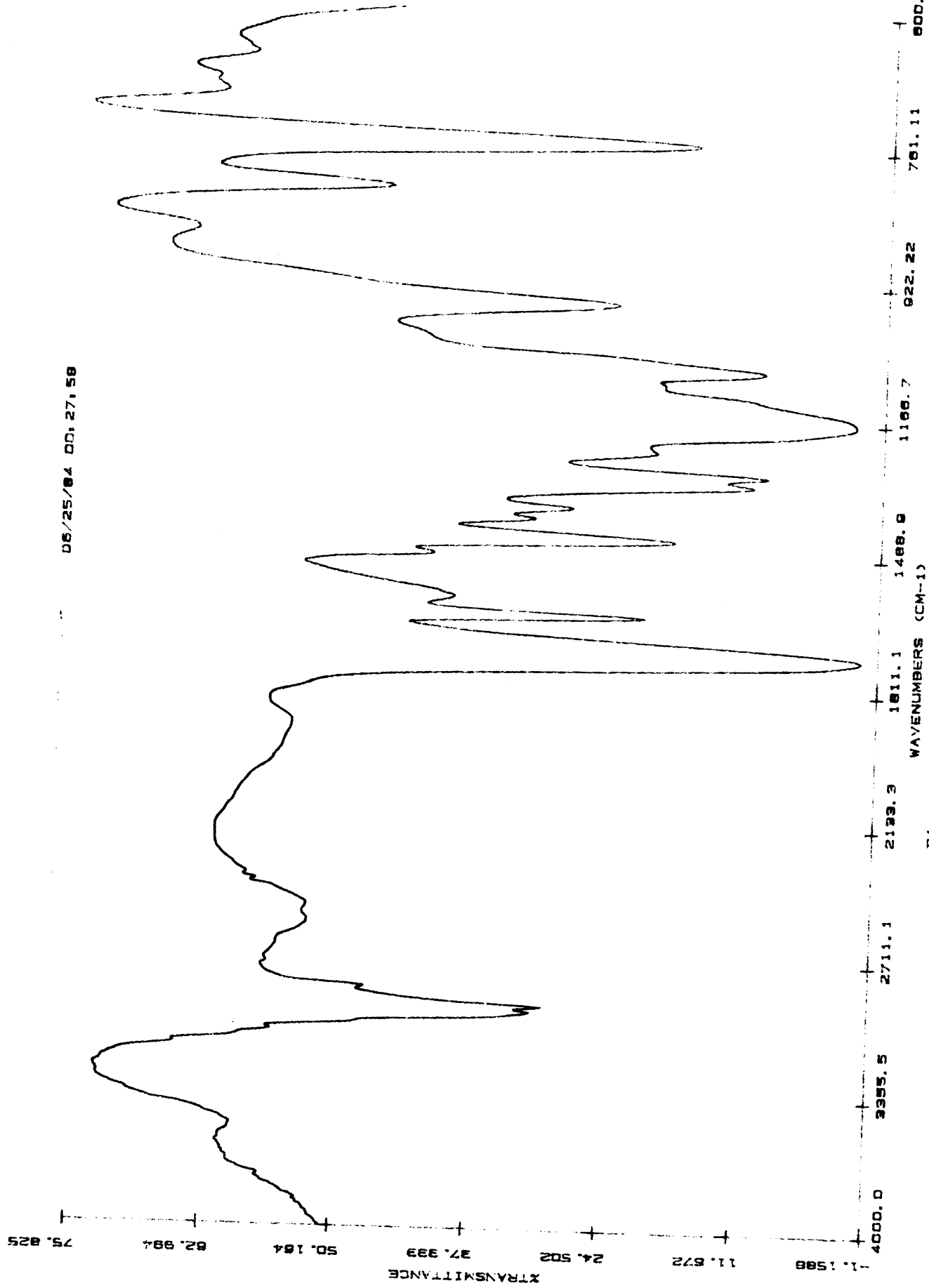
Fig. 17 IR of p-Nitrophenyl Tetra-O-methacryloyl-beta-D-glucopyranoside

62
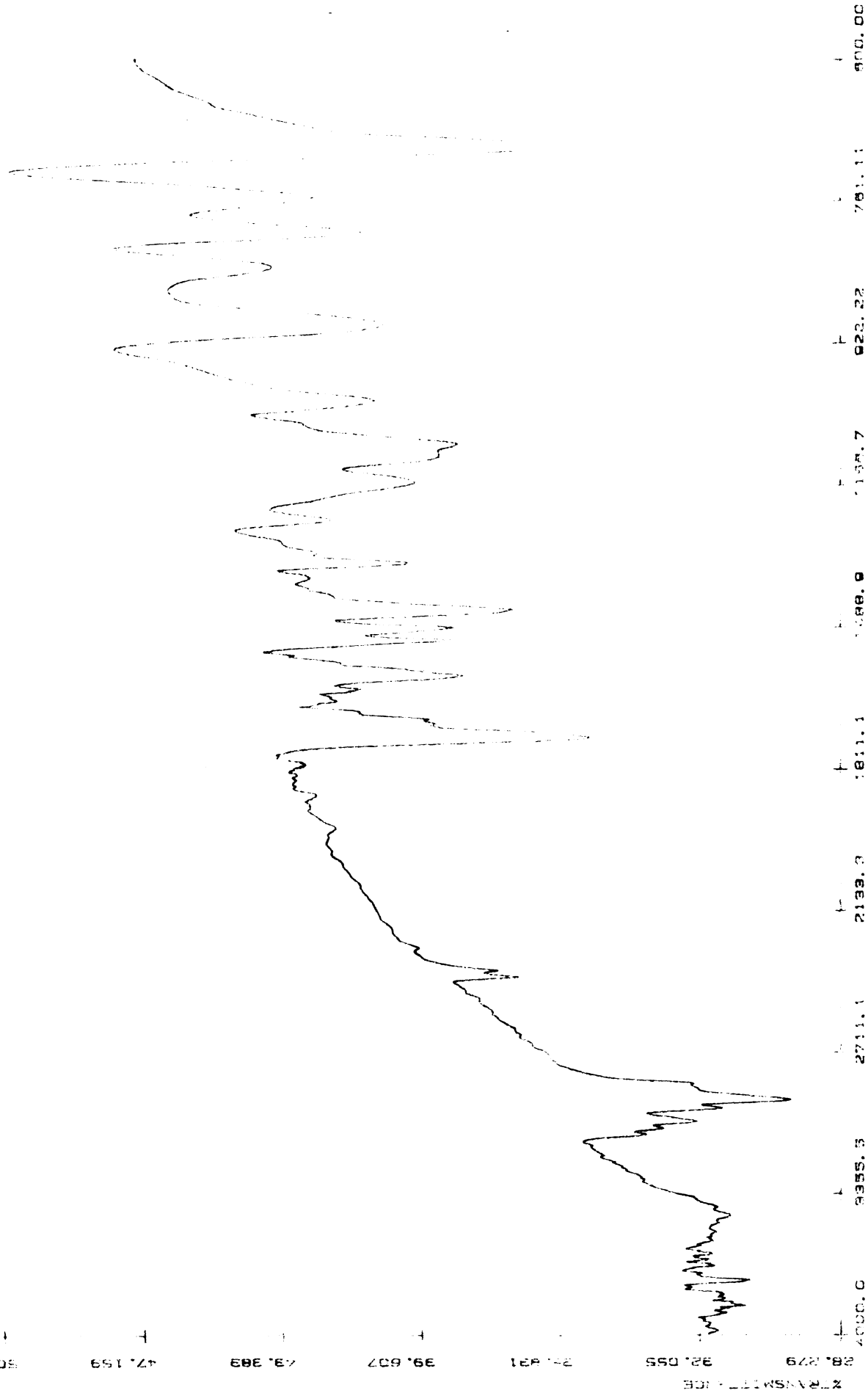
Fig. 18 IR of Copolymer of p-Nitrophenyl Tetra-O-methacryloyl-beta-
D-glucopyranoside, styrene and divinylbenzene (Before extraction from solvent)

63

(After extract from solvent)
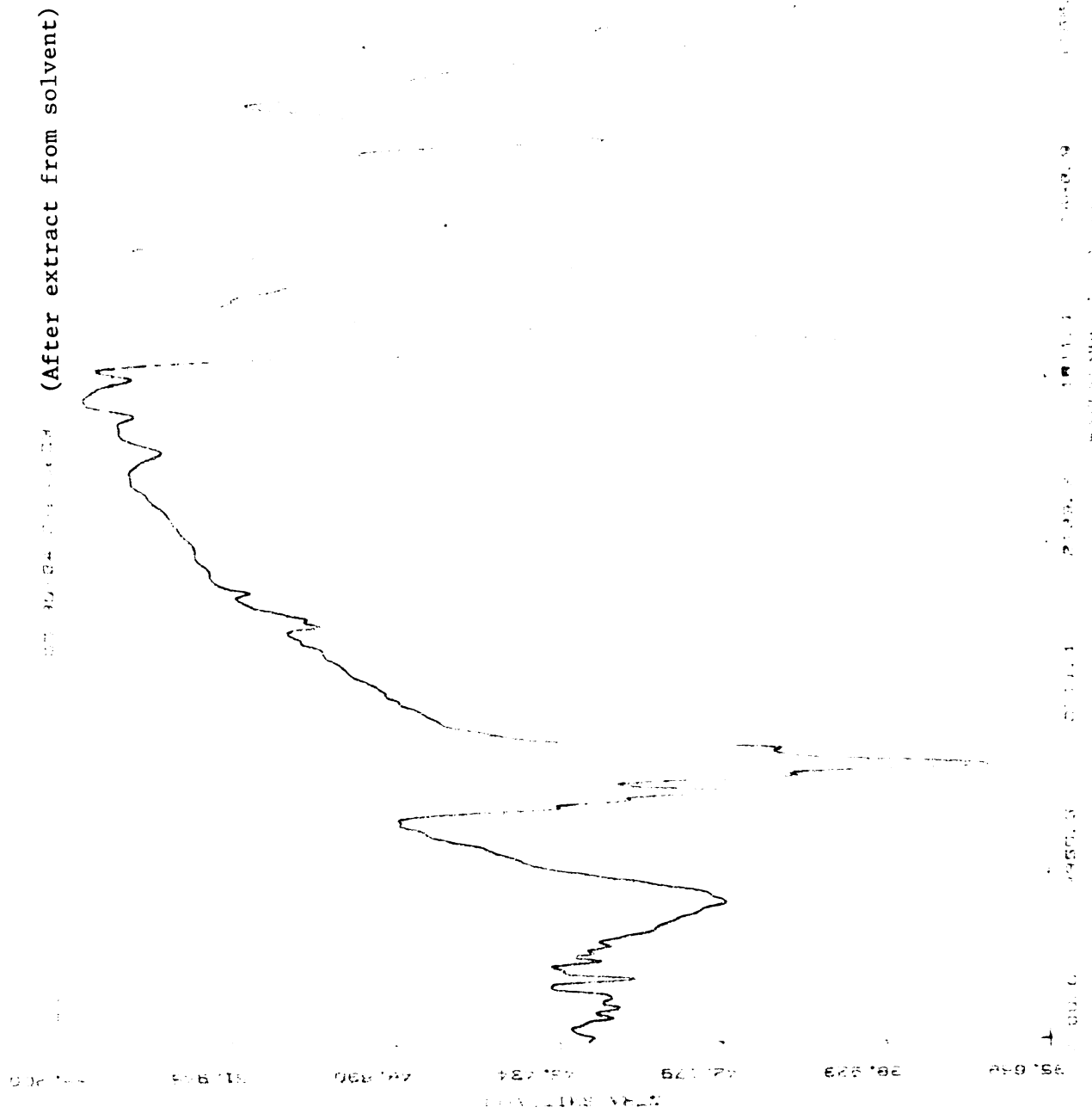
Fig. 19 IR of Copolymer of p-Nitrophenyl Tetra-O-methacryloyl-beta-D-glucopyranoside, styrene and divinylbenzene

64
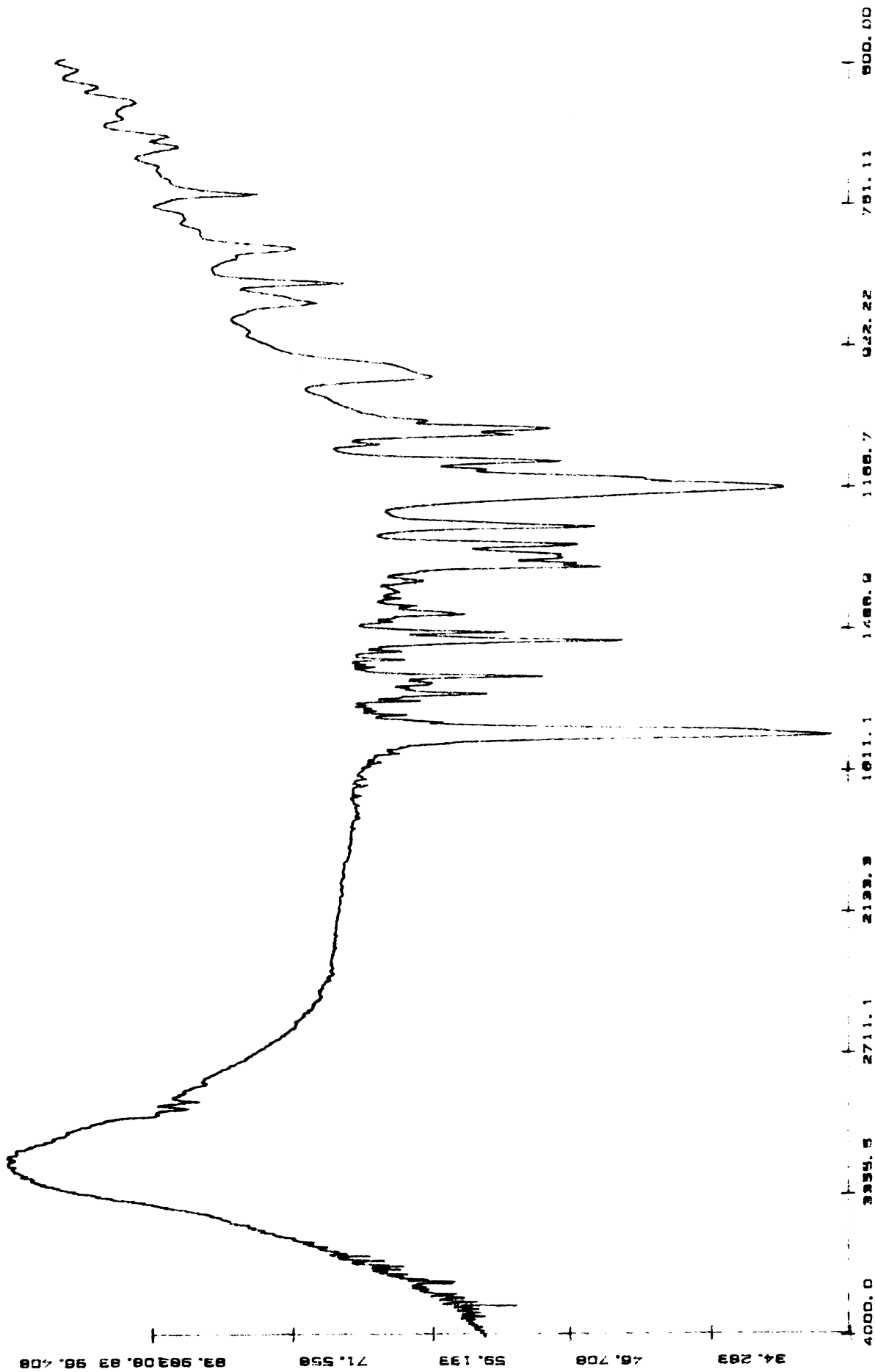
Fig. 20 IR of p-Nitrophenyl Tetra-O-methacryloyl-alpha-D-glucopyranoside

05/28/84 14:08:03

65
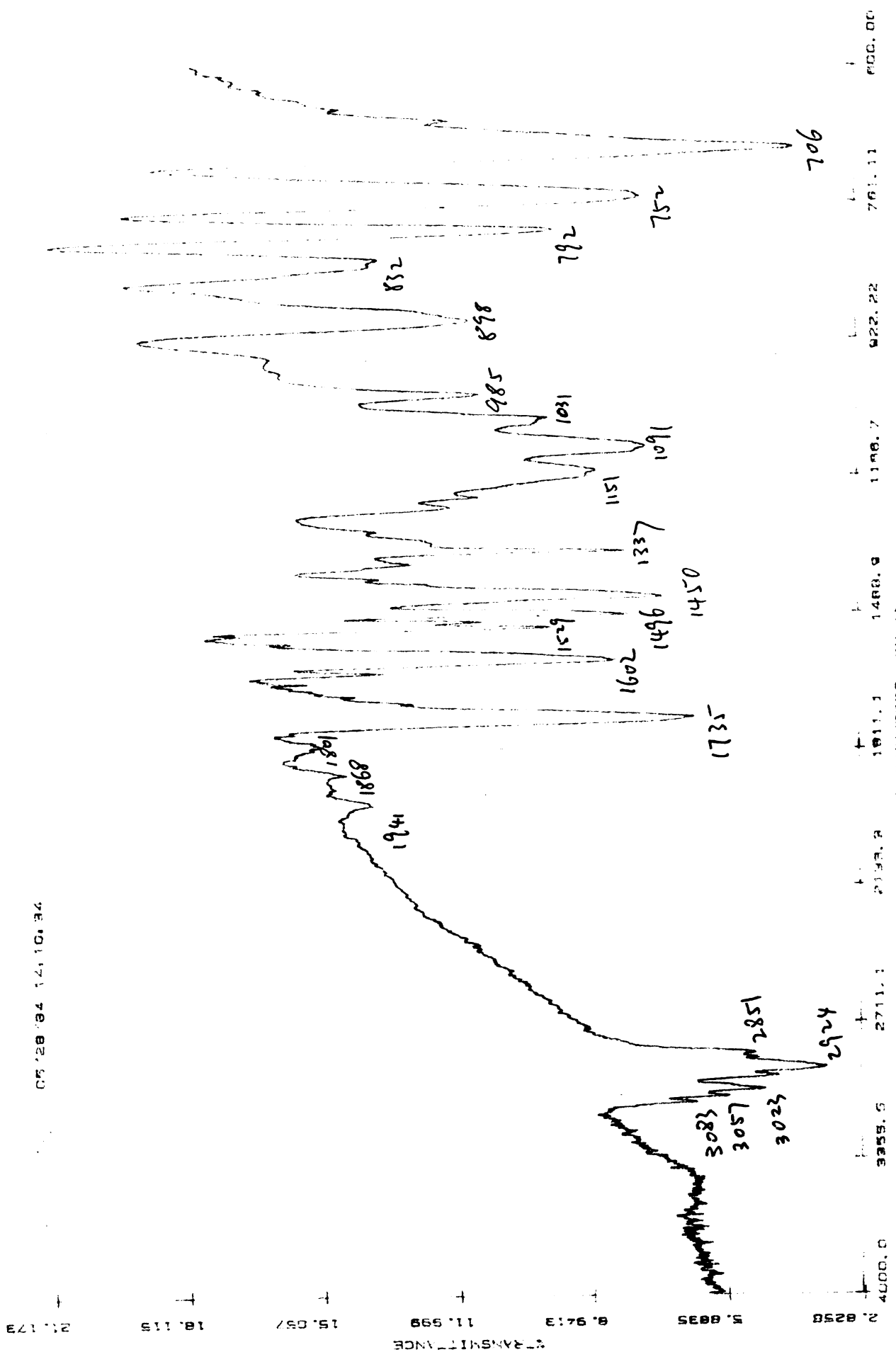
Fig. 21 IR of Copolymer of p-Nitrophenyl Tetra-O-methacryloyl-alpha-D-glucopyranoside,
Styrene and divinylbenzene
(Before extraction from solvent)

66
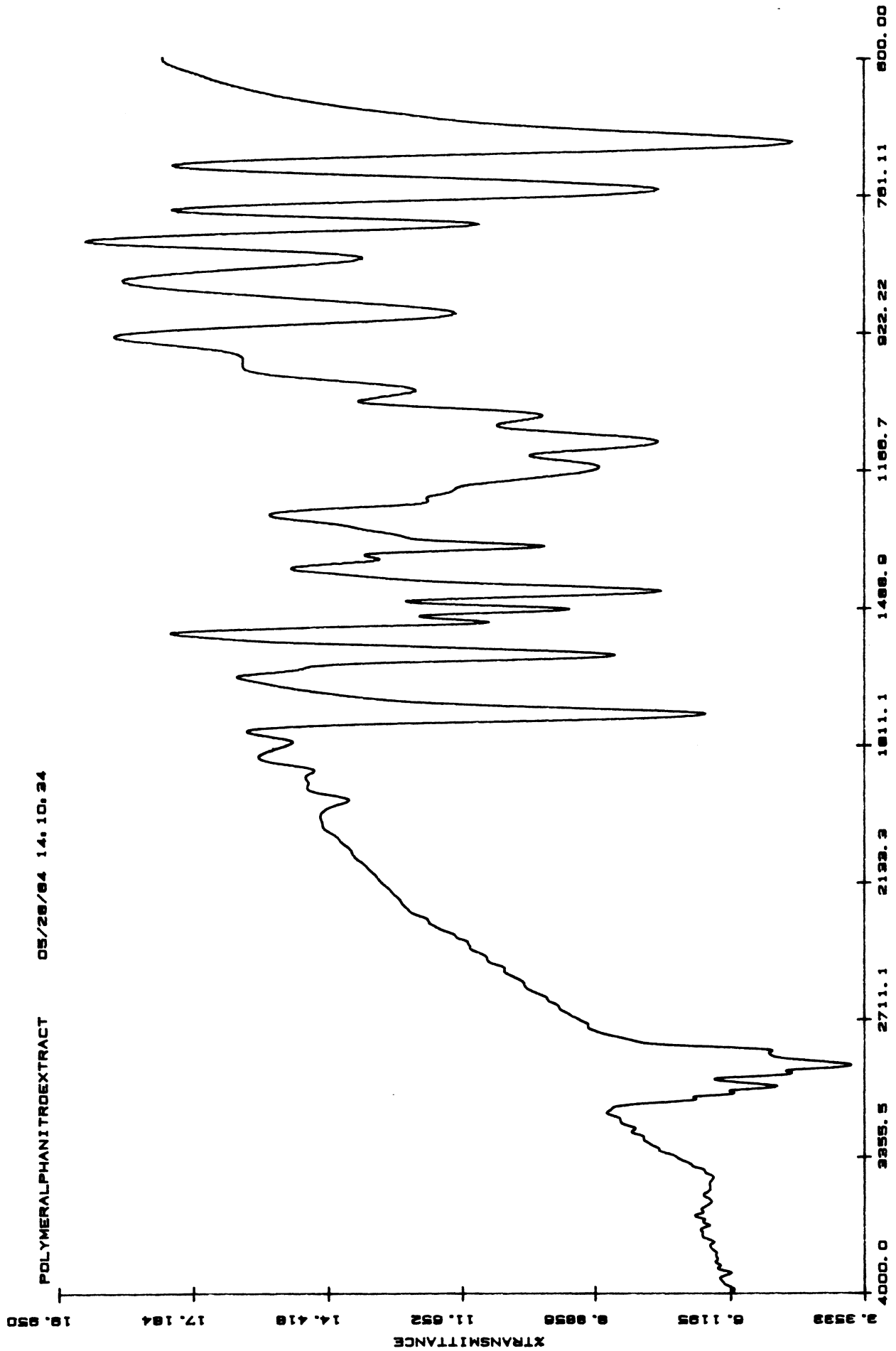
Fig. 22 IR of Copolymer of p-Nitrophenyl tetra-O-methacryloyl-alpha-D-glucopyranoside, Styrene and divinylbenzene (After extraction from sovlent)

67
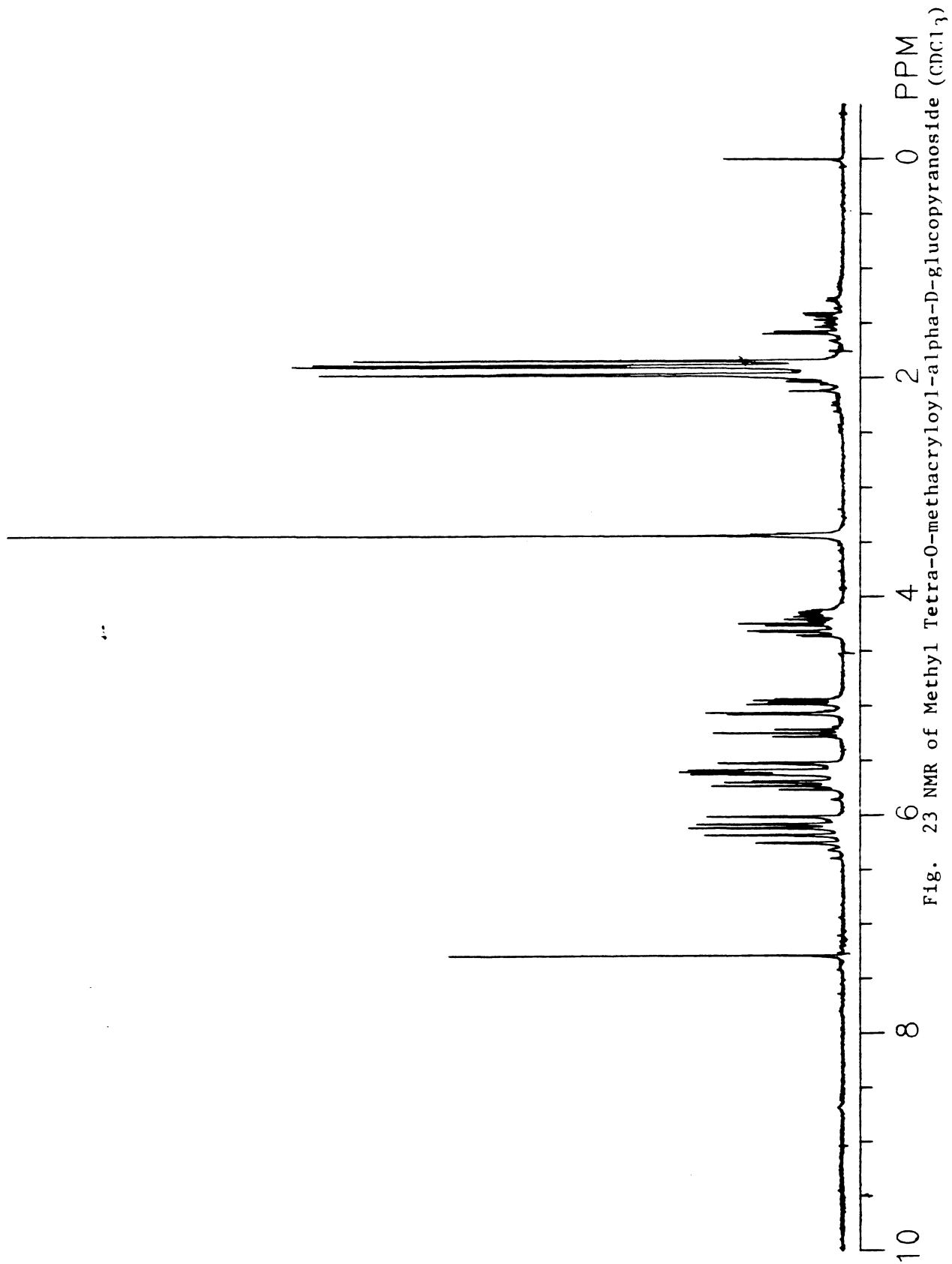
Fig. 23 NMR of Methyl Tetra-O-methacryloyl-alpha-D-glucopyranoside (CDCl₃)

68
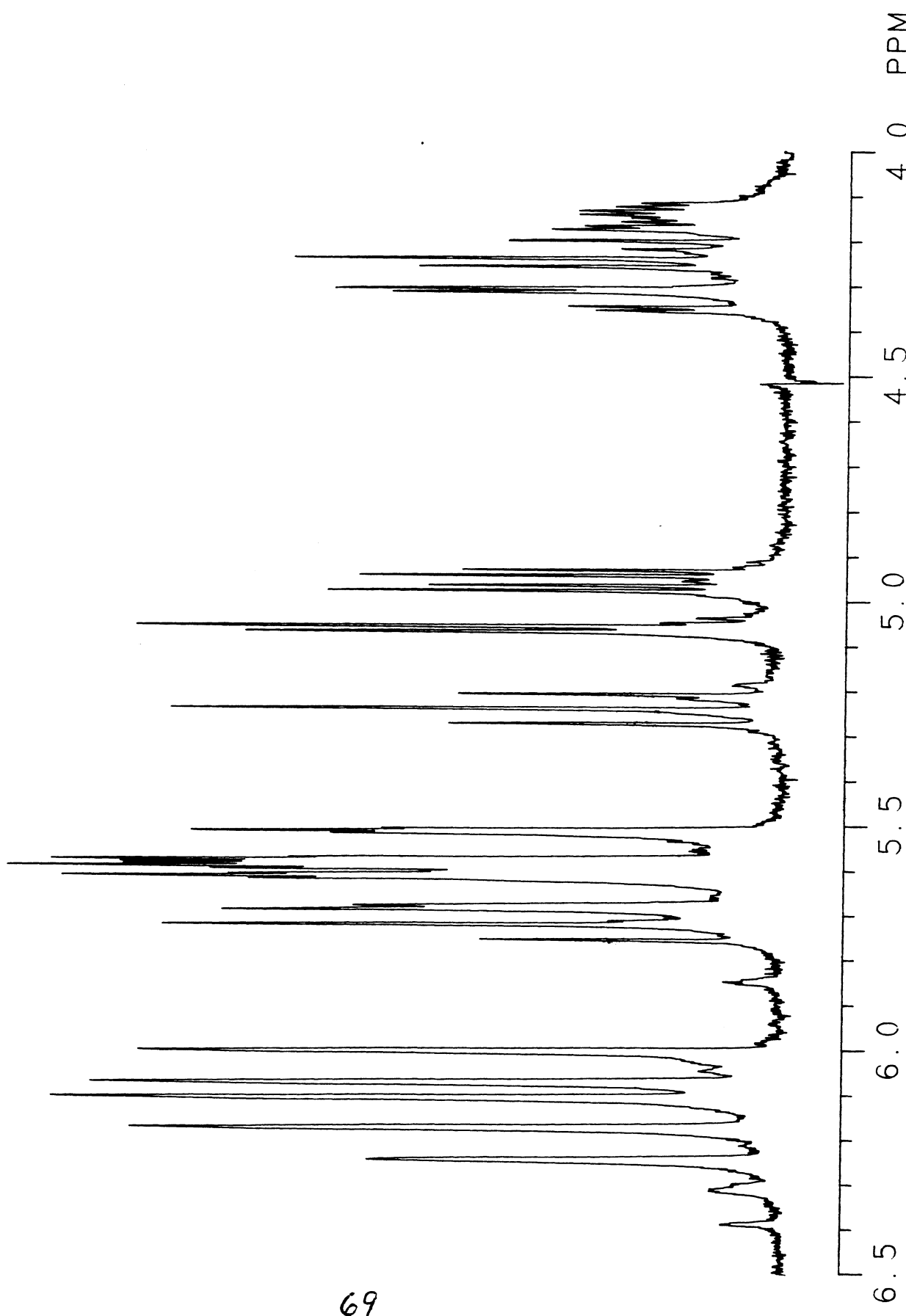
Fig. 24 NMR of Methyl Tetra-O-methacryloyl-alpha-D-glucopyranoside (CDCl₃)

69
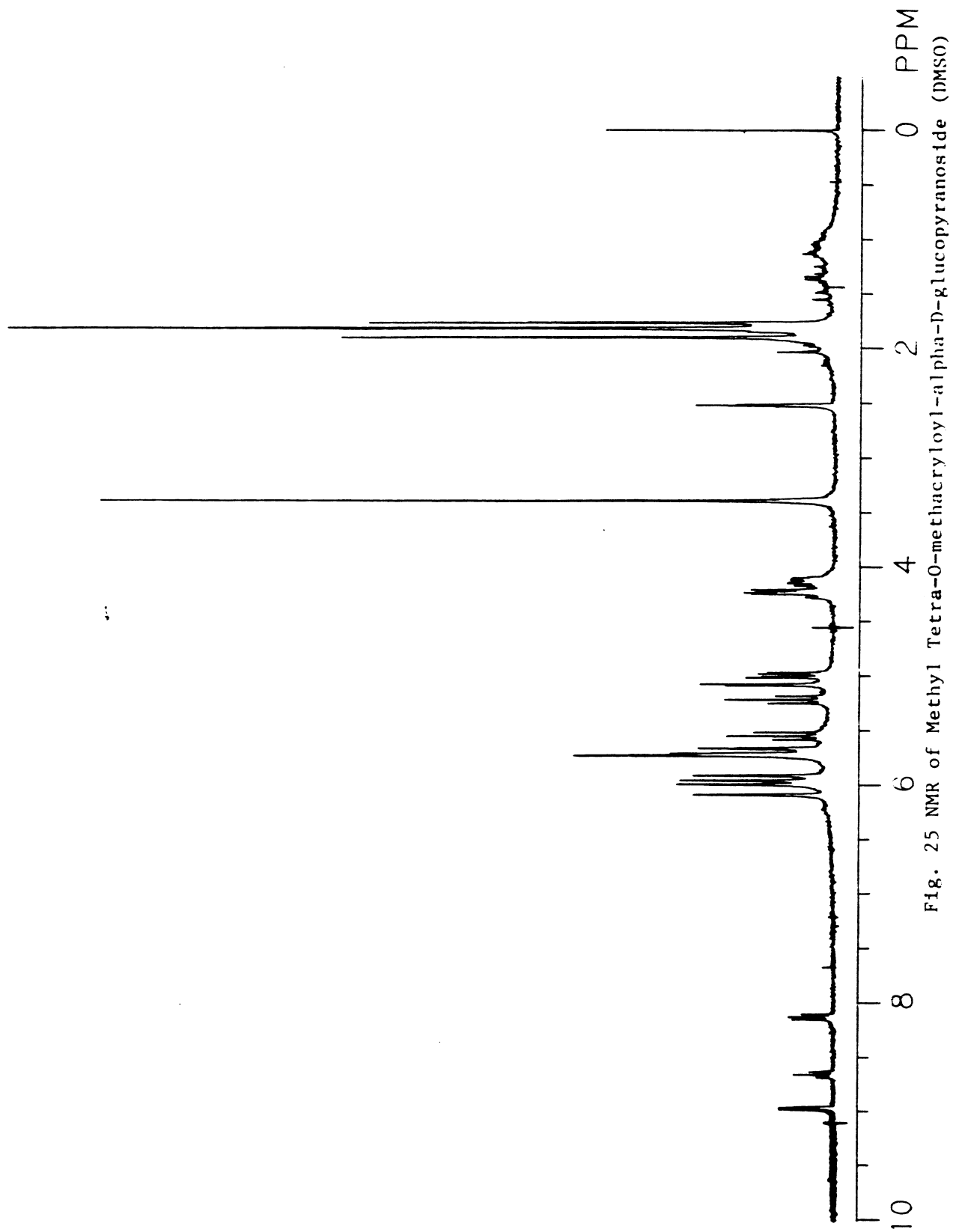
Fig. 25 NMR of Methyl Tetra-0-methacryloyl-alpha-D-glucopyranoside (DMSO)

70
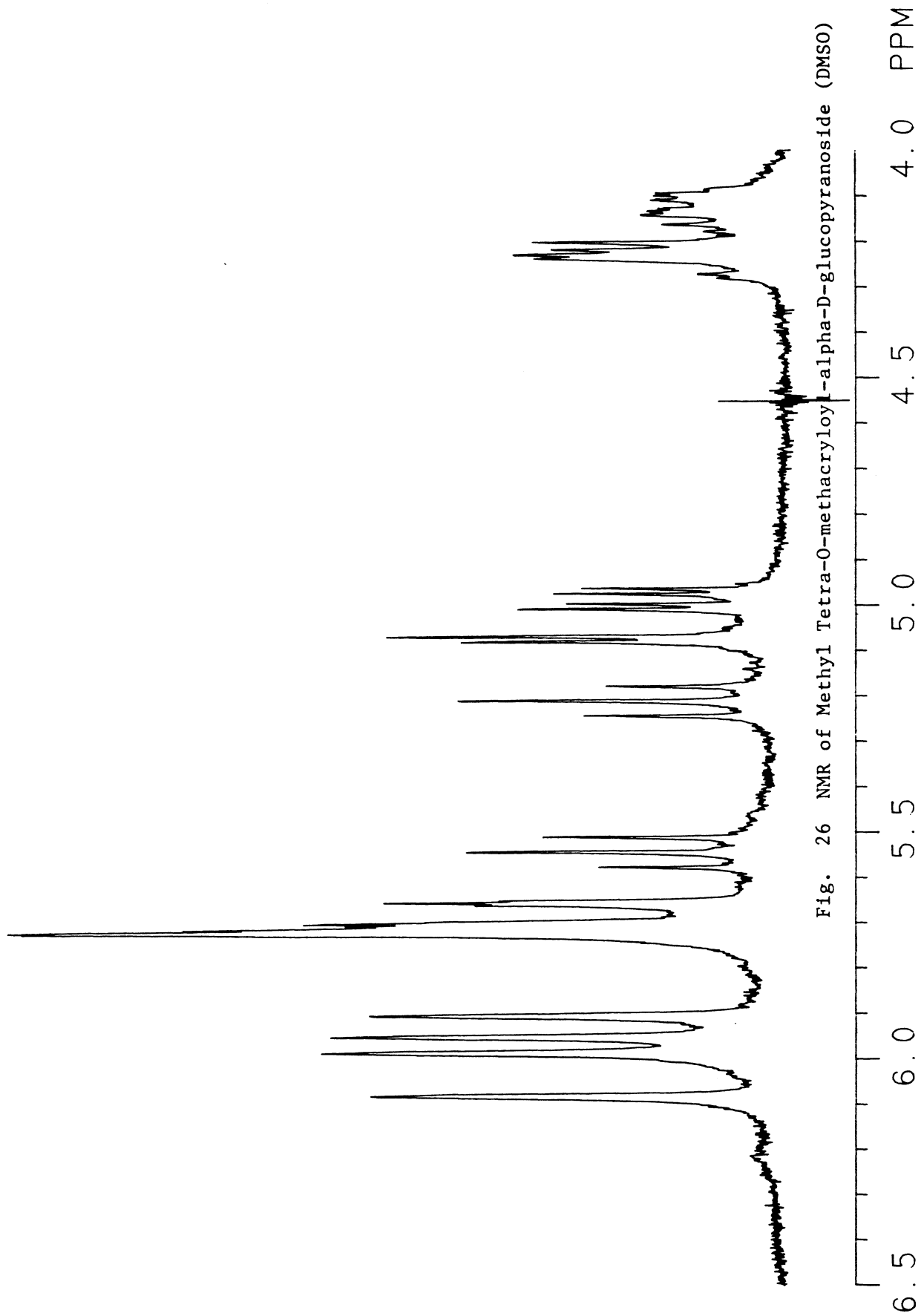
Fig. 26 NMR of Methyl Tetra-O-methacryloyl-alpha-D-glucopyranoside (DMSO)

71
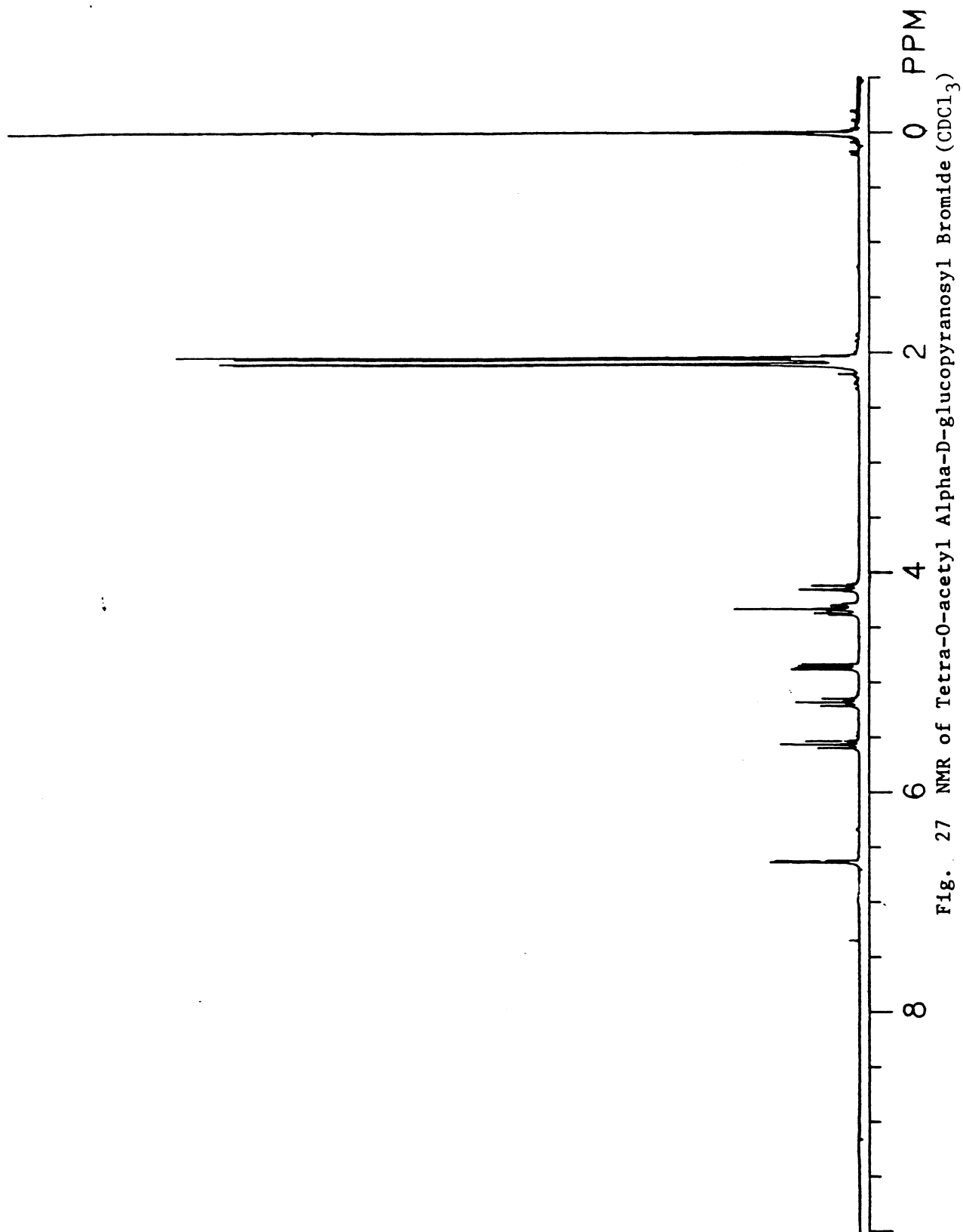
Fig. 27 NMR of Tetra-O-acetyl Alpha-D-glucopyranosyl Bromide (CDCl$_3$)

Fig. 6.28 NMR of Tetra-O-acetyl Alpha-D-glucopyranosyl Bromide (CDCl₃)
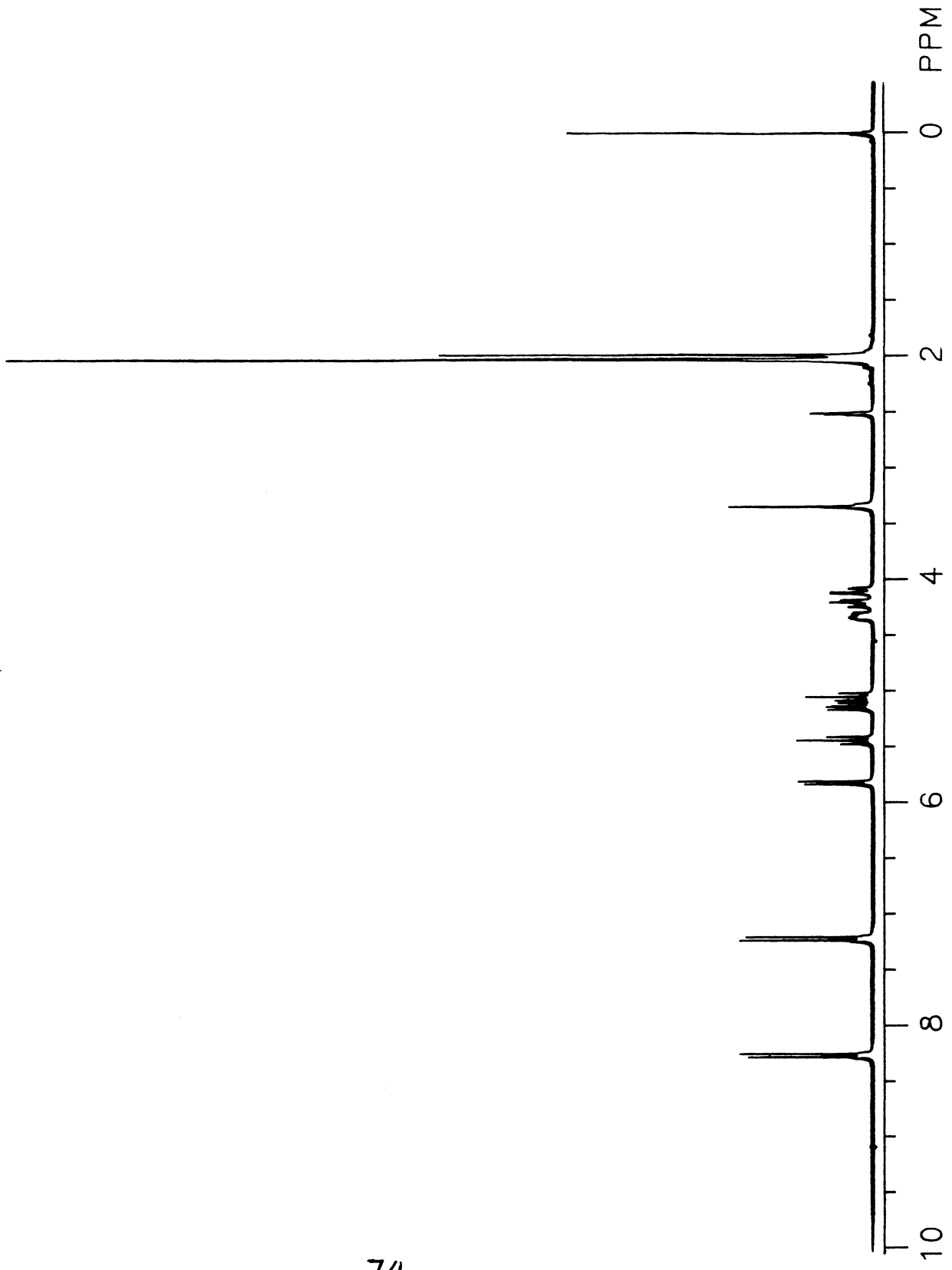
Fig. 29 NMR of p-Nitrophenyl Tetra-O-acetyl-beta-D-glucopyranoside (DMSO)

74
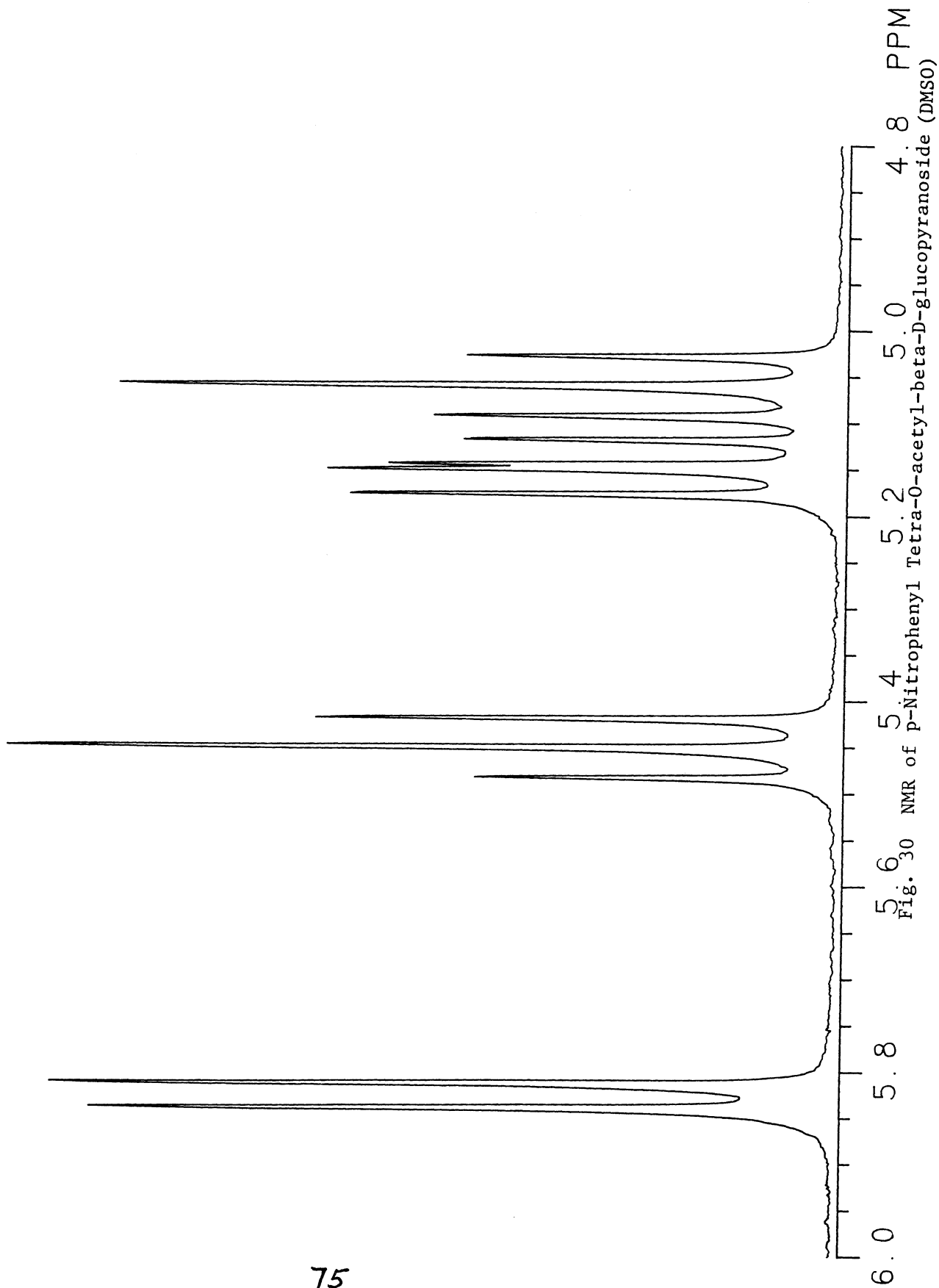
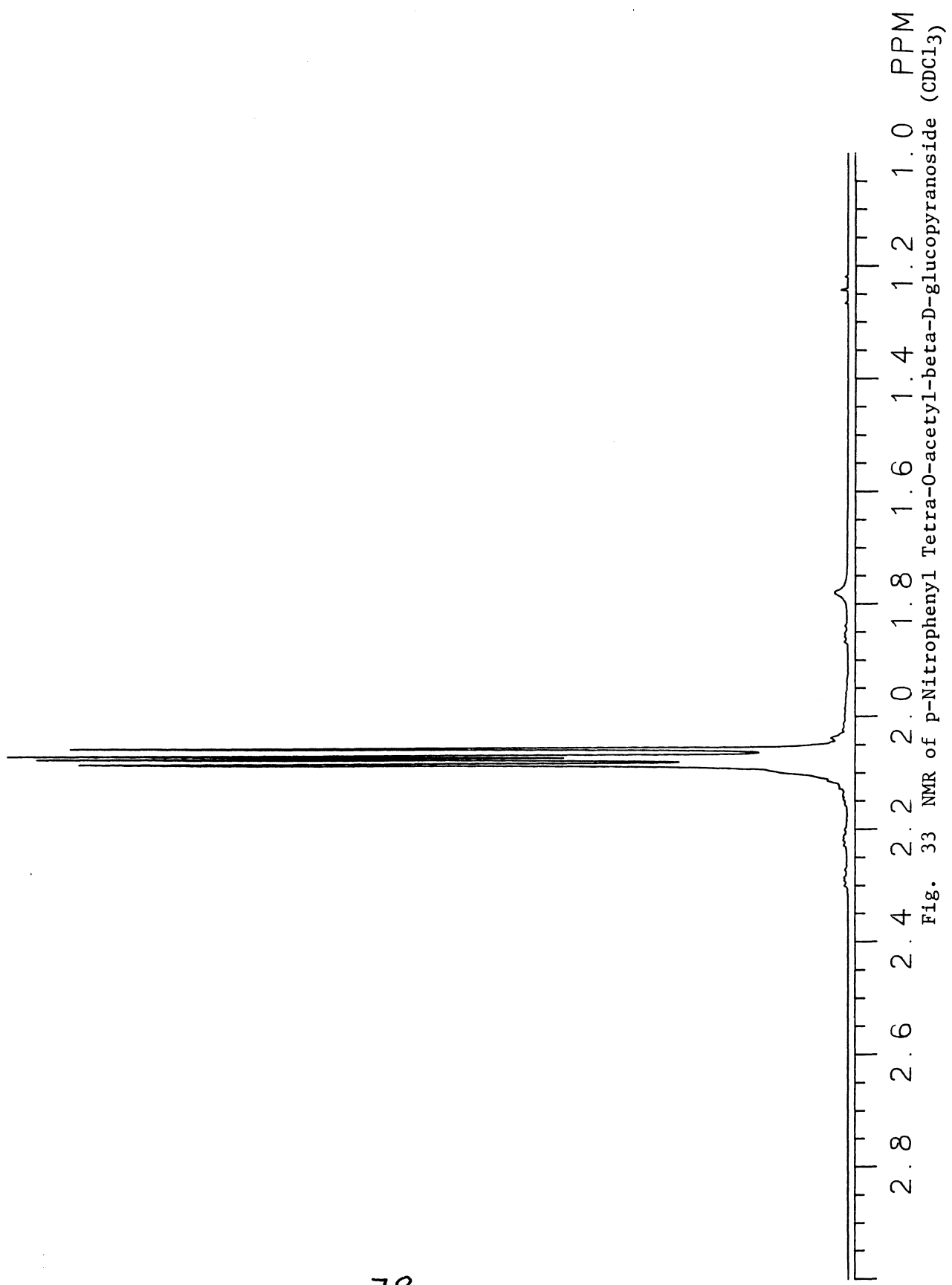Fig. 30 NMR of p-Nitrophenyl Tetra-O-acetyl-beta-D-glucopyranoside (DMSO)

75
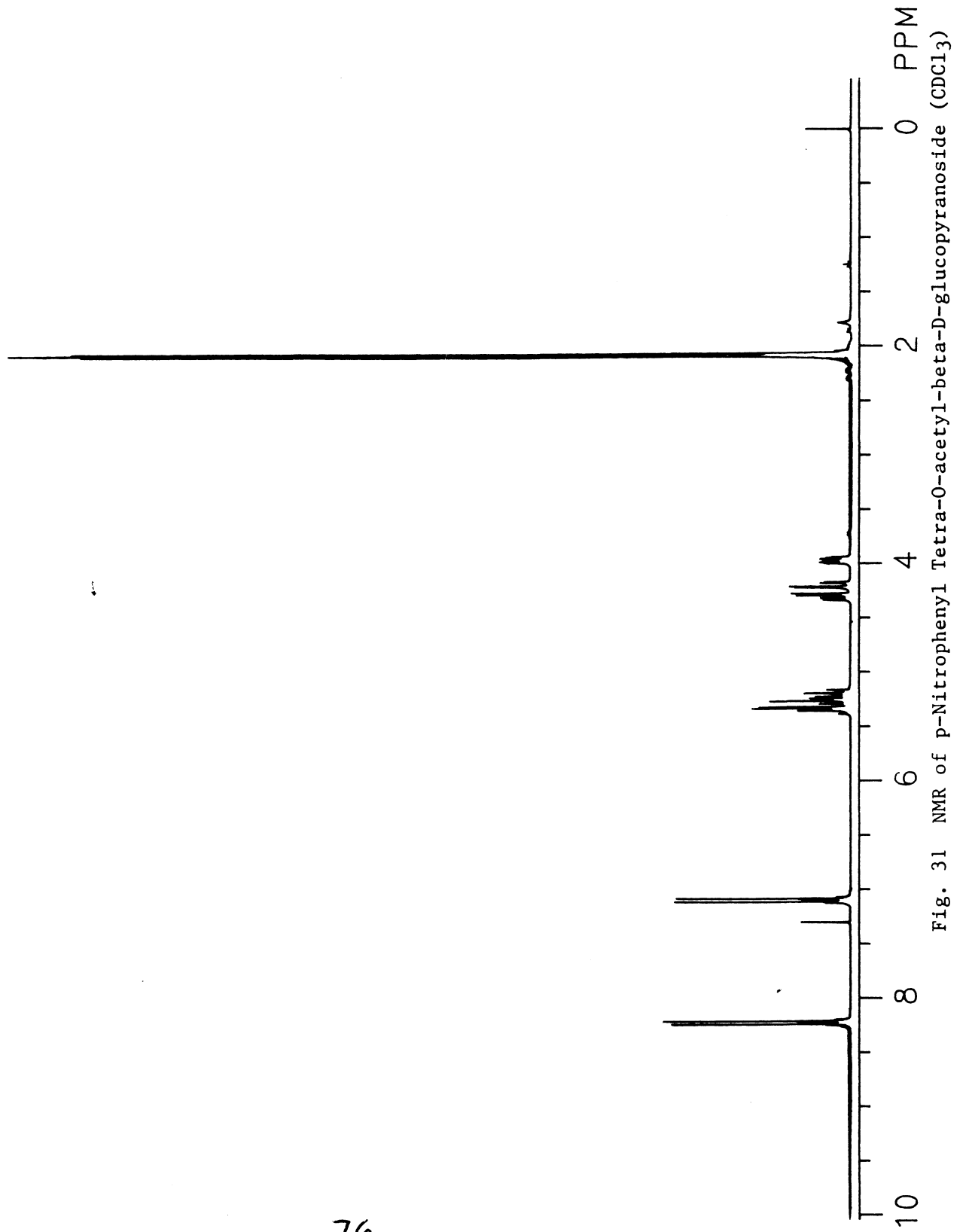
Fig. 31 NMR of p-Nitrophenyl Tetra-O-acetyl-beta-D-glucopyranoside (CDCl₃)
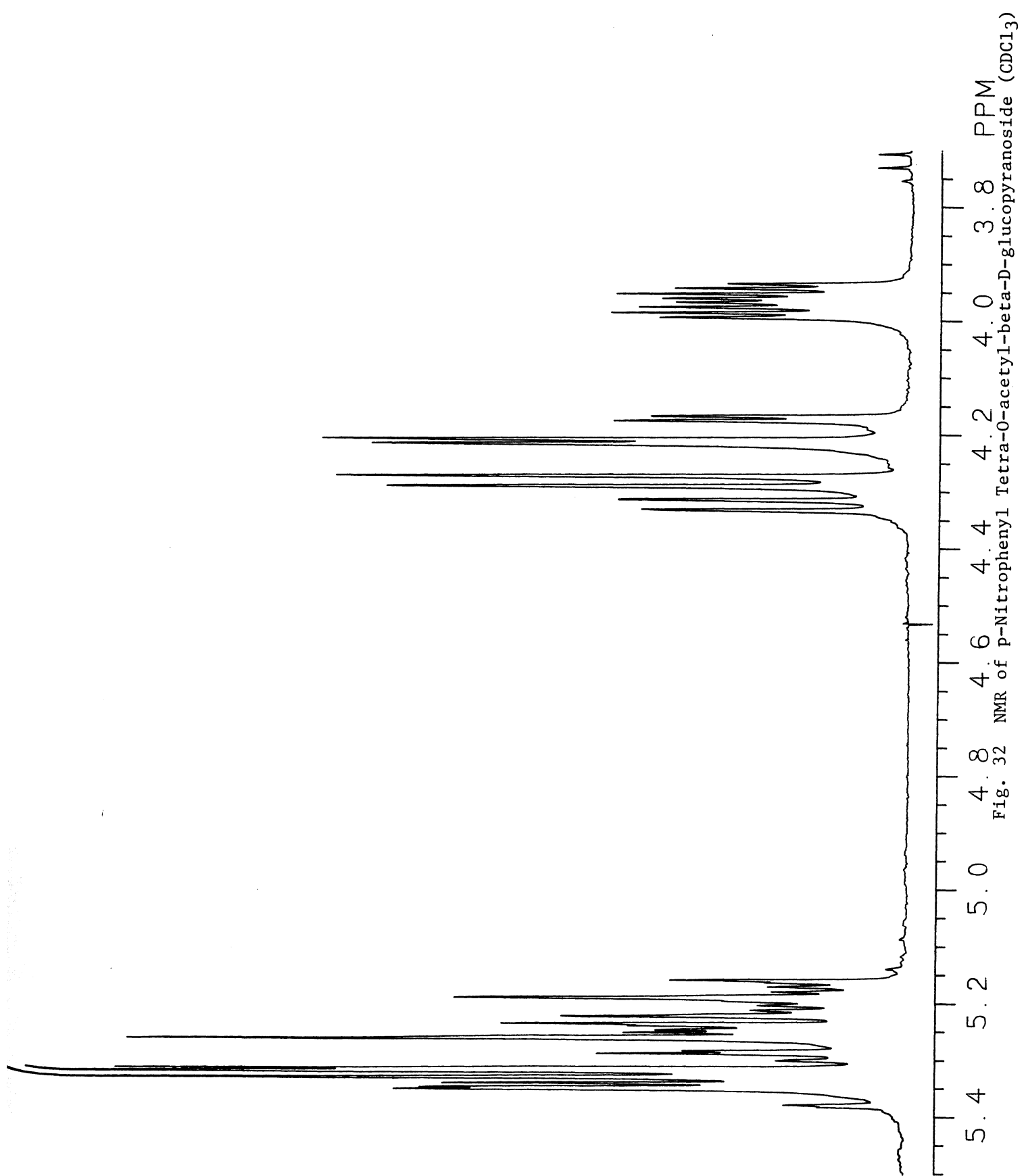
Fig. 32 NMR of p-Nitrophenyl Tetra-O-acetyl-beta-D-glucopyranoside (CDCl₃)

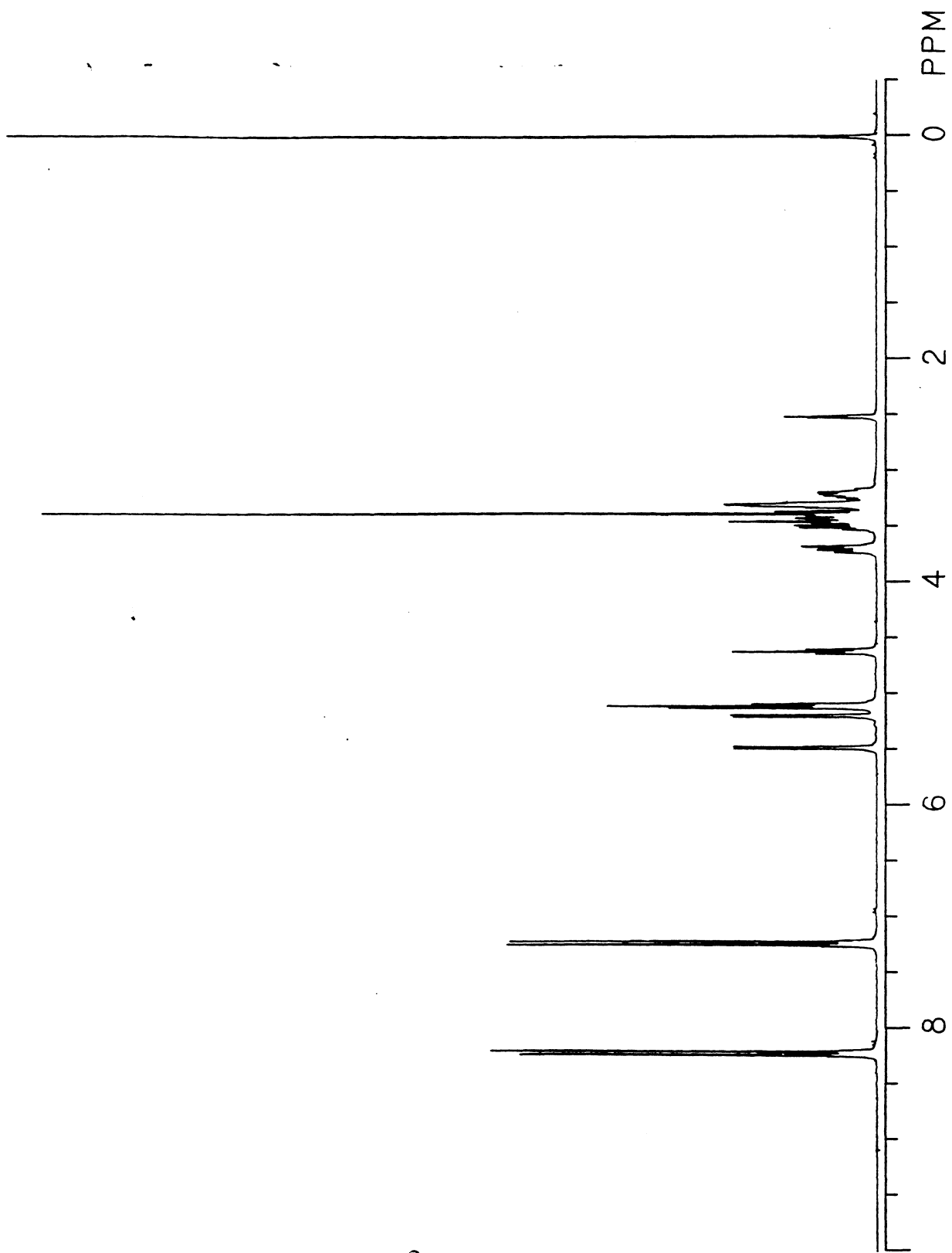Fig. 33 NMR of p-Nitrophenyl Tetra-O-acetyl-beta-D-glucopyranoside (CDCl$_3$)

78

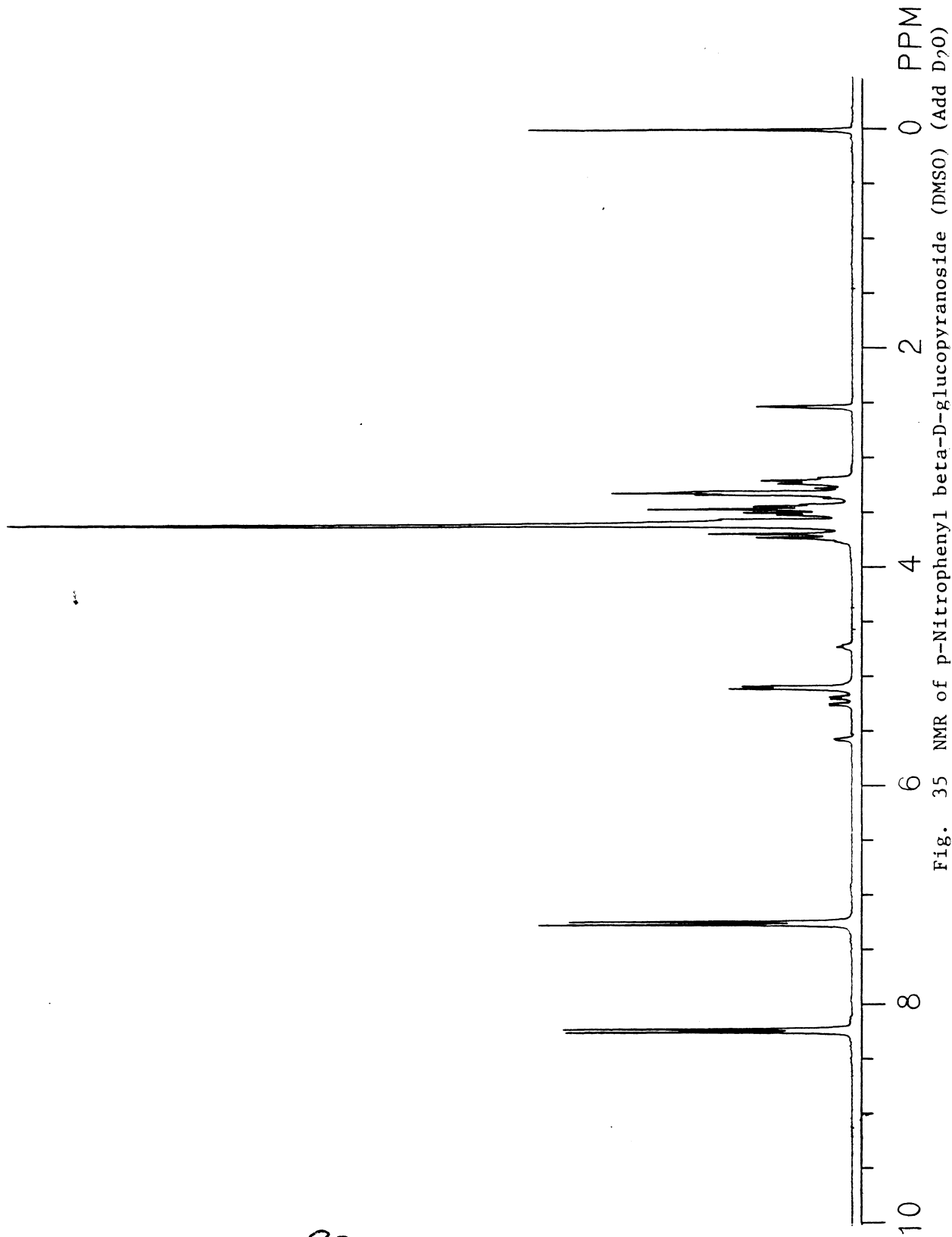Fig. 34 NMR of p-Nitrophenyl beta-D-glucopyranoside (DMSO)

79

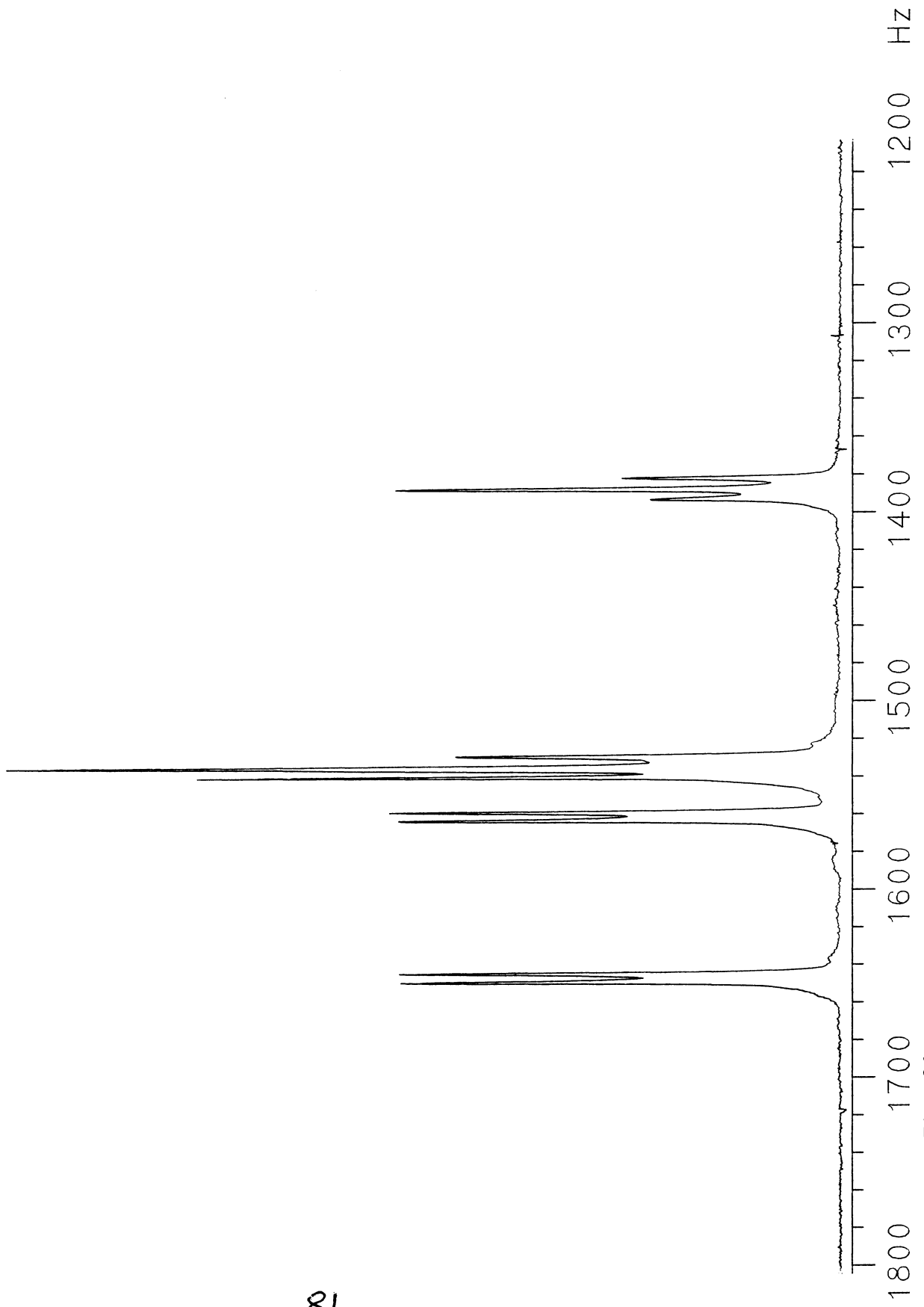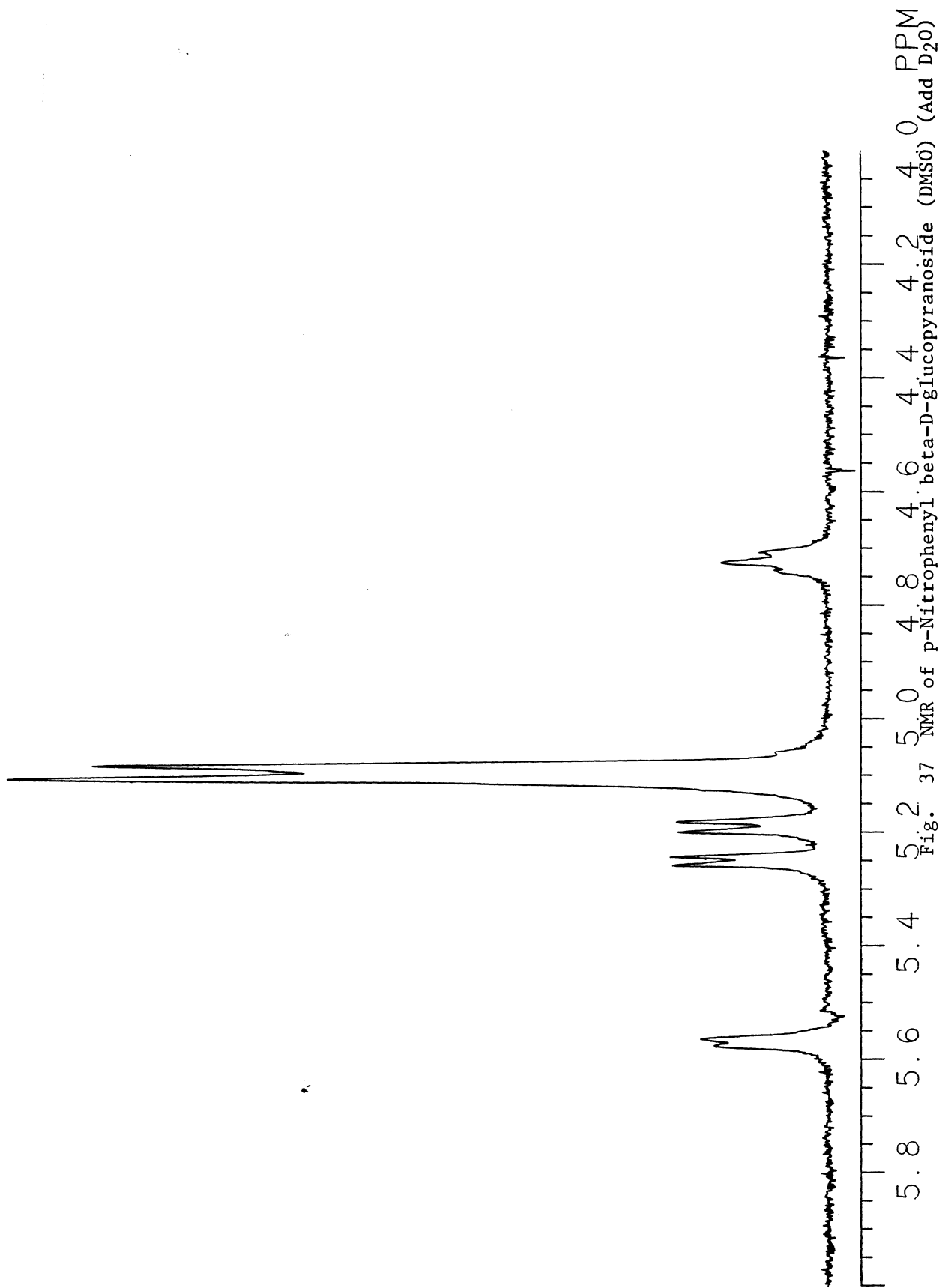Fig. 35 NMR of p-Nitrophenyl beta-D-glucopyranoside (DMSO) (Add D₂O)

80

Fig. 36 NMR of p-nitrophenyl beta-D-glucopyranoside (DMSO)

81

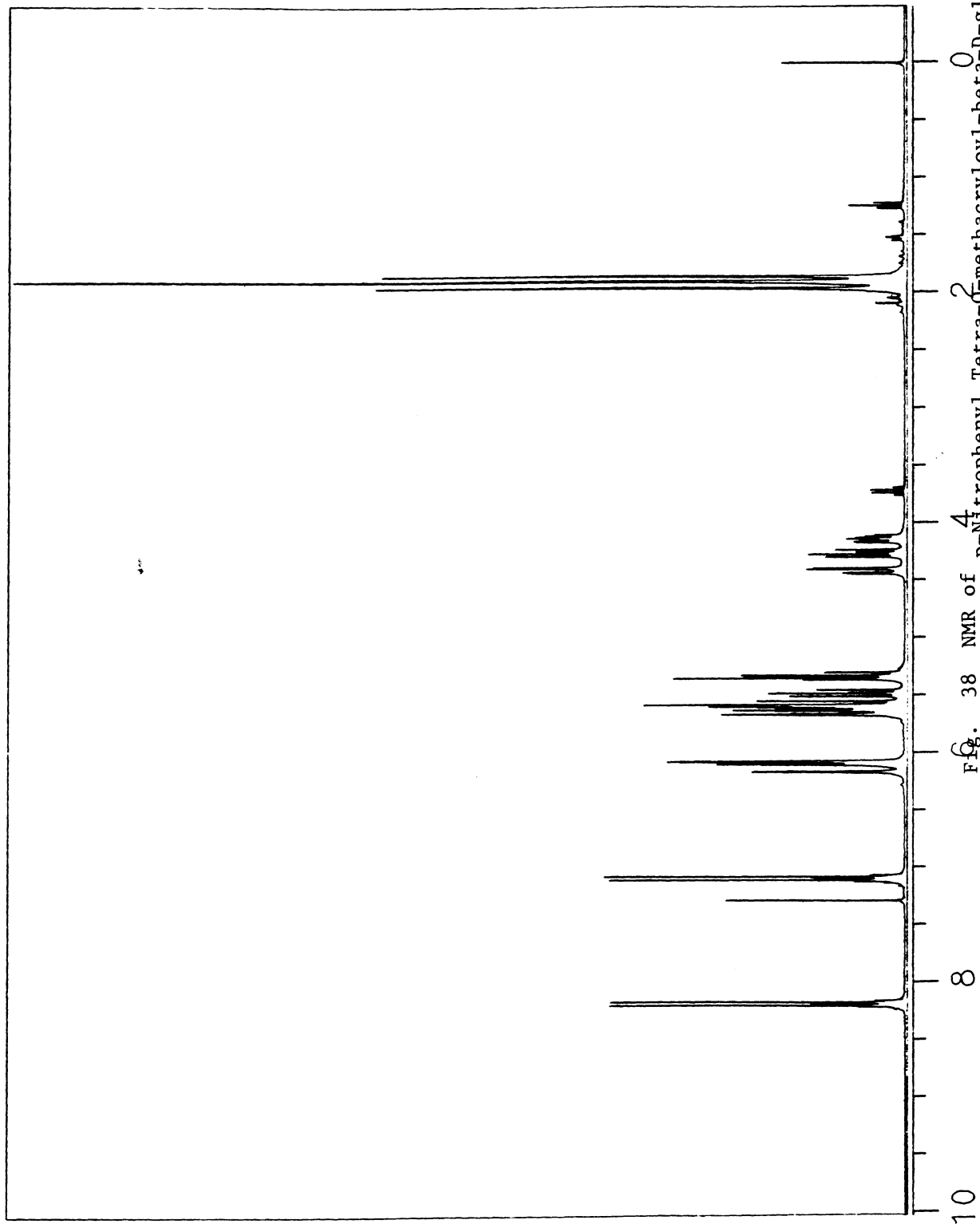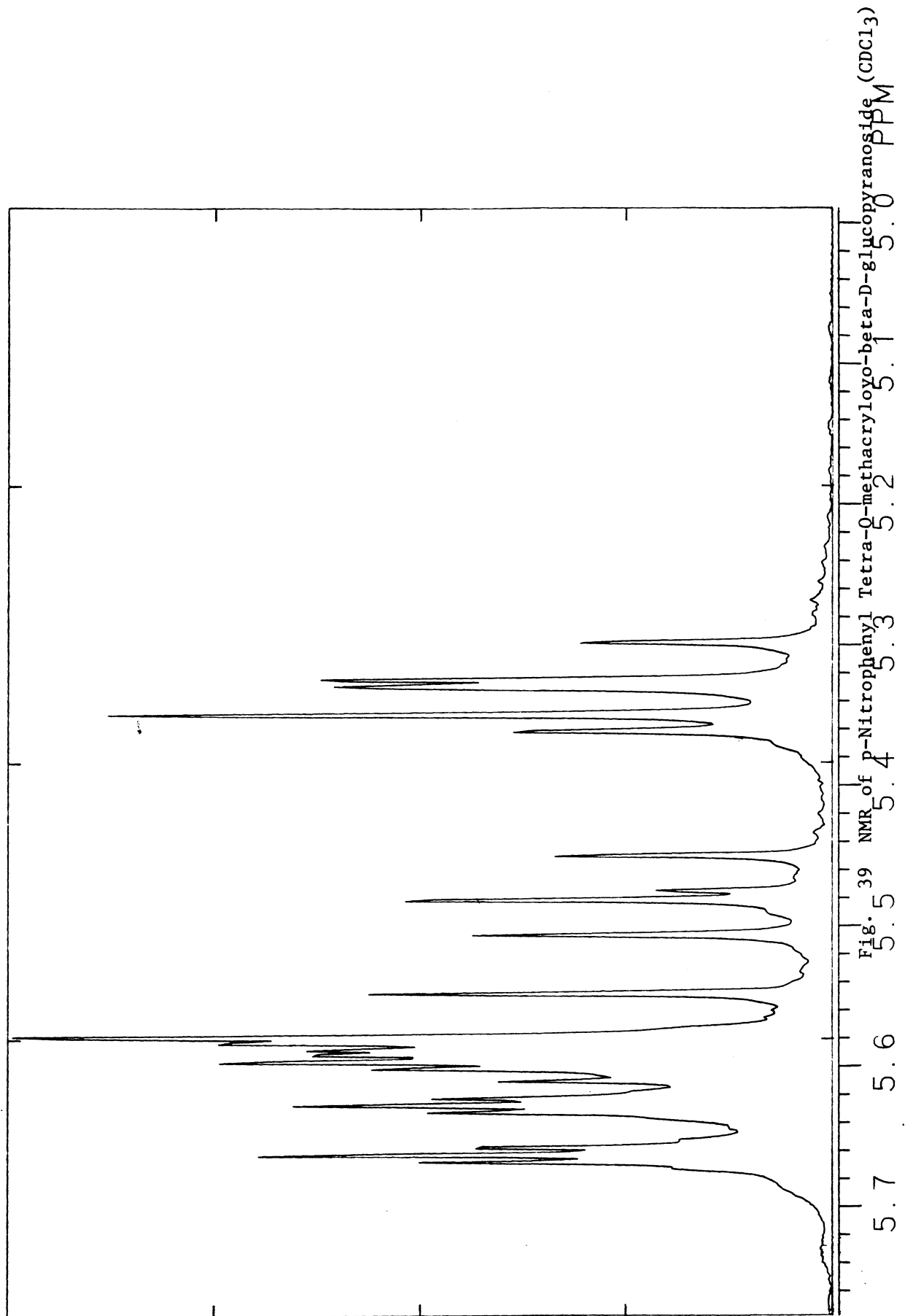Fig. 37 NMR of p-Nitrophenyl beta-D-glucopyranoside (DMSO) (Add D₂O)

82

Fig. 38 NMR of p-Nitrophenyl Tetra-0-methacryloyl-beta-D-glucopyranoside (CDCl$_3$)

83

Fig. 39 NMR of p-Nitrophenyl Tetra-O-methacryloyo-beta-D-glucopyranoside.(CDCl₃)

84

Fig. 40 NMR of p-Nitrophenyl Tetra-O-methacryloyl-beta-D-glucopyranoside (DMSO)

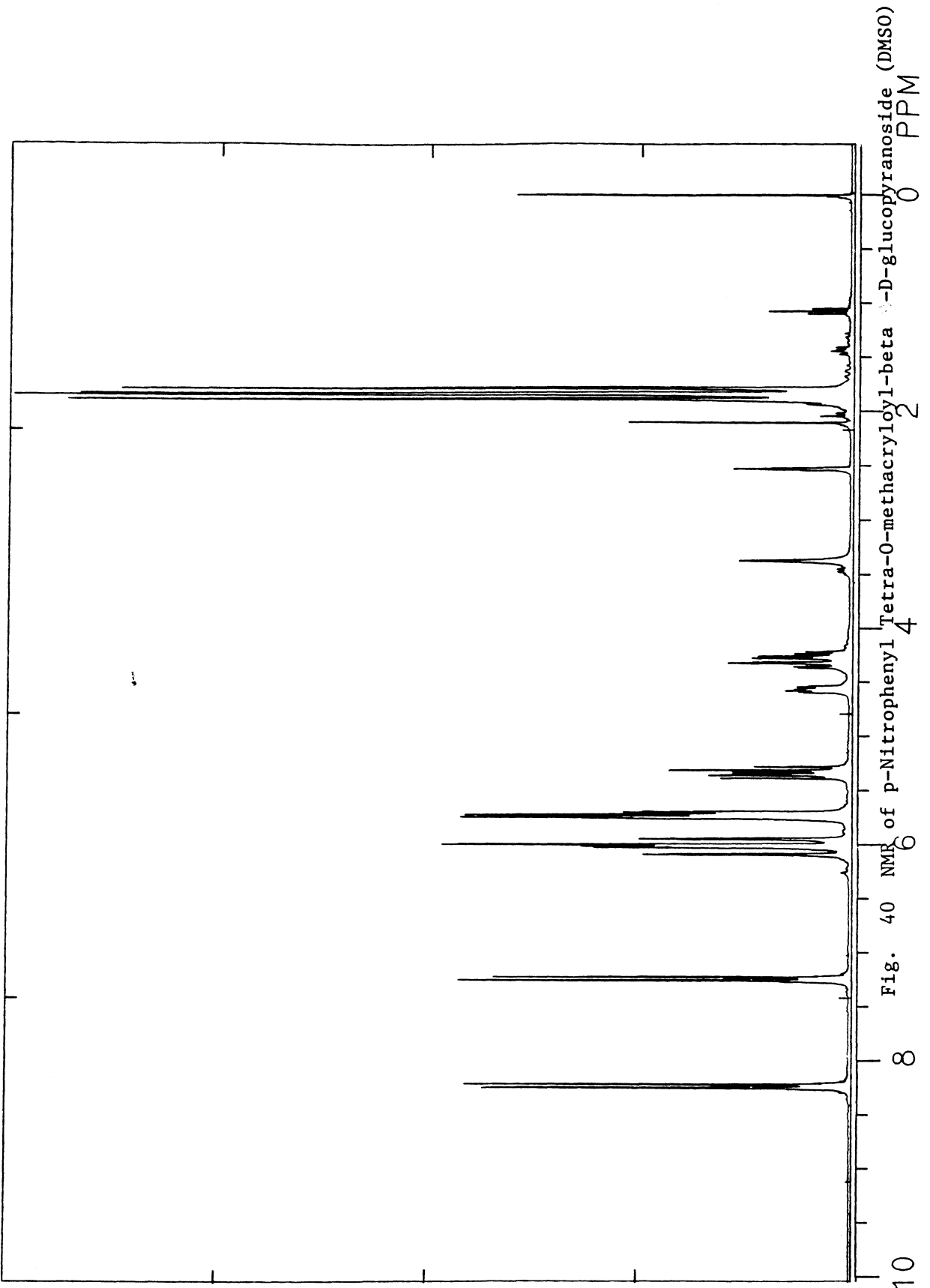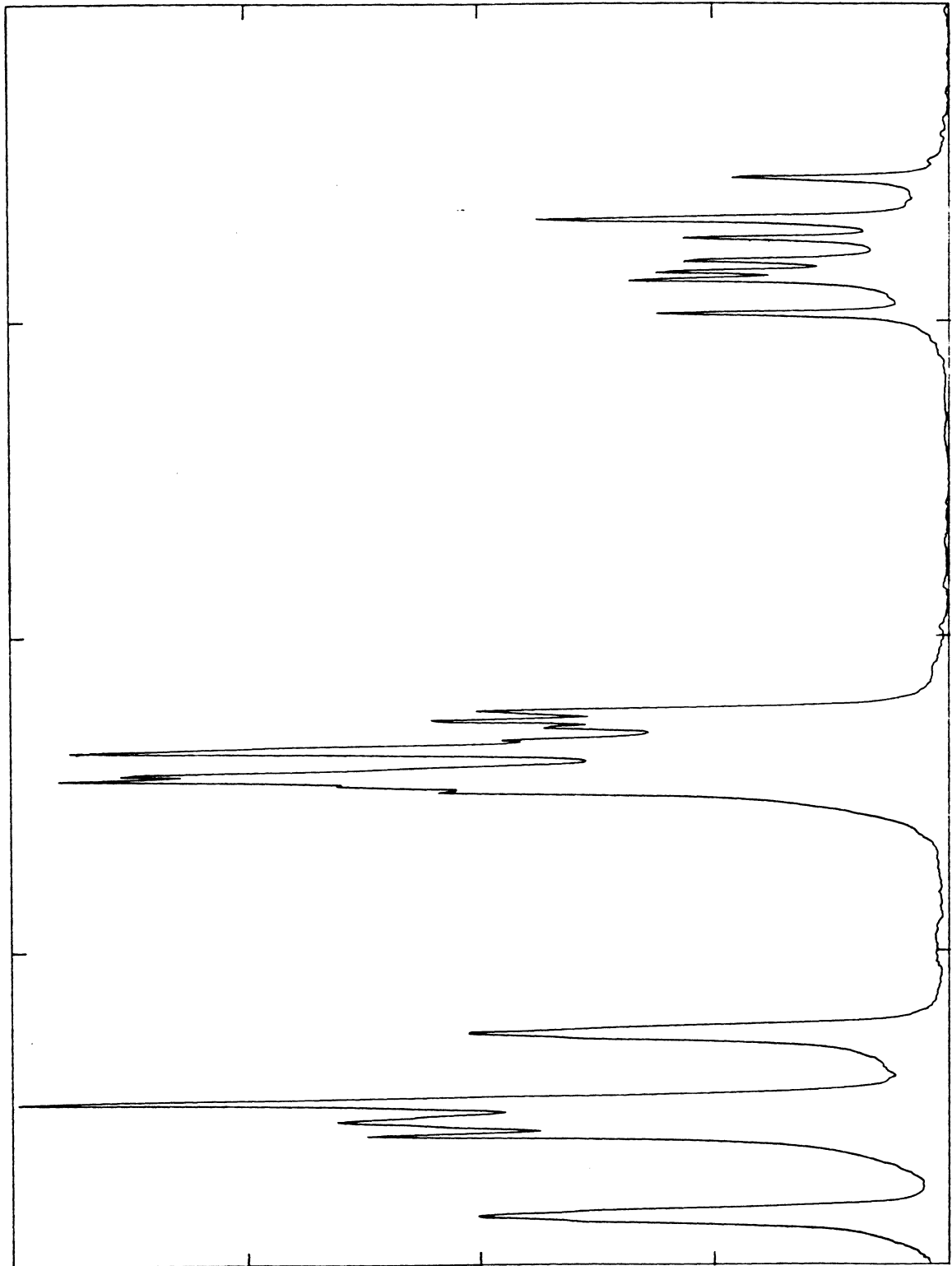85

Fig. 41 NMR of p-Nitrophenyl Tetra-O-methacryloyl-beta-O-D-glucopyranoside (DMSO)

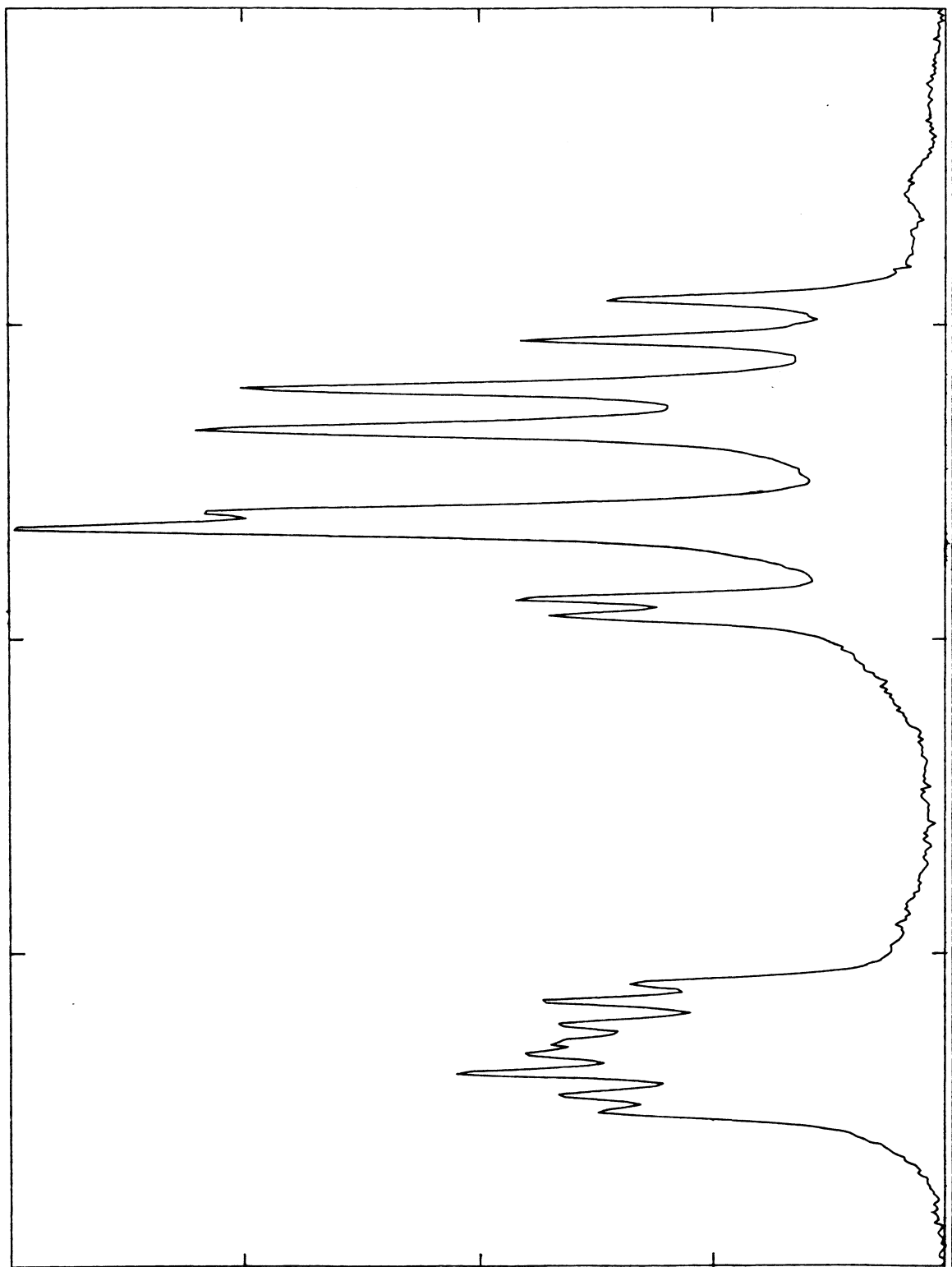Fig. 42 NMR of p-Nitrophenyl Tetra-0-methacryloyl-beta-D-glucopyranoside (DMSO)

Fig. 43 NMR of p-Nitrophenyl Tetra-O-methacryloyl-alpha-D-glucopyranoside (CDCl₃)

Fig. 44 NMR of p-Nitrophenyl Tetra-O-methacryloyl-alhpa-D-glucopyranoside (CDCl$_3$)
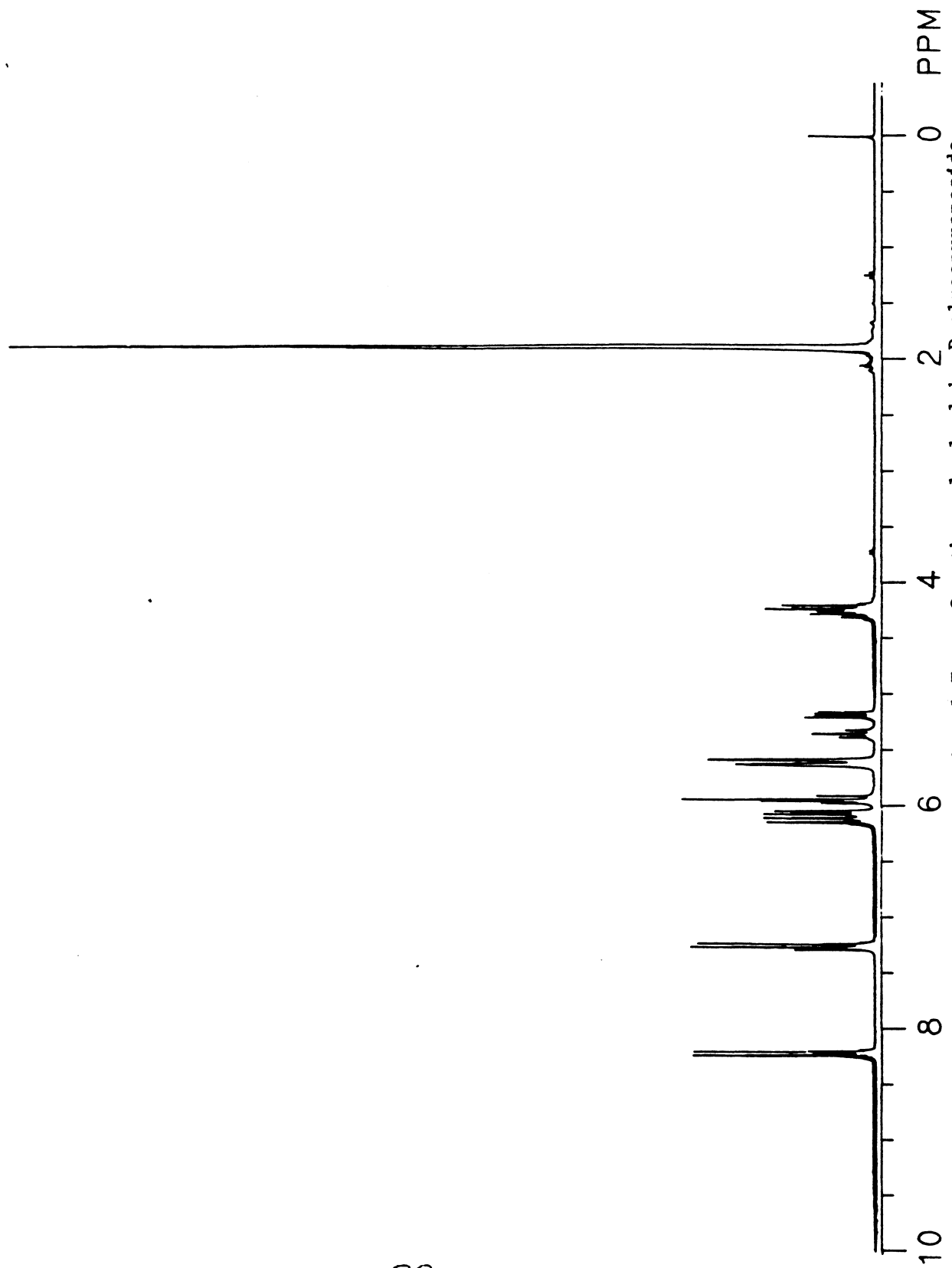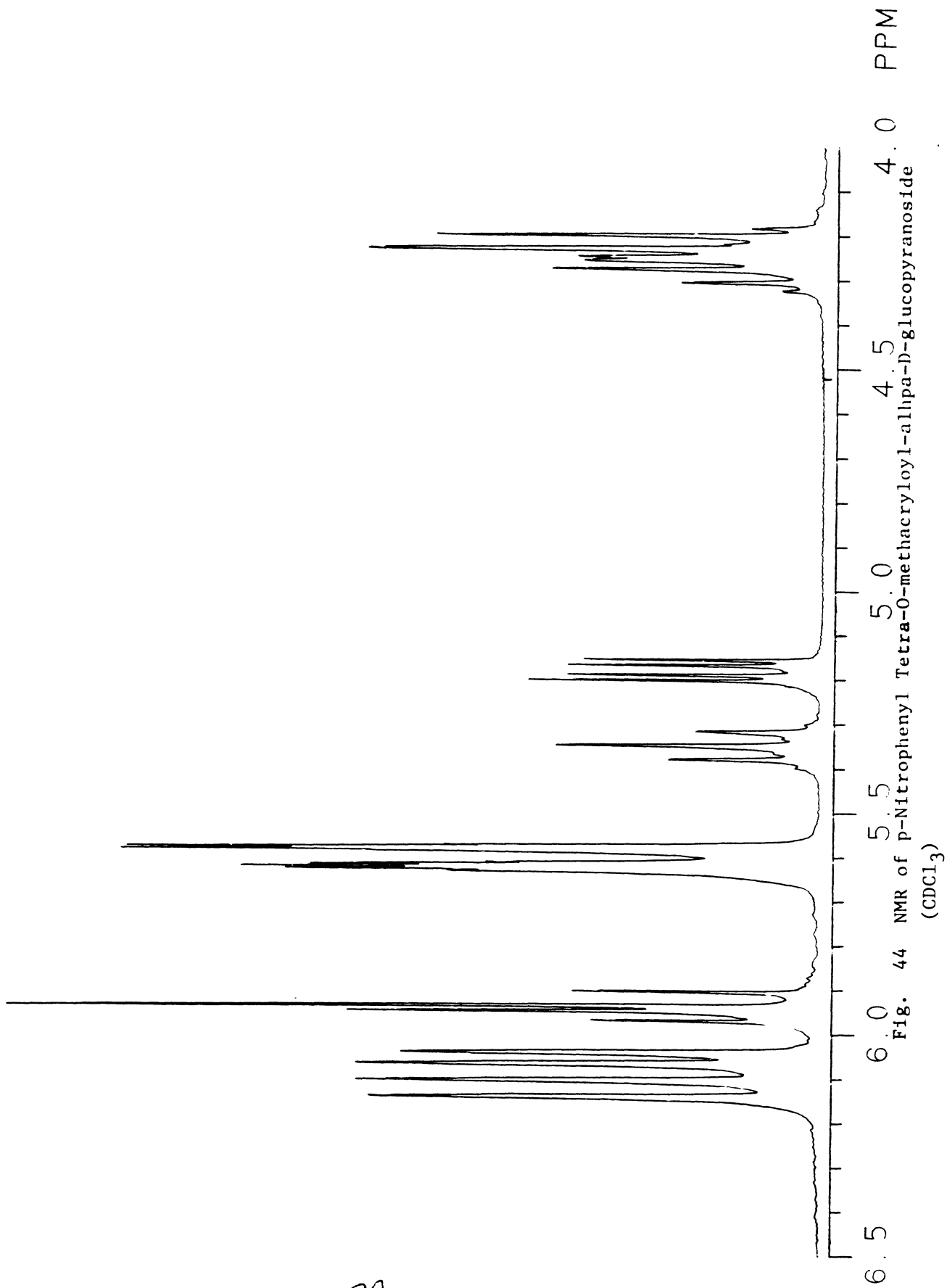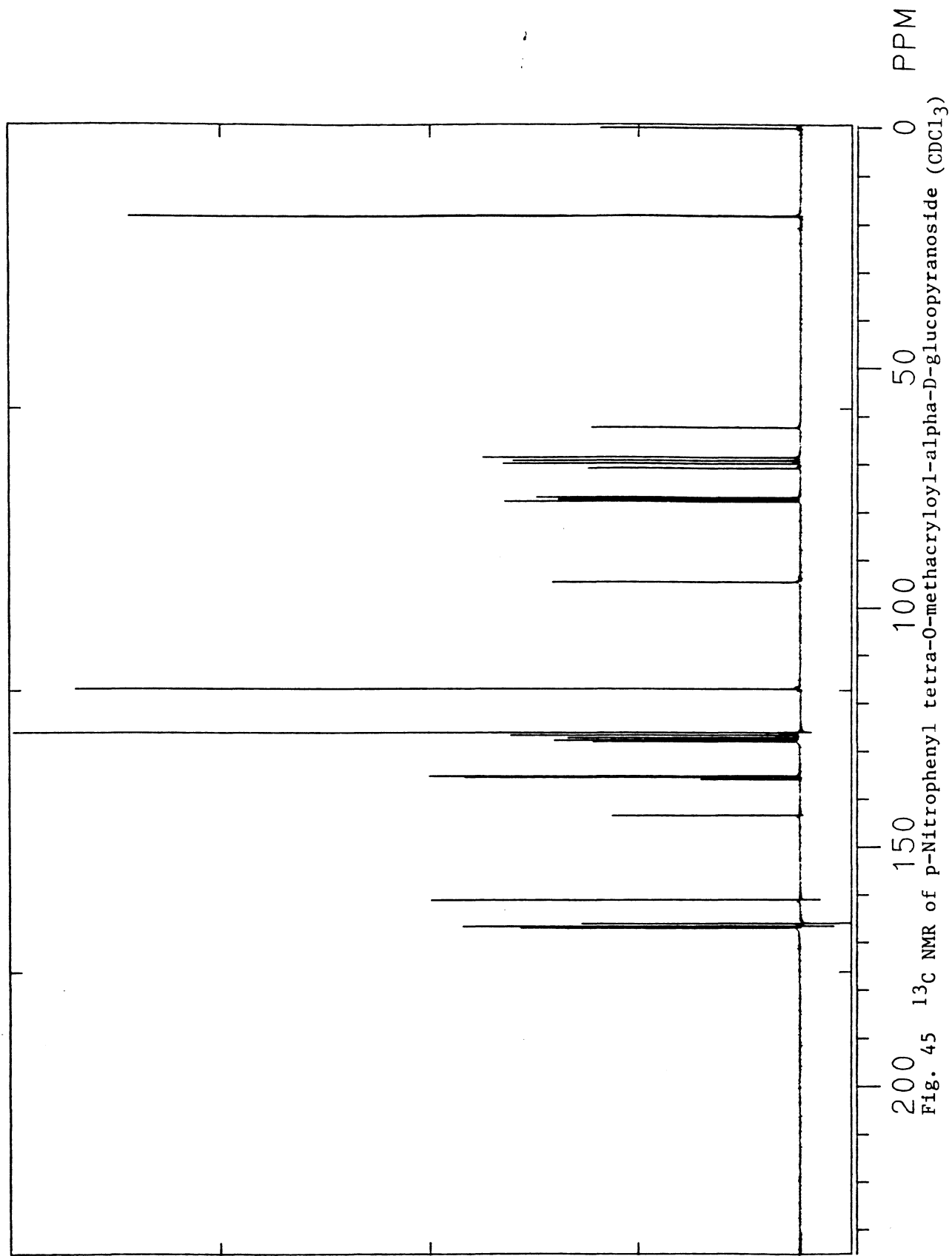
Fig. 45 ^{13}C NMR of p-Nitrophenyl tetra-O-methacryloyl-alpha-D-glucopyranoside (CDCl$_3$)

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